A Geotechnical, Geochemical and Human Health Risk Assessment of a Dry Oil Lake Site in Kuwait

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ABSTRACT

The main contribution of this study is to evaluate the effects of hydrocarbon contamination of soil with respect to geotechnical and geochemical properties and their impact on human health resulting from the Iraqi invasion of Kuwait in 1990. To fulfil this goal, the geotechnical and geochemical characteristics of soil at a dry *oil lake* have been investigated.

The Human Health Risk Assessment (HHRA) was investigated utilising Risk Integrated Software for Soil Clean-up Version-5 (RISC-5) to evaluate the effects of hydrocarbon contamination on human health via ingestion of soil, dermal contact with soil, ingestion of vegetables, inhalation of outdoor air and inhalation of particulates pathways.

In order to study these variations, two neighbouring sites at Al-Magwa area on the Greater Burgan Oil Field were selected. The first was chosen for a dry *oil lake* scenario, and the other adjacent site as an uncontaminated baseline control. Geotechnical tests were implemented on samples taken at different depths from both sites. These included Atterberg Limit, Particle Size Distribution (PSD), permeability and shear strength. Electronic micrographs were also taken for the upper layer (0.0 m depth). The geochemical investigations included Hydrogen Ion Concentration (pH), water soluble Chloride and Sulphate content, Vario Macro Elemental Analysis (EA) and Gas Chromatograph Mass Spectrometry (GC-MS). GC-MS was carried out to determine the specific hydrocarbon compounds and their concentrations within the soil. These values formed the basis of a HHRA.

The geotechnical results show that hydrocarbon contamination modifies the PSD together with a decrease in the angle of internal friction (φ). The geochemical results confirm that the hydrocarbon contamination causes a change in the pH, with the Chloride and Sulphate contents and hydrocarbon concentrations decreasing with depth. The HHRA demonstrated that certain hydrocarbon compositions at elevated levels encountered in the dry *oil lake* site had potential effects with regard to non-carcinogenic risks. The geotechnical and geochemical characterisation data used in this study are also analysed quantitatively using IBM SPSS Statistics in order to support robust results. The statistical analysis confirms that all the results are solid and compatible.

Key words: *Oil lakes; hydrocarbon contamination, geotechnical properties of hydrocarbon contaminated soil; geochemical properties of hydrocarbon contaminated soil; human health risk assessment.*

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DECLARATION

“Whilst registered as a candidate for the above degree, I have not been registered for any other research award. The results and conclusion embodied in this thesis are the work of the named candidate and have not been submitted for any other academic award”

Humoud Melfi Zayed Aldaihani.

Words Count: 63625 words (exclude references).

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GLOSSARY OF TERMS

AFCEE	**Air Force Centre for Environmental Excellence**
ALARP	**As Low As Reasonably Practicable**
ASE	**Accelerate Solvent Extraction**
ASTM	**American Society for Testing and Materials**
ATSDR	**Agency for Toxic Substances and Disease Registry**
BISS	**Background Incremental Sample Simulator**
BMD	**Benchmark Dose**
BMR	**Benchmark Response**
C	**Carbon**
CADD	**Chronic Average Daily Dose**
Cc	**Coefficient of Curvature**
CH	**High Compressibility Clay**
Cl-	**Chloride**
CL	**Low Compressibility Clay**
CLEA	**Contaminated Land Exposure Assessment**
CO	**Carbon Monoxide**
CO_2	**Carbon Dioxide**
COPCs	**Constituents of Petroleum Concern**
CR	**Carcinogenic Risk**
CSM	**Conceptual Site Model**
CTE	**Central Tendency Exposure**
Cu	**Uniformity Coefficient**
DEFRA	**Department for the Environment, Food and Rural Affairs**
DNAPL	**Dense Non-Aqueous Phase Liquids**
DQRA	**Detailed Quantitative Risk Assessment**
DRO	**Diesel Range Oil**
EA	**Elemental Analysis**
EC	**Equivalent Carbon**
ELCR	**Excess Lifetime Cancer Risk**
EOD	**Explosive Ordnance Disposal**
EPA	**Environment Protection Agency**
GAC	**Generic Assessment Criteria.**
GC	**Gas Centre**
GCC	**Gulf Cooperation Council**
GCI	**Green Cross International**
GC-MS	**Gas Chromatograph Mass Spectrometry**
GQRA	**Generic Quantitative Risk Assessment**
H	**Hydrogen**
HGG	**Hunting Geology and Geophysics**
HHRA	**Human Health Risk Assessment**
HI	**Hazard Index**
HQ	**Hazard Quotient**
HRA	**Health Risk Assessment**
H_2S	**Hydrogen Sulphide**
HS&E	**Health Safety and Environment Department**
IARC	**International Agency for Research on Cancer**
KCCC	**Kuwait Cancer Control Center**
KDP	**Kuwait Development Plan**
KEPA	**Kuwait Environment Public Authority**
KISR	**Kuwait Institute of Scientific Research**
KMP3	**Kuwait Master Plan**
KOC	**Kuwait Oil Company**
K-S	**Kolmogorov-Smirnoff**
LNAPL	**Light Non-Aqueous Phase Liquid**

LQM	**Land Quality Management**
Mg/kg	**Milligrams Per Kilogram (=ppm)**
MWs	**Monitoring wells**
N	**Nitrogen**
ND	**Non-Detect**
NO	**Nitrogen Oxides**
PAH	**Polycyclic Aromatic Hydrocarbon**
Part IIA	**Part IIA of the 1990 Environmental Protection Act (Part 2A in English documents)**
pH	**Hydrogen Ion Concentration**
PO	**Production Operation Department**
PPE	**Personal Protective Equipment**
ppm	**parts per million**
PSD	**Particle Size Distribution**
Q-Q	**Quantile-Quantile**
RAGS	**Risk Assessment Guidance for Superfund**
RAS	**Risk Assessment Stages**
RBCA	**Risk Based Corrective Action**
RBSLs	**Risk Based Screening Levels**
RfC	**Reference Concentrations**
RfD	**Reference Doses**
RISC-5	**Risk Integrated Software for soil Clean-up-version 5**
RME	**Reasonable Maximum Exposure**
R&T	**Research and Technology Department**
S	**Sulphur**
SEM	**Scanning Electron Microscope**
SGV	**Soil Guidelines Values**
SM	**Very silty sand**
S-M	**Silty sand (S-M)**
SNIFFER	**Scottish and Northern Ireland Forum for Environmental Research**
SO_4	**Sulphate**
SO_2	**Sulphur Dioxide**
SO_3	**Sulphur Trioxide**
SP	**Poorly Graded Sand**
SSAC	**Site Specific Assessment Criteria**
SSTLs	**Site-Specific Target Levels**
S-W	**Shapiro-Wilk**
T.P	**Trial Pit**
T.Ps	**Trial Pits**
T.P.C	**Trial Pit Coordinate**
T.P.Cs	**Trial Pit Coordinates**
TPH	**Total Petroleum Hydrocarbon**
TPHCWG	**Total Petroleum Hydrocarbon Criteria Working Group Series**
TSEM	**Total solvent extraction material**
UCLs	**Upper Confidence Limits**
UCM	**Unresolved Complex Mixture**
UoP	**University of Portsmouth**
USEPA	**United States Environment Protection Agency**
VOC	**Volatile Organic Compound**

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DEDICATION

I dedicate this thesis to my late father (Melfi Zayed Aldaihani) who has always been my source of inspiration. And also to my Mother, Wife, and all my Family Members whose support have been my pillar of strength.

PUBLICATION

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1. INTRODUCTION

1.1 Aim of the Study

The central goal of this study is to investigate and determine whether the dry *oil lake* contaminated soils in Kuwait have any influence on their geotechnical and geochemical properties which could lead to a structurally unstable soil condition. This study will also investigate the influence of dry *oil lake* on the Human Health Risk Assessments (HHRA) and determine the potential levels of risk posed to any future urban developments within the affected areas.

The main objectives with details are as follows:

(1) To study the geotechnical characteristics of hydrocarbon contaminated soil by investigating whether dry *oil lake* residue can cause deterioration of soil geotechnical conditions. This will be achieved by fulfilling the sub-objectives as set out below:

(a) to investigate the geotechnical properties of hydrocarbon contaminated soil;
(b) to investigate the geotechnical properties of non-contaminated (control) soil;
(c) to study the effect of dry *oil lake* residue on soil geotechnical properties by comparing contaminated with non-contaminated samples.

(2) To study the geochemical characteristics of hydrocarbon contaminated soil, and to test whether dry *oil lake* residue can create a chemically aggressive environment. This will be achieved by answering the sub-objectives as set out below:

(a) by investigating the geochemical properties of hydrocarbon contaminated soil;
(b) by investigating the geochemical properties of non-contaminated (control) soil;

(c) by studying the effect of dry *oil lake* residue on the geochemical properties of the soil to be achieved by comparing contaminated with non-contaminated (control) samples.

(3) To assess the influence of the dry *oil lake* contaminated soils on the Human Health Risk Assessment (HHRA) in the state of Kuwait from the existence of *oil lake* residue since the Iraqi invasion in 1990. This will be accomplished by fulfilling the sub-objectives as set out below:

(a) by classifying the pollutants in the hydrocarbon contaminated soils into carcinogenic and non-carcinogenic categories; this will be achieved by applying Risk Integrated Software for soil Clean-up (RISC-5) of the hydrocarbon contaminated soil in Kuwait;

(b) by developing the ‘ground modelling’ through obtaining the clean-up level for the dry *oil lake* contaminated soil using RISC-5 software. Even if the physical properties of the soil are suitable for construction purposes, it is essential to carry out and to evaluate any signs of carcinogenic elements that may influence the health of humans, animals and plants. The risk assessment will be carried out using RISC-5 software, indicating that human health is need addressing more than the strength of the soil.

1.2 Background

The impact on the environment - particularly towards public health and safety - due to hydrocarbon contamination, can be catastrophic irrespective of contamination of the air both above ground and below ground. As mentioned by Gay *et al*. (2010) and based on other available reports, some of the most seriously hydrocarbon contaminated sites in the world are: the Deepwater Horizon in the Gulf of Mexico; Northeast Ecuador; Exxon-

Valdezz in Alaska (U.S); Delta River in Nigeria; and Kuwait. According to Taylor *et al*. (2005) the water and food consumed by individuals are the main causes of health affect pollution. Humans and animals are not directly influenced by soil, however, water and plants which are bonded to soil and used by humans and animals are directly affected by contamination.

Thus the oil residue and heavy metal used in the war are likely to have resulted in the contamination of the environment which will consequently have adverse impact on people's health (Gay *et al*., 2010). Soil contamination is currently considered to be a vital global issue; the main causes of soil contamination are human activities, some examples being improper agricultural practices, faulty construction practices and industrial and military activities. According to Goi *et al*. (2009) within the European Union alone, 3.5 million sites could have been contaminated of which 500 thousand sites needed remediation. The emphasis of this study is on hydrocarbon contaminated soil present in Kuwait caused by the burning of the oil wells as well as the release of huge volumes of oil during the 1990 invasion by Iraq. During this war, approximately 604 oil wells were set alight, oil gushed from 45 wells and 149 were severely damaged; in fact, two million barrels of oil per day were estimated to have escaped from the affected wells (PAAC, 1999). In addition, it has been estimated that in 8 months 1.0 to 1.5 billion barrels of oil were lost. As a result of these fires the Kuwait sky was covered with clouds of oil smoke. When the fires were finally extinguished all the burnt oil landed on the ground and mixed with the soil which is still contaminated to the present day (Petroleum Economist, 1992).

Based upon a report by (Green Cross International (GCI), 1998), the residue from large (oil) lakes in particular, has been the cause of the main risk to the environment and to human health as they have been left untreated.

This research will examine the hydrocarbon contaminated soil from the geotechnical, geochemical and HHRA aspects since this hydrocarbon contamination might not only affect the physical properties of the soil but the chemical risks are also likely to threaten human health and the ecology.

A number of studies from various countries have investigated hydrocarbon contaminated soil from the geotechnical perspective. These investigations have usually been undertaken to examine the geotechnical properties of both contaminated and uncontaminated soil samples typically by using the: Atterberg Limit test; Particle Size Distribution (PSD); Scanning Electron Microscope (SEM); coefficient of permeability (Hydraulic Conductivity); and the Direct Shear test.

The purpose of the Atterberg Limit test is to determine whether the plasticity of the soil has changed due to the hydrocarbon contamination; the objective of PSD is to learn whether change has taken place to the grain size due to hydrocarbon contamination. The SEM test is used to further investigate the grain size distribution of the soil contaminated with hydrocarbon in order to realise clearly whether there have been changes in the particles from dry *oil lake* residue. The permeability coefficient (Hydraulic Conductivity) is utilised to define the permeability of hydrocarbon contaminated soil and the Direct Shear test is intended to determine any change in the internal friction angle (φ) and cohesion (c) of the clean soil strength after being contaminated by hydrocarbon.

According to Caravaca and Roldan (2003), Meegoda and Ratnaweer (1995), Ijimdiya (2013), and Srivastava and Pandey (1998), a number of studies have examined soil contaminated by hydrocarbon using the PSD test while others have utilised the Atterberg Limit Test to study soil plasticity including: Jia *et al*. (2011), Habib-ur-Rahman *et al*. (2007), Shah *et al*. (2003), Patel (2011), Pandey and Bind (2014), and Elisha (2012). The behaviour of the geotechnical characteristics of soil contaminated with hydrocarbon, including Direct Shear and permeability coefficient (Hydraulic Conductivity), has been examined by various studies including those of: Al-sanad (1995), Al-sanad and Ismael (1997), and Khamehchiyan *et al*. (2007), Puri *et al*. (1994), Rahman *et al*. (2010), Gupta and Srivastava (2010), Singh *et al*. (2009), Kermani and Ebadi (2012) and Shin *et al*. (1999). However, Mucha and Trzcinski (2008), examined soil particles contaminated with hydrocarbon using the SEM test so as to further investigate soil PSD (see section 3.3 for further explanations).

Various nations have carried out a number of studies examining the geochemical properties of hydrocarbon contaminated soil. Usually, the tests employed to examine the chemical characteristics of the contaminated and uncontaminated soil were: Hydrogen Ion concentration (pH); water soluble chloride (Cl-) and sulphates (i.e. sulphur trioxide (SO_3) & sulphate (SO_4)); vairo macro elemental analysis (EA); and gas chromatography mass spectrometry (GC-MS). The purpose of the pH coefficient test was to determine the acidity or alkalinity of the soils either hydrocarbon contaminated or uncontaminated. Both water soluble Cl- and SO_3 & SO_4 tests were performed to examine the suitability of the concrete type to be utilised in construction projects on hydrocarbon contaminated sites. The vairo macro elemental analysis (EA) test was aimed at examining the amount percentages (%) of the chemical constituents (nitrogen (N %), hydrogen (H %), carbon (C %), and sulphur (S %)) in hydrocarbon contaminated soil. The chemical composition and concentration of total petroleum hydrocarbon (TPH) (mg/kg) was determined by using the GC-MS test.

Numerous studies examined the soils contaminated with hydrocarbon by identifying the pH behaviour of both the uncontaminated and contaminated soils, see: Barua *et al*. (2011), Khuraibet and Attar (1995) and Al-Duwaisan and Al-Naseem (2011). A study carried out by others, including Onojake and Osuji (2012), examined the content of Cl- and SO_3 & SO_4 within the soil. Yet other researchers carried out investigations to determine the constituent percentages, for example: N (%); C (%); H (%); and S (%), in the hydrocarbon contaminated soil by means of the Elemental Analysis (EA) test (Sato *et al*., 1997; Perkinelmer, 2010; Benyahia *et al*., 2005). The concentrations of hydrocarbon contaminants within soils as well as their chemical compositions have also been studied with the help of GC-MS (see section 3.4 for detailed explanations).

Having looked at various works with regard to geotechnical and geochemical properties of hydrocarbon contaminated soil, it has become apparent that some pollutants have been amalgamated into the physical properties of the soil to become one of its constituents. As these pollutants may become carcinogenic and pose a potential risk to the environment, human and animal health could be severely affected. Additionally, a number of studies available from the literature deal with carcinogenic pollutants found in hydrocarbon contaminated soil. Certain particular mechanisms, scenarios and/or evaluations were employed in these studies in an effort to classify and determine the level of risk towards the surrounding environment from the carcinogenic pollutants.

Angehrn’s (1998) study claims that it is essential to have a clear understanding of the concentrations required and the methods used so as to move pollutants in the environment from the hydrocarbon contaminated site to possible receptors. The usual procedure employed in identifying and categorising risks to human health - as used by the U.S. Environmental Protection Agency (U.S. EPA) are: Hazard Identification; Exposure Pathways’ Assessment; Toxicity Assessment; and Risk Characterisation (La Grega *et al*., 1994).

Nathanail *et al*. (2007) have reported that the designed risk assessment was split into two phases and two sub-phases, i.e. Phase 1a-Hazard Identification, Phase 1b-Hazard Assessment, Phase 2a- Risk Estimation and Phase 2b-Risk Evaluation. These were designed so as to evaluate the threats originating from the contaminated areas.

In order to identify the various chemical substances detected within the oil residue at contaminated sites that could potentially affect health through the risk of exposure to hazardous chemicals, *Hazard Identification* is usually employed (La Grega *et al*., 1994). A method known as *Exposure Pathways' Assessment* is utilised to estimate the exposure to certain chemicals by any environmental receptor likely to be at risk. This analysis is necessary to ascertain how the hydrocarbon contaminants can be released from the site and how migration of these contaminants to a possible receptor can be accomplished. La Grega *et al*. (1994), have defined *exposure pathways* as follows by:

a contaminant source, e.g. landfill;
a chemical release mechanism, e.g. leaching;
a transport mechanism, e.g. groundwater flow;
an exposure point, e.g. well drinking water;
an environmental receptor, e.g. consumer of drinking water;
an exposure route, e.g., ingestion;

These examples must be existent to cause exposure.

According to La Grega *et al*. (1994), Toxicity Assessment offers toxicological data for the relevant chemicals and/or predicted potential for adverse effects.

These assessments are derived from calculations of the physico-chemical properties of chemicals combined with an integrated factor for safety. In other words, toxicity can be described as a mixture of detrimental changes to biological organisms that might be attributed to chemicals under certain circumstances - which can vary from minor changes of normal functions to death (cancer) (Millner *et al*., 1992).

Risk Assessment, on the other hand, is employed to compare the effective concentrations from exposure assessment against the accepted concentration derived from the toxicity assessment. This approach allows for determination of the relative safety or risk associated with the expected exposure (La Grega *et al*., 1994).

The evaluation of human health risk assessment of hydrocarbon contaminated soil has been carried out by applying their scenarios as described in a number of studies including those of Nathanail *et al*. (2007), Angerhn (1998), Hua *et al*. (2012), Dumitran and Onutu (2010), Sarmiento *et al*. (2005), Iturbe *et al*. (2004), Irvine *et al*. (2014), Brewer *et al*. (2013) and Bowers and Smith (2014).

On the other hand, other studies have carried out numerous models, e.g. Csoil, Contaminated Land Exposure Assessment (CLEA), Risk Based Corrective Action (RBCA), and RISC-4.02 which have been utilised in risk assessment aimed at evaluating the concentration of carcinogenic and non-carcinogenic substances found in hydrocarbon contaminated sites (Searl, 2012; GSI Environmental, 2014; Pinedo *et al*., 2012; Asharaf, 2011; Chen *et al*., 2004; Tomasko *et al*., 2001; Pinedo *et al*., 2014; Spence and Walden, 2001). Some authors have investigated diseases brought on as a result of hydrocarbon contamination, for example, Amat-Bronnert *et al*. (2007), Campbell *et al*. (1993), Ordinioha and Brisibe (2013) and Osman (1997) (section 3.5 for further clarification).

The aim of this research is to examine soil contaminated with hydrocarbon; this will be carried out by means of RISC-5 assessment. The RICS-5 assessment includes a mixture of procedural risk assessment which is limited only to: *Exposure Pathway's Assessment*, *Toxicity Assessment* and *Risk Characterisation* which excludes Hazard Identification. The software program is Windows based as it is capable of undertaking fate and transport modelling, HHRA and ecological risk assessments for hydrocarbon contaminated sites. In summary, it is intended to provide assessment of the potential adverse impacts to human health (both carcinogenic and non-carcinogenic) for hydrocarbon contaminated sites (Spence and Walden, 2001).

1.3 Significance of the Study

Based on the literature review in the previous section, it is noticeable that there is a high tendency for hydrocarbon contaminated soil to affect the soil's geotechnical properties which results in unstable soil conditions within its structure. Large hydrocarbon contents within the soil tend to reduce the integrity of the soil properties resulting in defective ground stability for any forthcoming development (Caravaca & Roldan, 2003; Meegoda & Ratnaweer, 1995; Gupta & Srivastava, 2010; Pandey & Bind, 2014; Al-sanad *et al*., 1995; Al-sanad & Ismael, 1997; Khamehchiyan *et al*., 2007).

Another concern is *oil lake* contamination which can affect the geochemical properties of the soil creating a chemically aggressive atmosphere. Hydrocarbon chemical composition present within sandy soil can potentially affect the soil's geochemical properties forming a chemical composition that can have damaging effects on the environment (Barua *et al*., 2011; Khuraibet & Attar, 1995; Al-Duwaisan & Al-Naseem, 2011; Onojake & Osuji, 2012; Sato *et al*., 1997; Perkinelmer, 2010; Benyahia *et al*., 2005; Rahman *et al*., 2010).

The major issue related to hydrocarbon contaminated soil is that it can greatly affect human health. Thus any proposed urban development planned in areas of concern can also be affected. The fact that carcinogenic substances are present within these hydrocarbon chemical compositions can cause an increase in respiratory diseases and cancer, e.g. asthma and lung cancer (Angerhn, 1998; La Grega *et al*., 1994; Hua *et al*., 2012; Dumitran & Onutu, 2010; Iturbe *et al*., 2004; Sarmiento *et al*., 2005; Irvine *et al*., 2014; GSI Environmental, 2014; Brewer *et al*., 2013; Pinedo *et al*., 2012; Asharaf, 2011; Spence & Walden, 2001).

The above issues, related to soil contaminated with *oil lakes* residue resulting from the 1991 Iraqi invasion of Kuwait, could create obstacles to future growth in construction projects and urban development within the vicinity of the area of concern.

As demonstrated by Al-Sarawi *et al*. (1998b), the Kuwaiti Greater Burgan Oil Field requires a detailed survey of the degree of contamination of the soil which is believed to be as high as 80 %.This site was selected because it is not only highly polluted but also because of its proximity to the metropolitan city since at any time in the near future, development and construction projects are likely to take place. In any case there is an urgent need to research and carry out a thorough exploration on the geotechnical and geochemical properties of the Greater Burgan Oil Fields. To that effect, ground modelling software RISC-5 should be used for risk assessment to human health. The area is highly contaminated with hydrocarbon but the land is expected to be in high demand for future developmental projects.

Furthermore, most of the research dealing with geotechnical and geochemical characterisation of the hydrocarbon contaminated soil utilises soil which is artificially contaminated by mixing virgin soil with various ratios of crude oil. To the best of author knowledge, no detailed study has been dealt with the Kuwaiti hydrocarbon contaminated soil after such long drying years of crude oil contamination.

Construction contaminated areas may include residential, commercial and healthcare building projects. The key issue is that since the 1990 invasion by Iraq, approximately 49.13 km^2 area of Kuwaiti land is covered with *oil lakes* (PEC, 1999). Most of the hydrocarbon contaminated sites (*oil lakes* in particular) are close to residential areas which the Kuwait Government plans to further develop. However, development should first take contamination into consideration before any development in the hydrocarbon contaminated sites takes place. Furthermore it is essential to assess the effect and risk of hydrocarbon residue on human health and to estimate the possible levels of risk.

1.4 Scope of this Work

The focus of the experimental work for this study is centred on the geotechnical and geochemical study of hydrocarbon contaminated soil and the way it could affect human health. To achieve this, risk assessment will be carried out using ground modelling software (RICS-5). The risk assessment will be developed and utilised as shown in Chapter 7.

To simplify the study, soil samples were obtained from two separate areas within the Greater Burgan Oil Field at Al Magwa area; that is, from the contaminated site with dry *oil lake* and also from a nearby site of soil before contamination. The latter being called the *non-contaminated site.* The laboratory tests conducted were focused on the geotechnical and geochemical properties, i.e. the physical, structural and chemical properties which include the following:

(1) To ascertain the variation in physical properties of the hydrocarbon contaminated soil performed by comparing samples taken from both contaminated and non-contaminated areas, typically applying Sieve Analysis test for PSD, SEM, Atterberg Limit and Constant Head permeability tests.

(2) To ascertain the variation in Shear strength, (both contaminated and non-contaminated soil samples were taken to perform a Direct Shear test).

(3) To undertake chemical tests including the: pH coefficient; water soluble Cl- and SO_3 & SO_4; EA and GC-MS; the aim was to ascertain: the acidity or alkalinity; the suitability of concrete type to be utilised in any future construction projects; the percentages of hydrogen, carbon, nitrogen and sulphur as finger printing and hydrocarbon chemical

composition and their value in mg/kg of the oil polluted soil in both the contaminated and non-contaminated sites.

The risk assessment on human health entails the use of the ground modelling method known as RISC-5 software. The software was developed with the aim of classifying the composition of hydrocarbon chemicals in the contaminated soil and the values in mg/kg.

1.5 Structure of the Study

This study comprises ten chapters showing the activities undertaken within the duration of the work as follows:

Chapter 1- provides the aims and objectives of the study (as defined above), presents the project background, identifies the importance of the study and outlines the scope of work and how the study has been organised.

Chapter 2 - presents a study context within the state of Kuwait, with particular reference to its location, climate, soil condition, geology, degradation of contaminated lands with *oil lakes,* pollution to ground and environment, urban expansion due to construction and human health risks from the 1991 *oil lakes*.

Chapter 3 – provides an overview of the hydrocarbon contaminants and covers a detailed literature review of *geotechnical and geochemical* characterisations of the soils contaminated by hydrocarbon residue and the affects on human health.

Chapter 4 - outlines the initial phases of the research programme identified as experimental plan and phases, hazards and restriction, sampling plan and strategy, soil characterisation and statistical data analysis.

Chapter 5 - illustrates the results of the laboratory tests with regard to geotechnical characteristics of both contaminated and non-contaminated soils. This chapter also discusses the main outcomes of the study demonstrating that the study aims have been achieved by connecting the experimental findings with other studies found in the literature.

Chapter 6 - outlines the laboratory program associated with the geochemical properties of the contaminated soil and hydrocarbon contaminated soil samples. Additionally, a discussion on the main outcomes of the study and how the research objectives were achieved using the experimental results linked with other studies in the literature.

Chapter 7 - describes Particulars of the HHRA scenarios which propose how to deal with hydrocarbon residue contamination. The analysis and results of the ground modelling development (RISC-5) software concerning human health and measuring the consequences of Kuwait’s dry *oil lake* contaminated soil on human health (the *oil lake* residue has existed since 1990) are also provided.

Chapter 8 - focuses on interpretation of the results exhibited in Chapters five, six and seven and the development of the understanding of the main research findings.

Chapter 9 - presents the final conclusion of the study.

Chapter 10- presents proposes recommendations for further work.

2. CONTEXT OF STUDY: KUWAIT

2.1 Introduction

This chapter aims to provide an introduction to: the location of Kuwait; assess and classify the soil conditions; describe its climatic conditions; explain the geology; provide an introduction and classification of the hydrocarbon contaminated lands; present descriptions and clarification of the Soil and Environment Pollution; to investigate the risks from oil spills on human health; and finally to report on the urban expansion of the construction sector in Kuwait.

This means that a detailed description will be presented pertaining to Kuwait's location, climatic conditions, ground conditions, geology, degradation of hydrocarbon contaminated land, ground and environment pollution, urban growth of construction and risks to human health due to residue of *oil lakes*.

2.2 Kuwait Location

Geographically, Kuwait is situated between latitude 28° 30' and 30° 05' north of the Equator and longitude 46' 30" and 48' 30" east of Greenwich; at the north-western corner of the Arabian Gulf. It is a small country with an area of only 17,818 km^2, (Murakami, 1995). Iraq is situated on its north-west border and Saudi Arabia on its south and south- west border (Figure 2.1 below).

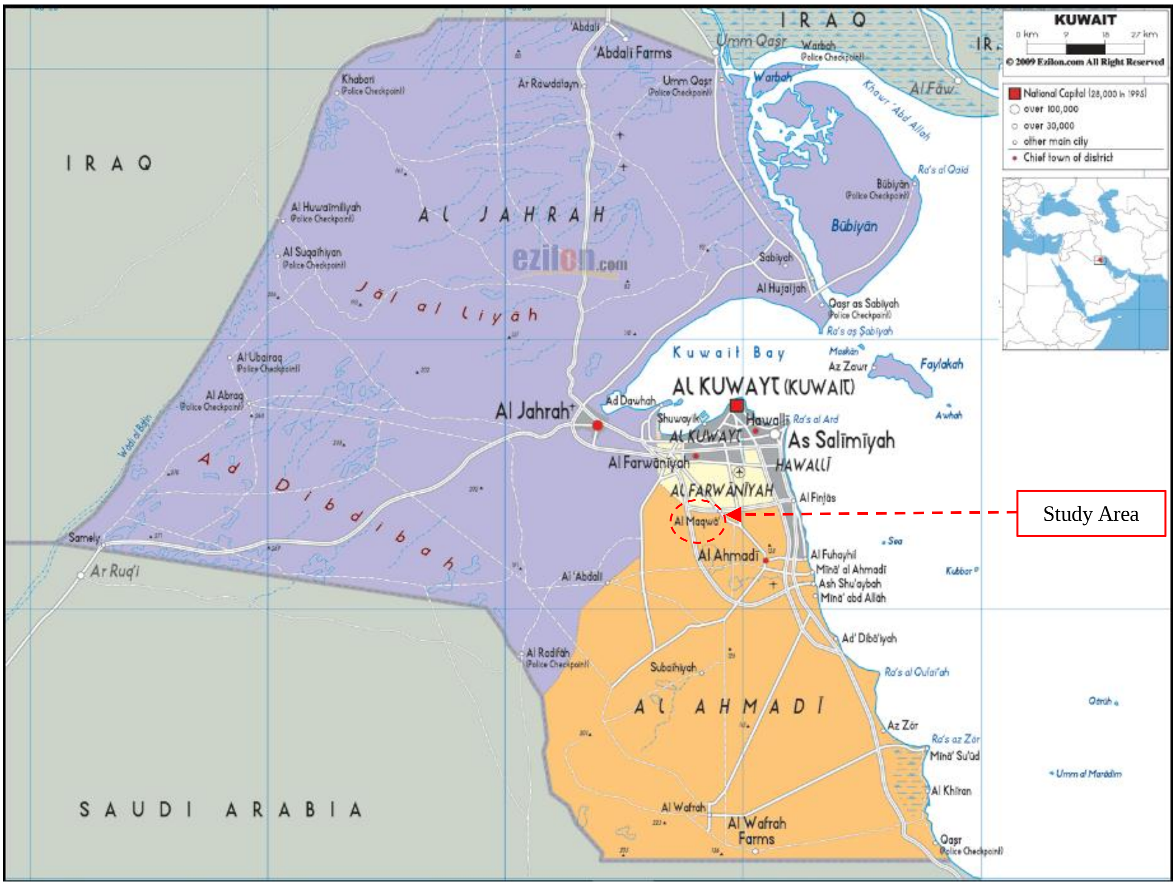


Figure 2.1. Kuwait borders with adjacent countries (Source: Ezilon, 2015).

Due to its strategic location, Kuwait is regarded as one of the main gateways to the Arabian Peninsula. The distance between the southern and northern most points of the country is about 200 km (124 miles) while the eastern border is approximately 170 km (106 miles) from the western border along latitude 29’.

The total length of its borders - or the perimeter of the country - is around 685 km (426 miles), which includes 195 km (121 miles) at the eastern border facing the Arabian Gulf. Therefore, 490 km (304 miles) is land frontier with 250 km (155 miles) fronting the Kingdom of Saudi Arabia in the south/west and 240 km (149 miles) bordering the Republic of Iraq in the north/west.

2.3 Kuwait Climate

According to Nayfeh (1990), the climate of Kuwait can be described as arid, i.e. hot, dry and lengthy summers with recurrences of dust phenomena and short, cold winters with very little rain. Summer usually starts at the end of March and continues towards the end of October. The true winter begins mid-December and usually ends towards mid-February.

Al-Kulaib (1984) claims that spring and autumn seasons are extremely short transitional periods. The temperature differences between peak summer and winter is enormous; for example, during summer, the long duration of direct sunshine onto the ground causes a spiralling increase in temperature that can peak at 50 °C or higher in comparison with an average monthly temperature of between 45 °C and 28 °C. The temperature during winter through December and January, however, is exceptionally low; the average winter temperature is between 21 °C and 8 °C. However, the lowest temperature may reach as low as 0 °C or, at times, even lower. Kuwait receives a low annual rainfall of only 110 mm.

Another prevalent aspect of Kuwait's climate is the recurrence of dust storms; the dust from the north west of the Arabian Gulf contributes to an annual deposit of 1 mm; similar depositions take place along the whole coastal line. Additionally, there is a clear variation in humidity which fluctuates from 60.9 % to 21.5 % from January to June. However, depending on the season, there is also a high rate of evaporation which can vary from one place to another with an average rate of 10.3 mm per day. Al-Jassar and Rao (2010, p. 4375), claim that the rate of evaporation varies in January and June from 4.6 mm/day to 22.9 mm/day respectively.

2.4 Kuwait Solid Geology

Kuwait's geological outline will be described in the following section. This will include the rock structure which underlines Kuwait and also the aquifer's structural control. The basic concerns are with the surface and sub-surface lithologies of the recent sediments. To examine these areas more closely they will be divided into 3 sub-divisions, as follows: 1) the surface geology of Kuwait; 2) the stratigraphy of Kuwait; 3) Kuwait's aquifer system.

2.4.1 Geology of Kuwait

The state of Kuwait is located at the north-eastern corner of the Arabian Plate between the Precambrian shield to the west and the Zagros Fold belt towards the northeast. It is bordered on the west and north by Iraq and on the south by Saudi Arabia (Figure 2.2).

As stated by Al-Sulaimi and Al-Ruwaih (2004), the state of Kuwait lies on three major physiographic areas. A sequence of sedimentary rocks belonging to the Arabian platform overlying the Precambrian Arabian Shield is present to the south and southwest.

The state of Kuwait lies on three major physiographic areas, i.e. a sequence of sedimentary rocks belonging to the Arabian platform overlying the Precambrian Arabian Shield is present to the south and southwest. These rocks of sedimentary outcrop are present within a large belt along the eastern margin, which has less resistivity and has eroded to become a series of low land strips. The Mesopotamian plain, with the Tigris and Euphrates Rivers' delta at the head of the Arabian Gulf, lies to the north-northwest of Kuwait while the shallow marginal Arabian Gulf Sea which fences Kuwait lies to the east (Figure 2.2) (Al-Sulaimi & Al-Ruwaih, 2004).

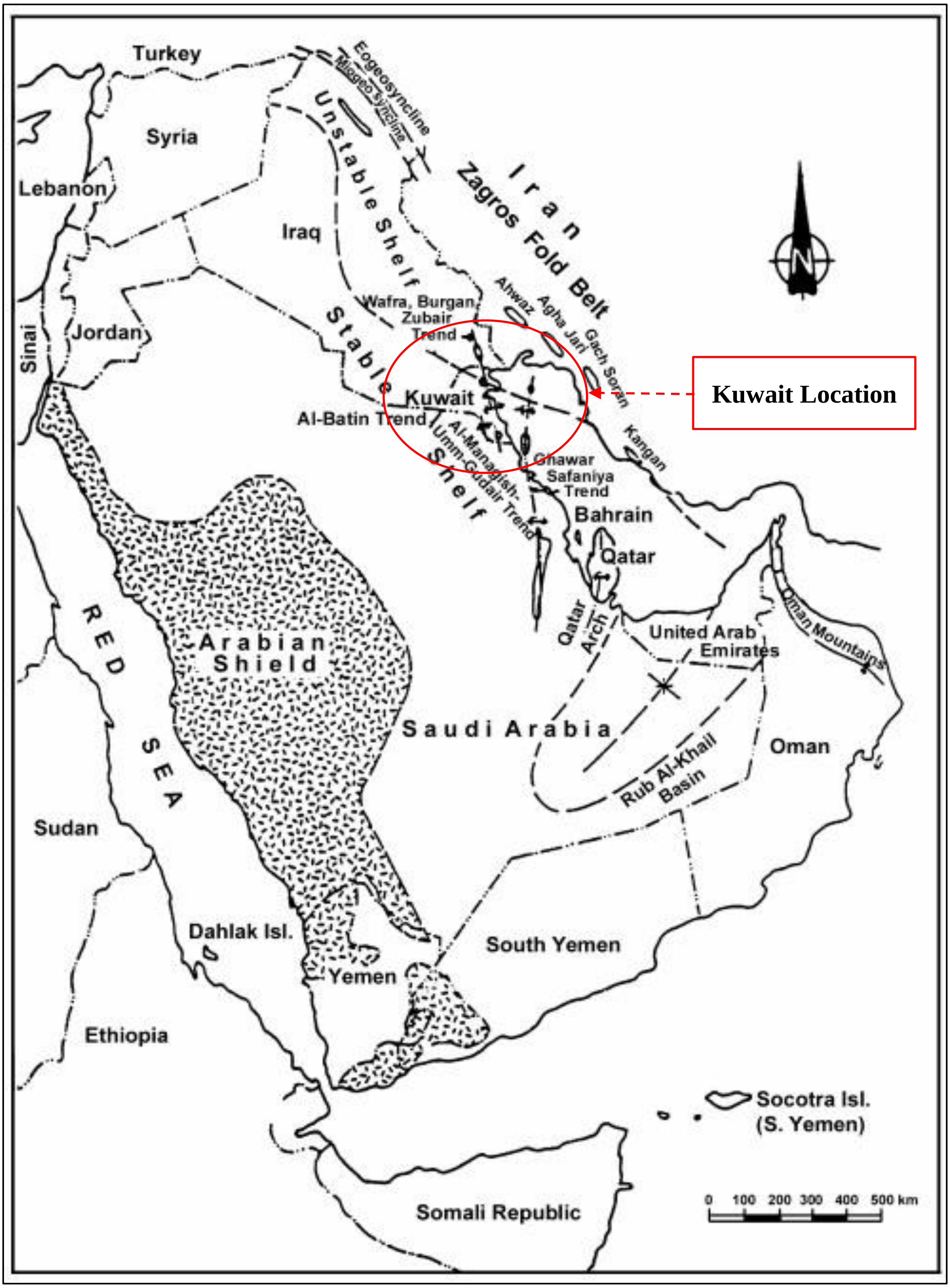


Figure 2.2. Major tectonic units of the Arabian Gulf region (Source: Al-Sulaimi & Al-Ruwaih, 2004).

The topography of Kuwait can generally be described as monotonously flat with moderately rolling plains separated by occasional scarps, small hills, valleys of ephemeral streams and shallow wide inland depressions. Only in the *Jal-Az-Zor* small *escarpment* along the north shore of Kuwait Bay *Ahmadi Ridge* paralleling the east coast of Kuwait hills at *Wara* and *Burgan*, and the *Wadi al Batin* along the western border, is the local relief not low (Al-Sulaimi & Al-Ruwaih, (2004)).

As shown in Figure 2.3, there are four physiographic provinces within the deserts of Kuwait, i.e. i) Al-Dibdibba gravelly plain; ii) sand flat; iii) coastal flat; and iv) coastal hills.

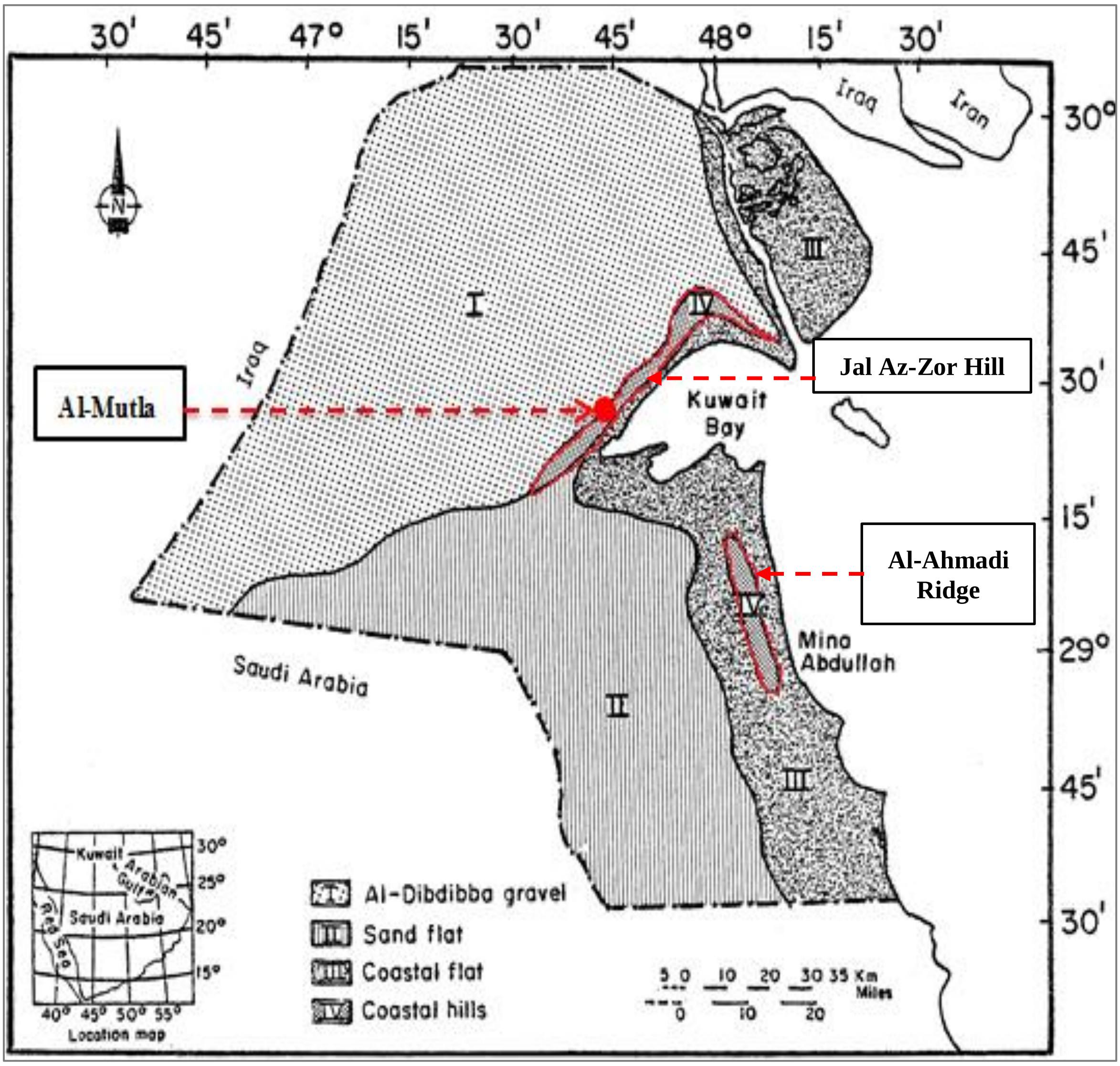


Figure 2.3. The physiographic provinces of Kuwait (Source: Al-Sulaimi & Mukhopadhyay, 2000).

The surface and near surface geology of Kuwait has been dominantly controlled by the Tertiary tectonic activity of the Arabian Plate. The northern and western sections of the country lie within a huge previous outwash fan which expands far beyond the international boundaries with Saudi Arabia and Iraq (Figure 2.4); this was originally deposited by a watercourse, a precursor of Wadi Al-Batin and ending in Khor Al-Hammar in Iraq and the northern coast of Kuwait Bay, it also extends well over the Dibdibba plain in Saudi Arabia and Iraq. The slope to the north of Kuwait is continuous until broken by a shallow wide inland depression caused by an inner drainage pattern (Umm Al-Aish, and Al-Raudhatain) trailed by an extremely gentle dome-Shaped hill (reflection of the Sabriyah Raudhatain Structures) controlling the watersheds (Al-Sulaimi & Al-Ruwaih, 2004).

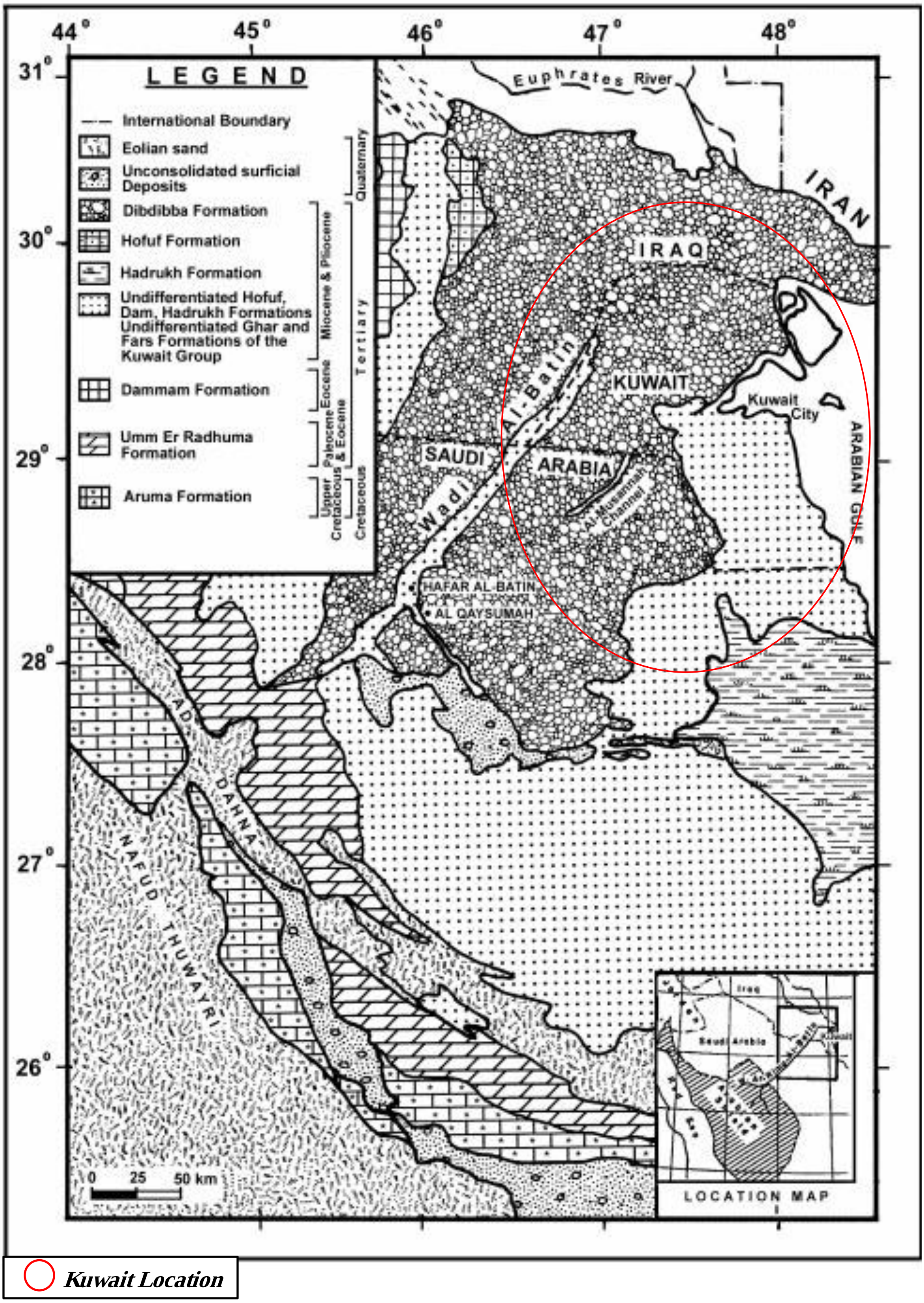
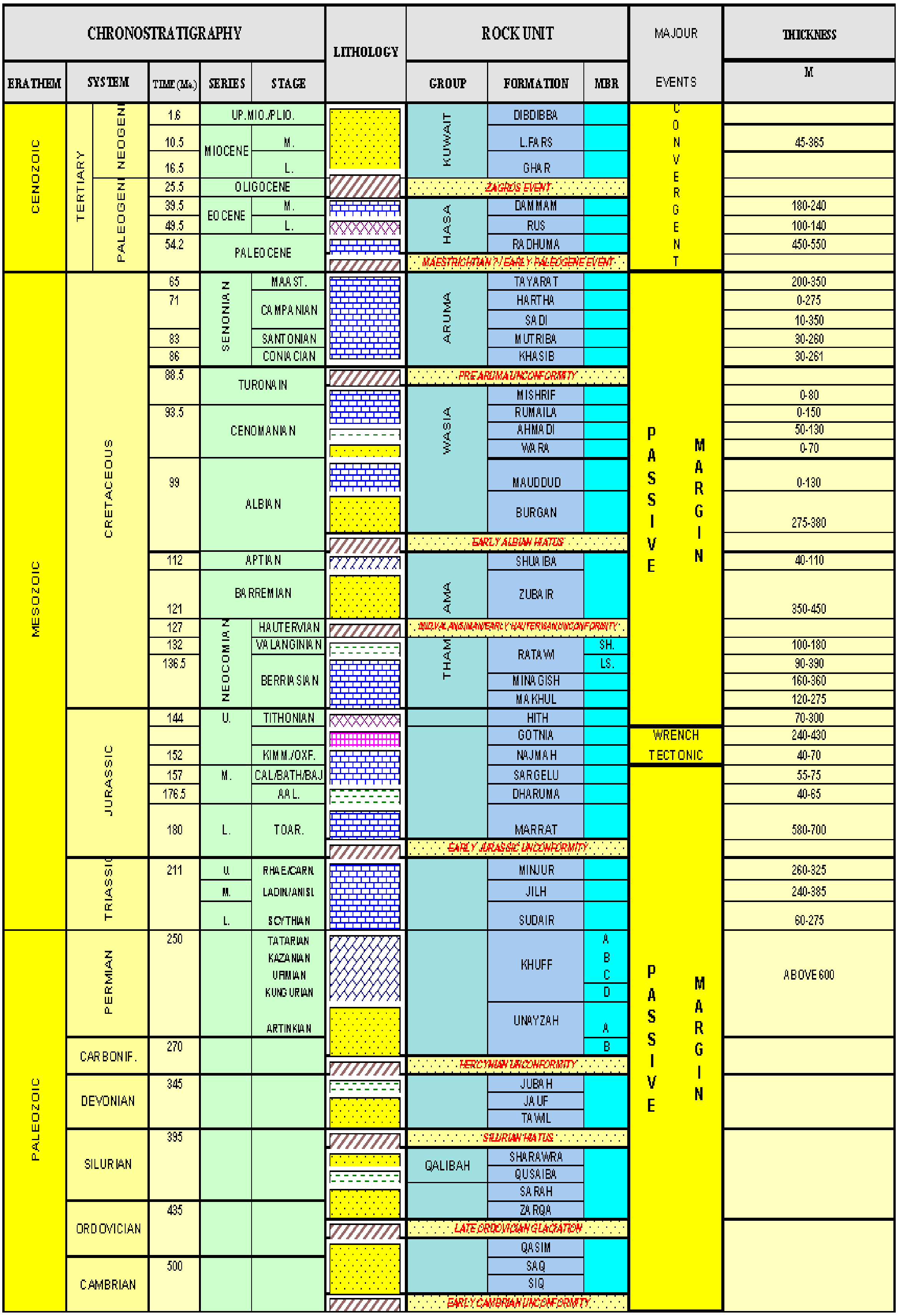


Figure 2.4.The geological map at the northern part of the Arabian Gulf region (Source: Al-Sulaimi & Al-Ruwaih, 2004).

2.4.2 Stratigraphy

The Homocline of the Arabian Peninsula is part of Kuwait's interior and from the Miocene to recent periods rocks have been exposed at the surface of this area - and throughout the whole of Kuwait. However, because of the very 'low dips and similarity of lithology' it can be difficult to accurately correlate their formations; additionally, the accuracy of tracing marker beds can only be sustained for a short while (Tanoli *et al.*, 2015).

In accordance to Al-Sulaimi and Mukhopadhyay's (2000), the stratigraphy of the tertiary succession of Kuwait can be generalised, (as illustrated in Figure 2.5). Kuwait's Stratigraphy contains several groups, e.g. the Kuwait, Hasa, Aruma, Wasia, Thamama, Riydh and Marrat groups - with each group being sub-divided into several formations. However, for the purposes of this study, only the strata close to the surface – the Kuwait and Hasa groups - will be dealt with in detail.



CHRONOSTRATIGRAPHY					LITHOLOGY	ROCK UNIT			MAJOUR EVENTS	THICKNESS
ERATHEM	SYSTEM	TIME (Ma.)	SERIES	STAGE		GROUP	FORMATION	MBR		M
CENOZOIC	TERTIARY NEOGENE	1.6	UP.MIO./PLIO.			KUWAIT	DIBDIBBA		CONVERGENT	
		10.5	MIOCENE	M.			L.FARS			45-365
		16.5		L.			GHAR			
	PALEOGENE	25.5	OLIGOCENE				ZAGROS EVENT			
		39.5	EOCENE	M.		HASA	DAMMAM			180-240
		49.5		L.			RUS			100-140
		54.2	PALEOCENE				RADHUMA			450-550
							MAESTRICHTIAN ?/ EARLY PALEOGENE EVENT			
MESOZOIC	CRETACEOUS	65	SENONIAN	MAAST.		ARUMA	TAYARAT		PASSIVE MARGIN	200-350
		71		CAMPANIAN			HARTHA			0-275
							SADI			10-350
		83		SANTONIAN			MUTRIBA			30-260
		86		CONIACIAN			KHASIB			30-261
		88.5	TURONAIN				PRE ARUMA UNCONFORMITY			
		93.5	CENOMANIAN			WASIA	MISHRIF			0-80
							RUMAILA			0-150
							AHMADI			50-130
							WARA			0-70
		99	ALBIAN				MAUDDUD			0-130
							BURGAN			275-380
							EARLY ALBIAN HIATUS			
		112	APTIAN			AMA	SHUAIBA			40-110
		121	BARREMIAN				ZUBAIR			350-450
		127	NEOCOMIAN	HAUTERVIAN			MID.VALANGINIAN/EARLY HAUTERIVIAN UNCONFORMITY			
		132		VALANGINIAN		THAM	RATAWI	SH.		100-180
								LS.		90-390
		136.5		BERRIASIAN			MINAGISH			160-360
							MAKHUL			120-275
	JURASSIC	144	U.	TITHONIAN			HITH			70-300
							GOTNIA		WRENCH TECTONIC	240-430
		152		KIMM./OXF.			NAJMAH		PASSIVE MARGIN	40-70
		157	M.	CAL/BATH/BAJ			SARGELU			55-75
		176.5		AAL.			DHARUMA			40-65
		180	L.	TOAR.			MARRAT			580-700
							EARLY JURASSIC UNCONFORMITY			
	TRIASSIC	211	U.	RHAE/CARN.			MINJUR			260-325
			M.	LADIN/ANISL			JILH			240-385
			L.	SCYTHIAN			SUDAIR			60-275
PALEOZOIC	PERMIAN	250		TATARIAN KAZANIAN UFIMIAN KUNGURIAN			KHUFF	A B C D		ABOVE 600
				ARTINKIAN			UNAYZAH	A B		
	CARBONIF.	270					HERCYNIAN UNCONFORMITY			
	DEVONIAN	345					JUBAH			
							JAUF			
							TAWIL			
							SILURIAN HIATUS			
	SILURIAN	395				QALIBAH	SHARAWRA			
							QUSAIBA			
							SARAH			
							ZARQA			
	ORDOVICIAN	435					LATE ORDOVICIAN GLACIATION			
							QASIM			
							SAQ			
	CAMBRIAN	500					SIQ			
							EARLY CAMBRIAN UNCONFORMITY			

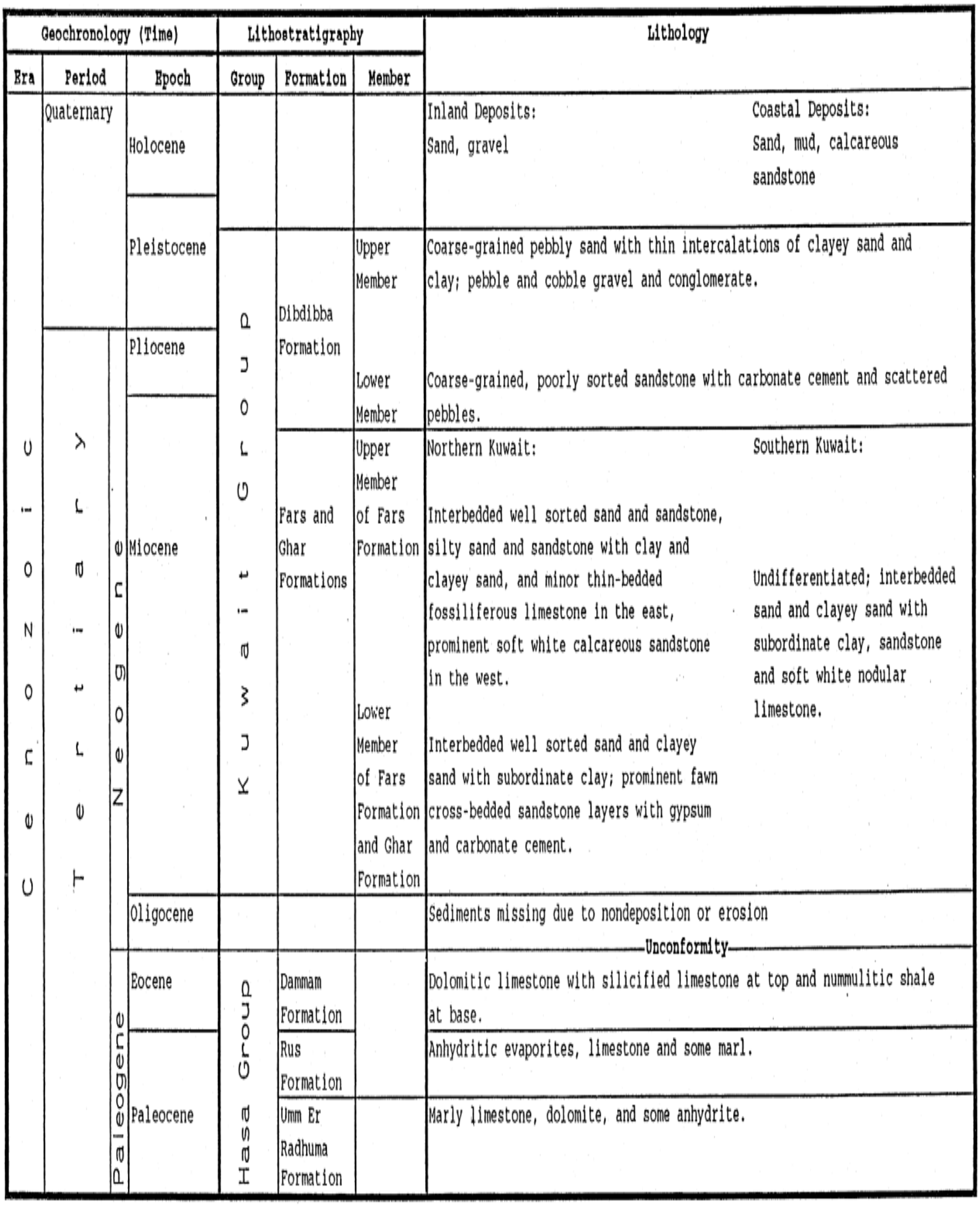
Figure 2.5. The chronostratigraphy and lithology of Kuwait (Source: Carman, 1996).

The Kuwait Group consists of the *Dibdibba*, *Lower Fars* and *Ghar* Formations (Table 2.1). The Dibdibba Formation can be categorised into two groups, namely, the Lower Member of the Mio-Pliocene age and the Upper Member of the Plio-Pleistocene age. Typically, the former is comprised of very coarse grained, sandy and pebbly sandstone with a carbonate cement. The latter constitutes gravelly sand and sandy gravel. The thickness of this Dibdibba Formation is about 107 m (Al-Sulaimi & Mukhopadhyay, 2000; Al-Awadi *et al*., 1997); while the lower Fars Formation is up to 350 m thick with a deposit of Lanhian–Serravalian; it consists of evaporites interbedded with clastic red beds and carbonates of a shallow marine environment (Al-Awadi *et al*., 1997). The Ghar Formation overlies the Dammam Formation non-conformably and consists of sands and gravels with some rare anhydrite, clays with the sandy limestone inter-bedded with a thickness of up to 274 m (Al-Awadi *et al*., 1997).

The Hasa Group is comprised of Dammam, Rus and Umm Er-Radhuma Formations. The Dammam Formation (middle to upper Eocene) - which varies in thickness from about 150 m in the southwest to about 275 m in the northeast - consists of a massive chalky dolomicritic upper member, laminated biomicrites and domomicrites of the middle member, and a nummulitic dense biomicritic lower member (Al-Sulaimi & Al-Ruwaih, 2004).

The Rus Formation (Lower-Middle Eocene) varies in thickness from 70-200 m and is characterised by low porosity; the succession is made of limestone that is soft, carbonate marly, gypsiferous plus minor sand and anhydrite **(**Al-Sulaimi & Al-Ruwaih, 2004**).** The Emm Er-Radhuma Formation (Paleocene-Lower Eocene) non-conformably overlies the Tayarat Formation of the Aruma Group. This Formation is encountered at depths of 164-256 m in the southwest of Kuwait. The general lithology is made up of dolomite and anhydrite, in places silicified and also intercalated with lignite.

Table 2.1. Surface stratigraphic classification and near-surface deposits in Kuwait (Source: Al-Sulaimi & Mukhopadhyay, 2000).



Geochronology (Time)				Lithostratigraphy			Lithology
Era	Period		Epoch	Group	Formation	Member	
Cenozoic	Quaternary		Holocene				Inland Deposits: Sand, gravel Coastal Deposits: Sand, mud, calcareous sandstone
			Pleistocene	Kuwait Group	Dibdibba Formation	Upper Member	Coarse-grained pebbly sand with thin intercalations of clayey sand and clay; pebble and cobble gravel and conglomerate.
	Tertiary	Neogene	Pliocene			Lower Member	Coarse-grained, poorly sorted sandstone with carbonate cement and scattered pebbles.
			Miocene		Fars and Ghar Formations	Upper Member of Fars Formation	Northern Kuwait: Interbedded well sorted sand and sandstone, silty sand and sandstone with clay and clayey sand, and minor thin-bedded fossiliferous limestone in the east, prominent soft white calcareous sandstone in the west. Southern Kuwait: Undifferentiated; interbedded sand and clayey sand with subordinate clay, sandstone and soft white nodular limestone.
						Lower Member of Fars Formation and Ghar Formation	Interbedded well sorted sand and clayey sand with subordinate clay; prominent fawn cross-bedded sandstone layers with gypsum and carbonate cement.
			Oligocene				Sediments missing due to nondeposition or erosion
							Unconformity
		Paleogene	Eocene	Hasa Group	Dammam Formation		Dolomitic limestone with silicified limestone at top and nummulitic shale at base.
					Rus Formation		Anhydritic evaporites, limestone and some marl.
			Paleocene		Umm Er Radhuma Formation		Marly limestone, dolomite, and some anhydrite.

Based upon Al-Sulaimi & Al-Ruwaih (2004), Hunting Geology and Geophysics (HGG) (1981), have prepared a simplified geological map of Kuwait as requested by the Kuwait Oil Company (KOC) (Figure 2.6).

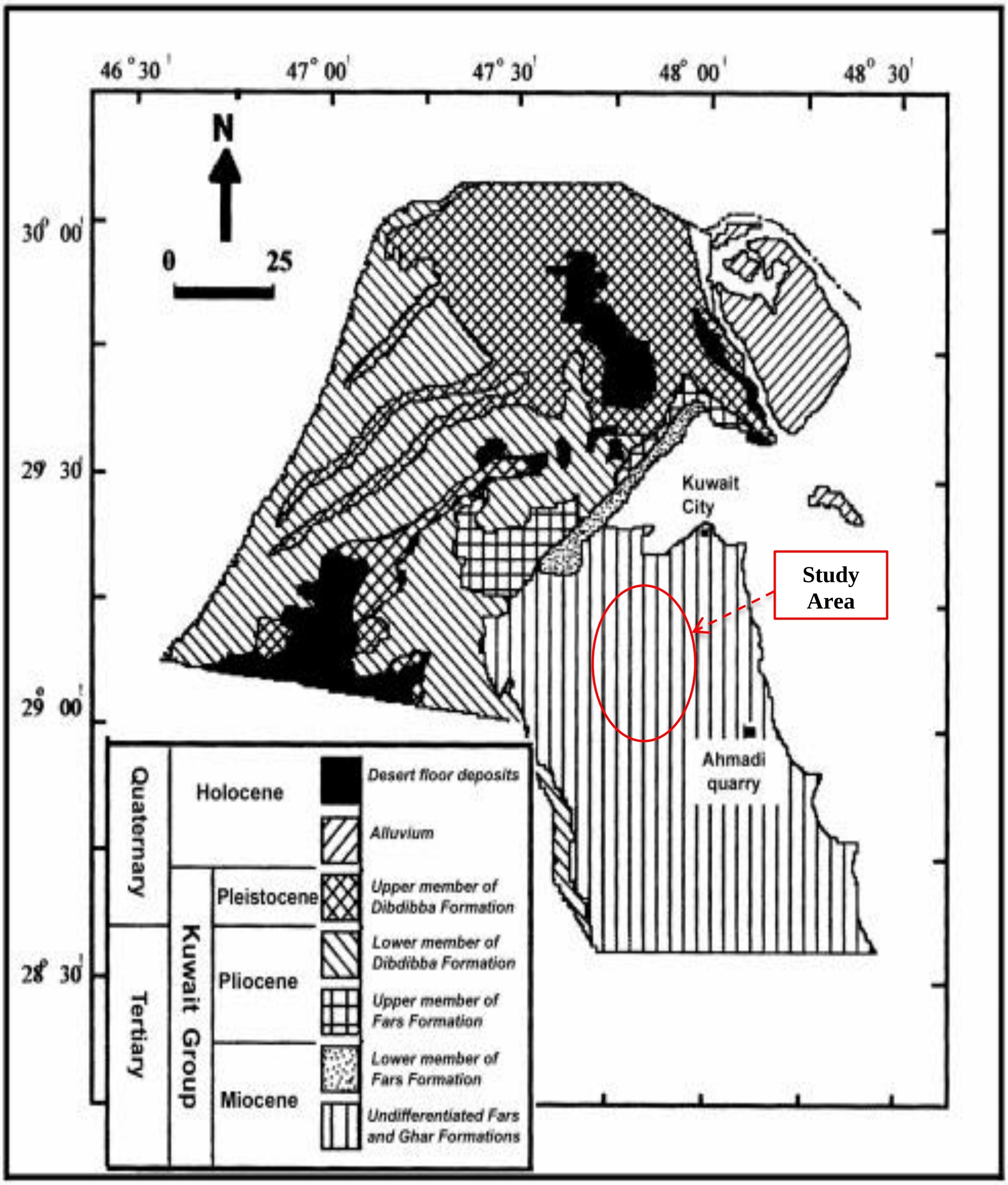


Figure 2.6. Kuwaiti surface geological map (Source: Al-Sulaimi & Al-Ruwaih, 2004).

The Dibdibba Formation gravels cover most of the area in northern Kuwait to the north and northwest of Kuwait Bay. Additionally, the Dibdibba Formation - as shown in Figure 2.6 - is limited to the northern part of Kuwait. The Lower Fars fossiliferous equivalent sediments do not extend to the north so the threefold subdivision of the clastic sediment does not exist there. Therefore, the clastic sediments of the Kuwait Group are located at southern part of Kuwait. They are classified as undifferentiated Ghar and Lower Fars. The area chosen to be studied in this work is part of the Burgan *oil lake* which lies in the south of Kuwait.

The formations of the main oil production areas in Kuwait differ from one location to another. Table 2.2 shows the summary of all the reservoirs producing the majority of oil in Kuwait.

Table 2.2. Formations of the main oil producing reservoirs based on oil fields locations in Kuwait.

Oil Field Name	Formations Names of the Main Oil Producing Reservoir	Formations Periods	References
Raudhatain Field	Ratawi, Zubair, Burgan and Mauddud Formations.	Cretaceous.	(Carman, 1996).
Sabiriyah Field	Burgan, Mauddud and thin oil sands in the Ratawi Formations.		
Bahrah Field	Burgan and Mauddud Formations.		
Khashman Field	Wara, Mauddud and Burgan Formations.		
Greater Burgan Field	Burgan, Mauddud and Wara Formations.		
Minagish Field	Burgan, Wara and Mishrif Formation/ Marrat, Sargelul and Najmah Formations.	Cretaceous/ Jurrasic.	
Abduliyah and Dharif Fields	Marrat Formation.	Jurrasic.	
Umm Gudair Field	Minagish Formation.	Cretaceous.	(Al-Khaled *et al*., 2012).

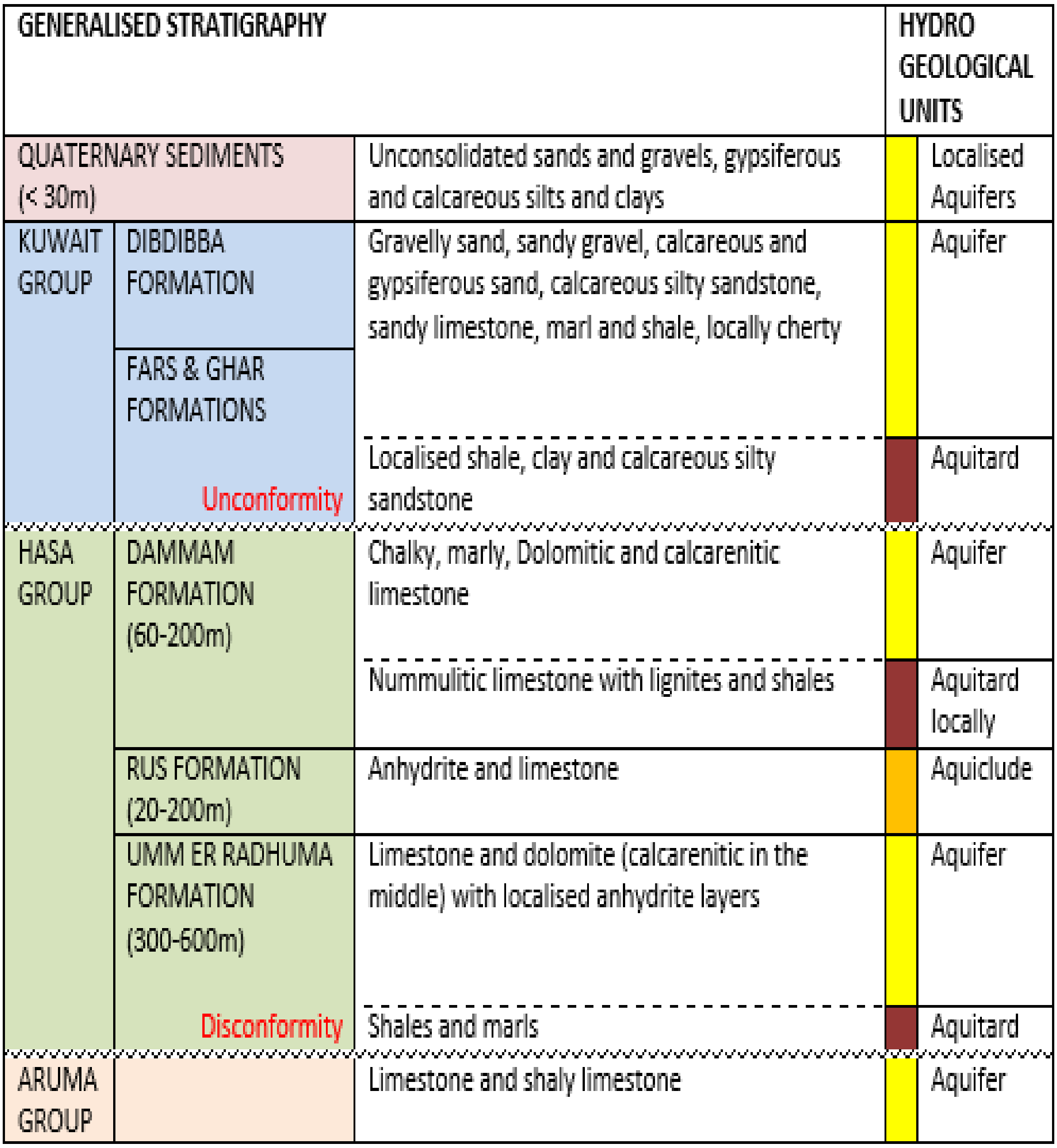
2.4.3 Hydrogeology

The lithological characteristic of the Arabian Peninsula has been controlled by the tectonic and depositional environment and thus has defined the aquifer and aquitards of the sedimentary sequences of Kuwait (Figure 2.7).

The annual rainfall in Kuwait is very low, e.g. 110 mm of rain falls between December and January, and Kuwait is known to be an arid region; there is, in fact very little run off or groundwater. There is also a high rate of evaporation, e.g. a rate of 10.3 mm per day (see Section 2.3). However, Recharge occurs in the areas of depression such as Umm-Alaish and Ar-Raudhatain, which, in fact, create isolated fresh "groundwater lenses floating on more saline water" (Alsharhan *et al.*, 2001, p. 149). Thus, it can be seen that the importance of both quantity and quality of groundwater is of vital importance.

Kuwait's aquifer system contains two major formations in descending order as follows: 1) The Kuwait Group (which includes Dibdibba, Fars and Ghar Formations) and 2) the Hasa Group (comprising Dammam, Rus and Radhuma Formations).

Accordiong to Hadi (n.d.) *"...the upper units, including the saturated part of the Kuwait Group and the underlying Dammam Formation",* are *"....separated from the deeper units by mostly impervious dense anhydrite layers of the Rus Formation*." Nevertheless, the apparent hydrogeological heterogeneity, notwithstanding, the system does provide a *"...relatively continuous flow in the region and may be characterized as a multi-layered semi-confined aquifer."*



GENERALISED STRATIGRAPHY			HYDRO GEOLOGICAL UNITS	
QUATERNARY SEDIMENTS (< 30m)		Unconsolidated sands and gravels, gypsiferous and calcareous silts and clays	🟨	Localised Aquifers
KUWAIT GROUP	DIBDIBBA FORMATION FARS & GHAR FORMATIONS	Gravelly sand, sandy gravel, calcareous and gypsiferous sand, calcareous silty sandstone, sandy limestone, marl and shale, locally cherty	🟨	Aquifer
	Unconformity	Localised shale, clay and calcareous silty sandstone	🟫	Aquitard
HASA GROUP	DAMMAM FORMATION (60-200m)	Chalky, marly, Dolomitic and calcarenitic limestone	🟨	Aquifer
		Nummulitic limestone with lignites and shales	🟫	Aquitard locally
	RUS FORMATION (20-200m)	Anhydrite and limestone	🟧	Aquiclude
	UMM ER RADHUMA FORMATION (300-600m)	Limestone and dolomite (calcarenitic in the middle) with localised anhydrite layers	🟨	Aquifer
	Disconformity	Shales and marls	🟫	Aquitard
ARUMA GROUP		Limestone and shaly limestone	🟨	Aquifer

Figure 2.7. Hydrogeological and stratigraphy subdivision of the aquifer system in Kuwait (Source: Mukhopadhyay *et al*., 1996).

Al-Rashed and Sherif (2001, p. 779) claim that the saturated sediments of the Kuwait Group can be separated hydrogeologically into three units (Figure 2.8). These are known as *Upper Kuwait Group aquifer, A*; *Lower Kuwait Group aquifer, C;* and *Middle Kuwait Group aquitard B.* The former two have the capacity to store and transmit water, the latter has low permeability bands and clayey lenses both of which, in combination, are used as an aquitard for large areas of the city. Figure 2.8 shows the hydrogeological system and groundwater flow in Kuwait.

According to Al-Rashed and Sherif (2001, p. 779) *"...the phreatic conditions occur in the upper unit of the Kuwait Group aquifer"*. However, depending on the thickness of the low permeable layers, the groundwater flow in the lower unit is subjected to semi-confined or confined conditions, within both the Kuwait Group and the Dammam Formation. The drainage system depends basically on the hydrogeological characteristics of the Kuwait group with its interactions with the underlying units. Al-Rashed *et al*. (2010, p.108) specify that the general flow of water in Kuwait comes from the southwest towards the northeast, it then discharges into the Arabian Gulf Shatt Al-Arab.

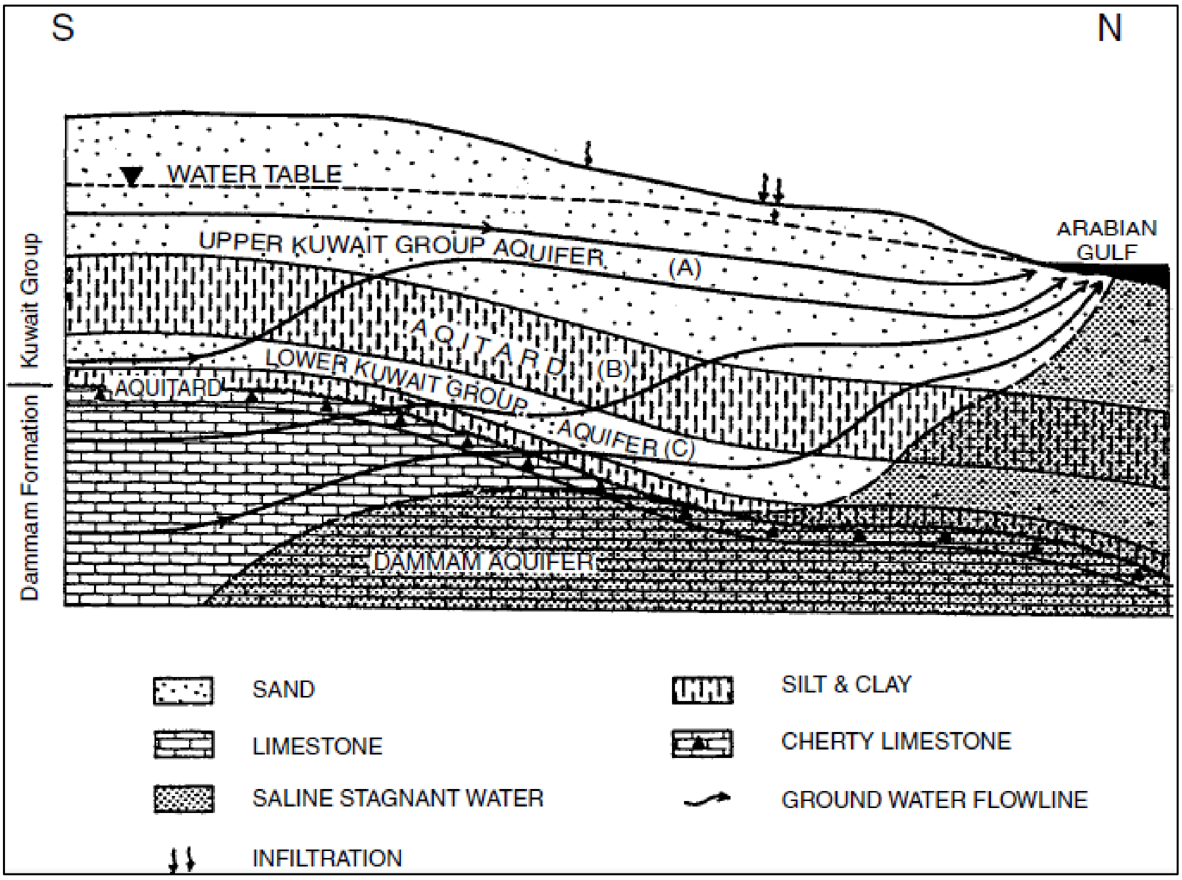


Figure 2.8. Schematic representation of the hydrogeological system and ground water flow in Kuwait (Source: Al-Rashed & Sherif, 2001, p. 779).

Bretzler (n.d., p.2) reports that the quality of groundwater ranges from mostly brackish to highly saline, in fact, only two small regions in the north of Kuwait, - Raudhatain and Umm Al-Aish - have freshwater lenses; these lie in the upper part of the Kuwait Group. The two areas have drainage basins with large catchment areas. When there is rainfall, recharged rainwater is taken from the playa lakes which have formed at the lowest point of the basins.

Kuwait's brackish and saline groundwater is recharged from Saudi Arabia. In fact, according to Al-Ali (2008, p. 156) Saudi Arabia provides the Kuwait Group with its water through the lateral inflow and upward leakage via the Dammam limestone.

Bretzler (n.d., p. 3) claims that huge amounts of brackish groundwater for irrigation and domestic purposes are extracted from the sites located in the centre and south of the country (Figure 2.9).

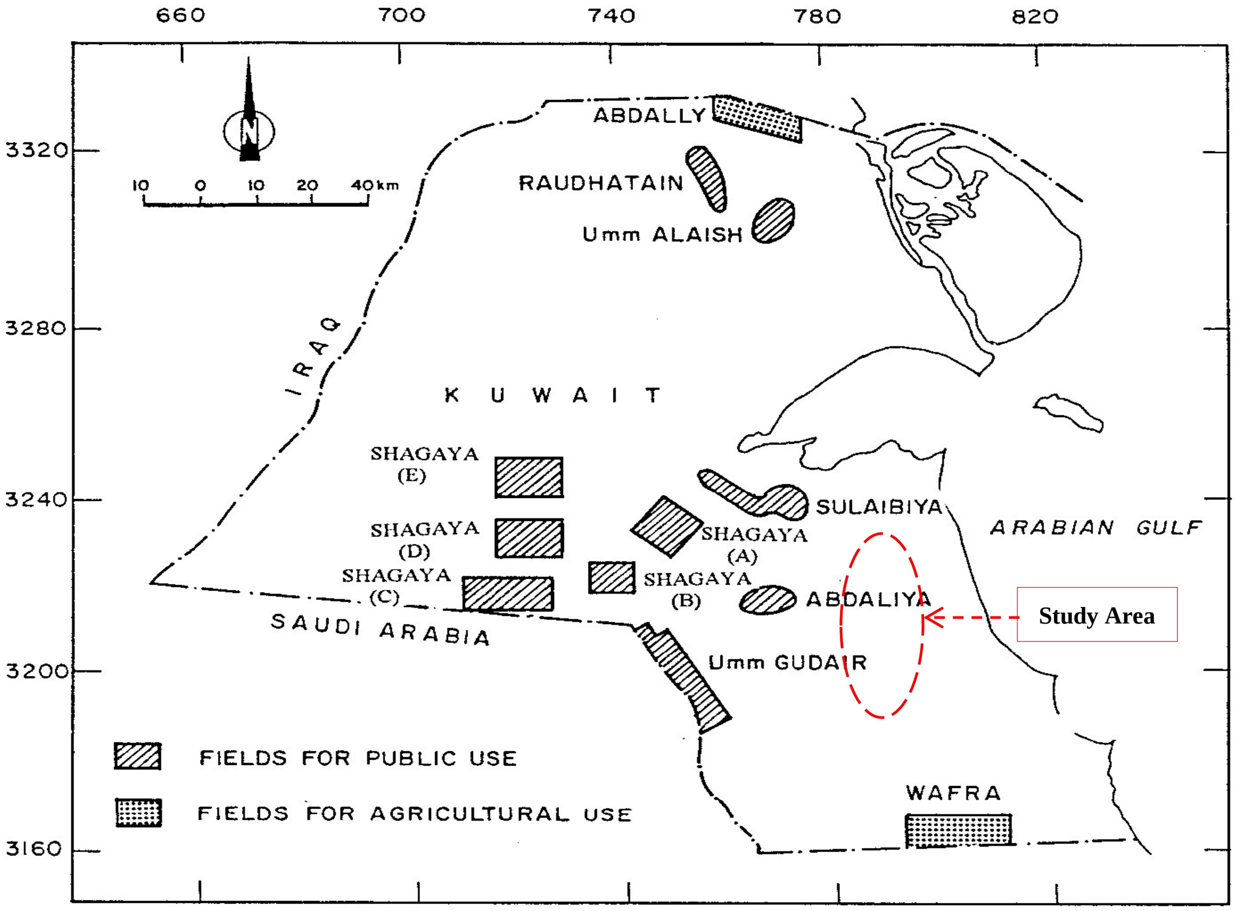


Figure 2.9. Groundwater source zones location in Kuwait (Source: Bretzler, n.d., p. 3).

This study is basically concerned with the soil contaminated with hydrocarbon located close to the Kuwait oil fields. It is important, therefore, to investigate the ground water depth near these oil fields in order to ascertain whether the hydrocarbon contamination lakes, i.e. soil contaminated with crude oil, might also have migrated into the groundwater if they are close to the ground surface. In fact, the depth of the groundwater in Kuwait varies from one location to another.

To conclude, according to Al-Awadhi *et al*. (1992) and A1-Awadhi *et al*. (1993), the ground water depths in Raudhatain and Sabriyah Oil Fields are approximately 30 m but the Wafra Oil Field ground water depth is between 7 m to 20 m. No nearer surface aquifers were observed in the Magwa, Ahamadi and Burgan Fields.

2.5 Kuwait Superficial Geology

As indicated by Nayfeh (1990), Kuwait, which lies at the north-eastern corner of the Arabian Peninsula, is within the semi-arid zone. In general, the Arabian Peninsula can be divided into two areas known as Arabian Shield and Arabian Shelf. The key components of the former are igneous and metamorphic rocks belonging to the pre-Cambrian age forming the western part of the peninsular. The latter controls the eastern section of the peninsular consisting of thick sequences of terrestrial and shallow marine deposits, which continue into Iraq and the Arabian Gulf along the north eastern border.

The Kuwait sedimentary sequence, which starts from the Middle Triassic to the modern age, is over 6,700 m (20,000 feet) thick. Rocks and sediments belonging to the Eocene Age extending to the modern age are the only remaining depositions left on the ground. Dammam limestone (Eocene), the Kuwaiti Group of Sands, gravels and evaporate (Micene-Pleistocene) are the rocks formed in the Eocene Age while the present deposits consist of desert plain, eolian sand, playa, sabkha and beach deposits. According to Allison (1969), the surface soil of Kuwait (including the majority of the Arabian Peninsula) consists of fine to medium-grained, non-plastic, calcareous, wind-blown sands accumulated in the area, with thicknesses of between 1m to 6 m - seldom exceeding 10 m.

Al-Sulaimi and Mukhopadhyay (2000) have stated that Kuwait is situated along the eastern border of the deep sedimentary basin that forms the Arabian Peninsula, and is underlain by fairly thick sedimentary rocks. Fairly undeveloped deposits belonging to the Dibdibba Formation (Upper Miocene to Pleistocene Epochs, approximately 2 to 10 million years old) extend above the surface. These deposits are further underlain by the Dammam formation (Upper Eocene Epoch, approximately 38 to 42 million years old). With the exception of Northern Kuwait, the intruding deposits which are usual feature from the Fars Formation do not exist.

The Dibdibba Formation naturally consists of silica sands and gravels with inconsistent amounts of silt and a few bands of thin clay and gypsum. Its cementation is comparatively poor and incomplete, consisting of gypsum and calcium carbonate.

Currently, the Dibdibba Formation is overlain by deposits which consist of windblown sand forming sheets and small sand dunes to the south of Kuwait. In general, calcareous deposits are present adjacent to the coastline which commonly consist of oolithic and bioclastic sands.

The amount of runoff discharging into the sea is small in view of the low seasonal rainfall which mostly seeps into the ground or evaporates into the air. Evaporation has a very dominant consequence on the normal groundwater movement pattern which is upward. This occurrence results in the high concentration of soluble substances above the ground, for example, gypsum and calcium carbonate. The prevailing materials obtainable close to the ground surface in the northern and southern parts of Kuwait are calcium carbonates and gypsum.

2.6 Degradation of Oil Lake Contamination in Kuwait

Soil contamination is considered one of the main environmental problems worldwide. Undeniably, it originates from human activities such as unsuitable implementation of agriculture, manufacturing, construction and military undertakings. An assessment by the Goi *et al*., (2009, p.185) indicated that 3.5 million sites have been contaminated within just the European Union. From this number, around 500,000 sites urgently require immediate remediation in view of their levels of hydrocarbon contamination.

For an arid and dry country like Kuwait, the rate of land degradation can be accelerated by the limited rain fall, water erosion and extreme wind conditions. Al-Awadhi *et al*. (2005) claim that seven land degradation categories have been specified, as follows: erosion of soil by water and/or wind; deteriorating quality of vegetation top soil; soil crusting and sealing; soil compaction; oil pollution of soil; and soil salinisation (Figure 2.10).

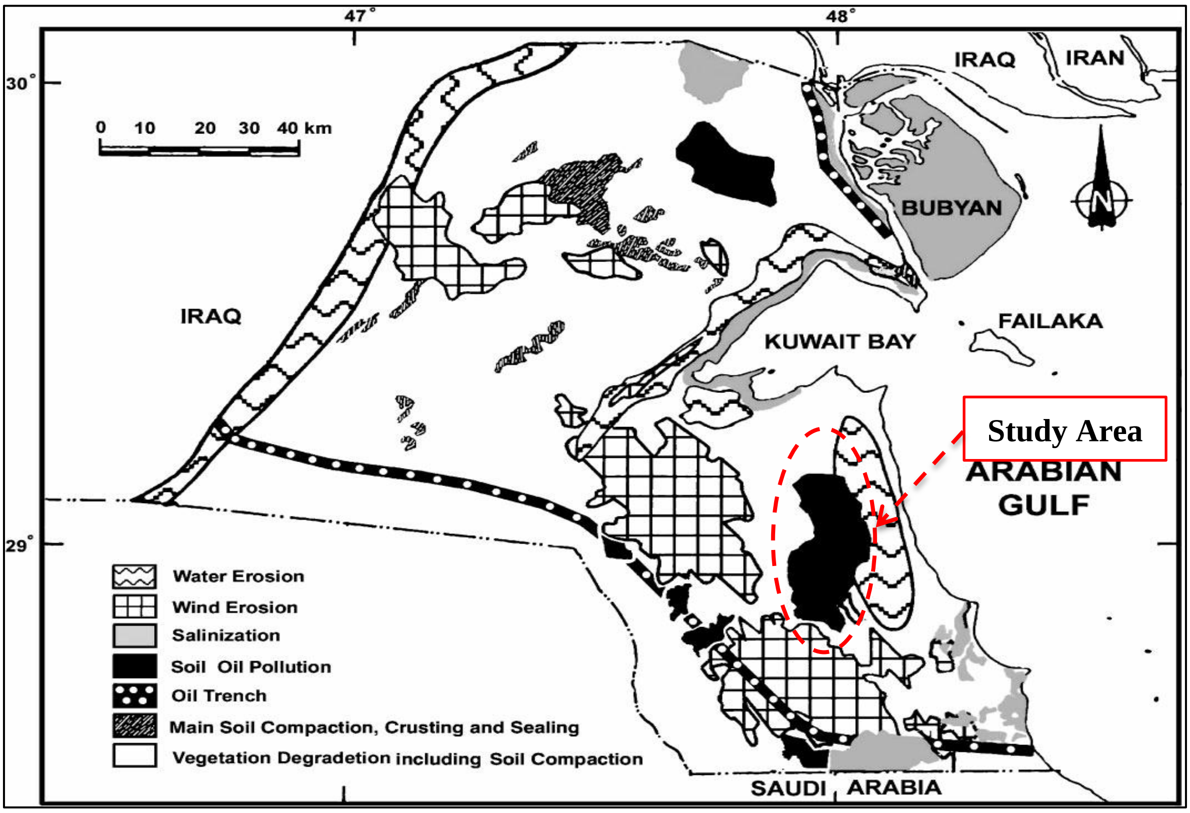


Figure 2.10. The mapping main indicators of land degradation in Kuwait (Source: Al-Awadhi *et al*., 2005).

The landscape of Kuwait is specifically characterised by a number of depressions which can easily contain dust and water throughout the year. Bashara (1991) realised that during the Gulf War, at least 250 depressions or lakes of the natural landscapes were found to contain crude oil spillage. Ground which has been severely contaminated has the potential to pose risk to the quality of groundwater, aquifers and the inhabitants of the desert (Al-Awadhi *et al*., 1992). Additionally, Amro (2004) claimed that the major causes of above-ground and groundwater contamination was seepages of oil from oil wells, pipelines, gas station storage tanks and the improper disposal of oil spills and petroleum waste.

Al-Awadhi *et al*. (2005) identified seven categories of land degradation occurring in Kuwait which includes soil contamination caused by hydrocarbon. In this respect, the author will endeavour to focus on *oil lakes* and soil pollution in an effort to assess the consequences of such hydrocarbon contamination for land and ground (Section 2.7. for explanation regarding *oil lakes*).

2.7 Kuwaiti Soil and Environment Pollution

Overall, the consequences of hydrocarbon contamination can be detrimental to the environment particularly to the safety and health of mankind irrespective of whether it takes place on the ground surface or below ground or indeed with ground water.

According to Taylor *et al*. (2005), the main sources of toxic pollution are from water and food consumed by humans; additionally, Gay *et al*. (2010) claim that the oil or heavy metal used in the war could potentially contaminate the environment causing severe effects on human health.

As revealed by Seacor (1994) and others, the toxic could generated from the explosions during the Gulf War contained heavy metal particulates and hydrocarbons. A number of respiratory problem cases experienced by civilian and army personnel were reported during the war, mainly due to the inhalation of toxic smoke (Smith *et al*., 2002). Based on numerous reports, the Deepwater Horizon in the Gulf of Mexico, Exxon-Valdezz in Alaska (U.S), Kuwait, the Delta River in Nigeria and Northeast Ecuador were regarded as amongst the most severely hydrocarbon contaminated sites in the world (Gay *et al*., 2010). This study will therefore focus principally on examining the sites in Kuwait which have been polluted by hydrocarbon arising from the explosions and burning of the oil wells and lakes due to the Iraq invasion (Figure 2.11).

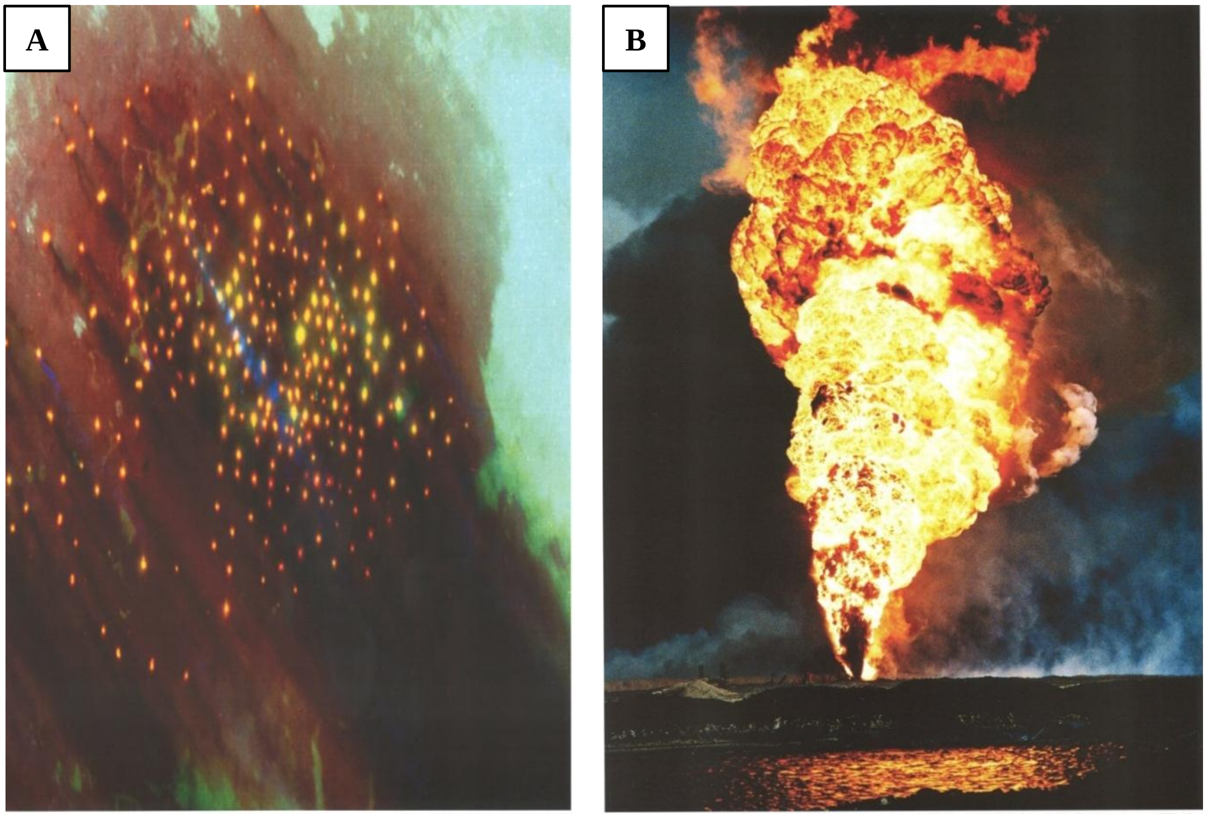
Figure 2.11. An oil well in flames in Kuwait during the Gulf war of 1991 (Source: Gay *et al*., 2010).

According to Din *et al*. (2008), Kuwait has experienced a major environmental calamity caused by the formation of *oil lakes* and *hydrocarbon surfaces* in the desert arising from the Gulf War at the beginning of the 1990s.

Al-Besharah (1991) stated that during the Gulf war, Kuwait's plain desert was covered with major oil spillages owing to the burning and destruction of the oil wells. Five hundred and sixty five oil wells were torched while 74 wells oozed uncontrollably from the ruined wellheads (Figure 2.11 and 2.12). The oil field fires resulted in enormous black plumes of smoke that finally settled as soot, tarmat and tarcrete deposits (El-Baz *et al*., 1994).

According to Seacor (1994), the scale of the plumes of smoke caused by the burning wellheads was both remarkable and horrific; they stretched 22,000 feet above ground covering 800 miles. Both soot and oil products, which had been partially burnt, were also part of the smoke. In fact, Preston (2011) claimed that the smoke was also mixed with a high content of carbon dioxide, sulphate and nitrogen.

The local environment was severely impacted by the catastrophe. In just nine months into the incidence, over 60 million barrels of oil had been spilled from both the northern and southern oil fields of Kuwait (Al-Saad, 1993). Furthermore, around 300 *oil lakes* (a total area of over 49 km^2) had been created within the northern and southern oil fields of Kuwait (Al-Awadhi *et al*., 1996). On average, around 2 to 6 million barrels of oil were set ablaze releasing a massive amount of sulphur dioxide and soot into the open air (Kwarteng & Bader, 1993).



A satellite captured this aerial view of the burning oil wells in Burgan Field.

منظر من الجو التقطه قمر اصطناعي لآبار نفطية مشتعلة في حقل برقان.

A raging oil well fire burns unrestrained in the Kuwaiti desert.

حرائق هائلة صعبت من جهود فرق الإطفاء وتسببت في كارثة بيئية واسعة النطاق.

The environmental damage caused by the fires and oil lakes have had a lasting impact on Kuwait's ecosystem.
Here a helicopter is pictured inspecting the damage that was caused.

أضرار بيئية فادحة استمرت تأثيراتها السلبية على النظام البيئي الكويتي لسنوات طويلة.

Figure 2.12. A satellite captured this aerial view of the burning oil wells in Burgan Field in Kuwait (A). Also, raging oil well fire burning unrestrainedly in the Kuwait desert (B) and the environmental damage caused by the fires and *oil lakes* which have had a lasting impact on Kuwait’s ecosystem (C) (Source: KOC, n.d.).

As a result of the uncontrolled and inexorable spillage of crude oil, *oil lakes* were formed. Many researchers, including Al-Besharah *et al*. (1992), Al-Ajmi *et al*. (1994), El-Baz *et al*. (1994), Salam (1996), Kwarteng (1998) and Al-Dousari (2001), have claimed that the creation of these *oil lakes* has brought about an interest in detailed investigations as they are unique; and considered to be one of the most disastrous environmental calamities of modern times.

In Kuwait at present, three categories of terrestrial oil contamination have been defined, these are:

> (1) *Oil lakes* - described as build-ups of crude oil which has been spilled from damaged well-heads and pipe routes in naturally low lying grounds within the vicinity of the oil fields. According to Kwarteng (1998) and Omar *et al*. (2000), currently, they can be divided into dry and wet lakes.
>
> (2) *Tarcrete* - defined as oil soot and oil mist which forms in the surface layers of the soil as a 2-8 mm thick layer of unconsolidated soil. It has been estimated that approximately 6 percent of the Kuwait land area has been contaminated by tarcrete (Kwarteng, 1998).
>
> (3) *Oil trenches* - consist of a part of the strategic hindrance systems built during the war by the Iraqi army over a stretch of 220 m. They include separate oil filled trenches of 4 - 5 m wide and 2 - 3 m deep stretching along the boundary of southern Kuwait, approximately 10 - 14 km away from the Saudi Arabian border (Al-Ajmi *et al*., 1997). Figure 2.13 shows the soil contamination at different depths and levels in a trench in the northern area.

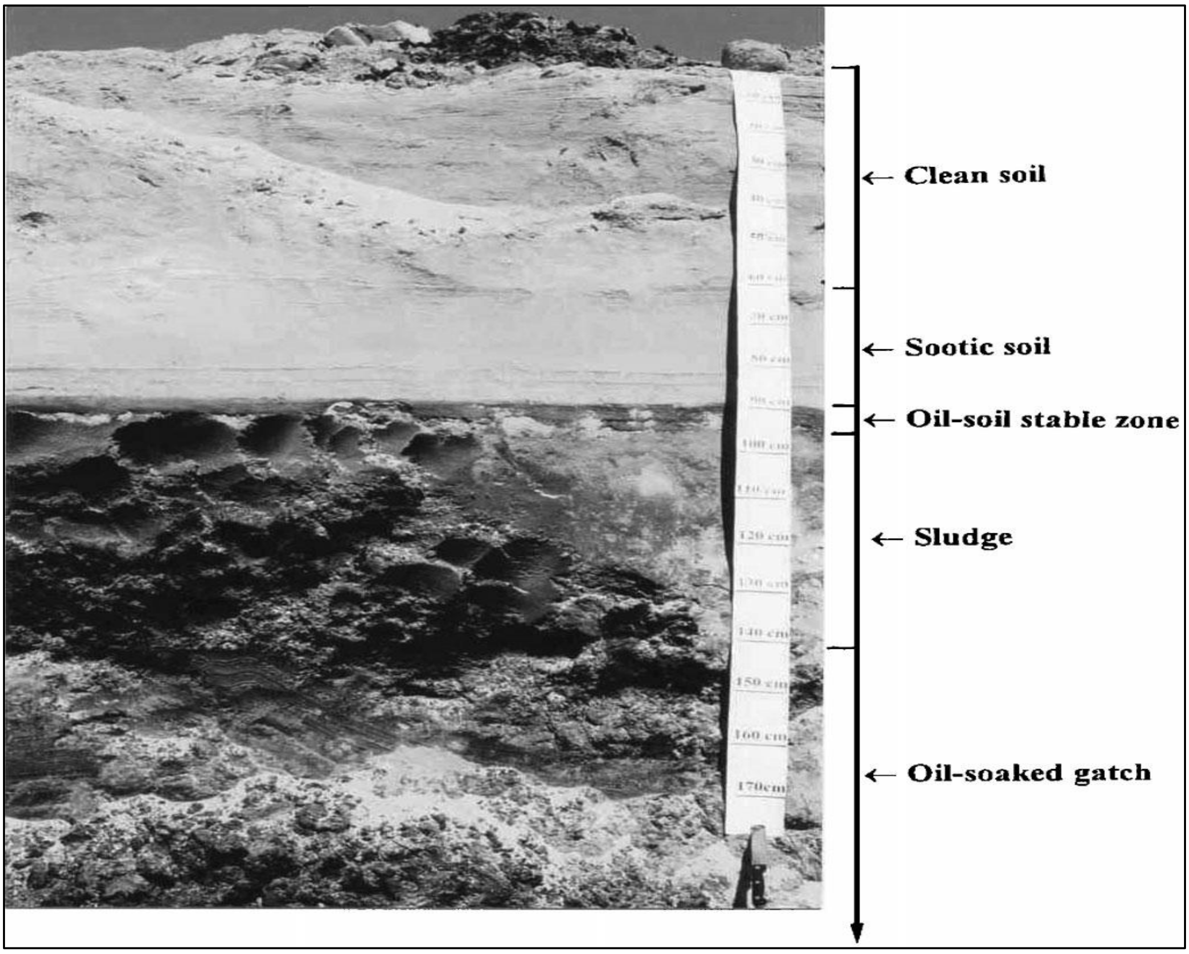


Figure 2.13. Oil trench in the north part of Kuwait (1999) showing different levels and depths of oil contamination (Source: Al-Awadhi *et al*., 2005).

According to Al-Besharah and Salman (1991), the *oil lakes* were of various sizes and shapes with depths that varied from a few centimetres to 1.5 meters (Figure 2.14). Furthermore, the range of their original depths was between 0.05 m to 1.2 m with an average depth of 0.3 m (Al-Awadhi *et al*., 1992; A1-Awadhi *et al*., 1993). Additionally, as indicated by Al-Awadhi *et al*. (1992) and A1-Awadhi *et al*. (1993), the oil infiltrated into the soil to a minimum depth of 0.4 m. These *oil lakes* were found in nine main oil fields of Kuwait namely: Rawdhatain; Sabriyah; Ratga; Bahra Minagish; Umm Gudair and Wafra; and the Greater Burgan Field (Ahmadi, Magwa, and Burgan Sectors) (Figure 2.15) (Cho *et al*., 1997; Al-Duwaisan & Al-Naseem, 2011).

The largest hydrocarbon contamination occurred in the Burgan Field which constitutes 40 % of the overall contaminated volume (Al-Duwaisan & Al-Naseem, 2011). Based on the assessment of pollution carried out in this area, the average penetration of oil into the soil was one meter of which the surface 300 mm consisted of oily sludge which contained oil penetration higher than 40 % (PEC, 1999). Massoud *et al*. (2000) claim that an investigation into soil profiles in the concerned areas indicated that soil layers in a number of places in Kuwait contained very high percentages of hydrocarbons - some up to a depth of below 80 - 95 cm, in other sites up to 50 cm.

It was also discovered that a *Gatch layer* exists beneath these lowest points serving as a moisture barrier preventing oil or water from penetrating further into the lower strata. According to Al-Yaqout and Townsend (2004), this calcareous sand layer may be regarded as linear in view of its low permeability. The Kuwait Oil Company (KOC) managed to recover a significant volume of oil once the oil fires were extinguished (Hussain, 1995). The remaining volume of oil which settled at the bed of the lakes however, is currently considered to be irrecoverable (Saeed *et al*., 1995).

Figure 2.14. An aerial view of the *oil lakes* formed as a result of the vandalism inflicted by retreating forces (Source: KOC, n.d.).

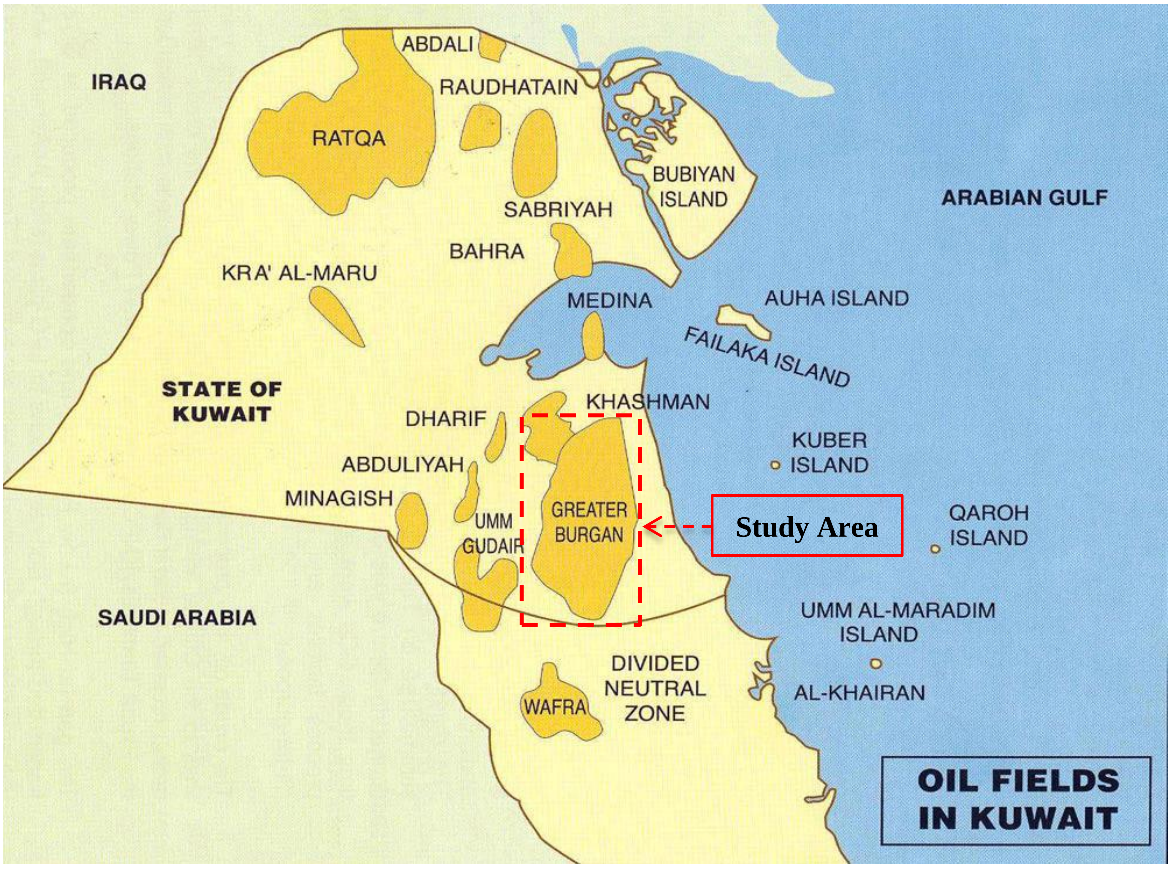


Figure 2.15. Location of the Kuwait oil fields (Source: KMO, n.d.).

Table (2.3) below shows that the Burgan region has the largest area of oil pollution; the oil polluted land area of the Burgan Oil Field is 25.6 km^2 whereas the total of oil polluted areas found in Kuwait is 49.13 km^2.

Table 2.3. The estimates of oil-polluted land areas and soil volumes in Kuwait (Source: PEC, 1999).

Oil Field Region	Oil-Polluted Area (Km^2)	Oil-polluted Soil Volume (m^2)
Wafra	3.26	1,956,000
Burgan	25.6	14,520,000
Managish	0.19	95,000
Umm Gudair	0.27	135,000
Raudhatain	12.28	2,456,000
Sabryia	6.85	3,082,500
Bahra	0.68	408,000
Total	49.13	22,652,500

Balba *et al*. (1998), claim that the worst oil residue contaminated materials are located on top of the *oil lake* bed which includes various items from stiff soil with a surface crust soil to viscous tarry sludge, with a total petroleum hydrocarbon content of 133 g/kg and 694 g/kg respectively.

Kwarteng (1999) has stated that in 1998, the balance of area of *oil lakes* was reported to be 24.13 km^2; in 2001 it was reported that the size of the *oil lakes* had not changed (Kwarteng, 2001). Owing to the climatic conditions, a significant portion of these lakes were concealed with dust and sand with the smaller *oil lakes* entirely covered, resulting in an inability to detect original sizes and locations (Kwarteng, 1998).

The hot and arid climate of Kuwait (ambient summer temperature of 50 °C caused the remaining oil in the majority of the lakes to thicken and become partly solid proving difficult to remove. As pointed out by Saeed *et al.* (1998), the possible oil extraction from the lake is estimated to weigh around 1.55 million tons. Continuing chemical tests of the oil samples have revealed that the asphaltene, aromatic and resin contents have risen because of the decrease in the quantity of volatile hydrocarbons and saturates (aliphatic compounds) weathering has taken place (Saeed *et al.*, 1998).

The prolonged decrease in volatile hydrocarbon from the oil surface has influenced the creation of a de-volatilised viscous layer on the surface skin. According to Bufarsan *et al*. (2002) and Barker and Burfarsan (2001), this skin layer has acted as a shield to the oil layers below and results in a decrease in the overall evaporation rate. The properties of the clean oil residue, which is water free, placed below the surface skin layer are comparable to those of a typical medium crude residue with a boiling point of above 300° C indicating that most of the light hydrocarbon within the oil has been lost (Khan *et al*., 1995).

Based on the numbers of *oil lakes* affected, the depths of the lakes and the oil concentration and extent of areas affected, it has become clear that the extent of the soil contaminated with hydrocarbon resulting from the Kuwait oil spills has been catastrophic. Furthermore, since the Gulf War of 1991, the uncontrolled *oil lakes* have spread affecting the soil below ground. Not only has the quality of the soil been affected as a result but this hydrocarbon contamination has also caused changes in the chemical and physical properties of the soil.

The Burgan Field is the largest contaminated *oil lake* as it constitutes 40 % of the overall volume of the contamination (Al-Duwaisan and Al-Naseem, 2011, p.440). As such, it has been selected as the case study for this research.

2.8 Urban Expansion in the Contaminated Zone

Due to the increase in the population one of the Kuwaiti government’s key targets is the provision of housing and the expansion of the residential homes’ market. In fact, according to the UK Foreign and Commonwealth Office (2014) a new five year development plan (2015/2020) has been debated, approved and referred to Parliament by the Kuwaiti Cabinet.

There are two proposals to the Kuwait Development Plan (KDP): 1) is to let the private sector a more significant role in the development, this will require economic reform; 2) is to carry out the long-term strategic vision by implementing the mega-projects. These include; a) a metro system; b) a rail project (as part of the Gulf cooperation Council's (GCC) - wide plans for connected rails network); c) a new media city; d) privatisation of education; e) expansion and improvement to Kuwait's Mubarak al-Kabeer port on Boubiyan Island. In fact, Almarshad (2014, p.49) has confirmed the *Foreign and Commonwealth Office of UK's (2014)* report, he states that the KDP has a budget of approximately £85bn. In total the projects number approximately 1100 including the above mentioned mega projects considered critical to the growth and revitalisation of Kuwait's economy (Table 2.4).

Table 2.4. Some of the Mega Projects that are Under Construction (Source: Almarshad, 2014, p. 49).

Project	Status	Cost	Expected Completion
Az-Zour Power and seawater treatment plant (phase 1 and 2)	Phase 1 under construction	£1.63 bn*	2017
Bobyan Port (Phase 1)	Under Construction	£0.78 bn*	2014
Expansion of Kuwait International Airport	Under Construction	£3.90 bn*	2016
Hospitals	Under construction/ bidding for other projects	£ 4.55 bn*	2013 onwards
Housing Projects	Under Construction	£3.25 bn*	2020
Kuwait Metro Rail System	Preparation of expression of interest for phase 1 (currently put on hold)	£4.55 bn*	2020
Kuwait National Rail Road Network	Feasibility Study (currently put on hold)	£6.50 bn*	Non Applicable (N/A)
Sabah Al-Salam University	Under Construction	£4.34 bn*	2018
Sheikh Jaber Bridge	Under Construction	£1.71 bn*	2018

Note:*bn is abbreviation of Billion.

As described and discussed above, the government of Kuwait has initiated a number of mega projects planned to be developed from 2013 to 2020, These projects ignited my interest in soil erosion and led to my undertaking further studies in soil contamination through hydrocarbon in Kuwait. For the projects to succeed it is of the utmost importance that investigation is carried out into the geotechnical and geochemical properties of the hydrocarbon contaminated soils. The information learned can be utilised for construction purposes; see sections 3.3 and 3.4 for detailed explanations regarding geotechnical and geochemical characterisation of the soils contaminated with hydrocarbon.

2.9 Potential Human Health Risks from Hydrocarbon Contamination

During the break-out of the oil residue, one of the biggest concerns in Kuwait was the possibility of health risks due to the emission of sulphur dioxide (SO_2) and acid rainfall (Al-Ajmi & Marmoush, 1996).

For decades it has been known that contaminated soil due to hydrocarbon and metal contamination can affect humans causing environmental health risks (Certini *et al*., 2013). As reported by Cho *et al.* (1997), the expansive nature of contaminated oil residue in the Kuwaiti desert has caused an immense threat of contaminated subsurface water causing detrimental effects on human health. The extent of contamination caused by petrochemicals in Kuwait has, in fact, caused many health problems due to the different range of exposure which can arise from the water, the land and the air (Abramson *et al*., 2004). Due to the extensive nature of contamination by hydrocarbon, when the affected area is ignited the crude oil becomes more dangerous and toxic as compared to its other low sulphur substance (better known as sweet crude). As reported by Husain (1998), contaminated soil can be detrimental to human health and can affect areas of vegetation since burning oils emit huge amounts of toxic gasses including hydrogen sulphide (H_2S), carbon monoxide (CO), sulphur dioxide (SO_2), oxides of nitrogen (NO(x)) and carbon dioxide (CO_2). Conditions are further exacerbated when the air is polluted by the partially burned hydrocarbons and metals. The most common illnesses related to the Gulf War are: respiratory problems; reproductive disorders; cancer risks; and psychological mood swings (Gay *et al.*, 2010). The identification of dangerous illnesses and diseases are associated with soil contamination through hydrocarbon due to the 1991 Gulf War in Kuwait.

Due to the rise in such illnesses, it is paramount that the soil contaminated with hydrocarbon be remediated so as to minimise the risks to human health, which is the focus of this study. The study also seeks to investigate the extent to which soil contaminated with hydrocarbon affects human health in general, e.g. illnesses such as cancer and respiratory problems (Section 3.5).

2.10 Summary

Seven types of land degradation have already been identified and categorised including soil contaminated by hydrocarbon (Al-Awadhi *et al*., 2005). This study will revolve around soil contaminated with dry *oil lakes* (Section 2.7 for further elaboration).

This study examines the extent of contaminated soil caused by the dry *oil lake* in Kuwait by investigating the hydrocarbon concentrations (mg/kg) under different depths and its effects on geotechnical and geochemical properties of soil in this lake. It also examines the extent of its adverse impact on human health since the Gulf War in 1991. In short the study explores the quality of the soil affected by hydrocarbon contamination but also the extent to which the soil might be altered in terms of its physical and chemical properties.

Due to the mega planning projects undertaken by the Kuwaiti government planned from 2013 to 2020, there is, in fact, an urgent need - for the purposes of construction - to investigate geotechnical and geochemical properties of the soil polluted with hydrocarbon. Studying the soil contaminated with hydrocarbon is crucial as Kuwait is embarking on an expansion of its infrastructure with various mega constructions in the planning stage (See sections 3.2 and 3.3 respectively for further clarification concerning the geotechnical and geochemical characterisation of soil contaminated by hydrocarbon).

The preliminary findings of the study has encouraged the researcher to further probe into the extent to which contaminated soil directly contributes to serious illnesses such as respiratory problems, cancer risk, bronchitis etc. Therefore an investigation into the dangerous illnesses and diseases resulting from soil contamination due to oil residue (Gulf War 1991) will also be carried out. The increasing number of these illnesses gives rise to an urgency to remediate the soil polluted with hydrocarbon in order to minimise the risks to human health (Sections 3.5 for further explanations).

3. LITERATURE REVIEW

3.1 Introduction

Soil contamination with hydrocarbon is regarded as one of the key issues in Kuwait as the oil spills from the oil wells has had a huge impact upon the virgin soil. In this respect, it is vital for a study to be undertaken regarding the geotechnical and geochemical properties of hydrocarbon contaminated soils in order that they can be used in environmental and construction applications (Khamehchiyan *et al*., 2007). The migration of hydrocarbons through the soil profile has the potential to affect the properties of the soil, e.g. Particle Size Distribution, Moisture Content, Compaction, Shear Strength, Sulphate and Chloride Content (Al-Sarawi *et al*., 1998b).

It is a key undertaking to investigate the geochemical properties of the soil contaminated with *oil lakes* residue as petroleum hydrocarbon is a complex chemical which contains organic composites; there are derived from a number of organic materials chemically transformed over very long duration through varying geological environments. Oil is mainly composed of hydrogen and carbon which contains a broad spectrum of hydrocarbon sprightly gasses that will eventually transform themselves into heavy residues. According to Wang *et al*., (1999), oil contains a small quantity of nitrogen, sulphur and oxygen and metals such as iron, nickel and vanadium. Oil also comprises a broad range of toxicities which can easily mix with soil which alters the soil’s physical and chemical properties (Barua *et al*., 2011). Oil will affect the population of microbes, plant root systems and the oxygen content as soon as it penetrates any layer of soil. It should be noted that soil which has been contaminated with hydrocarbon has inadequate properties to allow plants to grow; this is mainly caused by the high level of toxic constituents present, e.g. zinc and/or iron, and the reduction in the quantity of plant nutrients as a direct result of the presence of toxins in the oil.

Discharges of petroleum hydrocarbons, in the past, into the soil environment can expose human health, watercourses, ecosystems, properties and other receptors to potentially serious threats. As mentioned by the Environment Agency (2003), it is vital to understand the potential impacts of exposure to petroleum on each of these receptors. In order to manage these risks research into this area will enable the development of a structured risk assessment framework.

This chapter provides the information and parameters influencing the geotechnical and geochemical classification of sandy soil contaminated with hydrocarbon. An introduction will be given on the evidence and data of the oil residues and their impact on human health so as to classify hydrocarbon contaminated Kuwaiti soil since the Gulf War (1990) - as cited in previous studies whilst also recognising the limits of the studies.

An overview of the hydrocarbon contaminants is provided in section 3.2.The geotechnical descriptions, i.e. strength and physical characterisations of sandy soils polluted with hydrocarbon are explained in section 3.3. The geochemical investigation into soil contaminated with hydrocarbon and the concentration of the hydrocarbon contaminant in sandy soil is outlined in section 3.4. Former research explaining the potentially serious effects of soil contaminated with oil residue and their risks to human health are presented in section 3.5. The contribution of the literature review is provided in section 3.6; this includes the agreed approach of this study taking into account some of the gaps identified in earlier works.

3.2 Overview of Hydrocarbon Contaminants

In all forms, hydrocarbons are widely considered to be the most common contaminants to be remediated in view of their prevalent existence and their potential threats to human health and controlled waters (Churngold, n.d.).

According to (ATSDR, 1999), the term TPH is used to describe a large group of a few hundred chemical compounds originating from crude oil. Crude oil is the basic ingredient used in producing petroleum products with the potential to pollute the environment. In view of the various chemicals present in crude oil, as well as other petroleum products, it is impractical to carry out measurements on each chemical individually. Nonetheless, it is beneficial to measure total amounts of TPH at contaminated sites (ATSDR, 1999). Common types of fuel considered to be within the TPH family are: petrol; diesel; kerosene; and lubricating oil/greases. Given the variety of compounds which consist of TPH and the potential human health and environmental risks posed by them, the proposed remediation techniques considered to control them ought to be taken into consideration based on the actual site requirements (Baah, 2011).

According to Baah (2011), hydrocarbons consist of simple organic elements (containing hydrogen and carbon), a number of different compounds are also available, each compound displays various chemical and physical characteristics (Table 3.1).

Table 3.1. Classification of the Hydrocarbons.

Hydrocarbon Classification	Hydrocarbon Group	Definition	Example of a Hydrocarbon Substance and their Formula	References
Saturated Hydrocarbon	***Alkanes***	They are considered the simplest form of hydrocarbon species made exclusively from individual bonds and are saturated with hydrogen. For saturated hydrocarbon, their general formula is CnH2n+2 (considering non-cyclic structures). As the base of petroleum fuels, saturated hydrocarbon can be present in the form of linear or branched species. Hydrocarbon having similar molecular formula however with different structure formula are categorised as structural isomers.	*Ethane* *(C2H6)*	*(Silberberg, 2004)*
Unsaturated Hydrocarbon	***Alkenes***	These are hydrocarbons with single or multiple double or triple bonds between carbon atoms. The hydrocarbons with double bond are known as alkenes while hydrocarbons which have single double bond have a general formula of CnH2n (considering non-cyclic structures).	*Ethene* *(C2H4)*	
	Alkynes	Alkynes are the term used for hydrocarbons with general formula CnH2n-2 which contain triple bonds.	*Ethyne* *(C2H2)*	
Cycloalkanes	***Cycloalkanes***	Hydrocarbon are formed when minimum of one carbon ring is attached to hydrogen atmos. CnH2n is formulated when a saturated hydrocarbon contains one ring.	*Cyclopropane* *(C3H6)*	
Aromatic Hydrocarbon	***Arenes***	Hydrocarbon have a minimum of one aromatic ring.	*Benzene* *(C6H6)*	

In order to understand how TPH behaves when it is released into the atmosphere, it is simplest to view the structure and size of the particular elements (Churngold, n.d.). TPH mixtures having an aliphatic structure, i.e. straight or branched chains of carbon molecules, will act in different ways to aromatic compounds (ringed chains of carbons). Likewise, TPH mixtures with fewer molecules of carbon will also perform differently (Churngold, n.d.).

Lighter ranges of TPH compounds (containing 16 carbon atoms or less) are likely to be more mobile in view of their superior solubility, higher volatility and lower organic partitioning coefficients. As indicated by Baah (2011), lightweight aromatic compounds, for example benzene, tend to be highly toxic which can cause major threats in the event that they escape into the environment. Compounds with heavier TPH usually have contrasting characteristics in that they are likely to be adsorbed by the soil's organic fraction. Aromatic compounds that are heavier, also known as Polycyclic Aromatic Hydrocarbons (PAH), can be of higher toxicity and are generally highly obstinate in the environment; according to (Baah, 2011), they usually exist in coal tar, heavy oils and creosotes.

Tomlinson *et al*. (2014), have indicated that crude oil comprises a blend of linear, branched, cyclic and aromatic hydrocarbons including asphaltenes and resins which have high molecular mass components. Crude oil is distilled in refineries for the purpose of separating the components into fractions characterised by having a common range of boiling points (Table 3.2).

Table 3.2. Hydrocarbon fractions obtained from the distillation of crude oil (TPH) (Source: Tomlinson *et al*., 2014).

Fraction Name	**Typical Number of Carbon Atoms**	**Boiling Point Range (°C)**	**Uses (Examples)**
Refinery Gas	3-4	< 30	Bottled Gas (propane or butane)
TPH-G	6-10	-	Gasoline range organics
Petrol	6-10	100-150	Fuel for spark-ignition engines (e.g., cars, motorbikes, vans)
TPH-D	12-28	-	Diesel range organics
Naphtha	6-11	70-200	Solvents and used in petrol
Kerosene (paraffin)	10-12	150-200	Fuel for jet engines and stoves
Diesel Oil	12-18	200-300	Fuel for compression ignition engines (e.g., road vehicles, boats and trains)
Lubricating Oil	18-25	300-400	Lubricant for machinery
Fuel Oil	20-27	350-450	Fuel for ships and heating
Greases and Wax	25-30	400-500	Lubricants and candles.
Bitumen	>35	>500	Road surfacing

Most of the TPH mass partitioning will be carried out in the soil phase itself. In some specific cases, it is also possible to find TPH in the form of phase separated liquid which floats on the water-surface because of its buoyancy (ATSDR, 1999). Phase separated TPH is usually termed *Light Non-Aqueous Phase Liquid* (LNAPL). A portion of TPH will turn into liquid upon absorption by the groundwater or is stuck in the form of vapour in the soil pores within the unsaturated area. In accordance with Churngold (n.d.), the actual separation of phases is associated with the original source composition, hydrogeology and geological conditions and the period since the spillage took place.

Based upon ATSDR, (1999), the densities of the TPH components are lower than or nearly the same as that of water, these lighter non-aqueous phase liquids (LNAPLs) are usually less likely to cause groundwater pollution as compared to most chlorinated solvents, e.g. PCBs or TCE, which have densities higher than water (denser non-aqueous phase liquids (DNAPLs)). The non-aqueous phase liquids denote liquids which are immiscible in water; however, the potential risks for shallow groundwater supplies still exist which could perhaps be utilised for private drinking water wells.

Table 3.3 Typical crude oil compositions of Kuwaiti, also shows that these fractions lie within the general range of fractions indicated in table 3.2.

Table 3.3 Kuwait crude oil composition (Source: IARC, 1989).

***Characteristic or Component**		***Crude Oil Values**
API Gravity (20 °C, °API)		3.14
Sulphur (% by Weight)		2.44
Nitrogen (wt %)		0.14
Nickel (ppm; mg/kg)		7.7
Vanadium (ppm; mg/kg)		28.0
****Naptha fraction (wt %)**		22.7
Alkanes %		16.2
Cycloalkanes %		4.1
Aromatic hydrocarbons %	**Benzenes**	0.1
	Toluene	0.4
	C8	0.8
	C9	0.6
	C10	0.3
	C11	0.1
Indans		0.1
*****High-boiling fraction (by weight %)**		77.3
n-Alkanes	**C11**	0.12
	C12	0.28
	C13	0.38
	C14	0.44
	C15	0.43
	C16	0.45
	C17	0.41
	C18	0.35
	C19	0.33
	C20	0.25

Table 3.3. Continuous (Source: IARC, 1989).

***Characteristic or Component**		***Crude Oil Values**
n-Alkanes	**C21**	0.20
	C22	0.17
	C23	0.15
	C24	0.12
	C25	0.10
	C26	0.09
	C27	0.06
	C28	0.06
	C29	0.05
	C30	0.07
	C31	0.06
	C32 plus	0.06
Iso-alkanes %		13.2
1-ring cycloalkanes %		6.2
2-ring cycloalkanes %		4.5
3-ring cycloalkanes %		3.3
4-ring cycloalkanes %		1.8
5-ring cycloalkanes %		0.4
6-ring cycloalkanes %		---
Aromatic hydrocarbon (by weight %)	**Benzenes**	4.8
	Indans and tetralins	2.2
	Dinapthenobenzenes	2.0
	Napthalenes	0.7
	Acenapthenes	0.9
	Phenanthrenes	0.3
	Acenaphthalenes	1.5
	Pyrenes	---
	Chrysenes	0.2
	Benzothiophenes	5.4
	Dibenzothiophenes	3.3
	Indanothiophenes	0.6
******Polar material (by weight %)**		17.9
*******Insolubles**		3.5

***Notes:** *This analyse represent values for Kuwaiti typical crude oil; variations in composition can be expected for oils produced from different formations or field from National Research Council (1985).*

*****Fraction boiling from 20 to 205 °C.***

******Fraction boiling above 205 °C.***

*******Clay-gel separation according to ASTM method D-2007 using pentane on un-weathered sample.***

********Pentane-insoluble materials according to ASTM method D-893.***

3.3 Geotechnical Review of Soil Contaminated with Hydrocarbon

The following researchers - Meegoda and Ratnaweera (1995), Ijimdiya (2013), Al-Sanad *et al*. (1995), Al-Sanad and Ismael (1997), Singh *et al*. (2009), Shah *et al*. (2003), Puri *et al*. (1994), Alhassan and Fagge (2013), Khamehchiyan *et al*. (2007), Patel (2011), Pandey and Bind (2014), Gupta and Srivastava (2010), Jia *et al*. (2011), Srivastava and Pandey (1998), Rahman *et al*. (2010), Elisha (2012), Habib-ur-Rahman *et al*. (2007), Caravaca and Roldan (2003), Mucha and Trzcinski (2008), Shin *et al*. (1999) and Kermani and ebadi (2012) - have carried out studies to determine the behaviour of soils contaminated with hydrocarbon utilising various types of petroleum products mixed with soils of various kinds. In order to examine variations in the soil properties, comparison of the differences in the performances between contaminated and non-contaminated soils were made.

The main emphasis in this section will be on the geotechnical properties of the soil contaminated with hydrocarbon with the aim of examining the strength and physical properties of the soil. This can be achieved by means of geotechnical tests, namely, the Atterberg Limit, PSD, SEM, permeability coefficient (Hydraulic Conductivity) and Direct Shear strength. A number of studies will be discussed in this section which will be classified based on the geotechnical tests carried out.

3.3.1 Plasticity

A study was undertaken by Alhassan and Fagge (2013) who reported that their samples were mixed with varying amounts of contaminants, i.e. 2 %, 4 % and 6 % based on weight. Over the range of contaminated hydrocarbon the sand samples demonstrated consistent non-plastic behaviour. None of the hydrocarbon contaminants had an effect upon the sand's Atterberg properties as was the case with virgin sand of non-plastic properties. The Atterberg properties for clay and laterite samples showed no clear pattern. The reduction in the liquid limit was noted by increasing the used oil content from 2 % to 6 %. Other soil properties, such as plastic limit, plasticity index and the shrinkage, demonstrated no consistent change. When the used oil was added to the lateritic soil samples, the soil's properties changed similarly to the behaviour of clay. It is apparent that similar behavioural trends were shown resulting from the black oil and crude oil effects on given samples.

An assessment was carried out by Khamehchiyan *et al*. (2007) on the effects of crude oil contamination on the geotechnical properties of the Irani coastal clay and sandy soil such as SM, CL and SP by mixing the samples with varying amounts of contaminants, i.e. 2 %, 4 %, 8 %, 12 %, and 16 % based on dry weight. As revealed by the results, the Atterberg Limits decreased with the increase in hydrocarbon contaminant for CL soil. The reduction behaviour was noted as a result of the water nature in the clay minerals' structures and the effects of existing non-polar and viscous fluids within the soil.

In a similar finding, Rahman *et al*. (2010) examined the properties of granitic and meta sedimentary soils contaminated with hydrocarbon. They investigated the correlation between the Atterberg Limit and quantity of oil by adding to the soil samples' varying quantity of oil, i.e. 4, 8, 12 and 16 % of the dry weight of base soils. The results showed that the hydrocarbon contaminant lowered the values of liquid and plastic limits for both types of weathered soils. For grade V soil, a reduction of 21 % and 39 % were noted in their liquid and plastic limits respectively. For soil grade VI however, a relatively larger decrease in liquid limit (39 %) and smaller for plastic limit (19 %) were noted for grade VI as compared with grade V soil.

Patel (2011) took into consideration the change in the geotechnical properties as a result of contamination. In his study, black cotton soil was blended with castor oil of 5 %, 10 % and 15 % based on weight. It was noted that the liquid and plastic limits of the black cotton soil decreased with the increase of the contaminant.

Pandey and Bind (2014) performed an evaluation on the characteristics of the alluvial soil contaminated with engine oil. A varying quantity of oil was used as contaminants to soil from 0 %, 4 %, 8 % and 12 % of the dried weight of samples. It was noted from the result that the liquid limit, plastic limit and shrinkage limits of the soil were decreased. It was clear that the index properties of the contaminated soil were affected due to the addition of the engine oil. By increasing the oil content in soils, the water content in the liquid and plastic limit reduces.

It can be noted that all the above studies found a decrease in plasticity characteristic of soil due to contamination by hydrocarbon. In contradiction, the following studies found an increase in the plasticity of soil due to contamination by hydrocarbon.

Shah *et al*. (2003) demonstrated that comparisons with non-contaminated CL soils, showed that the contaminated soils decreased their plastic index and increased their plastic and liquid limits. They attributed this to the increase in double layer thickness of clay particles.

Gupta and Srivastava (2010) examined the geotechnical properties of non-contaminated soil and samples of soil polluted with used engine oil - with percentage contaminations of 2 %, 4 %, 6 % and 8 % of the dry weight of the soil - for two types of soil, namely, CL and high compressibility clay (CH). In their study, a direct relationship between the liquid limit and content of oil was observed. This indicates that the values of the liquid limit increases with the increase in the percentage of oil contaminants.

Jia *et al*. (2011) investigated the effect of contamination by crude oil. The soil samples were extracted from trial pits manually excavated within the Hai-gang region of the Yellow River Delta. The result revealed that severely polluted samples exhibited higher clay particle content (< 0.05 mm) - identified as organic and inorganic composite compounds - as well as an increase in their liquid and plastic limits.

According to Elisha's (2012), investigation regarding the Atterberg Limit, which was carried out with the aim of comparing certain engineering properties of both hydrocarbon contaminated and virgin (non-contaminated) soft clays extracted from the area of the Niger Delta in Nigeria. The outcome of the investigation revealed that increases in liquid limit of 17.9 %, plastic limit of 6.9 % and plasticity index of 37.5 % were registered due to the crude oil addition. The cohesiveness of the contaminated clay had increased probably due to the bonding strength increase caused by the oil residue particles. As such it was necessary to introduce water to make changes in the level of consistency for a thick layer of contaminated clay.

A detailed program on laboratory testing was also undertaken by Habib-ur-Rahman *et al*. (2007) in order to compare the engineering properties of hydrocarbon contaminated and non-contaminated clay samples. They discovered that there was an approximate increase of 2 % in the plastic limit, 13 % in the liquid limit and 13 % in the plasticity index of the hydrocarbon contaminated clay sample. According to Habib-ur-Rahman *et al*. (2007) the increase in Atterberg Limits could be due to *'the extra cohesion provided to the clay particles by the oil.'*

From the above researchers, it is indicated that hydrocarbon contamination had various effects on the plasticity characteristics of the original soil. In fact, there was a contamination decrease in the plasticity liquid limit and plastic limit; however, the liquid limit and plastic limit increased with increments of contamination with other soils.

This may be attributed to many factors could affect the double layer water thickness. These variations could be attributed to the water content nature in the clay minerals structure and the influence of existing non-polar and viscous fluids within the soil (Khamehchiyan *et al*., 2007).

3.3.2 Particle Size Distribution (PSD)

Based upon a study by Caravaca and Roldan (2003), an assessment of the variations in the physical properties of sludge oil and contaminated clay loamy sand indicated a soil gradation variation. The contents of the silt and clay dropped from 21.3 % to 20.5 % and 33.3 % to 21.7 % respectively whereas the sand content registered an increase from 45 % to 58 %. The fine contents are altered by the hydrocarbon absorption into the soil mineral colloids that are responsible for changing their sedimentation rate (Caravaca and Roldan, 2003). Because of this change in the content of components, the soil classification changed from clay loam to sandy clay loam. Srivastava and Pandey (1998) carried out an investigation to understand the influence of hydrocarbon contamination on the alluvial soil gradation. It was noted that the particle size increased due to the coating of oil.

Additionally an experiment carried out by Meegoda and Ratnaweera (1995) discovered that by adding oil of 3 % and 6 % to clay soil, the clay fraction decreased from 96 % to 87 % and 87 % to 84 %, respectively signifying an increase in soil aggregation with the introduction of oil. They this attributed to the crude oil viscosity and the surface tension between water and oil which lead to the suction pressure in aggregating soil particles. The results would finally show an increase in the percentage of large particles and decrease in the finer particles.

Furthermore, Ijimdiya (2013) carried out an assessment which was conducted to study the effects of hydrocarbon contamination on the lateritic soil on the geotechnical properties. He investigated the effects of motor oil contamination on the PSD of soil. A major decrease in the quantity of fines fraction with high doses of oil by dry weight of soil was observed. Initially, the silt size fraction ratio in the virgin soil was 86 %, however, upon contamination with motor oil content at 2 %, 4 % and 6 % oil content by dry weight of soil, the percentage reduced to 25.1 %, 13.6 % and 1.4 % respectively. According to Ijimdiya, the great reduction of silt or the fine fraction was a result of the bonding between the silt sizes allowing them to form pseudo-sand sizes and also of the sand sizes to form larger sand or clog sizes.

None of the above works was done to compare the change in PSD after long period of crude oil drying under hot arid climate.

3.3.3 Scanning Electron Microscope (SEM)

A study was carried by Mucha and Trzcinski (2008) to investigate the change in the microstructure of clay soil – glacial till resulted from in-situ contamination by diesel oil. STINMAN software was utilised to perform a quantitative analysis in the SEM-based photographs. Caused by the contamination, the microstructure experienced major qualitative alterations; i.e. a decrease in the packing of particles and clayey micro-aggregates; disintegration of part of the micro-aggregates; the warping of the edges and corners of some clay particles; and the amount of intermicroaggregate pores and edge-to-face (EF) contacts among clay microaggregates increased.

Pollution from diesel oil causes major quantitative alterations in the space of the till pores. A major notable increase was seen in the amount of mesopores, the maximum and average pore areas, the maximum, minimum and average pore perimeters and the maximum and average pore diameters. On the other hand, there was a decrease in the total pore perimeter. These alterations could have resulted from the reduction of interparticle forces on pollution with a fluid which has a dielectric constant less than water.

3.3.4 Permeability (Hydraulic Conductivity)

An investigation was conducted by Al-Sanad *et al*. (1995, p.409) who undertook a permeability test on Kuwaiti sand contaminated with hydrocarbon from the destroyed oil production facilities after the Gulf War. As the soil samples could not be excavated from the bottom of the *oil lake* during the investigation, it was decided to adopt reference sand termed - *Jahra sand* (typical surface desert sand in Kuwait) – and deliberately contaminate it with 6 % of crude oil taken from the field. The determination of hydraulic conductivity of Kuwaiti virgin and contaminated sands has confirmed a decrease of approximately 20 % in the permeability coefficient due to the soil contaminant. The results of the experiment showed that the coefficient of permeability (k) in clean and contaminated sand was k $=1.72\times10^{-5}$ m/s and k $=1.38\times10^{-5}$ m/s respectively. It was also noted that the reduction of 20 % in value could be attributed to the reduction of pore volume *'contributing to the hydraulic conductivity due to trapped oil.'*

Puri *et al*. (1994), agreed with the findings after an experiment was carried out to study the effect of contamination by crude oil on geotechnical properties of sandy soil such as the coefficient of permeability. The permeability was noted to be a factor of the initial viscosity and the level of saturation due to the crude oil contaminant. The reduction in the permeability coefficient was attributed to the increasing of the soil content and to the filling of pore spaces by oil.

Additionally, Khamehchiyan *et al*. (2007, p.228), carried out tests - to determine how the geotechnical properties of the clay and sandy soils, such as SM, CL and SP - by mixing them with different amounts of crude oil – 2 %, 4 %, 8 %, 12 %, and 16 % by dry weight - can be affected by crude oil contamination. A number of permeability tests were conducted on soil samples and the outcomes demonstrated an inverse relationship between the soil permeability and the *oil content*.

Similar findings were reached by Rahman *et al*. (2010, p.956) who explored and compared the permeability properties of granitic (V) and meta sedimentary (VI) soils which were contaminated with hydrocarbon. The soil was mixed with different percentages of crude oil (i.e. 4 %, 8 %, 12 % and 16 %) of the dry weight of base soils. It was observed that the soil permeability reduced due to the oil contamination. For soil grade V and VI, their permeability was reduced from 3.74 - 0.22 and 2.65 - 0.22 cm/sec, respectively. The tests clarified that the decrease in permeability of *crude oil contaminated soil* was due to the clogging of some *inter-particles spaces* by the oil. As such, increasing the quantity of oil would reduce the available "*inter-particles space"* for any seepage of water.

However, Gupta and Srivastava (2010) investigated two types of soil plasticity states, namely, CL and CH for the coefficients of the permeability of non-contaminated soils and samples of soils contaminated with used engine oil with percentage contamination of 2 %, 4 %, 6 % and 8 % of the dry weight of the soil. They noted that the coefficient of permeability increases with the increase in the concentration of contaminants for the types of clay.

In fact the Hydraulic Conductivity of oil contaminated soil may be influenced by many factors, e.g. granularity, plasticity of soil, percent of oil and its molecular weight. For instance, the permeability is expected to decrease in granular soil due to the clogging of some voids in the soil while in fine soil of high plasticity it is expected that the permeability increases due to aggregation of fine particle to form coarser ones and so lead to increase in pore sizes.

3.3.5 Shear Strength

Singh *et al*. (2009), Al-Sanad *et al*. (1995), Khamehchiyan *et al*. (2007) and Shin *et al*. (1999) tested the influence of adding different percentages of crude oil to non-cohesive soil on its angle of internal friction (φ).

All the above researchers found that angle of internal friction (φ) was decreased due to the lubricating action of oil in reducing the friction between the particles. Furthermore, they found that angle of internal friction (φ) was further decreased by adding higher contents of oil. The shear strength tests were conducted immediately or shortly after oil addition.

Al-Sanad and Ismael (1997) performed a laboratory test to determine the geotechnical characteristics of this material and the aging impact upon their properties. Crude oil was added to sand soil samples at 2 %, 4 % and 6 % concentration; as in the above works the samples, which were tested immediately after mixing the oil with soil, showed a decrease in their angle of internal friction (φ) values associated with a further decrease in φ when the oil content was increased. Furthermore, to assess the effect of aging, the contaminated sand samples with crude oil were tested in normal environmental conditions after aging for one, three and six months. The outcome of the test demonstrated an increase in the soil strength (i.e. φ) and decrease in the content of oil owing to the evaporation of volatile constituents.

A testing procedure on clay soil was carried out by Alhassan and Fagge (2013) who combined the clay soil with different amounts of crude oil, i.e. 2 %, 4 % and 6 %. The results indicated a decrease in cohesion intercept (c) with an increase in angle of internal friction (φ) of the soil and a further decrease in cohesion intercept (c) with a further increase in angle of internal friction (φ) as the contamination level increased was determined. The reductions in cohesion intercept, according to the authors, could be the result of the oil increasing the ratio of surface area to volume of clay mineral particles; surface forces therefore, predominated over the mass-derived gravitational forces.

Comprehensive laboratory tests were carried out by Kermani and Ebadi (2012), looking for the effects of adding various amounts of crude oil to fine grained soil, also, different water contents were investigated to study the effect of oil and water contents on the shear strength. The tests showed that the cohesion intercept (c) was decreased and that the angle of internal friction (φ) was increased with an increase in oil content for all water contents.

Their results are compatible with (Alhassan and Fagge, 2013) in terms of both cohesion intercept (c) and angle of internal friction (φ) variations with oil variation contents. Furthermore, with the oil content being the same, the cohesion intercept (c) was found to increase as the water content increased; this was associated with a decrease in the angle of internal friction (φ).

The samples of Kermani and Ebadi (2012) were also subjected to different aging times of up to 90 days; results indicated that the cohesion intercept (c) decreased with an increase in sample age although the angle of internal friction (φ) was not specifically affected by aging.

The foregoing clearly shows that contaminating the non-cohesive soil with crude oil leads to a decrease in its angle of internal friction (φ) if the test is done immediately.

The researcher in this instance, therefore, believes that in cohesive soil, the cohesion intercept (c) and angle of internal friction (φ) may be affected differently by many factors e.g. the water content of soil before mixing with oil, the clay mineral type and its fabric form (cluster or dispersed) and the salts within the soil which may affect the double layer.

3.4 Geochemical Review of Soil Contaminated with Hydrocarbon

A number of studies characterised and explored the influence of hydrocarbon contamination on the soil geochemical properties, including those of Onojake and Osuji (2012), Barua *et al*. (2011), Khuraibet and Attar (1995), Al-Duwaisan and Al-Naseem (2011), Jean-Philippe *et al*. (2012) and Perkinelmer's (2010).

For chemical substances and concentration see TPHCWG (1998), Wang and Fingas (1995), Bufarsan *et al*. (2002), Barker and Bufarsan (2001), Al-Sarawi *et al*. (1998a), Pathak *et al*. (2011), Wuana and Okieimen (2011), Sato *et al*. (1997), Benyahia *et al*. (2005), Ahamad and Barke (2011), Saeed *et al*. (1998), Jiang *et al*. (2011) and Okop and Ekpo (2012).

This section will emphasise the geochemical properties of soil contaminated with hydrocarbon so that an assessment can be made as to the soil's chemical properties. This will be determined by means of the relevant geotechnical tests on samples, namely: pH; water soluble Cl- and (SO_3 & SO_4); EA; and GC-MS. Various studies will be discussed in this chapter and will be classified based on the geochemical tests adopted.

3.4.1 Hydrogen Ion Concentration (pH)

Based on Onojake and Osuji's (2012), report the extent of pollution can be assessed; determination of the physico-chemical properties of the hydrocarbon levels in Ebocha-8 was performed within six months of the spillage. The area affected by the incident was first plotted into grids of 200 mm x 200 mm. Samples were then extracted using the grid technique from three replicate quadrants at two levels below ground, namely - surface (0-15 cm) and subsurface (15-30 cm). A neighbouring site, approximately 50 m away and unpolluted was used as a reference site; samples were also extracted from this site which is within a similar geographical area. From the results of the pH tests carried out at the polluted site, the hydrocarbon contamination at depths of 0-15 cm and 15-30 cm were found to be 6.50 ± 0.21 and 6.48 ± 0.20 respectively; however, the non-contaminated site showed a pH value of 5.33 ± 1.16 at both levels. It was noted that although the pH value in the soil was affected it still lies in the acidic rang that may prevent crops from developing (Table 3.4).

In contrast with the findings of Onojake and Osuji (2012) - who found that the acidity of soil is reduced due to contamination - Barua *et al*. (2011) and Khuraibet and Attar (1995) found that the acidity (in general) was increased due to contamination (pH values generally decreased).

Table 3.5 shows the resultant pH values found from the above works explaining the findings through the testing of samples taken from eight contaminated oil field sites from different depths below ground level. The table also shows the pH values of soil samples taken from correspondingly non-contaminated oil field sites near that of the contaminated one. The table furthermore shows the observations of the researchers about the results of their work. It should be noted that Khuraibet and Attar's (1995) work was carried out a year after the disaster in Kuwait.

Table 3.4. The pH classification in the soil (Source: Horneck *et al*., 2011).

pH Range Value	Description
< 5.1	Strongly acidic
5.2 - 6.0	Moderately acidic
6.1 - 6.5	Slightly acidic
6.6 - 7.3	Neutral
7.4 - 8.4	Moderately alkaline

Table 3.5. Summaries results of studies made by different researchers about the changes in soil pH values due to crude oil contamination.

References	**Name of Oil field**	**Depth below Ground Level**	**Non-contaminated Site**		**Contaminated Site**		**Change in pH value due to contamination**	**Notes**
			pH value	**Description**	**pH value**	**Description**		
(Onojake and Osuji, 2012)	***Ebocha-8 oil field in Nigeria***	0-15 cm	5.33 ± 1.16	*Moderately acidic*	6.50 ± 0.21	*Slightly acidic*	+ 1.17	They noted that for the affected soils, their pH values still lie within the acidic range which may prevent crops from developing.
		15-30 cm	5.33 ± 1.16		6.48 ± 0.20		+ 1.15	
(Barua *et al*., 2011)	***Rudrasagar oil field in india***	0-10 cm	6.40 ± 0.20	*Slightly acidic*	5.80 ± 0.30	*Moderately acidic*	- 0.6	They stated that the contaminated soils are naturally a little more acidic possibly because of the toxic acid formed in the spilled oils.
	Lakwa oil field in india	0-10 cm	6.33 ± 0.20		5.72 ± 0.30		- 0.61	
(Khuraibet and Attar, 1995)	***Al-Magwa field in Kuwait***	0-5 cm	7.08	*Neutral*	7.12	*Neutral*	+ 0.04	They indicated that the acidity of the soil was increased due to contamination.
		5-30 cm	8.14	*Moderately alkaline*	7.58	*Moderately alkaline*	- 0.56	
		30-60 cm	8.44		8.21		- 0.23	
	Burgan field in Kuwait	0-5 cm	6.86	*Neutral*	6.46	*Slightly acidic*	- 0.4	
		5-30 cm	6.66		6.76	*Neutral*	+ 0.1	
		30-60 cm	6.74		7.56	*Moderately alkaline*	+ 0.82	

Table 3.5. Continuous.

References	Name of Oil field	Depth below G.L	*Non-conta. site		**Conta. site		Change in pH value due to contamination	Notes
			pH values	Description	pH values	Description		
(Khuraibet and Attar, 1995)	***Baharah field in Kuwait***	0-5 cm	7.16	*Neutral*	6.12	*Slightly acidic*	- 1.04	They stated that the acidity of the soil was increased due to contamination.
		5-30 cm	7.1		6.44		- 0.66	
		30-60 cm	7.12		7.12	*Neutral*	0	
	Rawdatain field in Kuwait	0-5 cm	7.46	*Moderately alkaline*	6.66	*Neutral*	- 0.8	
		5-30 cm	7.38		7.02		- 0.36	
		30-60 cm	7.78		7.60	*Moderately alkaline*	- 0.18	
	Wafra field in Kuwait	0-5 cm	7.48	*Moderately alkaline*	7.18	*Neutral*	- 0.3	
		5-30 cm	7.38		7.36	*Moderately alkaline*	- 0.02	
		30-60 cm	8.26		7.50		- 0.76	

The results shown in Table (3.5) indicate that mostly, and in general, the contamination increased the acidity of soil; only the results of the research of Onojake and Osuji (2012), shows a wide range in pH values of non-contaminated soil, however, no solid conclusion can be reached about these results.

3.4.2 Water Soluble Chloride (Cl-) and Sulphate Content (SO_3 & SO_4)

A study was carried out by Onojake and Osuji (2012), investigating the physico-chemical properties of the hydrocarbon levels in Ebocha-8, six months after the spillage in order to determine the extent of contamination. The area of concern was mapped into grids of 200 m x 200 m with samples taken utilising the grid technique from three duplicate quadrants at two depths, i.e. surface from 0 - 15 cm and subsurface from 15 - 30 cm below ground. For the hydrocarbon contaminated sites at surface (0 - 15 cm) and subsurface (15 - 30 cm), the results for the chloride tests were 973.94 ±55.63 and 366.06 ±17.29, respectively. The results for the control sites, however, indicated chloride values of 56.00 ±17.76. It was also noted that the values of sulphate for the hydrocarbon contaminated sites were 1.06 ± 0.10 and 0.25 ± 0.02 at depths of 0 - 15 cm and 15 - 30 cm respectively. At non-contaminated sites, however, the sulphate value of only 0.60 ± 0.37 were recorded.

3.4.3 Vario Macro Elemental Analysis (EA)

As mentioned by Wuana and Okieimen (2011), there are various phases at which contaminated soils can be studied, namely solid, gaseous or liquid. In order for this to take place, a complex analysis data interpretation is essential. Accordingly, the usual technique to determine the concentration level of oil polluted soil was the elemental analysis method (USEPA Method 3050) used. The unit for contamination level is $mg\ metal\ kg^{-1}\ soil$ if this method is utilised to ascertain the level of metal. The moisture content requirements in the soil is not stated in the elemental analysis technique, as such this analysis may include soil water and be used on dry soil to determine the concentration of elements such as C, H, and N.

In accordance with Benyahia *et al*. (2005), an analysis test for soil contaminated with crude oil was performed in the laboratory as the soil was required to undergo treatment comprising aerated contaminated soils modified by adding crude oil. Moreover, in this particular research, the elemental analysis of the treated soil demonstrated that the simpler and most bio available elements in the crude oil tend to degrade faster than the rest of the elements.

Based on Sato *et al.*'s (1997) study, a normal molecular structural analysis was carried out on the soil samples collected from sediment at the: Shuaiba site in June 1995, soils from the Sabriya site in November 1993 and November 1994; the Jaidin site in November 1993 and November 1994; all using the heavy fraction (boiling point > 34O °C) of Kuwait crude oil. As observed from the findings of the elemental analysis, the average molecules of saturate-free fractions comprised only one fused ring system, i.e. 52 - 64 hydrogens, 1 sulphur atom, 10 - 14 aromatic carbons and 35 - 42 total carbons, which comprised a dibenzothiophene or benzothiophene type structure. The samples of oil obtained from the soils consisted of 1 - 2 Oxygen atoms.

Compared with other oil, the oil extracted from the Sabriya soils in November 1994 contained more rings which showed further degradation. By comparing the average molecular structural parameters, it was clearly seen by the researchers that the degradation of oils in soils came about through the process of condensation, aromatization, cyclization, and oxidation reactions. Compared with these oils, the degradation of oil in sediment came about through the formation of naphthenic rings and the reduction in the chains of aliphatic that could be due to some effects of microorganisms.

As stated by Jean-Philippe *et al.* (2012), soil contaminated with hydrocarbon can be identified using conventional means based on expensive inefficient samples. Perkinelmer's (2010), elemental analyser of the Dumas organic in soil, took account of the combustion of soil particles in the presence of Oxygen turning them into simple gasses or molecules, for example H_2O, CO_2 and N. This was followed by the separation of these gasses using chromatography methods. Except for soils from the last batch, all soil samples were taken to the EA2400 CHNS/O Elemental Analyser; other soil samples were analysed using the *EA2410 N Nitrogen Analyser*. The former has been recognised as an effective device for the analysis and variation of organic contents in soil samples.

3.4.4 Gas Chromatograph Mass Spectrometry (GC-MS)

Gas Chromatograph Mass Spectrometry (GC-MS), an apparatus utilised in laboratories for measuring TPH, can detect a broad range of individual hydrocarbon components and their concentration. In particular, the gas chromatography is able to identify a wide range of hydrocarbons and also specify their ranges and quantities, (TPHCWG (1998)). However, it does require an analyst familiar with petroleum products.

The gas chromatograph is able to detect mixtures of chemicals and divide them into their individual components; this is done by putting a sample into the apparatus where boiling point, polarity and affinity differences of the sample are separated into their component parts (TPHCWG, 1998). The retention time, i.e. time compounds are on specific columns, is reproducible. A Mass Spectrometry detector is then able to ionize the various compounds into their molecular ions; this apparatus is able to find nearly all compounds successfully and library research enables the results to be confirmed. Usually, the compounds detected procedure achieved, when the gas sample or liquid eluted is injected to detect any hydrocarbon which elute from the column; when this occurs, they are identified and ionized by laboratory match (TPHCWG, 1998).

TPHCWG (1998), however, claims that there are limitations to the GC; these are as follows:

- It cannot quantitatively detect compounds below C6 which are highly volatile.
- It has problems in quantifying some constituents such as nitrogen, oxygen and sulphur containing molecules.
- Many isomers and compounds, especially those above about C8, coelute with isomers having the same boiling point. They are called unresolved complex mixtures (UCM) which cannot quantify the hydrocarbon compounds in samples individually from peak to peak. However, it requires quantifying all hydrocarbon compounds from baseline to baseline as integration mode (TPHCWG, 1998).

Wang and Fingas (1995) mentioned that the Gas Chromatography-Mass Spectrometry (GC-MS) technique utilises a high-performance capillary, operating with the aid of a specific oil analysis, (also known as the Ion Monitoring (SIM)). This method has been used to determine the characteristics of the oils, for example, biodegradation oils, weathered oils, crude oils, and oil-spills. It relates to varying concentrations, natures and compositions of oil specimens which include environmental samples. The GC-MS technique is useful as it quantifies and identifies specific targets for petroleum hydrocarbons, which includes a spectrum of regular alkanes from C8 to C40.

A study was carried out by Bufarsan *et al*. (2002) to assess the compositional changes resulting from the evaporation of crude oil from the Burgan Field which spilled into the Southern Kuwait desert. Making use of GC-MS data for Hopane and Sterane biomarkers, it was verified that the *oil lakes* indeed originated from the massive Burgan Field. As indicated from the analysis of sulphur compounds, the oils from the exposed lakes were photo oxidised with a decrease in benzothiophenes concentration and an increase in volatile sulphur compounds. The volatile hydrocarbon loss resulted in compositional layering. The author noted the formation of a surface layer which constrained the process of evaporation.

Barker and Bufarsan (2001) undertook a study aimed at examining losses due to evaporation from the '*oil lakes*' surfaces in southern Kuwait. Based on their observations, evaporation is considered one of the key degradation mechanisms from oil spillage. Using simulation of evaporation of crude oil from the Burgan Field Kuwait and a Venezuelan crude oil field, evaporation took place at a number of temperatures and air flow rates, a fast initial weight loss followed by an increase in viscosity were observed. As an outcome of evaporation, the volume of *oil lake* decreases and the shoreline showed movement due to the reduced surface area. Nevertheless, the decrease in shoreline was noted to be a lot smaller than anticipated. The authors assumed that this was due to a high viscosity dense layer that formed on the oil surface which covered the oil below thus reducing the overall evaporation rate.

Further to a study by Ahamad and Barke (2011) on the function of evaporation in the *oil lake* degradation, it was found that without water being present oil spills can only be degraded via oxidation and evaporation. This observation is accurate especially in the Kuwait desert where *oil lakes* are still present even 20 years after the spillage. They also observed that the compositional variations supervised by gas chromatography displayed volatile components losses (< C8), including naphthenes, aromatics and alkanes. The losses in normal alkanes are faster than other kinds of hydrocarbons bearing similar carbon numbers. It was additionally noted that the evaporation caused an increase in density and viscosity which leads to compositional stratification forming a skin layer that protects the oil below and decreases the evaporation rate.

Al-Sarawi *et al*. (1998b) carried out an analysis on hydrocarbon contaminated soils taken from the Al-Ahmadi and Greater Burgan Oil Fields and discovered that for both sites, the soils contained high concentrations of TPH. While the soil from Al-Ahmadi profile contained high TPH even at the lower depth of (80-95 cm), soil samples from the Burgan site exhibited high TPH concentration on the surface only (upper 50 cm).

As mentioned by Saeed *et al*. (1998), an investigation was carried out to study the changes in oil chemical composition which had been exposed to weather for five years in the *oil lakes* of Kuwait. Samples of oil were extracted from within the northern and southern oil fields. The differences were compared against the previous data for the initial 21 months of weathering of the oil samples taken from the same lakes. The results displayed a substantial increase in the asphaltene content of the remaining oil in the lakes or their beds. Saturates demonstrated an increase within the past 39 months of weathering with a substantial loss noted for the initial 21 months. Meanwhile, in the majority of samples, the aromatic oil fraction indicated a reduction. The amount of resins in the samples continued to show a steady rise. Generally, there was no major change in the concentration and overall composition. However, for the higher PAH their concentration showed an increase.

Jiang *et al*. (2011) studied the distribution, level, compositional pattern and probable sources of PAH contained in Shanghai's agricultural soil. As revealed from the results, the concentrations for 21 PAH and 16 priority PAH varied from 140.7 to 2,370.8 μg kg^{-1} and between 92.2 to 2,062.7 μg kg^{-1}, respectively. The areas in the south and west of Shanghai showed higher PAH concentration but Chongming Island displayed lower values. In general, the compositional pattern of PAH was characterized by the high molecular weight of the PAH, the seven possible carcinogenic PAH constituted 4.8 % - 50.8 % of the total PAH, with the key constituents in soil samples such as fluoranthene, pyrene, and benzo[b]fluoranthene.

Okop and Ekpo (2012) investigated soil contamination due to crude oil spillage from the Niger Delta region of Nigeria ninety days after a major spillage. A total of sixty samples were taken from a number of locations in the South-South region of the Niger Delta. Soil samples were extracted at depths of 0 - 15 cm, 15 - 30 cm and 30 - 60 cm below ground. Analysis of the samples was performed by gas chromatography equipped with a flame ionisation sensor. Analysis of the results showed that total petroleum hydrocarbon concentrations for topsoil, subsoil and soils at greater depths ranged from 9 - 289 $mgkg^{-1}$, 8 - 318 $mgkg^{-1}$ and 7 - 163 $mgkg^{-1}$ respectively. In comparison with the reference sites, the results demonstrated higher concentrations of total hydrocarbon contents. The outcome of the study suggests that it is necessary to have a complete and sustainable environmental monitoring system and remediation.

An investigation was conducted by Pathak *et al*. (2011) regarding the effect of petroleum oil on soils located in the area of Jaipur, India. Soil extraction was carried out in July 2010 to a maximum depth of 6 cm below ground from the neighbourhood of the Indian Motor Garage at Transport, Nagar. The soils were analysed for their chemical content by means of the GC-MS technique to ascertain the concentration of TPH on the soil samples taken from both contaminated & non-contaminated sites. The analysis results revealed that the chemical content for Petroleum Contaminated Soil-1 (PCS-1) and Petroleum Contaminated Soil-2 (PSC-2) were 11149 mg/kg and 14244 mg/kg, respectively. For the Normal Soil-1 (NS-1) and Normal Soil-2 (NS-2) taken from non-contaminated sites however, the results were 700 mg/kg and 614 mg/kg, respectively.

3.5 Human Health Risk Assessment (HHRA) from Hydrocarbon Contaminated Soil

Some studies have been focussed on the influence of hydrocarbon contaminated soil on human health in terms of the presence of carcinogenic and non-carcinogenic substances.

These studies have employed HHRA scenarios, including those of Nathanail *et al*. (2007), Angehrn (1998), Hua *et al*. (2012), Dumitran and Onutu (2010), Sarmiento *et al*. (2005), Iturbe *et al*. (2004), Irvine *et al*. (2014), Brewer *et al*. (2013) and Bowers and Smith (2014).

Risk assessment tools (software) as a means of identifying and assessing the extent of risks from the carcinogenic pollutants on the surrounding environment were used by: Searl (2012), GSI Environmental (n.d.), Pinedo *et al*. (2012), Asharaf (2011), Chen *et al*. (2004), Tomasko *et al.* (2001), Pinedo *et al.* (2014) and Spence and Walden (2001). Additionally, Amat-Bronnert *et al*. (2007), Campbell *et al*. (1993), Ordinioha and Brisibe (2013) and Osman (1997) researched how severe hydrocarbon contamination effects were on human health.

This assessment can be achieved using the appropriate HHRA approach and by the application of simulation for the contamination hazards on human health by means of a few modelling methods; for example, RBCA and RISC, to address severe diseases caused by hydrocarbon contamination. As such, the classification in this section is based upon the HHRA scenarios, which indicates a number of risk assessment tools utilised for HHRA, demonstrating the RISC-5 as adapted for HHRA and the associated risks from hydrocarbon contamination on human health.

3.5.1 Human Health Risk Assessment (HHRA) Scenarios

Other studies conducted on risk assessment to evaluate the risk caused by hydrocarbon contaminant on human health are reviewed in this research. Angehrn (1998) conducted the risk assessment by following the U.S. EPA framework for assessing risk scenarios including Hazard Identification, Exposure Assessment, Toxicity Assessment and Risk Characterisation on residual mineral oil contaminants in bioremediated soil. This procedure was used to assess the potential risk on the environment related to oil residue contaminants in bioremediated soil.

His study revealed that all the oil residual contaminants within the bioremediated soil have an extremely low mobility in the environment caused by their low volatility coupled with their high hydrophobicity (Kow > 106). This was determined through the analytical concept that underpins the Hazard Identification process. At the exposure assessment stage, the relevant transport and transformation processes were identified and tabulated. The results revealed, at the exposure assessment stage, a significant portion of the oil residual contaminants (93 % of the initial total solvent extraction material (TSEM), even after one year of application as top soil) will linger in the bioremediated soil for quite a considerable time. In fact, 7 % of the initial TSEM of the residual, which may be lost during this time period, could be separated into different processes; a majority (98 %) of the total losses was due to transformation processes, a combination of biodegradation and aging effects.

However, negligible losses are traced to volatilization of the oil residue contaminants into the atmosphere as well as to plant uptake which was estimated to be < 0.001 % of such losses. In the transport process, leaching, - identified as the most significant - only accounted for 1.7 % of the losses.

As such, a conclusion can be reached that emissions from this soil is extremely low. From the toxicity assessment conducted, which included laboratory experiments and model calculations, it has been revealed that oil residual contaminants in the bioremediated soil are not hazardous to the environment nor to water organisms and plants. Based on the risk assessment conducted, the case study on the bioremediated soil could be reused even to receptors that are exposed by several pathways, e.g., as top soil in residential areas. From the findings presented in this study, an alternative method was recommended for the purpose of evaluating the bioremediated soils and mineral oil residue contaminated soils. Instead of evaluating a single surrogate parameter (TPH) in soils, the possible risks related to oil residual contaminants can be ascertained based on the possible emissions (Angehrn, 1998).

In the same vein, Hua *et al*. (2012) researched the health risk assessment caused by exposure to organic contaminated soil at an oil refinery. An assessment was carried out by combining health risk methods of the U.S. EPA, the ASTM (American Society for Testing and Materials) and VROM (Ministry of Housing, Spatial Planning and the Environment in the Netherlands).

Nevertheless, localized parameters, such as the characteristics of the Chinese demographic and site features, were also used in the study conducted by Hua *et al*. (2012). In their study, they applied risk assessment situations including: Hazard Identification; Exposure Assessments; Toxicity Assessment; and Risk Characterisation. The results obtained showed that the concentration of benzo(a)anthracene, benzene and benzo(a)pyrene in the soil of the site all exceeded their risk screening values, with hydrocarbon contaminants concentrated in soil at 0.1–5.5 m under the ground surface. In order to calculate the health risks of the site with above 95 % confidence the limit of the pollution, three main exposure pathways including oral digestion, skin contact and breath inhalation were identified.

These three main exposures indicated carcinogenic risk (CR) and the non-carcinogenic Hazard Quotient (HQ) of the polluted soil which reached 9.59×10^{-5} and 15.46, respectively; this exceeded the acceptable level of 10^{-5} and 1. As such, this could pose severe health risk to the residents at the site.

To differentiate between carcinogenic risk (CR) and non-carcinogenic hazard quotient (HQ), (Hosford, 2009), it should be noted that CR is concerned with non-threshold substances where human nature has not evolved a mechanism and/or enzymes to cope with it, therefore (in theory) one molecule (or a quantity of 10^{-5}) could lead to harm, but with a low probability. Nevertheless, there is always some likelihood of an adverse effect, and the higher the dose the higher the harm probability. This is why excess lifetime cancer risk (ELCR) is defined as the excess dose which cannot increase risk of cancer by 10^{-5} (for instance) above the baseline risk. This can be converted to a concentration which must not be exceeded, (in this respect return to Hosford, (2009)).

On the hand, the non-carcinogenic HQ is concerned with threshold substances that a body can deal with a certain amount of a threshold substance (because often it naturally exists in the environment). In the other words, certain amounts can be metabolised and excreted without harm. However, above certain concentrations (called the threshold concentration = reference concentration (RfC) / reference dose (RfD)) harm may occur. For risk assessment it can be said that as long as one ingests/inhales less than x mg/kg, where x is lower than the acceptable concentration of substance (or its threshold concentration) then it should be fine.

Figure 3.1 clarified the difference between the concept of non-threshold and threshold toxicity.

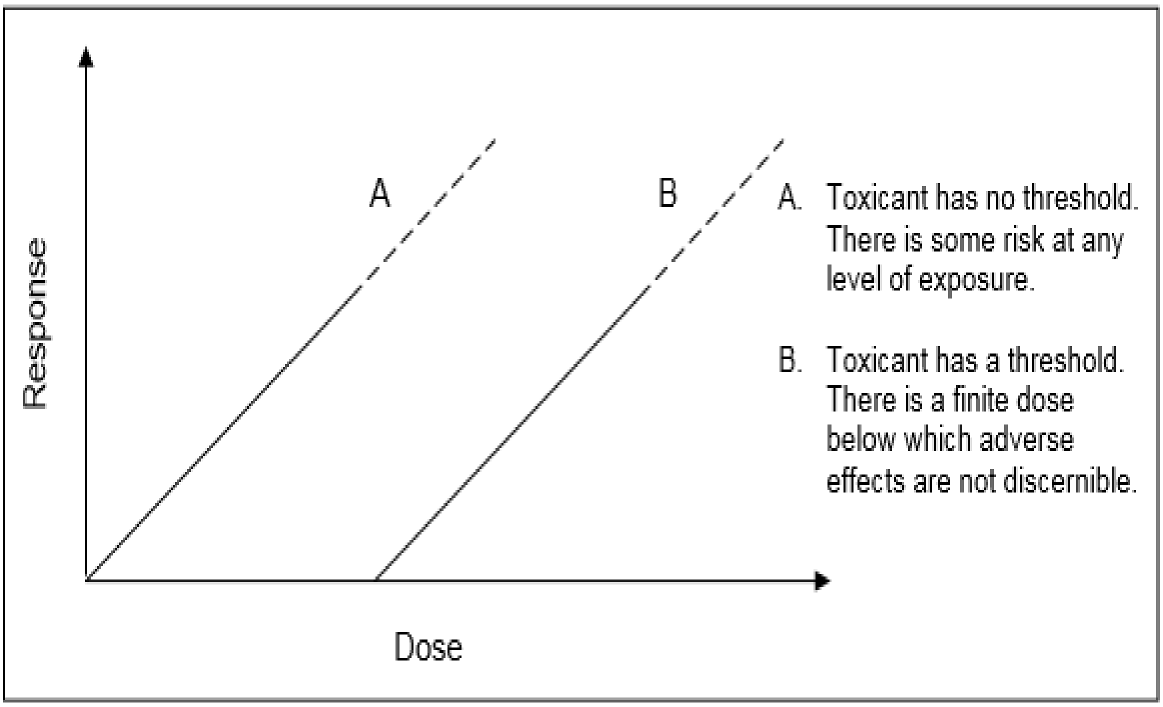


Figure 3.1. Graphic clarification of the non-threshold and threshold toxicity (Source: Hosford, 2009).

According to Dumitran and Onutu (2010), the assessment on environmental risk from crude oil which includes five modules related to Hazard Identification, Hazard Assessment, Risk Estimation, Risk Assessment and environmental risk management. These five modules are based on risk criteria of *as low as reasonably practicable* (ALARP) and environmental risk management. In order to conduct the experiment, the modules had to be fed with data which had to include technical data for: the equipment in the upstream manufacturing activities; analysis of physico-chemicals; soil pollutants; extraction and separation of gas-oil; soil properties which have an impact on the severity and consequences of the default risk; mathematical equations; charts and the framework assessment of ecological risk intensity. The methodology section spells out the steps needed to calculate the alert threshold and treatment and other related studies, i.e. pedological and chemical and geotechnical studies.

A study by Iturbe *et al*. (2004), based on the soil of a refinery located by the sea found that the area was hydrocarbon contaminated and concentrations of up to 130000 mg/kg as TPHs were detected. The study revealed that the hydrocarbon contamination was traced back to the main contributors which were pipelines, valves, old storage tanks, additionally, hydrocarbon contaminants were also caused by the land fill used for untreated hydrocarbon sediments originating from the cleaning of storage tanks. The study evaluated the Health Risk Assessment (HRA) by measuring the hazard indexes as well as the clean up level values using the refinery soil.

Taken from the HRA compilation, the following actions were recommended: benzene concentrations must be minimised in 8 of the 16 studied refinery regions to 0.0074-0.0078 mg/kg. Similarly, the concentration of vanadioum must be decreased in two regions up to a concentration of 100 mg/kg. In the reduction of benzo(a) pyrene concentration from the studied zones, only one zone needed to reduce to 0.1 mg kg(-1). The recommendations were made in order to reduce the risks of the oil refinery substances on human health. The overall results showed that the TPHs were reduced by around 52 %.

Sarmiento *et al.*'s (2005) study showed that three principle approaches were utilised in assessing potential human health risks from exposure to the hydrocarbon contamination of TPH, i.e. the indicator approach, the surrogate approach and a mixed version. The differences between these approaches were discussed in Sarmiento *et al.*'s case study research which was carried out in an area previously used as an industrial site affected by petroleum products and planned for redevelopment as a recreational spot. They assessed and took into account the TPH hazard elements towards human health using three ways of possible exposure, i.e. inhalation of hydrocarbon vapour, digestion and dermal contact.

Initially, only *indicator compounds* were appraised. This was followed by classifying the product as gasoline in the Quantitative Risk Assessment. Next an input parameter, a simple hydrocarbon chains fractionation, was introduced. Lastly, the fractionation between the aliphatic and aromatic terms of every group of hydrocarbons was measured. For each specified pathway, the Site-Specific Target Levels (SSTLs) were computed. The evaluation of results from various theories was carried out from the perspectives of both the technical and economical. Scenarios whereby input concentration for a compound was higher than the soil saturation boundary were also investigated.

A number of PAH are recognised mutagenic carcinogens; Irvine *et al.*'s (2014) investigation quantified the soil and atmospheric PAH concentrations in the Cold Lake area to measure the excess lifetime cancer risk posed to the First Nations' populations of the Alberta area, Canada. Both probabilistic and deterministic methods of risk assessment were adopted and excess lifetime cancer risks were computed for exposures from inhalation or unintentional consumption of soil. As indicated in the results, the mean excess cancer risk for the First Nations' people involved in traditional rough country activities in the area of Cold Lake through consumption was 0.02 new cases for every 100,000 with an upper 95 % risk level of 0.07 cases for every 100,000. Exposure to PAH by means of breathing showed a maximum excess lifetime cancer risk of under 0.1 for every 100,000 cases.

Crump's (1984) proposed benchmark dose (B.M.D.) was to estimate which doses could produce an adverse change in the benchmark response (B.M.R.) taking into account the background (see Hosford (2009)).*"B.M.D methods were applied particularly to animal data"* (Hosford, 2009, p.8), however, the uncertain numerical factors (generic term) had to be considered when extrapolating from the high doses in animal cases; these then had to be divided by the '*uncertainty factor'* (fold factor) for human cases. Table (3.6) shows a typical uncertainty factor as suggested in chemical risk assessment.

Table.3.6. Examples of uncertainty factors utilised in chemical risk assessment (Source: Hosford, 2009).

Consideration	Typical Uncertainty Factor Applied
Interspecies variability	A 10-fold factor is normally used to account for variability in species susceptibility between humans and animal species.
Intraspecies variability	A 10-fold factor is normally used to account for variability of responses in human populations.
Lowest-Observed Adverse Effect Level (LOAEL) to No-Observed Adverse Effect Level (NOAEL)	*A 10-fold factor may be used when a LOAEL instead of a NOAEL is used in the derivation. For a minimal LOAEL, an intermediate factor of three may be used.
Data gaps	A factor, usually three-to 10-fold, may be used for "incomplete" databases (with missing studies, such as no chronic bioassays or no reproductive toxicity data). It accounts for the inability of any study to consider all toxic endpoints.
Steep dose-response curve	**Where the dose-response curve is steep and a small error in the extrapolation would have dramatic consequences, an additional factor may be applied.

Notes: *It is appropriate to use a LOAEL to set an HCV if the undetermined NOAEL is judged to be (likely) more than ten times less than the LOAEL.

*****A steep dose-response curve dose, however, provide greater confidence in the NOAEL.***

An evaluation was carried out by Brewer *et al*. (2013), with regards to the risk of the TPH in vapour intrusion based upon the quantitative method of research. Vapours originating from petroleum fuels are characterised by a complex aliphatic mixture with aromatic compounds to a lesser degree. These substances can be quantified and defined in terms of TPH carbon ranges. Similar to individual compounds, for example benzene, toxicity factors issued by USEPA and other bodies permit for the development of risk-based, air and soil vapour screening levels for each range of carbon. At certain TPH ratios of the individual compound concerned, the vast proportion of TPH will initiate risk of vapour intrusion over the individual compound. This is predominantly the case for vapours linked to diesel and other middle distillate fuels, however, it may also happen to low-benzene and high-benzene gasolines should the sufficiently conservative, target risk not be applied to individually targeted chemicals. This requires a re-assessment of the dependence on benzene and other individual compounds as a separate tool in the evaluation of vapour intrusion risk associated with petroleum.

Nathanail *et al*. (2007), claim that in assessing the risk derived from the polluted areas, risk assessment is formed and grouped into two phases and two sub-phases namely Phase 1a- Hazard Identification, Phase 1b- Hazard Assessment, Phase 2a -Risk Estimation and Phase 2b- Risk Evaluation.

Bowers and Smith (2014) carried out an assessment on the risk to human health caused by vehicle petroleum fuels within the soil. A suitable set of Constituents of Petroleum Concern (COPCs) ought to be evaluated and managed in order to provide vigorous management of potential risks and to minimise redundant chemical analyses and evaluation of constituents that hardly (or never) cause any risk to human health. A procedure in identifying COPCs for petroleum fuel releases has been proposed based on widely accepted practices for human health risk assessment and available data related to fuel composition and the toxicity of chemicals. Lists of COPC are used to assist in investigating and assessing the risks at sites where petrol, diesel, and kerosene/jet fuels are believed to have been released. Broadly, these lists are relevant and may reinforce site-specific assessment of environmental settings and related risks.

3.5.2 Human Health Risk Assessment (HHRA) Models

As mentioned by Searl (2012), besides CLEA, SNIFFER and LQM models, there are some computer software packages which are accessible commercially in the UK which support detailed quantitative risk assessment (DQRA) for human health risks. These packages were designed mainly to assist in the assessment of contaminated risk in the U.S. (RBCA and RISC-5 models). The software packages for the U.S. market involve more sophisticated techniques to model behaviour of contaminants in air and water in comparison with the method used by CLEA. As such, the comparative influence of these pathways to overall exposure by the contaminant will vary accordingly.

Tables 3.7 and 3.8 were prepared (by the author) to allow for comparisons between CLEA, SNIFFER, RBCA and RISC 5 model packages, so as to choose the most relevant package (model) acknowledging local conditions in Kuwait (Nathanail *et al*., 2002; Jeffries and Martin, 2009; Searl, 2012; RISC-5, 2011).

Table 3.7. Comparison between different model applications in the risk assessment.

Model Name	Exposure Pathway Assessment Models													Risk Assessment	References
	Air		Ground Water							Soil					
	Inhalation indoor	Inhalation outdoor	Ingestion	Dermal	Inhalation	Vegetable Uptake	Shower	Shower Surface	Irrigation Water	Ingestion	Dermal	Inhalation of Particulates	Vegetable Uptake		
CLEA-2002	•	•	×	×	×	×	×	×	×	•	•	•	•	In Human Health	(Nathanail *et al*., 2002, p.49 and Jeffries and Martin, 2009)
SNIFFER	•	•	×	×	×	×	×	×	×	•	•	•	•	In Human Health	(Nathanail *et al*., 2002, p.37)
RBCA	•	•	•	•	•	×	×	•	×	•	•	•	•	In human health and ecosystem	(Nathanail *et al*., 2002, p.39 and Searl, 2012, p.29)
RISC-5	•	•	•	•	•	•	•	•	•	•	•	•	•	In human health and ecosystem	(Searl, 2012, p.29 & 30 and RISC-5, 2011)

Notes:* •*Considered in model application,* × *Not considered in model application.

Table 3.8. Limitations and suitability of various models in relation to Kuwait conditions.

Model Name	Limitation	Appropriation for Kuwait Climate
CLEA	Does not consider the domestic use of on-site groundwater (ingestion of groundwater, dermal contact of showering) (Nathanail *et al*., 2002, p.49)	Very specific model for UK. As such, it takes consideration of UK climate.
SNIFFER	Exposure via the consumption of drinking water or by inhalation of vapour through the use of water (swimming) is not included (Nathanail *et al*., 2002, p.37).	
RBCA	Exposure from vegetable uptake via groundwater; and exposure via showering and irrigation water are not taken into consideration (Searl, 2012, p.29).	Specific model for U.S. where the climate in Kuwait nearer than that in UK. Furthermore, it is old model compared with RISC-5.
RISC-5	Take into consideration all the above models limitations (Searl, 2012, p.29 &30 and RISC-5, 2011).	Specific model for U.S. nearer to Kuwait climate.

Various studies which relate to the risk assessment evaluation of soil contaminated with oil residue as well as their influence on human health were reviewed. It was discovered in a number of studies that the Risk Based Corrective Action (RBCA) toolkit is able to integrate the risk assessment procedures, e.g. Hazard Identification, Exposure Pathways Assessment, Toxicity Assessment and Risk Characterisation.

As stated in the GSI Environmental (n.d.), Risk-Based Corrective Action (RBCA), is regarded as a practical management procedure with clear emphasis on safeguarding human health and the environment and at the same time encouraging energy and cost-efficient remedies to allow limited resources to be aimed at the most hazardous areas. The basis of the RBCA framework is the establishment of a criteria for site-specific environmental clean-up resulting from a tiered risk evaluation methodology. In other words, the RBCA Tool Kit for Chemical Releases is a complete modelling and software for characterising risks. It is intended to conform to the ASTM Standard Guide for Risk-Based Corrective

Action (E-2081) requirements for Tier 1 and Tier 2 RBCA evaluations for chemical release sites alongside the traditional calculations for risk assessment.

The contaminant transport models and risk assessment tools are incorporated into the software to compute baseline risk levels and develop standards for risk-based clean-ups for a wide range of soil, groundwater, surface water, and air exposure pathways. The features which are user friendly coupled with reorganised graphical interface features of this software are the key elements for making a main instrument to manage RBCA and generic risk assessment calculations for both straight forward and complex problems (GSI Environmental, n.d.).

A study was undertaken by Pinedo *et al.* (2012) comprising a site specific risk assessment for the distribution and concentration of TPH fractions using the RBCA framework. This study was conducted in the Spanish, densely inhabited, average sized city of Santander with approximately 182,000 inhabitants; it was also used as a case study. In this study, two hydrocarbon contamination routes were considered, namely Volatilization and Particulates to Outdoor Air Inhalation (through ambient air volatilization of hydrocarbon contaminants from affected soils and small particles of superficially affected soil) and Surface Soil (through direct ingestion, dermal contact and inhalation). From the results, it appears that the Outdoor Air pathway registered lower risk as shown from the HQ values which are less than the upper limit of 1.0. Individual fraction soil risks are also lower than the HQ limit; however the cumulative risk is nearly 1.6 times above this threshold. This high cumulative risk was primarily the result of the aromatic EC16- EC21 fraction, which constituted nearly half of the total risk. It was found only in the total TPH of the superficial soil, registering a value of 1.6 times above the Site-Specific Target Levels (SSTLs).

Similarly, Asharaf (2011) studied the method employed by the Bahrain Petroleum Company (Bapco) to: identify the sites contaminated with hydrocarbon; assess the potential risk to human health and the environment; and to suggest any necessary preventive measures by adopting the fundamentals of Risk Based Corrective Action (RBCA).

Together with a desk based study, a phased strategy was used followed by a comprehensive assessment consisting of the boring of 40 window sample locations for soil and installing a total of 28 groundwater monitoring boreholes. More than 200 soil and groundwater samples were taken and analysed for hydrocarbons and heavy metals. This was followed by developing a conceptual site model in accordance with the Site-Pathway-Receptor linkage. The outcomes of the soil and groundwater analysis were used in deciding the likely risk to human health and the environment.

Chen *et al*. (2004) applied a method related to health risk assessment in deriving the levels of clean-up at a site contaminated with a fuel oil spill. The application was described in four different risk assessment techniques in an effort to undertake a risk assessment exercise and demonstrate the application method at the site of the fuel oil spill. These techniques included the North Carolina risk analysis framework, the Illinois tiered approach to correction objectives, the RBCA software for chemical releases, and Exposure and Risk Assessment Decision Support System. On completion of the risk evaluation procedures, a determination of the groundwater and soil treatment aimed at object compounds, (namely TPH), xylenes, toluene, ethylbenzene and benzene) was performed. The computed remediation levels satisfy the minimum requirement for target risk benchmarks, i.e. a cancer risk of 1×10^{-6} and risk proportion of one. From the results of this research, RBCA appears to be a more comprehensive and conservative base for closure of site.

Tomasko *et al*. (2001), presented an engineering method which could be utilised in predicting maximum NAPL concentrations in the groundwater caused by NAPL spills. The risks associated with NAPL within the site were evaluated by means of the U.S. Environmental Protection Agency's tiered risk-based corrective action (RBCA) system. Conservative assumptions were utilised in Tier 1 with minimal site-specific information whilst more detailed site-specific information was needed under Tier 2. This method of screening was formulated by deriving a systematic solution for a partial differential equation defining the movement of NAPL through the unsaturated sector.

3.5.3 Risk Integrated Software for Soil Clean-up (RISC) for HHRA

An appraisal was carried out on previous studies concerning the evaluation of risk assessment of oil residue contaminated soil as well as on their effect on human health by means of the RBCA toolkit. A number of studies noted RISC-5, software that can be used with other risk assessment methods including the Exposure Pathways Assessment, the Toxicity Assessment and Risk Characterisation.; Hazard Identification was, however, not included in the assessment. It was also discovered that RISC-5 and RBCA software were similar; but the former was found to be more useful, flexible and easier to use.

The main differences between RISC software and RBCA are that the former offers highly intuitive graphical interface, allows for pathways, compound and receptor additivity; additionally, the results of transport models can be utilised in the presence of a phase-separated product; the vadose zone model is present and transient groundwater models, probabilistic. (Monte Carlo) exposure capabilities are also available in the software (RISC-5) and includes a critical pathway - indoor showering which is not provided in the RBCA Toolkit. It also includes a number of other models which are not available in the RBCA model in ASTM E1739 but are required for some typical risk cases. Other models are: Johnson and Ettinger (1991) indoor air model; Domenico (1987) model for groundwater; and Green-Ampt (1911) model for considering biodegradation of dissolved chemicals in the vadose zone (Spence and Walden, (2001)).

RICS-5 software can be employed in the assessment of severe effects to human health (carcinogen and non-carcinogen) based on fourteen exposure pathways at contaminated sites. Further, RICS-5 offers distinctive features and is able to perform a reverse computation on risk. This entails performing calculations on the extent of a clean-up for a given risk value including the conventional forward risk calculation. According to Spence and Walden (2001), RICS-5 offers fate and transport models in assessing concentration of receptors in groundwater as well as indoor and outdoor air.

Armah *et al.*'s (2012), study assessed the risks of water sediment and biota and their adverse impact on human health by means of RISC-4.02 in the Tarkwa Gold mining area. The research was formulated to evaluate the risks to human health through Central Tendency Exposure (CTE) and Reasonable Maximum Exposure (RME) scenarios to residents. The residents were comprised of grown-ups and youngsters from arsenic, manganese and lead exposures on the ground surface and in groundwater. The outcome revealed that HQ for these contaminants are mainly within the tolerable risk range outlined by the United States Environment Protection Agency (USEPA). The RME of Mn from oral contact for Youngsters (HQ of 18) is noticeably greater than the USEPA acceptable risk figure of 1.0.

At some sites, the RME of Mn through oral contact for adults also surpassed the standard, however, a comparison of contributions of dermal and oral contact to the health risk, revealed that the former accounted for more. Carcinogenic risks to resident grown-ups caused by the exposure to arsenic demonstrated RME values which varied from 5.0 x 10^{-4} to 1.1 x 10^{-3}. They constitute up to 11 folds higher than the USEPA acceptable range for excess risk of cancer. Arsenic-linked cancer risks to resident grown-ups for CTE varied from 3.7 x 10^{-4} to 6.7 x 10^{-4}; these are higher than the acceptable range (based on USEPA) for excess risk of cancer. Similarly, the risks of cancer to resident youngsters for CTE and

RME cases were higher than the USEPA acceptable range for excess cancer risk. These figures were more than 210 times higher than the USEPA acceptable range for excess risk of cancer.

3.5.4 Oil Contamination Risks on Human Health

Various studies were carried out and appraised with respect to evaluating the risk assessment of soil contaminated with oil residue as well as their severe effects on human health. A number of studies focussed on the human diseases caused by the exposure to contamination whether the term of illness was short or long. As stated by Amat-Bronnert *et al*. (2007), Campbell *et al*. (1993), Ordinioha and Brisibe (2013) and Osman (1997), the influence of hydrocarbon contamination on human health can occur at various stages of illness, including - physical, mental, genetic, heart, headaches, throat irritation and itchy eyes, infertility, cancer, lumbar pain, migraine and dermatitis.

A cross-sectional study was conducted by Campbell *et al*. (1993) whereby a number of people exposed to the MV Braer oil spill (N = 420) were matched against a control group (N = 92) in Hillswich, about 95 km to the north of the site. As revealed from the result, immediately after the incident, the population suffered from headaches, throat irritation and itchy eyes for a period of two days. As for the long term effects, 7 % of the population exposed to the contamination felt that the oil spill had had a huge influence on their health. According to Ordinioha and Brisibe (2013), published data on crude oil spills in the Niger Delta Region, Nigeria, and animal studies confirmed that direct contact with the crude oil of Nigeria could be hemotoxic and hepatotoxic and could result in infertility and cancer.

Osman (1997) examined the adverse health effects resulting from the Kuwaiti *oil lakes* residue in 1991. Based on his study, a survey performed in Kuwait healthcare centres demonstrated a rise in respiratory complaints directly proportional to the rise in air particulates recorded during the same period after 1991. Within that period, the number of people looking for treatment for psychiatric illness, bronchiecteasis, chronic bronchitis and emphysema, gastrointestinal illness and heart disease showed a sharp rise.

3.6 Summary

Considering that Kuwait is considered one of the countries in the world which has been most seriously contaminated since 1990 (Gay *et al*., 2010), the main contribution of this study is to develop a ground model for the *oil lake* contaminated soil of Kuwait (caused by the Iraqi invasion in 1990) using RISC-5 model. This contamination might not only affect the physical properties of soil but is also likely to threaten the ecology and human health through chemical risks. This study investigates the geotechnical and geochemical properties and classifies the pollutants existing in the hydrocarbon contaminated soils, also the carcinogenics and non-carcinogenics.

The study will also investigate the influence of *oil lakes* residue on the Human Health Risk Assessments and determine the potential levels of risk posed to any future urban developments within the affected areas. More specifically, this will be achieved by using the risk assessment of the RISC-5 software to evaluate chemically any signs of carcinogenic elements found in the hydrocarbon contaminated soils that may influence the health of human, animal and plant life, even if the geotechnical properties of the hydrocarbon contaminated soils are physically ready for construction.

To the best of author knowledge, no studies have investigated the geotechnical and/or geochemical characterisation of the actual hydrocarbon contamination of the soil in the Greater Burgan Field of Kuwait since 1990; so far all studies have been based on replicating the effect of contamination by mixing the soil with artificial crude contamination in the laboratory. Al-Sanad and Ismael (1997) admitted that researchers could not extract actual samples from the base of the dry Burgan *oil lakes* because there is no access to these lakes for security reasons, i.e. the existence of mines and oil-sand sludge which covered the ground in nearby areas. It is worth mentioning that this study is considered a pioneer study since it has collected the actual hydrocarbon contaminated soil samples from the dry *oil lakes* found in the Kuwaiti Burgan Oil Field. All required permissions and safety precautions insisted on by the Kuwait Oil Company (KOC) and the University of Portsmouth (UoP) were signed and followed by the researcher who takes full responsibility regarding any risk that might he might face during the sample collections. (Figures from A.4.5a to A.4.6f in Appendix-D)

The following significant reasons encouraged the researcher to select the Greater Burgan Oil Field (Al-Magwa area) as the main site for this study:

(1) No study has investigated the geotechnical and geochemical characterisations of the actual dry *oil lake* contaminated soil in the Greater Burgan Oil Field (Al-Magwa area) for 25 years.

(2) The Greater Burgan Field (among other sites) contains the largest hydrocarbon polluted area (25.6 Km^2) and Volume (14,520,000 m^3) in Kuwait. (Table (2.2) Chapter two, page (38)).

(3) The largest hydrocarbon contamination occurred in Kuwait in the Burgan Oil Field since it constitutes 40 % of the overall contaminated volume (Al-Duwaisan and Al-Naseem, 2011).

(4) It is located near to the city and urban areas and the surrounding areas of the Burgan Oil Field will be undergoing some engineering construction in the next five years.

(5) A high percentage of Kuwaiti citizens have contracted fatal diseases, including asthma and lung cancer, since 1990 due to carcinogenic substances, i.e. hydrocarbon chemical compositions found in oil contaminated soil which can greatly influence human health.

4. GREATER BURGAN OIL FIELD INVESTIGATION

4.1 Introduction

The objectives of this research will be attained through the implementation of an experimental methodology which will include collection of samples followed by geotechnical and geochemical tests in the laboratory. This chapter will describe and outline the experimental programme, including Phase I concerning preliminary selected sites for the study (both contaminated and non-contaminated), initial soil sample collection, final selected sites (both contaminated and non-contaminated) and Phase II which will request the soil sample collection at two different final selected sites.

The methods and procedures followed in conducting the necessary tests on the soil samples collected from contaminated (dry *oil lake*) and non-contaminated sites are described in terms of their geotechnical, geochemical and hydrocarbon characteristics. Statistical analysis has been undertaken to further integrate the data and to support the results.

Section 4.2 describes the phases and the experimental scope of the study. The selection process of the initial site is described in Section 4.3. Details of the location finally selected, i.e. the Greater Burgan Oil Field-Al Magwa area and the main soil sampling approach followed are described in sections 4.4 and 4.5, respectively. Section 4.6 clarifies the sampling method at contaminated and non-contaminated sites. Section 4.7 outlines the soil characterisation and the methodology. Section 4.8 explores and classifies the data from the laboratory via statistics method.

4.2 Investigation Design

The experimental phases set out in this chapter are aimed at achieving the goal of the study as described in Section 1.1. A comprehensive experimental research programme was then designed (Figure 4.1). The programme was split into six phases as follows:

Phase I

Preliminary site selection - carried out by identifying the hydrocarbon contaminated sites in Kuwait. The closest site to the most densely populated area of Kuwait together with the amount of hydrocarbon contamination encountered was chosen in order to select sites for preliminary soil sampling and to verify that the hydrocarbon contamination was still present after 25 years.

Phase II

Confirmation of the final site location, i.e. dry *oil lake*; identification of field hazards & restrictions; requirements for Health and Safety; walkover survey and description of the site.

Phase III

Collection of major soil samples at the chosen site of the Greater Burgan Oil Field (Al-Magwa region) involving the detailed collection of soil samples at both a dry *oil lake* site (hydrocarbon contamination) and a non-contaminated site for control purposes.

Phase IV

Investigation of the geotechnical characteristics of the soil samples at both the dry *oil lake* and the non-contaminated sites. These include the Atterberg Limits; PSD; SEM; permeability (Hydraulic Conductivity); and Direct Shear strength parameters. A geochemical investigation was undertaken on both the contaminated (dry *oil lake*) and the non-contaminated sites by means of characterising the soil samples chemical properties including - the pH value; water soluble Cl- and (SO_3 & SO_4); EA and GC-MS tests.

Phase V

Carrying out an assessment of the risk on human health due to hydrocarbon contaminated soil from the dry *oil lake* site – (detected soil samples with hydrocarbon). This will be done by means of applying human health risk assessment scenarios, e.g. Hazard Identification; Hazard Assessment; Risk Estimation and Risk Evaluation.

Phase VI

Utilising RISC-5 software (RISC-5, 2011) on hydrocarbon contaminated soil from the dry *oil lake*, i.e. soil samples with hydrocarbon, to determine concentration of hydrocarbons which may cause adverse impacts on human health as categorised in terms of carcinogenic and non-carcinogenic elements. Developing ground models by assessing the probable magnitude of risk and calculating soil clean-up values where appropriate in the site to be selected for any prospective urban developments.

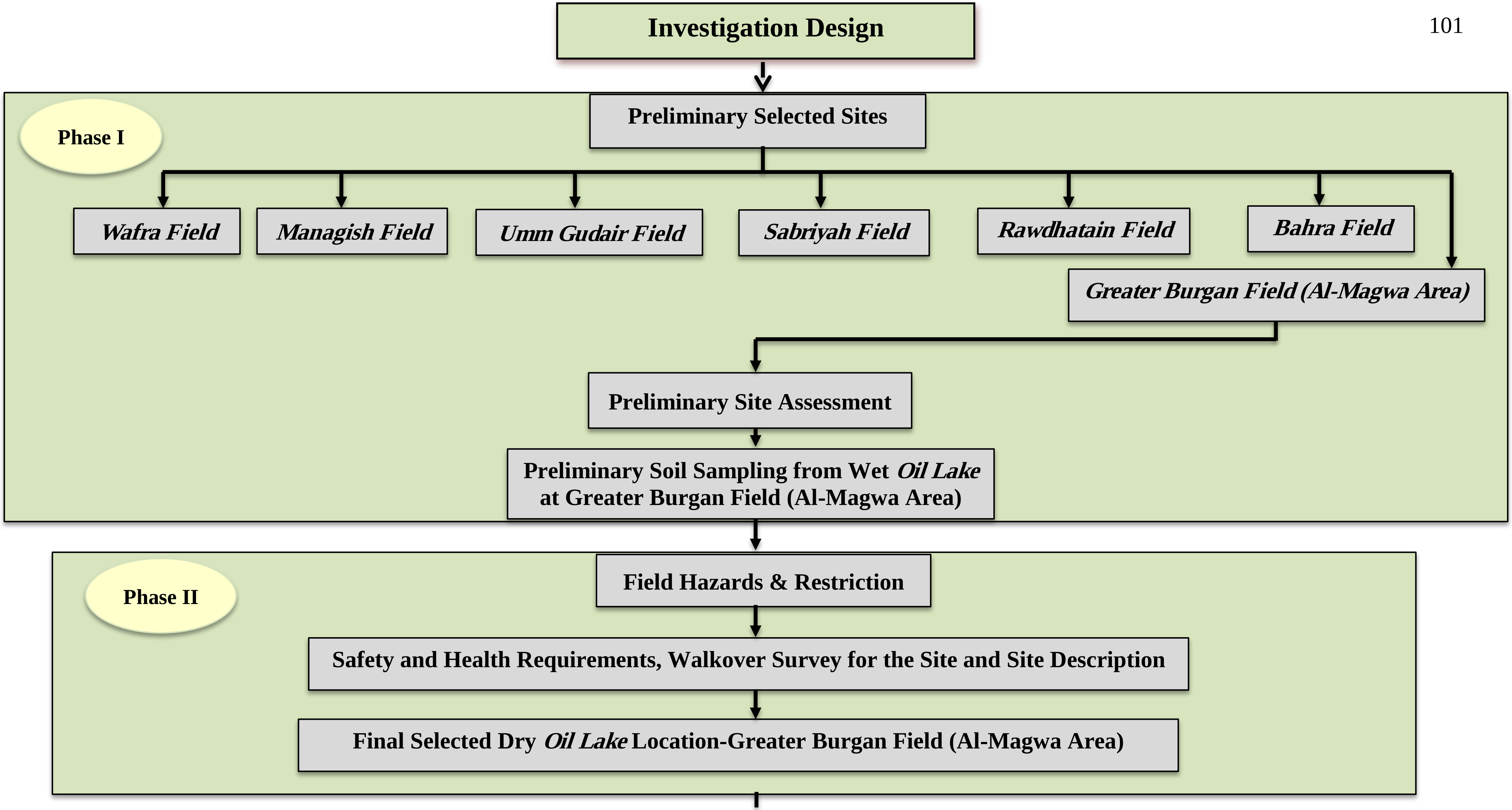


Figure 4.1. Investigation design followed in this study.

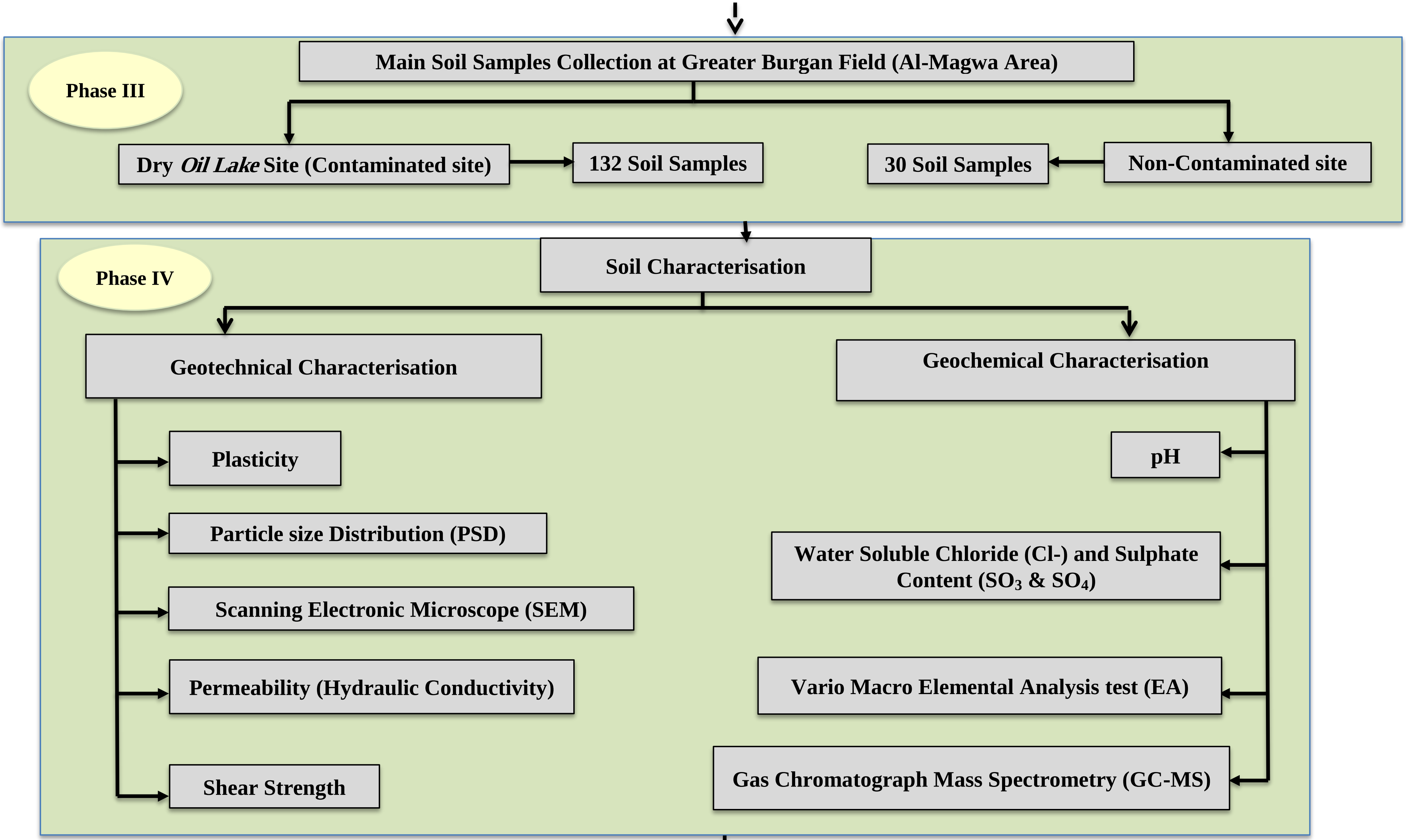


Figure 4.1. Continuous.

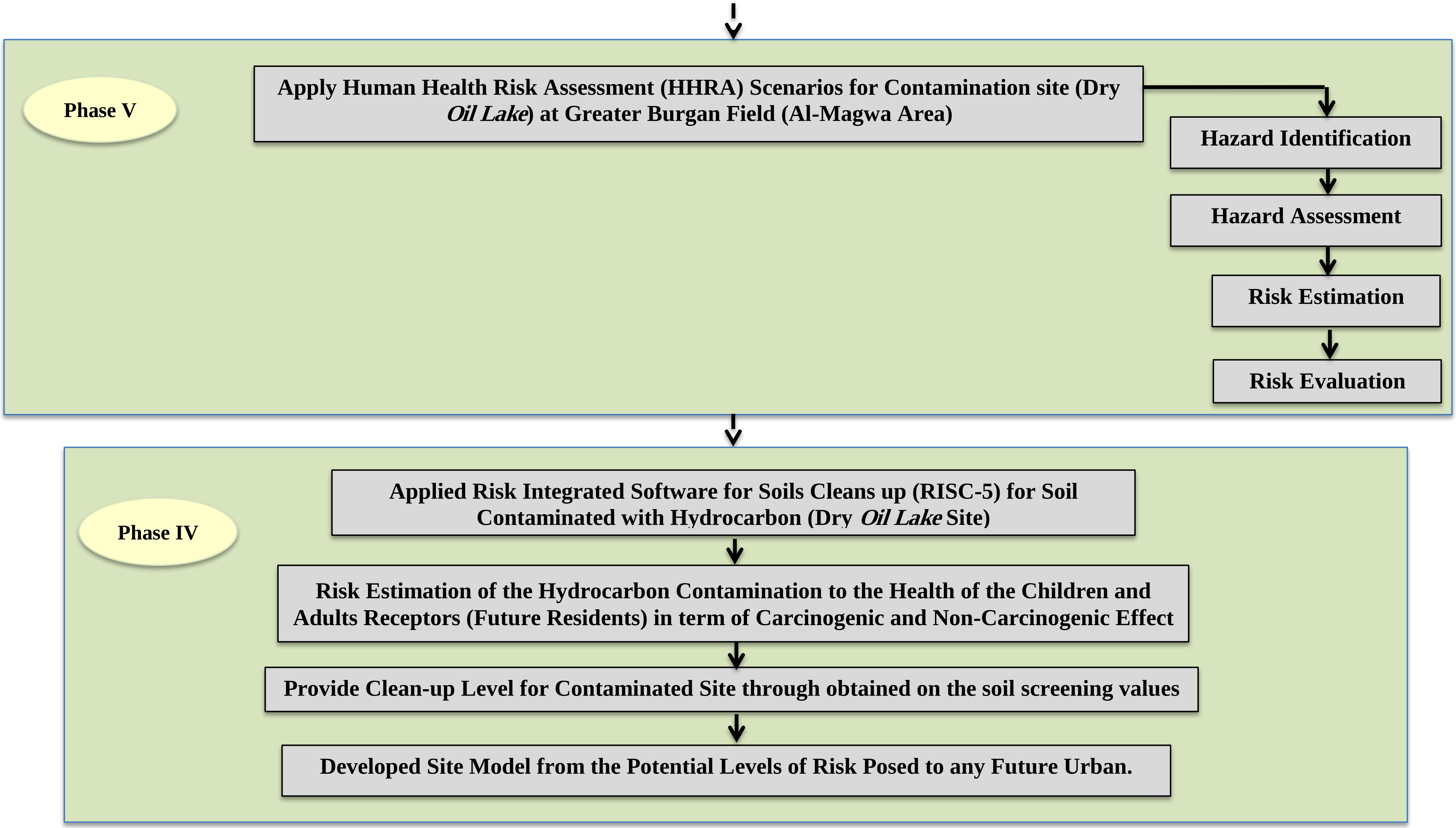


Figure 4.1. Continuous.

4.3 Preliminary Site Selection

Cho *et al*. (1997) and PEC (1999) have stated that hydrocarbon soil contamination and the remnant *oil lakes* are situated in the seven main oil-producing fields of Kuwait, namely: Rawdhatain; Sabriyah, Umm Gudair; Managish; Wafra, Bahra; Greater Burgan Field (Ahmadi, Magwa; and Burgan Sectors) (as illustrated above, Figure 2.15 and Table 2.3). Therefore, the chosen sampling area was situated adjacent to the main oil producing areas of Kuwait, i.e. the Greater Burgan Field (Ahmadi, Al-Magwa and Burgan Sectors) in the south of Kuwait. This site was selected for the following reasons:

- The worst hydrocarbon contamination incident took place in the Burgan Field which accounts for 40 % of the entire hydrocarbon contaminated volume in Kuwait (Al-Duwaisan and Al-Naseem, 2011, p.440).
- The Greater Burgan site contains the largest *oil lake* area in Kuwait originating from the Iraq invasion. According to PEC (1999), the coverage of soil contaminated with *oil lakes* residue in the Greater Burgan field covered an area of 25.6 km^2 with a 14,520,000 m^3 volume of soil.
- Its location is near both the city and the urban areas of Al-Ahmadi, Jaber Al-Ali, Sabah Al-Salam and Jeleeb Al-Shuyoukh. All of these areas are heavily populated (Figure 4.2). The adjacent areas are, therefore, likely to be developed in the future as urban expansion demands grow thus requiring construction work.
- It is predicted that these areas will be in high demand for prospective development projects; the Kuwaiti Government intends to start a mega project in 2013 which will last until 2020 (UK Foreign and Commonwealth Office, 2014; Almarshad, 2014, p.49).

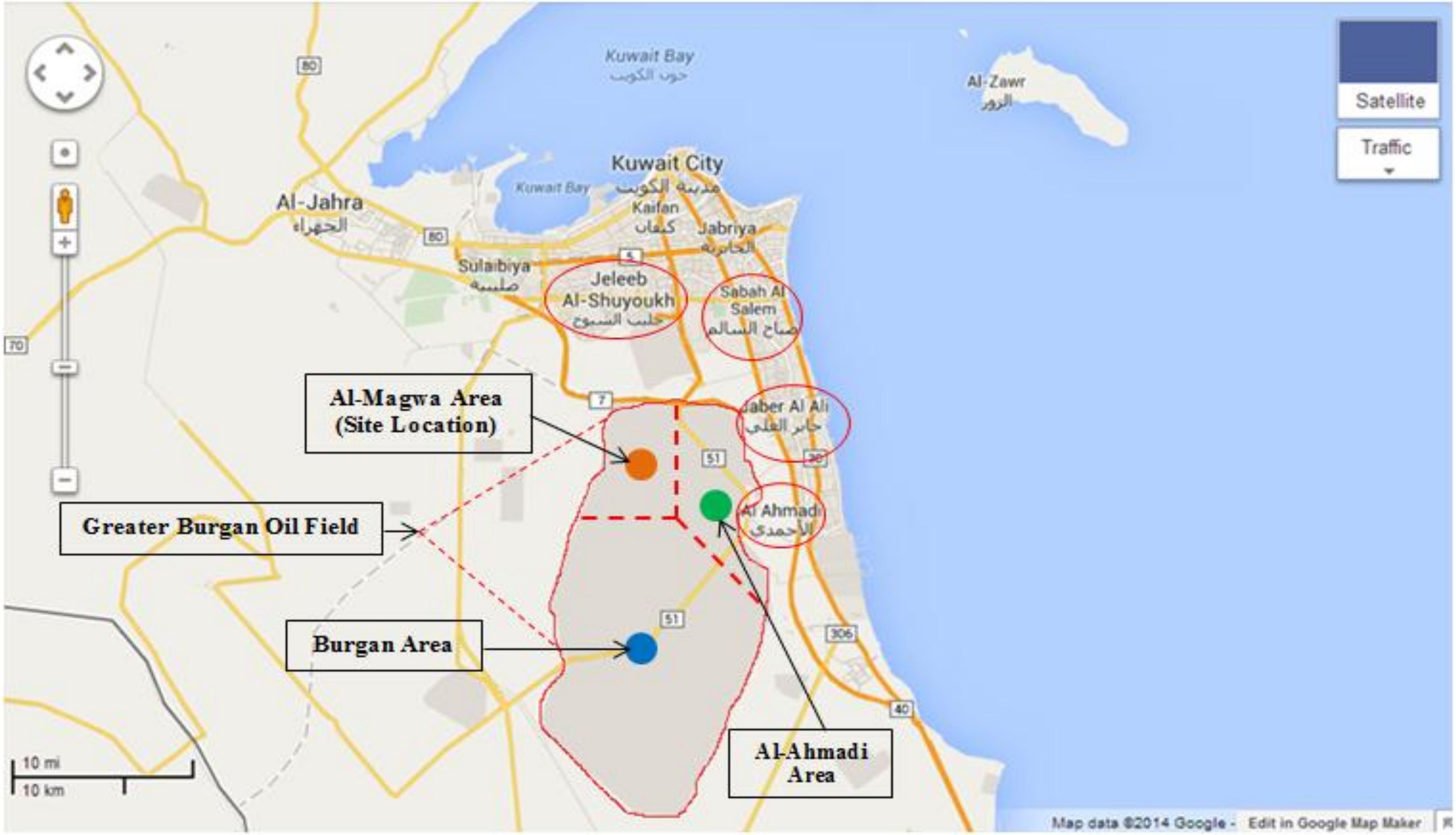


Figure 4.2. Distance of the Greater Burgan Oil Field and the main residential areas (Source: GM, n.d.).

4.3.1 Location of the Greater Burgan Zone (Al-Magwa Area).

Towards the end of the First Gulf War in 1991, the withdrawing Iraqi force set ablaze the Burgan Field. Smoke plumes from the fires covered an area up to 50 km wide and was 2.5 km thick on any given day. Additionally pipeline leakages resulted in the formation of *oil lakes* that contaminated the soil and the surrounding environment (Figure 4.3).

Figure 4.3. ***Oil lakes*** **in Burgan Field (Source: Kaufman** ***et al***.**, 2000).**

The Greater Burgan Oil Field is situated within the Arabian Basin in Kuwait. It is the world's largest clastic oil field which covers an area of approximately 320 square miles (828 km^2) in the south-east of Kuwait. The field is split into the Al-Magwa, Al-Ahmadi and Burgan areas based upon the presence of three structural domes as shown in Figure 4.4. The border along the northern Al-Ahmadi/ Al-Magwa and the Burgan sectors is the complex of the Central Graben Fault. The Burgan Field, being the largest sandstone oil field in the world, is situated 35 km south of Kuwait's capital City close to Ahmadi.

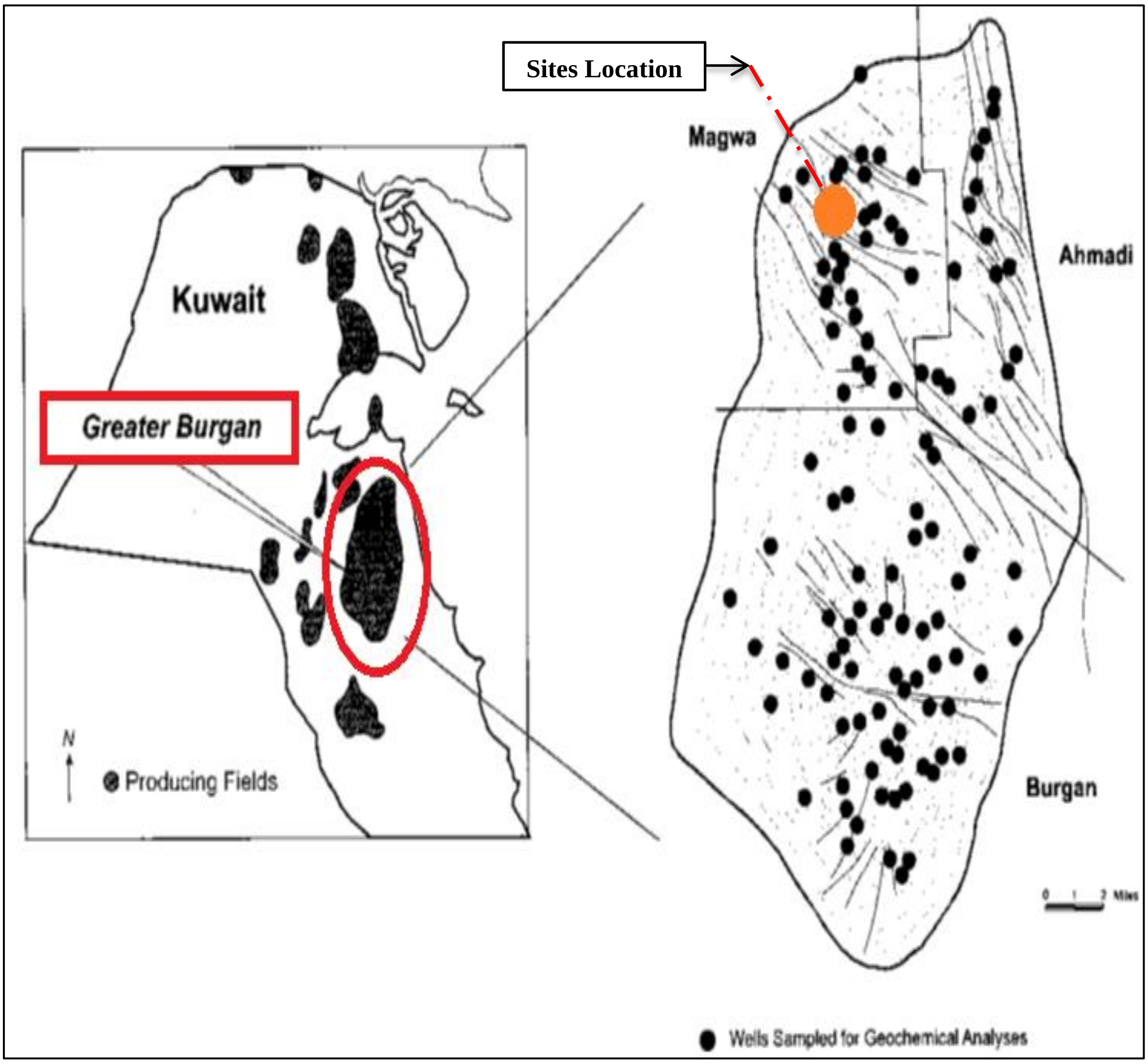


Figure 4.4. The Greater Burgan sectors (Burgan, Al-Magwa & Al-Ahmadi Fields) in Kuwait (Source: Kaufman *et al*., 2000).

4.3.2 Preliminary Assessment

A preliminary investigation was undertaken to determine the most suitable initial sampling locations and the sample sizes, this was carried out by reviewing and analysing the gathered data. The received information had been collected from websites and also from requests to relevant personnel from private contractors for the Greater Burgan Oil Field and the Kuwait Oil Company (KOC). Information from the test areas provided by these firms was investigated and examinations were carried out on the test area. It was essential that the preliminary sampling locations were determined based upon the consistency of the soil conditions to find out whether they could provide accurate representation of the test area. In order to assess the location of sampling points and sample sizes, a large quantity of data was required to be collected.

4.3.3 Preliminary Soil Sampling

A total of 5 soil samples were taken from two separate sites within the Greater Burgan Field (Al-Magwa area) consisting of 2 kg each of contaminated and non-contaminated samples. One disturbed hydrocarbon contaminated soil sample was extracted manually from a wet *oil lake* at a depth of 0.5 m using a shovel. For the non-contaminated samples, a total of 4 undisturbed control soil samples were taken from various depths, i.e. 0.5 m, 1.0 m, 2.0 m and 4.0 m below ground within the same area using borehole equipment (Plate A.4.1).

Samples collected from the wet *oil lake* (contaminated) and non-contaminated sites were delivered to the University of Portsmouth laboratory for classification and testing. A preliminary testing procedure was carried out on these soil samples to ascertain the TPH concentration level. Preliminary characterisation tests, includes GC-MS, was performed on the soil samples to examine the total TPH concentration.

The average TPH concentration was 9.81 mg/kg. for the 4 soil samples extracted from the designated non-contaminated site of the Greater Burgan Field (Al-Magwa area), In comparison, the TPH concentration for disturbed soil samples taken at the designated contaminated site within the same area was 18683.37 mg/kg (Tables A.4.1 & A.4.2 and Figures A.4.1 & A.4.2).

4.4 Final Selected Location (Greater Burgan Field - Al-Magwa Area)

Based on the results from the preliminary soil sampling, it was confirmed that the Greater Burgan Field (Al-Magwa area) has remained contaminated since the 1st Gulf War (1990). During the soil investigation process, a number of obstacles were encountered-especially in the early part of the work- allowing entry into the Greater Burgan Field, this had affected the soil sample schedule, these obstacles were:

- These *oil lakes* are categorised as being within the authority of the Kuwait Oil Company (KOC) and the Kuwaiti Defense Ministry. As such, entry to the project site is limited to employees of the private contracting companies. The non-contaminated site has no entry conditions for the collection of soil samples.
- Gaining admission to the KOC’s officer-in-charge of the issuance of official permits to enter the site legally to take samples was a lengthy process.
- In view of the large organisational structure of the KOC - which is divided into several sectors - it took a very long time to assess, search for and collect the required information from relevant departments. The problems included complying with their Quality System requirements to identify the correct department-in-charge and present them with all project documentation plans; main samples plan; and the official letter from the

University of Portsmouth. The Greater Burgan Oil Field comes under more than two sectors.

- The area where the *oil lakes* are located is extremely dangerous as it contains mines and unexploded ordnance left behind after the war.
- Collecting samples during the summer season (hot and arid climate) at these hazardous sites is not permitted. This is because during the hot and arid climate, the hydrocarbon contamination evaporates into the air.

Towards the end of the finalised location, an entry permit was issued so that the work plan for sampling and methodology could be submitted to the relevant department of the KOC.

4.4.1 Site Hazards and Restrictions

A number of meetings and visits were scheduled with the relevant managers from various departments in the KOC responsible for the *oil lake* sites at the Greater Burgan Field. These included the: Health Safety and Environment Department (HS & E); Production Operation Department (PO); and Research and Technology Department (R & T). Furthermore, on 17th July, 2012. A confidentiality agreement was executed at KOC’s main office in the Al-Ahmadi area outside the Greater Burgan Field security fence, between their Research and Technology Department (R & T) and the University of Portsmouth (UoP).

The UoP was represented by the PhD Research student on behalf of his supervisors. Upon signing of the agreement, on 22nd August, 2012, an Explosive Ordnance Disposal (EOD) clearance was requested from the HS&E Department by the T&C department for entry into the main samples’ site (Figures A.4.3a, A.4.3b, A.4.3c, A.4.4a, A.4.4b, A.4.4c, A.4.4d, A.4.4e and A.4.4f).

The area of the Greater Burgan Field is regarded as the major economic region for generating revenues for the State of Kuwait; it is vibrant with numerous engineering projects, therefore, a lengthy procedure was required to schedule meetings with the HS&E and PO departments to finalize the entry permit for the site. Furthermore, collection of samples at the hydrocarbon contaminated field area was not permitted during the summer season due to the increase in hydrocarbon evaporation - potentially highly dangerous – this was one of the major obstacles to the project.

Finally, on 11th November, 2012, a temporary entry permit was obtained allowing for a meeting with the experts from the HS&E and PO departments: Meeting one was to finalize and select the specific site location (dry *oil lake*) and present the main sampling plan. The second and final meeting was conducted on 18th November, 2012 with the same personnel to discuss and present the final sampling plan and to determine the number of skilled labourers required for the collection of samples (Figures A.4.5, A.4.6 and A.4.7).

All meetings with regards to the main sampling plan and time schedule were finalised in accordance with the conditions and requirements, as follows:

- Reducing sample collection quantity from 400 to only 132 samples.
- Disagreement as to extraction of the hydrocarbon contaminated soil samples using borehole truck method so as to obtain undisturbed soil samples for Direct Shear test; agreement was only with the trial pit method. This was because of health and safety issues, e.g. the ground condition of the dry oil site was very dense, unstable and dangerous which could pose serious risks to KOC labourers. As such enquiries were raised with KOC technical staff, i.e. project supervisors and the INCO Lab firm in Kuwait in order to collect undisturbed samples without a borehole truck. They suggested that the only means of collecting the samples would be to fabricate tubes with fixed lengths and diameters so that the undisturbed soil samples could be extracted (Figure A.4.8).

- The time for sample collection was limited from 7.00 a.m. to 11.00 a.m. as the dry *oil lake* area can be very hazardous to the labourers health due to the increasing of hydrocarbon evaporation in the afternoon period. As such the working hours were based on this constraint.
- The sample collection should be halted in the case of rain because the wet conditions of the site would be dangerous for the workers.

The existing KOC site conditions were studied by means of site visits, reviewing reports from private construction firms operating within the Greater Burgan Oil Field (Al-Magwa area) as well as requesting any relevant information regarding the site. In fact, Al-Duwaisan and Al-Naseem (2011, p. 441) stated that the highest hydrocarbon content of the contamination area was encountered at a depth range of 0.15 m to 1.2 m; the soil sampling plan at the contaminated site became clearer with this information. The dimensions of the sample area were 100 m x 100 m. A total of 25 Trial Pits (T.Ps) were excavated to obtain more contaminated soil samples. The depths of the trial pits varied from 0.0 m, 0.25 m, 0.5 m, 1.0 m and 2.0 m (section 4.5 for further details).

4.4.2 Site Safety Requirements

Due to the nature of the site precautionary measures the following had to be complied with at all times:

- No food or drink should be consumed at site during the collection of samples.
- No smoking allowed within the site as the area is flammable due to the presence of hydrocarbon in the ground.

- Workers are to be reminded to ensure hands are washed before drinking, eating or even smoking due to possible hydrocarbon contamination.
- A risk assessment form from the University of Portsmouth (UoP) was prepared and approved prior to data collection so as to ensure that the researcher was fully aware of the risks expected at the sample collection area (Figures A.4.9a, A.4.9b, A.4.9c & A.4.9d).

4.4.3 Site Walkover Survey

A walkover survey was undertaken at the site so as to identify, analyse, and characterise the dry *oil lake* sites and also to note any changes in texture and colour of the potentially contaminated soil. The survey was also carried out to: physically view the type of contaminant of the dry *oil lake*; appreciate the general conditions of the field; make the sampling team familiar with site characteristics; and explore the site by identifying the locations of oil hotpots prior to the selection of sampling Trial Pits (T.Ps) locations and sample extraction methods.

A number of construction firms with ongoing construction works within the test area were approached and details concerning the ground conditions, boreholes, trial pits and variations in groundwater were requested and collected.

The site walkover survey provided an organised, on-site field map indicating the sampling locations. Additionally, data obtained from these construction firms operating within the same area was collated, reviewed and incorporated into the map. Towards the end of the walkover survey, a final map of the sampling zone, showing possible sampling points, was prepared. The workforce and equipment required to perform the sampling work was also identified.

4.4.4 Site Description Dry Oil Lake

Information with regards to ground conditions was collected from previous surveys carried out by private construction firms (INCO, 2007). In general, the below ground profile sequence encountered at the Greater Burgan Field (Al-Magwa area) consisted of SP and silty sand (S-M) layers. The groundwater levels were measured in the field by INCO (2007). The water level in boreholes was observed during drilling and no water was encountered in the 10 m deep boreholes (Figures A.4.10a and A.4.10b).

According to Al-Sulaimi and Mukhopadhyay (2000), geologically, Kuwait was dominated by rocks of the Tertiary Age dating from the Palaeocene to the Eocene. Limestone, dolomite and evaporitic sequences (anhydrites) originated from the Umm Er Radhuma, Rus and Dammam Formations are unconformably overlain by sandstones of the Kuwait Group which is comprised of the Fars and Ghar Formations, also overlain by the Dibdibba Formation.

The geological setting of the Greater Burgan site includes the Fars and Ghar Formations with interbedded sands and clays, some sandstones and weak white nodular limestone (Al-Sulaimi and Al-Ruwaih, 2004). Superficial deposits consist of predominantly aeolian sands, with intermittent gravels with sands, silt clay and calcareous sandstones at the coastal areas. Moreover, the major oil reservoirs are within the Cretaceous Burgan, Mauddud and Wara Formation at the Greater Burgan Oil Field.

4.5 Soil Sampling Plan and Strategy

Upon completion of the preliminary site selection process, the final location was determined taking into consideration the field hazards and constraints, health and safety requirements, site walkover survey and description of the sites.

The main soil sampling area was divided into two separate sites, i.e. potentially contaminated and non-contaminated site. The main sampling for the contaminated soil with hydrocarbon was undertaken within a period of one month from 18th November to 17th December, 2012 (Figures A.4.11 and A.4.12). The sampling period was selected as this was the winter season when the hydrocarbon evaporation in the potentially contamination area was at its minimum level and so posed lower health risks to the site workers. Nevertheless, the main sampling for the non-contaminated site was carried out in January 2013.

The sampling method and procedure for both potentially contaminated and non-contaminated sites were carried out based upon square grid pattern as there is inadequate information about the site (i.e. contaminated site) in order to indicate the likely locations of pollutants in the site (Nathanial *et al.*, 2002). Therefore, the sampling trial pits at both sites have been selected upon exact dimensions, i.e. length, width and depth. Furthermore, from the research, a total of 25 Trial Pits were planned and excavated at the hydrocarbon contaminated site. The distance between each T.P. was 25 m. However, the KOC staff reduced the number of T.Ps to only 22.

The sampling area covered a 100 m x 100 m plot of land with 25 m grids in x and y directions. Samples were taken at depths of 0.0 m (top soil), 0.25 m, 0.5 m, 1.0 m, 1.5 m and 2.0 m below ground level. At the non-contaminated site however, only 5 T.Ps were dug within the same plot size (100 m x 100 m) and the same depths (0.0 m, 0.25 m, 0.5 m, 1.0 m, 1.5 m, and 2.0 m).

The distance between the T.Ps was generally 100 m with the exception of one T.P. in the centre which was at a distance of 50 m. (Figures 4.5 & 4.6).Finally, the distance between the potentially contaminated (dry *oil lake*) and non-contaminated site was 4.4 km. (Figure 4.7)

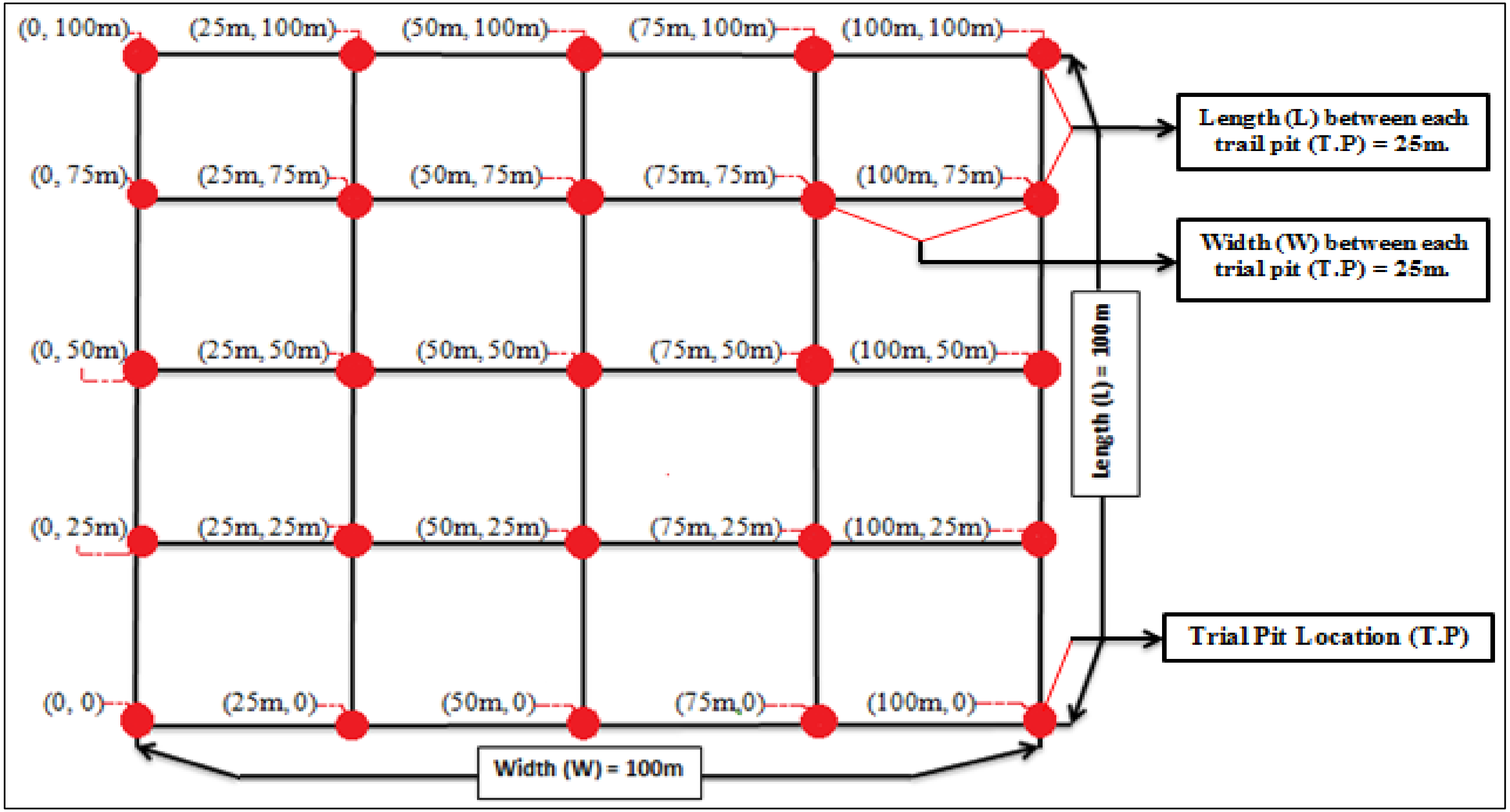


Figure 4.5. Top view plan of Trial Pits (T.Ps) locations for soil samples at potentially contaminated site in Greater Burgan Oil Field (Al-Magwa area).

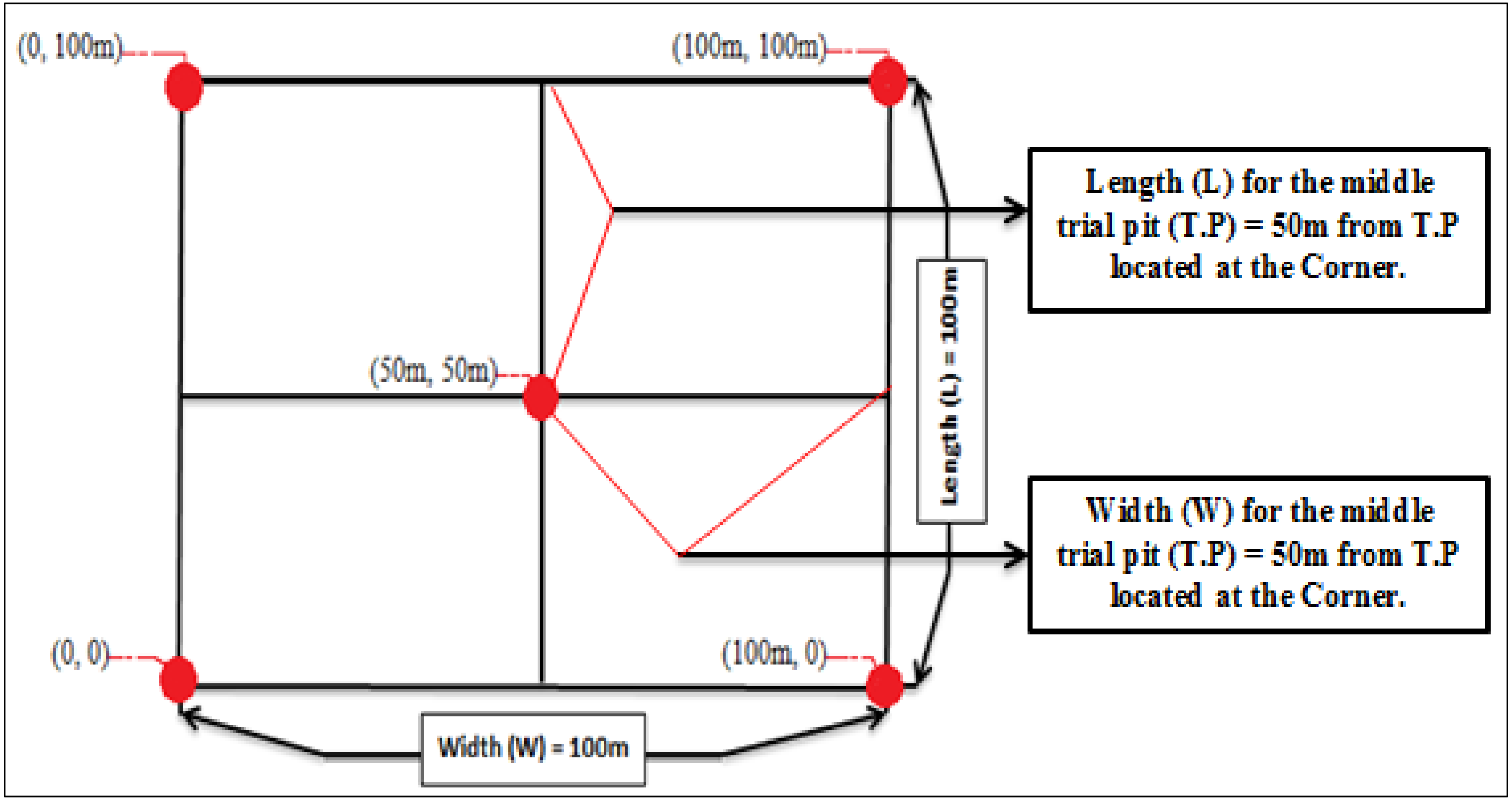
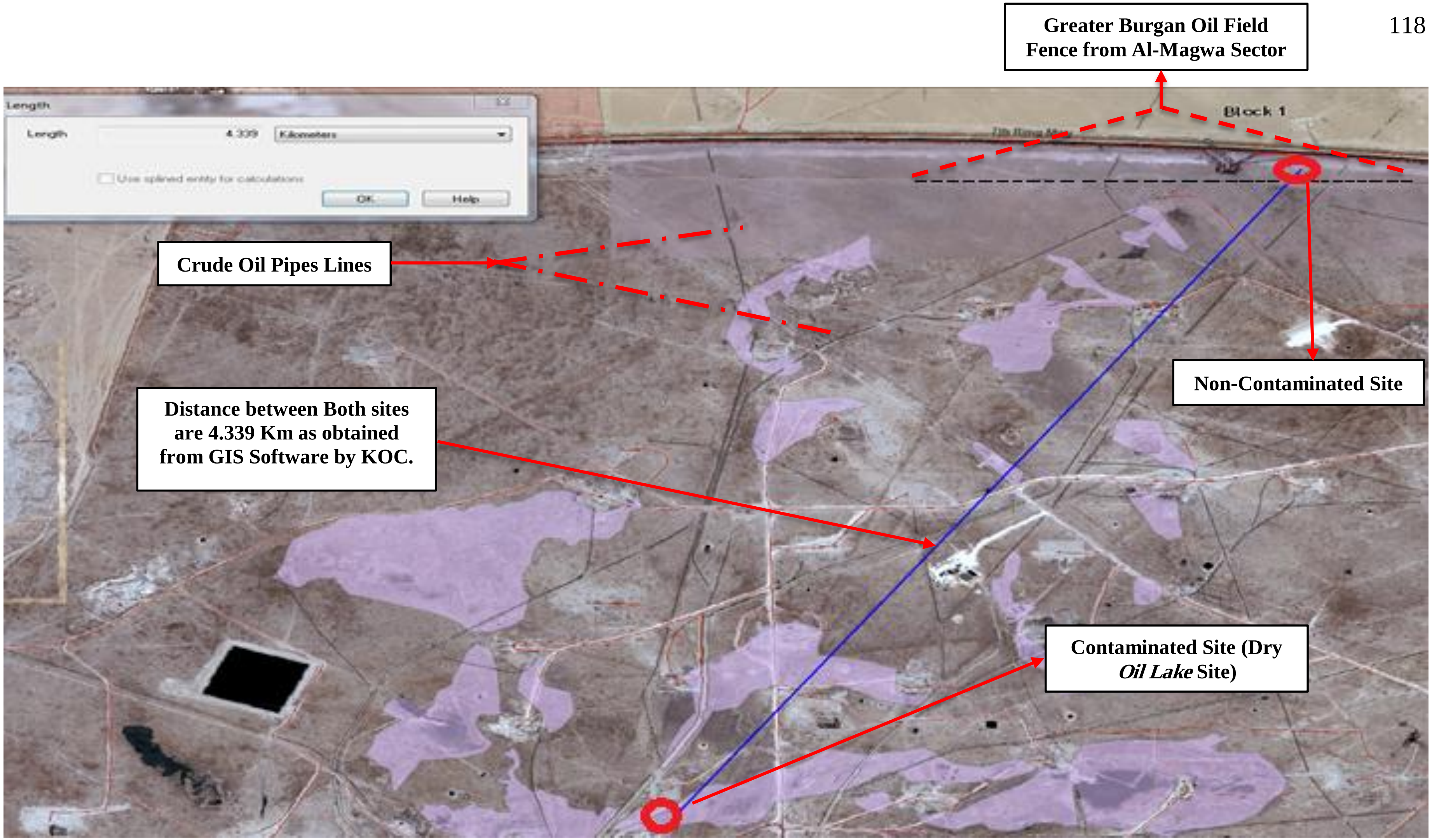


Figure 4.6. Top view plan of Trial Pits (T.Ps) locations for soil samples at potentially non-contaminated site in Greater Burgan Oil Field (Al-Magwa area).



Greater Burgan Oil Field Fence from Al-Magwa Sector

Crude Oil Pipes Lines

Non-Contaminated Site

Distance between Both sites are 4.339 Km as obtained from GIS Software by KOC.

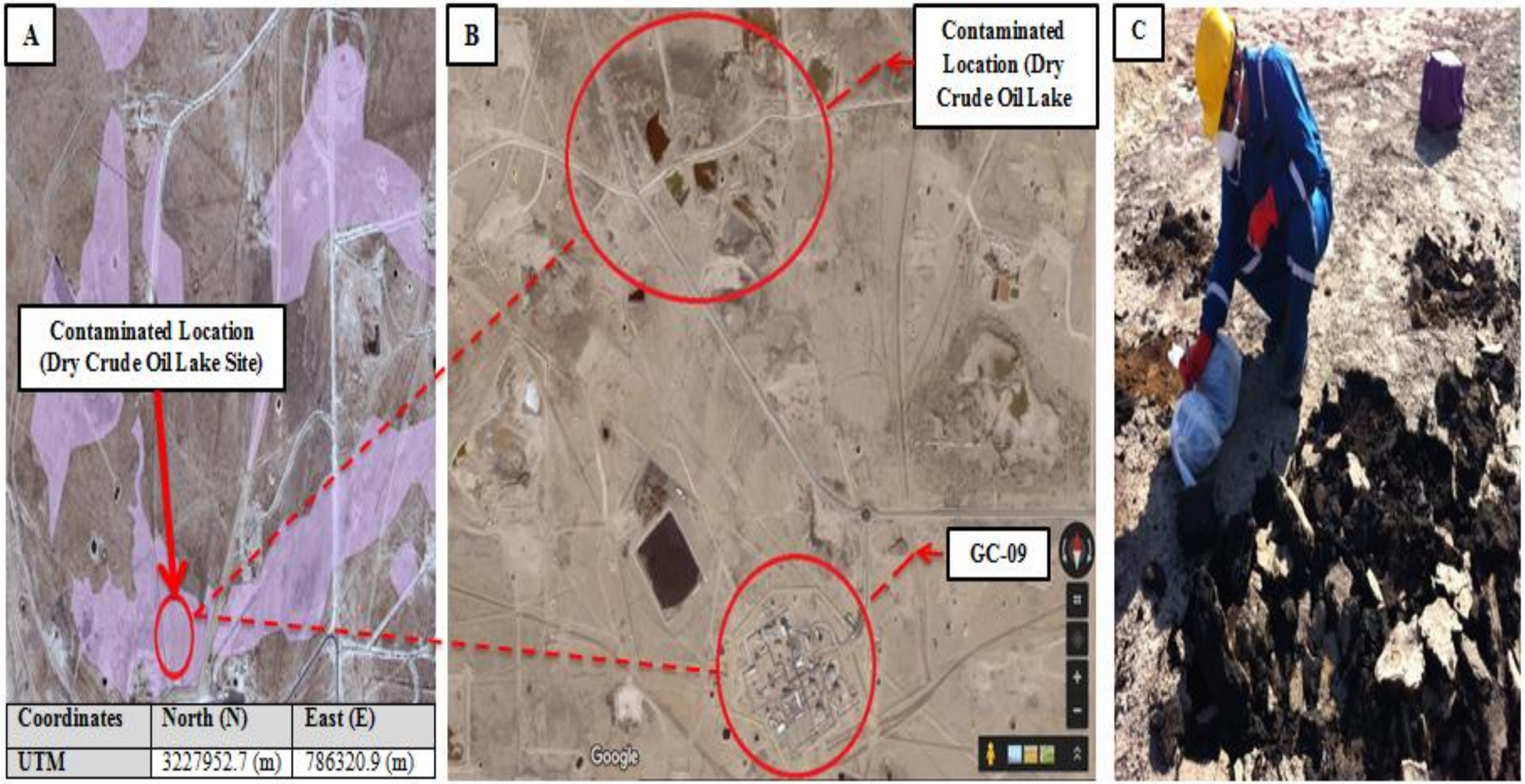
Contaminated Site (Dry *Oil Lake* Site)

Figure 4.7. Location of the potentially contaminated (dry *oil lake*) and non-contaminated sites in Greater Burgan Oil Field (Al-Magwa area).

4.6 Sampling Methods for Potential Contaminated and Non-Contaminated Sites

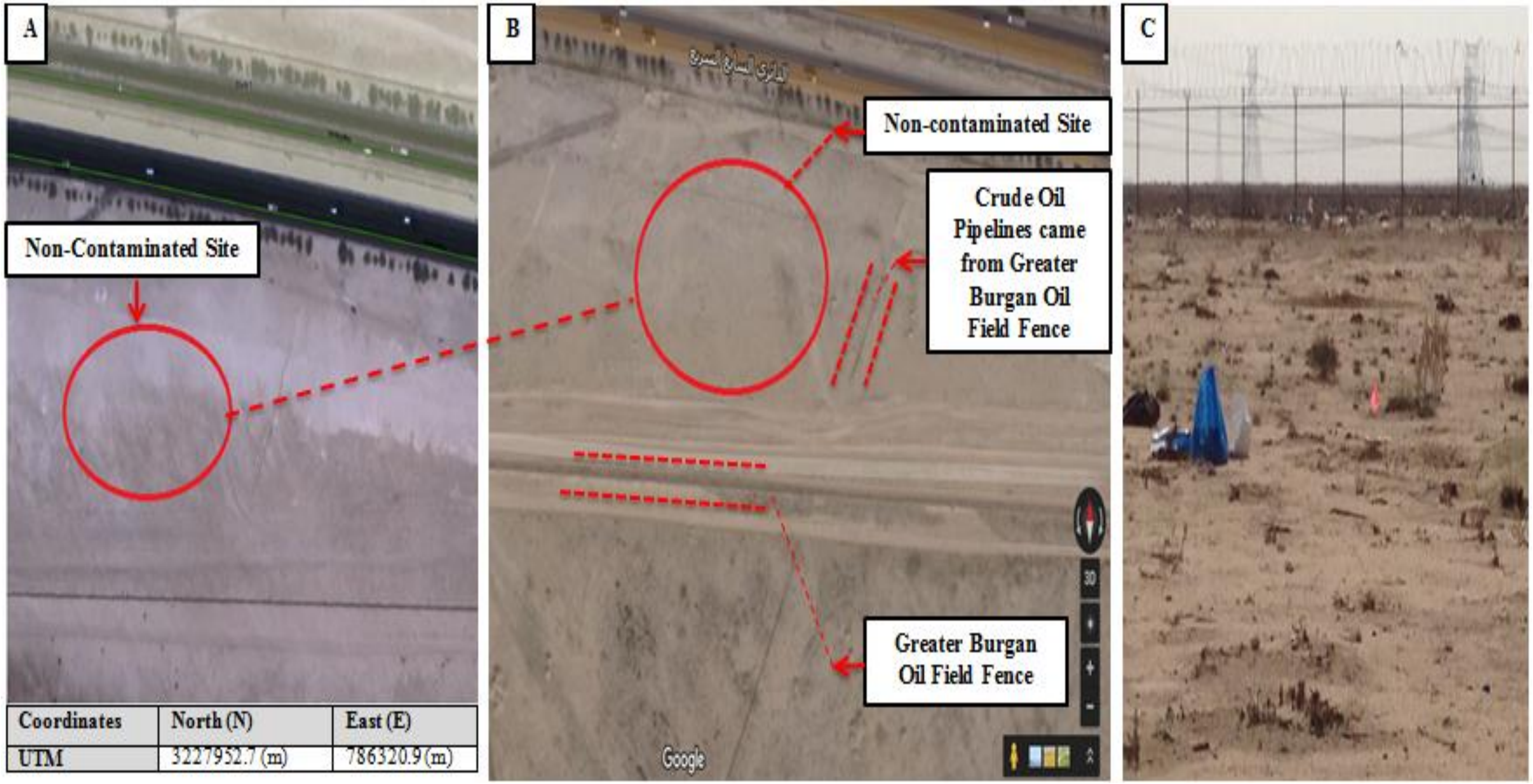
The chosen potential contaminated site is close to the Gas Centre (GC-09) and several oil well pipeline. Some of these had been destroyed during the Iraqi invasion of Kuwait, consequently the area looked like an old, dry, *oil lake*. Photographs were obtained from KOC's GIS software (including site coordinates) and Google Earth to indicate the position of the sampling site. Small coloured flags were used as markers so as to easily locate the position of Trial Pit Coordinate (T.P.C) within the site before digging and sample collection commenced.

The non-contaminated site where the samples were taken from, on the other hand, was relatively clean with some scattered shrubberies and small plants. A photographs was also obtained from KOC's GIS software and Google Earth (including site coordinates) to indicate the position of the sampling site. The non-contaminated site was located beyond the KOC's security fence. Small, coloured flags were also used as markers to demarcate the location of T.P.C at the non-contaminated site prior to digging and collection of samples (Figures 4.8 and 4.9). During this sampling phase, disturbed and undisturbed samples were taken from both sites.



Coordinates	North (N)	East (E)
UTM	3227952.7 (m)	786320.9 (m)

Figure 4.8. Coordinates from GIS software for potentially contaminated locations (dry *oil lake* site) at Al-Magwa area (A), dry *oil lake* location that near to the GC-09 at Al-Magwa area (B) and the dry oil contamination in soil at the site location (C).



Coordinates	North (N)	East (E)
UTM	3227952.7 (m)	786320.9 (m)

Figure 4.9. Coordinates from GIS software for potentially non-contaminated site location at Al-Magwa area (A) Plus the non-contaminated site location that out of the Greater Burgan Oil Field fence (B) and one of the Trial Pit (T.P.) located and desert plants in the site (C).

4.6.1 Disturbed Sampling

Manual digging equipment (chisel and shovel) was used to extract disturbed samples from several depths (0.0 m, 0.25 m, 0.5 m, 1.0 m, 1.5 m & 2.0 m) below ground level at both potentially contaminated and non-contaminated sites. All disturbed samples were collected in plastic bags and carefully sealed with plaster. Each plastic bag was labelled according to the site name, trial pit coordinate and sample depth. Each plastic bag was labelled according to the site name, trial pit coordinate and sample depth. They were then transferred to storage under controlled temperature conditions of 18 C°. This was carried out according to the sampling preservation method of these studies, i.e. ASTM D 4220-95 (2000) and Landon (2007) (Plate 4.1).

- For the purposes of **PSD, Atterberg Limits, pH and water soluble Cl- and (SO_3 & SO_4) tests**, **132** samples, each weighting **2.5** Kg, were taken from the **22** T.Ps (**22** samples from each sampling depth) at the potentially contaminated site as well as **30** samples collected from the **five** T.Ps at the non-contaminated site.
- Another **132** samples each weighting **50** g, were taken from the 22 T.Ps from six different depths (i.e. 0.0 m, 0.25 m, 0.5 m, 1.0 m, 1.5 m and 2.0 m) in the potentially contaminated site, and **10** samples, each weighting **50** g from two depths of 0.0 m and 0.25 m only, from the potentially non-contaminated site. Each one of the above samples was taken for the purpose of the elemental analysis test.
- Another **110** samples, each weighting **100** g, were obtained from five depths of 0.0 m, 0.25 m, 0.5 m, 1.0 m and 1.5 m from the 22 T.Ps in the potentially contaminated site; **10** samples, each weighting **100** g, were obtained from two depths of 0.0 m and 0.25 m only, from the

potentially non-contaminated site. All the above samples were obtained for the purpose of the **GC-MS test**.

All the plastic bag samples collected for the elemental analysis and GC-MS tests were placed inside conservation (heatproof) boxes and transported to the chemical laboratory at KISR Ahmadi Branch and stored under 3°C. For the purpose of this test, sampling was undertaken in the morning (5 a.m.) during the winter season and transported directly by car (a distance of 19 km) to the laboratory. The U.S. EPA Method 8270D (1998) and Hesnawi and Adbeib (2013) method was used during the sampling process. Figure 4.10 details the sampling site and chemical laboratory at KISR Ahmadi.

4.6.2 Undisturbed Sampling

- For the Purpose of the **Direct Shear test**, undisturbed samples were obtained from different T.Ps at depths of 0.0 m, 0.25 m, 0.5 m, 1.0 m and 2.0 m. Sampling was undertaken by means of pushing a sharp-edged stainless steel tube of 25 mm diameter by 45 mm height through the soil by tamping the tube gently through the soil (ASTM D 2937-04, 2008). The soil inside the tube was trimmed at both top and bottom sides. The tubes were then secured using rubber cups at the top and bottom, placed into a plastic bag and sealed with plaster. Bags were then transferred to the conservation box to be transported directly to the soil laboratory in order to find the natural density and water content. The soil was then taken from these tubes and compacted again inside the shear box to ascertain the natural density and water content as it had been on the site, in other words, inside the sampling tube. **42** samples were obtained from the potentially contaminated site and **18** samples from the potentially non-contaminated site.

- For the purpose of the permeability test, sampling was undertaken using the same method as that used for obtaining undisturbed samples inside the stainless steel sampling ring. The difference being that the sampling ring size was 50 mm diameter by 50 mm height and that the permeability test was conducted on the undisturbed sample inside the sampling ring itself. **24** samples were taken from the potentially contaminated site while **12** samples were collected from the potentially non-contaminated site. Plates 4.2 and 4.3 are photographs taken during the field sampling works (plate A.4.2).

Plate 4.1. Soil samples were stored within 18 °C temperatures before transferring to the lab to be tested for Atterberg Limit, Sieve Analysis, pH and Water soluble Chloride (Cl-) and Sulphate (SO_3 & SO_4) contents.

Figure 4.10. Location of the sampling site and chemical laboratory at KISR Ahmadi branch clarifying the distance between the two locations.

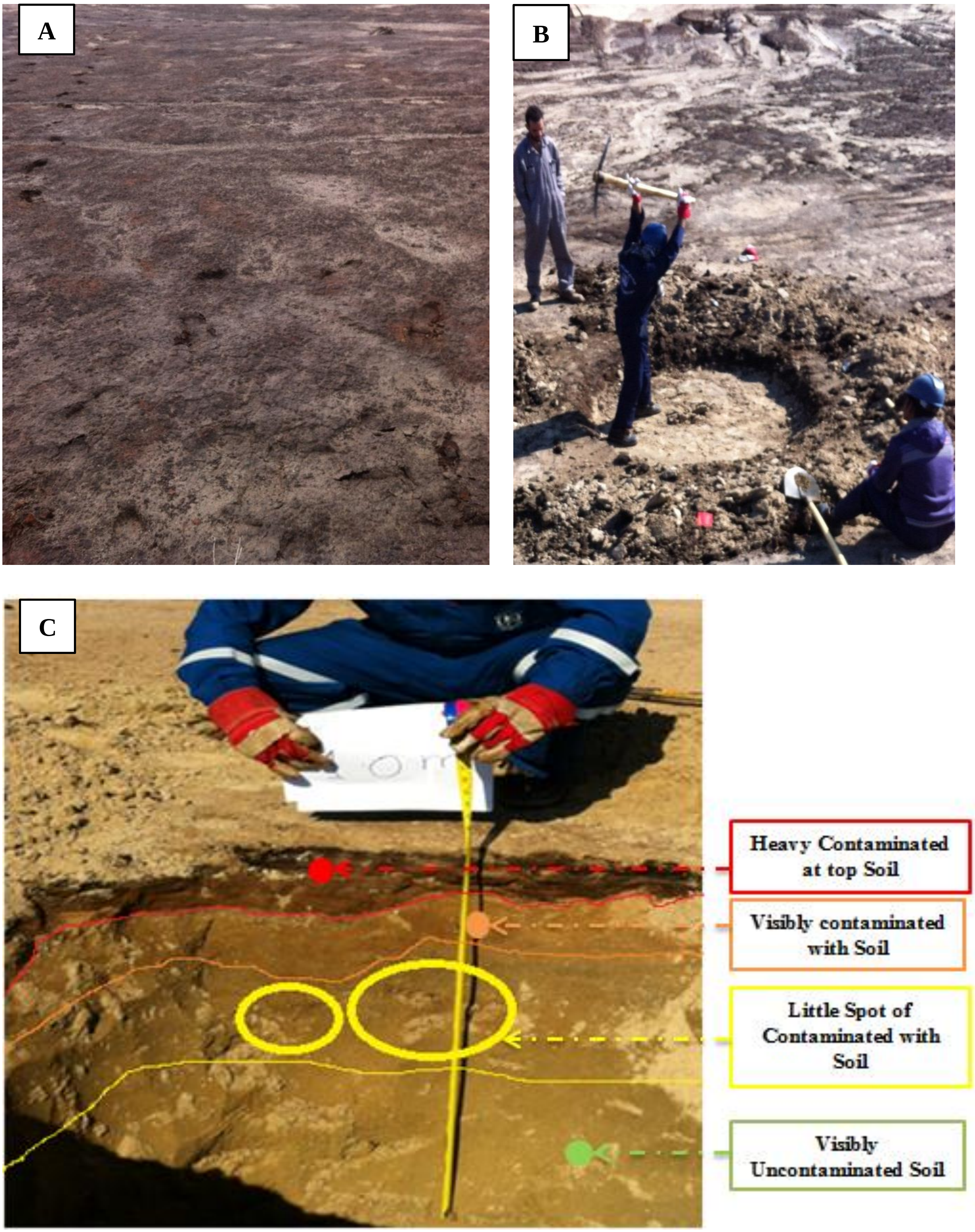


Plate 4.2. Dry *oil lake* at contaminated site (A), the works of digging at the contaminated site (B) and the soil profile in the contaminated site (C).

Plate 4.3. Non-contaminated soil samples (A) plus the undisturbed soil sample taken for Direct Shear test at non-contaminated site (B) and the soil profile in the non-contaminated site (C).

4.7 Soil Characterisation

This section showing the methodology for the soil characterization of potentially contaminated and non-contaminated sites will be outlined and classified into aspects, i.e. geotechnical and geochemical characterisation as well as hydrocarbon pollutants characterisation.

Geotechnical testing was carried out in order to determine whether dry *oil lake* residue had had any significant effect on the geotechnical properties, i.e. physical and strength properties, of the soil; this was undertaken by comparing the contaminated and non-contaminated soils. The geochemical testing was carried out to see whether dry *oil lake* residue had any influence on the geochemical properties; also performed through a comparison of the contaminated and non-contaminated soils. The hydrocarbon pollutants test was carried out to see whether dry *oil lake* residue had created a chemically aggressive problem for the environment; this was performed through detecting chemical compositions of the hydrocarbon pollutants and their concentration in the contaminated soil.

The geotechnical, geochemical and hydrocarbon pollutants' analysis of the contaminated samples collected at the dry *oil lake* site in the Greater Burgan Oil Field (Al-Magwa area) was essential to this study as the area will see significant construction and development over the next five years.

4.7.1 Geotechnical Characterisation

As realised from the sample collection phase of this project, the oil spills' contamination was no longer found at depths lower than 2.0 m. Therefore, the investigation was limited to this depth 2.0 m.

The geotechnical tests carried out for this study included the PSD, Atterberg Limit, permeability (hydraulic conductivity), Direct Shear and SEM tests. The PSD and Atterberg Limit test were conducted on samples collected from two sites (contaminated and non-contaminated), whereas the SEM test was utilised to further investigate the grain size and shape of the samples. The permeability test (hydraulic conductivity) gave an idea of the extent of hydrocarbon entrances through the soil layers and of hydrocarbon contamination migration into the ground water. While the Direct Shear test gave an idea as to the bearing value of soil which might be affected by hydrocarbon contamination.

The material collected from each site was divided into two portions using a mechanical splitter. One of these was then shipped to the University of Portsmouth in the UK and stored in a laboratory for SEM work; the other remained in three laboratories in Kuwait, including those of INCO in the Sabhan region, SMATCO in the Alrayi region and at the soil material laboratory in the Kuwait Institute of Scientific Research (KISR) (Figure A.4.13).

Sieve analyses and Atterberg Limit tests were carried out at the INCO laboratory. The Direct Shear tests were conducted at the SMATCO laboratory, while the permeability test took place at the KISR's soil laboratory.

4.7.1.1 Plasticity

The Atterberg Limit test for Liquid Limits and Plastic Limits were carried out on soil samples in this study in accordance with the methods described by BS 1377, part 2: 1990: 4.5 and 5.3 (BSI, 1990a), respectively. The laboratory work on this test is shown in Figures A.4.14, A.4.15 and Plate A.4.3 in Appendix A.

4.7.1.2 Particle Size Distribution (PSD)

The technique known as *dry sieving* is appropriate for soils with very little content of silt and clay particles (sizes of less than 6 µm) normally used in the UK under (BSI, 1990a), therefore, this technique was chosen for this study. Some photographs were taken in the laboratory showing the author performing this test (Figure A.4.16 and Plate A.4.4).

4.7.1.3. Scanning Electron Microscope (SEM)

The SEM method is regularly used to produce images of shapes of objects (SEI) in high-resolution to indicate spatial variations in chemical compositions (GIA, n.d.). Thus, SEM tests were performed to further analyse the distribution of particle sizes in high resolution images of the sample in an effort to study the effect of the dry *oil lake* upon the shape of surface grains. Two samples were tested, one taken from the hydrocarbon contaminated area and another from the non-contaminated area (Figure A.4.17). This means that multiple grains for each soil sample (contaminated and non-contaminated) were obtained and attached to an Aluminium pin stub using a carbon adhesive disk. This was then coated with a fine coating of Gold/Palladium which was done by using a manual sputter coater.

4.7.1.4 Permeability (Hydraulic Conductivity)

The permeability coefficient test performed on soil samples was undertaken in accordance with the procedures defined in ISO/TS 17892-11: 2013, with constant-head conditions. For more details about the test procedures see Table A.4.3 and Plate A.4.5 in appendix A.

4.7.1.5 Shear Strength

The Direct Shear tests were performed in accordance with the BSI (1990b) by means of testing apparatus (MATEST) equipped with a mechanical loading system. All samples were prepared by compacting a fixed amount of soil in a square shear box with dimensions of 60 mm x 60 mm and 23 mm thick in order to have the same natural density in the site (of undisturbed sample).

The soil in the square shearing box was then tested under consolidated drained conditions. Vertical loads were gradually applied incrementally to provide the required normal (vertical) stress. Three different normal stresses of 50, 100, 150 kPa were applied during the test in order to determine the angle of internal friction (φ) of the soil. Each normal stress was applied for a certain period of time (around 45 minutes), this was required to ensure the full settlement of the sample. The soil sample was subsequently sheared at a displacement rate of 0.35 mm/min, during which readings of shear displacements (horizontal displacement) and shear force were recorded at suitable intervals. Photographs of the sample tests in the laboratory are illustrated in Plate A.4.6.

4.7.2 Geochemical Characterisation

This section details the geochemical characterisations including: names pH; water soluble (Cl-, SO_3 & SO_4); Vario Macro elemental analysis (C %, N %, H % & S %); and GC-MS (TPH concentration and their compositions). Tests were carried out to establish the geochemical properties of the potentially contaminated and non-contaminated samples.

The pH test was conducted to determine soil acidity or alkalinity, while the water soluble Cl-, SO_3 and SO_4 tests analysed the soils’ chloride and sulphate content. These chemicals could lead to chemically aggressive corrosion of concrete and the reinforcements in reinforced steel particularly in foundation of structures.

An elemental analysis test was performed to assess the percentages of carbon (C %), hydrogen (H %), Nitrogen (N %) and sulphur (S %) in the samples. Meanwhile, the GC-MS test was carried out to determine the TPH concentration and its chemical composition in the soil. These tests were conducted in two laboratories in Kuwait, namely the KISR-Ahmadi branch and the INCO laboratory in Sabhan.

4.7.2.1 Hydrogen Ion Concentration (pH)

The soil pH test in this study was carried out in accordance with the method described by BS-1377-part 3, 1990 (BSI, 1990c). A 30g mass of each soil sample (contaminated & non-contaminated) was dried in a drying cabinet at 40 °C for 24 h (Lec, UK). Each sample was re-weighed and poured into a beaker, 75 mL of distilled water was then added to the beaker and mixed for 5 minutes by a mechanical stirrer (CP Cole-parmer). The mixture was allowed to stand for one hour so that most of the suspended materials could settle. The pH reading was then taken for samples by a pH meter after being calibrated for pH 7. Plate A.4.7 illustrates the testing procedure undertaken in the laboratory.

4.7.2.2 Water Soluble Chloride (Cl-) and Sulphate (SO_3 & SO_4) Content

For this study, the tests on soil samples were carried out in accordance with BSI-1377, part 3:1990: 7.2 and 5 (BSI, 1990c).The works laboratory for the water soluble Cl-, SO_3 and SO_4 tests are shown in Plate A.4.8.

4.7.2.3 Vario Macro Elemental Analysis (EA)

The elemental analyser test was performed using CHNS in accordance with the Vario Macro apparatus for soil samples to determine the percentage of carbon, hydrogen, nitrogen and sulphur content present in the soil. In principle, the operation involved digestion of samples at very high temperatures of between 800 °C to 1200 °C followed by scrubbing of non-analytes from the combustion gasses. A Helium career stream was employed to transport the analyte gasses. After the formed nitrogen oxide was reduced, the gas mixture was separated into its components which were then released to a detector (TCD) in sequence.

Moreover, percentage contents of the elements were determined from the detector signal which was linked to the sample weight and the stored calibration curve (The Universal Way of Macro Analysis, n.d.). The separation of gas was carried out using computer controlled absorber/desorber tubes specifically designed to absorb the analyse gasses of H_2O, CO_2 or SO_2 and to release them by increasing the temperature. This resulted in an immense dynamic concentration and an overlap-free peak separation (The Universal Way of Macro Analysis, n.d.).

Samples were weighed into 45 mg by electronic scale weight and then well wrapped in small foil. All the samples prepared for this test, were taken into the sample holder of the elemental device (1 sample took 20 minutes to test). The samples' results (N %, H %, S % and C %) were presented in a PC computer linked to an elemental device (Plate A.4.9).

4.7.3 Hydrocarbon Characterisation

As explained in Chapter 3 (p.51) by ATSDR, 1999, the term TPH is employed to define a large group of hundreds of organic compounds derived from crude oil. Although it is unrealistic to perform measurements on each individual compound, for the purposes of this study, analysed hydrocarbon pollutant in soil samples has been termed TPH.

4.7.3.1 Hydrocarbon Extraction

In order to extract the hydrocarbon from the soil sample, an Accelerated Solvent Extractor (ASE350 Dionex) was used (Plate 4.4). The ASE is capable of extracting hydrocarbon samples in a much shorter time and with a considerably less amount of solvents as compared with other usual methods such as Sonication and Soxhlet. During this phase, soil samples were taken for analysis of the dry weight. It is important not to use heat in drying the samples to avoid losses of some TPH.

The weight of soil sample used is dependent upon the concentration of hydrocarbon contamination. In the case of samples with low concentration hydrocarbon contamination, sample weights of between 1 to 5 g are recommended while 0.5 to 3 g is recommended for samples with high hydrocarbon contamination. This approach was employed in the chemical laboratory at KISR with regards to the TPH analysis for soil samples using GC-MS tests. Furthermore, Dionex (2011) states that the recommended sample weight used for TPH extraction in soil through ASE-350 should be between 3 and 20 g.

For this study, so as to minimise the risk of contamination of the GC column, smaller sample weights, for example 3 g, were suggested. This is in line with the development method defined in by Dionex (2011) and KISR.

During this phase, the 3 g of sample soils were thoroughly mixed with an equal volume of Diatomaceous Earth (Thermo Scientific, USA) drying agent and packed between acid washed sand (BDH, USA) and cellulose filters (Dionex, UK) in an extraction cell and positioned on the Dionex ASE-350.

The extraction process was completed using ASE-350 (Dionex, UK) in accordance with the technique adapted from the Dionex method-324 ‘accelerated solvent extraction of TPH contaminants in soils’ (Dionex, 2011).

Plate 4.4. Accelerate Solvent Extractor (ASE-350) device used to extract the hydrocarbon from the soil samples.

The ASE-350 conditions used based on method-324 (Dionex, 2011) following US EPA Method 3545A are shown in Table 4.1.

Table 4.1. The Conditions utilised in ASE.

Conditions	**TPH**
Solvent used	1:1 Hexane: Acetone
Preheat up time	0 min
Heat time	9 min
Static time	5 min
Flush volume	60 %
Nitrogen purge	60 sec
Oven temperature	200 °C
Pressure	1500 psi
Cycles	1

Upon extraction, the sample was transferred into a 50 ml volumetric flask and mixed with 3 g in volume of activated silica gel to prevent contamination of the GC column. The polar compounds in the samples were removed. The extract was then filtered by means of 0.45 µm Chromacol filters to remove any particles that may cause blockage in the GC column. After filtration, samples were retained for 3 hours to allow the silica gel to settle. The liquid layer was then separated and transferred to a sample beaker. Next, the samples were blown down to 1ml using heat and Nitrogen by placing the tube into the Turbo Evaporator (EQP-11, Athena technology) so that it could be transferred into the GC vial for the GC-MS analysis (Plate 4.5).

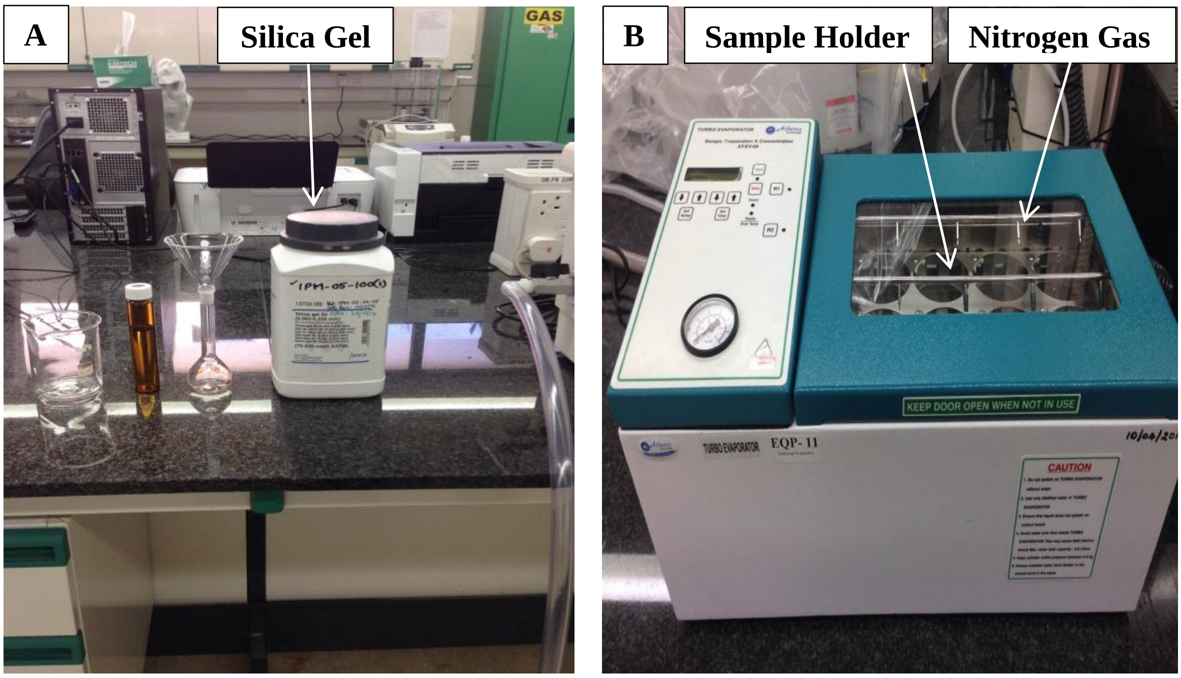


Plate 4.5. Extract sample filtration (A) and the turbo evaporation system used to concentrate the extract sample (B).

4.7.3.2 Gas Chromatograph Mass Spectrometry (GC-MS)

In accordance with Bul, (2008), GC-MS was utilised in mixtures to segregate the volatile compounds so that they could be quantified and identified. Within this technique, ASE was employed to extract the petroleum hydrocarbons from solid samples. The extracts were subsequently analysed using the GC-MS technique.

TPH was further analysed by means of Agilent Technologies (USA) 6890N GC with 5975B MSD, 7683B Automatic liquid sampler and an Agilent HP-5MS (P/N# 19091S-433) column, in accordance with the methods described in Table 4.2 (Plate 4.6):

Table 4.2. The method used in GC-MS instrument.

GC-MS Instrument Parameters		Methods
MS Modes		Scan Mode
Software used		Agilent MSD Chemstation.
Scan parameters	***Lower mass***	20 m/z.
	Higher mass	450 m/z.
Solvent Delay		2 min.
MS Parameters	***MS-Source***	230 °C.
	MS-Quad	150 °C.
Multimode injection		2µl in split less mode
Column Used		Agilent HP-5MS (P/N# 19091S-433) 30 m × 250 µm × 0.25 µm
Temperature Program	***Injector temperature***	220 °C
	Oven Temperature	Initial temperature 60 °C held for 10 minutes and then increased under two different temperature rate.
	Temperature Rate (1)	Increased 15 °C/minute to 220 °C and held for 5 minutes.
	Temperature Rate (2)	Increased to 260 °C at the same rates of 15 °C/minute and held for 5 minutes.
	Total Run time	33.33 minutes.

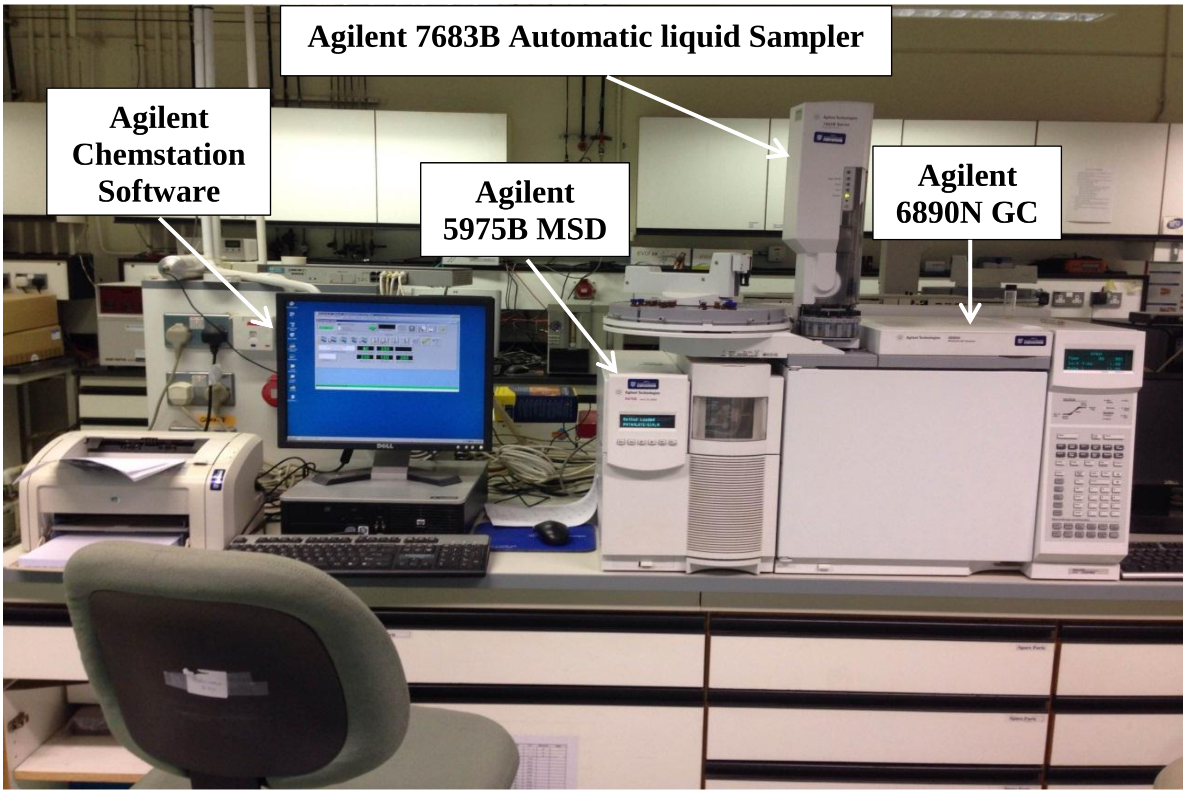


Plate 4.6. Agilent Technology 6890N GC with 5975B MSD and 7683B Automatic Liquid Sampler.

Using the Kuwait Diesel Standard, the TPH calibration peaks were prepared at concentrations of between 20-1000 µg/ml. A Diesel Range Oil (DRO) which contains C10-C28 was injected on a regular basis to confirm the retention time repeatability. The retention time for the area under the peak for the DRO’s was measured at between 6 and 23 minutes, this area under the peaks was integrated according to standards (Figure 4.13). A linear regression equation was formed by plotting the calibration peak of diesel in µg/ml against the area under the peak and this was used to convert the area under the peak into TPH in µg/ml. This was converted to concentration per dry weight of soil.

$$\frac{\text{Dry Wt}}{\text{Wet Wt}} \times 100 = \text{Dry Mass (\%)} \text{------------------} \text{(EQ. 4.1)}$$

$$\frac{\text{Wet Wt.} \times \text{Dry Mass}}{100} = \text{Dry Wt. of Soil (Actual used in ASE)} \text{------------------} \text{(EQ. 4.2)}$$

$$\frac{\text{TPH (µg/ml) obtained from the Integration}}{\text{Dry Wt. of Soil Used}} \times 1000 = \text{TPH of Dry Soil (µg/g)} \text{------------} \text{(EQ. 4.3)}$$

4.7.3.3 Unresolved Complex Mixture (UCM)

Hump or unresolved complex mixture (UCM) - as shown in GC-MS chromatograms (Figure 4.11) - resulted from incomplete degradation of petroleum hydrocarbon in environmental samples along biogenic organic compounds such as alkanes, steroids, sterones, fatty alcohols, fatty acids and wax esters. When this chromatogram (Figure 4.13) is integrated with baseline at retention time for 6 min and to baseline at retention time for 23 min (this method was advised by the (TPHCWG) (1998, p.27)), it was found that the area under the curve of UCM increased more than for the area under individual spikes.

The chromatograms of DRO could be integrated by either considering only the area under individual spikes without considering the area in UCM part or by considering both the area under individual spikes and corresponding area in the UCM part - the latter was followed in this study. This method has been used in many published papers investigating environmental samples including those of Muijs and Jonker (2009), Bregnard *et al*. (1998) and Wang *et al*. (1995). This method of analysis was preferential for this study to one involving the measuring of each peak height due to the lack of distinct peaks found in the chromatogram during the development of the methodology. The GC-MS method used during sample testing is presented in detail in Figure A.4.18.

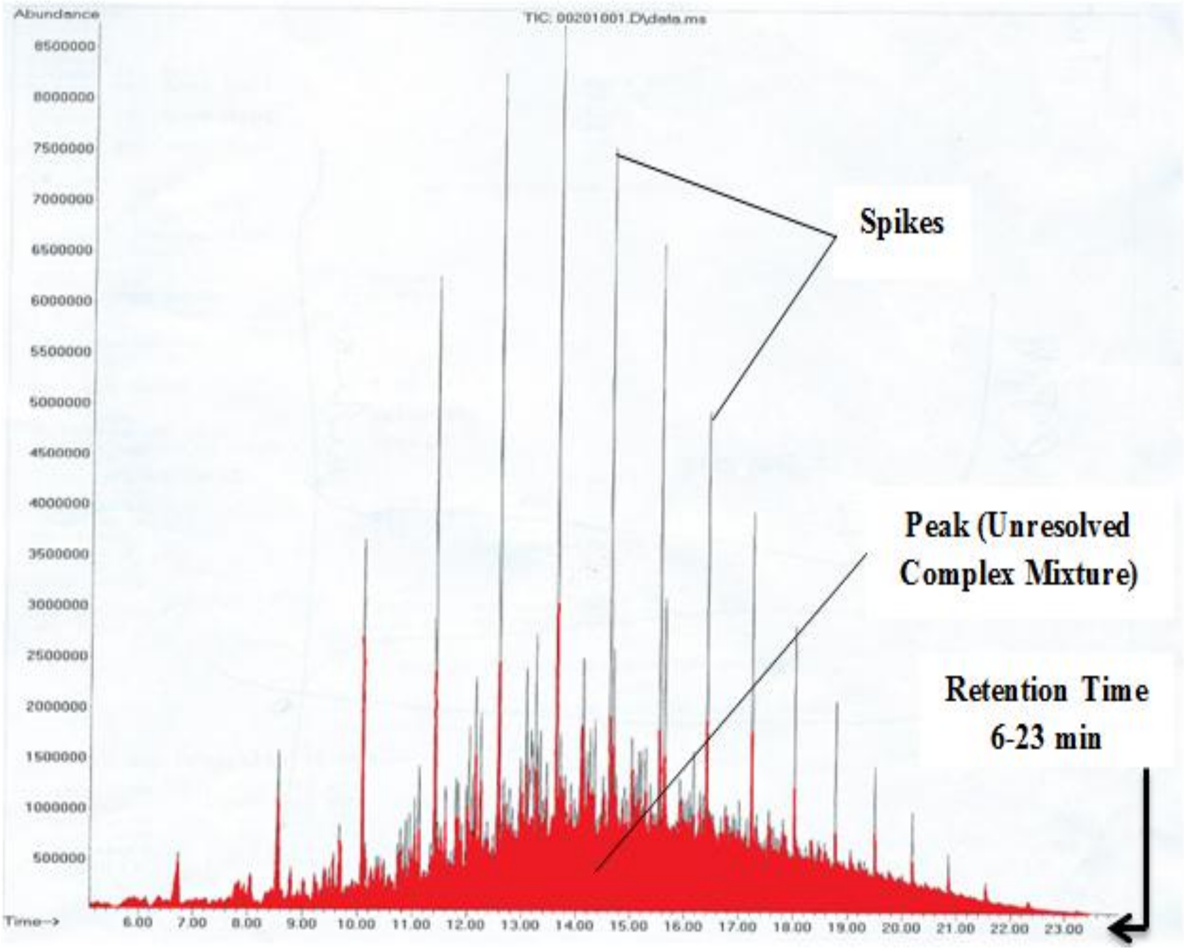


Figure 4.11. An example of an area under the peak of DRO.

4.8 Statistical Data Analysis

The geotechnical, geochemical and hydrocarbon pollutants characterisation tests data used in this study were analysed quantitatively using IBM SPSS Statistics (Statistical Package for the Social Sciences) version 21 using $p < 0.05$ to define statistical significance. In order to carry out the statistical analysis, the data analysis framework was first outlined, this was followed by data classification and then application of the following quantitative tests:

- Outlier Testing (Boxplot and Outlier Labeling Rule)
- Normality Testing (Shapiro of Normality)
- Parametric or Non-Parametric Tests (i.e. T-Test or Mann Whitney U Test)
- Linear Regression and Wilcoxon Signed Rank tests.

4.8.1 Data Classification

Soil samples were taken at various depths from two different sites, i.e. contaminated and non-contaminated sites, for geotechnical, geochemical and hydrocarbon characterisation. These samples are briefly classified within this sub-section to assess their ability to confirm the type of statistical analysis tests to be used for the geotechnical, geochemical and hydrocarbon analysis in this study (Tables 4.3 to 4.5). Therefore the design is a between-groups study (group 1: contaminated data, group 2: non-contaminated data) with three test samples (geotechnical, geochemical, and hydrocarbon soil samples). Each to be taken at six depths: 0.0 m; 0.25 m; 0.5 m; 1.0 m; 1.5 m; and 2.0 m. The comparison between the mean values (if parametric data) or median values (if non-parametric data) taken from the contaminated and non-contaminated sites will, therefore, be used for the statistical analysis.

Table 4.3, Table 4.4 and Table 4.5 (below) summarise the soil samples collected for the geotechnical test, geochemical test, and hydrocarbon analysis, respectively.

Table 4.3. Number of soil samples utilised for the geotechnical tests.

Depth (m)	Geotechnical Tests							
	Atterberg limit		Sieve analysis		Permeability (constant head)		Direct shear	
	*Conta.	**Non-conta.	*Conta.	**Non-conta.	*Conta.	**Non-conta.	*Conta.	**Non-conta.
0.0	***22	***5	***22	***5	***22	***5	***22	***5
0.25	***22	***5	***22	***5	***22	***5	***22	***5
0.5	***22	***5	***22	***5	***22	***5	***22	***5
1.0	***22	***5	***22	***5	***22	***5	***22	***5
1.5	***22	***5	***22	***5	***22	***5	***22	***5
2.0	***22	***5	***22	***5	***22	***5	***22	***5

*Note: * contaminated site, **Non-contaminated site, ***samples number collected from both sites for Geochemical tests.*

Table 4.4. Number of soil samples utilised for the geochemical tests.

Depth (m)	Geochemical Tests									
	pH		Water Soluble Chloride (Cl-)		Water Soluble Sulphates				Vairo Macro Elemental Analysis (N %, C %, H % & S %)	
					SO_3		SO_4			
	*Conta.	**Non-conta.	*Conta.	**Non-conta.	*Conta.	**Non-conta.	*Conta.	**Non-conta.	*Conta.	**Non-conta.
0.0	***22	***5	*22	***5	*22	***5	***22	***5	***22	***5
0.25	***22	***5	*22	***5	*22	***5	***22	***5	***22	***5
0.5	***22	***5	*22	***5	*22	***5	***22	***5	***22	---
1.0	***22	***5	*22	***5	*22	***5	***22	***5	***22	---
1.5	***22	***5	*22	***5	*22	***5	***22	***5	***22	---
2.0	***22	***5	*22	***5	*22	***5	***22	***5	***22	---

*Note: * contaminated site, **Non-contaminated site, ***samples number collected from both sites for Geochemical tests.*

Table 4.5. Number of soil samples utilised for hydrocarbon pollutants analysis test.

Depth (m)	Hydrocarbon Test	
	GC-MS	
	Contaminated site	*Non-contaminated site*
0.0	*22	*5
0.25	*22	*5
0.5	*22	---
1.0	*22	---
1.5	*22	---
2.0	---	---

*Note: *samples number collected from both sites for GC-MS test.*

4.8.2 Outlier Labelling Rule and Normality Tests

Boxplots were initially used to visually search for outliers on each boxplot, after which the '*Labelling Outlier Rule'* procedure was performed on the data for both contaminated and non-contaminated sites to identify lower and upper outliers through the use of the following formula:

*Lower outlier values = Q1- (1.5 * (Q3-Q1))*---------------------------------*(EQ. 4.4)*

*Upper outlier values = Q3+ (1.5 * (Q3-Q1))*--------------------------------*(EQ. 4.5)*

Where Q1 is lower quartile, Q3 is upper quartile (obtained via Quartile, Percentiles in SPSS), and g is a standard value of 1.5. (Hoaglin *et al*., 1986) For this procedure, a low outlier is defined as a value that is lower than the lowest lower outlier; whereas a high outlier is defined as a value that is higher than the highest upper outlier value. These values are then looked into the SPSS, descriptives explore, extreme values table. Outliers are deleted from the dataset.

Prior to statistical analysis, the normality assessment of data is a prerequisite due to the fact that the normal data is the fundamental assumption for parametric tests. On the other hand, the non-normal data follows the assumption of a non-parametric test. The numerical approach is employed mathematically using two primary tests namely Kolmogorov-Smirnoff (K-S) and Shapiro-Wilk (S-W), the latter is more appropriate for small sample size ≤ 30 cases. Based on (Storey, n.d.), these tests compare the set of scores in a sample to a normally distributed set of scores having the same mean and standard deviation. Should the test prove to be non-significant (i.e. p-value > 0.05 where the p-value obtained from the software is considered as being significant value of (K-S) & (S-W) tests), this demonstrates that the data is not considerably different from a normal distribution i.e. the data is normally distributed. However, in the case the test is found to be significant, i.e. p-value

<0.05, the data is not normally distributed (Storey, n.d.). As mentioned by Storey (n.d.) and Pallant (2005), the S-W test is employed when sample size is small, i.e. less than 100.

4.8.3 Parametric and Non-Parametric Method

The parametric method is typically employed in circumstances where the data follows a normal distribution (Pallant, 2005) According to Sullivan (2016), the parametric test includes specific probability distribution or normal distribution. It provides estimation for the important parameters of the data distribution such as the mean or difference in the means from the sample data. In contrast, if it is obvious that the data is not normal distribution, the non-parametric method can be employed instead. As clarified by Sullivan (2016), the non-parametric test is occasionally termed a distribution-free test as it is based on fewer assumptions, e.g., they do not consider that the outcome is normally distributed.

As classified by Pallant, (2005) and Kasule (2001), the common statistical tests employed in parametric and non-parametric methods for the data are as displayed in Table 4.6.

Table 4.6. The tests used for parametric and non-parametric statistics (Source: Pallant, 2005; Kasule, 2001).

State	Parametric test	Non-Parametric test
One sample	z-test, One sample T-Test	Sign test
Two independent sample means/mean ranks/medians between groups	Independent samples T-Test	Wilcoxon Rank Sum Test, Mann Whitney Test
Two paired sample means/mean ranks/medians within groups	Paired T-Test	Wilcoxon Signed Rank Test
Three or more independent sample means/mean ranks/median between groups	Between Groups ANOVA (one-way)	Kruskall Wallis Test
Multiple comparison of means/mean ranks/median within groups	Repeated Measures ANOVA (compares mean)	Friedman Test

4.8.3.1 T-Test

The T-Test is a parametric statistical test used to determine whether the mean difference between two normally distributed groups is statistically significant (Pallant, 2005). It supports a null hypothesis which specifies that:

H0: the population means of both groups are similar (when the p-value is > 5%).

H1: the population means are significantly different (when the p-value is ≤ 5%).

The T-Test is expressed as:

t(DF) = t-value.

DF = Degrees of Freedom.

P = *p*-value.

4.8.3.2 Mann-Whitney U Test

The purpose of the non-parametric Mann-Whitney U Test (non-parametric version of the independent samples T-Test above, Shier, (2004)) is to assess whether two independent groups differ significantly in some dependent variable, which is either ordinal or continuous, or whether the data is not normally distributed (Field, 2009).

Its purpose is to test the null hypothesis for two samples which come from the same population, i.e. have the same median, or alternatively, whether observations in one sample are inclined to be greater than observations in the other. It compares two distributions across their mean ranks, rather than mean values. While it is regarded as a non-parametric test, it still considers that both distributions have a similar shape.

The hypotheses assumed in Mann-Whitney U test are:

H0: the population medians are similar (used if the *p*-value > 5%).
H1: the population medians are significantly different (used if the *p*-value ≤ 5%).

4.8.3.3 Wilcoxon Signed Rank Test

According to Voraprateep (2013), the Wilcoxon signed-rank test is a rank based alternative to the parametric T-Test where the distribution of differences within pairs is symmetrical without the need for normal distribution (Oyeka and Ebuh, 2012). Shaw *et al.* (2000), reiterated that this assumption for normal distribution is not considered in the Wilcoxon signed rank test as the test is based on the rank order of differences instead of the actual mean differences value. Nonetheless, it is still required to assume that the distribution of the differences is symmetric.

The hypotheses assumed in Wilcoxon Signed Rank Test are:

H0: the population medians are similar (used if the *p*-value > 5%).

H1: the population medians are significantly different (used if the *p*-value ≤ 5%).

4.8.3.4 Regression Analysis

Linear regression analysis was used to investigate and model the relationship between a response variable (dependent variable) and one or more predictor variables, to determine the contribution of response variable(s) to the dependent variable (outcome in a scatterplot), the predictor is displayed on the x-axis and the response variable on the y-axis. A line of best fit can be added to show the direction of the relationship, and the accuracy of the prediction based on the R Square value, which shows how the actual data fits the predicted data values along the regression line. The linear regression equation is expressed as (Yates, 2012):

m = slope or gradient

c = the y intercept

Linear regression is based on the assumption that the data is normally distributed. Additional assumptions to assess model fit include multi-collinearity (multiple predictors should not be correlated highly above .8); independence of errors (assessed using Durbin

Watson statistic which should be below 2); normality of residuals (errors) assessed via histogram of residuals; homogeneity of variance (assessed via plot of residuals), and Cook's maximum distance values in residual diagnostics (which should be below 1) (Field, 2009). Regression analysis produces three key statistics to assess model fit: The R Square value, which indicates how much variation in the dependent variable is explained by the predictor(s). The F statistic, which indicates the overall fit of the model, which should be significant. The regression coefficients (unstandardized B and standardised Beta values) indicate the unique contribution of each predictor on the dependent variable scores.

4.8.4 Analysis Framework

The following analysis framework was developed to test the geotechnical and geochemical data in a logical fashion, starting with the geotechnical data, followed by geochemical data:

Step 1 – Screen data for outliers using boxplots and Labelling Outlier Rule procedure.

Step 2 –The Shapiro of normality was used to assess whether the assumption of normality was met for all distributions. When the assumption of normality was violated, non-parametric statistics were performed on the data.

Step 3 – Perform an independent sample's T-Test or Mann Whitney U Test, depending on the normality of the data, to compare the mean or median difference between the contaminated and non-contaminated site data groups at six different depths. These tests were used to determine the significant difference of the soil properties in terms of their geotechnical and geochemical properties.

Step 4 – If data violates the assumption of normality, perform a non-parametric Wilcoxin Signed Ranks test to compare soil properties in terms of their geotechnical and geochemical properties across six different depths within each contaminated and non-contaminated site, to examine whether relationships exist between the property values across six different depths.

Step 5 – If the data is normally distributed and the above T-Test is significant, perform linear regression to compare soil properties in terms of their geotechnical and geochemical properties across six different depths within each contaminated and non-contaminated site, so as to predict relationships between property values and depth.

4.9 Summary

After detailing the: experimental programme; selecting the tentative site; detailing the location of the eventual site (Greater Burgan Oil Field – Al Magwa area); final soil sampling for both contaminated and non-contaminated sites; appraising the appropriate geotechnical and geochemical tests; and performing required technical procedures for these tests (geotechnical and geochemical); for the two selected sites at the Al- Magwa area, the properties of the soils at the contaminated and non-contaminated sites can then be characterised.

It is imperative to make a note at this juncture that the conducted tests were more relevant and precise thus delivering more detailed and accurate results. Statistical tests' analyses were conducted in order to support robustness of the results. Further details and outcomes of geotechnical and geochemical characterisation for the soil samples, obtained from both the contaminated and non-contaminated sites, as described in this study, will be provided in Chapters 5 and 6 respectively.

5. GEOTECHNICAL CHARACTERISATION

5.1 Introduction

This Chapter presents the findings of the geotechnical characteristics of soil samples taken from two different locations of the contaminated (dry *oil lake*) and non-contaminated sites (see sections (4.5.1 and 4.5.2)). Both these sites are located at the Greater Burgan Field (Al-Magwa area). It also discusses the main outcomes and shows how the study objectives have been addressed by linking the experimental findings with several studies in the literature. Finally, the chapter will give a statistical analysis of the geotechnical characterisations of the soil samples thus supporting the findings of this work.

The geotechnical characterisation results in this chapter include: the Atterberg Limit; PSD; SEM; permeability (Hydraulic Conductivity); and Direct Shear tests.

The test results showing similar tables and figures will be put into appendix B; those with only limited tables and figures will be shown in this chapter as an example or representative.

5.2 Plasticity

As expected, the findings show that the hydrocarbon contamination has no effect on the Atterberg limits because the soil was originally silty sand (non-plastic). These results are in line with various past studies, e.g. Alhassan and Fagge (2013), for example who mixed clean sand samples with different amounts of 2 %, 4 % and 6 % - by weight - of the crude oil. Their analysis results showed that the sand samples consistently demonstrated non-plastic behaviour.

On the other hand, studies carried out by Khamehchiyan *et al.* (2007), Rahman *et al.* (2010) and Pandey and Bind (2014) concluded that for fine-grained soils such as clays and alluvium, hydrocarbon contamination reduced both their liquid and plastic limits.

Since the petroleum material (both at liquid or other phases) is known to be hydrophobic the consistency of the contaminated soil would not change the plasticity of soil if it was originally non-plastic (before contamination).

5.3 Particle Size Distribution (PSD)

5.3.1 Laboratory Results of PSD

The results of PSD for soil samples taken from the contaminated dry *oil lake* are shown in figures 5.1 and B.5.1, while figures 5.2 and B.5.2 display the results for the non-contaminated soil samples from the non-contaminated site.

Due to the significant number of curves representing samples taken from many Trial Pit Coordinates (T.P.Cs) - which are all drawn in each figure, where each figure represents one depth - the curves interfered in-between these figures and did not become clear enough. Therefore, only the extreme PSD are represented clearly and are shown by different colours.

Tables B.5.1, B.5.2, B.5.3, B.5.4, B.5.5 and B.5.6 in appendix B, show the percentages of each soil class as part of the soil sample corresponding to the position of the T.P.Cs of the contaminated site (dry *oil lake*) at different depths, i.e. 0.0 m, 0.25 m, 0.5 m, 1.0 m, 1.5 m and 2.0 m respectively. Similarly, the percentages of each soil class part against the position of the T.P.Cs of non-contaminated soil samples at the respective depths mentioned above are indicated in tables B.5.7, B.5.8, B.5.9, B.5.10, B.5.11 and B.5.12 Furthermore, the final column of the above tables shows the soil group of the whole sample according to (BS 1377: Part 2:1990:9.2).The minimum and maximum values of each soil class part found in the samples representing the same depth are recorded in the above mentioned tables. The mean and standard deviation values of each soil class part were also calculated and listed in these tables.

From the resulting PSD, curves of the contaminated site (figures 5.1 and (B.5.1)), it was noted that there were wide ranges in the gradation of soil samples taken from the same depth but from different locations (T.P.C). It was particularly evident in the top soil (figure 5.1 at depth 0.0 m). However, although this range is still wide it becomes narrower at other depths (Figures 5.1 and B.5.1. at depths 0.5 m & 2.0 m). From this behaviour it is expected (logically) that the hydrocarbon contamination is higher in the top soil.

In the non-contaminated area (figures 5.2 and B.5.2), it was noted that (at one depth), the gradation range between a sample taken from one T.P.C and another is smaller than in the corresponding contaminated site. Furthermore, the gradation does not vary much with depth.

The wide ranges in PSD of contaminated soil samples with hydrocarbon taken from the same depth but from different pit locations (different T.P.C) may be related to the differences in the ground level of the contaminated oil spill lake caused by higher oil spill depths leading to higher oil contents at the low ground level of the *oil lake* during the earlier stages (before dryness of the lake).

Table (5.1) shows the mean calculated percentage values of soil class as apart from all soil samples taken from the same depth. The table illustrates a comparison between the two sites (contaminated and non-contaminated). From the Table, it should be noted that the mean small grain size percentage values (passing No. #230) for the samples taken from the contaminated site are all slightly higher than for samples taken from the non-contaminated site. The larger fraction is due to the drying of hydrocarbon in the contaminated area forming small, asphaltane particles, as will be explained in sub-section 8.2.1 (see chapter 8, section 8.2.1).

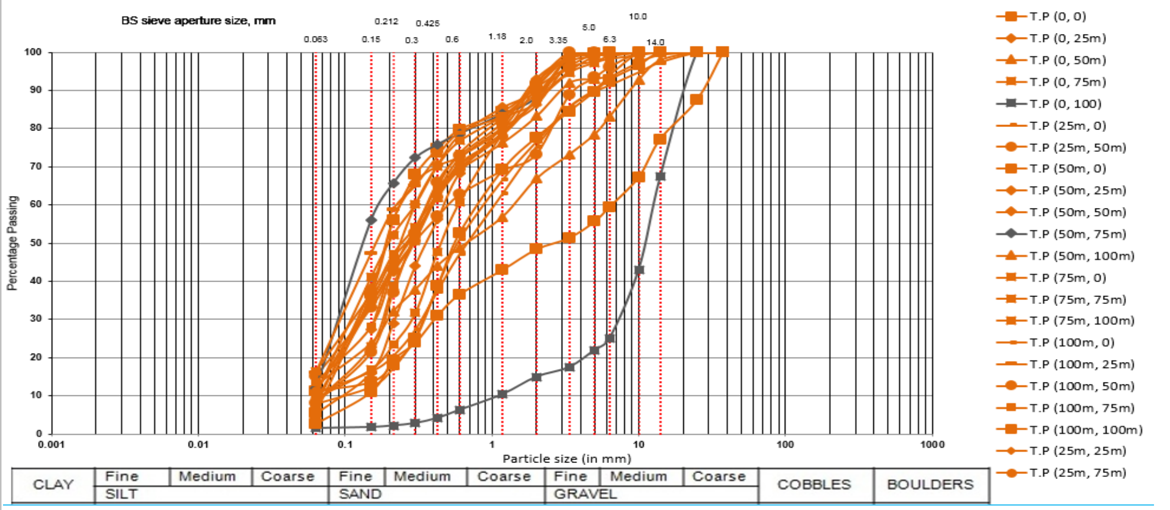
According to the Unified Classification System (Casagrande, 1948), the soil could be classified as well graded when the uniformity coefficient (Cu) is more than 6.00 and the coefficient of curvature (Cc) is more than 1.0. Table (5.1) and figures (5.4 and 5.5) further show that both the Cu and Cc values clearly differ between the contaminated and non-contaminated sites. The Cu of the top soil at depths (0.0 m and 0.25 m) of both contaminated and non-contaminated sites were more than six; this is the first requirement for soil to be classed as well graded. However, in the contaminated site only it drops to values much lower than six at lower depths. On the other hand, Cu values in the non-contaminated soil were still higher than six or nearly equal to six - at lower depths.

The second requirement, in respect of Cc is to be between one and three for the well graded soil; thus it can be seen that all values of Cc for the contaminated soil at all tested depths were less than one. One the other hand, Cc values were more than one at depths of 0.0 m, 0.25 m and 0.5 m for the non-contaminated soil. Cc however drops to less than one at deeper levels. This means that the PSD of soil tends to be poorer at lower depths in the non-contaminated site. It can also be seen from the above that contamination changed the soil (at least the top soil from 0.0 m to 0.5 m) class from well graded to poorly graded. This behaviour proves what is shown in section 6.5, i.e. that hydrocarbon was detected down to 0.5 m from ground level.

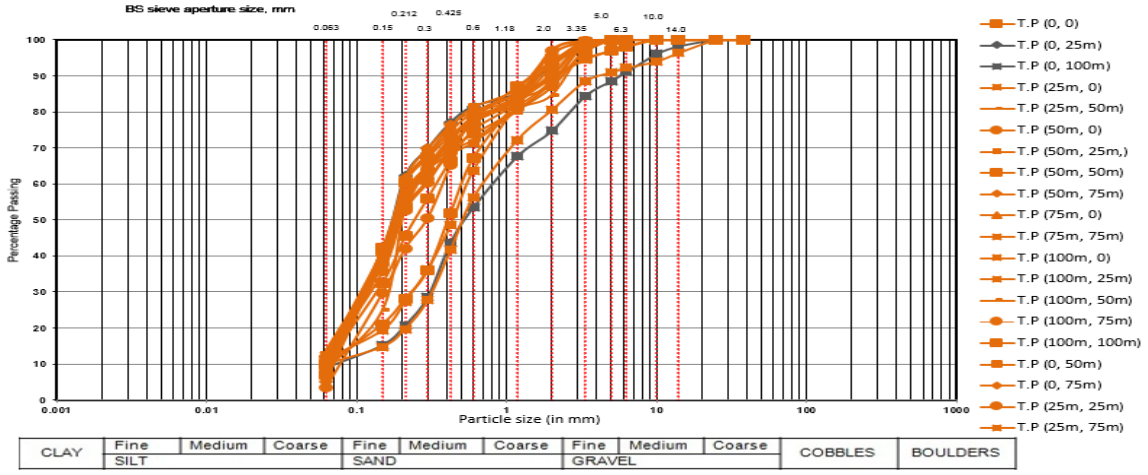
Furthermore, figure 5.3 shows that the grain size distribution of the non-contaminated site does not change much with the depth, but in the contaminated site there is a considerable change with the depth. The two mechanisms (particle aggregation by hydrocarbon cementation and hydrocarbon residues) are responsible for the differences in PSD curves of contaminated and non-contaminated soils.

Several studies of hydrocarbon contaminated soils have shown a correlation between hydrocarbon contamination and grain size distribution. Caravaca and Roldan (2003, p.56) studied clay loam sand contaminated by oil sludge, they showed that the clay content of these soil samples decreased considerably from 33.3 % to 21.3 % while the silt content decreased only slightly from 21.7 % to 20.5 % while the content of sand increased from 45 % to 58 %. This change in the constituent content changed the classification of the soil from clay loam to sandy clay loam. Meegoda and Ratnaweera (1995) found that the addition of 3 % and 6 % oil to clay soil reduced the clay fraction from 96 % to 87 % and 87 % to 84 % respectively, indicating an increase in soil aggregation with the addition of the oil.

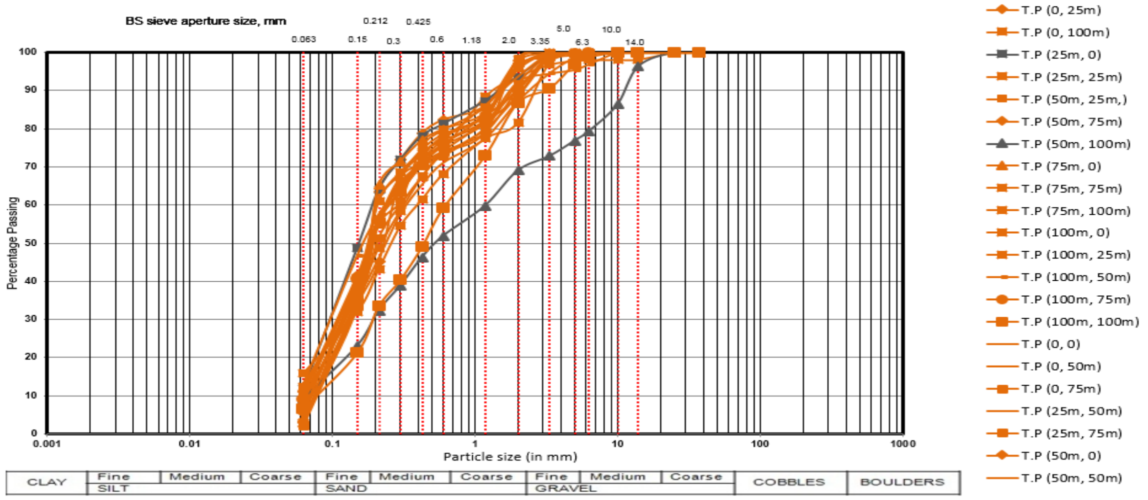
A study by Gupta and Srivastava (2010) on non-contaminated soils and soil samples artificially mixed with used engine oil for CL and CH, showed that the size of grains of the soil-contaminant mixes increases in tandem with the increase in oil content.



At depth (0.0 m)

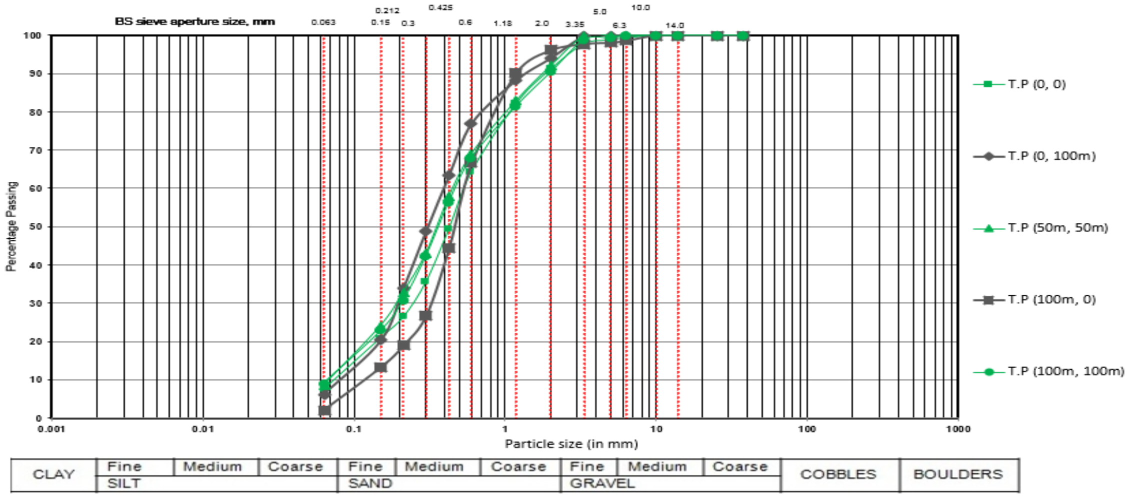


At depth (0.5 m)

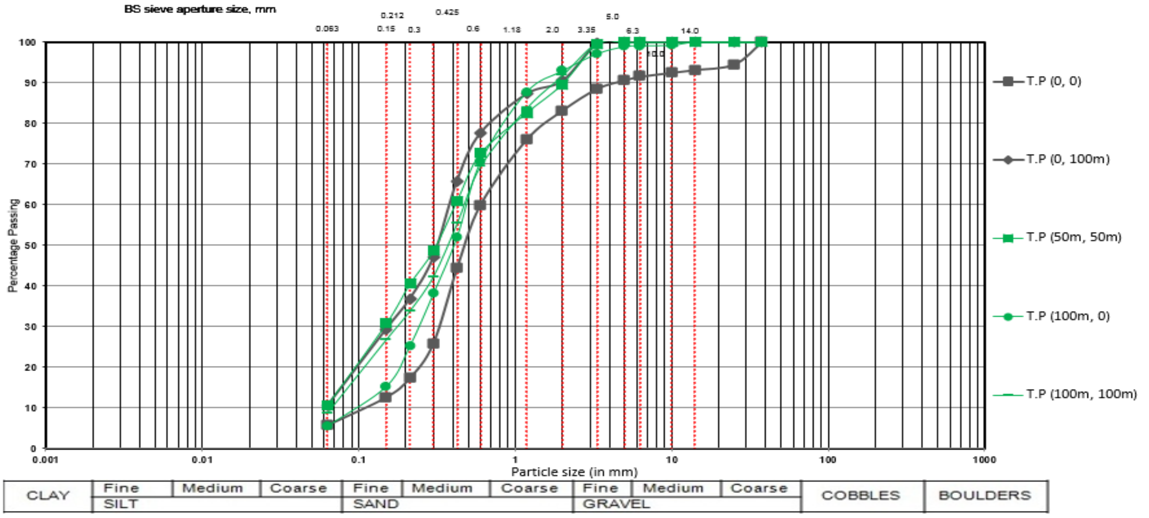


At depth (2.0 m)

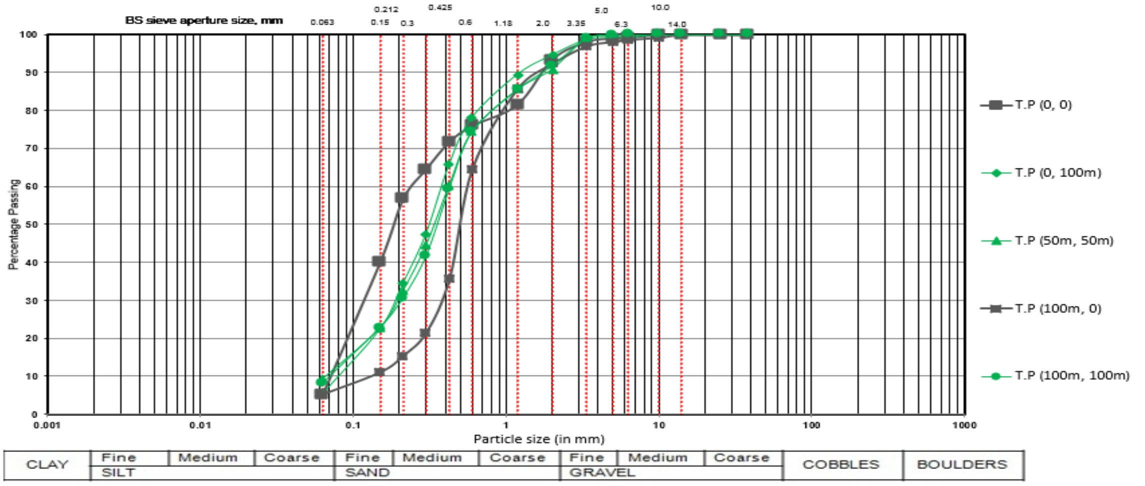
Figure 5.1. PSD curves for contaminated samples at depths (0.0 m, 0.5 m & 2.0 m).



At depth (0.0 m)



At depth (0.5 m)



At depth (2.0 m)

Figure 5.2. PSD curves for non-contaminated samples at depth (0.0 m, 0.5 m & 2.0 m).

Table 5.1. Comparing mean values of soil classification constituents between contaminated and non-contaminated samples at six different depths of 0.0 m, 0.25 m, 0.5 m, 1.0 m, 1.5 m & 2.0 m.

Depth (m)	**Samples Classification**	**Mean Percentages Value**					**Exact Soil Percentage Passing No. (#230)**	**Grading Analysis (Casagrande, 1948)**		**Soil Group (BSI-1377:Part 2:1990a)**
		Silty/ clay %	***Fine sand %***	***Medium Sand %***	***Coarse Sand %***	***Gravel %***		***Coefficient of Uniformity (Cu)***	***Coefficient of Curvature (Cc)***	
0.0 m	***Contaminated***	10.00	28.00	25.00	17.00	11.00	9.70	8.10	0.90	S-M
	Non-Contaminated	7.00	22.00	40.00	24.00	1.00	6.60	6.08	1.28	S-M
0.25 m	***Contaminated***	11.00	30.00	30.00	17.00	4.00	10.50	6.41	0.88	S-M
	Non-Contaminated	8.00	23.00	37.00	22.00	2.00	8.00	6.53	1.18	S-M
0.5 m	***Contaminated***	9.00	40.00	25.00	16.00	3.00	9.50	5.40	0.85	S-M
	Non-Contaminated	8.00	23.00	39.00	20.00	3.00	8.20	6.71	1.34	S-M
1.0 m	***Contaminated***	8.00	49.00	21.00	14.00	2.00	7.90	3.48	0.95	S-M
	Non-Contaminated	7.00	26.00	36.00	22.00	1.00	7.40	6.71	0.93	S-M
1.5 m	***Contaminated***	8.00	45.00	20.00	17.00	3.00	7.80	4.12	0.89	S-M
	Non-Contaminated	7.00	28.00	34.00	22.00	3.00	7.00	6.62	0.87	S-M
2.0 m	***Contaminated***	8.00	46.00	21.00	17.00	3.00	7.80	4.12	0.86	S-M
	Non-Contaminated	7.00	27.00	40.00	19.00	2.00	6.60	5.87	0.93	S-M

Table 5.2. Mean value of the sieve analysis result for contaminated and non-contaminated samples at six different of 0.0 m, 0.25 m, 0.5 m, 1.0 m, 1.5 m, and 2.0 m).

B.S. SIEVE mm	B.S. SIEVE (in/#)	Mean Percent Passing value for *conta. sample at depth (0.0 m)	Mean Percent Passing value for **control sample at depth (0.0 m)	Mean Percent Passing value for *conta. sample at depth (0.25 m)	Mean Percent Passing value for **control sample at depth (0.25 m)	Mean Percent Passing value for *conta. sample at depth (0.5 m)	Mean Percent Passing value for **control sample at depth (0.5 m)	Mean Percent Passing value for *conta. sample at depth (1.0 m)	Mean Percent Passing value for **control sample at depth (1.0 m)	Mean Percent Passing value for *conta. sample at depth (1.5 m)	Mean Percent Passing value for **control sample at depth (1.5 m)	Mean Percent Passing value for *conta. sample at depth (2.0 m)	Mean Percent Passing value for **control sample at depth (2.0 m)
37.6	(11/2")	100.00	100.00	100.00	100.0	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
25.0	(1")	99.40	100.00	99.60	100.00	100.00	98.90	100.00	100.00	100.00	100.00	100.00	100.00
14.0	(3/5")	97.20	100.00	99.20	99.60	99.80	98.60	99.80	100.00	100.00	100.00	99.80	100.00
10.0	(3/8")	95.10	100.00	98.90	99.20	99.50	98.30	99.70	99.90	99.80	99.80	99.30	99.80
6.3	(1/4")	92.30	99.60	98.20	98.70	99.10	98.10	99.40	99.70	99.10	99.20	98.70	99.40
5.00	(#5)	91.00	99.20	97.70	98.40	98.70	97.90	99.10	99.40	98.60	98.80	98.30	99.20
3.35	(#6)	88.60	98.80	96.10	97.60	97.40	97.00	98.20	98.60	97.30	97.30	97.10	98.30
2.00	(#10)	80.40	92.70	87.80	90.90	90.40	89.60	92.50	92.00	90.20	91.50	91.50	92.60
1.18	(#16)	72.50	84.90	80.40	84.60	82.20	83.40	84.30	85.90	79.80	83.90	81.10	85.50
0.600	(#30)	63.50	69.00	70.90	68.90	74.20	70.00	78.30	69.90	73.00	69.30	74.20	73.60
0.425	(#40)	56.00	54.30	61.70	53.90	66.80	55.70	73.10	56.20	68.30	55.40	69.40	58.60
0.300	(#50)	46.80	39.30	50.50	40.00	58.00	40.40	65.90	43.30	61.60	44.00	62.30	44.00
0.212	(#70)	38.10	28.50	40.70	31.50	49.60	30.70	56.90	33.80	53.20	35.00	53.40	34.00
0.150	(#100)	27.50	20.20	30.70	23.50	34.20	22.90	38.60	25.20	36.40	25.40	36.40	23.90
0.063	(#230)	9.70	6.60	10.50	8.00	9.50	8.20	7.90	7.40	7.80	7.00	7.80	6.60

Note; *Conta: Contaminated samples.

*****Control: Non-Contaminated samples.***

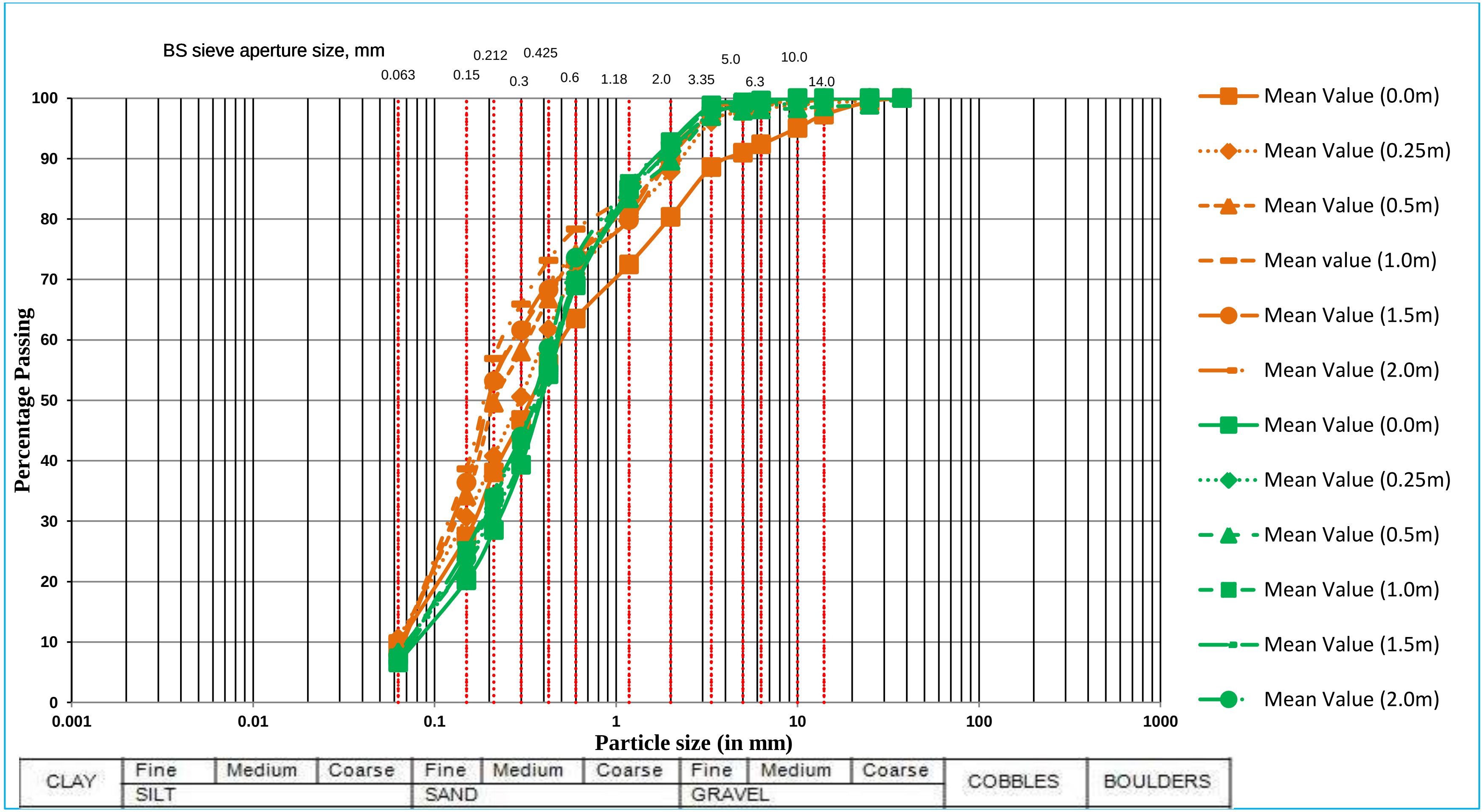


Figure 5.3. Mean values of PSD for contaminated (brown colour) and non-contaminated (green colour) samples at six different depths of 0.0 m, 0.25 m, 0.5 m, 1.0 m, 1.5 m and 2.0 m.

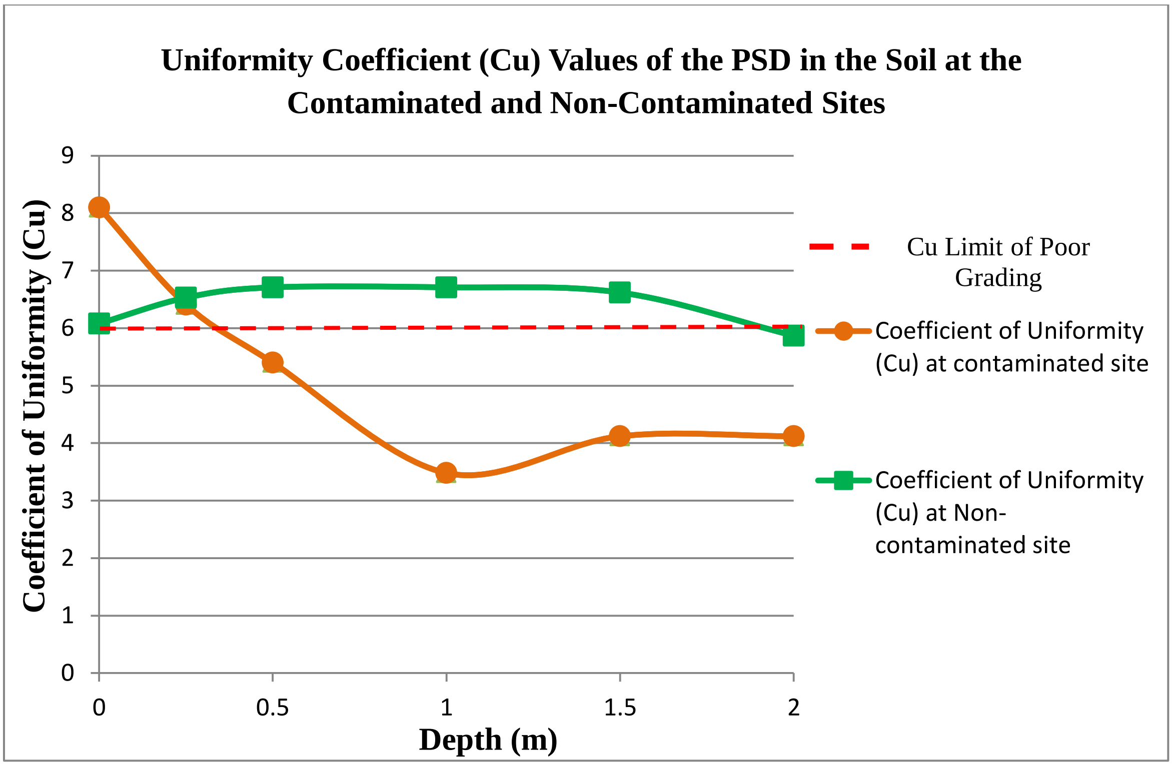


Figure 5.4. Cu values of PSD in the soil for contaminated (brown colour) and non-contaminated (green colour) samples at six different depths of 0.0 m, 0.25 m, 0.5 m, 1.0 m, 1.5 m and 2.0 m.

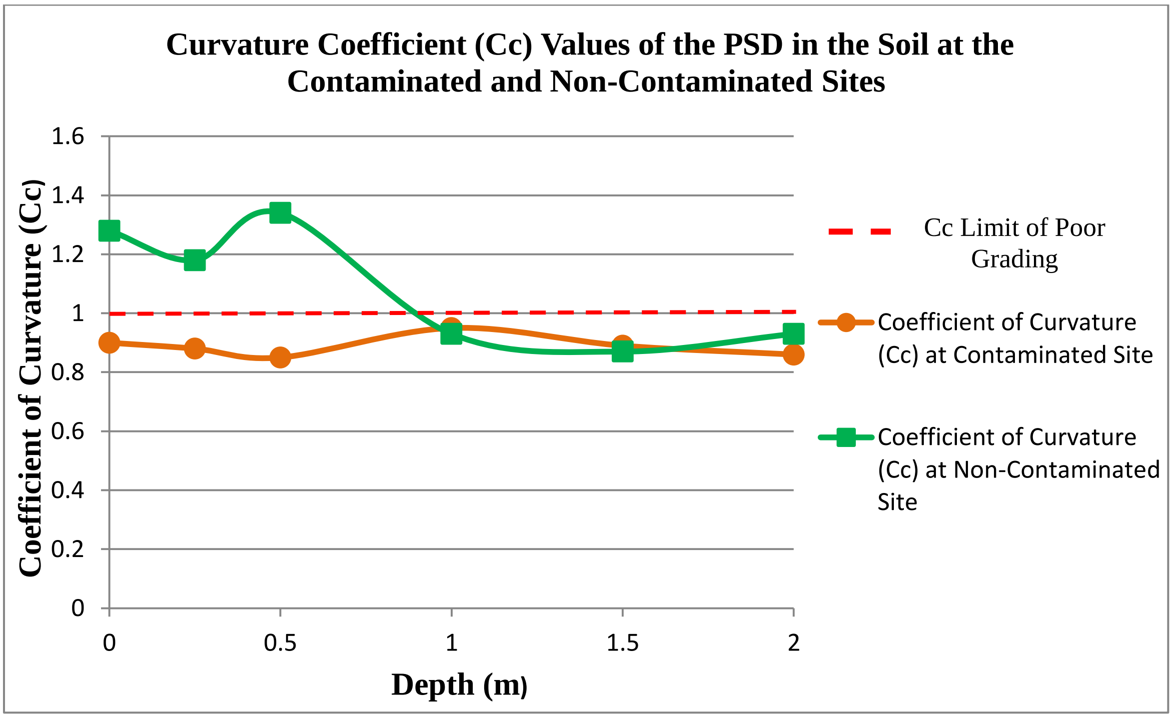


Figure 5.5. Cc values of PSD in the soil for contaminated (brown colour) and non-contaminated (green colour) samples at six different depths of 0.0 m, 0.25 m, 0.5 m, 1.0 m, 1.5 m and 2.0 m.

5.3.2 Statistical Summary of PSD

Figure 5.6 and 5.7 display the outliers percentage values existing in the silty clay, fine sand, medium sand, coarse sand, gravel and exact soil, passing sieve No. #230 data. The normality of the data was then examined using the Shapiro Wilk Test of Normality after outliers were deleted from the dataset. The assumption of normality was largely met, with <50 % of skewed distributions; this is considered acceptable for performing parametric statistical tests to only silty clay, fine sand, medium sand, coarse sand, and exact soil, passing sieve No.#230 data. However, the assumption of normality was violated for gravel % data at both sites (Tables B.5.13 and B.5.14).

Table 5.3 and figures (5.8 and 5.9) show the independent samples T-Test and Mann Whitney U Test results concerning the mean and median percentage values, respectively, of each soil constituent at each depth of the contaminated site as compared with its counterpart in the non-contaminated site (Tables B.5.15 and B.5.16). The T-Test analysis revealed that there were significant differences in the mean percentages values of the following constituents:

-**Fine sand %** ((at depth 0.5 m, t(21) = 7.28, *p*= 0.001), (at depth 1.0 m, t(14) = 4.36, *p*= 0.001), (at depth 1.5 m, t(8) = 3.01, *p*= 0.016) and (at depth 2.0 m, t(8) = 6.12, *p*= 0.001)),

-**Medium sand %** ((at depth 0.0 m, t(10) = -5.04, *p*= 0.001), (at depth 0.25 m, t(11) = -2.78, *p*= 0.01), (at depth 0.5 m, t(23) = -5.93, *p*= 0.001), (at depth 1.0 m, t(24) = -6.84, *p*= 0.001), (at depth 1.5 m, t(24) = -6.33, *p*= 0.001) and (at depth 2.0 m, t(23) = -8.89, *p*= 0.001)).

-**Coarse sand %** ((at depth 0.0 m, t(25) = -2.59, *p*= 0.01), (at depth 1.0 m, t(22) = -4.18, *p*= 0.001) and (at depth 1.5 m, t(10) = -2.57, *p*= 0.02)).

-Exact soil passing sieve No. #230 ((at depth 0.0 m, t(23) = 3.70, *p*= 0.001) and (at depth 0.25 m, t(18) = 3.28, *p*= 0.004)).

However, there were no significant differences between the sites in mean percentage values of the following constituents:

-Silty clay % (at each of the six different depths).

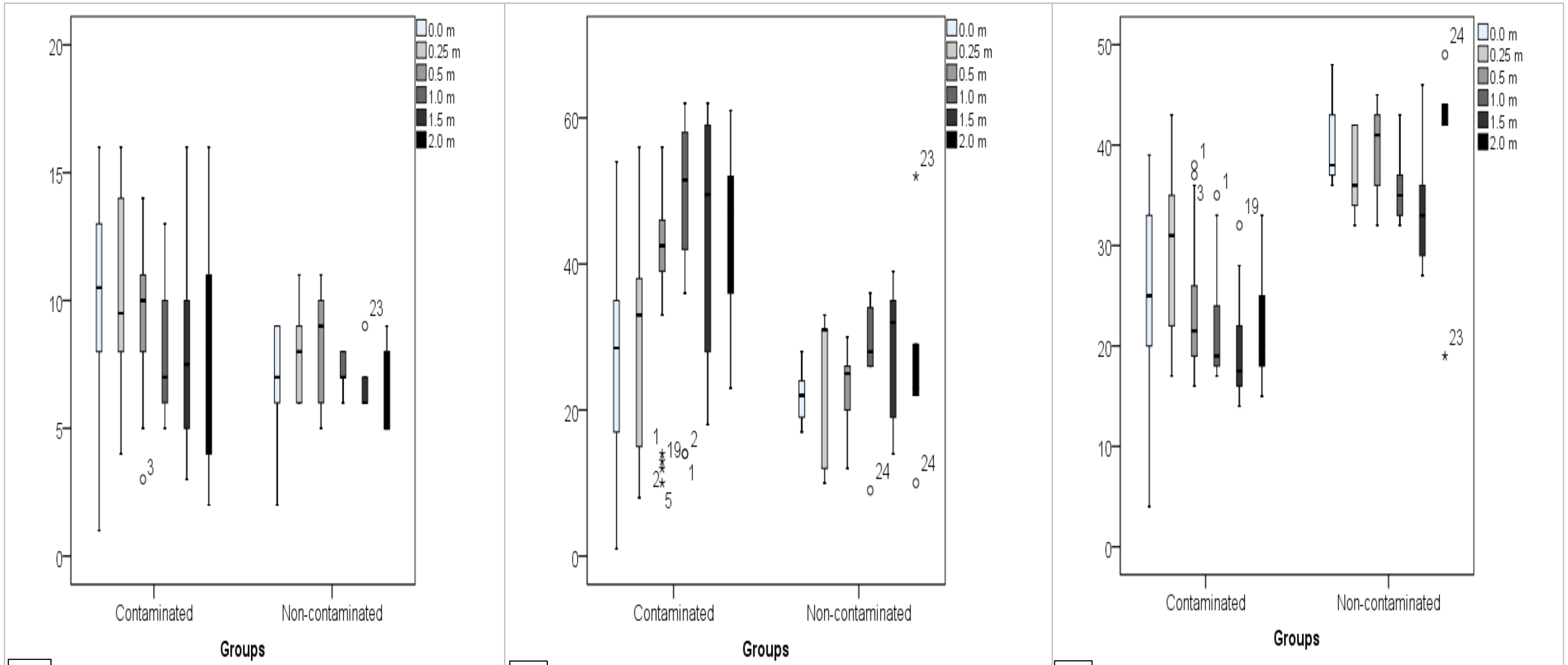
-Fine sand % (at 0.0 m and 0.25 m).

-Coarse % (at 0.25 m, 0.5 m and 2.0 m).

-Exact soil passing sieve No. #230 (at 0.5 m, 1.0 m, 1.5 m and 2.0 m).

A non-parametric Mann Whitney U test showed significant differences in the median values of gravel between the sites at depth of only 0.0 m (Z= -2.06, U= 20.00, *p*= 0.04) and 0.25 m (Z= -2.24, U= 12.00, *p*= 0.03). Nevertheless, no significant differences were found at depths of 0.5 m, 1.0 m, 1.5 m and 2.0 m.

These above results indicate that the hydrocarbon contamination has a significant effect on the general PSD of soil which confirms the explanation in the previous section (5.3.1).

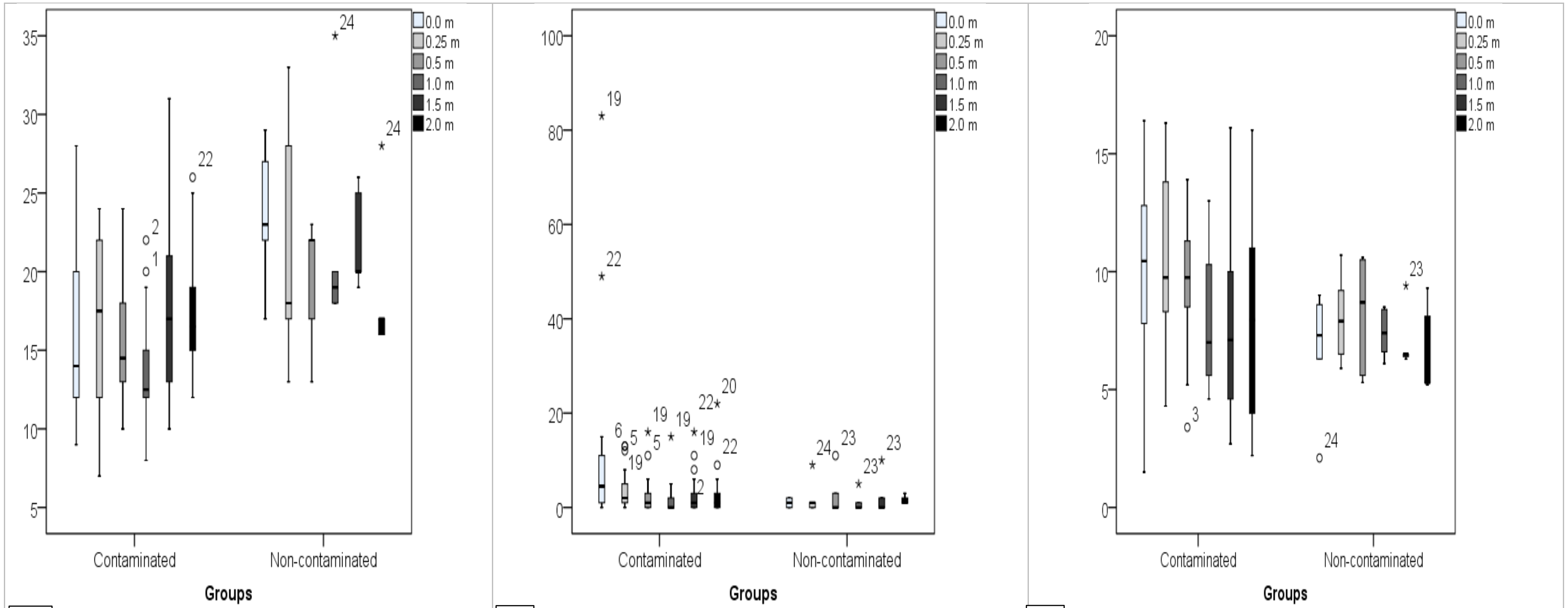


A *Silty Clay % values*

B *Fine Sand % values*

C *Medium Sand % values*

Figure 5.6. Boxplots of silty/clay % (A), fine sand % (B) and medium sand % (C) percentages values at six different depths for both contaminated site and non-contaminated site. (*Note: the symbol of "*" and "°" in the graph denotes outlier*).



A *Coarse Sand % values*

B *Gravel % values*

C *Exact Soil- passing No. #230 % values*

Figure 5.7. Boxplots of coarse sand % (A), grave % (B) and exact soil-passing No. #230 % (C) percentages values at six different depths for both contaminated site and non-contaminated site. (*Note: the symbol of "*" and "°" in the graph denotes outlier*).

Table 5.3. Indicates the significant differences of soil classification constituents at six different depths between contaminated and non-contaminated sites. ***(Note: outlier values were deleted in this table).***

Depth (m)	Variable	Site Name	N	Mean	Median	SD	Min	Max	Z	U	t-value	*p*-value
0.0 m	***Silty/Clay%***	*Conta.***	22	9.86	10.50	4.09	1.00	16.00	------	------	2.09	0.06
		*Non-conta****	5	6.60	7.00	2.88	2.00	9.00				
	Fine Sand%	*Conta.***	22	27.41	28.50	13.49	1.00	54.00	------	------	1.56	0.13
		*Non-conta****	5	22.00	22.00	4.30	17.00	28.00				
	Medium Sand%	*Conta.***	22	25.82	25.00	8.51	4.00	39.00	------	------	-5.04	0.001*
		*Non-conta****	5	40.4	38.00	5.03	36.00	48.00				
	Coarse Sand%	*Conta.***	22	16.18	14.00	5.96	9.00	28.00	------	------	-2.59	0.01*
		*Non-conta****	5	23.60	23.00	4.67	17.00	29.00				
	Gravel%	*Conta.***	22	5.45	4.00	4.97	0.00	15.00	-2.06	20.00	------	0.04*
		*Non-conta****	5	1.00	1.00	1.00	0.00	2.00				
	Exact soil passing No. #230	*Conta.***	22	10.00	10.45	4.11	1.50	16.40	------	------	3.70	0.001*
		*Non-conta****	5	7.80	7.95	1.23	6.30	9.00				
0.25 m	***Silty/Clay%***	*Conta.***	22	10.41	9.50	3.54	4.00	16.00	------	------	1.98	0.07
		*Non-conta****	5	8.00	8.00	2.12	6.00	11.00				
	Fine Sand%	*Conta.***	22	29.14	33.00	14.31	8.00	56.00	------	------	0.96	0.36
		*Non-conta****	5	23.40	31.00	11.37	10.00	33.00				
	Medium Sand%	*Conta.***	22	29.64	31.00	8.32	17.00	43.00	------	------	-2.78	0.01*
		*Non-conta****	5	37.2	36.00	4.60	32.00	42.00				
	Coarse Sand%	*Conta.***	22	16.82	17.50	5.32	7.00	24.00	------	------	-1.70	0.10*
		*Non-conta****	5	21.80	18.00	8.35	13.00	33.00				
	Gravel%	*Conta.***	22	2.31	1.00	2.05	0.00	8.00	-2.24	12.00	------	0.03*
		*Non-conta****	5	0.50	0.50	0.57	0.00	1.00				
	Exact soil passing No. #230	*Conta.***	22	9.82	9.75	2.09	5.20	13.90	------	------	3.28	0.004*
		*Non-conta****	5	8.14	7.90	2.57	5.30	10.60				
0.5 m	***Silty/Clay%***	*Conta.***	22	9.85	10.00	2.03	5.00	14.00	------	------	1.56	0.13
		*Non-conta****	5	8.20	9.00	2.59	5.00	11.00				
	Fine Sand%	*Conta.***	22	44.83	44	5.81	33	56	------	------	7.28	0.001*
		*Non-conta****	5	22.60	25	6.91	12	30				
	Medium Sand%	*Conta.***	22	22.70	21.00	5.68	16.00	36.00	------	------	-5.93	0.001*
		*Non-conta****	5	39.40	41.00	5.32	32.00	45.00				
	Coarse Sand%	*Conta.***	22	15.64	14.50	4.22	10.00	24.00	------	------	-1.79	0.08
		*Non-conta****	5	19.40	22.00	4.28	13.00	23.00				
	Gravel%	*Conta.***	22	1.50	1.00	1.73	0.00	6.00	-1.05	27	------	0.34
		*Non-conta****	5	0.75	0.00	1.50	0.00	3.00				
	Exact soil passing No. #230	*Conta.***	22	9.82	9.90	2.09	5.20	13.90	------	------	0.88	0.41
		*Non-conta****	5	8.14	8.70	2.57	5.30	10.60				

Note: *p < .05 indicates to the significant difference in the variables between two different groups.
***** Contaminated site.***
****** Non-contaminated site.***

Table 5.3. Continued.

Depth (m)	Variable	Site Name	N	Mean	Median	SD	Min	Max	Z	U	t-value	*p*-value
1.0 m	***Silty/Clay%***	*Conta.***	22	7.91	7.00	2.76	5.00	13.00	------	------	1.01	0.32
		*Non-conta****	5	7.20	7.00	0.83	6.00	8.00				
	Fine Sand%	*Conta.***	22	47.63	51.00	13.62	14.00	62.00	------	------	4.36	0.001*
		*Non-conta****	5	31.00	31.00	4.76	26.00	36.00				
	Medium Sand%	*Conta.***	22	20.62	19.00	4.54	17.00	33.00	------	------	-6.84	0.001*
		*Non-conta****	5	36.00	35.00	4.35	32.00	43.00				
	Coarse Sand%	*Conta.***	22	13.00	12.00	2.67	8.00	19.00	------	------	-4.18	0.001*
		*Non-conta****	5	18.75	18.50	0.95	18.00	20				
	Gravel%	*Conta.***	22	0.95	0.00	1.62	0.00	5.00	-0.58	35.50	------	0.64
		*Non-conta****	5	0.25	0.00	0.50	0.00	1.00				
	Exact soil passing No. #230	*Conta.***	22	7.87	7.00	2.86	4.60	13.00	------	------	1.61	0.12
		*Non-conta****	5	7.40	7.40	1.07	6.10	8.50				
1.5 m	***Silty/Clay%***	*Conta.***	22	7.82	7.50	3.94	3.00	16.00	------	------	1.79	0.08
		*Non-conta****	5	6.25	6.00	0.50	6.00	7.00				
	Fine Sand%	*Conta.***	22	45.27	49.50	15.17	18.00	62.00	------	------	3.01	0.01*
		*Non-conta****	5	27.80	32.00	10.76	14.00	39.00				
	Medium Sand%	*Conta.***	22	18.85	17.00	4.16	14.00	28.00	------	------	-6.33	0.001*
		*Non-conta****	5	34.20	33.00	7.46	27.00	46.00				
	Coarse Sand%	*Conta.***	22	17.23	17.00	5.42	10.00	31.00	------	------	-2.57	0.02*
		*Non-conta****	5	22.00	20.00	3.24	19.00	26.00				
	Gravel%	*Conta.***	22	1.26	1.00	1.91	0.00	6.00	0.00	47.50	------	1.0
		*Non-conta****	5	0.50	0.00	1.00	0.00	2.00				
	Exact soil passing No. #230	*Conta.***	22	7.79	7.10	4.00	2.70	16.10	------	------	-0.89	0.38
		*Non-conta****	5	6.42	6.45	0.09	6.30	6.50				
2.0 m	***Silty/Clay%***	*Conta.***	22	7.73	8.00	3.89	2.00	16.00	------	------	1.10	0.29
		*Non-conta****	5	6.40	5.00	1.95	5.00	9.00				
	Fine Sand%	*Conta.***	22	44.50	47.00	11.19	23.00	61.00	------	------	6.12	0.001*
		*Non-conta****	5	24.66	23.00	3.78	22.00	29.00				
	Medium Sand%	*Conta.***	22	20.86	20.00	4.28	15.00	33.00	------	------	-8.89	0.001*
		*Non-conta****	5	43.33	44.00	1.15	42.00	44.00				
	Coarse Sand%	*Conta.***	22	16.66	16.00	2.92	12.00	25.00	------	------	-0.23	0.81
		*Non-conta****	5	16.50	16.50	0.57	16.00	17.00				
	Gravel%	*Conta.***	22	1.35	1.00	1.69	0.00	6.00	-1.11	34.50	------	0.30
		*Non-conta****	5	1.60	1.00	0.89	1.00	3.00				
	Exact soil passing No. #230	*Conta.***	22	7.85	7.95	4.04	2.20	16.00	------	------	-0.31	0.65
		*Non-conta****	5	6.64	5.30	1.93	5.20	9.30				

Note: *p < .05 indicates to the significant difference in the variables between two different groups.
***** Contaminated site.***
****** Non-contaminated site.***

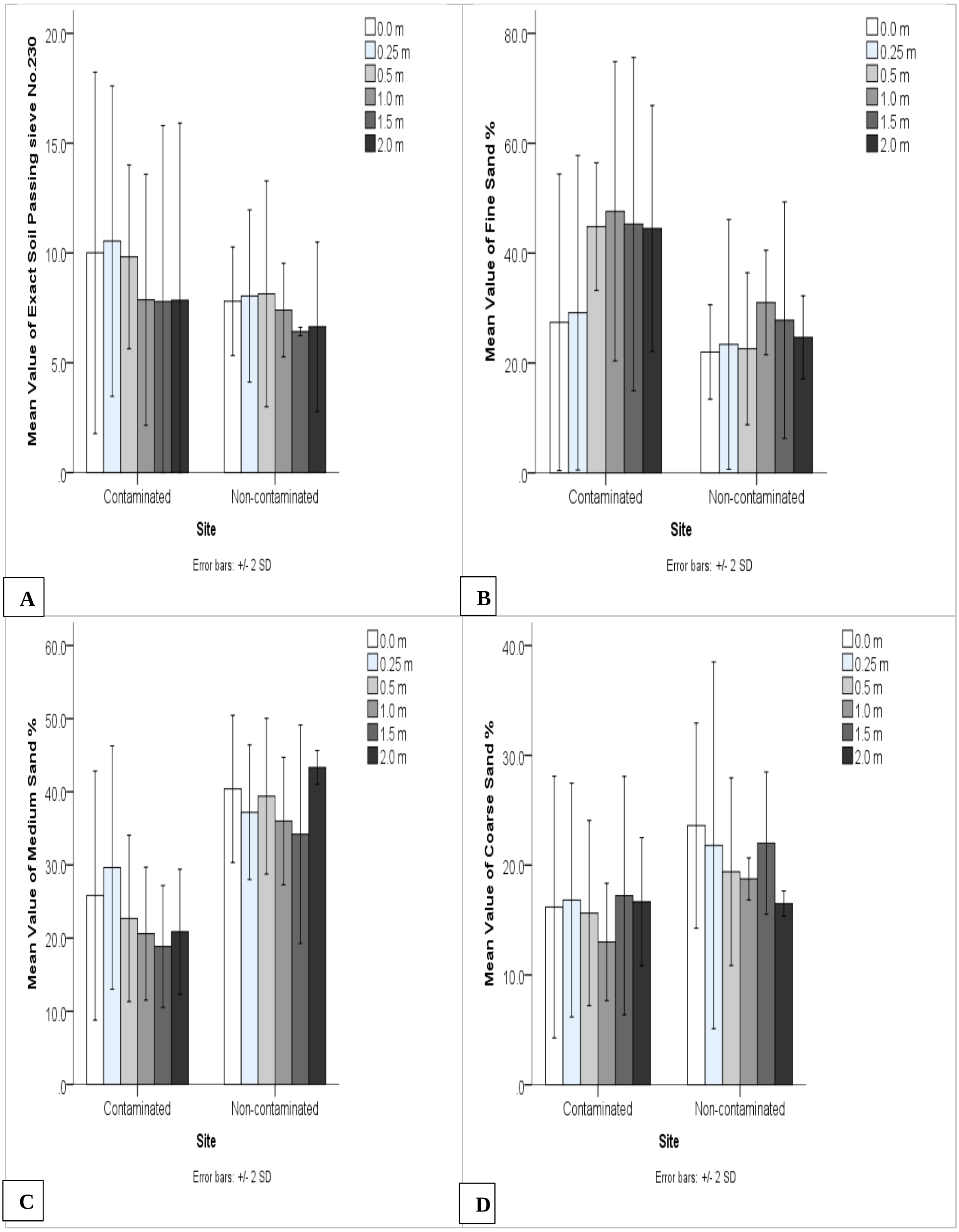


Figure 5.8. Comparing mean percentage values of exact soil passing sieve No. #230 (A), fine sand (B), medium sand (C) and Coarse Sand (D) at six different depths (in metres) between contaminated and non-contaminated sites. ***(Note: Error bars denote standard deviation).***

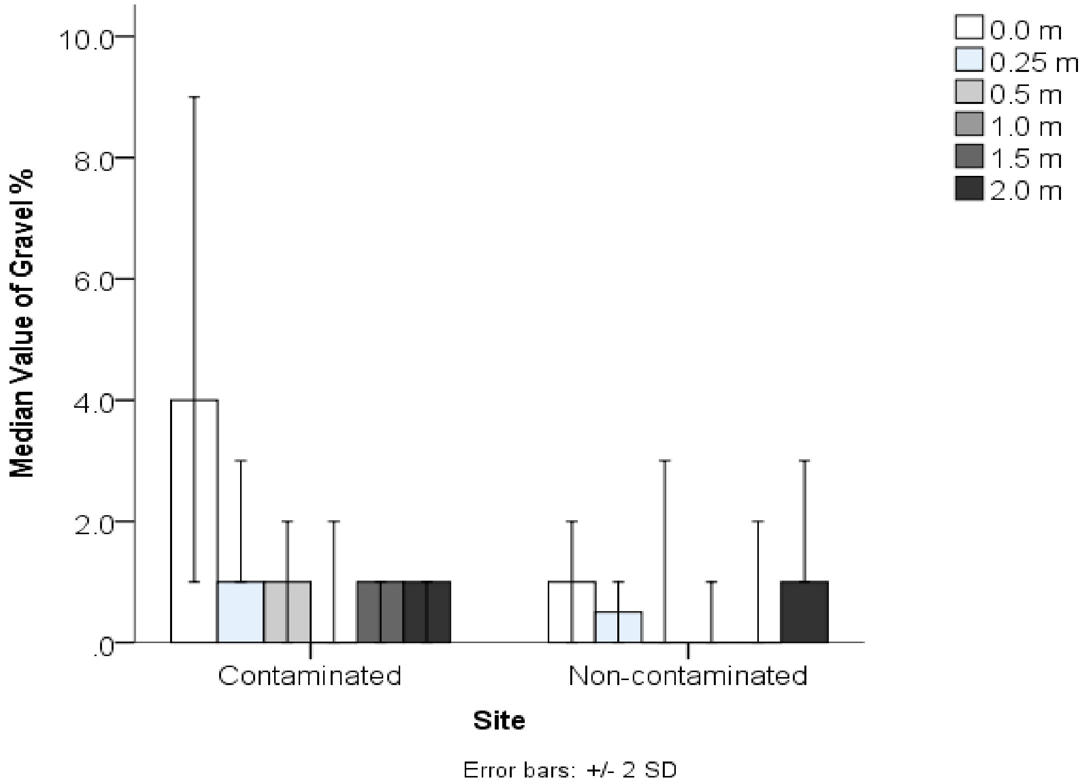


Figure 5.9. Comparing median percentage values of gravel at six different depths (in metres) between contaminated and non-contaminated sites. ***(Note: Error bars denote 95 % lower and upper confidence intervals).***

As the T-Test results showed some consistent significant results more than four different depths for the medium sand variable at many different depths, a further statistics linear regression analysis was performed to determine whether the depth predicts medium sand (at T.P.C (50 m. 50 m)), at each contaminated and non-contaminated sites.

The linear regression results shown that the depth does predict medium sand % (B= -7.36, SEB= 4.18, Beta= -0.66, *p*= 0.15) in contaminated site. Hence, there is no relationship between the depth and medium sand %. Nevertheless, there was a significant relationship between medium sand % and depth (B= -11.11, SEB= 2.41, Beta= -0.91, *p*= 0.01) at non-contaminated site. This outcome signifies that for every 1 meter increase in depth, medium sand percent decreased by 11.11 degrees, and vice versa. The R Square value of 0.84 point out that depth accounted for approximately 84.1 % of the variation in medium sand in the non-contaminated site (Figure 5.10).

These finding indicates that a significant change has been taken place in the percentage of medium sand of original soil with depth due to hydrocarbon contamination.

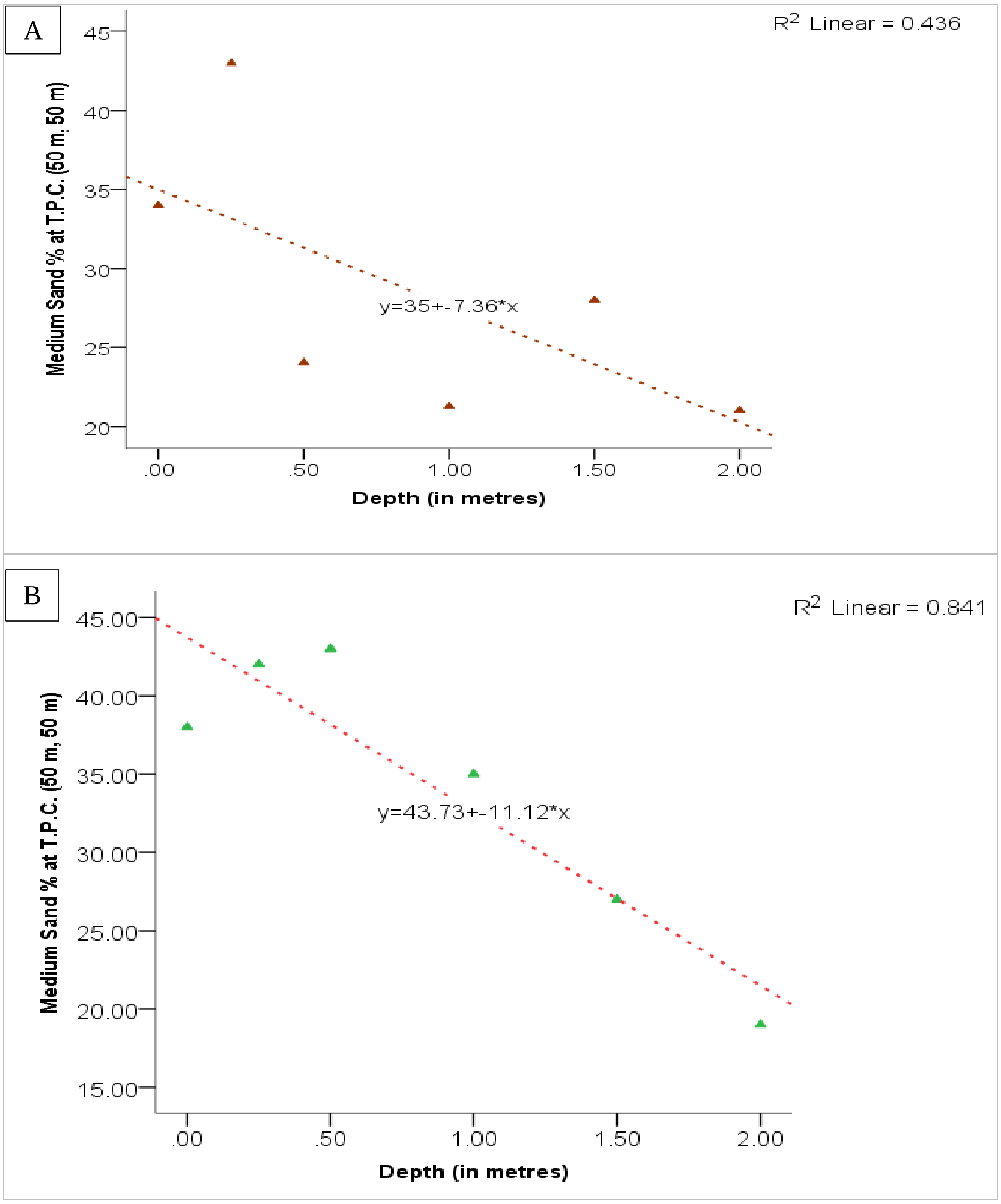


Figure 5.10. Scatterplot of relationship between six different depths and medium sand % values of T.P.C. (50 m, 50 m) at contaminated site (A), and non-contaminated site (B).

Outlier testing was carried out individually for Cu and Cc data and the outlier values were deleted prior to analysis (Figure 5.11). Following this the normality of the Cu and Cc data were assessed using the Shapiro-Wilk test of normality. The Cc data at both sites met the assumption of normality for parametric statistics; however the Cu data violated the normality assumption, therefore non-parametric statistics were performed on the Cu data (Tables B.5.17 and B.5.18).

Tables 5.4 and Figures 5.12 & 5.13 below show the significant difference in the median values of Cu and mean values of Cc in the soil at six different depths between both site (Table B.5.19). The Mann Whitney U and independent samples T-Test were conducted for Cu and Cc data, respectively. For Cu data, the Mann Whitney U analysis revealed that there were significant differences in median values of Cu between contaminated and non-contaminated sites at only depths 0.0 m (Z= -2.03, U= 4.00 , *p*= 0.05) and 0.25 m (Z= -2.15, U= 5.00, *p*= 0.04). However, this did not achieve significant difference level at other depths, i.e. 0.5 m, 1.0 m, 1.5 m and 2.0 m. In terms of Cc data, the independent T-Test analysis revealed that there were significant differences in the mean values of Cc between the two different sites at depths of 0.0 m (t(21) = -3.93, *p*= 0.01), 0.25 m (t(25) = -0.82, *p*= 0.04) and 2.0 m (t(8) = -3.06, *p*= 0.01). Nevertheless, it did not reach significant difference level at depths 0.5 m, 1.0 m, 1.5 m and 2.0 m.

The above results (i.e. of Cu and Cc) signify that high contamination leads to a significantly poorer PSD particularly at the high contamination depth from 0.0 m to 0.5 m. This phenomenon was generally decreased with depth proving lower contamination at lower depths.

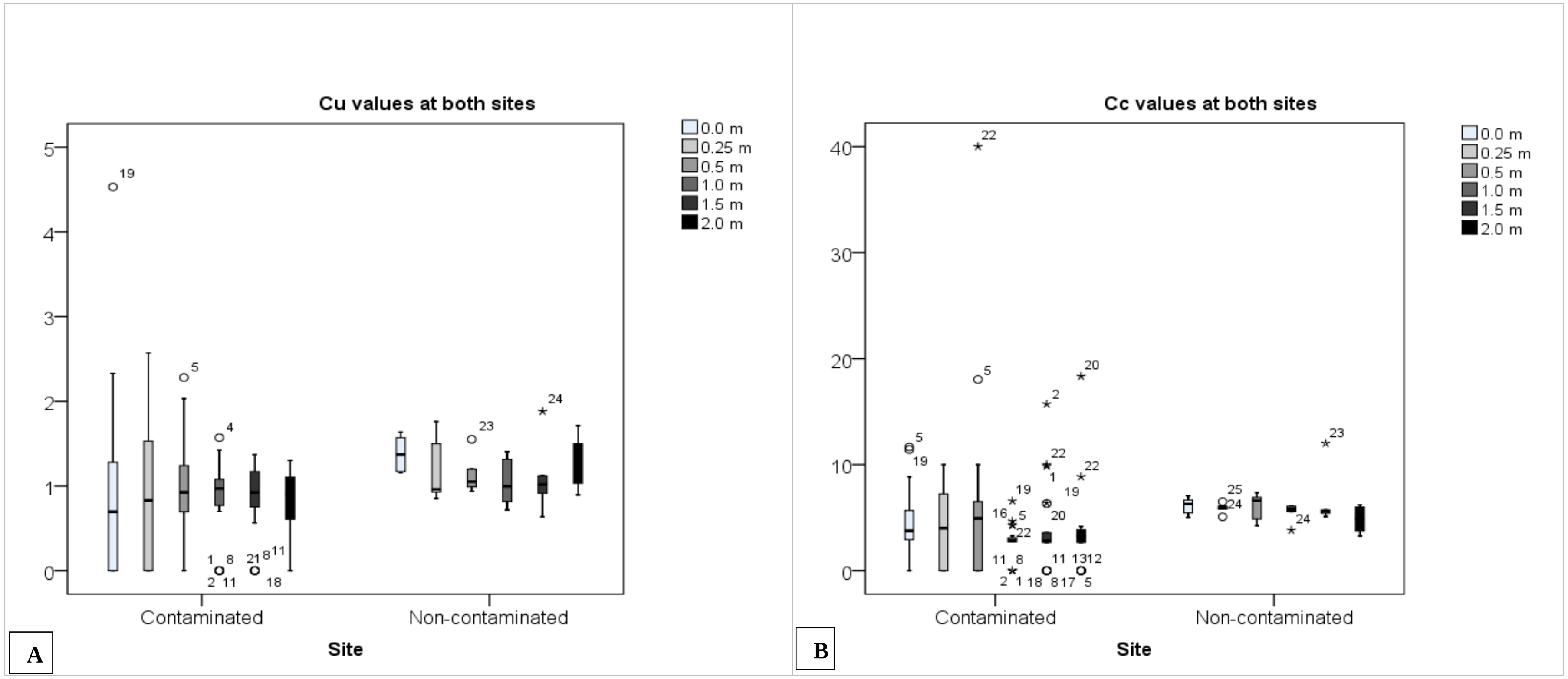


Figure 5.11. Boxplots of uniformity coefficient (Cu) (A) and curvature coefficient (Cc) (B) values at six different depths for contaminated site and non-contaminated site. (*Note: the symbol of "*" and "°" in the graph denotes outlier*).

Table 5.4. The significant differences of the Cu and Cc variables in the soil at six different depths between contaminated and non-contaminated sites. *(Note: outlier vales were deleted in this table).*

Depth (m)	Variable	Site Name	N	Mean	Median	SD	Min	Max	*Z*	*U*	*t*-value	*p*-value
0.0	**Cu**	***Contaminated***	22	4.35	3.74	3.23	0.00	11.6	-2.03	4.00	----	0.05*
		Non-contaminated	5	6.09	6.29	0.84	5.00	7.05				
	Cc	***Contaminated***	22	0.69	0.69	0.68	0.00	2.33	----	----	-3.93	0.01*
		Non-contaminated	5	1.38	1.37	0.22	1.16	1.64				
0.25	**Cu**	***Contaminated***	22	3.99	4.00	3.60	0.00	10.00	-2.15	5.00	----	0.04*
		Non-contaminated	5	5.88	6.00	0.51	5.08	6.50				
	Cc	***Contaminated***	22	0.84	0.78	0.87	0.00	2.57	----	----	-0.82	0.04*
		Non-contaminated	5	1.20	0.96	0.40	0.85	1.76				
0.5	**Cu**	***Contaminated***	22	6.07	4.92	8.83	0.00	40.00	-0.79	11.00	----	0.53
		Non-contaminated	5	6.00	6.61	1.35	4.25	7.36				
	Cc	***Contaminated***	22	0.81	0.87	0.55	0.00	2.03	----	----	-1.61	0.12
		Non-contaminated	5	1.14	1.05	0.24	0.94	1.55				
1.0	**Cu**	***Contaminated***	22	2.74	2.85	1.60	0.00	6.57	-0.18	14.00	----	0.93
		Non-contaminated	5	5.47	5.79	0.95	3.81	6.12				
	Cc	***Contaminated***	22	0.77	0.97	0.43	0.00	1.19	----	----	-1.65	0.13
		Non-contaminated	5	1.04	0.99	0.30	0.72	1.40				
1.5	**Cu**	***Contaminated***	22	3.90	2.80	3.77	0.00	15.71	-0.96	7.50	----	0.35
		Non-contaminated	5	6.77	5.63	2.93	5.10	12.00				
	Cc	***Contaminated***	22	0.78	0.90	0.46	0.00	1.31	----	----	-1.26	0.21
		Non-contaminated	5	1.11	1.01	0.46	0.64	1.88				
2.0	**Cu**	***Contaminated***	22	3.56	3.28	3.86	0.00	18.33	-0.80	13.0	----	0.48
		Non-contaminated	5	4.81	4.875	1.31	3.28	6.21				
	Cc	***Contaminated***	22	0.76	0.93	0.45	0.00	1.30	----	----	-3.06	0.01*
		Non-contaminated	5	1.32	1.48	0.34	0.89	1.71				

***Note: p < .05 indicates to the significant difference in the varibales between two different groups.**

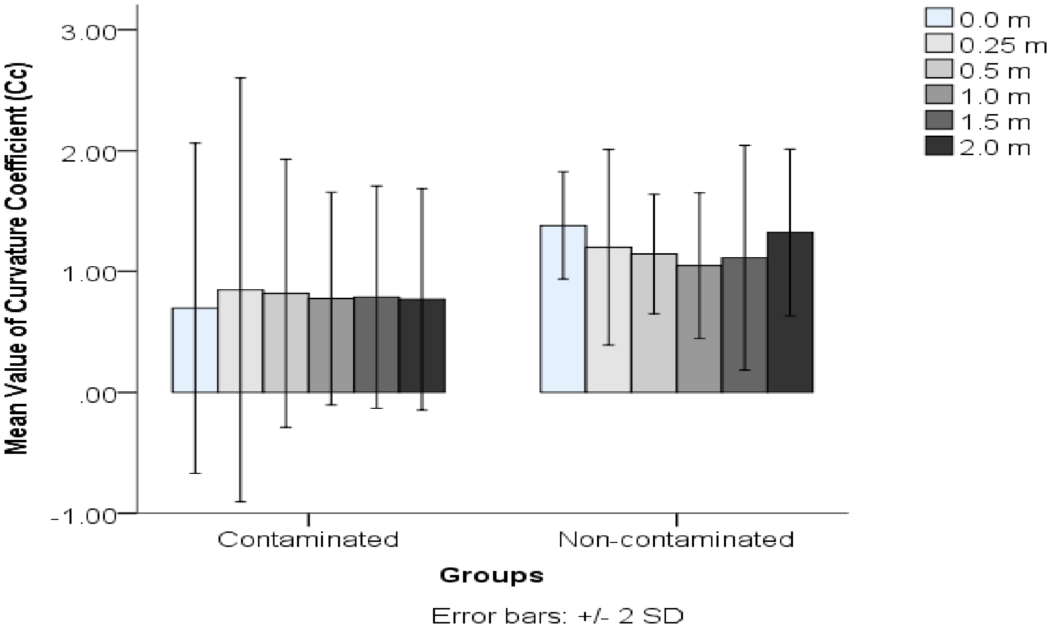


Figure 5.12. Comparing mean values of uniformity curvature (Cc) in the soil at six different depths between contaminated and non-contaminated site. ***(Note: Error bars denote standard deviation).***

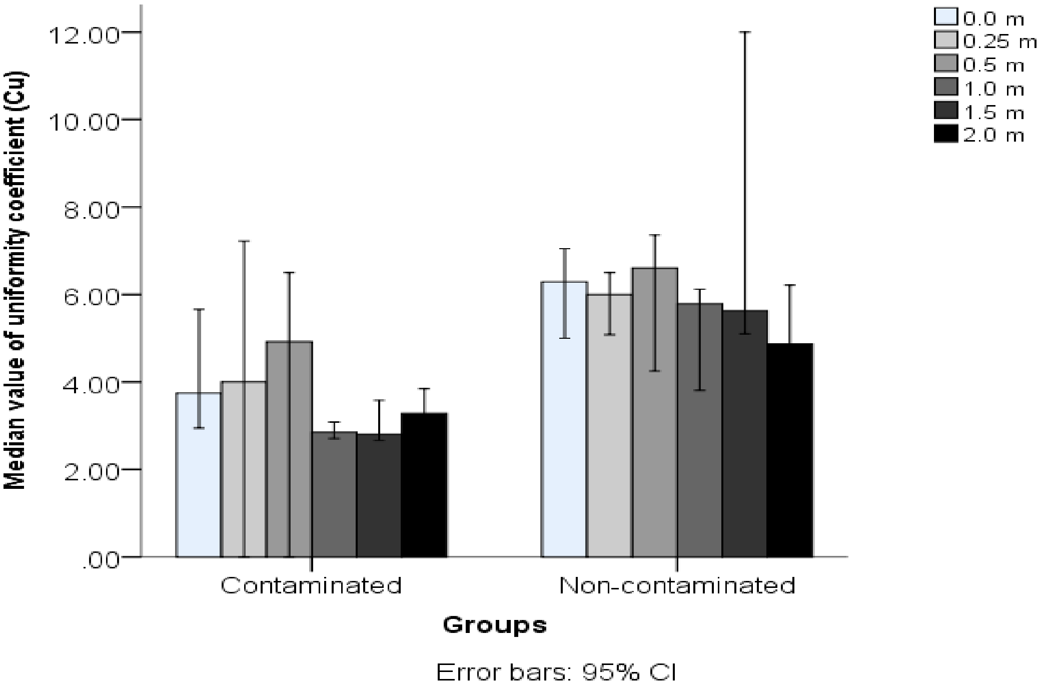


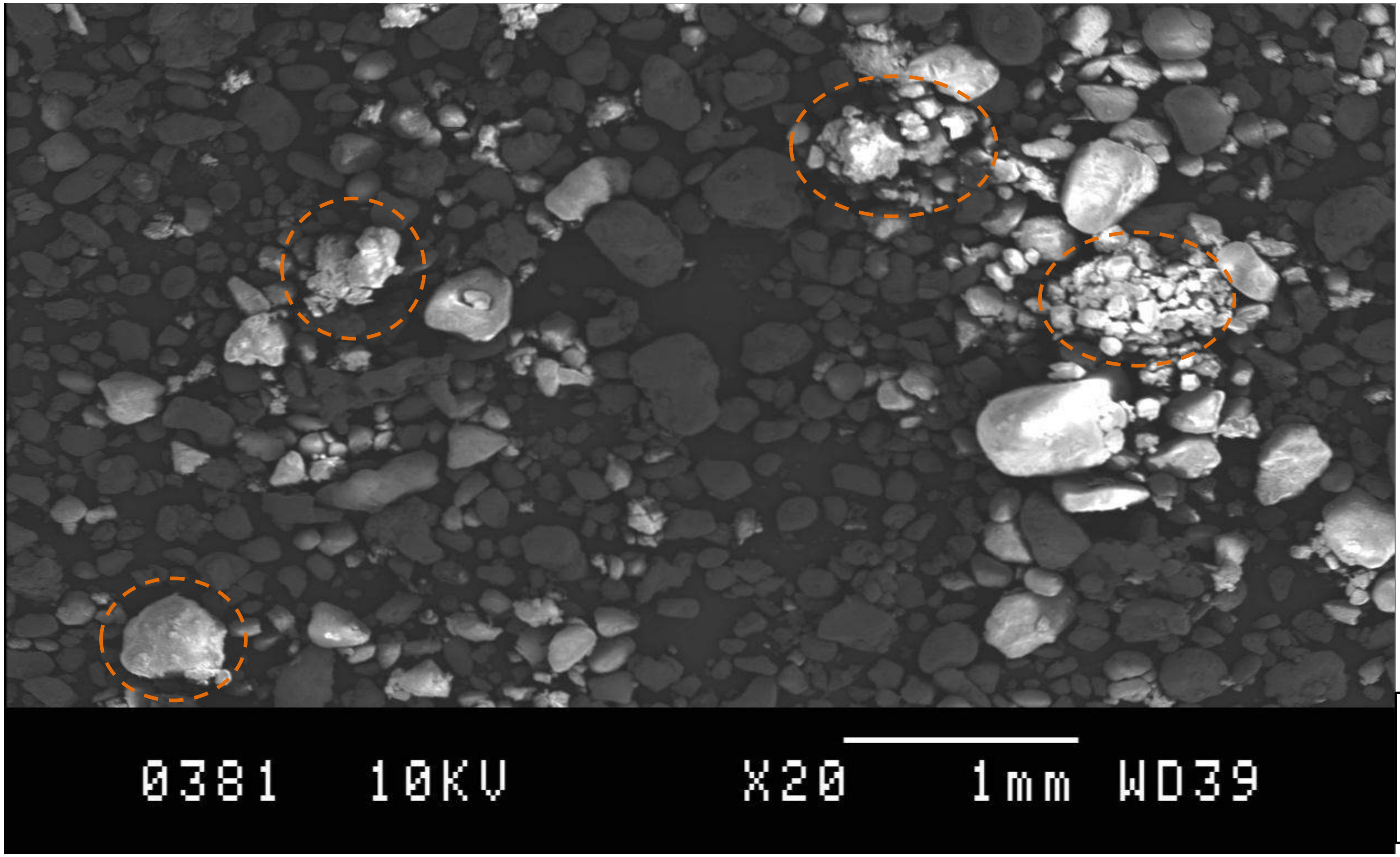
Figure 5.13. Comparing median values of uniformity coefficient (Cu) in the soil at six different depths between contaminated and non-contaminated site. ***(Note: Errors bars denote 95 % confidence interval).***

5.4 Scanning Electron Microscope (SEM)

To validate and support the PSD tests, one contaminated and one non-contaminated sample obtained from the sampling pits were subjected to further study under scanning electron microscopy (SEM). The samples were taken from the top soil and were not treated or washed prior to scanning.

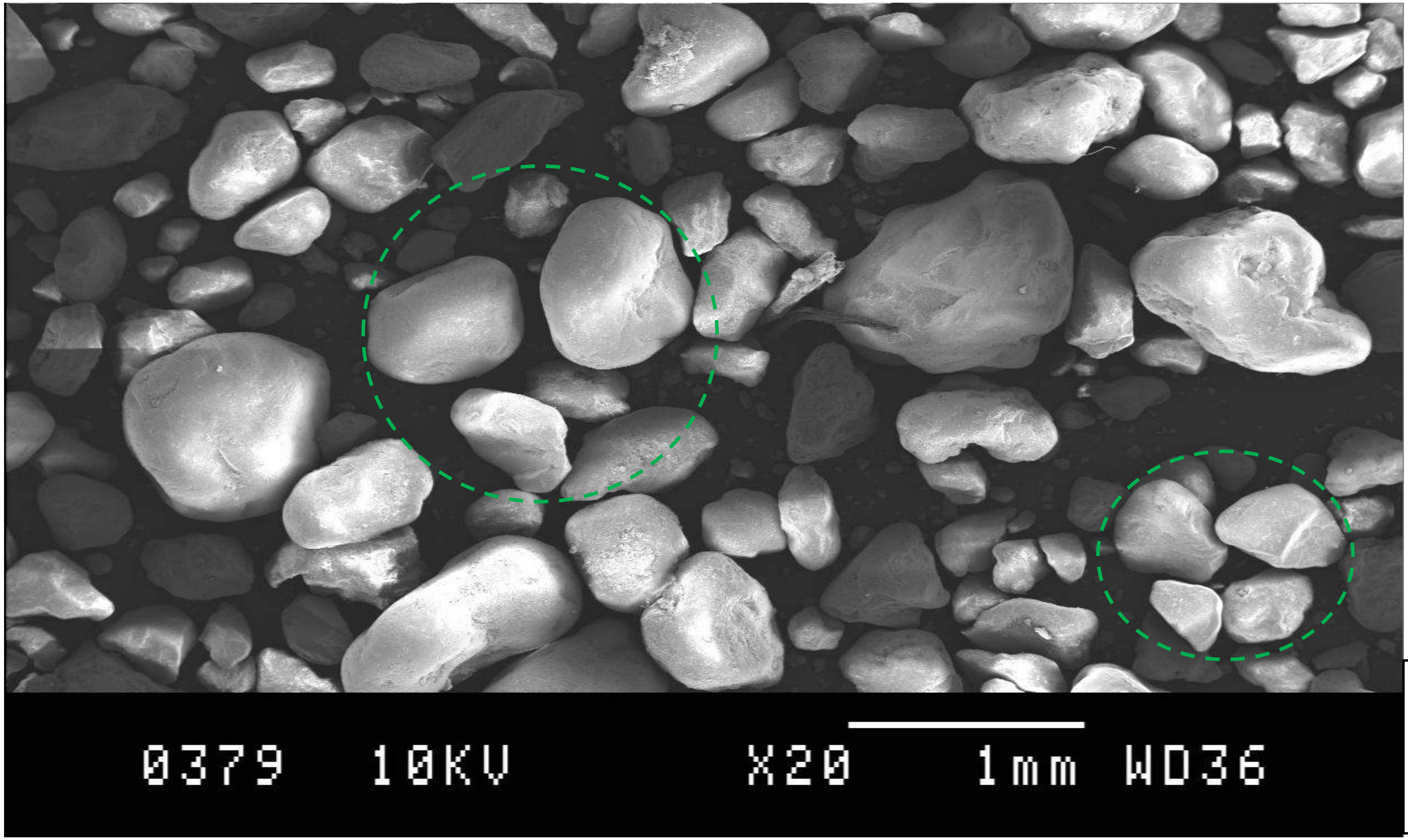
Figures 5.14 and 5.15 are photographs taken by the SEM enlarged 20 times and figure 5.16 is enlarged by 200 times. They show clear pictures of the soil grains.

From Figures 5.14 to 5.16, it is clearly observed that (as illustrated in section 5.3) some particles were binded together to form larger particles resulting in one large particle during the sieving operation. However, the very small particles resulted from the dryness of oil leaving residue or asphaltane which cannot be seen under the resolution in these photographs which was not very high.



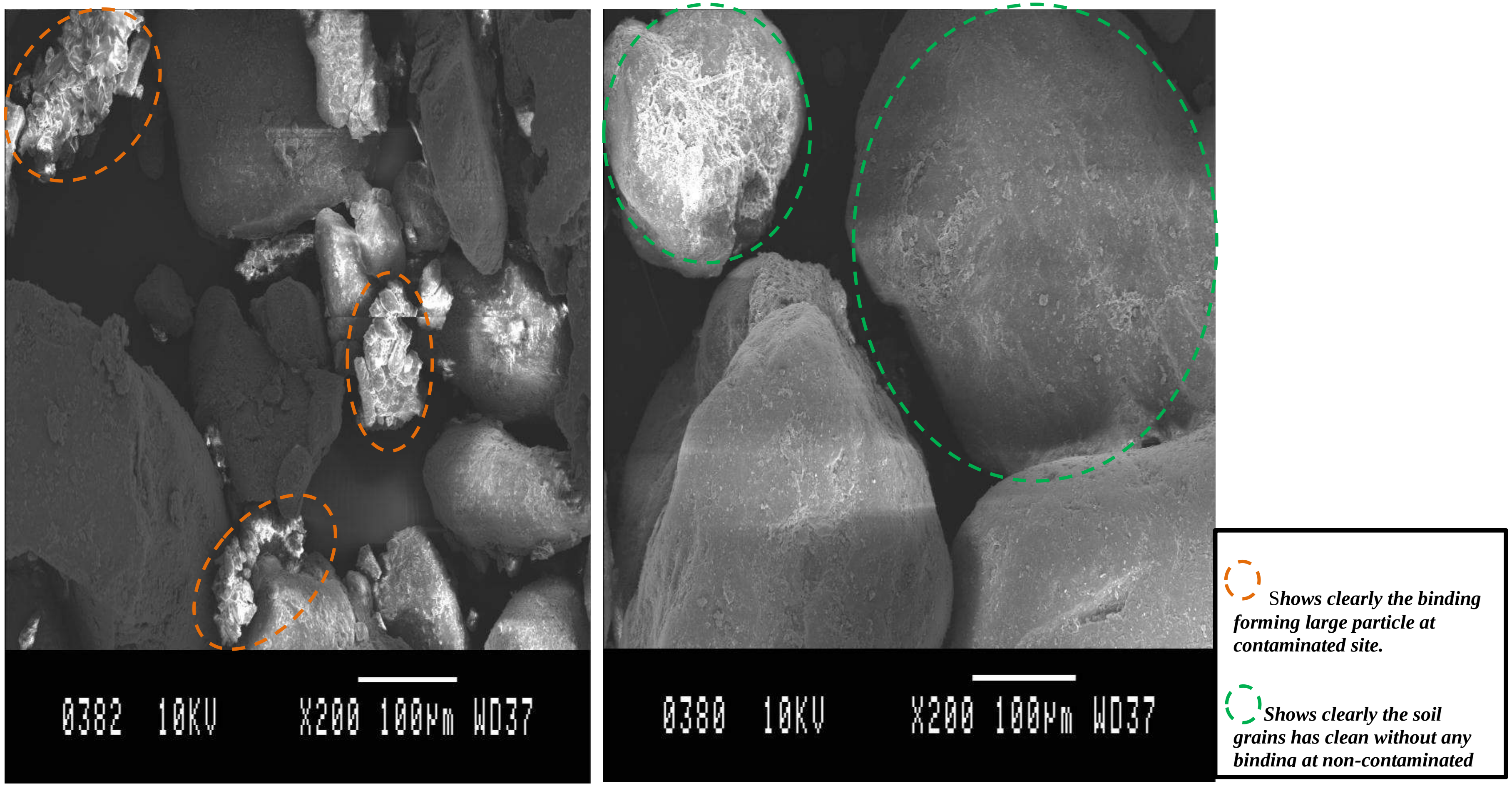
◌ *Large Particles formed from binding many particles together at contaminated site.*

Figure 5.14. A photograph enlarged by 20 times for soil sample taken from the top soil of dry *oil lake* site at T.P.C (0 m, 100 m).



◌ *Shows no binding material between particles at non-contaminated site.*

Figure 5.15. A photograph enlarged by 20 times for soil sample taken from the top soil of non-contaminated Site at T.P.C (0 m, 100 m).



Shows clearly the binding forming large particle at contaminated site.

Shows clearly the soil grains has clean without any binding at non-contaminated

Figure 5.16. A photograph enlarged by 200 times for soil particles sample taken from the top soil of contaminated (A) and non-contaminated site (B) at T.P.C (0 m, 100 m) so that show the difference between these sites.

5.5 Permeability (Hydraulic Conductivity)

5.5.1 Laboratory Results of Permeability

Table B.5.20 illustrates the results of the permeability coefficient of 24 undisturbed soil samples collected from the contaminated site (dry *oil lake*); the coefficient of permeability of the 12 undistributed soil samples obtained from the non-contaminated site are shown in Table B.5.21. The minimum, maximum, mean and standard deviation values have also been recorded in the tables for samples taken from each depth.

Table 5.5 shows the mean calculated permeability values against the depth from ground surface of samples taken from both contaminated and non-contaminated sites. Figure 5.17 represents these mean values against the depth. It should be noted that generally there is no clear difference between the permeability of the contaminated and non-contaminated soil and no clear interpretation for the change in permeability with the depth except at a depth of 0.25 m of the non-contaminated site. This odd change may be attributed to the shortage in the number of tests made on samples (only two trial pits were chosen from the non-contaminated site for this test).

Considering Hazen's Rule of approximation for permeability of soil and according to the following equation (Cedergren, 1997, p.43):

$K = C \times (D_{10})^2$, Where:

K= Permeability (hydraulic conductivity m/day).

D_{10}= the effective diameter (mm), which can be found from the PSD of soil. i.e. the diameter of sieve where 10 % of the grains pass through.

C= Constant value range from 1000 to 1500 (unit less).

Hazen's equation is justified for sands having uniformity coefficients below 5 and an effective grain size of 0.1 to 3.0 mm. The permeability was calculated based on the above equation taking an average value of C= 1250.

The results are shown in the same figure 5.17. The figure indicates that the calculated values are in the same order of measured values. However, there was not much difference between the calculated permeability of contaminated and non-contaminated soil.

Khamehchiyan *et al*. (2007), investigated the influence of crude oil on the permeability of clay and sandy soils such SP, SM and CL by mixing them with different amounts of crude oil; i.e. 2 %, 4 %, 8 %, 12 %, and 16 % by dry weigh. They have suggested that there is an inverse relationship between permeability and oil content, since there was a decrease in the coefficient of permeability when the oil content was increased. Rahman *et al*. (2010) also showed that hydrocarbon contaminated soil led to a decrease in permeability because oil clogs some inter-particle spaces. Therefore, any increase in the oil amount will decrease any available inter-particle spaces for any water leakage. Other studies on similar soil, such as Al-Sanad *et al*. (1995) and Al-Sanad and Ismael (1997) have supported the above findings.

It is important to note that the majority of these studies were conducted with a comparatively short duration of hydrocarbon contamination prior to testing as compared to more than two decades of contamination of the soil under Kuwait's hot climate in the present study. Furthermore, the interaction of hydrocarbon contamination can change the particle size distribution in the soil. More uniformly graded soil with gap grading, as in the present study, would leave more inter-particle voids, allowing higher water permeability than for a well-graded soil.

In fact, this study has found no clear correlation between hydrocarbon contamination and permeability of the soil, particularly at the top soil (from around 0.0 m to 0.5 m). However, at deeper depths, (as expected) and as shown in figure 5.17, the permeability for both sites becomes closer which infers a lower contamination, at deep depths, of the contaminated site.

Further work should be done to attain a solid conclusion. Therefore, since the rainfall in Kuwait is low and in conjunction with the hard layers below 2.00 m, hydrocarbon contamination has not been taking place in layers below 2.00 m throughout the more than two decades. There should be no worry about contaminating the ground water in the Al-Magwa area (ground water depth of more than 10.0 m).

Table 5.5. Mean value of the permeability coefficient (m/s) for contaminated and non-contaminated samples at depths (0.0 m, 0.25 m, 0.5 m, 1.0 m, 1.5 m, 2.0 m) and its results via Hazen rule approximation.

Depth (m)	Samples Classification	Mean Values of the Permeability Coefficient (m/s)	Mean Values of the Permeability Coefficient via Hazen Rule Approximation
0.0 m	*Contaminated*	2.67*	5.56*
	Non-contaminated	2.09*	8.13*
0.25 m	*Contaminated*	0.61*	5.56*
	Non-contaminated	10.5*	6.8*
0.5 m	*Contaminated*	0.48*	5.74*
	Non-contaminated	5.17*	6.68*
1.0 m	*Contaminated*	3.18*	6.30*
	Non-contaminated	2.46*	7.08*
1.5 m	*Contaminated*	3.76*	6.49*
	Non-contaminated	2.56*	7.29*
2.0 m	*Contaminated*	4.08*	6.49*
	Non-contaminated	1.27*	7.5*

Note: * it means that all the Mean values of permeability Coefficient are times x10^{-5} however it used as number in order to draw these values and the calculations via Hazen Rule Approximation in one graph.

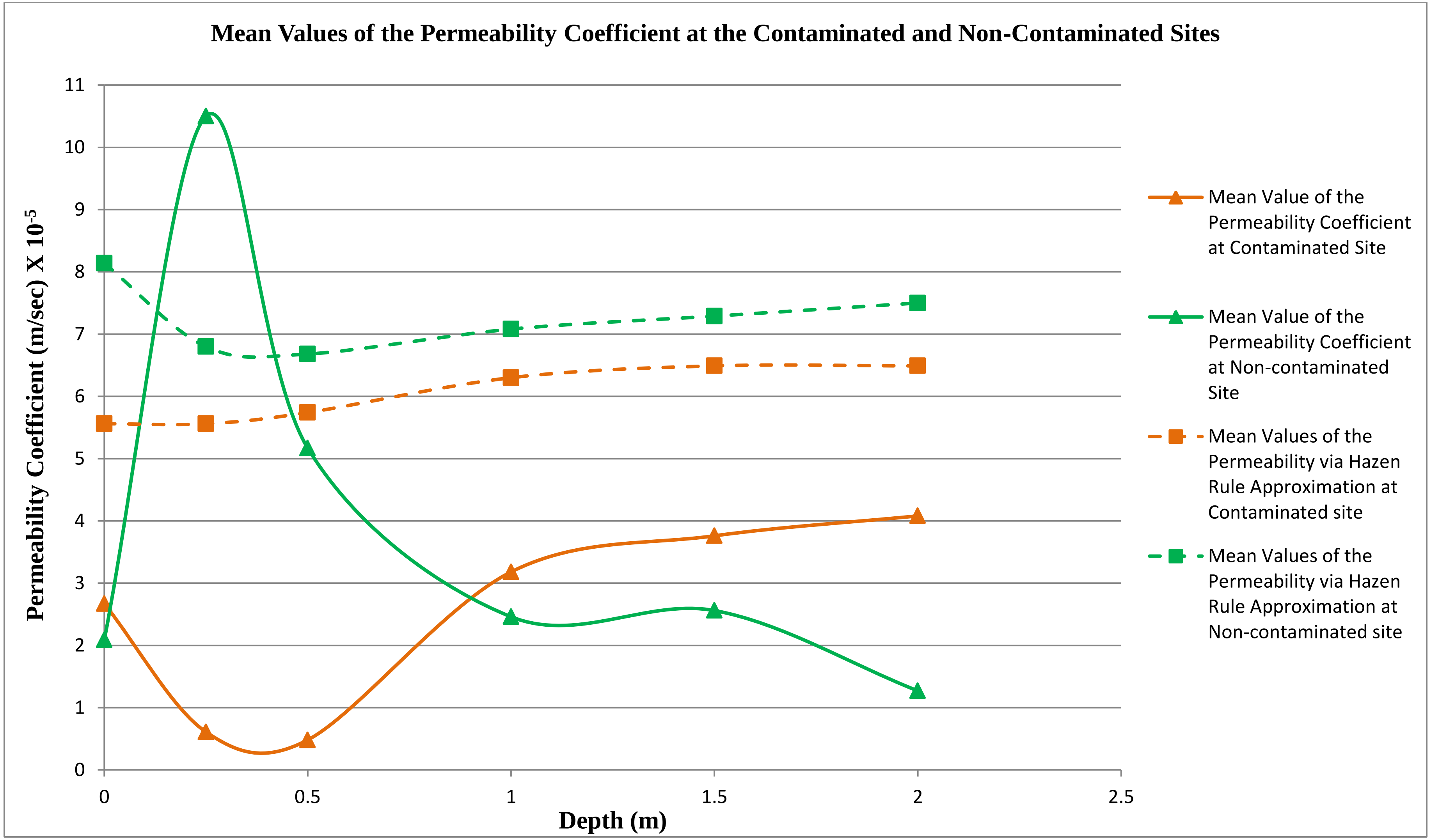


Figure 5.17. Comparison of the mean values of the permeability coefficient for contaminated and non-contaminated samples at depths (0.0 m, 0.25 m, 0.5 m, 1.0 m, 1.5 m & 2.0 m) and the permeability coefficient mean values via Hazen Rule approximation.

5.5.2 Statistical Summary of Permeability

Outliers in the permeability data were assessed and, as Figure 5.18 shows, there were no outliers (extreme values) present in the permeability data, for the contaminated and non-contaminated sites. Normality was assessed, which indicated that the contaminated data met the assumption of normality (Table B.5.22).

The independent samples T-Test (Tables 5.6 and B.5.23) revealed that there was a significant difference in the mean values of permeability coefficient (m/s) between the two sites only at the depth of 0.25 m (t(4) = -5.34, *p*= 0.006). On the other hand, no significant alteration was found at other depths, i.e. 0.0 m, 0.5 m, 1.0 m, 1.5 m and 2.0 m (Figure 5.19).

The combined effects of clogging voids in soil and changes in PSD may have great influence on the unclear contamination of permeability results of contaminated soil at the top layer. However, at deeper depths (1.0 m, 1.5 m and 2.0 m) the permeability of two soil types were approximately the same which was confirmed by statistical analysis (no significantly permeability changes due two contamination). These results are confirming similar finding that has been displays in previous section (5.5.1) and Figure 5.17.

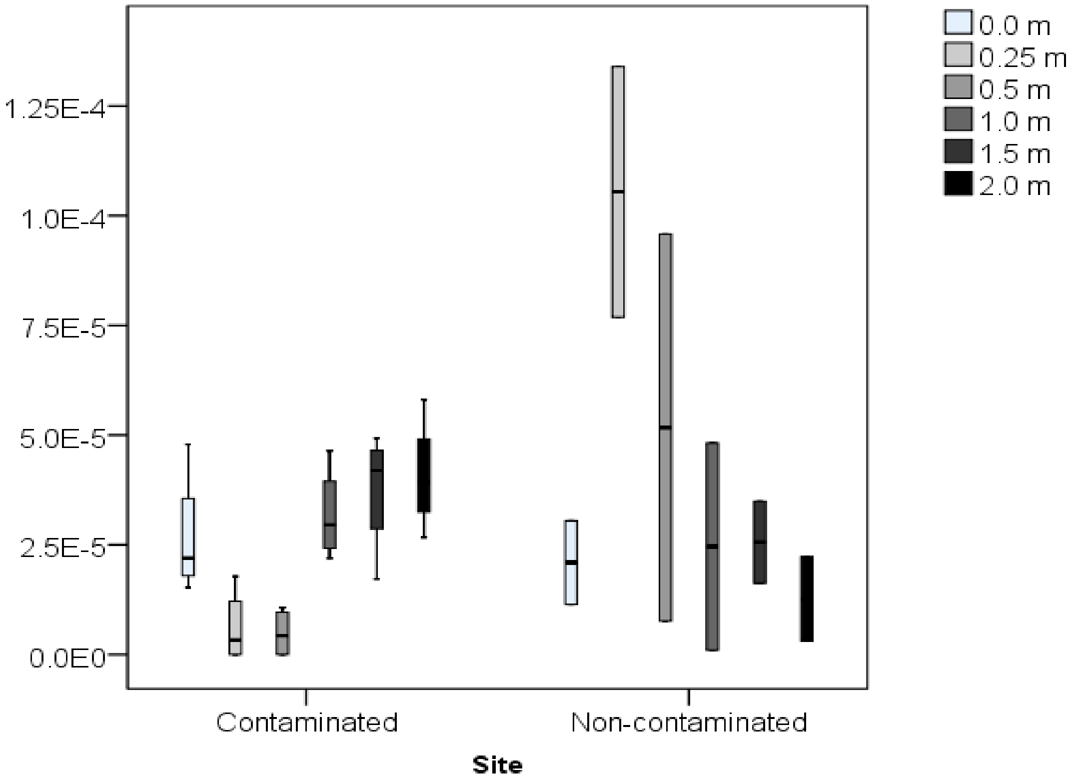


Figure 5.18. Boxplots of permeability coefficient (m/s) values in the soil at six different depths for contaminated site and non-contaminated site.

Table 5.6. The significant differences of the permeability coefficient (m/s) variable in the soil at six different depths between contaminated and non-contaminated sites.

Depth (m)	Site Name	N	Mean	SD	Min	Max	*t*-value	*p*-value
0.0	***Contaminated***	4	2.68x10^{-5}	1.44 x 10^{-5}	2.0 x 10^{-5}	5.0 x 10^{-5}	0.48	0.67
	Non-contaminated	2	2.10 x 10^{-5}	1.35x10^{-5}	1.0 x 10^{-5}	3.0 x 10^{-5}		
0.25	***Contaminated***	4	6.0x10^{-6}	8.3x10^{-6}	0	1.78 x 10^{-5}	-5.34	0.006*
	Non-contaminated	2	1.0 x10^{-4}	4.03x10^{-5}	7.69x10^{-5}	1.34x10^{-4}		
0.5	***Contaminated***	4	4.81x10^{-6}	5.6x10^{-6}	0	1.07x10^{-5}	-1.17	0.44
	Non-contaminated	2	5.1x10^{-5}	6.2x10^{-5}	7.6x10^{-6}	9.5x10^{-5}		
1.0	***Contaminated***	4	3.1x10^{-5}	1.06x10^{-5}	2.19x10^{-5}	4.64x10^{-5}	0.29	0.81
	Non-contaminated	2	2.4 x10^{-5}	3.3x10^{-5}	1.0x10^{-6}	4.82x10^{-5}		
1.5	***Contaminated***	4	3.76x10^{-5}	1.4x10^{-5}	1.72x10^{-5}	4.93x10^{-5}	1.02	0.40
	Non-contaminated	2	2.56x10^{-5}	1.3x10^{-5}	1.63x10^{-5}	3.49x10^{-5}		
2.0	***Contaminated***	4	4.0x10^{-5}	1.29x10^{-5}	2.67x10^{-5}	5.81x10^{-5}	2.47	0.06
	Non-contaminated	2	1.27x10^{-5}	1.35x10^{-5}	3.1x10^{-6}	2.23x10^{-5}		

Note, $p < .05$ indicates to the significant difference in the variable between two different groups.

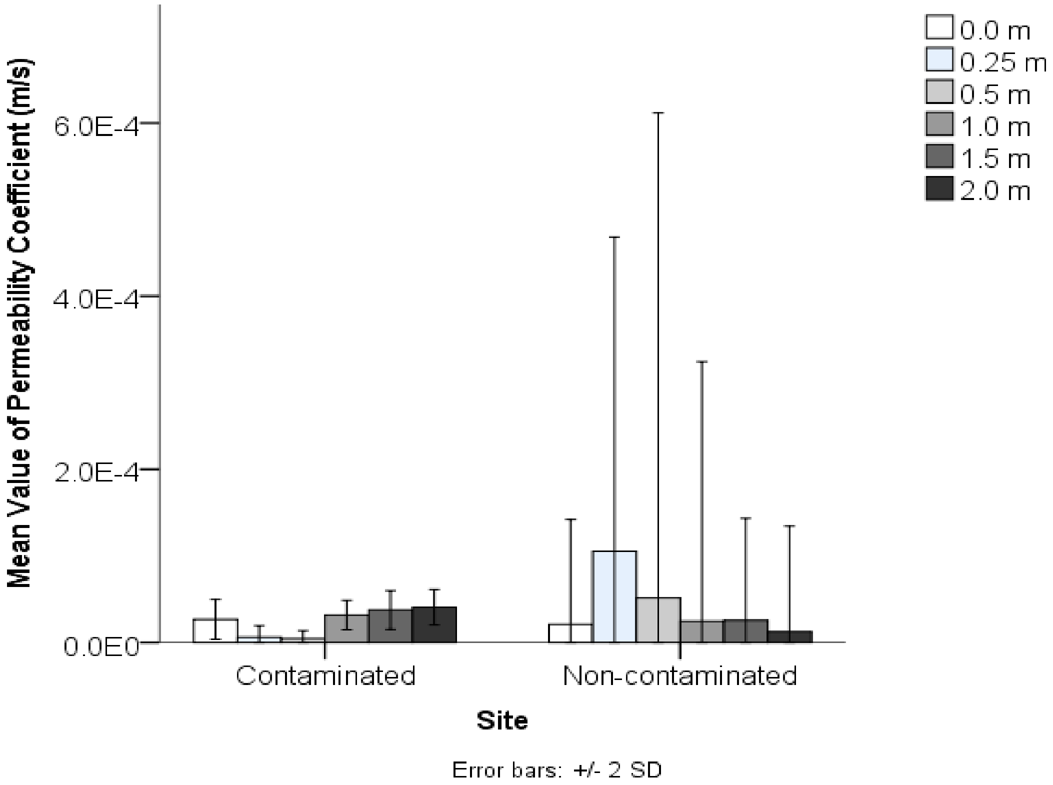


Figure 5.19. Comparing mean values of permeability coefficient (m/s) in the soil at six different depths between contaminated and non-contaminated site. ***(Note: Error bars denote standard deviation).***

5.6 Shear Strength

5.6.1 Laboratory Results of Shear Strength

Table (B.5.24) shows the results of Direct Shear strength tests on contaminated samples with hydrocarbon at different depths; the shear strength test of samples collected from control sites are shown in Table (B.5.25). The cohesion parameters (c) were zero for all the soil samples for both sites indicating that this level of hydrocarbon contamination does not generate cohesion in such types of soil. Therefore, only the angles of friction parameters (φ) were listed in the tables. The minimum, maximum, mean and standard deviation values of angle of friction parameter (φ) for samples taken from each depth were recorded in the tables. For more details, some typical shear behaviour curves (showing strain under different shear and normal stresses) are shown in figures B.5.3 to B.5.62.

Table 5.7 and figure 5.20 show the mean values of strength parameter (φ) of both contaminated and non-contaminated sites. The angle of internal friction is shown to be steadily and clearly decreased due to hydrocarbon contamination in all samples. However, the decrease due to hydrocarbon contamination was generally lowered with depths which may be consistently related to the lower soil contamination with hydrocarbon at the deeper depths.

In an experimental study by Singh *et al*. (2009), soil was mixed with different percentages of used motor oil and subjected to a shear test. The results showed that the effective angle of internal friction for poorly graded sand decreases significantly. On mixing with 9 %, the angle of friction decreased from 36.58 in the virgin state to 24.58. Shin *et al*. (1999) reported a reduction in the shear strength of sandy soil between 23 % and 27 % due to 1.3 % oil addition. The reduction was attributed to the oil coating soil grain surfaces resulting in the slipping of soil grains over each other. Al-Sanad *et al*. (1995) also conducted a test in Kuwait (Jahra Sand) by mixing it in the lab with crude oil of 2 %, 4 % and 6 %.

In agreement with the studies shown above, they showed a reduction in shear strength with an associated increase in the oil content; this reduction depended on the viscosity of the oil. However, reduction in shear strength of non-cohesive soil of the above study cannot be compared with the current study because, in the current study, the oil was dry and an increase in the viscosity between particles was not expected. In fact, it actually binds some particles leading to higher uniformity in PSD as discussed in section 5.3. The higher uniformity in PSD may thus be responsible for the lower strength in the contaminated soil of the current study.

Table 5.7. Comparing the mean values of the angle of internal friction (φ) for contaminated and non-contaminated soil samples at six different depths of 0.0 m, 0.25 m, 0.5 m, 1.0 m, 1.5 m and 2.0 m.

Depth	**Samples Classification**	**Mean Value of the Strength Parameters**
		Angle of Internal Friction (φ)
0.0 m	*Contaminated*	30.8
	Non-Contaminated	37.16
0.25 m	*Contaminated*	32
	Non-Contaminated	36
0.5 m	*Contaminated*	32.8
	Non-Contaminated	39.3
1.0 m	*Contaminated*	33
	Non-Contaminated	37.9
1.5 m	*Contaminated*	33
	Non-Contaminated	37.13
2.0 m	*Contaminated*	33.6
	Non-Contaminated	36.63

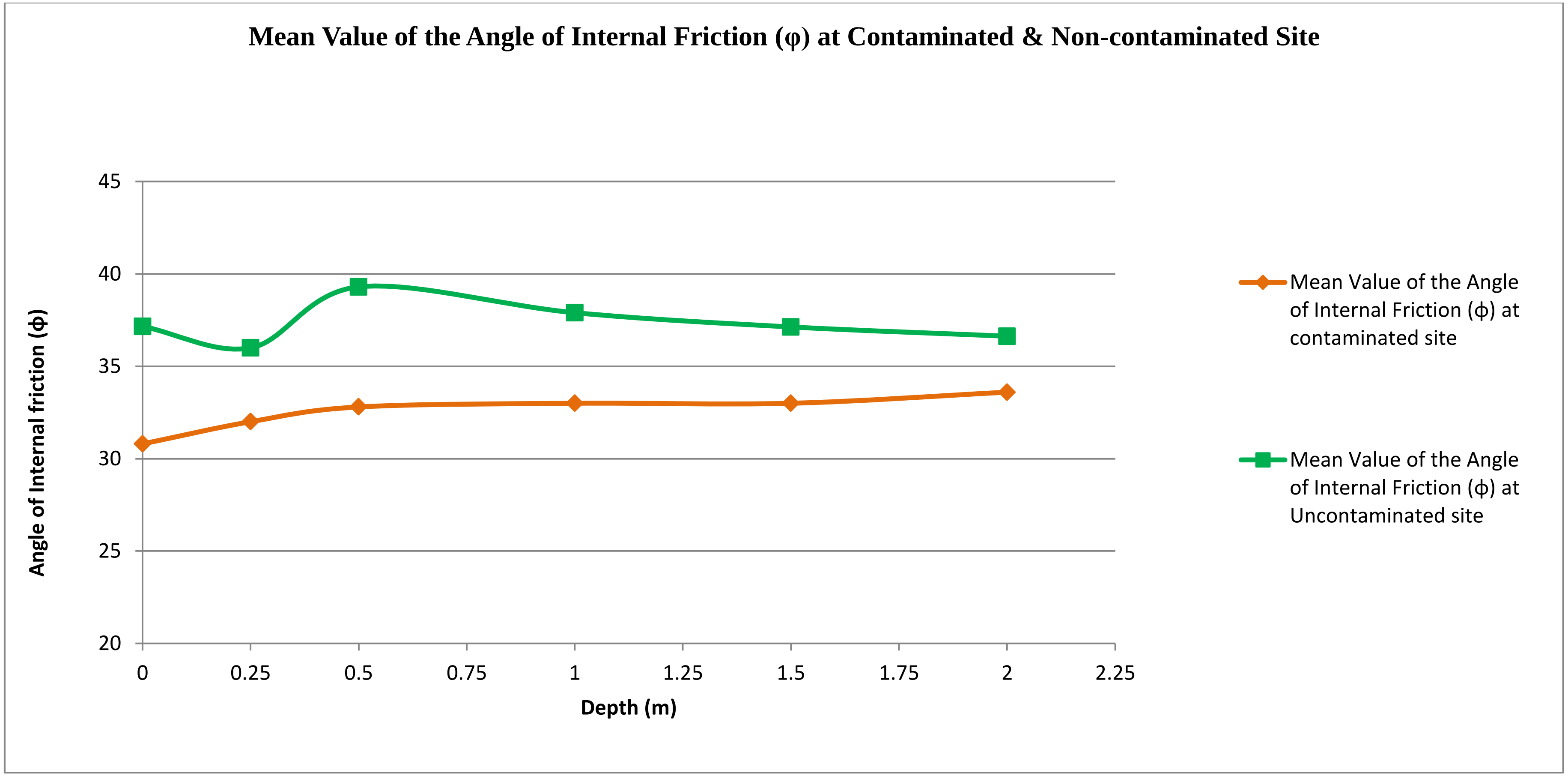


Figure 5.20. Comparing the mean values of the angle of internal friction (φ) for contaminated (brown colour) and non-contaminated (green colour) soil samples at six different depths of 0.0 m, 0.25 m, 0.5 m, 1.0 m, 1.5 m & 2.0 m.

5.6.2 Statistical Summary of Shear Strength

Figure 5.21 shows no outliers present in the angle of internal friction data. The assumption of normality was also largely met as ten of the twelve Shapiro-Wilk *p*-values were above 0.05. Therefore, parametric statistics were appropriate for the analyses. (Table B.5.26).

An independent samples T-Test found a significant difference in mean angle of internal friction (φ) values between contaminated and non-contaminated sites (Table 5.8 and B.5.27). Consistent across the six different depths, mean values were lower in the contaminated site than the non-contaminated site. The analysis revealed that there were significant differences in the mean values of angle of internal friction (φ) between both sites at depths 0.0 m (t(8) = -6.46, *p*= 0.01), 0.25 m (t(8) = -3.25, *p*= 0.01), 0.5 m (t (8) = -9.07, *p*= 0.001), 1.0 m (t (8) = -4.46, *p*= 0.02), 1.5 m (t (8) = -4.52, *p*= 0.01) and 2.0 m (t (8) = -3.08, *p*= 0.01) (Figure 5.22).

These results confirm those illustrated in section (5.6.1), i.e. that hydrocarbon contamination reduces strength.

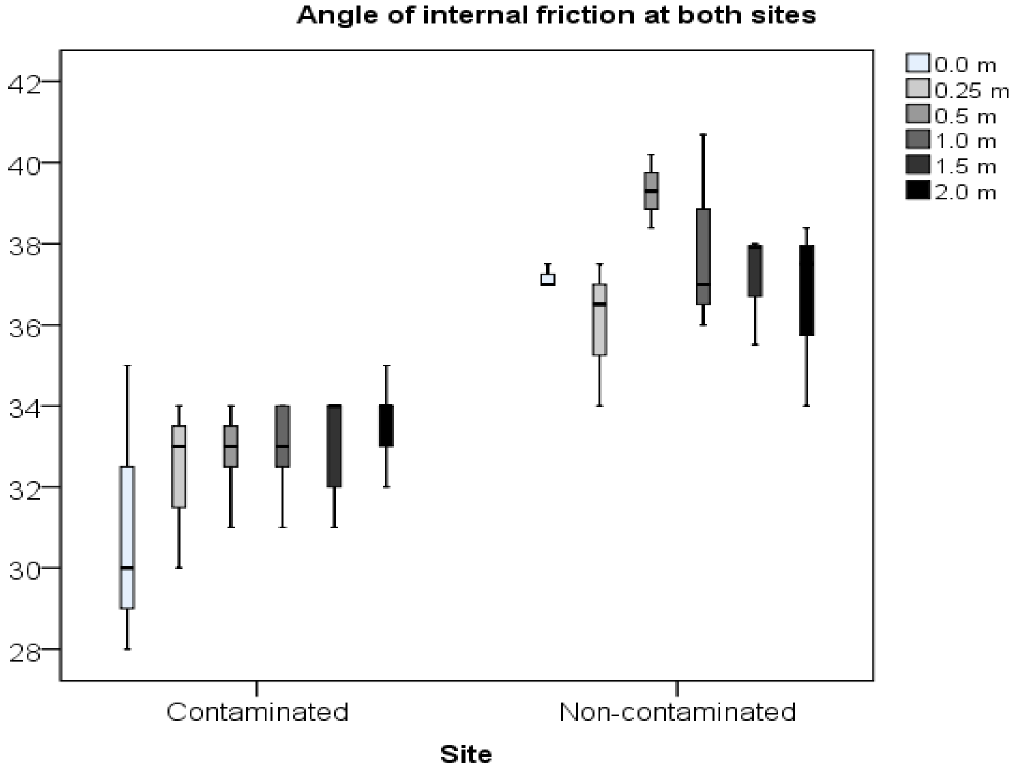


Figure 5.21. Boxplots of angle of internal friction (φ) values in the soil at six different depths for contaminated site and non-contaminated site.

Table 5.8. The significant differences of the angle of internal friction (φ) variable in the soil at six different depths between contaminated and non-contaminated sites.

Depth (m)	**Site Name**	**N**	**Mean**	**SD**	**Min**	**Max**	***t*-value**	***p*-value**
0.0	***Contaminated***	7	30.85	2.54	28	35	-6.46	0.001*
	Non-contaminated	3	37.16	.28	37	37.5		
0.25	***Contaminated***	7	32.42	1.51	30	34	-3.25	0.012*
	Non-contaminated	3	36.00	1.80	34	37.5		
0.5	***Contaminated***	7	32.85	1.06	31	34	-9.07	0.001*
	Non-contaminated	3	39.30	.90	38.4	40.2		
1.0	***Contaminated***	7	33.00	1.15	31	34	-4.46	0.002*
	Non-contaminated	3	37.90	2.47	36	40.7		
1.5	***Contaminated***	7	33.00	1.29	31	34	-4.52	0.002*
	Non-contaminated	3	37.13	1.41	35.5	38		
2.0	***Contaminated***	7	33.57	.97	32	35	-3.08	0.015*
	Non-contaminated	3	36.63	2.32	34	38.4		

Note, $p < 0.05$ indicates to the significant difference in the variable between two different groups.

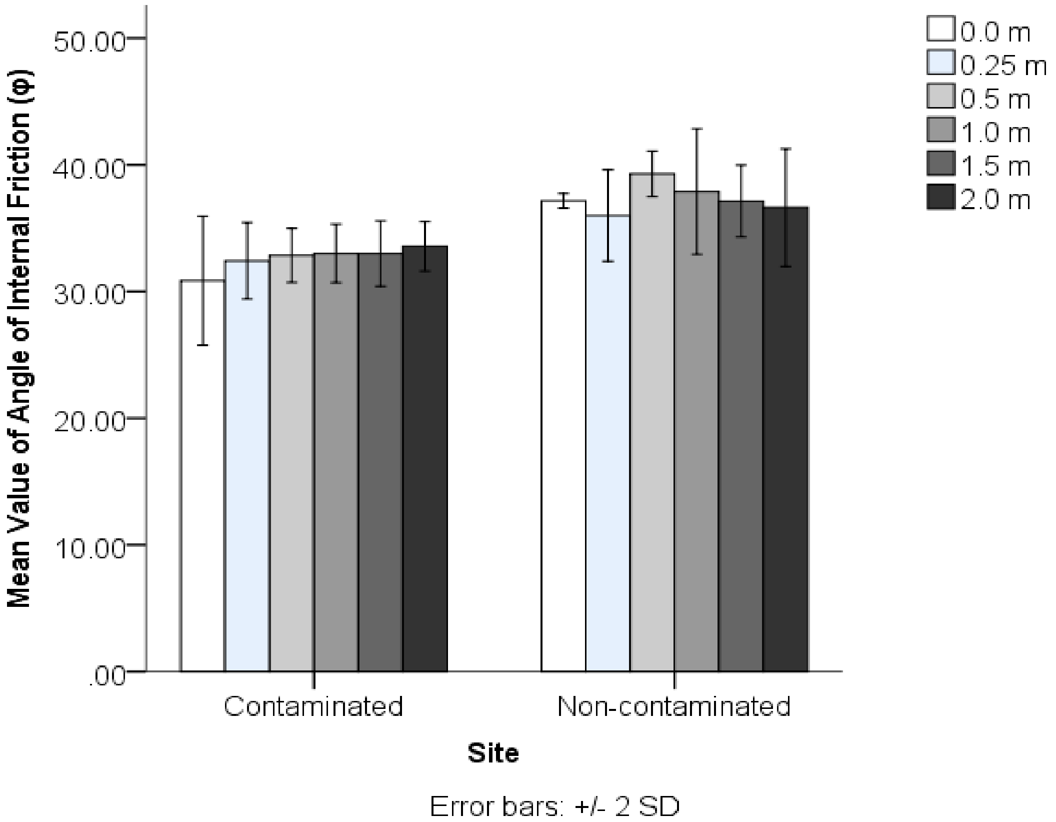


Figure 5.22. Comparing mean values of the angle of internal friction (φ) in the soil at six different depths between contaminated and non-contaminated site. ***(Note: Error bars denote standard deviation).***

As the T-Test results and figure 5.22 (above) showed significantly different results for the mean values of angle of internal friction at six different depths between the two sites, a further statistical linear regression analysis was conducted to determine whether the depth predicts angle of internal friction (φ) at T.P.C (50 m, 50 m), at each of the contaminated and non-contaminated sites.

The analysis of the contaminated site found a significant, positive relationship between the six different depth categories and the angle of internal friction (φ) values (B= 2.69, SEB= 0.84, Beta= 0.84, *p*= 0.03). The R Square value of 0.719 indicates that depth categories accounted for approximately 71.9 % of the angle of internal friction (φ) values. For every 1 meter increase in depth, the angle of internal friction increased by 2.69 degrees. On the other hand, the analysis found that there was no significant relationship between depth categories and the angle of internal friction values at the non-contaminated site (B= 0.01, SEB= 0.85, Beta= 0.007, *p*= 0.98). The R Square value of 0.000 indicates that the depth categories accounted for none (0 %) of the angle of internal friction values (Figure 5.23).

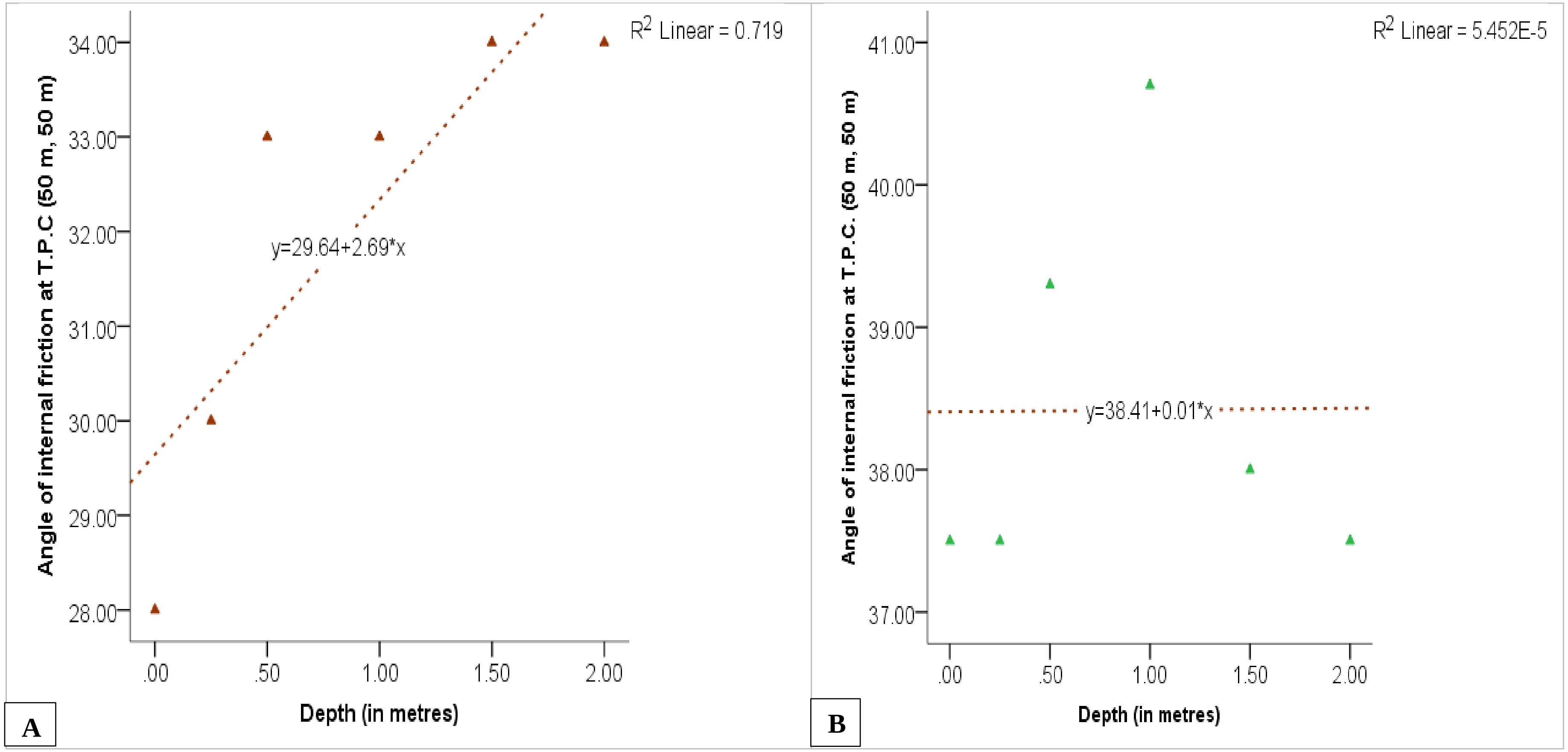


Figure 5.23. Scatterplot showing relationship between six different depth categories and angle of internal friction (φ) at T.P.C (50 m, 50 m), at contaminated site (A) and non-contaminated site (B).

5.7 Summary

This Chapter has presented the findings of the geotechnical characteristics of soil samples taken from two different locations, i.e. the contaminated (dry *oil lake*) and non-contaminated sites. All the findings of the geotechnical characterisation of soil were subjected to a statistical analysis in order to support and provide a solid conclusion. The investigated properties were plasticity, PSD, SEM, permeability coefficient (hydraulic conductivity) and shear strength. The following conclusions were drawn from this analysis:

- None of the samples showed any plastic behavior so the soil is considered to be non- plastic (in both contaminated and non-contaminated sites).

- Wide ranges were found in the gradation of soil samples taken from the same depth but from different T.P.C locations at the contaminated site, particularly in the top soil; however, it becomes narrower at lower depths. This was expected because the hydrocarbon contamination content differs from point to point in the top soil. In the non-contaminated site, it was noted that (at one depth), the gradation range between a sample taken from one T.P.C and another was smaller than in the corresponding contaminated site. The small particles (passing No.#230) and large (gravel %) percentage values of the soil classification for the samples taken from the contaminated site were slightly higher than those for samples taken from the non-contaminated site, especially from the top soil where hydrocarbon contamination was found to be higher. The statistical analysis proved that there were significant differences in the percentage values of soil classification constituents with only medium sand, coarse sand, gravel and exact soil (passing sieve No.#230) between both sites at a depth of 0.0 m. Additionally, a significant differences were found at both sites for the percentage values of fine sand (at depths 0.5 m, 1.0 m and 2.0 m) medium sand (at depths 0.25 m, 0.5 m, 1.0 m, 1.5 m and 2.0 m), coarse sand (at depths 1.0 m and 1.5 m) and gravel (at depth 0.25 m).

- In terms of the results of the Coefficient of Permeability no clear difference was found between the contaminated and non-contaminated soil and no clear change was found in the permeability with the depth except at depth 0.25 m for the non-contaminated site. A statistical analysis also confirms that there was significant difference in the mean value of permeability coefficient between the two sites at only 0.25 m depth.

- The angle of internal friction decreased due to hydrocarbon contamination in all samples. Although, this decrease was lower at deeper depths. The statistical finding ascertained that there were significant differences in the mean values of the angle of internal friction between the two sites at all six different depths of 0.0 m, 0.25 m, 0.5 m, 1.0 m, 1.5 m and 2.0 m. Furthermore, it found statistically that the angle of internal friction (φ) values increased with an increase in the depth at the contaminated site; however, it found no relationship between the angle of internal friction (φ) values and depth at the non-contaminated site.

The next chapter will investigate the changes in geochemical characteristics of soil due to hydrocarbon contamination through comparing the geochemical properties of the soil samples extracted from both contaminated and non-contaminated sites.

6. GEOCHEMICAL CHARACTERISATION

6.1 Introduction

This chapter presents the results of changes in geochemical characteristics of soil due to hydrocarbon contamination of two decades at the Greater Burgan Oil Field region (Al-Magwa area-dry *oil lake* site). Results were achieved by comparing the findings of the soil's geochemical properties extracted from both the contaminated and non-contaminated sites. These results will be discussed to demonstrate how the study aims can be achieved by correlating the findings of the experiment with the studies found in the literature. The results of the geochemical characteristics of the soil samples will also be statistically analysed in this chapter so as to support any solid findings. The results of geochemical characterisations include: pH; water soluble Cl- and (SO_3 & SO_4); (EA); and GC-MS.

Some of the test findings are presented in this chapter in the form of limited typical tables and figures, however, most of the tables and figures can be seen in appendix C.

6.2 Hydrogen Ion Concentration (pH)

6.2.1 Laboratory Results of pH

Table 6.1 displays the pH results of contaminated soil samples taken from the dry *oil lake* while the corresponding results for the non-contaminated soil samples are shown in Table 6.2. The maximum and minimum values are also shown in these tables.

Table 6.1 shows that there is a wide range between the maximum and minimum pH values of samples taken from different T.P.C. at the same depth for the hydrocarbon contaminated site as compared with the corresponding values of the non-contaminated site (Table 6.2). Table 6.3 and figure 6.1 further emphasises the range between maximum and minimum values at different depths. This wide range from the hydrocarbon contaminated site was expected and was the justification for taking more numerous testing samples from this site than those from the non-contaminated site. This was a common factor in testing greater sample numbers (for all testings in this study) from the hydrocarbon contaminated sites.

Furthermore, the table and figure show that there is a considerable decrease in the minimum values of pH due to contamination which means that contamination increased the acidity of soil which increases the difficulty for growing plants.

From Table 6.3, it can be seen that the lowest value of the pH for the contaminated soil was 7.02 through all depths which, according to the classification of Horneck *et al*. (2011), is within the limiting range of neutral soil (6.6 - 7.3) (Table 3.4). The contaminated soil is therefore considered to be still available for agricultural activities although contamination lowers its validation.

Table 6.3 shows that the pH values in the contaminated area ranges from (7.02 to 9.37). Other studies, including those of Al-Duwaisan and Al-Naseem (2011, p.441) found that the pH values range from 7.59 to 8.1. Their research was also carried out in the Burgan area.

Barua *et al*. (2011), Khuraibet and Attar (1995) and Rahman *et al*. (2007) reported an increase in acidity of hydrocarbon contamination due to the formation of toxic acids in the spilled oil. Furthermore, a study by Barua *et al*. (2011) indicated that crude oil contaminated soil is slightly more acidic in nature which may be due to the formation of toxic acids in the spilled oils.

A study of five different oil polluted sites by Khuraibet and Attar (1995) concluded that the soil was generally neutral in pH, becoming slightly more alkaline with depth, suggesting that the presence of oil may lower soil pH which could have a detrimental effect on plant growth. Additionally, Habib-ur-Rahman *et al*. (2007), investigated the pH of soil contaminated with crude oil; they found that the pH values of non-contaminated and contaminated soil were 7.605 and 7.511 respectively. They also indicated that there was a slight reduction of pH for crude oil contaminated clays, showing the acidic nature of the crude oil.

Table 6.1. pH coefficient values for the contaminated soil samples at six different depths of 0.0 m, 0.25 m, 0.5 m, 1.0 m, 1.5 m and 2.0 m.

Trial Pits Coordinates. (T.P.Cs)	**pH Value**					
	at depth (0.0 m)	**at depth (0.25 m)**	**at depth (0.5 m)**	**at depth (1.0 m)**	**at depth (1.5 m)**	**at depth (2.0 m)**
(0 m, 0 m)	7.07	7.21	7.1	7.31	7.52	7.12
(25 m, 0 m)	7.24	2.29	7.83	8.15	8.23	8.24
(50 m, 0 m)	7.12	8.24	7.75	7.93	8.12	8.34
(75 m, 0 m)	7.12	7.39	7.75	7.93	8.12	8.34
(100 m, 0 m)	7.93	8.71	9.37	8.95	8.64	8.58
(0 m, 25 m)	7.83	8.34	8.19	8.27	8.52	8.67
(25 m, 25 m)	7.42	7.39	7.57	7.98	8.12	8.43
(50 m, 25 m)	7.84	7.83	8.14	8.23	8.57	8.46
(100 m, 25 m)	7.05	7.59	7.84	8.27	8.39	8.29
(0 m, 50 m)	7.04	7.02	7.96	7.62	7.52	7.24
(25 m, 50 m)	7.59	7.84	8.36	8.28	8.43	8.29
(50 m, 50 m)	8.21	8.21	7.98	8.05	8.31	8.23
(100 m, 50 m)	7.39	7.82	7.93	8.43	8.12	8.54
(0 m, 75 m)	7.11	7.19	8.24	8.63	8.54	8.36
(25 m, 75 m)	7.45	8.09	8.02	8.36	8.14	8.26
(50 m, 75 m)	7.95	8.02	7.84	8.12	8.12	8.24
(75 m, 75 m)	7.99	8.04	8.57	8.11	8.11	8.24
(100 m, 75 m)	8.45	8.38	8.72	8.23	8.40	8.46
(0 m, 100 m)	8.69	8.14	8.43	7.95	8.57	8.42
(50 m, 100 m)	7.74	8.52	8.12	8.34	7.99	8.43
(75 m, 100 m)	7.84	7.69	8.24	8.19	8.11	8.52
(100 m, 100 m)	8.15	8.23	8.19	7.95	7.98	8.06
Min. Value	7.04	7.02	7.1	7.31	7.52	7.12
Max. Value	8.69	8.71	9.37	8.95	8.64	8.58

Table 6.2. pH coefficient values for the non-contaminated soil samples at six different depths of 0.0 m, 0.25 m, 0.5 m, 1.0 m, 1.5 m and 2.0 m.

Trial Pits Coordinates. (T.P.Cs)	pH Value					
	at depth (0.0 m)	at depth (0.25 m)	at depth (0.5 m)	at depth (1.0 m)	at depth (1.5 m)	at depth (2.0 m)
(0 m, 0 m)	7.93	7.85	8.23	8.06	8.15	8.24
(100 m, 0 m)	7.59	8.02	8.12	8.19	8.24	8.26
(50 m, 50 m)	8.12	8.04	8.19	8.24	8.27	8.24
(0 m, 100 m)	8.12	8.15	8.27	8.39	8.31	8.36
(100 m, 100 m)	7.84	7.93	8.11	8.04	8.12	8.06
Min. Value	7.59	7.85	8.11	8.04	8.12	8.06
Max. Value	8.12	8.15	8.27	8.39	8.31	8.36

Table 6.3. Minimum, maximum and range of pH values in the soil at six different depths for contaminated and non-contaminated sites.

Depth (m)	Samples Classification	pH Minimum Value	pH Maximum Value	pH Range Value
0.0 m	***Contaminated***	7.04	8.69	1.65
	Non-contaminated	7.59	8.12	0.53
0.25 m	***Contaminated***	7.02	8.71	1.69
	Non-contaminated	7.85	8.15	0.3
0.5 m	***Contaminated***	7.1	9.37	2.27
	Non-contaminated	8.11	8.27	0.16
1.0 m	***Contaminated***	7.31	8.95	1.64
	Non-contaminated	8.04	8.39	0.35
1.5 m	***Contaminated***	7.52	8.64	1.12
	Non-contaminated	8.12	8.31	0.19
2.0 m	***Contaminated***	7.12	8.58	1.55
	Non-contaminated	8.06	8.36	0.3

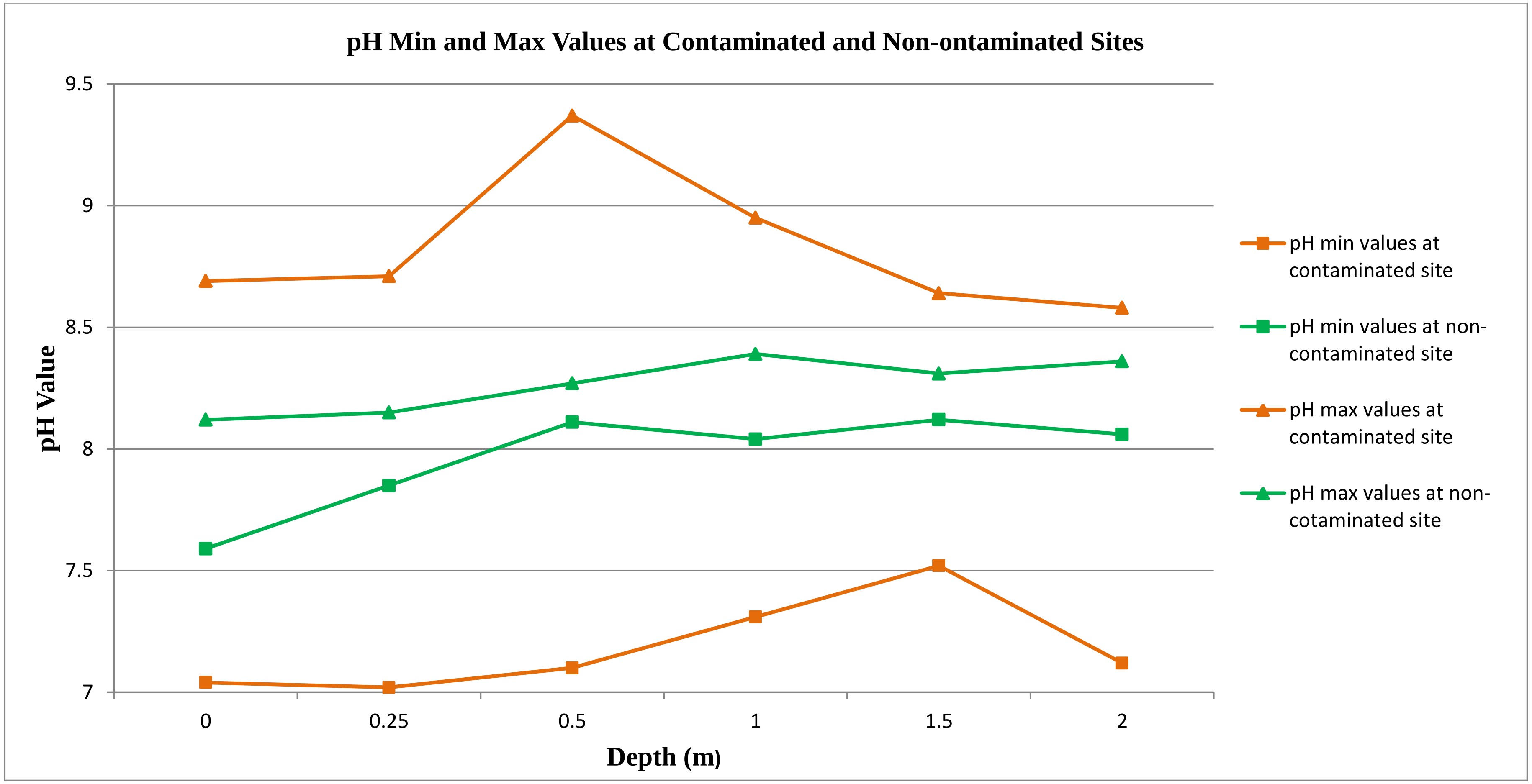


Figure 6.1. Comparing range values of pH coefficient in the soil at six different depths between contaminated and non-contaminated sites.

6.2.2 Statistical Summary of pH

Figure 6.2 displays outliers in contaminated and non-contaminated pH data, which were deleted from the dataset. Table 6.5 and figure 6.3 show minimum and maximum values of pH coefficient in the soil samples at six different depths between contaminated and non-contaminated sites.

The table and figure show that there is a significant increase in the maximum and minimum pH values of contaminated soil at all depths, particularly at the top layer, indicating that the range between maximum and minimum pH values increased due to contamination. This increase in the range was more obvious at the top layer, (it generally decreases at deeper depths).

Comparing the results in Tables (6.3 and 6.4) show that the minimum value of pH did not change and so it cannot be stated that the statistical analysis displays a difference in the availability of soil for agricultural activities.

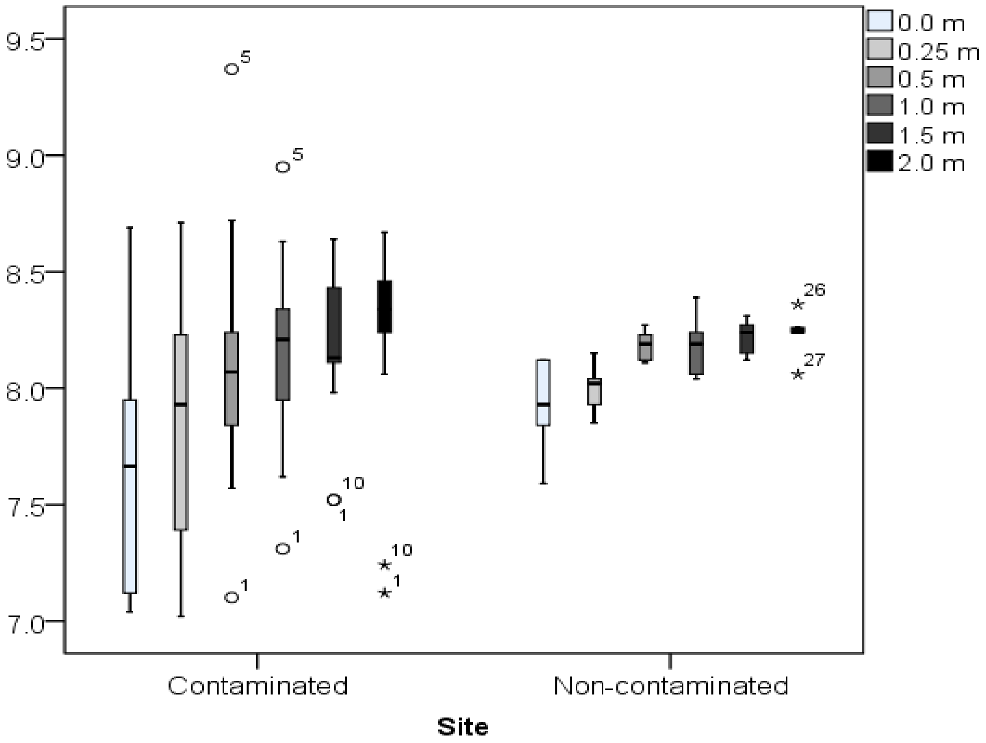


Figure 6.2. Boxplots of pH values at six different depths for both contaminated site and non-contaminated site. (*Note: the symbol of "*" and "°" in the graph denotes outlier*).

Table 6.4. The significant differences in the pH range variable in the soil at six different depths between contaminated and non-contaminated sites.

Depth (m)	**Site Name**	**N**	**Min**	**Max**	**Range**
0.0	***Contaminated***	22	7.04	8.69	1.65
	Non-contaminated	5	7.59	8.12	0.53
0.25	***Contaminated***	22	7.02	8.71	1.69
	Non-contaminated	5	7.85	8.15	0.30
0.5	***Contaminated***	22	7.57	8.72	1.15
	Non-contaminated	5	8.11	8.27	0.16
1.0	***Contaminated***	22	7.62	8.63	1.01
	Non-contaminated	5	8.04	8.39	0.35
1.5	***Contaminated***	22	7.98	8.64	0.66
	Non-contaminated	5	8.12	8.31	0.19
2.0	***Contaminated***	22	8.06	8.67	0.61
	Non-contaminated	5	8.24	8.26	0.02

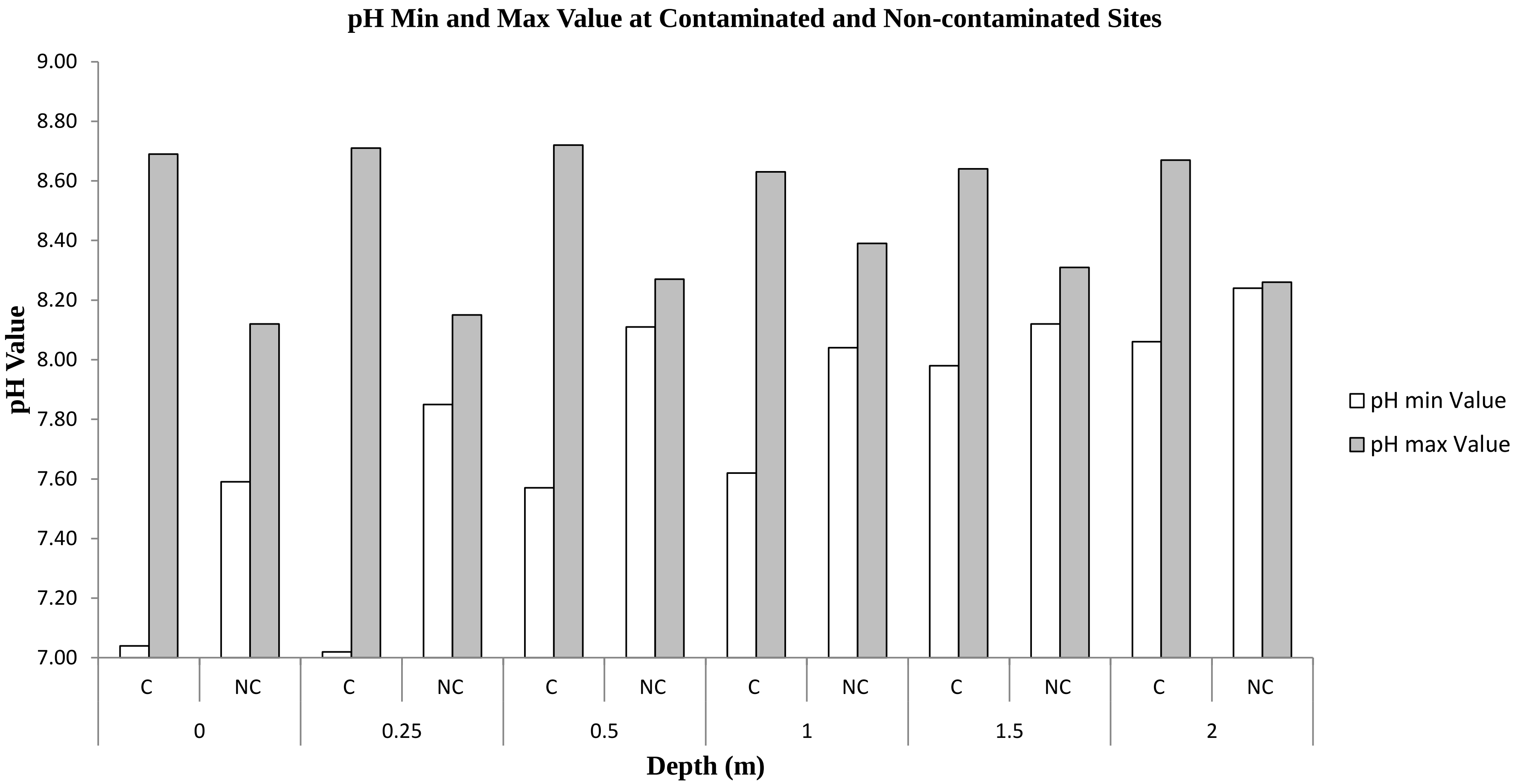


Figure 6.3. Comparing pH minimum and maximum values in the soil at six different depths (in metres) between contaminated and non-contaminated sites. (*Note: the C and NC indicate to the contaminated and non-contaminated site, respectively*.)

6.3 Water Soluble Chloride (Cl-) and Sulphate (SO_3 & SO_4) Content

6.3.1 Laboratory Results of Cl-, SO_3 and SO_4 Content

The results of the Cl-, SO_3 and SO_4 tests conducted on contaminated soil samples with hydrocarbon at various depths are displayed in Tables C.6.1, C.6.2, C.6.3, C.6.4, C.6.5 and C.6.6; Table C.6.7 shows the results of similar tests on non-contaminated samples. The maximum, minimum, standard deviation and mean values of these samples at each depth are documented in the tables.

Table (6.5) and figures from 6.4 to 6.6 show the mean values of water soluble chloride and sulphates at different soil depths for the contaminated and non-contaminated sites.

As is obvious from tables 6.5 and figure 6.4, the Cl- concentration was very high (approximately 13000 mg/kg) at the top layer of the hydrocarbon contaminated site. The concentration was then decreased to less than 4000 mg/kg at depths lower than 0.5 m.

However, at the non-contaminated site, the Cl- concentration was approximately zero.

As noted from Table 6.5 and figures 6.5 and 6.6, for both SO_3 and SO_4, concentrations at the top soil layer of the hydrocarbon contaminated site were considerably higher than those in the non-contaminated site. However, both SO_3 & SO_4 dropped down suddenly and considerably at depth to become lower than that in the non-contaminated site at depths lower than 0.25 m.

The concentration was then further decreased (at the hydrocarbon contaminated site) at lower depths until it reached an approximately constant value of between 1.0 m and 2.0 m depths. In the non-contaminated site the concentration of both SO_3 & SO_4 were approximately constant throughout the depths.

The Cl- values obtained in this study were in line with the study conducted by Onojake and Osuji (2012). They also investigated the Cl- and SO_3 & SO_4 content for soil contaminated with crude oil after six months of the spill incident and compared it with the control site.

For the contaminated sites at surface (0 - 15 cm) and subsurface (15 - 30 cm), the results for Cl- tests were 973.94 ± 55.63 mg/kg and 366.06 ± 17.29 mg/kg, respectively. However, for the control sites, the Cl- value was 56.00 ± 17.76 mg/kg. It was also noted that the values of SO_3 and SO_4 for the crude oil contaminated site were 1.06 ± 0.10 mg/kg and 0.25 ± 0.02 mg/kg at depths of 0-15 cm and 15-30 cm respectively. At the non-contaminated site, however, the sulphate value of only 0.60 ± 0.37 mg/kg was recorded.

Table 6.5. Mean values of water soluble Cl-, SO_3 and SO_4 content (mg/kg) at different depths for the contaminated and non-contaminated sites.

Depth(m)	**Samples Classification**	**Water Soluble Chloride (Cl-)**		**Water Soluble Sulphate**			
				as SO_3		**as SO_4**	
		%	**PPM**	**%**	**PPM**	**%**	**PPM**
0.0 m	*Contaminated*	1.2788	12788.59	0.2484	2484.5	0.297	2979.27
	Non-contaminated	0.0187	186.8	0.17542	1754.2	0.2104	2104.4
0.25 m	*Contaminated*	0.8852	8852.54	0.1248	1248.81	0.14983	1498.36
	Non-contaminated	0.00902	90.2	0.19154	1915.4	0.22982	2298.2
0.5 m	*Contaminated*	0.4025	4025.5	0.079	789.95	0.0947	861.045
	Non-contaminated	0.00762	76.2	0.1816	1816	0.21808	2180.8
1.0 m	*Contaminated*	0.3421	3421.63	0.0637	637.136	0.07644	764.5
	Non-contaminated	0.0181	181	0.17362	1736.2	0.20826	2082.6
1.5 m	*Contaminated*	0.2513	2513.72	0.0481	481.045	0.0577	577.18
	Non-contaminated	0.00958	95.8	0.16278	1627.8	0.1953	1953
2.0 m	*Contaminated*	0.338	3380.136	0.05881	588.18	0.0705	705.681
	Non-contaminated	0.0133	133	0.1624	1624	0.19482	1948.2

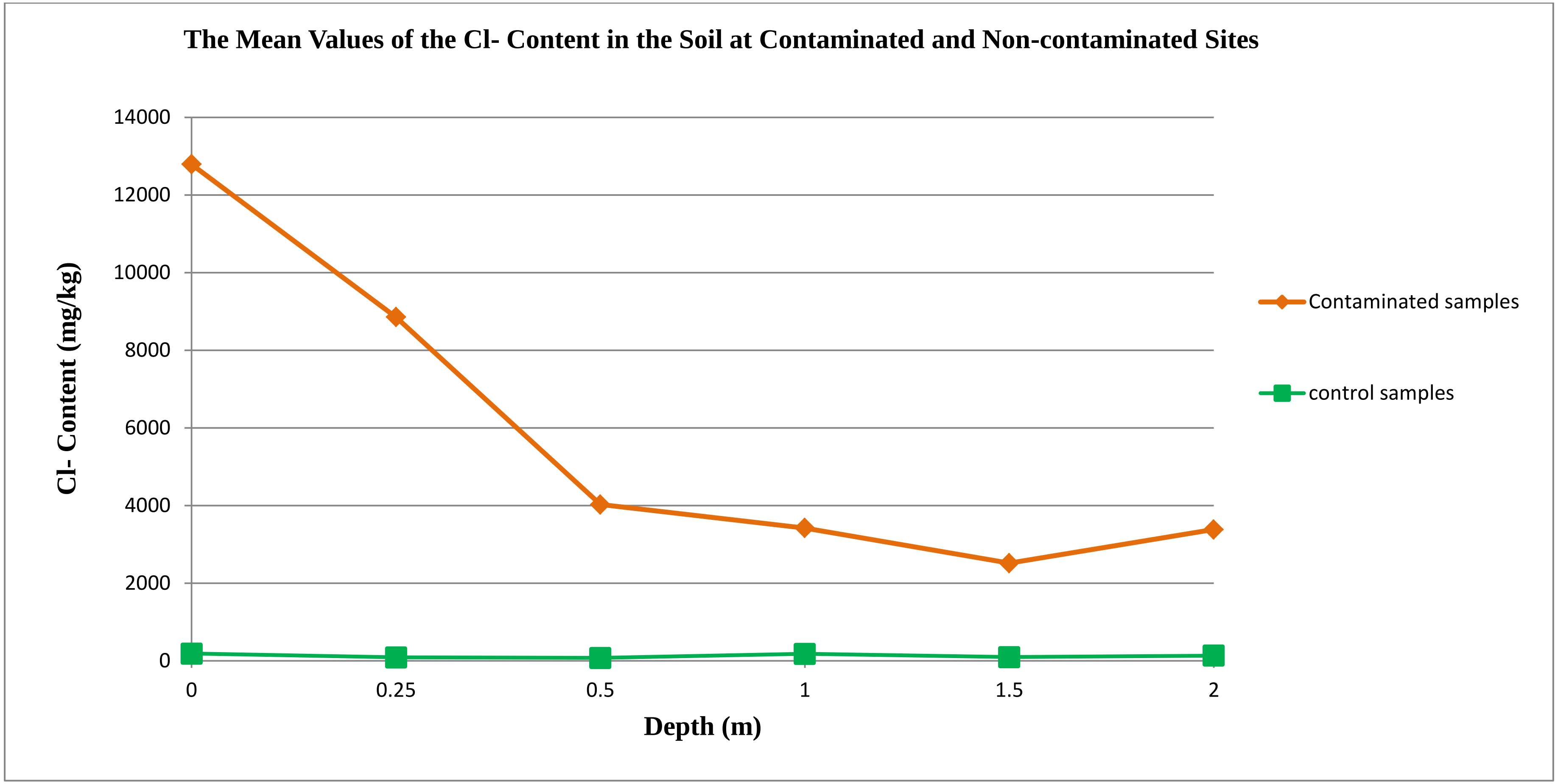


Figure 6.4. Comparing the mean values of the water soluble Cl- content (mg/kg) in the soil at six different depths between contaminated and non-contaminated sites.

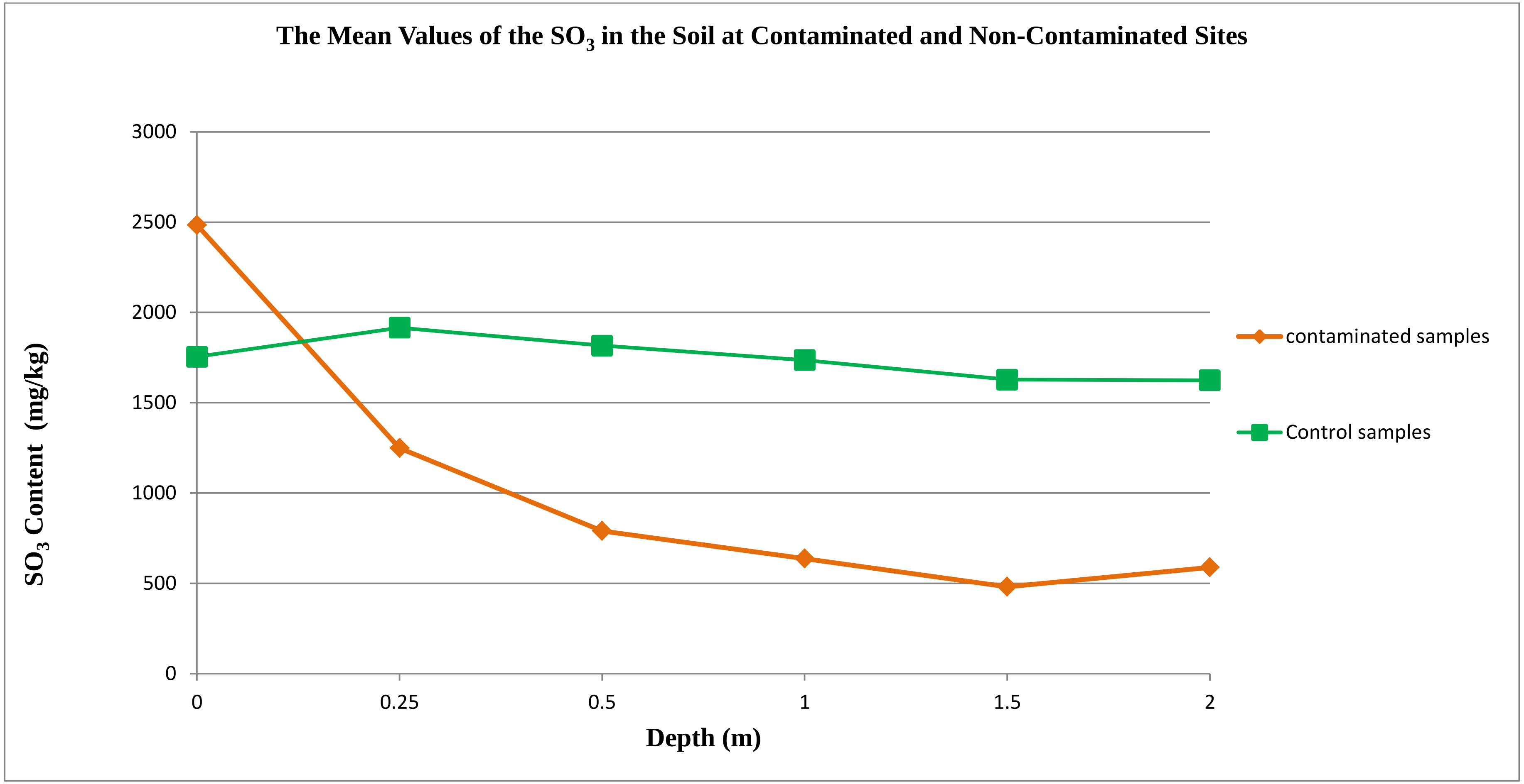


Figure 6.5. Comparing the mean values of the water soluble SO_3 content (mg/kg) in the soil at six different depths between contaminated and non-contaminated sites.

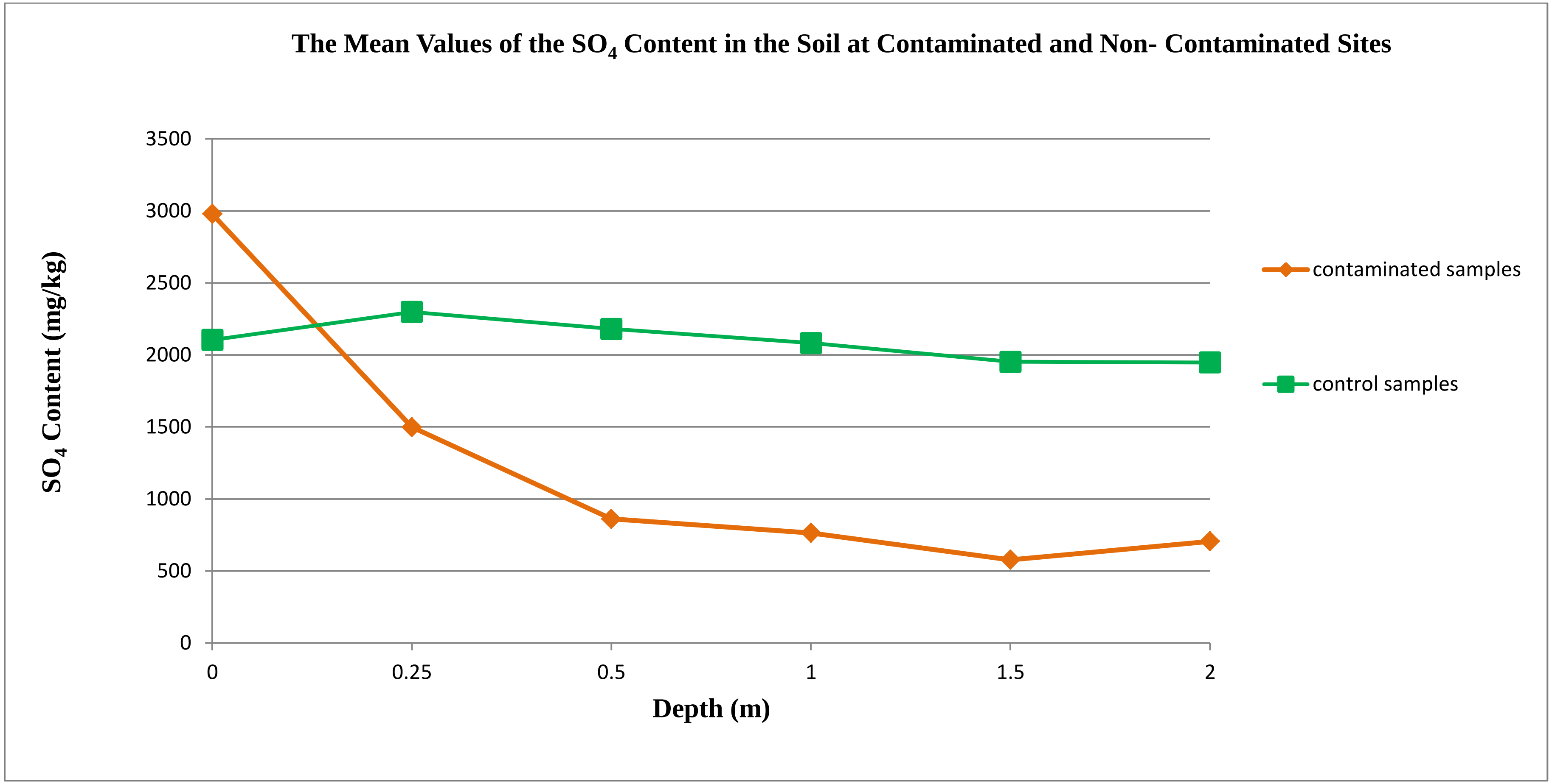


Figure 6.6. Comparing the mean values of the water soluble SO_4 content (mg/kg) in the soil at six different depths between contaminated and non-contaminated sites.

6.3.2 Statistical Summary of Cl-, SO_3 and SO_4 Content

Figure 6.7 shows the outliers present in the Cl-, SO_3 and SO_4 data. These outliers were deleted from the dataset. Data were normally distributed for SO_3 and SO_4, but the assumption of normality was violated for CI- data at both sites (Tables C.6.8 and C.6.9). Table 6.6 shows the median and mean differences between Cl-, SO_3 and SO_4 values at both sites.

A non-parametric, Mann Whitney U test found significant differences in the median concentration values of Cl- (mg/kg) between the two sites at all six depths: 0.0 m depth (Z= -3.28, U= 2, p= 0.001), 0.25 m depth (Z= -2.95, U= 6, p= 0.01), 0.5 m depth (Z= -2.95, U= 6, p= 0.001), 1.0 m depth (Z= -3.05, U= 5, p= 0.001), 1.5 m depth (Z= -3.26, U= 2, p= 0.001) and 2.0 m depth (Z= -2.98, U= 2, p= 0.001) (Figure 6.8 and Table C.6.10).

An independent samples T-Test found significant differences in the mean concentration values of SO_3 and SO_4 (mg/kg) between contaminated and non-contaminated sites at all six depths. For SO_3, the results revealed that there are significant difference at depths 0.0 m (t(15) = 1.92, p= 0.005), 0.25 m (t(24) = -2.38, p= 0.02), 0.5 m (t(25) = -2.90, p= 0.008), 1.0 m (t(24) = -4.80, p= 0.001), 1.5 m (t(23) = -7.01, p= 0.001) and 2.0 m (t(25) = -4.19, p= 0.001). Also, mean values of the SO_4 showed significant variance at 0.0 m (t(15) = 1.91, p= 0.04), 0.25 m (t(14) = -2.49, p= 0.02), 0.5 m (t(25) = -3.20, p= 0.004), 1.0 m (t(12) = -5.60, p= 0.001), 1.5 m (t(25) = -4.70, p= 0.001) and 2.0 m (t(25) = -4.19, p= 0.001) (Figures 6.9 and 6.10 and Table C.6.11).

The above statistical analyses indicate that the oil spills are responsible for contaminating the soil with Cl- content but that SO_3 and SO_4 concentration values (at different depths) may have been changed by both hydrocarbon oil spill contamination and fire extinguishing materials used in the contaminated area.

Furthermore, figures 6.8, 6.9 and 6.10 show the concentration of Cl-, SO_3 and SO_4 against depth after deleting the outlier values from the laboratory data. These figures indicate no change in the trend (behaviour) of the relationship between depth and concentrations of Cl-, SO_3 and SO_4, as explained in section (6.3.1).

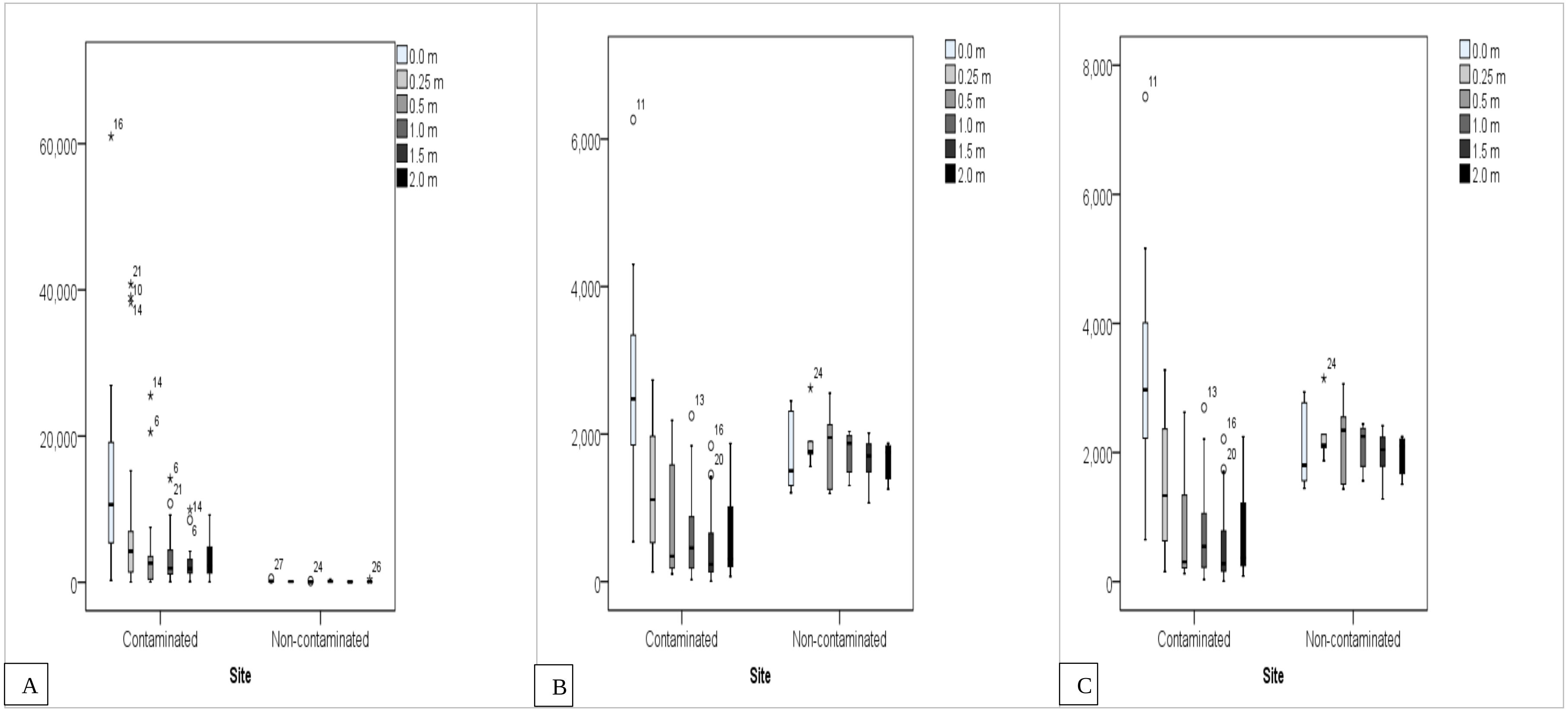


Figure 6.7. Boxplots of Cl- (A), SO_3 (B) and SO_4 (C) values in the soil at six different depths for both contaminated and non-contaminated sites. (*Note: the symbol of "°" and "*" in the graph denotes outlier*).

Table 6.6. The significant differences of the variables of Cl-, SO_3 and SO_4 concentration (mg/kg) in the soil at six different depths between contaminated and non-contaminated sites. ***(Note: outlier values were deleted in this table).***

Depth (m)	Variable	Site Name	N	Median	Mean	SD	Min	Max	*Z*	*U*	*t*-value	*p*-value
0.0	***Cl-***	***Contaminated***	22	10638	10493.2	7441.7	255	26950	-3.28	2.0	-----	0.001*
		Non-contaminated	5	106	106	73.9	42	170				
	SO_3	***Contaminated***	22	2442	2304.6	985.8	541	4303	-----	-----	1.92	0.05*
		Non-contaminated	5	1503	1754.2	583.4	1204	2450				
	SO_4	***Contaminated***	22	2930	2763.4	1211.9	649	5162	-----	---	1.918	0.042*
		Non-contaminated	5	1804	2104.4	699.8	1445	2939				
0.25	***Cl-***	***Contaminated***	22	2837	4035.4	3747.1	43	15248	-2.95	6.0	-----	0.001*
		Non-contaminated	5	113	90.2	57.919	28	141				
	SO_3	***Contaminated***	22	1111	1248.8	907.3	129	2733	-----	-----	-2.381	0.026*
		Non-contaminated	5	1746	1738.5	139.61	1561	1901				
	SO_4	***Contaminated***	22	1333	1498.3	1088.52	155	3279	-----	---	-2.491	0.026*
		Non-contaminated	5	2095	2086	167.5	1873	2281				
0.5	***Cl-***	***Contaminated***	22	1985.5	2123.1	2025.6	43	7518	-2.95	6.0	-----	0.001*
		Non-contaminated	5	49	52.7	24.3	28	85				
	SO_3	***Contaminated***	22	345.5	789.95	735.17	104	2187	-----	-----	-2.904	0.008*
		Non-contaminated	5	1953	1816	583.76	1196	2554				
	SO_4	***Contaminated***	22	306	861.04	854.70	125	2624	-----	---	-3.203	0.004*
		Non-contaminated	5	2343	2180.8	697.9	1435	3064				
1.0	***Cl-***	***Contaminated***	22	1687.5	2127.1	1636.2	85	6525	-3.05	5.0	-----	0.001*
		Non-contaminated	5	113	181	158.8	56	425				
	SO_3	***Contaminated***	22	530	643.8	564.9	27	1841	-----	-----	-4.804	0.001*
		Non-contaminated	5	1876	1736.2	322.79	1304	2036				
	SO_4	***Contaminated***	22	471	672.52	622.85	33	2209	-----	---	-5.605	0.001*
		Non-contaminated	5	2251	2082.6	387.6	1563	2442				
1.5	***Cl-***	***Contaminated***	22	1702	1843.1	1194.6	85	4255	-3.26	2	-----	0.001*
		Non-contaminated	5	56	95.8	62.23	56	198				
	SO_3	***Contaminated***	22	228	418.5	409.6	5	1422	-----	-----	-7.013	0.001*
		Non-contaminated	5	1704	1627.8	369.11	1067	2014				
	SO_4	***Contaminated***	22	273	467.4	453.9	7	1706	-----	-----	-4.707	0.001*
		Non-contaminated	5	2044	1953	442.8	1280	2416				
2.0	***Cl-***	***Contaminated***	22	2269.5	3380.13	2723.28	57	9220	-2.98	2.00	-----	0.001*
		Non-contaminated	5	70.5	67	21.55	42	85				
	SO_3	***Contaminated***	22	307.5	588.18	530.44	71	1872	-----	-----	-4.19	0.001*
		Non-contaminated	5	1753	1624	280.01	1256	1874				
	SO_4	***Contaminated***	22	368.5	705.68	636.4	86	2246	-----	-----	-4.190	0.001*
		Non-contaminated	5	2103	1948.2	335.64	1507	2248				

Note, *p < .05 indicates to the significant difference in the variable between two different groups.

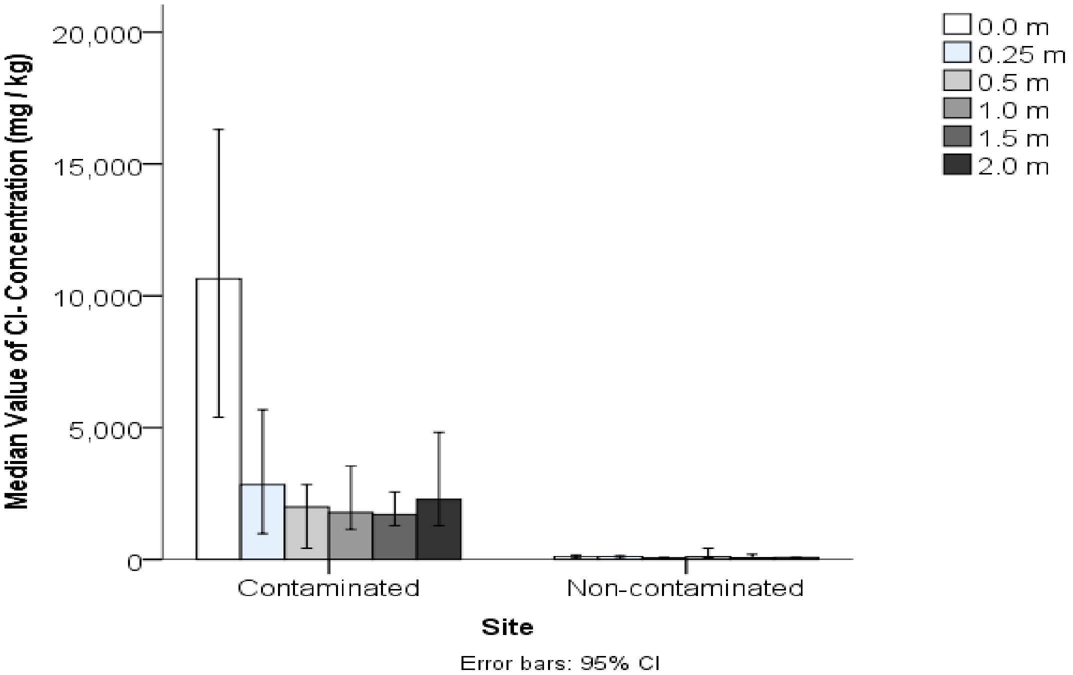


Figure 6.8. Comparing median values of Cl- concentration (mg/kg) in the soil at six different depths between contaminated and non-contaminated site. ***(Note: Error bars denote 95 % lower and upper confidence intervals).***

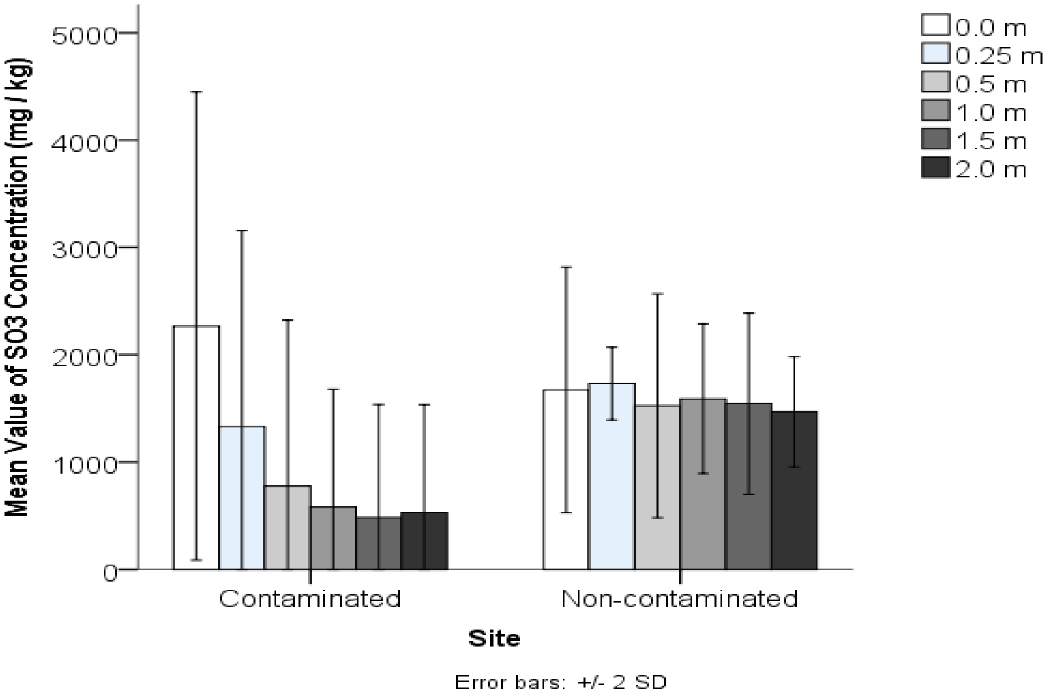


Figure 6.9. Comparing mean values of SO_3 concentration (mg/kg) in the soil at six different depths between contaminated and non-contaminated site. ***(Note: Error bars denote standard deviation).***

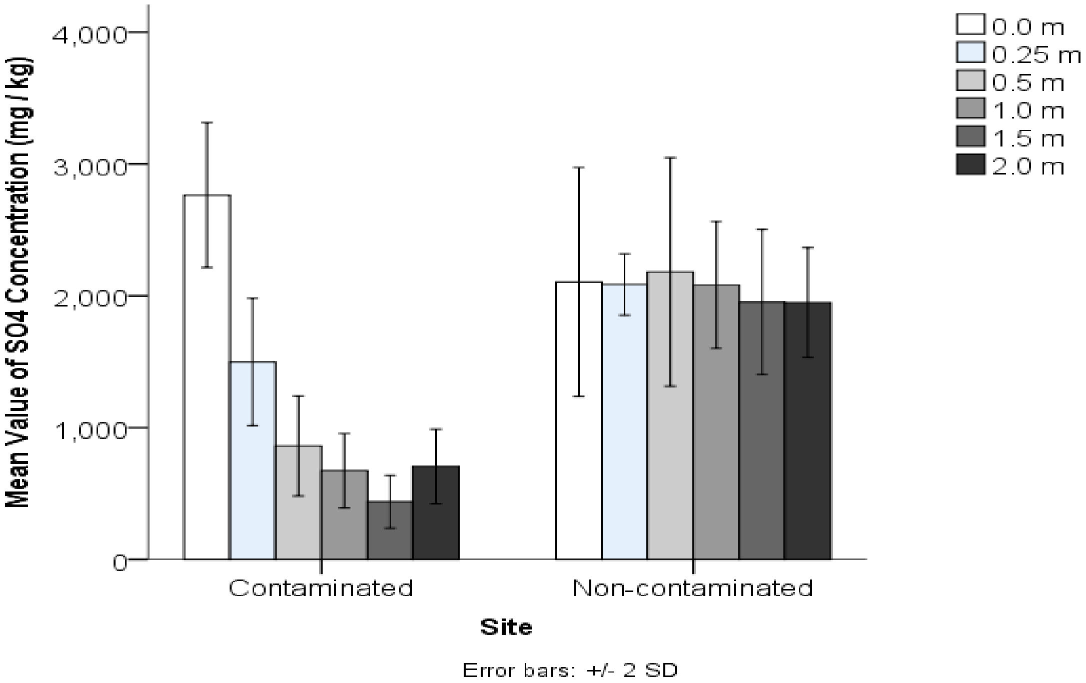


Figure 6.10. Comparing mean values of SO_4 concentration (mg/kg) in the soil at six different depths between contaminated and non-contaminated site. ***(Note: Error bars denote standard deviation).***

As Mann Whitney U and independent samples T-Test results were significant, a follow-up non-parametric Wilcoxon test was conducted to compare differences in Cl- values across the six different depths, and a linear regression analysis was conducted, separately, to predict SO_3 and SO_4 values at T.P.C (50 m, 50 m) from the depth categories, at both sites.

For Cl- concentration (mg/kg)**,** the Wilcoxon analysis revealed that at the contaminated site, there were significant differences between depth 0.0 m (Median=10638) and all other depths, i.e. depths of 0.25 m (Median= 2837), Z= -2.80, *p*= 0.005; depth 0.5 m (Median= 1985.5), Z= -3.92, *p*= 0.001; depth 1.0 m (Median= 1687.5), Z= -3.658, *p*= 0.001; depth 1.5 m (Median= 1702), Z= -3.65, *p*= 0.001; and depth 2.0 m (Median= 2269.5), Z= -3.229, *p*= 0.001.

On the other hand, at the non-contaminated site, there was only one significant difference between depth 0.0 m (Median= 106) and depth 0.25 m (Median= 113), Z= -2.03, *p*= 0.04. All other comparisons were non-significant (Table C.6.12).

For SO_3 content, linear regression showed that at both sites, depth does not predict SO_3 concentration values, i.e. at the (*contaminated site*: B= -280.12, SEB = 282.19, Beta = -0.44, $p = 0.37$ and at the *non-contaminated site*: B = -127.49, SEB =178.04, Beta = -0.337, $p = 0.51$). It therefore shows that there is no significant association between depth and SO_3 content at either site (Figure 6.11). Additionally, the results of SO_4 content showed that the depth does not predict SO_4 concentration values (*contaminated site*: B= 336.21, SEB= 338.63, Beta= -0.44, $p= 0.37$; *non-contaminated site*: B= 153.13, SEB= 213.60, Beta= -0.33, $p= 0.51$). Hence, it can be stated that there is no significant relationship between depth and SO_4 values at both sites at T.P.C. (50 m, 50 m) (Figure 6.12).

These results mean that the depth at certain points cannot predict the concentrations of SO_3 and SO_4 at either site.

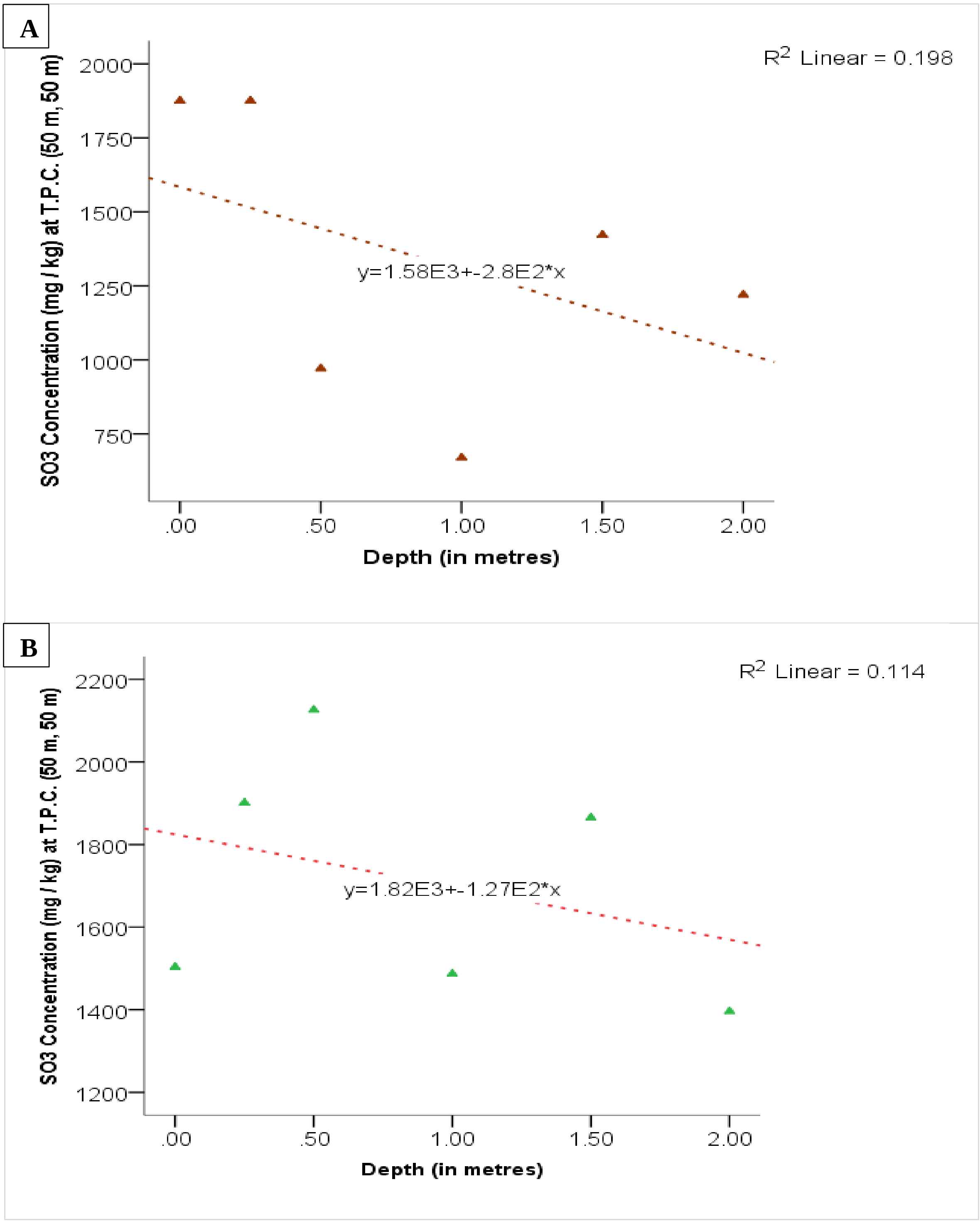


Figure 6.11. Scatterplot showing relationship between six different depths and SO_3 concentration (mg/kg) at T.P.C (50 m, 50 m), at contaminated site (A) and non-contaminated site (B).

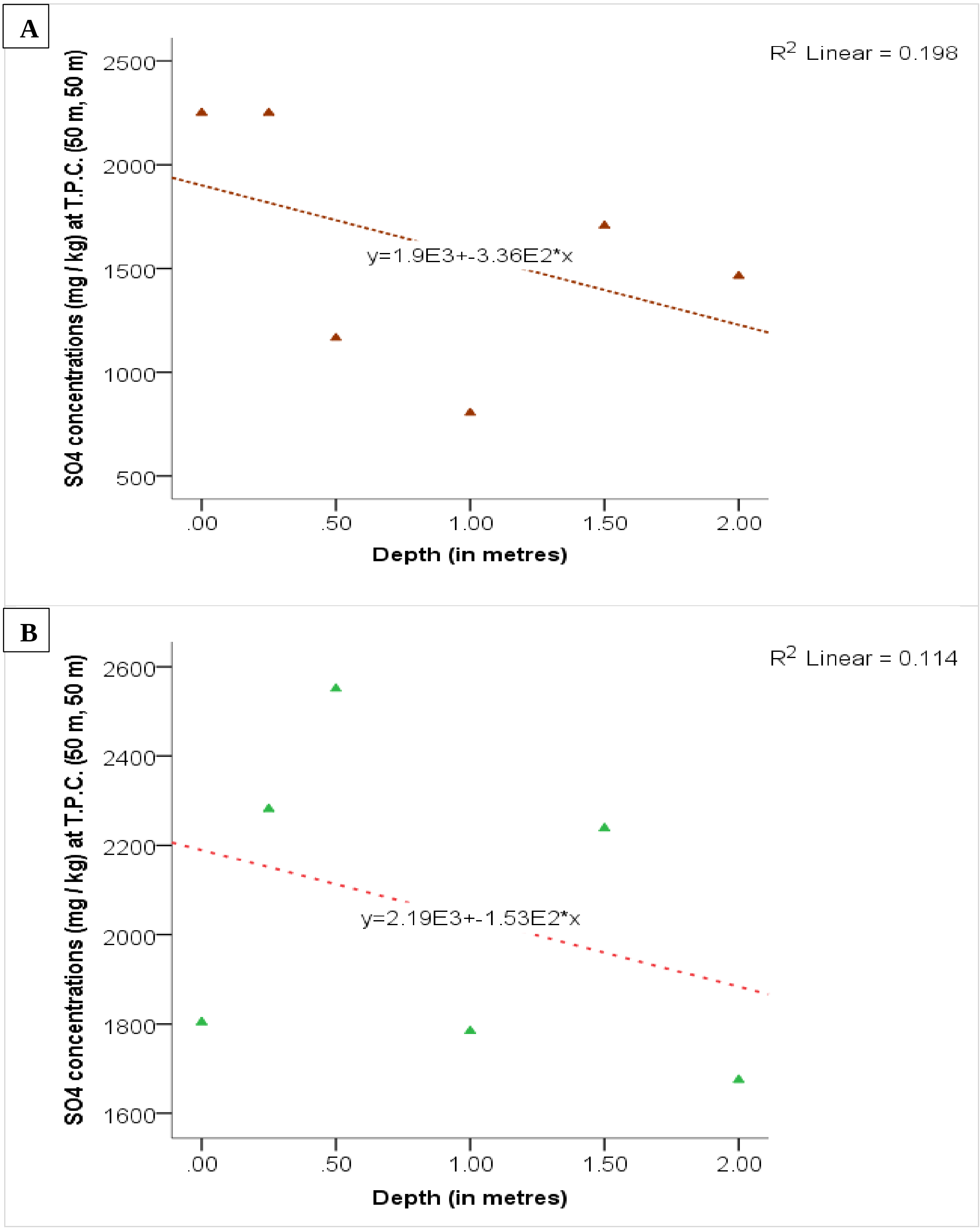


Figure 6.12. Scatterplot showing relationship between six different depths and SO_4 concentration (mg/kg) at T.P.C (50 m, 50 m), at contaminated site (A) and non-contaminated site (B).

6.4 Vario Macro Elemental Analyses (EA)

6.4.1 Laboratory Results of EA

Tables C.6.13 to C.6.18 present the Elemental Analysis (EA) test results for the soil samples taken from the contaminated site; the results for similar tests performed on samples obtained from the non-contaminated site are shown in Table C.6.19. Similarly, the maximum, minimum, standard deviation and mean values were calculated and tabulated against the depth.

Tables 6.7 and 6.8 show the mean percentage values of nitrogen, carbon, sulphur and hydrogen against the layer depths for contaminated and non-contaminated sites. Figure 6.13 shows how the carbon percentage changes with the depth at the contaminated site. The followings should be noted from Tables (6.7 & 6.8) and figure (6.13):

(a) The carbon content was very high (nearly 21 %) at the top layer of the contaminated site. It however, decreased sharply with depth down to 0.5 m where it reached nearly 2 % and a further slight decrease was recorded down to 2.0 m. On the other hand, at the non-contaminated site a negligible carbon content was clearly shown, (as shown in Table 6.8) even at the top layer.

(b) Nearly the same trend of changes in the carbon, as discussed above, was noted for the changes of Nitrogen, Sulphur and Hydrogen with the depth, although the concentrations of these materials were low even at the top layer of the contaminated site as compared with the carbon content. The lower values of these materials were expected as the oil itself mostly contains hydrogen and carbon and the hydrogen mostly evaporates when exposed to the air and high sun temperatures. However, at the non-contaminated site, these materials were negligible.

Table 6.7. Mean percentages values of Nitrogen, Carbon, Sulphur and Hydrogen in soil samples at six different depths in contaminated site.

Trial Pits Coordinates (T.P.Cs)	Sample Weight (g)	Content of N, C, S & H (%) by elemental analysis			
		N %	C %	S %	H %
0.0 m	45.40	0.54	20.86	2.43	2.72
0.25 m	45.95	0.45	8.33	0.97	1.10
0.5 m	44.56	0.26	2.12	0.09	0.02
1.0 m	45.49	0.39	2.12	0.10	0.07
1.5 m	44.94	0.21	1.59	0.12	0.02
2.0 m	45.06	0.14	0.62	0.09	0.01

Table 6.8. Mean percentages values percentages of Nitrogen, Carbon, Sulphur and Hydrogen in soil samples at two different depths (0.0 m, 0.25 m) in non-contaminated site.

Trial Pits Coordinates (T.P.Cs)	Sample Weight (g)	Content of N, C, S & H (%) by elemental analysis			
		Nitrogen N %	Carbon C %	Sulphur S %	Hydrogen H %
0.0 m	36.79	0.0027	0.048	0.008	0.0054
0.25 m	44.96	0.00026	0.00066	0.001	0.0011

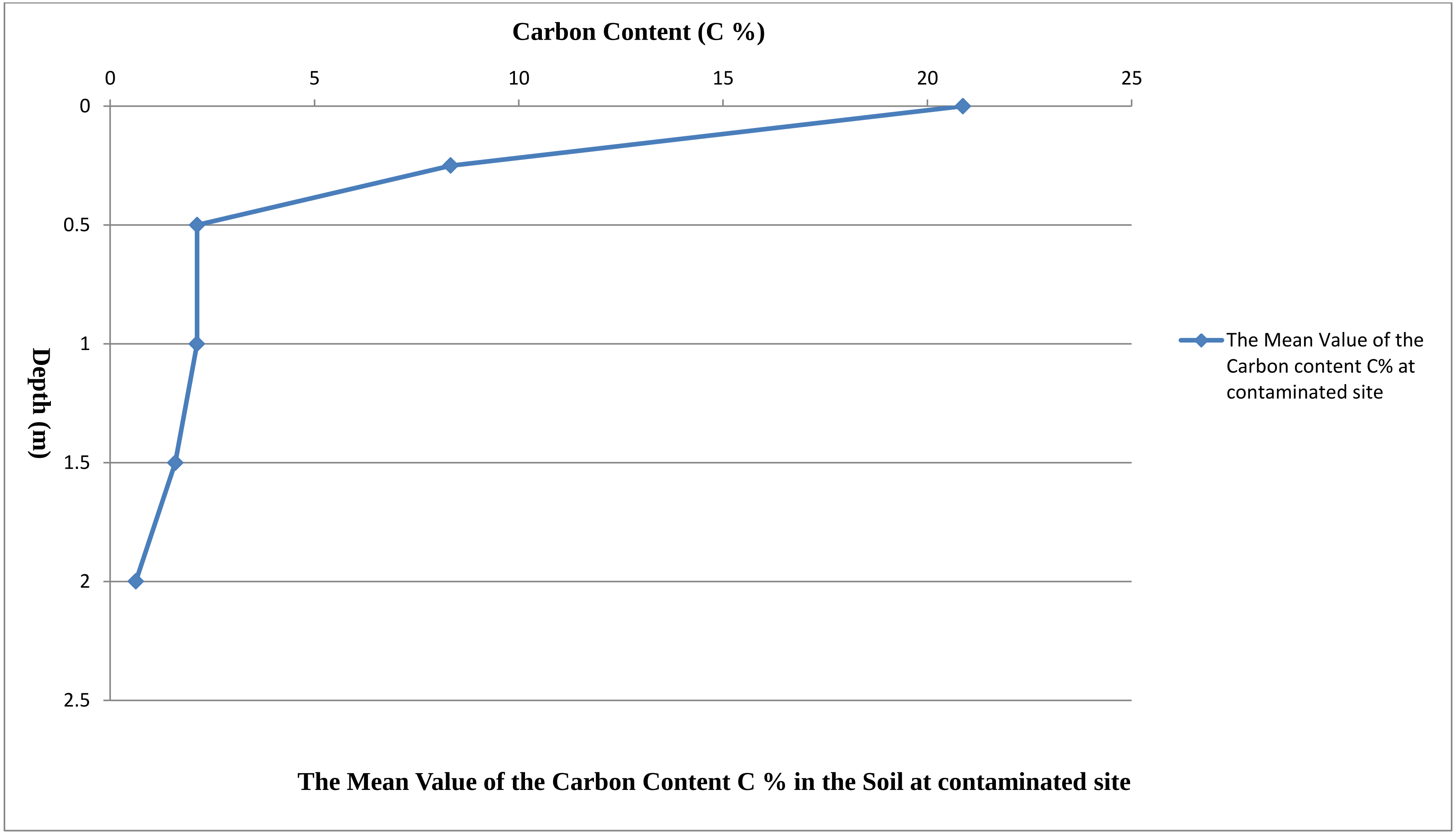


Figure 6.13. Mean percentages values of carbon in soil samples at six different depths in contaminated site.

6.4.2 Statistical Summary of EA

Figures 6.14 and 6.15 shows the outliers present in the nitrogen (N %), carbon (C %), sulphur (S %) and hydrogen (H %) data for the contaminated site only, as the N %, C %, S % and H % data had low percentage values at depths 0.0 m and 0.25 m and were not detected at other depths in non-contaminated site. Outliers in the contaminated data were deleted prior to analysis. The C %, N % and S % data had normal distributions. However, the H % data were skewed; therefore non-parametric tests were performed on this data. (Tables C.6.20 and C.6.21)

Table 6.9 shows the independent samples T-Test results for C %, N % and S % data, and Mann Whitney U results for the H % data, at both sites at the two depths of 0.0 m and 0.25 m (Tables C.6.22 and C.6.23). The T-Test showed significant differences in mean percentage values of C % (at depth 0.0 m, t(25) = 4.83, *p*= 0.002; at depth 0.25 m, t(21) = 4.65, *p*= 0.001); N % (at depth 0.0 m, t(25) = 17.05, *p*= 0.001; at depth 0.25 m, t(25) = 19.41, *p*= 0.001) and S % (at depth 0.0 m, t(21) = 7.48, *p*= 0.001, at depth 0.25 m, t(19) = 4.32, *p*= 0.001) (Figure 6.16).

The Mann Whitney U analysis found significant differences in median percentage values of H % between contaminated and non-contaminated sites at the two depths investigated: 0.0 m (Z= -3.43, U= 0.000, *p*= 0.001) and 0.25 m (Z= -3.41, U= 0.00, *p*= 0.001) (Figure 6.17).

The above results show that the statistical analysis (after deleting the outliers from the mean/median values) do not much change the general values found in tables 6.8 and 6.9, i.e. it does not much vary the trend towards the concentration of elements against the depths. Furthermore, it indicates that the oil spill contamination is responsible for the existence of these element materials at the contaminated site.

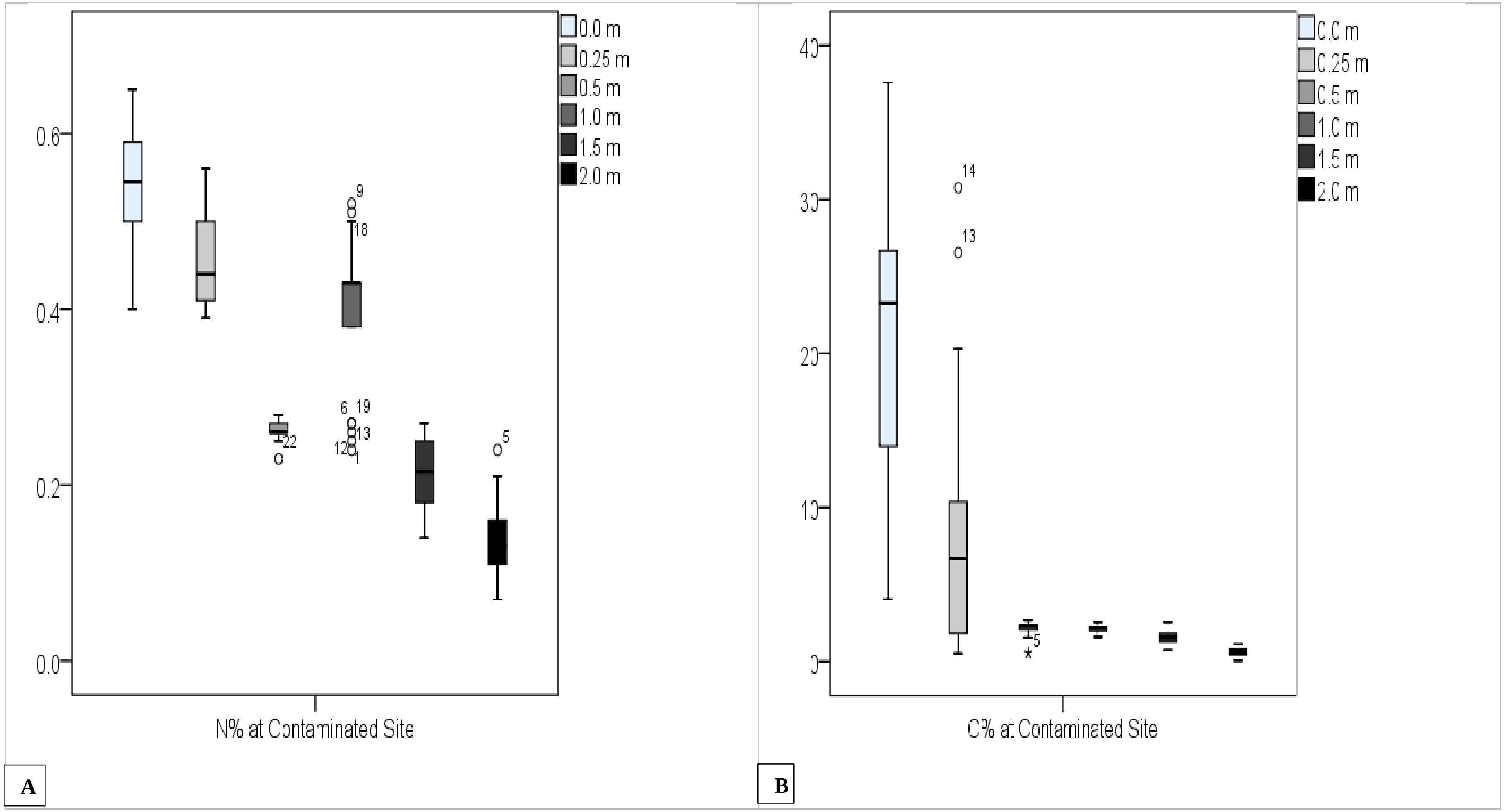


Figure 6.14. Boxplots of N % (A) and C % (B) percentages values in the soil at six different depths for contaminated site. (*Note: the symbol of "*" and "°" in the graph denotes outlier*).

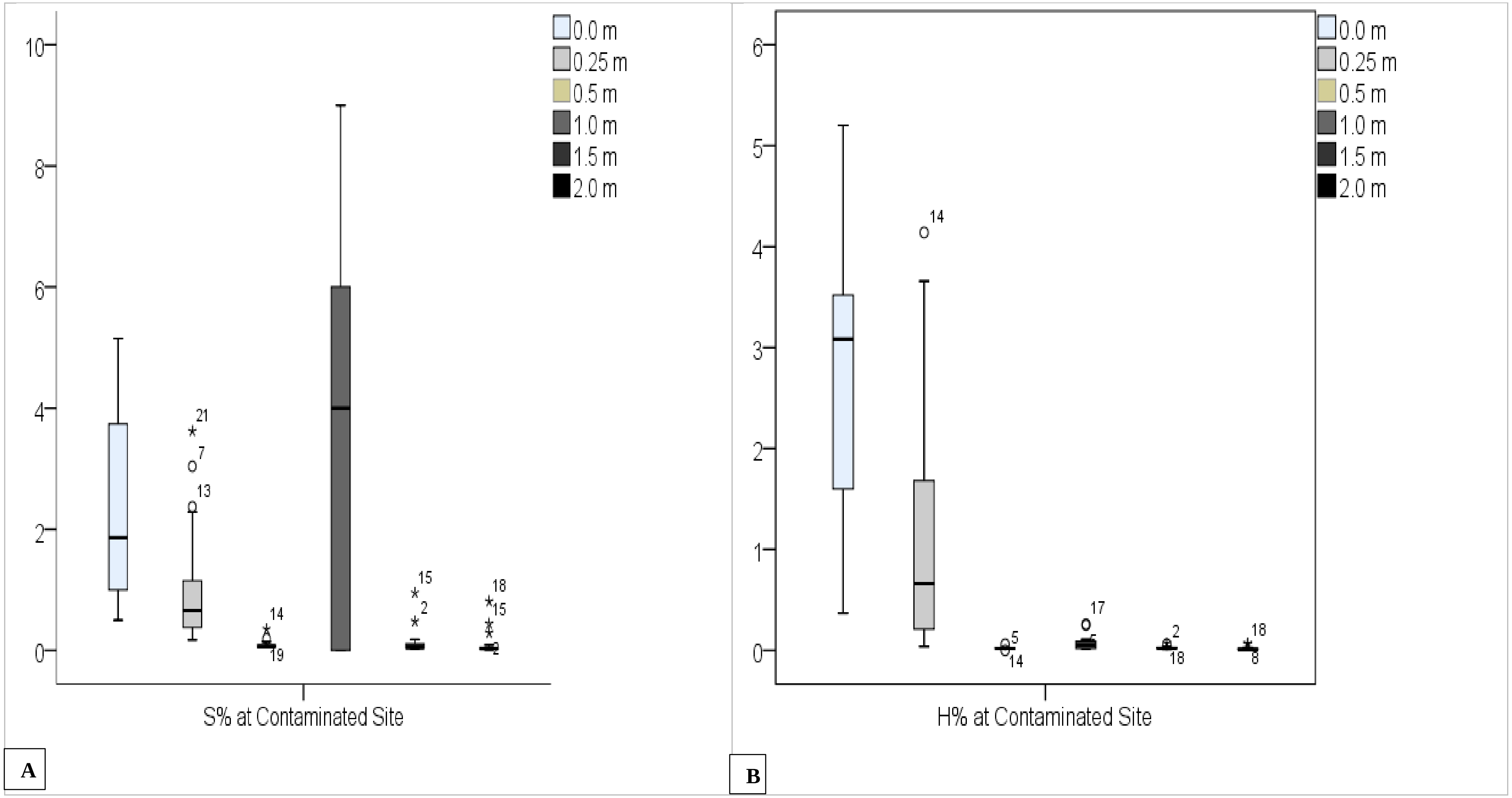


Figure 6.15. Boxplots of S % (A) and H % (B) percentages values in the soil at six different depths for contaminated site. (*Note: the symbol of "*" and "°" in the graph denotes outlier*).

Table 6.9. The significant differences of the variables of elemental analysis (N %, C %, H % & S %) at two different depths (0.0 m & 0.25 m) between contaminated and non-contaminated sites. ***(Note: outlier values were deleted in this table).***

Depth (m)	Variable	Site Name	N	Median	Mean	SD	Min	Max	*Z*	*U*	*t*-value	*p*-value
0.0	***N%***	***Contaminated***	22	0.57	0.56	0.059	0.446	0.652	-------	-------	17.05	0.001*
		Non-contaminated	5	0.0029	0.0030	0.0006	0.0025	0.0037				
	C%	***Contaminated***	22	23.275	20.86	9.485	4.058	37.58	-------	-------	4.83	0.001*
		Non-contaminated	5	0.036	0.048	0.036	0.01	0.09				
	H%	***Contaminated***	22	3.00	2.64	1.36	0.37	5.19	-3.43	0.00	-------	0.001*
		Non-contaminated	5	0.0052	0.0054	0.0029	0.0	0.01				
	S%	***Contaminated***	22	2.81	2.47	1.57	0.49	5.15	-------	-------	7.48	0.001*
		Non-contaminated	5	0.008	0.008	0.0056	0.001	0.014				
0.25	***N%***	***Contaminated***	22	0.439	0.450	0.050	0.387	0.556	-------	-------	19.41	0.001*
		Non-contaminated	5	0.0	0.0003	0.00053	0.0	0.0				
	C%	***Contaminated***	22	6.698	8.333	8.405	0.516	30.77	-------	-------	4.65	0.001*
		Non-contaminated	5	0.001	0.0007	0.0006	0.0	0.0				
	H%	***Contaminated***	22	0.6270	0.9904	1.096	0.039	3.6550	-3.41	0.00	-------	0.001*
		Non-contaminated	5	0.001	0.0012	0.0007	0.0	0.0				
	S%	***Contaminated***	22	0.479	0.649	0.839	0.173	3.617	-------	-------	4.32	0.001*
		Non-contaminated	5	0.0	0.001	0.001	0.0	0.003				
0.5**	**N%**	***Contaminated***	22	0.2595	0.2597	0.0070	0.2480	0.2710	-------	-------	-------	-------
	C%	***Contaminated***	22	2.27	2.129	0.446	0.546	2.669	-------	-------	-------	-------
	H%	***Contaminated***	22	0.022	0.022	0.0026	0.0180	0.0270	-------	-------	-------	-------
	S%	***Contaminated***	22	0.0710	0.0993	0.0700	0.053	0.346	-------	-------	-------	-------
1.0**	**N%**	***Contaminated***	22	0.4255	0.4225	0.0586	0.2460	0.4980	-------	-------	-------	-------
	C%	***Contaminated***	22	2.177	2.124	0.246	1.593	2.553	-------	-------	-------	-------
	H%	***Contaminated***	22	0.046	0.0488	0.0259	0.017	0.096	-------	-------	-------	-------
	S%	***Contaminated***	22	4.499	3.91784	3.212	0.125	9.100	-------	-------	-------	-------
1.5**	**N%**	***Contaminated***	22	0.2050	0.2058	0.0340	0.1370	0.2560	-------	-------	-------	-------
	C%	***Contaminated***	22	2.251	2.198	0.2480	1.365	2.538	-------	-------	-------	-------
	H%	***Contaminated***	22	0.019	0.020	0.0075	0.013	0.035	-------	-------	-------	-------
	S%	***Contaminated***	22	0.0530	0.1338	0.223	0.026	0.953	-------	-------	-------	-------
2.0**	**N%**	***Contaminated***	22	0.139	0.1389	0.0367	0.0690	0.2050	-------	-------	-------	-------
	C%	***Contaminated***	22	0.726	0.628	0.291	0.037	1.145	-------	-------	-------	-------
	H%	***Contaminated***	22	0.0100	0.0102	0.0041	0.0030	0.0180	-------	-------	-------	-------
	S%	***Contaminated***	22	0.0310	0.1076	0.2003	0.011	0.805	-------	-------	-------	-------

Note, *p < .05 indicates to the significant difference in the variable between two different groups. ** No further deteced percentages values of N %, C %, H % and S % at depths 0.5 m, 1.0 m, 1.5 m and 2.0 m in non-contaminated site.

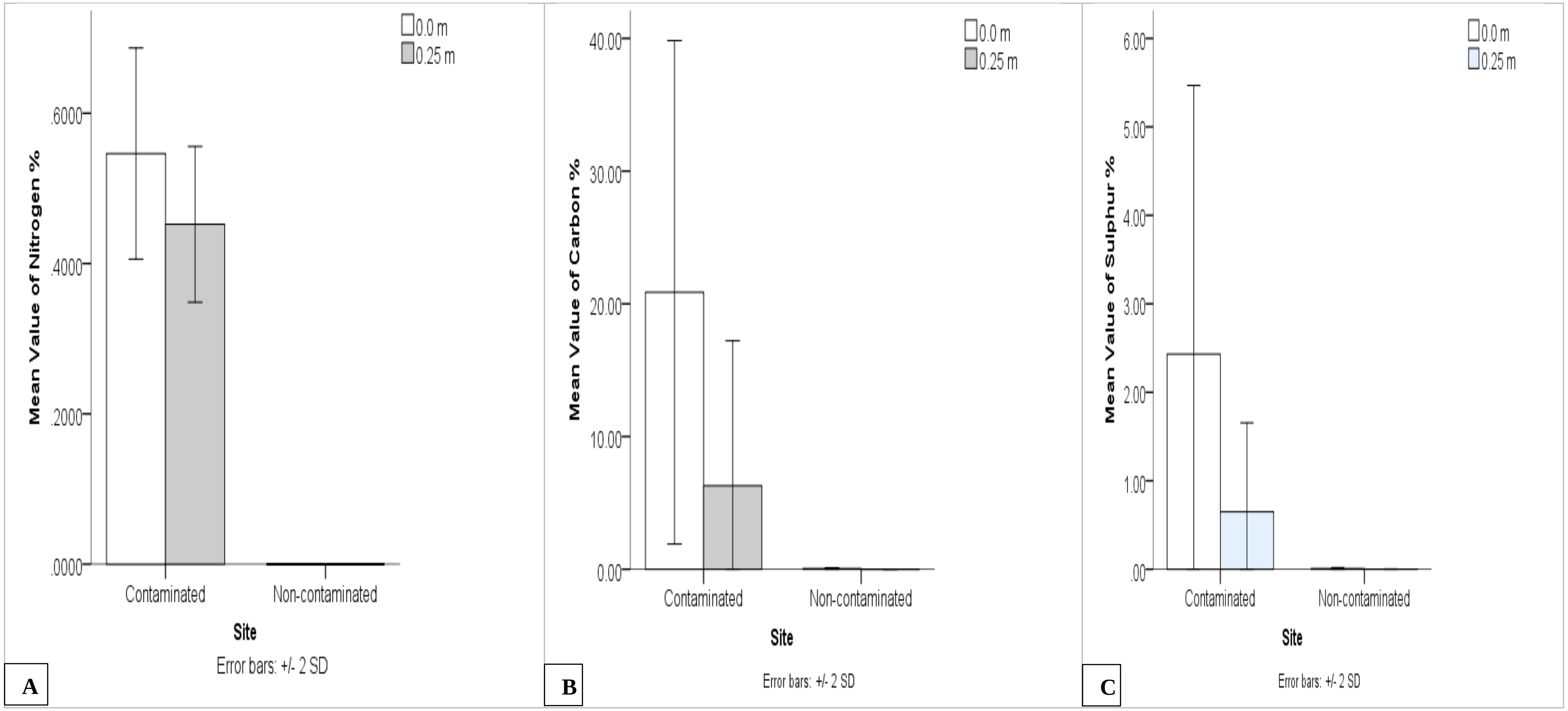


Figure 6.16. Comparing mean values of N % (A), C % (B), S % (C) at two different depths (i.e. 0.0 m, 0.25 m) between contaminated and non-contaminated sites. ***(Note: Error bars denote standard deviation).***

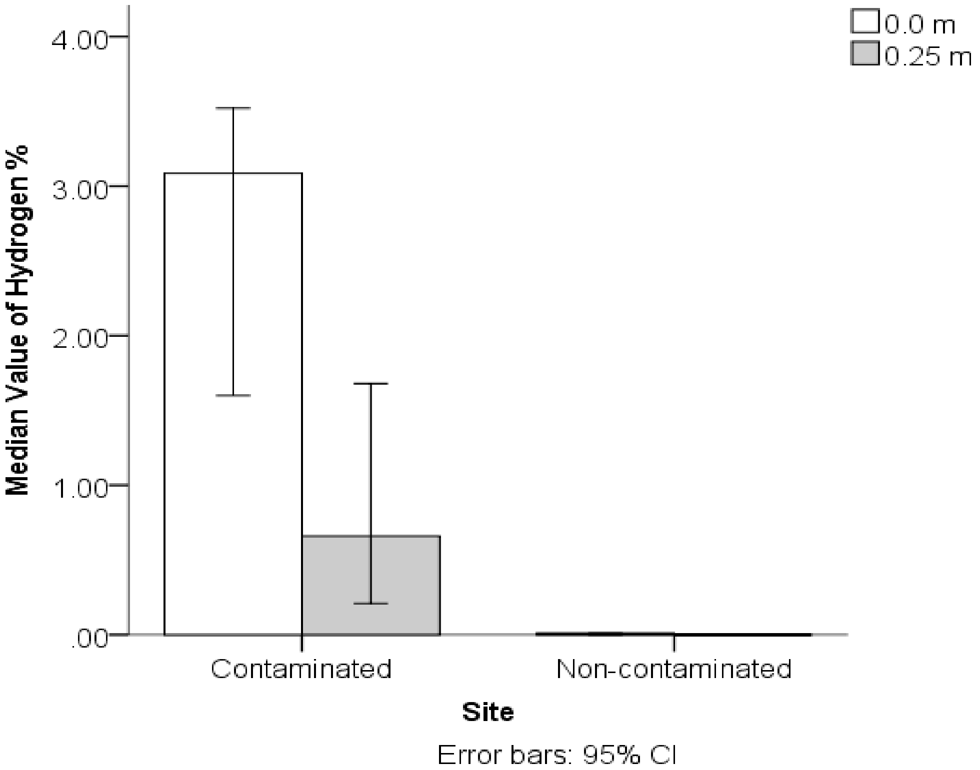


Figure 6.17. Comparing median percentages values of H % at two different depths (in metres) between contaminated and non-contaminated sites. ***(Note: Error bars denote 95% lower and upper confidence intervals).***

The C %, N % and S % predictors were entered individually into three separate linear regression models to examine their contribution towards predicting depth degrees in the contaminated site at T.P.C. (50 m, 50 m). The results revealed that the depth was a significant of N % (B= -0.13, SEB= 0.04, Beta= 0.83, *p*= 0.03). For every one meter increase in depth, N % decreased by 0.139 degrees. The R Square value of 0.699 indicates that depth accounted for approximately 69.9 % of the Nitrogen % in the contaminated data. On the other hand, the depth was not found to be significant for predicating the carbon % (B= -4.49, SEB= 3.00, Beta= -0.59, *p*= 0.20) and sulphur % (B= -0.98, SEB= 0.67, Beta= -0.58, *p*= 0.22) (Figure 6.18).

For H % percentage values, the Wilcoxon analysis revealed that there was a significant difference between depth 0.0 m (Median = 3.08) and all other depths, including depth 0.25 m (Median = 0.65), Z= -3.12, *p*= 0.002; depth 0.5m (Median = 0.02), Z= -4.10, *p*= 0.001); depth 1.0 m (Median = 0.05), Z= -4.10, *p*= 0.001); depth 1.5 m (Median = 0.02), Z= -4.10, *p*= 0.001); and 2.0 m (Median = 0.01), Z= -4.10, *p*= 0.001). Note that the Z value and statistical significance shows an identical difference between 0.0 m depth and 0.5 m to 2.0 m depths (Table C.6.24).

From the above, it can be claimed that the depth is significant in predicating N % and H % but not significant for predicating S % and C % contents.

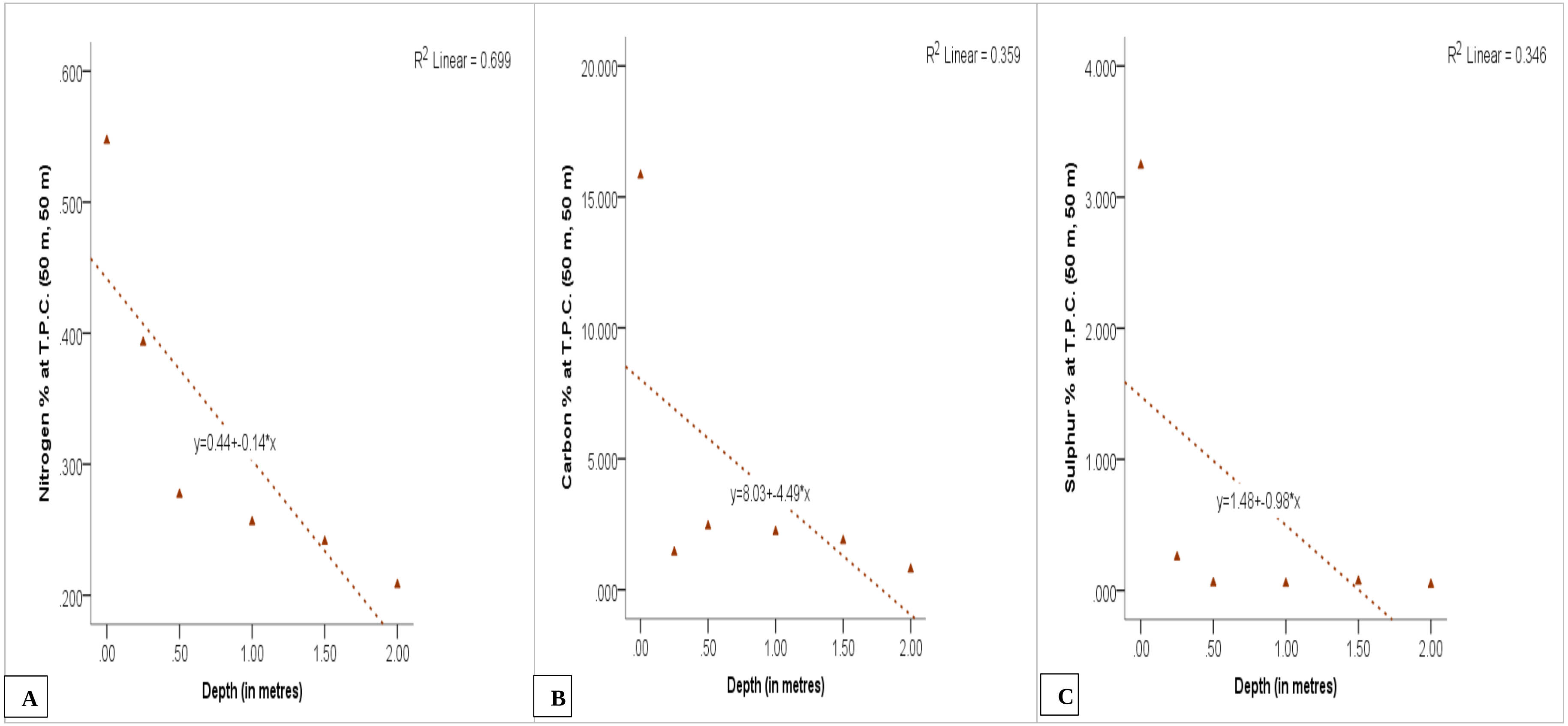


Figure 6.18. Scatterplot showing relationship between six different depths and N % (A), C % (B) and S % (C) percentages at T.P.C (50 m, 50 m), at contaminated site.

6.5 Gas Chromatograph Mass Spectrometry (GC-MS)

6.5.1 Laboratory Results of GC-MS

Of the 22 tested samples extracted from the hydrocarbon contamination site, the total number found to be contaminated with TPH are shown in Table 6.10.

The findings from the GC-MS tests, e.g. the TPH concentration (mg/kg) and chemical composition, conducted on samples detected with TPH obtained from the contaminated (dry *oil lake*) site taken at depths of 0.0 m, 0.25 m and 0.5 m below ground, are shown in appendix C; Tables C.6.25 to C.6.47 and Figures C.6.1 to C.6.23. One example of a sample detected with TPH from T.P.C of (0 m, 25 m) at 0.0 m depth via GC-MS instrument is shown in Table 6.11 and Figure 6.19.

As clarified in chapter 2 (section 2.7, p. 36), the contaminated site in this study resulted from crude oil spills from the Iraqi invasion, - more than 26 years ago - therefore, this petroleum hydrocarbon contaminant mixtures has been subjected to the time factor which has caused several alterations through weathering (dissolution or evaporation), chemical degradation (effects of sunlight, heat, and air and soil chemistry) and biological alteration (impact of microorganisms).

Figure 6.19 represents the total ion chromatogram (TIC) of typical soil contaminated samples analysed by the GC-MS test; i.e. results were obtained through sample injected into the GC-MS system for subsequent separation and identification according to their boiling point and characteristic mass fragments, respectively. Whereas, TIC displayed of typical compounds which might be related to: paraffin’s mono aromatics; bi aromatics; or tri aromatic; which these substances are related to in TPH terms. For example, all the chemical compositions detected in contaminated soil samples for T.P.C. (0 m, 25 m) at a depth of 0.0 m via the GC-MS instrument, belong to paraffin’s compounds (considered to be part of the TPH) (Table 6.11 & Figure 6.19).

Therefore, figure 6.19, clearly shows a hump and spiky peak of individual compounds which represent a TPH composition of around 19.8 to 24.2 minutes of retention time for contaminated samples.

The GC-MS results for samples taken from the contaminated site but not detected with TPH are shown in figures C.6.24 up to C.6.108 at depths of 0.0 m, 0.25 m, 0.5 m, 1.0 m and 1.5 m belowground. Figure 6.20 illustrates an example of the result of a sample found without any TPH for T.P.C. (0 m, 0 m) at a depth of 0.0 m. On the other hand, the GC-MS results for samples obtained from the non-contaminated site are displayed in figures C.6.109 to C.6.117. An example of one control sample for T.P.C. (50 m, 50 m) at 0.0 m depth is given in Figure 6.21.

The TPH concentrations (mg/kg) detected in contaminated samples (contaminated site) at depths of 0.0 m, 0.25 m and 0.5 m are shown in Tables C.6.48 to C.6.50. The same tables (C.6.48 to C.6.50) also exhibit the minimum, maximum, mean and standard deviation values of TPH (mg/kg) for samples obtained from depths of 0.0 m, 0.25 m, 0.5 m.

Table 6.12 and Figure 6.22 show the mean values of TPH concentration against the layer depth for both contaminated and non-contaminated sites. The Table indicates that the highest TPH value was in the top layer of the contaminated site recording 257.8 mg/kg. However, this decreases dramatically at depths reaching 103.6 mg/kg at 0.25 m depth and 1.0 mg/kg at 0.5 m depth. It was not detected at lower depths. The table also shows that the TPH was not detected at the non-contaminated site which confirms that the non-contaminated site has not been contaminated with hydrocarbon.

Similar tests were carried out in other areas using the (GC-MS) technique, Al-Sarawi *et al.* (1998b) used the GC-MS technique on hydrocarbon contaminated soils in the Al-Ahmadi and Greater Burgan Oil Fields and have found that soils in both regions had high concentrations of TPH. The soil from the Al-Ahmadi profile was found to have high TPH even at greater depths (80-95 cm) whereas the soil from the Burgan Oil Fields had high levels of TPH only on the surface (upper 50 cm layer). The results at the Burgan Field study very closely matched those of the present study where depth of influence for hydrocarbon contaminated soil in the Greater Burgan Field was also found to be 0.5 m from the surface.

Additionally, Okop and Ekpo (2012) investigated the spillage of crude oil which contaminated the soil within the Nigeria's Niger Delta area, approximately three months after that major incidence. Samples of soil were extracted from depths of 0.0 m to 0.15 m, 0.15 m to 0.3 m and 0.30 m to 0.60 m belowground; the samples were examined using GC equipped with a device to detect flame ionisation. The result showed that the TPH concentrations for the topsoil, sub-soil and lowest depth measured were 9 – 289 mg/kg, 8 – 318 mg/kg and 7 – 163 mg/kg respectively. It also indicated that the levels of total hydrocarbon contents were higher in comparison with the reference site. The results prove that there is an urgent need to develop a complete and sustainable remediation and monitoring plan for the environment.

Pathak *et al*. (2011) investigated the effect of petroleum oil on the soil in the Jaipur area (India). Soil samples were taken at a depth of 60 mm below ground close to the India Motor Garage in Transport Nagar India. Chemical analysis of soil was performed using the GC-MS test in order to find the TPH concentration in the soil samples from two different sites, i.e. contaminated & non-contaminated areas. They observed significantly high TPH concentrations in soils from the contaminated site as compared to the non-contaminated site.

Thus, the present study is also in line with past studies, and has confirmed the hydrocarbon contamination at the contaminated dry *oil lake* site; also showing that the top 50 cm of depth is an effective zone of contamination with hydrocarbon presence (Table 6.12 and Figure 6.22).

Table 6.10. Number of detected and not detected samples with TPH tested by GC-MS test at contaminated site.

Depth (m)	Total Number of Samples Detected with Total Petroleum Hydrocarbons (TPH) out of 22 Samples Collected at each Depth	The Percentage of the Detected Samples out of the Total 22 Samples.
0.0 m	16	73.00 %
0.25 m	7	32.00 %
0.5 m	1	5.0 %
1.0 m	ND*	ND*
1.5 m	ND*	ND*

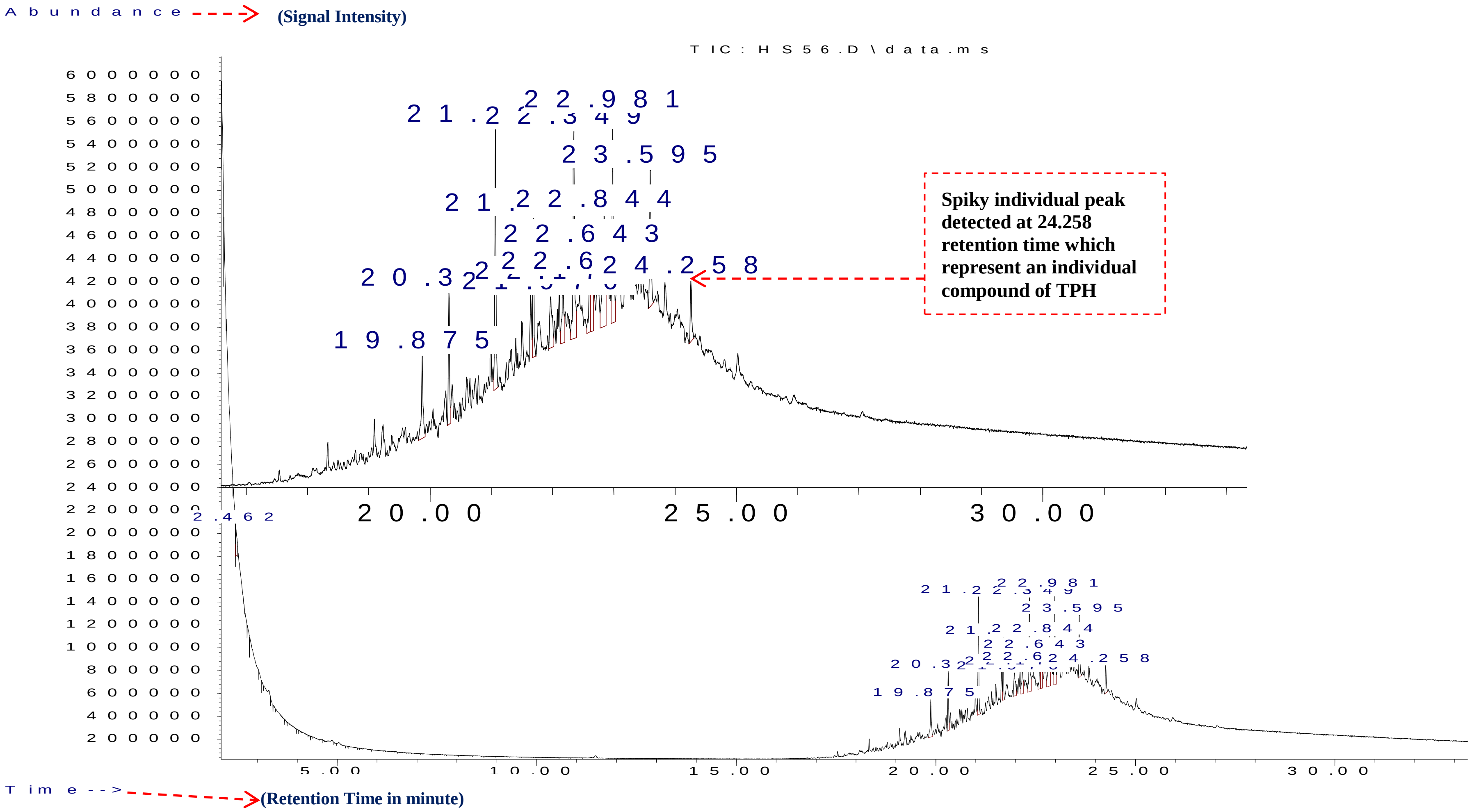
Note: ND*: not detected with petroleum hydrocarbon.

Table 6.11. An example shows the results for one of the detected sample with TPH which tested by GC-MS instrument for T.P.C (0 m, 25 m) at depth (0.0 m) of contaminated site.

Peak	Ret. Time	Chemical Composition of the TPH in the Contaminated Soil Sample	Area Under the Curve (m2)	Chemical Composition Formula	Classification of the TPH Substance based on Aliphatic or Aromatic	Concentration of each TPH Chemical Composition Detected in the Contaminated Soil Sample (µg/ml)	Concentration of each TPH Chemical Composition Detected in the Contaminated Soil Sample (mg/kg)	Total Concentration of the Total TPH Compositions Detected in the Contaminated Soil Sample (mg/kg)	References
1^{*2}	2.462 PV	---------	5656160	---------	---------	46.62	15.54	352.37	---------
2^{*1}	19.875 PV	2-Methyldodecane	6480023	$C_{13}H_{28}$	Aliphatic C12-C16	57.30	19.1		(Two-Methyldodecane, n.d.)
3^{*1}	20.311 PV	Tetramethylpentadecane	7042148	$C_{19}H_{40}$	Aliphatic C16-C35	64.56	21.52		(Pristane, n.d.)
4^{*1}	21.069 VV	Tetramethylhexadecane	14937449	$C_{20}H_{42}$	Aliphatic C16-C35	166.812	55.604		(Two, 6, 10, 14-tetramethylhexadecane, n.d.)
5^{*1}	21.689 VV	Nonadecane	7206111	$C_{19}H_{40}$	Aliphatic C16-C35	66.70	22.233		(Nonadecane, n.d.)
6^{*1}	21.970 PV	Dimethylhexadecane	5585519	$C_{18}H_{38}$	Aliphatic C16-C35	45.70	15.233		(Two, 2-dimethylhexadecane, n.d.)
7^{*2}	22.172 VV	---------	5274027	---------	---------	41.67	13.89		---------
8^{*1}	22.349 VV	Eicosane	14529974	$C_{20}H_{42}$	Aliphatic C16-C35	161.53	53.843		(Icosane, n.d.)
9^{*1}	22.608 VV	Eicosane	4485710	$C_{20}H_{42}$	Aliphatic C16-C35	31.46	10.486		(Icosane, n.d.)
10^{*1}	22.643 VV	Pentadecane	6449501	$C_{15}H_{32}$	Aliphatic C12-C16	56.89	18.963		(Pentadecane, n.d.)
11^{*1}	22.844 VV	9,10-Dimethylanthracene	13104405	$C_{16}H_{14}$	Aromatic C16-C21	143.07	47.69		(Nine, 10-dimethylanthracene, n.d.)
12^{*1}	22.981 VV	Heneicosane	13477178	$C_{21}H_{44}$	Aliphatic C16-C35	147.90	49.3		(Heneicosane, n.d.)
13^{*1}	23.595 PV	Docosane	8978255	$C_{22}H_{46}$	Aliphatic C16-C35	89.64	29.88		(Docosane, n.d.)
14^{*1}	24.258 PV	Octadecane	4029007	$C_{18}H_{38}$	Aliphatic C16-C35	25.547	8.515		(Octadecane, n.d.)

Notes: ^{1*}***Brown colour clarify the hydrocarbon compounds and their concentrations detected in soil sample.***

^{2*}***Blue Colure clarify the unknown chemical compounds and their concentrations (not identified by diesel standard) detected in soil sample which are excluded from the total concentration of the TPH.***



Spiky individual peak detected at 24.258 retention time which represent an individual compound of TPH

Figure 6.19. An example of Total Ion Chromatograms (TIC) of detected soil sample with TPH for coordinate (0 m, 25 m) at depth (0.0 m), at contaminated site (Al-Magwa area).

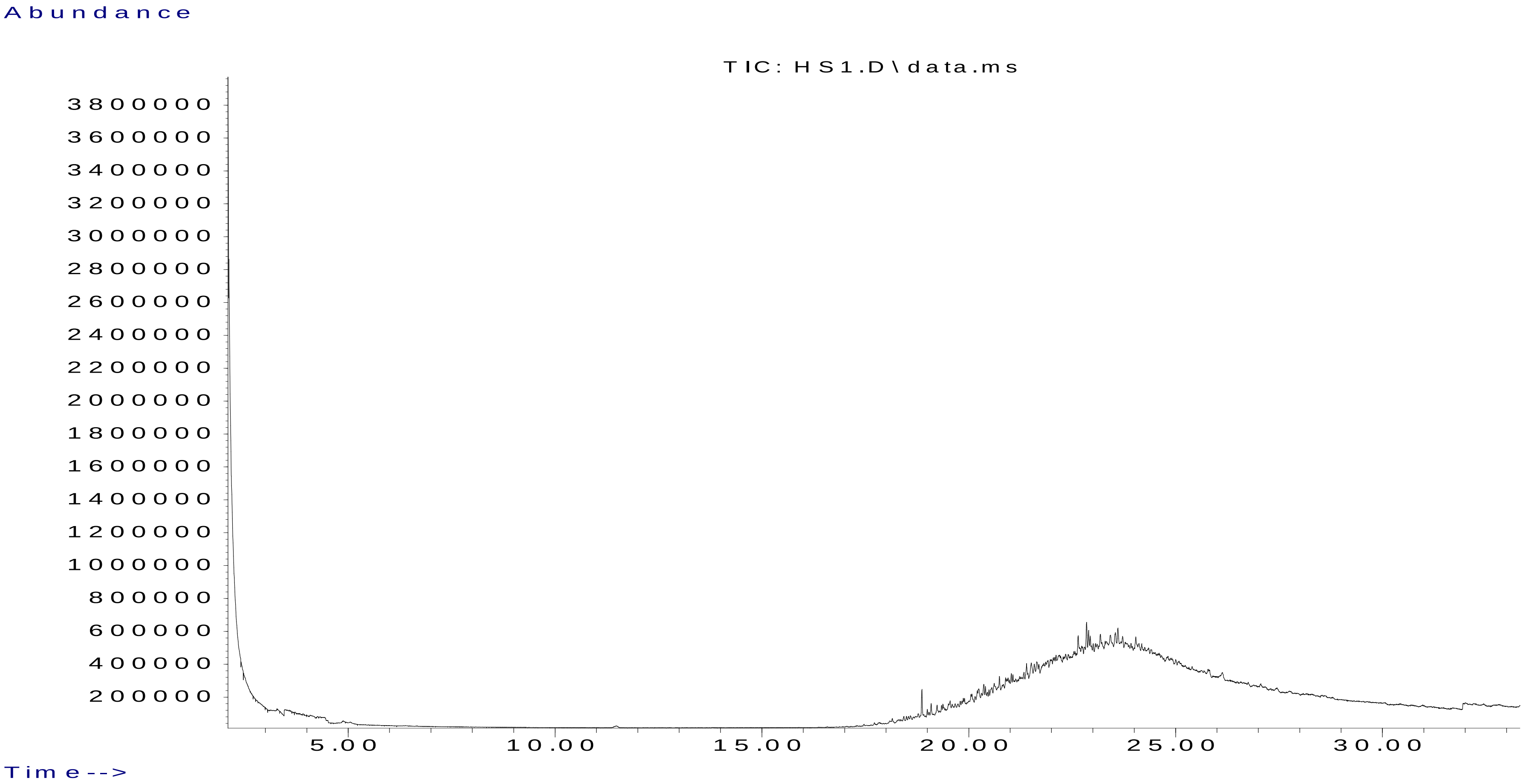


Figure 6.20. Example of Chromatograph shows one of the non-detected samples for the TPH tested by GC-MS instrument for T.P.C (0 m, 0 m) at depth (0.0 m) of contaminated site.

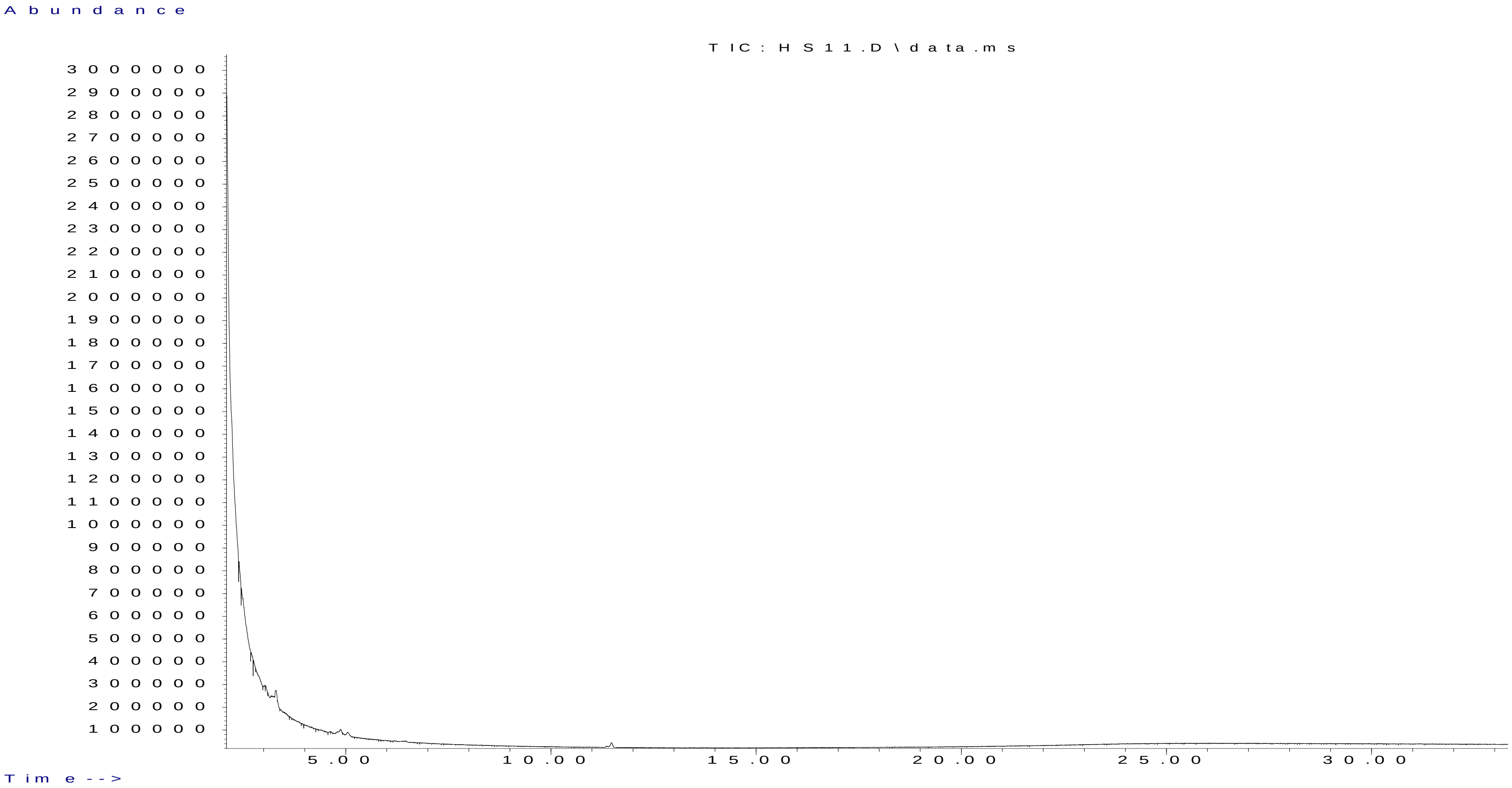


Figure 6.21. Example of Chromatograph shows one of the control sample tested by GC-MS instrument for T.P.C (50 m, 50 m) at depth (0.0 m) of control site.

Table 6.12. Mean values of the TPH concentration (mg/kg) in the soil samples at contaminated and non-contaminated site at different depths.

Depth (m)	**The Mean Value of the TPH Concentration in the Soil Samples (mg/kg)**	
	At Contaminated site	***At Non-contaminated site***
0.0	257.80	0
0.25	103.65	0
0.5	1.0	0
1.0	0	0
1.5	0	0
2.0	0	0

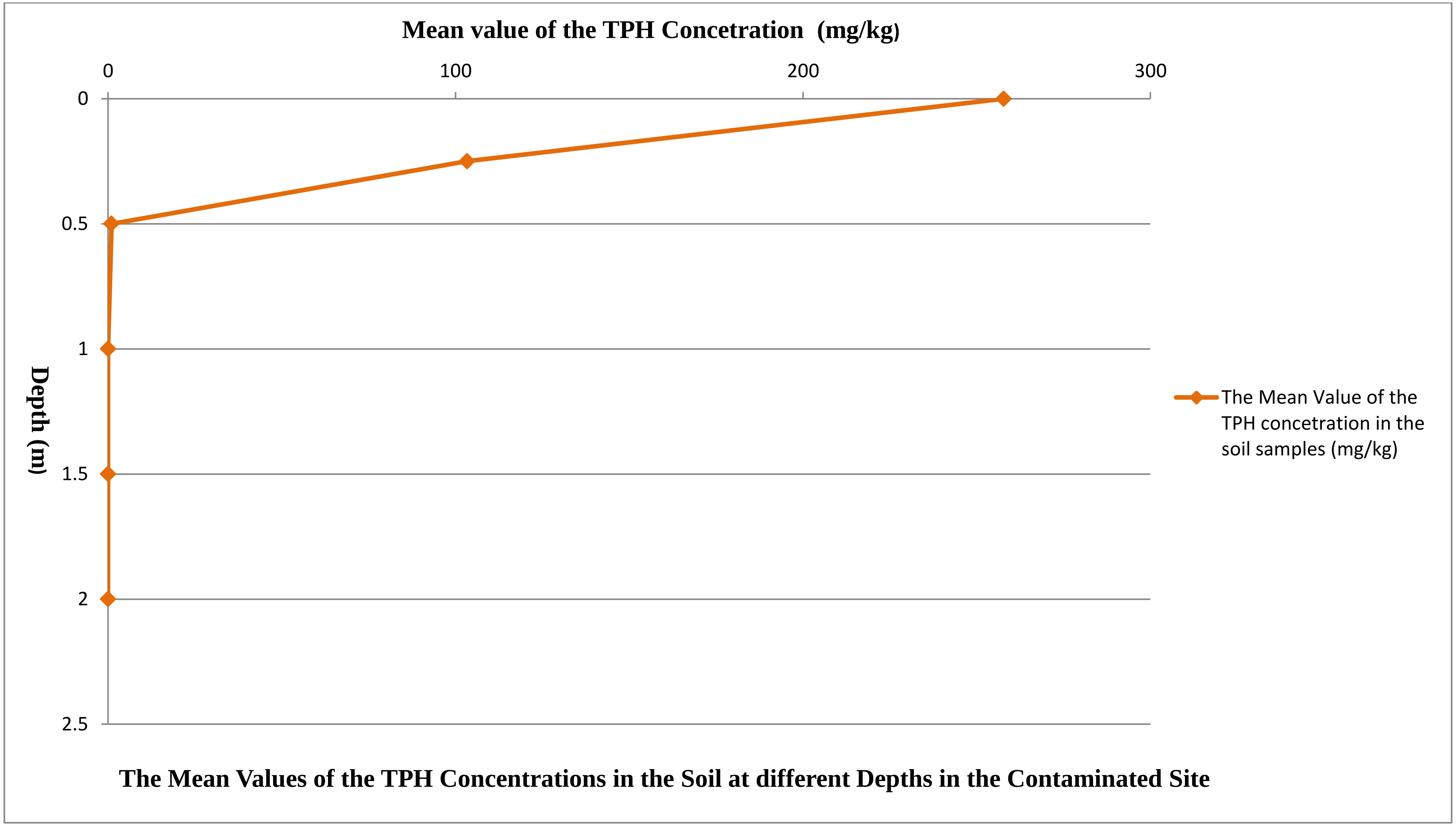


Figure 6.22. Comparing the mean value of the TPH concentrations (mg/kg) in the soil and depth at contaminated site.

6.5.2 Statistical Summary of GC-MS

Boxplots revealed outliers at all three depths - 0.0 m, 0.25 m, and 0.5 m - in the TPH concentration (mg/kg) data detected at contaminated site. (Figure 6.23) These extreme values were retained in the data, as they were a true reflection of the hydrocarbon concentration (mg/kg) values in this type of soil sample. The data was also skewed at these three depths, as Shapiro-Wilk results violated the assumption of normality; therefore non-parametric tests were performed (Table C.6.51).

Wilcoxon analysis revealed that at the contaminated site, there was a significant difference in TPH concentration (mg/kg) between depth 0.0 m (Median = 83.48) and depth 0.25 m (Median = 0.00), Z= -2.58, p= 0.01; and depth 0.5 m (Median = 0.00), Z= -3.51, p= 0.001). TPH concentration (mg/kg) is significantly higher in top soil than in next two levels (Tables 6.13 & C.6.52 and Figure 6.24).

In summary the statistical analysis showed that the concentration of TPH at the top layer was significantly higher than the concentration at deeper depths, confirming that the concentration values at depths of 0.25 m and 0.5 m were lower than at the top layer – as found in the laboratory results.

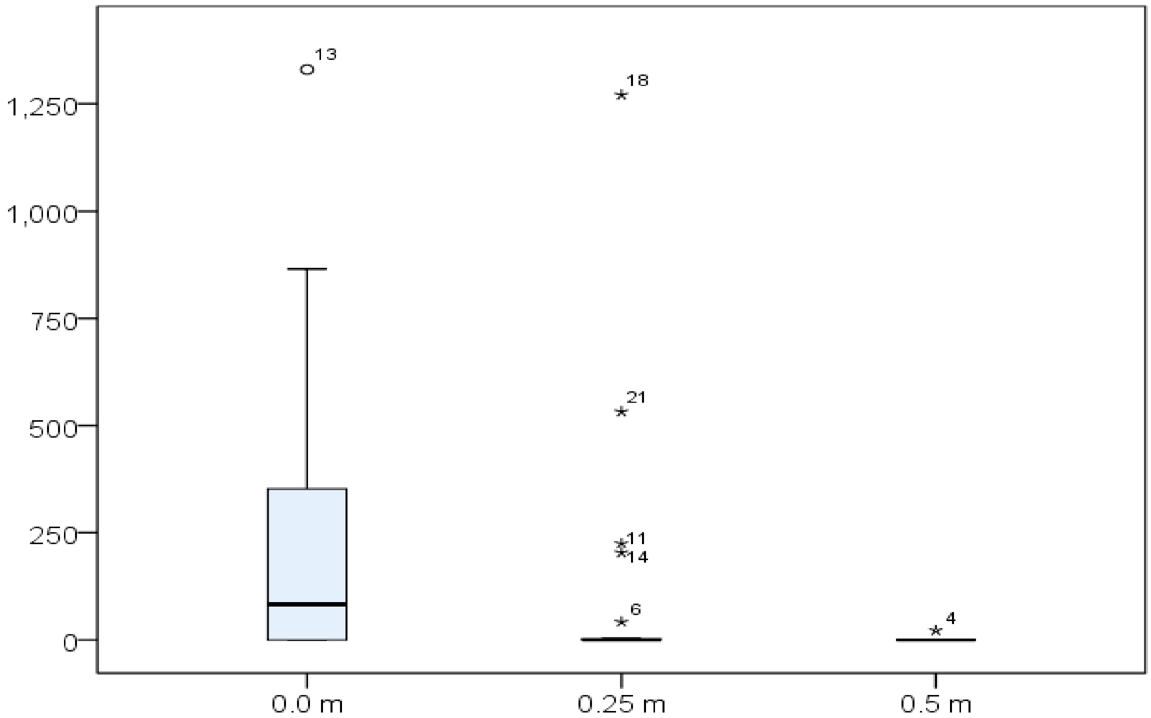


Figure 6.23. Boxplots of TPH concentrations values (mg/kg) in the soil for contaminated site. (*Note: the symbol of "*" and "°" in the graph denotes outlier*).

Table 6.13. The significant differences of the TPH variable in the soil between different depths (0.0 m, 0.25 m & 0.5 m) at contaminated site.

Depth (m)	N	Mean	Median	SD	Min	Max	Z (0.0 m-0.25 m)	Z (0.0 m-0.5 m)
0.0	22	257.15	83.48	345.77	0.00	1330.08	-2.58	-3.51
0.25	22	103.65	0.00	289.20	0.00	1271.03		
0.5	22	0.99	0.00	4.66	0.00	21.86		
***p*-value**							0.010*	0.001*

Note, *p < .05 indicates to the significant difference in the variable between two different groups.

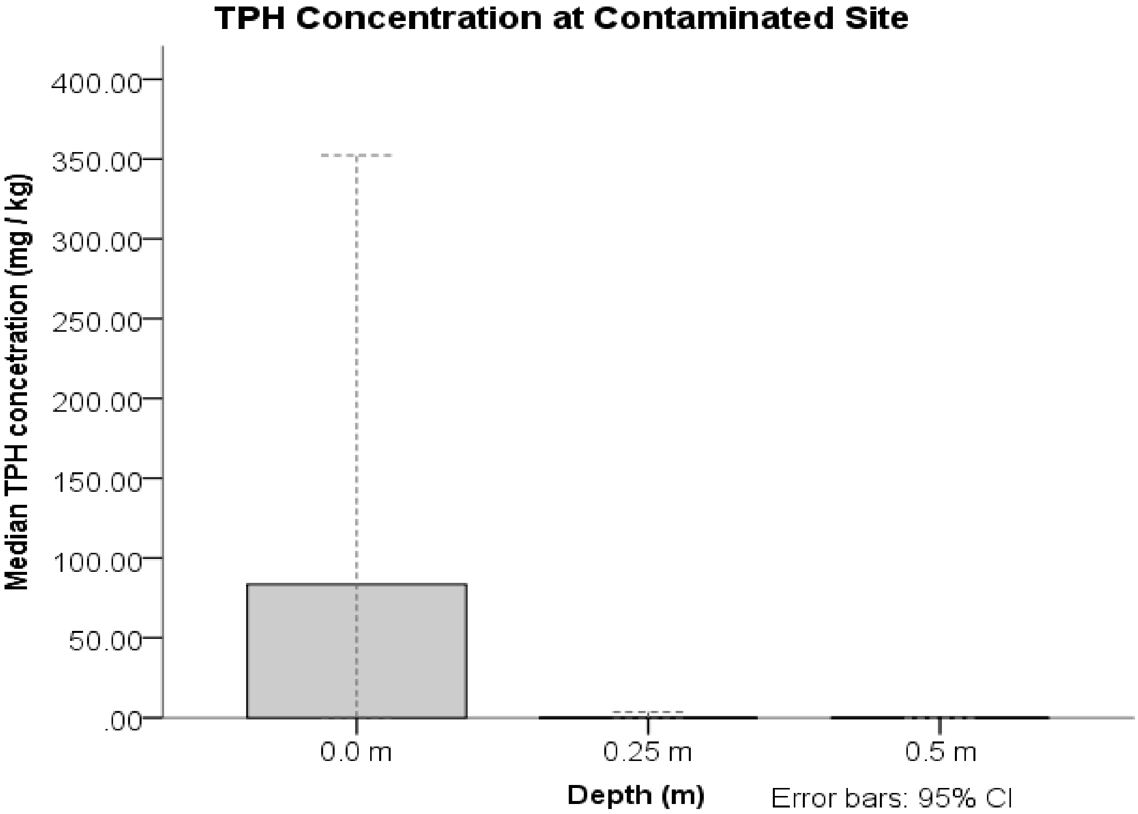
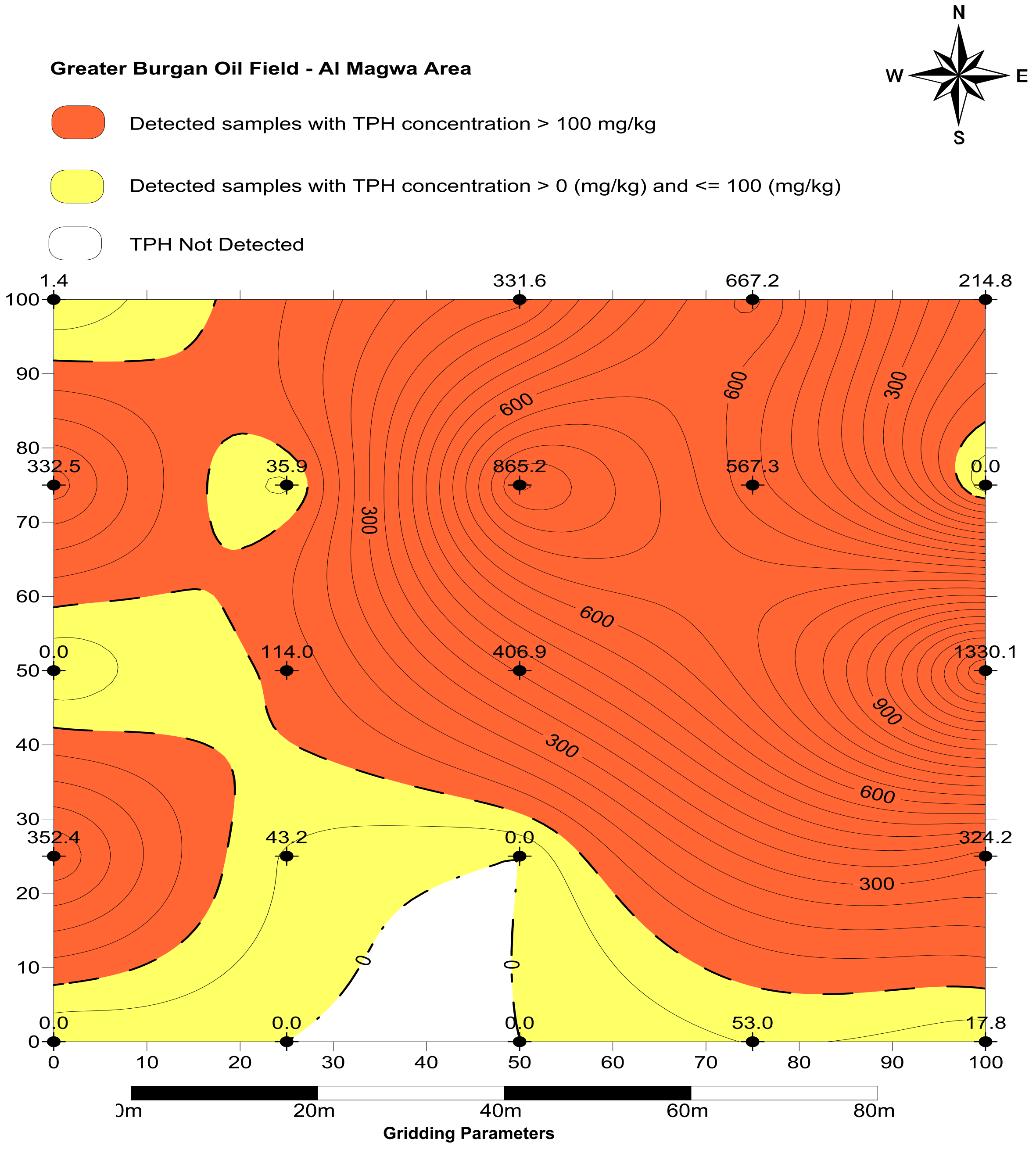


Figure 6.24. Comparing the median values of TPH concentration (mg/kg) between different depths (i.e. 0.0 m, 0.25 m & 0.5 m) at contaminated site. ***(Note: Error bars denote 95 % lower and upper confidence intervals).***

6.5.3 Spatial Modelling of GC-MS Results (Contour Map)

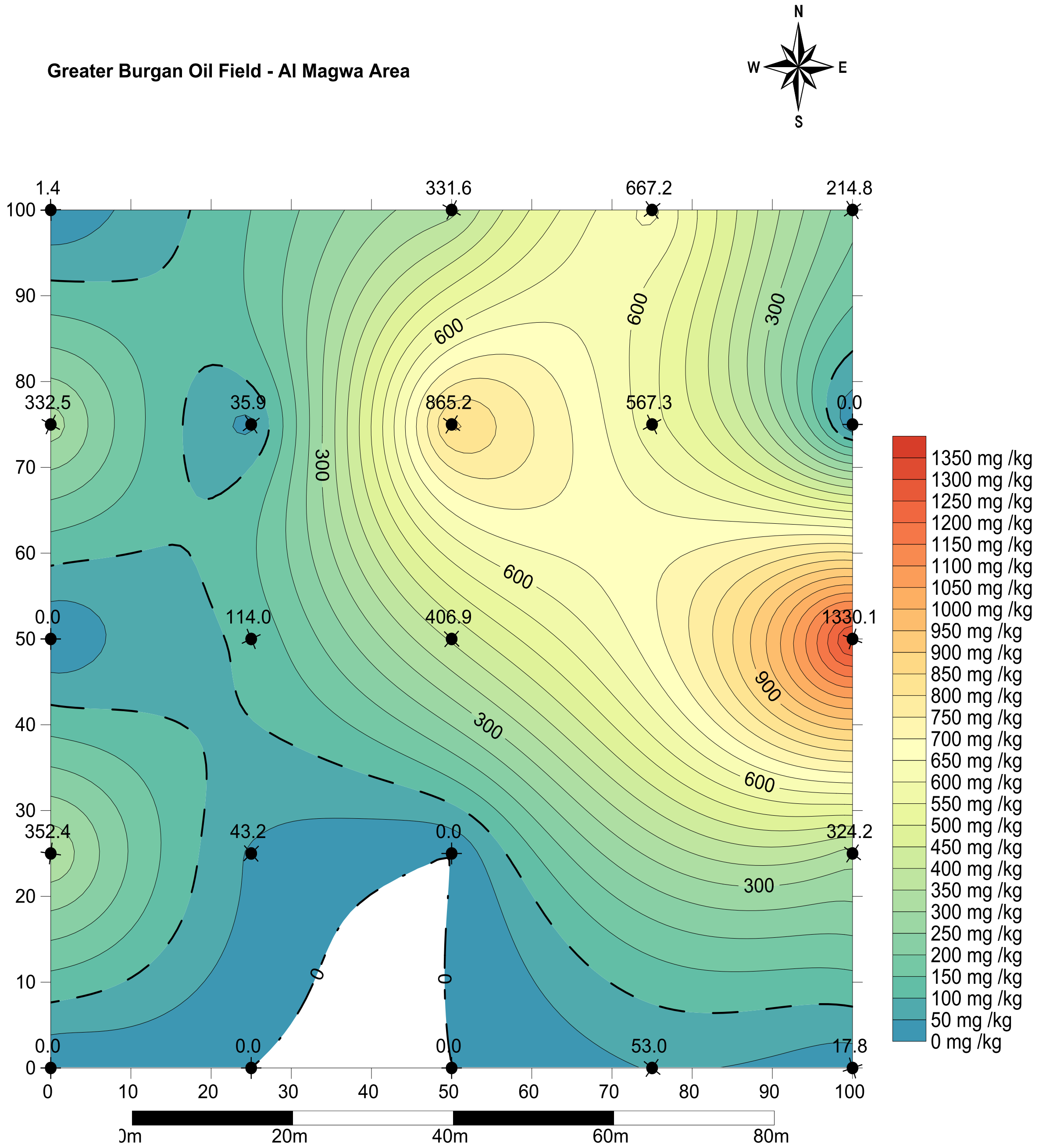
The TPH concentrations (mg/kg) detected in contaminated samples (contaminated site) at depths of 0.0 m, 0.25 m and 0.5 m are shown in Figures of contour maps 6.25 to 6.30. The contour maps demonstrate the concentration of oil spillage (mg/kg) based on three contrasting colours; this was carried out according to the TPH value recommended by the U.S. EPA for soil clean-up (exceeding 100 mg/kg).

As such the TPH values of higher than 100 mg/kg are represented by the colour brown. The yellow signifies the detected samples with TPH values of below 100 mg/kg and more than the limit of TPH detection (in accordance with U.S EPA which states that such concentrations does not need clean-up). White indicates the limit of detection samples with TPH.



Interpolation Algorithm: Kriging
Grid Spacing: 1m
Grid Size: 100 rows x 100 columns
Contour Spacing: 50 mg/kg

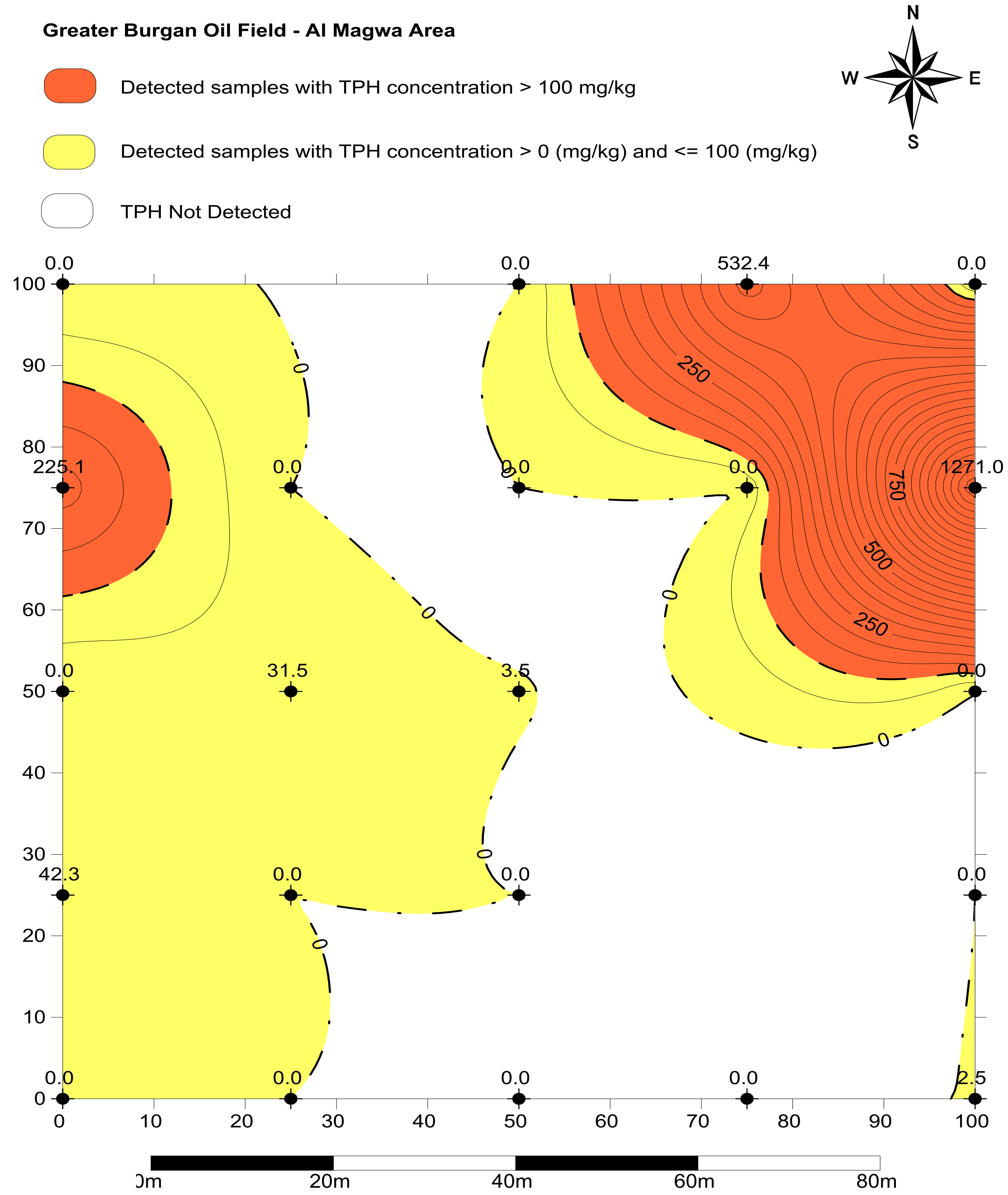
Figure 6.25. Contour Map illustrated the top view of dry *oil* spilled in the soil at depth 0.0 m in Greater Burgan Oil Field (Al-Magwa area).



Gridding Parameters

Interpolation Algorithm: Kriging
Grid Spacing: 1m
Grid Size: 100 rows x 100 columns
Contour Spacing: 50 mg/kg

Figure 6.26. Contour map indicated the detected soil samples with TPH concentration at depth 0.0 m in Greater Burgan Oil Field (Al-Magwa area).



Gridding Parameters

Interpolation Algorithm: Kriging
Grid Spacing: 1m
Grid Size: 100 rows x 100 columns
Contour Spacing: 50 mg/kg

Figure 6.27. Contour Map illustrated the top view of dry *oil* spilled in the soil at depth 0.25 m in Greater Burgan Oil Field (Al-Magwa area).

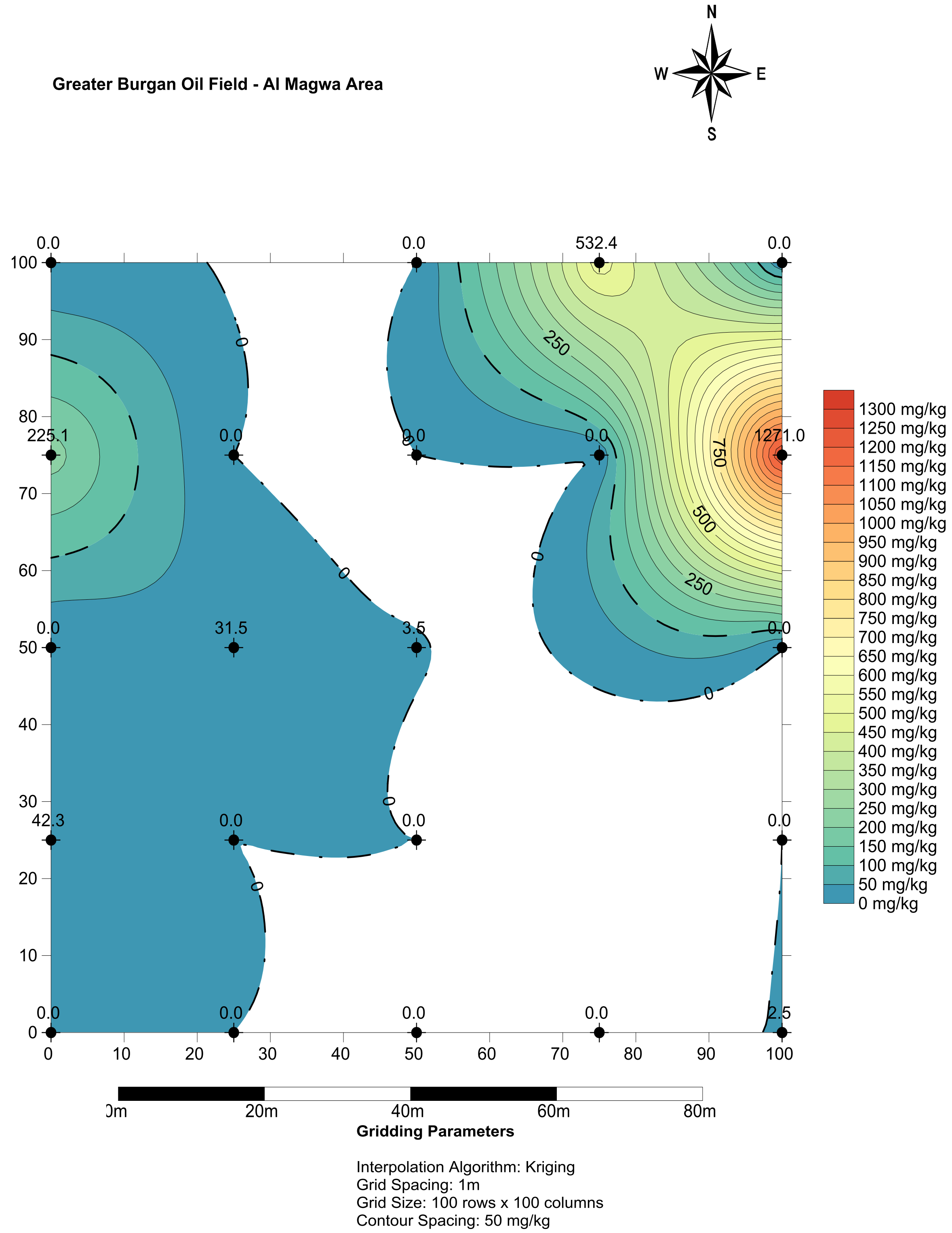


Figure 6.28. Contour map indicated the detected soil samples with TPH concentration at depth 0.25 m in Greater Burgan Oil Field (Al-Magwa area).

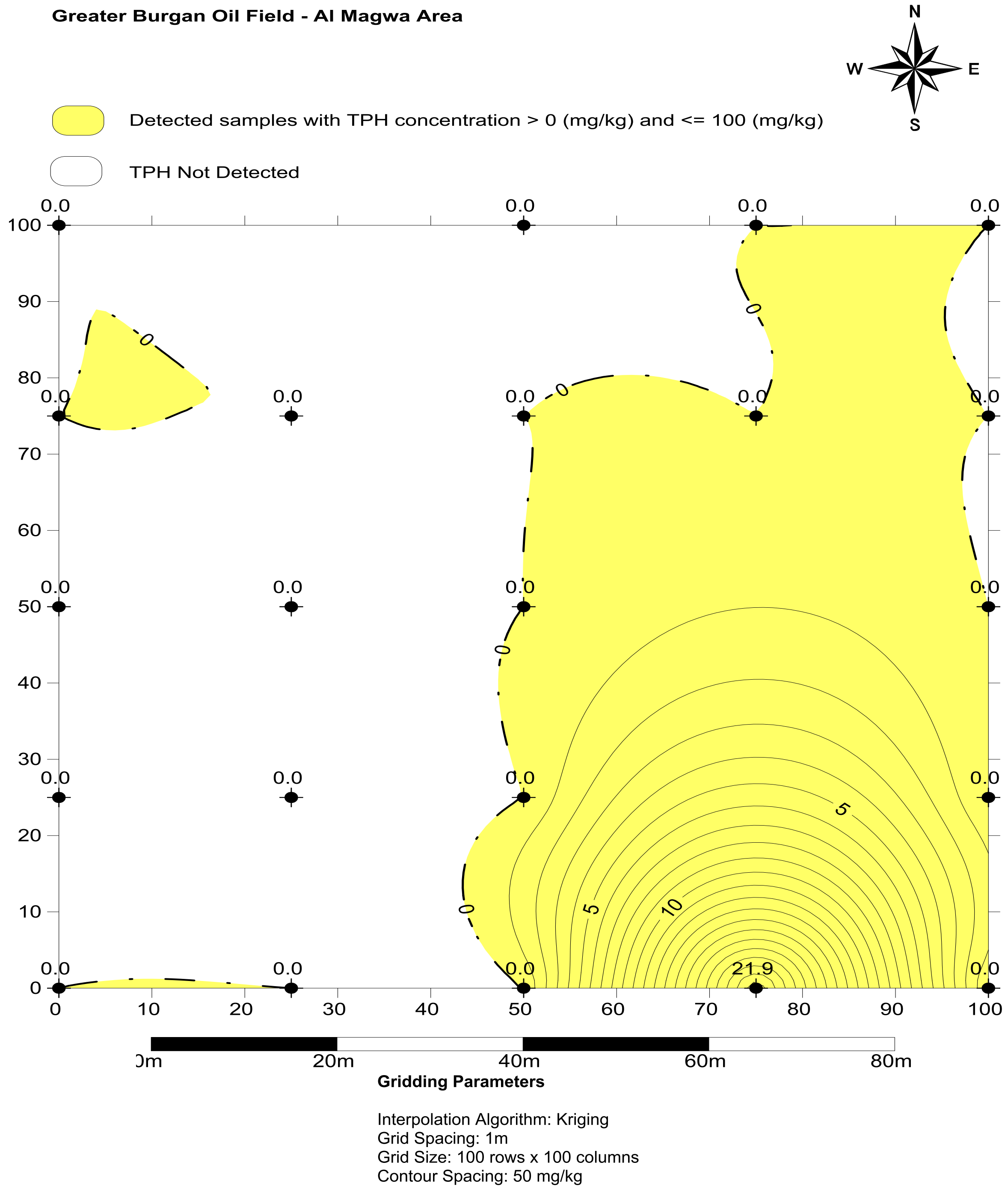
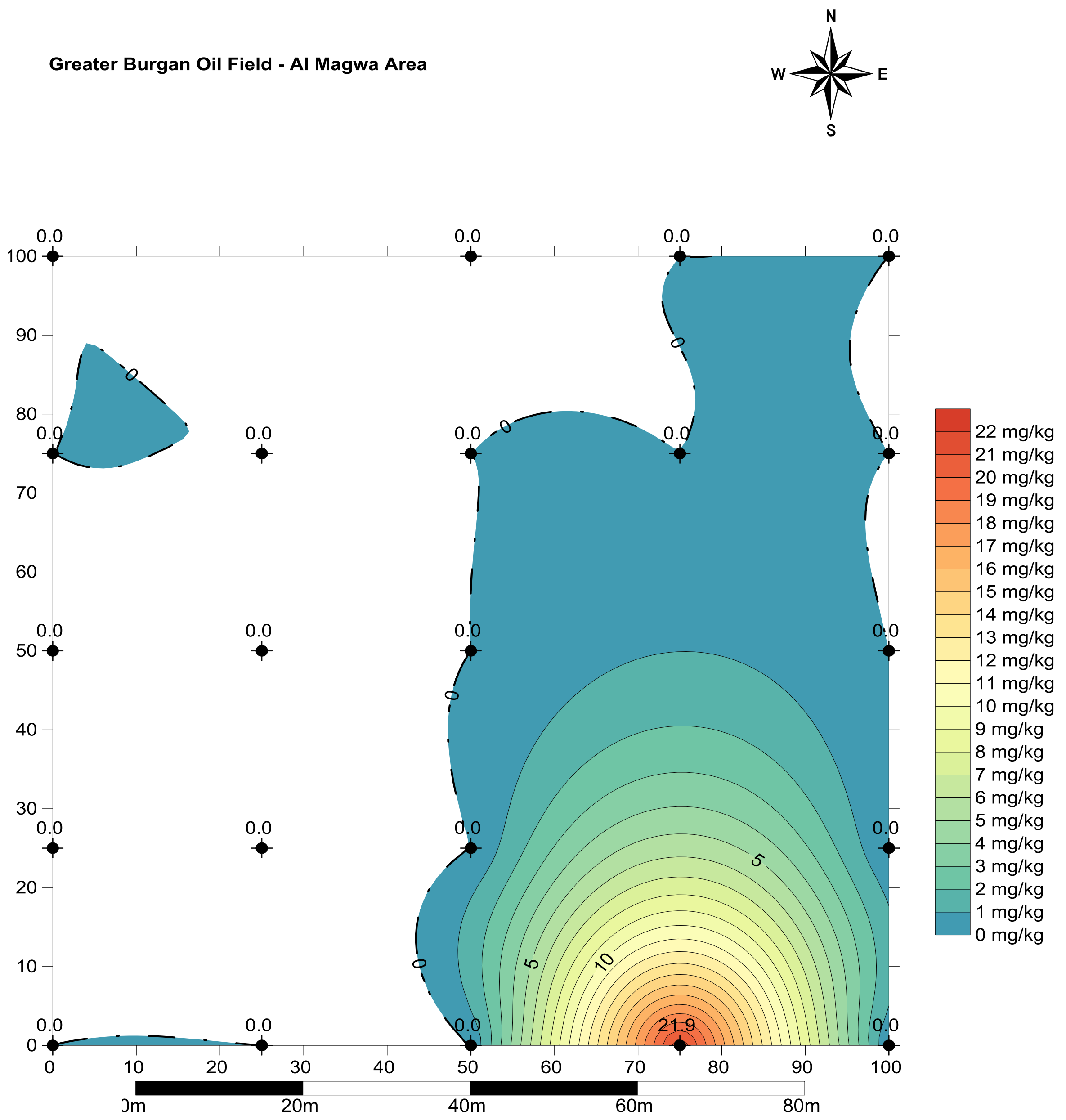


Figure 6.29. Contour Map illustrated the top view of dry *oil* spilled in the soil at depth 0.5 m in Greater Burgan Oil Field (Al-Magwa area).



Gridding Parameters

Interpolation Algorithm: Kriging
Grid Spacing: 1m
Grid Size: 100 rows x 100 columns
Contour Spacing: 50 mg/kg

Figure 6.30. Contour map indicated the detected soil samples with TPH concentration at depth 0.5 m in Greater Burgan Oil Field (Al-Magwa area).

6.6 Summary

This Chapter has presented the findings of the geochemical characteristics of soil samples taken from two different locations of the contaminated (dry *oil lake*) and the non-contaminated sites. All the findings of the geochemical characterisation of soil were undertaken to a statistical analysis. The investigated properties were pH, water soluble Cl-, SO_3 and SO_4 content, EA (i.e. N %, C %, S % & H %) and GC-MS (i.e. TPH content) analysis. The following conclusions were drawn from these analyses:

- The difference between minimum and maximum pH values from the hydrocarbon contaminated site was higher than those from the non-contaminated site. Additionally, the minimum values of pH decreased due to contamination. Statistical analysis proved the above findings, i.e. after deleting outlier values.

- Cl- concentration was very high at the top layer of the hydrocarbon contaminated site and then decreased at depths lower than 0.5 m. However, at the non-contaminated site, the chloride concentration was approximately zero. Statistical analysis proved that there was a significant difference in Cl- concentration between contaminated and non-contaminated sites. Furthermore, there was significant difference in Cl- concentration between depth 0.0 m and all other depths at contaminated site, while, there was only one significant difference between depth 0.0 m and 0.25 m at non-contaminated site.

- In terms of SO_3 and SO_4, concentrations were found to be higher only at the top soil layer of the hydrocarbon contaminated site than the non-contaminated site. At depths lower than 0.25 m in the contaminated site, however, both SO_3 & SO_4 dropped down suddenly to become lower than that in the non-contaminated site. The concentration was then further decreased (at the hydrocarbon contaminated site) at lower depths until it reached approximately a constant value between 1.0 m and 2.0 m depths. At the non-contaminated site the concentration of both sulphate types were approximately constant throughout the depths. Statistical analysis confirmed that the above finding was significantly true. While, statistically, no relationship was found between the SO_3 and SO_4 content and the depth at T.P.C. (50 m, 50 m) at both sites.

- The C % content was very high in the top layer of the contaminated site. However, it decreased sharply with depth. On the other hand, at the non-contaminated site a negligible carbon content was shown even for the top layer.

  Nearly the same trend of changes in the C % content was noted regarding the changes of N %, S % and H % contents with the depth levels; although the concentrations of these materials were comparatively low even at the top layer of the contaminated site as compared with the C % content. At the non-contaminated site, however, these materials were negligible. Statistical analysis proved that the mean percentage values of the N %, C % & S % and median percentage of H % had significant differences between soil samples taken the contaminated and non-contaminated sites. Additionally, the percentage values of N % and H % in the soil at T.P.C. (50 m, 50 m) in the contaminated site was found to be significantly decreased with the increase in depth while no significant relationship was found between depth and S % & C % contents.

- The TPH value was higher in the top layer of the contaminated site but decreased with depth down to 0.5 m; it was not detected at lower depths. TPH was never detected at the non-contaminated site. Statistical analysis proved that the TPH concentration had significant differences in the contaminated soil between depths 0.0 m, 0.25 m and 0.5 m only.

The influence of ground hydrocarbon contamination on human health will be assessed in the next Chapter. This will be done by classifying the pollutants in the hydrocarbon contaminated soils into carcinogenic and non-carcinogenic categories as well as by developing ‘ground modelling’ through obtaining the clean-up levels for this contaminated site using RISC-5 software.

7. HUMAN HEALTH RISK ASSESSMENT (HHRA) OF HYDROCARBON CONTAMINATED SOILS

7.1 Introduction

Petroleum Hydrocarbon Standards for Soil Clean-up are described in this chapter. Also, the explanations of HHRA phases as follows: (1a), Hazard Identification (1b), Hazard Assessment; (2a) Risk Estimation and (2b) Risk Evaluation are provided for the purpose of applying these stages to the potential hydrocarbon contamination site (Al-Mgawa area) showing how they have been adhered to.

The results of the HHRA carcinogenic and non-carcinogenic risk found in the soil samples detected with hydrocarbon contamination (at dry *oil lake*) by means of RISC-5 modelling software (Spence and Walden, 2001), will also be presented in this chapter.

This analysis was achieved through modelling the TPH aliphatic and aromatic hydrocarbons fractions including their concentrations (mg/kg) of the detected samples determined by the GC-MS test as well as some hydrocarbon compounds associated with Anthracene and Pheneanthrene (i.e. linked to PAH which could be toxic (Wenzl *et al*., (2006)) which were determined by the GC-MS test.

This HHRA was examined so as to estimate the risk and to calculate the clean-up levels required for the identified locations - particularly for the safety of inhabitants who may wish to reside in these area in the future.

Section 7.2 presents the important criteria of the HHRA within the concerned site; the standards for soil clean-up of petroleum hydrocarbon are described in section 7.3. Section 7.4 outlines the HHRA scenarios assumed for the contaminated sites. The applications for the HHRA scenarios for the site under study are explained in Section 7.5 including the estimation of the potential risks (carcinogenic and non-carcinogenic risks) and clean-up levels for the site by means of RISC-5 software.

7.2 Human Health Risk Assessment (HHRA)

This section will explain how the application of HHRA was performed only on soil samples detected with petroleum hydrocarbons obtained from the contaminated site of the Al-Magwa area. Assessment was carried out on whether the contaminated soil had any influence on human health with regards to carcinogenic and non-carcinogenic health impacts. It also ascertained the extent of any potential risk expected from the site bearing in mind that the contaminants have been present since the 1990 Gulf War.

As such, the HHRA performed within this research was very much dependent on the accredited concentration of the TPH screening value for the soil - as approved by international environment regulations, (U.S EPA, UK EPA etc). This was carried out through comparing the screening value of the TPH, i.e. TPH screening value approved by international environment regulations with the detected hydrocarbon concentrations found at the site. For example, if the total of detected hydrocarbon concentrations (mg/kg) at the site exceeds the TPH screening value, then there is an urgent need to evaluate the HHRA. This was accomplished by implementing the RAS which entails identifying a practical measure in managing risks in the contamination sites utilising four steps. These consist of: Phase-1a Hazard Identification; Phase-1b Hazard Assessment; Phase-2a Risk Estimation; and Phase-2b Risk Evaluation.

In an effort to carry out risk assessment to ascertain whether the presence of the dry *oil lake* residue could cause serious concern to human health, i.e. carcinogenic material, the RISC-5 software was employed. This also helped to calculate the clean-up values for the contaminated site; this will be necessary since the Kuwait mega housing project will be due to be launched (see Chapter 2).

The difference between the terms of ‘screening level’ and ‘clean-up level’ values that the ‘Screening level’ role in the contamination site will help to identify that the site require further evaluated for potential risks to human health. In other words, no action is required of applied HHRA at the site if the concentration of hydrocarbon contamination falls to levels below screening values. However, further HHRA will be necessary if it exceeds the screening value (U.S. EPA, 2016a).

On the other hand, the roles of the “clean up level” will assist to determine that the site requires a remediation or not. In the other words, no further remediation is necessary in the site if the ‘clean-up level’ exceeds the ‘detected hydrocarbon contamination level in the site’. However, if the clean-up level fall below the ‘detected hydrocarbon contamination level’, further remediation is needed (U.S. EPA, 2016a).

7.3 Petroleum Hydrocarbon Standards for Soil Clean-up

Utilisation of TPH concentrations in determining the screening level value for water or soil is the method usually employed by statutory bodies in the United States of America. According to TPHCWG (1998), around 75 % of the states employ the TPH-based screening level value method since these values have become the remediation criteria. McMillen *et al.* (2000) claim that an assessment of upstream TPH regulations in the USA show the highly inconsistent regulations encompassing soils within a TPH concentration of 100 to 20,000 mg/kg.

As stated by Blaisdell and Smallwood, (1993), the State of Maryland has the most stringent standards (based on US EPA for TPH) with recommended screening level values to backgrounds on non-detectable levels. The highest screening level value of TPH was set in California, at 10,000 mg/kg. However, the most cited screening level value for TPH is 100 mg/kg; in fact, a total of seventeen states in the US have set this value as the recommended threshold level for screening value one of which is Texas. On the other hand, five states have confirmed 50 mg/kg TPH as their recommended screening level value and four other states have set only 10 mg/kg TPH (Blaisdell & Smallwood, 1993).

Based on these scenarios, it is evident that there is no particular consensus value worldwide that can be set for the TPH screening level value. In other words, the *screening level value* values of the TPH adopted by the USA alone, even varies between States. However, it has been observed that the most commonly used value for petroleum screening level value, is 100 mg/kg which is followed by the State of Texas (Blaisdell & Smallwood, 1993). Details of TPH screening level value Regulations for Gasoline and Diesel in the U.S can be found in tables D.7.1 and D.7.2 in appendix D (Blaisdell & Smallwood, 1993).

A procedure to determine TPH Risk based on Screening Levels (RBSLs) for petroleum products in protecting human health has been established and issued by TPHCWG (McMillen *et al*., 2000). Essentially, TPH RBSLs are derived from the possibility of hydrocarbons causing non-cancer related detrimental effects on health. Further, according to McMillen *et al*. (2000), RBSLs are based on the concentrations of specific carcinogens in products of petroleum, e.g., benzo [a] pyrene and benzene which are dealt with separately.

McMillen *et al*. (2000), state that the main issue for validating RBSLs (for refined products) is because refined petroleum contains a thousands of individual hydrocarbons (as well as other mixtures), individually with a separate set of chemical and physical properties such as solubility and volatility.

Approximately 250 of these mixes have already been explicitly recognised, therefore, it is just not possible to analyse all the constituents present in most petroleum products. As such, the TPHCWG has opted for a fractionation method to assess the petroleum product's composition; 13 TPH fractions have, therefore, been identified and established on equivalent carbon (EC) numbers ranging from > EC8 - EC10 to > EC10 - EC12.

The EC number index of a compound corresponds to its boiling point. It is also correlated to its retention time in a boiling point gas chromatography (GC) column. Choosing the EC number instead of the carbon number of the TPH working group, is because it is more logical to relate the compound mobility within the environment (TPHCWG, 1999).

Aromatic and aliphatic compounds, which have the same EC number, do not behave similarly in the environment. For example, aromatics are usually more soluble in water than aliphatics of similar EC numbers and are slightly less volatile. The leaching and volatilisation factors within the two groups thus differ by many magnitude orders; for this reason the TPHCWG divided petroleum into these two main groups (TPHCWG, 1999).

However, the Environment Agency (2005) claims that the three heavier fractions – aliphatic EC 35 – EC 44, aromatic EC 35 – EC 44 - and both the aliphatic and aromatic - EC 44 – EC 70 – must be included with the 13 TPH fractions as identified by (TPHCWG). It considered that the TPHCWG method was pertinent for refined products, including petrol and diesel, however, it was not pertinent for the *"...heavier petroleum fractions associated with mineral oils, petroleum jelly and crude oil."* Although it may be required for future use, for the purposes of this work, the 3 heavier factions were not necessary because they had not been incorporated into the RISC-5's software.

Table 7.1. The 13 aromatic and aliphatic fractions with their leaching and volatilisation (boiling point) that differ by approximately one order (magnitude) (Source: TPHCWG, 1999).

*Equivalent Carbon number	Solubility (mg/L)	Vapor Pressure (atm)	Log Koc (c/c)	Boiling Point (°C)	**Henrys Law Constant	Molecular Weight (g/mole)	Diffusivity in air (cm2/s)	Diffusivity in water (cm2/s)
Aliphatic Fractions								
>EC 5- EC 6	3.6E+01	3.5E–01	2.9E+00	5.1E+01	3.3E+01	8.1E+01	1.0E–01	1.0E–05
>EC 6- EC 8	5.4E+00	6.3E–02	3.6E+00	9.6E+01	5.0E+01	1.0E+02		
>EC 8- EC 10	4.3E–01	6.3E–03	4.5E+00	1.5E+02	8.0E+01	1.3E+02		
>EC 10- EC 12	3.4E–02	6.3E–04	5.4E+00	2.0E+02	1.2E+02	1.6E+02		
>EC 12- EC 16	7.6E–04	4.8E–05	6.7E+00	2.6E+02	5.2E+02	2.0E+02		
>EC 16- EC 21	2.5E–06	1.1E–06	8.8E+00	3.2E+02	4.9E+03	2.7E+02		
Aromatic Fractions								
>EC 5- EC 7 (Benzene)	1.8E+03	1.3E–01	1.9E+00	8.0E+01	2.3E–01	7.8E+01	1.0E–01	1.0E–05
>EC 7- EC 8 (Benzene)	5.2E+02	3.8E–02	2.4E+00	1.1E+02	2.7E–01	9.2E+01		
>EC 8- EC 10	6.5E+01	6.3E–03	3.2E+00	1.5E+02	4.8E–01	1.2E+02		
>EC 10- EC 12	2.5E+01	6.3E–04	3.4E+00	2.0E+02	1.4E–01	1.3E+02		
>EC 12- EC 16	5.8E+00	4.8E–05	3.7E+00	2.6E+02	5.3E–02	1.5E+02		
>EC 16- EC 21	6.5E–01	1.1E–06	4.2E+00	3.2E+02	1.3E–02	1.9E+02		
>EC 21- EC 35	6.6E–03	4.4E–10	5.1E+00	3.4E+02	6.7E–04	2.4E+02		

Notes: *Equivalent Carbon Number (EC)—carbon number correlated with the retention time of constituents in a boiling point gas chromatography (GC) column, normalized to the n-alkanes.
*****Calculated Henry's law constant based on vapour pressure, solubility, and molecular weight relationship.***

An analysis based on the Gas Chromatography (GC) approach and the EPA SW-846 procedures to separate hydrocarbons into fractions was established. Initially, the diluted petroleum compounds and extracts were passed via a silica gel chromatography column aimed at segregating the saturate and aromatic hydrocarbons as outlined by modified EPA Method 3630. The analysis for aromatic and aliphatic fractions were performed independently by means of GC and were measured by totalling the "...signals within each of the 13 specified equivalent carbon number ranges" (McMillen *et al*., 2000).

Essentially, EC ranges are linked to the chemical's boiling point normalized to the boiling point of the n-alkanes or its retention time within a GC column. For instance, benzene has six carbons with 80 ºC boiling point. McMillen *et al.* (2000), state that it has the equivalent carbon number of 6.5 based on boiling point of benzene and its retention time in a boiling point GC column. This indicates that the retention time and boiling point for benzene are comparable to an n-alkane with a carbon number of between 6 and 7 (McMillen *et al*., 2000). Figure D.7.1 (p.538) of TPHCWG (1998) in Appendix-D indicates the correlation between ranges of boiling points and the carbon number for a number of typical petroleum products. It is evident from the figure that there is an overlap between the range of carbon number for various products and the overlap in equivalent analytical methods.

Based on McMillen *et al*. (2000), the criteria for toxicity were established for the EC number fractions by performing a detailed review of literature based on all available information related to pure compounds, specific petroleum fractions and refined products. The established toxicity criteria are expressed as oral reference doses (RfD) in mg/kg/day or as reference concentrations (RfC) in mg/m^3 for inhalation exposure based on U.S EPA as exhibited in Table 7.2. RfD are the expected exposure to human population in one day.

Table 7.2. The TPHCWG Petroleum Fractions (Source: Environment Agency, 2003).

Equivalent Carbon Number	**Reference Dose (mg/kg bw/d)**	**Reference Concentration (mg/m^3)**
TPH-Aliphatic fractions		
>EC5- EC6	5.0	18.4
>EC6 - EC8	5.0	18.4
>EC8 - EC10	0.1	1
>EC10 - EC12	0.1	1
>EC12 - EC16	0.1	1
>EC16 - EC21	2.0	*NA
TPH-Aromatic Fractions		
>EC5 - EC7	**0.004	**0.03
>EC7 - EC8	0.2	0.4
>EC8 - EC10	0.04	0.2
>EC10 - EC12	0.04	0.2
>EC12 - EC16	0.04	0.2
>EC16 - EC21	0.03	*NA
>EC21 - EC35	0.03	*NA

Note: *NA: Not available, ** Based on USEPA benzene value.

The methods in determining TPH RBSLs were set up by integrating the fractionation scheme, fate and transport properties as well as criteria for toxicity established for the equivalent carbon number fractions in the ASTM RBCA framework (McMillen *et al*., 2000).

The TPHCWG employs risk assessment techniques and assumptions in accordance with those specified in the ASTM standard. RBSLs were developed by totalling the Hazard

Quotients (HQ) for the 13 corresponding carbon number fractions. For any given fraction, the HQ refers to the ratio of exposure level of that fraction against a stipulated period of time to the reference dose allocated to that fraction. The sum of the individual HQ is referred to as the Hazard Index (HI) (McMillen *et al.*, 2000).

As a general indication, a greater HQ value signifies a higher level of concern (i.e. potential risk). HQ indices with values higher than unity indicate higher probability of detrimental health effects (i.e. potential risk); there is a proposal to undertake a additional detailed investigation or plan for remedial action (RISC-5, 2011). As stated by McMillen *et al*. (2000), for each EC number fraction, the HQ was computed by taking the fraction weight multiplied by the total TPH (mg/kg) and divided by the RBSLs of the fraction. Hua *et al*. (2012), claim that the globally suitable non-carcinogenic HQ for the site-specific risk level is $HQ \leq 1$; however the acceptable carcinogenic risk (excess lifetime cancer risk) differs between countries. For the Netherlands, for instance, it is less stringent at 10^{-4} as compared to 10^{-5} practiced in the UK. The recommendation from the U.S. ASTM standard is 10^{-6} and 10^{-4} for the single pollutant risk target and accumulated contaminants risk target, respectively, (Hua *et al.*, 2012).

The generic quantitative risk assessment (GQRA) screens risks to human health through the use of published generic screening values, which have been derived from a set of conservative assumptions; therefore, the GQRA or a detailed quantitative risk assessment (DQRA) is generally used to discover risk targets. Human health risks from exposure to contaminated soil and vapour are also determined by GQRA (PB, 2011). These generic screening values usually incorporate risk-based Soil Guideline Values (SGVs) or other Generic Assessment Criteria (GACs) typically based on UK legislation which was in turn based on the Environment Agency’s Contaminated Land Exposure Assessment (CLEA) model (see Environment Agency's SR2, SR3 and SR7 reports **(**CL: AIRE, 2014 **&** PB, 2011).

When there is a plausible pollutant linkage, GQRA is used to compare concentrations of the contaminants – if remediation is not already planned. The comparisons will be made of the soil, water and/or soil vapour, which will be assessed for the generic criteria (GAC) values most appropriate (CL: AIRE, 2014).

The site specific assessment criteria (SSAC) was developed by DQRA; this assessment includes examining *"...each of the exposure pathways and modifying the generic assumptions"* derived from the GACs so that site conditions are thoroughly investigated (Searl, 2012). In other words, should levels of contaminant be greater than the GAC, or if generic screening criteria are not applicable to various sites, then DQRA will be used for to develop SSAC. Additionally, pollutant linkages will be taken into greater account within DQRA evaluation; consideration regarding remedial options can then be carried out (CL: AIRE, 2014).

CL: AIRE (2014), recognises that doubt caused by using SGV/GACs within a GQRA is typically greater than that associated with the use of SSACs within a DQRA. However, including site-specific information which would take into account *details of the exposure scenario, receptor behaviour, soil type and foundation construction,* i.e. the derivations of the SSAC, permits a more realistic and thus more accurate estimate of risk; in fact, GACs, are derived from a wider application and more conservative range of sites.

In fact, when a GAC becomes more inclusive, it loses its ability to be applicable to individual sites and therefore becomes more uncertain.

To conclude, this study evaluated the human health risk through the use of DQRA; utilising the derivation of the SSAC instead of GQRA allowed more realistic and more accurate research. This was necessary in light of the fact that the study site (in Kuwait) has a hot and arid climate; the GQRA (as it was derived from GACs values used under cold climate) is better suited to colder climates such as UK.

7.4 Risk Assessment Stages (RAS)

In performing a risk assessment, a four-stage process approach was developed by the U.S. National Academy of Sciences which was subsequently adopted by the U.S. EPA (La Grega *et al*. 1994). This broadly acceptable approach entails certain processes, namely Hazard Identification, Exposure Assessment, Toxicity Assessment and Risk Characterisation. Nathanail *et al*. (2007) divided risk assessment into two phases with two sub-phases for each, as listed below:

- Phase 1a-Hazard Identification.
- Phase 1b-Hazard Assessment.
- Phase 2a-Risk Estimation.
- Phase 2b- Risk Evaluation.

These risk assessment stages formulated by Nathanail *et al*. (2007) and the U.S National Academy of Sciences (La Grega *et al*., 1994) attained similar targets and objectives in assessing the risks from contaminated soils from areas affected with hydrocarbon. Furthermore, the detailed evaluation carried out during the risk assessment process could form the basis for choosing a suitable regulatory response to a potential environmental risk, also known as risk management (La Grega *et al*., 1994). Therefore, for this particular study, risk assessment scenarios as defined by Nathanail *et al*. (2007) were implemented.

The soil screening level value with regards to the TPH value at the contaminated site, (dry *oil lake* at the Al-Magwa area) for this study, is in accordance with the recommendations from the Texas State (U.S EPA) which is 100 mg/kg.

The reasons the researcher followed the U.S EPA (in particular Texas State) are shown below:

- The Kuwait Environment Public Authority (KEPA) complies with the U.S EPA standard (ASA, 2012).
- The HHRA software (RISC-5) employed in this study is in compliance with the U.S. EPA standard (RISC-5, 2011).
- The Kuwaiti climate is hot and dry, i.e. very similar to that of Texas State.
- The most commonly used value for petroleum clean-up in USA is 100 mg/kg as is the hydrocarbon petroleum clean-up value in Texas State. (Blaisdell & Smallwood, 1993).

The following four sections provide descriptions of all four phases as an introduction to the state of the art in risk assessment in accordance with Nathanail *et al*. (2007).

7.4.1 Hazard Identification (phase 1a)

As defined by Sniffer (2007), Hazard Identification is the process at the initial phase of risk assessment which requires identification and characterisation of the threats arising from links to the conditions under consideration. As such, the aim at this preliminary stage is to identify the likely risks at the study site as stipulated by the following questions:

- What are the concerned constituents/pollutants/contaminants, i.e. the source(s)?
- What is the nature of the hazard, i.e. naturally occurring or anthropogenic (man-made)?
- Are there any particular circumstances to be considered such as leachate and emission in the soil?

- Who is likely to be affected, i.e. the receptor (s)?
- What are the likely methods (the routes or pathways) by which they may be affected, i.e. inhalation (of gasses, dust and vapour), ingestion (of contaminated home-grown plants, soils or water) and/or dermal contact (with contaminated water, soils or dust)?

In view of these considerations, a number of processes and criteria should be set out during the initial stages which concern Hazard Identification (Phase 1a) at the selected site of this project. Nathanail *et al*. (2007), have provided a summary and illustration of the main criteria that should be reviewed and assessed at the concerned site during this initial stage. Furthermore, these criteria and processes are considered to be the main activities and require the collection of background data from the site and the development of a Conceptual Site Model (CSM).

Further explanation is detailed in Table 7.3 below:

Table 7.3. The main steps and their activities for phase 1a (Hazard Identification) (Source: Nathanail *et al*., 2007).

Main Steps for Phase 1a (Hazard Identification)	Actions Involved in Each Main Steps
Collect Background Information to Establish Former Uses of the Site	Identify current and previous site uses.
	Collect physical information about the site.
	Identify potential receptors.
	Site visit and walkover survey.
	Consult with local authorities.
	Identify contaminants of concern both from industrial uses and other sources.
Develop a Conceptual Site Model	Show potential sources, pathways, receptors and other uncertainties.
	Identify components of the conceptual model.
	Update the conceptual model.

NHBC *et al*. (2008) also provide a detailed description of the procedures and guidance when performing the site aspects of the work for the first stage (Figure 7.1 in next page).

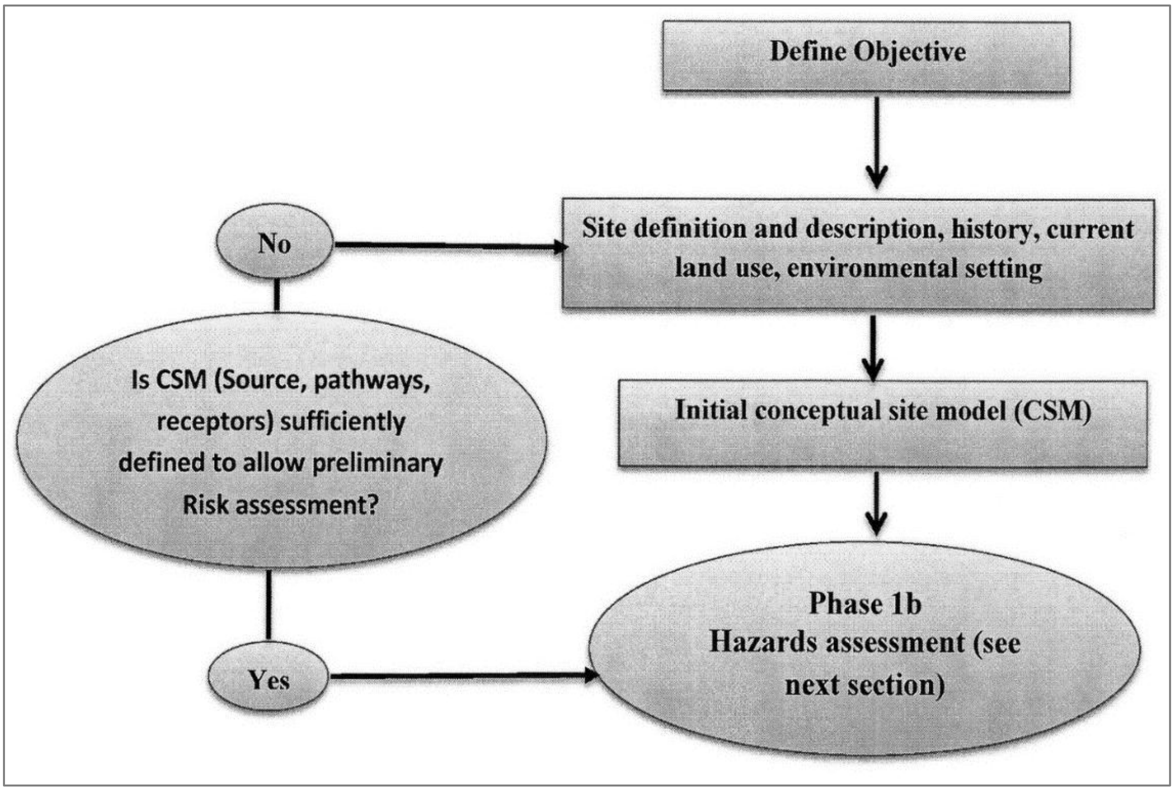


Figure 7.1. Flowchart for the Hazard Identification (phase 1a) process (Source: NHBC *et al.*, 2008).

Within this phase of Hazard Identification (1a) of the risk assessment, it is essential to generate a CSM as one of the processes for the contaminated site. As explained in (LQM, 2012), the HHRA components of the CSM includes a site plan view, cross sections for the entire site and a network diagram which should consist of sources, pathways and receptors for the contaminated site. Further details with regards to practical examples of CSM can be seen from Figures 7.2, 7.3 and 7.4 in next page.

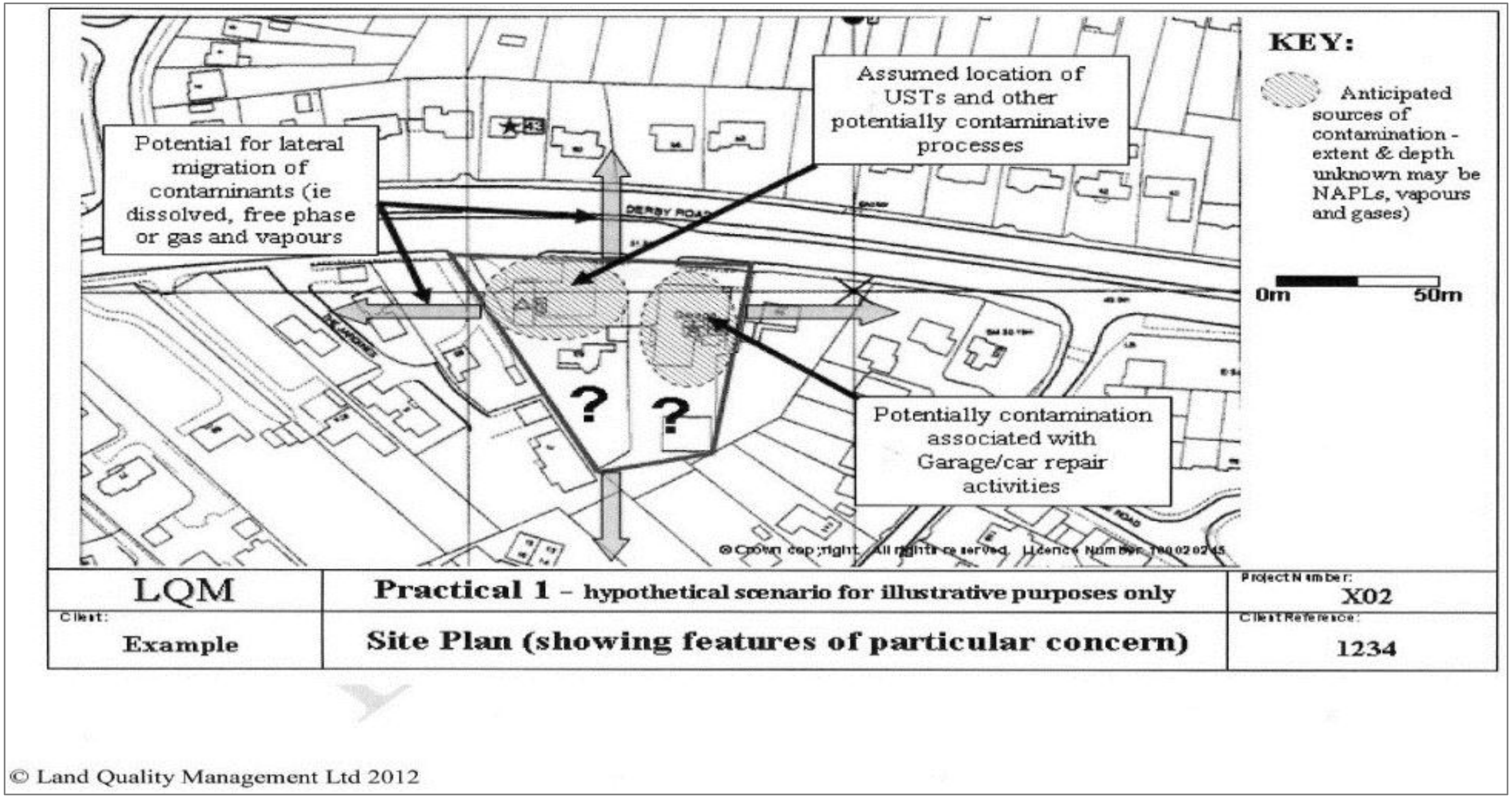


Figure 7.2. An example of top view plan for some site as Conceptual Site Model (CSM) part in phase 1a of risk assessment (Source: LQM, 2012).

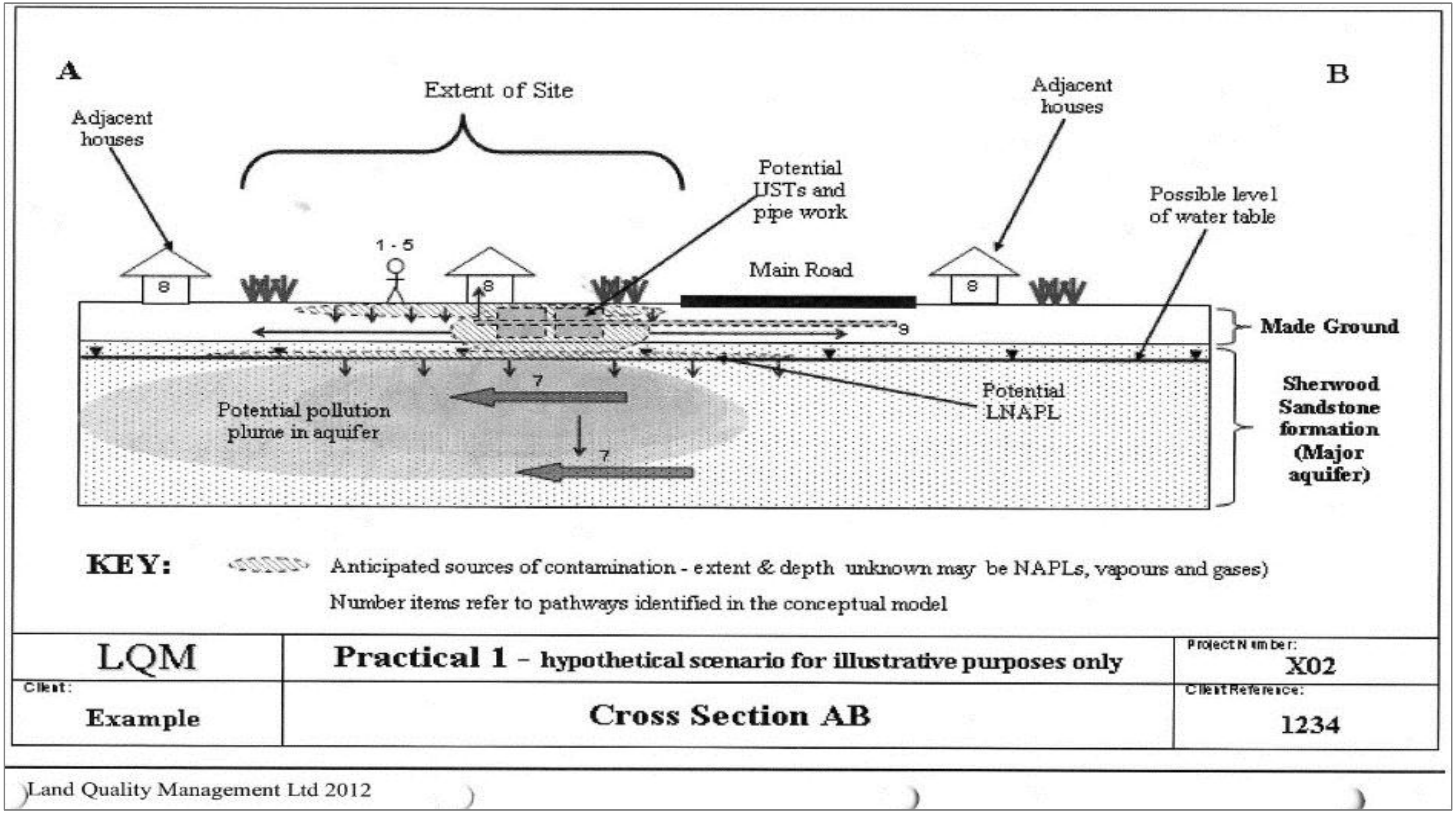


Figure 7.3. An example of cross section for some site as Conceptual Site Model (CSM) part in phase 1a of risk assessment (Source: LQM, 2012).

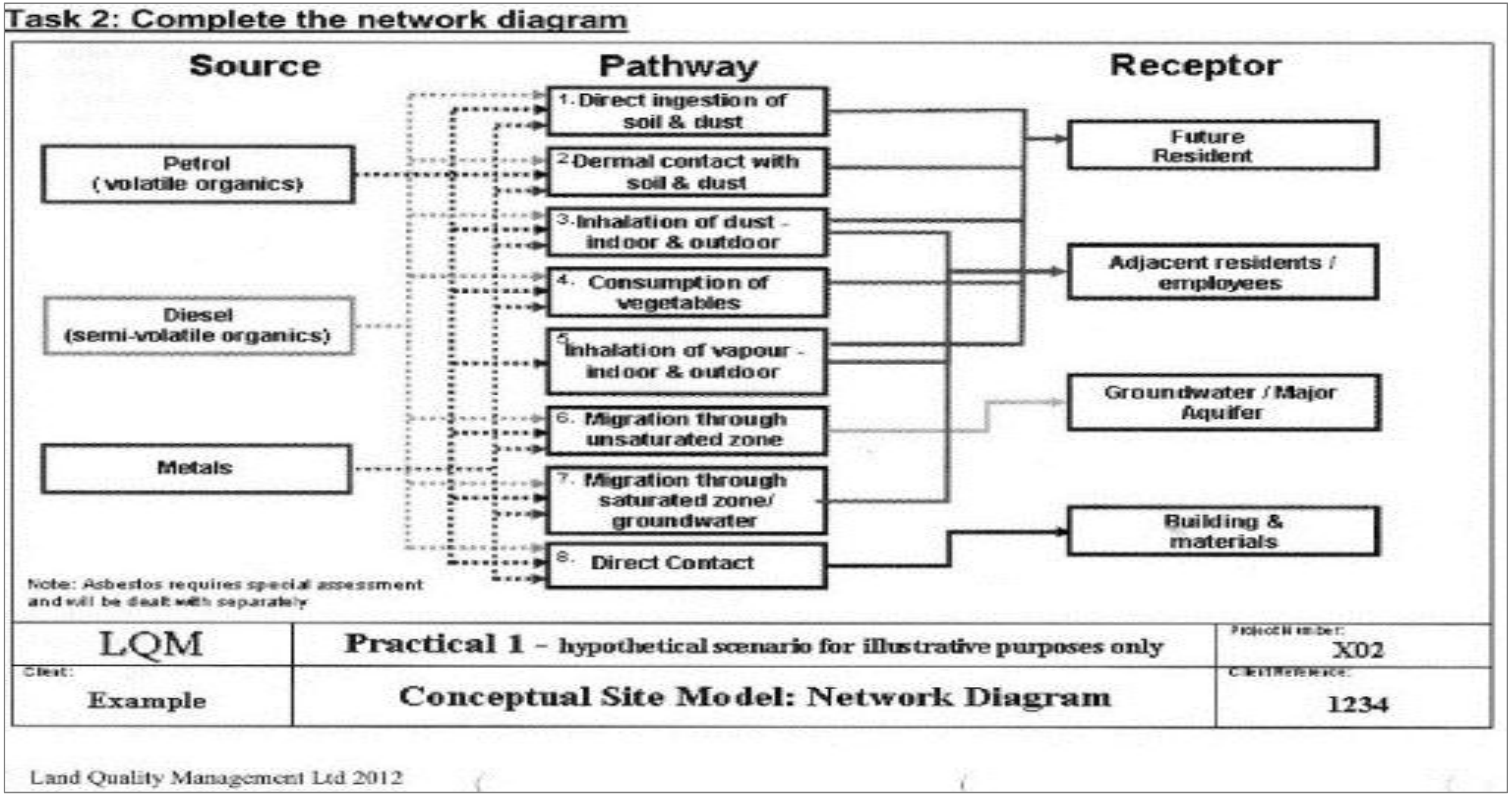


Figure 7.4. An example of network diagram for some site as Conceptual Site Model (CSM) part in phase 1a of risk assessment (Source: LQM, 2012).

In order to perform a risk assessment, it is necessary to fully understand the types of chemicals present, the level of concentration and the way these chemicals travel (pathways) in the environment of the contaminated area to the potential receptors (Angehrn, 1998).

It is therefore essential within this study to understand the chemical composition of the TPH contaminants as well as their level of concentration at the contaminated site in the Greater Burgan Oil Field (Al- Magwa area). Equally important is to identify the source of TPH contaminants, pathway routes and the potential receptors. In fact, the Hazard Identification stage at the contamination site deals with aliphatic and aromatic hydrocarbons (TPH) including the level of their concentration (mg/kg), the pathway connections, e.g.: dermal contact, ingestion of the soil and inhalation, and the receptors affected, e.g. children and adults.

7.4.2 Hazard Assessment (phase 1b)

A review of the site and an appropriate exploratory investigation should be performed during this stage, so as to carry out phase 1b of the Hazard Assessment at the contaminated site (dry *oil lake*). (Nathanail *et al*., 2007) At this stage, the conceptual model is reviewed in more detail, so as to ascertain the probability of the presence of any potential contaminant linkages (Sniffer, 2007).

According to Sniffer (2007), a number of questions should be raised, for example: whether the exposure is uninterrupted or intermittent; what the spatial scale is, e.g. whether its effect is localised or more extensive; what the likely period is; the destiny and movement of the constituents within the environment, i.e. the likelihood of aerial deposition; discharges to the water environment; reaction within the soil; and how the receptors behave, e.g. how frequently are they exposed?

As specified in NHBC *et al*. (2008), the processes and actions required to carry out Hazard Assessment for the affected site is as illustrated in Figure 7.5 below:

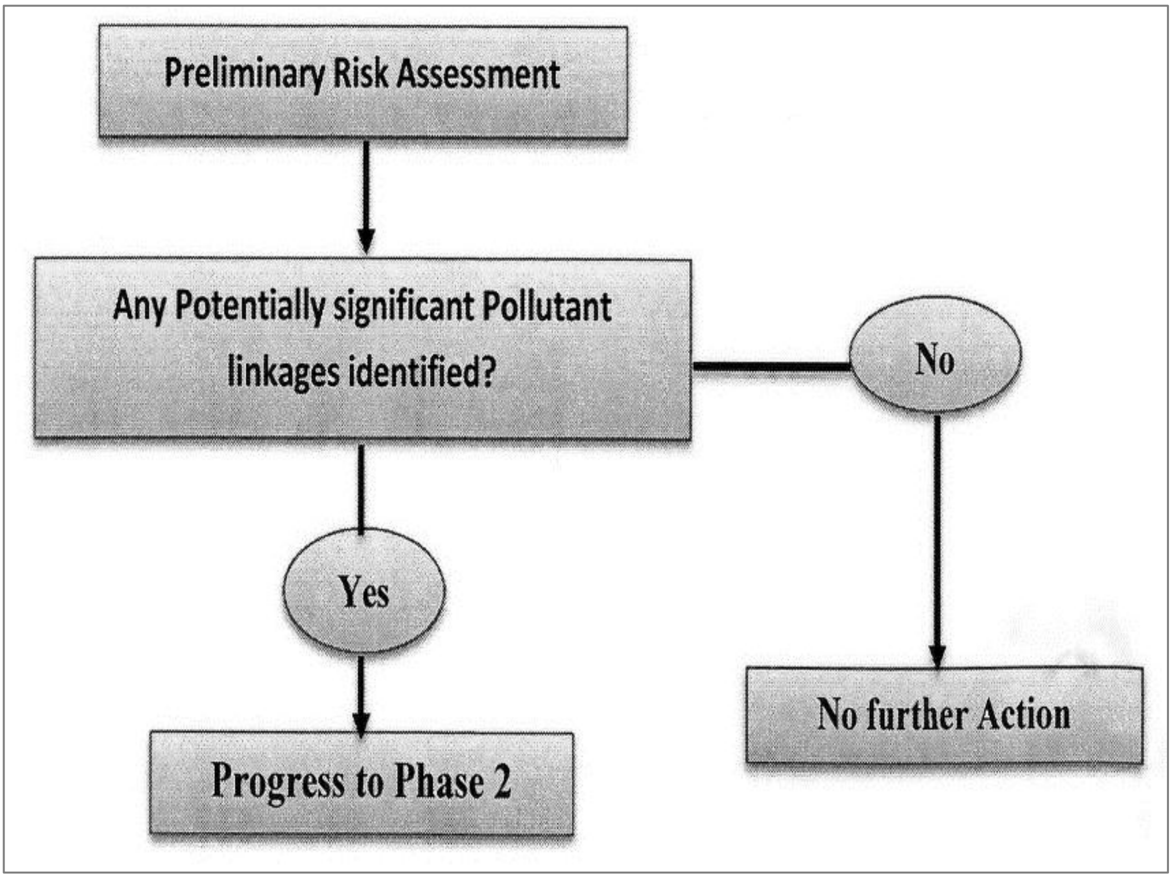


Figure 7.5. Flowchart for the Hazard Assessment (Phase 1b) process (Source: NHBC *et al*., 2008).

It is therefore essential for an analysis to be conducted to determine how the contaminants are released from the site and the way they travel to a potential receptor. In order for the exposure to take place, it is necessary for the exposure pathways, defined by a contaminant source, e.g. landfill; chemical release mechanism; leaching, e.g. transport mechanism; groundwater flow; exposure point; drinking water well; environmental receptor, e.g., consumer of drinking water; and exposure route, e.g., ingestion; to exist (La Grega *et al*., 1994). The possible chemical exposure pathways released from the contaminated soils are shown in Figure 7.6.

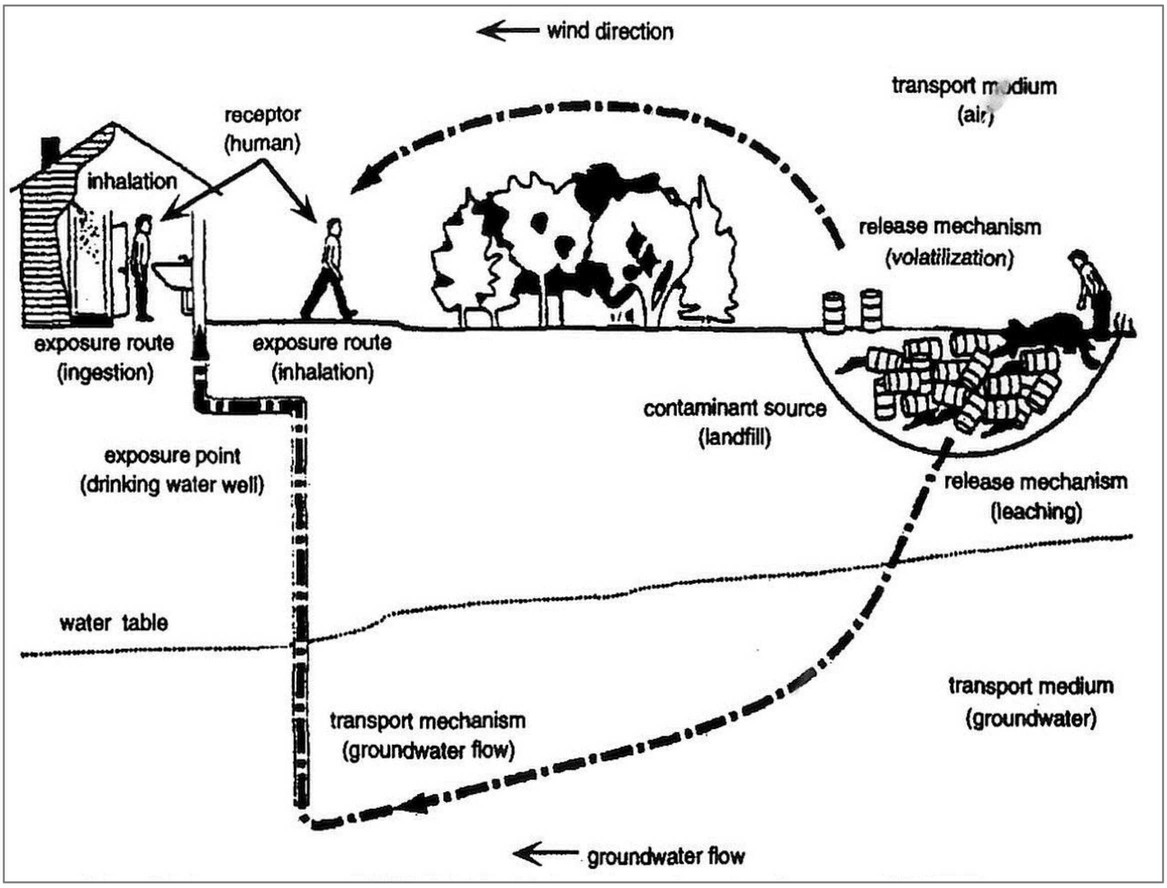


Figure 7.6. An example of potential exposure pathways of chemicals from contaminated soils (Source: La Grega *et al*., 1994).

7.4.3 Risk Estimation (Phase 2a)

Risk Estimation entails assessing the probability of a severe consequence as a result of the exposure of the receptor to the hazardous chemicals (Sniffer, 2007). Within this stage, the likely risks to the receptor are identified through each of the pollutant linkages defined normally equating the optimal dose to the receptor (through the exposure pathways) with the appropriate or minimum level of threshold. Sniffer (2007), also claims that it typically consists of the extent of exposure, i.e. the amount of the hazardous chemicals that reach the receptor through the defined exposure pathways. Furthermore, Nathanail *et al*. (2007), describe a procedure for Risk Estimation (Phase 2a) which should be employed in performing risk assessments of contaminated land. A description of the steps and processes for phase 2a of the Risk Estimation is provided in Table 7.4. The Risk Estimation (phase

2a) procedures are also detailed by NHBC *et al*. (2008) as illustrated in the following Figure 7.7.

Table 7.4. The main steps and their activities for phase 2a (Risk Estimation) (Source: Nathanail *et al*., 2007).

Main steps for phase 2a (Risk Estimation)	Actions included in each main step
Design and implement ground investigation	Design of investigation.
	Use of investigation techniques.
	Analysis of results.
	Consideration of uncertainty.
	Evaluation of costs.
Quantitative or qualitative Risk Estimation	Risk Estimation using guidelines values for human health.
	Derivation of site specific risk assessment criteria for human health from toxicity data and likely exposure.
	Non-human health assessment criteria
Estimation of short-term exposure.	

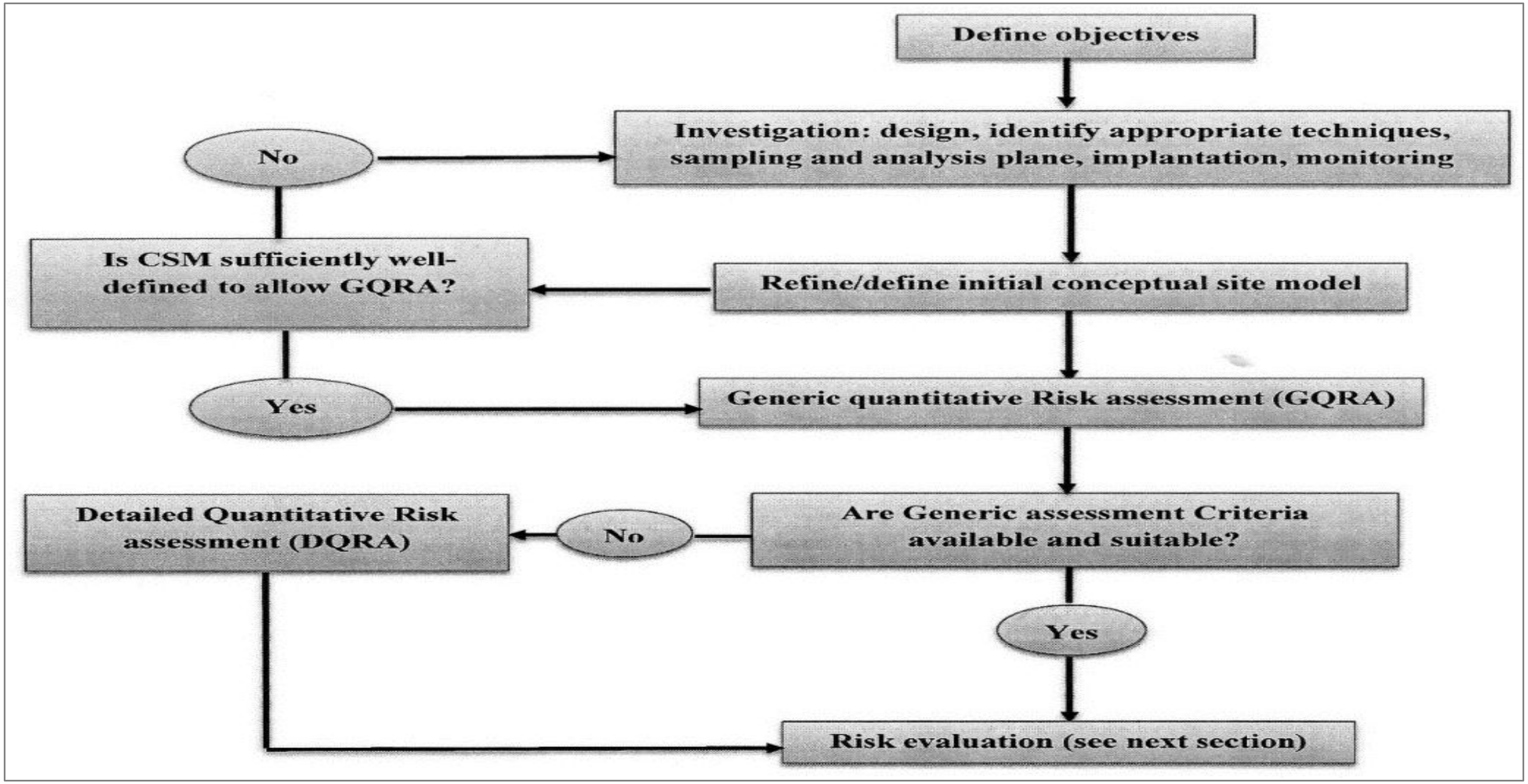


Figure 7.7. Flowchart for the Risk Estimation (phase 2a) process (Source: NHBC *et al*., 2008).

7.4.4 Risk Evaluation (Phase 2b)

According to NHBC *et al*. (2008), a conceptual phase of risk assessment entails measuring the adequacy of the estimated risk, considering the nature and magnitude of risk estimations, any doubts linked to the estimate as well as the general advantages and disadvantages of taking appropriate action to alleviate such risk.

The aim of performing Risk Evaluation is to appreciate the result of the previous phases and to decide whether risk management action is required. It is important that the risk evaluation be performed on a site specific approach taking into account all potential pollutant linkages. Based upon Sniffer (2007), remedial action may or may not be required for any given estimate of risk, subject to the legal system under which the assessment is being performed.

As stated by Nathanial *et al*. (2007), Risk Evaluation (Phase 2b) is performed by identifying unacceptable risks and developing provisional risk management objectives. Additionally, the processes in performing Risk Evaluation (Phase 2b) were described and specified based on (NHBC *et al*., 2008) as indicated in Figure 7.8.

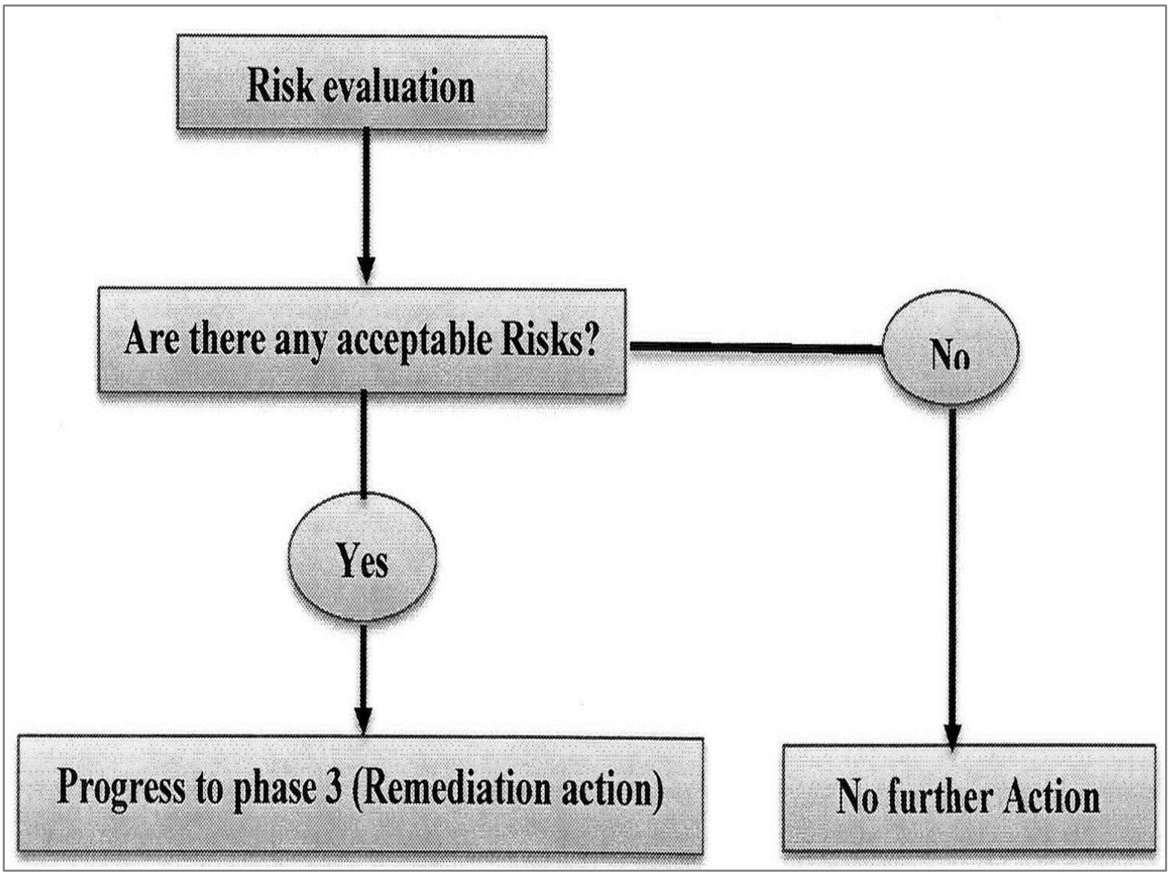


Figure 7.8. Flowchart for the Risk Evaluation (Phase 2b) process (Source: NHBC *et al*., 2008).

7.5 Risk Assessment Stages (RAS) Implementation on the Contaminated Site (Al Magwa area)

A risk assessment was undertaken for the Al-Magwa site. RICS-5 software was utilised to determine the concentrations of hydrocarbon contamination with regards to carcinogenic and non-carcinogenic health effects and their effect on human health as well as to obtain appropriate clean-up target levels required for any future development.

7.5.1 Hazard Identification (phase 1a)

7.5.1.1 Site Definition and Description

The dry *oil lake* site located on the Al-Magwa Oil Field is considered one of the three sectors of the Greater Burgan Oil Field located 20 km away from the densely populated City of Kuwait. The study site (dry *oil lake*) is close to Gas centre (GC-09) and several oil well pipelines some of which had been destroyed during the Iraqi invasion of Kuwait 25 years ago; their destruction created a series of "*oil lake*s" with hydrocarbon contamination within the ground near to the GC-09. A photograph of the *oil lake* site which was taken immediately after the invasion in 1991 by the Media Department at KOC is shown in Figure 7.9.

Figure 7.9. A previous photograph of the *oil lake* site obtained immediately after the invasion in 1991 by media department at KOC.

7.5.1.2 Previous and Current Site Uses

The *dry oil lake* site is close to several oil well pipelines which have subsequently been used to transport crude oil for export (Plates 7.1 and 7.2). This site is likely to be developed under a major civil construction within the next 5 years. Furthermore, the Kuwait government is looking into expanding the local infrastructure, i.e. housing, other buildings, railways, airports etc., in the next 5 years (see chapter 2 - Table 2.3); therefore, for the purpose of this study, the site is assumed to be being used for building residential housing. This will be the scenario adopted for the risk assessment.

Plate 7.1. The oil wells pipelines nearby to the dry *oil lake* site (Al-Magwa Area).

Plate 7.2. Dry *oil lake* site (Al-Magwa Area).

7.5.1.3 Conceptual Site Model (CSM)

As indicated in Section 4.4.4 of Chapter 4, the data concerning the ground conditions of the site was obtained from surveys conducted earlier by a construction company (INCO, 2007). The below-ground geological sequence encountered at the Greater Burgan Field site (Al-Magwa area) are broadly comprised of layers of poorly graded sand (SP) and silty sand (S-M). Water was discovered during drilling of the boreholes by INCO Lab at 10 m below ground surface (Figures A.4.12a and A.4.12b).

Al-Sulaimi and Mukhopadhyay (2000), pointed out that the geology of Kuwait is dominated by rocks from the Tertiary Age dating from the Palaeocene to the Eocene. Limestones, dolomites and evaporitic profiles (anhydrites) of the Dammam, Rus and Umm Er Radhuma Formations which are uncomfortably overlain by sandstoness from the Kuwait Group consisting of the Ghar and Fars Formations, which also lie above the Dibdibba Formation. According to Hunting Geology and Geophysics (HGG), (1981), the solid geology of the Greater Burgan site is underlined with the Ghar and Fars Formations with inter-bedded sands and clays, some sandstones and weak white nodular limestone. Superficial deposits are composed of primarily Aeolian sands with intermittent gravels with sands, muds and calcareous sandstones along the shorelines. Furthermore, the main oil reservoirs are located within the Cretaceous Burgan, Mauddud and Wara Formations of the Greater Burgan Oil Field.

7.5.1.4 Initial Conceptual Site Model (CSM)

A CSM was used in order to identify all the potential hydrocarbon pollutant linkages in the dry *oil lake* site in order to drive the risk assessment process. The physical state of the hydrocarbon contamination at the dry *oil lake* site could be classified as either a Volatile Organic Compound (VOC) or a LNAPL as assumed at the initial CSM. However, the

DNAPL was excluded. These assumptions were expected through investigation of the site during sample collections based on the following:

- Hydrocarbon contamination located was shown at the upper ground level (reaching 0.5 m depth).
- The type of soil was sand, i.e. unsaturated zone soil.
- The water table was more than 10 m deep.

Therefore, the initial CSM was built based on the site description and physical and hydrogeological information collected from private construction firms (INCO, 2007). Figure 7.10 shows a cross-section of the hydrocarbon contamination site in order to identify the pollutant linkages of the oil spill contamination for any future housing construction and residents. The potential sources, pathways, intake routes and receptors at the dry *oil lake* site (Al-Magwa Area) are displayed in Table 7.5 and Figure 7.11.

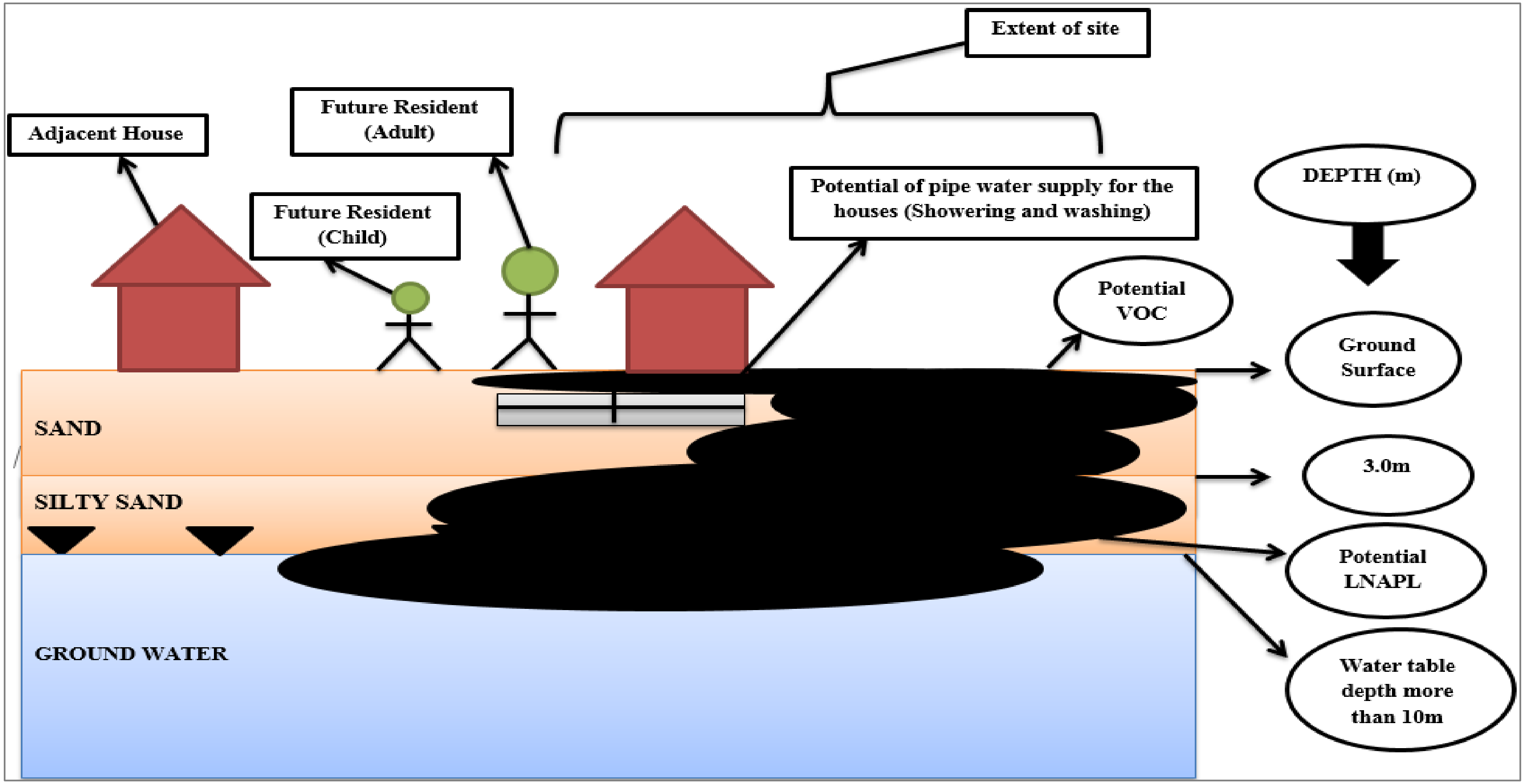


Figure 7.10. A cross section for the Greater Burgan site (Al-Magwa area) as initial Conceptual Site Model (CSM) in risk assessment.

Table 7.5. The Potential sources, pathways, intake route and receptors in the contamination dry *oil lake* site (Al-Magwa Area).

Sources	Pathways	Intake Routes	Receptors
Oil Spills	Direct Exposure	Dermal contact and soil Ingestion.	Future residents such as child & Adult Residents on site
	Volatilizes hydrocarbon substances,	Inhalation indoor air, Inhalation Outdoor air,	Future residents such as child & Adult Residents on site
	Soil adheres vegetables	Ingestion of the vegetables	Future residents such as child & Adult Residents
	Soil Erosion	Inhale Particulates air	Future residents such as child & Adult Residents on site and off site
	Leaching to Ground Water and Ground water transport to Borehole	Ingestion water, Showering Dermal contact and Showering Vapor in halation.	Future residents off site such as child & Adult Residents and drinking Water Consumer
	Ground Water	---------	Marin Ecosystem, Fresh water Ecosystem
	Diffusion through water supply pipes and air condition	Showering Dermal contact and Showering Vapor in halation.	On site
	Chloride and Sulfate substances	-------------	Building Material

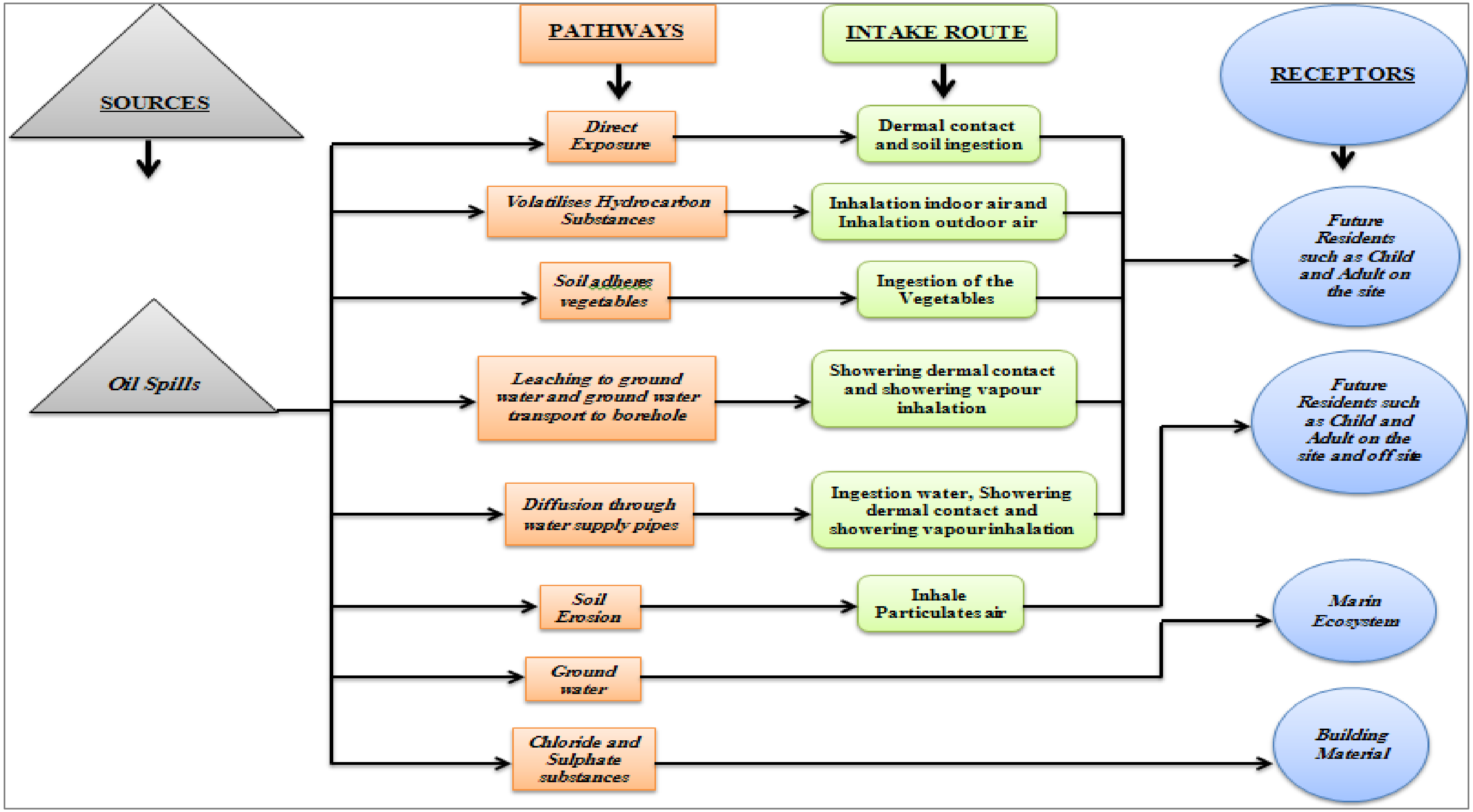


Figure 7.11. Network diagram for dry *oil lake* site (Al-Magwa Area) as Conceptual Site Model (CSM) part in phase 1a of risk assessment.

7.5.2 Hazard Assessment (phase 1b)

7.5.2.1 Hydrocarbon Contamination Detected in the Site

As mentioned in section (6.5), 110 samples were collected from different depths of (0.0 m, 0.25 m, 0.5 m, 1.0 m, 1.5 m and 2.0 m) 22 samples of which were taken from each of the above depths. GC-MS tests were conducted on these samples with only 24 samples found to be polluted with hydrocarbon. The number of samples which were found to be polluted with hydrocarbon at the site, can be separated related to TPH fractions such as aliphatic (EC10 to EC35) and aromatic (EC8 to EC35) are as follows:

- 16 samples from 0.0 m depth.
- 7 samples from 0.25 m depth.
- 1 sample from 0.5 m depth.

Furthermore, 7 chemical substances were detected in the soil samples related to Anthracene and Phenanthrene compounds (which might be toxic because these compounds are non-volatile and related to PAH).

According to DEFRA (2005), the PAH compounds have proven to be toxic, human carcinogens; they are the results of incomplete carbon combustion from fuels containing carbon. PAH are the results of two (or more) aromatic (benzene) rings; these may fuse together when a carbon pair atoms is shared between them. Naphthalene and benzo(a)pyrene, for example, are compounds which have been formed by fusing together 2 (naphthalene) and 5 (benzo(a)pyrene) rings which have fused (BC, n.d.), Chemical and physical characteristics of the above compounds related to PAH vary in molecular weight. In fact, with increases of vaporisation their weight of molecular is increased; however, their solubility of aqueous decreases. Additionally, their behaviour, distribution in the environment, and their effects on biological systems are different. Lower weight of molecular, i.e. 2 to 3 ring groups, for example, naphthalenes - are particularly toxic for aquatic organisms, but PAH with higher weight of molecular, i.e. 4 to 7 rings for example benzo(a)pyrene are not although several members of the high molecular weight PAHs have been known to be carcinogenic (BC, n.d.).

The PAH referred to above were taken into consideration during investigation at the contamination site; however, the GC-MS testing instrument did not identify them during the contaminated soil sample testing. This could be attributed to the following reasons:

- The behaviour of Naphthalene chemical substances, according to DEFRA (2005), degrades extensively *in soil under aerobic and anaerobic conditions*. It could, therefore, be considered to have been degraded at the study site (Al-Magwa area) since it had been there for more than 23 years.
- The behaviour of Benzo(a)pyrene chemical substances is regarded to have evaporated hugely (BC, n.d.); it could have evaporated at the site since the climate in the area is particularly hot and arid and the conditions have existed for more than two decades.

Various unknown GC-MS peak (not identified by the Kuwait diesel standard used during calibration as standard and might not be hydrocarbon concentrations) were found in some soil samples by the GC-MS test at depths of 0.0 m and 0.25 m. All the concentrations (mg/kg) of these varied hydrocarbons found in the dry *oil lake* are displayed in Table 7.6.

Table 7.6. The TPH fraction (aliphatic & aromatic), non-volatile chemical substances (anthracene & phenanthrene related to PAH) and unknown substances concentrations for the detected soil samples found at dry *oil lake* in Greater Burgan Oil Field at depths (0.0 m, 0.25 m & 0.5 m).

T.P. Coordinates	Depth (m)	*TPH Fraction (Aliphatic & Aromatic) Based on the RISC-Software*							** Anthra	**Phena.	***Unknown Substance
		Aliphatic (mg/kg)		Aromatic (mg/kg)				TPH (mg/kg)			
		EC12 - EC16	*EC16 -EC35*	*EC8 - EC10*	*EC10 - EC12*	*EC12 - EC16*	*EC16 - EC21*				
(0 m, 25 m)	**0.0 m**	38.063	266.614	*ND	*ND	*ND	47.69	352.367	47.69	*ND	29.43
(0 m, 75 m)	**0.0 m**	14.7	112.837	19.44	*ND	122.672	40	309.649	51.06	*ND	15.73
(0 m, 100 m)	**0.0 m**	*ND	1.36	*ND	*ND	*ND	*ND	1.36	*ND	*ND	*ND
(25 m, 25 m)	**0.0 m**	*ND	9.526	*ND	*ND	14.436	19.204	43.166	19.204	*ND	*ND
(25 m, 50 m)	**0.0 m**	*ND	32.514	33.398	*ND	43.778	4.276	113.966	*ND	*ND	14.387
(25 m, 75 m)	**0.0 m**	*ND	7.787	*ND	*ND	18.549	8.421	34.757	7.044	1.377	*ND
(50 m, 50 m)	**0.0 m**	*ND	300.99	*ND	46.713	*ND	59.156	406.859	6.788	52.368	53.084
(50 m, 75 m)	**0.0 m**	*ND	524.579	*ND	66.942	44.008	229.694	865.223	*ND	44.008	*ND
(50 m, 100 m)	**0.0 m**	*ND	*ND	24	*ND	188.235	119.373	331.608	23.388	*ND	104.204
(75 m, 0 m)	**0.0 m**	*ND	0.469	9.372	*ND	20.828	22.35	53.019	*ND	13.959	8.391
(75 m, 75 m)	**0.0 m**	38.834	248.6	*ND	*ND	118.703	161.199	567.336	49.933	69.917	47.269
(100 m, 0 m)	**0.0 m**	*ND	5.186	*ND	*ND	12.615	*ND	17.801	*ND	*ND	*ND
(100 m, 25 m)	**0.0 m**	7.481	129.443	*ND	*ND	115.524	71.752	324.2	12.253	38.831	*ND
(100 m, 50 m)	**0.0 m**	34.967	733.098	*ND	141.986	*ND	420.79	1330.841	53.426	*ND	120.949
(75 m, 100 m)	**0.0 m**	*ND	121.761	*ND	*ND	21.135	524.351	667.247	40.385	89.075	*ND
(100 m, 100 m)	**0.0 m**	*ND	18.183	*ND	*ND	*ND	196.622	214.805	20.627	*ND	86.539
(0 m, 25 m)	**0.25 m**	8.877	8.622	*ND	*ND	11.206	13.594	42.299	8.138	*ND	*ND
(0 m, 75 m)	**0.25 m**	27.139	167.961	*ND	*ND	15.425	14.574	225.099	14.574	*ND	*ND
(25 m, 50 m)	**0.25 m**	*ND	0.197	*ND	*ND	20.05	11.282	31.529	*ND	*ND	14.387
(50 m,50 m)	**0.25 m**	*ND	*ND	*ND	*ND	3.506	*ND	3.506	*ND	*ND	*ND
(75 m, 100 m)	**0.25 m**	36.577	247.101	*ND	*ND	34.944	213.754	532.376	*ND	*ND	*ND
(100 m, 0 m)	**0.25 m**	*ND	*ND	*ND	*ND	2.532	*ND	2.532	*ND	*ND	*ND
(100 m, 75 m)	**0.25 m**	30.255	515.241	*ND	389.559	103.513	232.464	1271.032	55.42	48.093	134.522
(75 m, 0 m)	**0.5 m**	*ND	*ND	*ND	2.484	*ND	*ND	2.484	*ND	*ND	*ND

Note: *ND: Not Detected with hydrocarbon specific classification based on aliphatic and aromatic.

***** Anthracene and Phenanthrene are belong to the 18 polycyclic aromatic hydrocarbon (might be toxic) in accordance with wenzl et al., (2006).therefore, all the concentrations of the detected chemical substances related to the anthracene and phenanthrene are calculated.***

********Unknown substances: are not identified and matching with Kuwaiti diesel standard which used during calibration in the GC-MS test as standard for testing soil contaminated. Therefore, these unknown substances might be or not hydrocarbon concentration so it is excluded from the evaluation of risk assessment by RISC-5 software.***

ProUCL Statistics Software for the Quantitative data

As mentioned by Barnett *et al*. (2013), USEPA has funded the development of ProUCL 5.0 software in an effort to instigate rigorous and defensible statistics so as to assist the decision makers allowing them to arrive at correct decisions at contaminated sites in order to help and protect human health as well as the environment.

For data sets with and without non-detect (ND) considerations, the statistics were calculated by ProUCL by means of parametric and non-parametric techniques encompassing a wide-range of data skewness, data distributions and sizes of samples (Barnett *et al*., 2013).

According to Barnett *et al*. (2013), non-parametric methods were devised so as be used when the researcher has no knowledge of the existing parameters, i.e. has no assumptions regarding the variables of interests that the population may have. In other words, assessment of parameters is not reliant upon non-parametric methods.

This software can calculate the Upper Confidence Limits (95 % - UCLs of the mean) which can correct any skewed data. Explanatory graphical methods for uncensored data sets as well as left-censored data sets comprising non-detect (ND) observations are available in the ProUCL (Barnett *et al*. 2013). This software includes graphical methods consisting of histograms, multiple quantile-quantile (Q-Q) plots, and side-by-side box plots. Graphic displays help to provide additional understanding of the information contained in a data set which may not otherwise be shown by utilising estimates, e.g. 95 % upper limits in term of whether the sample sets are normal distribution or non-normal distribution (Barnett *et al*. 2013).

The non-parametric method for the 95 % - UCLs of the mean (via ProUCL software) might be used for concentrations of the detected hydrocarbon contamination at the site in order to establish confident answers and a correct decision on the samples concentrations. Thus, the normality of the data was then examined using the Shapiro Wilk Test of Normality after outliers were deleted from the dataset. The data followed the non-normal distributions which is considered acceptable for performing non-parametric statistical tests (95 % UCLs of the mean) to detect TPH concentrations fraction (aliphatic and aromatic) and chemical substances related to Anthracene and Phenanthrene compounds at depths of 0.0 m, 0.25 m and 0.5 m (Figures D.7.2 to D.7.9).

One example of a Q-Q plot for the detected aliphatic (EC12 - EC16) concentrations found in soil contaminated with TPH shows non-normal distribution as displayed in Figure 7.12. Therefore, the 95 % UCL of mean (mg/kg), of the detected hydrocarbon contamination of concern (as mentioned above), are shown in Table 7.7. The minimum/maximum, mean and standard deviation values are also recorded in this Table. (Figures D.7.10 to D.7.18 at Appendix-D).

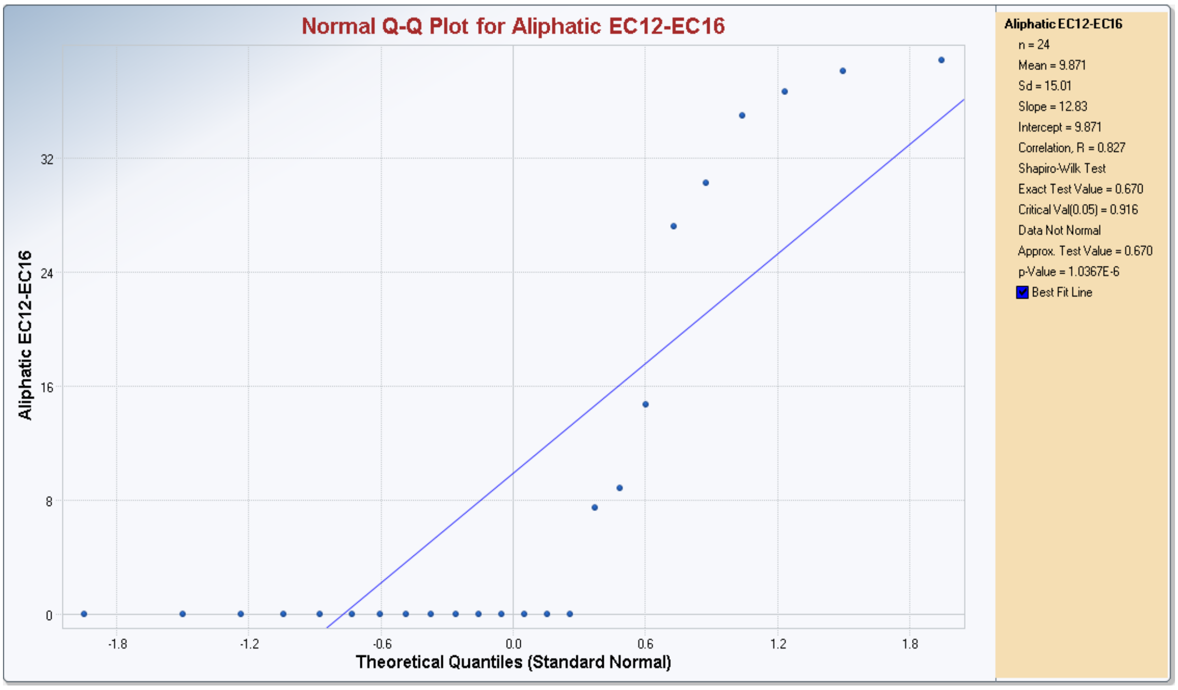


Figure 7.12. An example of the Q-Q plot for TPH aliphatic EC12 - EC16 in dry *oil lake* site (Al- Magwa area).

Table 7.7. The 95 % Upper Confident Limit (UCL) of the mean value of aliphatic & aromatic fractions and chemicals related to PAH detected in Greater Burgan Oil Field (Al-Magwa area).

TPH Fractions	Total Number of the Contamination Samples in the site	The Samples Number Found for Specific TPH Friction	Concentration Evaluated by Statistics (mg/kg)				
			Max. Value	**Min. Value**	**Mean Value**	**SD. Value**	**95 % UCL of Mean**
Aliphatic EC12 - EC16	24	10	38.83	0	9.871	15.01	23.23
Aliphatic EC16 - EC35	24	21	733.1	0	143.8	202.2	323.7
Aromatic EC8 - EC10	24	4	24	0	2.201	6.344	7.845
Aromatic EC10 - EC12	24	5	142	0	10.76	32.34	39.53
Aromatic EC12 - EC16	24	19	188.2	0	37.99	51.69	83.98
Aromatic EC16 - EC21	24	20	524.4	0	100.4	140.7	225.6
TPH total	24	24	1331	1.36	283.2	343.3	588.7
Some non- volatile chemical composition might be Toxics related to Anthracene and Phenanthrene (PAH) found in the dry oil lake detected by GC-MS test							
Anthracene	24	15	55.42	0	17.08	20.64	35.44
Phenanthrene	24	9	89.08	0	14.9	26.53	38.51

7.5.2.2 Hydrocarbon Contamination Exceed Screening Value

This study has adopted the most common figure for the clean-up level values used in Texas State (U.S) which is 100 mg/kg for TPH as recommended by Blaisdell and Smallwood (1993) to determine whether or not a risk assessment is required for a clean-up of the contaminated site (Al-Magwa area). The result for the Al-Magwa site shows that the 95 % upper confidence limit (UCL) of mean value of the total TPH concentration contaminated with soil is 588.7 mg/kg which is well above the screening value for Texas State of 100 mg/kg. This indicates that an urgent risk assessment is required for this site; in carrying out this risk assessment, 95 % UCL concentrations of the mean values of the TPH fractions (aliphatic and aromatic) and the chemicals discovered connected to Anthracene and Phnanthrene (PAH) were employed in the RISC-5 modelling (Table 7.8 below and Figures D.7.19 & D.7.20 Appendix-D).

Table 7.8. Comparison between the mean value of 95 % UCL of the of TPH concentration (mg/kg) in the site and the approved Screening Value in the soil by U.S. EPA.

Mean values of 95% UCL of TPH Concentration in the Soil at Greater Burgan Oil Field (Al-Magwa Area)	Screening Value in the Soil by Texas State (Blaisdell & Smallwood, 1993)	Comments
588.7 mg/kg	100 mg/kg	It needs to evaluate the human health risk assessment by using RISC-5 software.

7.5.2.3 Final Conceptual Site Model (CSM)

After identifying the hydrocarbon contamination depth and concentrations by GC-MS results, it was found that the TPH concentration in the soil exceeds the screening value. CSM has been updated and reviewed; the final cross-section diagram of the contaminated site is shown in Figure 7.13. The potential sources, pathways, intake routes and receptors at the dry *oil lake* site (Al-Magwa area) are as displayed in Table 7.9 and Figure 7.14.

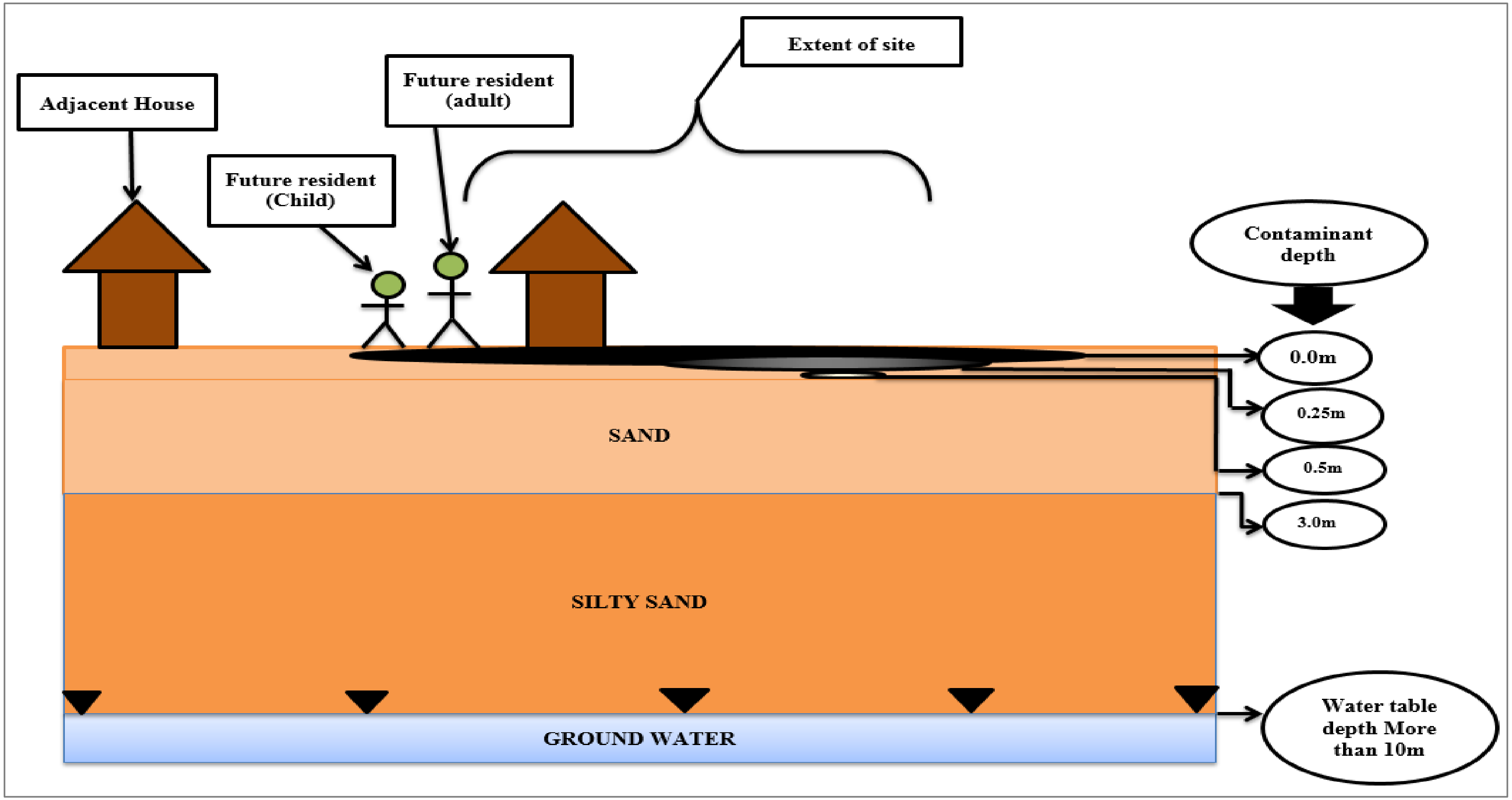


Figure 7.13. A cross section for the Greater Burgan site (al-Magwa area) as Final Conceptual Site Model (CSM) in risk assessment.

Table 7.9. Final potential sources, pathways, intake route and receptors in the contamination dry *oil lake* site (Al-Magwa area).

Sources	*Pathways*	*Intake Routes*	*Receptors*	*Comments*	*Continue Yes/No*
**Aliphatic EC12 - EC16 *Aromatic EC8 - EC10 *Aromatic EC10 - EC12 *Aromatic EC12 - EC16*	*Volatilizes hydrocarbon substances*	*Inhalation Outdoor air*	*Future residents such as child & Adult Residents on site*	*Most of the contaminated samples were taken from the top soil (0.0 m depth). Also, the concentration of the oil contamination was over the U.S EPA standard which is 100 ppm.*	*yes*
	Soil Erosion	*Inhale Particulates air*	*Future residents such as child & Adult Residents on site and off site*	*The soil condition was loose and sandy. Moreover, Kuwait has long summer session rather than the winter which has got strong windy in the summer. These reasons let the contamination soil (top soil) can move by wind to the adjacent area.*	*yes*
	Leaching to Ground Water and Ground water transport to Borehole	*Ingestion water, Showering Dermal contact and Showering Vapor in halation.*	*Future residents off site such as child & Adult Residents and drinking Water Consumer*	*The type of the contaminant is dry and exists since 25 years. Also it is very seldom rains in Kuwait which could not migrate the contaminants downwards into the groundwater.*	*No*
	Ground Water	----------	*Marin Ecosystem, Fresh water Ecosystem*	*The depth of the oil contaminated reached 0.5m at the site with only found one detected soil sample. Moreover, the water table depth is more than 10 m (as mentioned in section 4.4.4 in chapter 4).*	*No*
	Diffusion through water supply pipes and air condition	*Showering Dermal contact, Showering Vapor inhalation and inhalation from air condition*	*On site*	*As Johnson and Ettinger in 1991 recommend using vapor intrusion model for houses when the contamination presence underneath the foundation because they assumed the vapor of the contamination will migrate inside the house from the foundation pile (EQM, 2004). On the other hand, the soil contamination was observed in the top of the ground (0.0 m, 0.25 m & 0.5 m) and the foundation depth is reached 1.0m (in the same zone of the contamination) which let the builder to remove the hydrocarbon contamination during excavation in order to build house.*	*No*
**Aliphatic EC16 - EC35 *Aromatic EC16 – EC21*	*Direct Exposure*	*Dermal contact and soil Ingestion.*	*Future residents such as child & Adult Residents on site*	*The soil contamination with oil spills at the top soil (0.0 m depth) was observed and over the U.S EPA standard which is 100 ppm.*	*yes*
	Soil adheres vegetables	*Ingestion of the vegetables*	*Future residents such as child & Adult Residents*	*Most of the residents in Kuwait planting some vegetables such a tomato, potato, carrot and lettuce which their roots small in the ground and do not exceed more than 0.25m depth (at contamination zone).*	*yes*
**Aliphatic EC12 to EC35 *Aromatic EC8 to EC21*	*Chloride and Sulphates substances*	-------------	*Building Material*	*The Foundation for the house will start with depth 1.0 m moreover, the contamination only reached from zero to depth 0.5 m.*	*No*

Note: * all the TPH fractions were divided into the relevant pathways as such, the behaviour of the TPH fractions are differ in the environment (i.e. soluble, volatilisation etc.) (CCME, 2008).

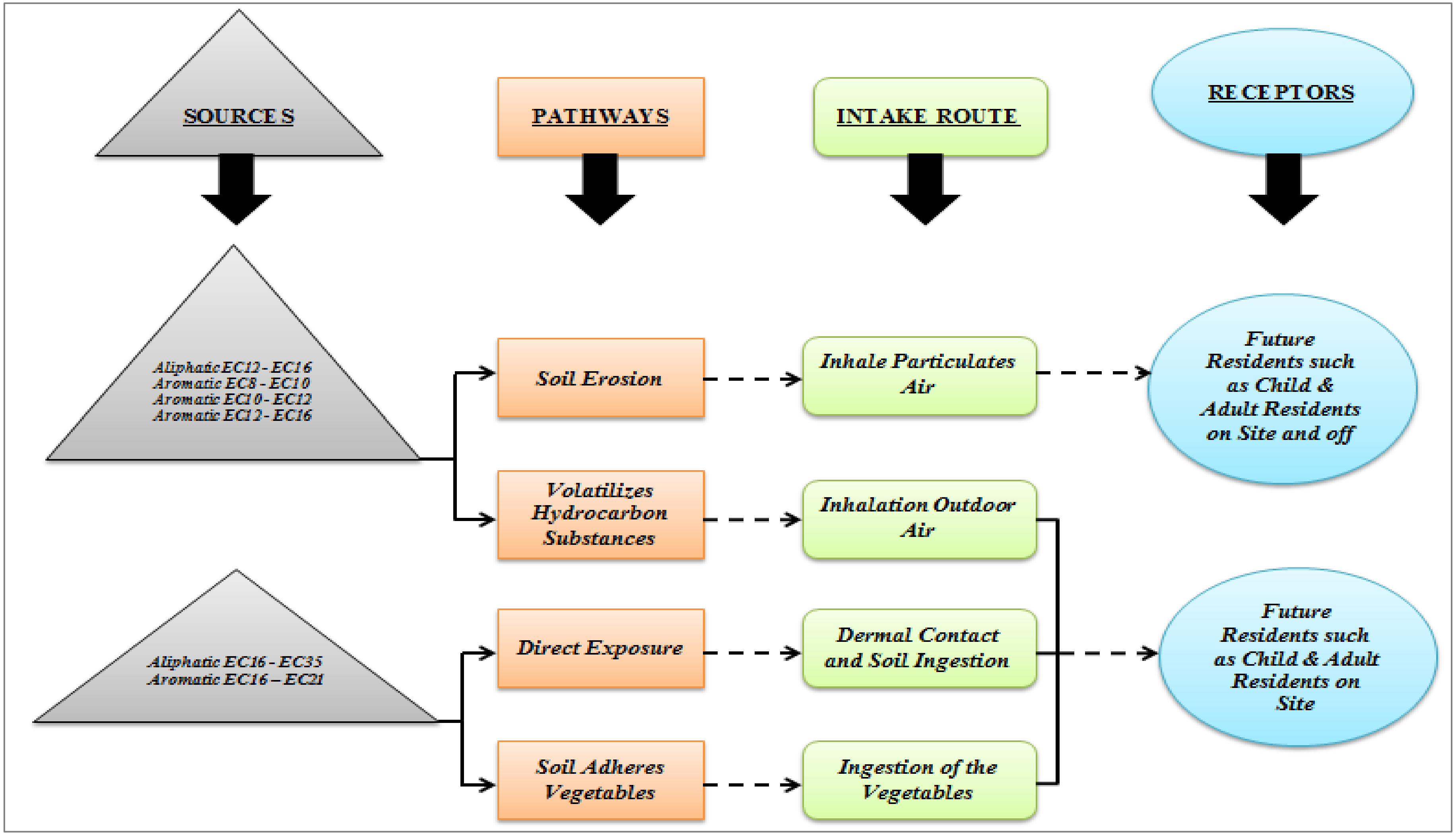


Figure 7.14. A network diagram for Greater Burgan oil site (Al-Magwa area) as Final Conceptual Site Model (CSM) in risk assessment.

7.5.3 Risk Estimation (phase 2a)

7.5.3.1 Routes Assessed Based on Final CSM and Parameters of the Site Specific and Contaminants of Concern

Based on the final CSM from the previous stage (see section 7.5.2, Hazard Assessment-Phase 1b), one hydrocarbon contaminated pathway was evaluated in the RICS-5 modelling using fate and transport techniques; for example, the unsaturated zone soil pathway with the assumption of different routes. These pathways are: Soil Ingestion; Dermal Contact; and Ingestion of Home-Grown Vegetables; i.e. transport routes through direct contact. This also includes Inhalation of Outdoor Air (from volatiles) and Particulates Air pathways which are transported via the contaminants volatilization from the affected soil to ambient air in the site as well as the spread of small particles of superficially affected soil during the dust season into adjacent areas (Table 7.10).

The values for the site specific parameters assumed in estimating the exposure point concentration of the contaminated site, for instance, the outdoor air model, particulate parameters, source geometry, unsaturated zone, and unsaturated zone lens, are exhibited in Table 7.11. These values for the site specific parameter employed were based on the chosen pathway, namely unsaturated zone soil; however, the exception was that of Kuwait’s average wind speed (m/s) for the outdoor air model and particulates of parameters which were obtained in accordance with Al-Ajmi (1994). Other parameters used were the default values recognised by the RISC-5 software as used by the U.S EPA. In addition, the values of the source geometry were used based on the site investigation for the dry *oil lake*.

Table 7.12 shows the chemical properties and toxicity figures of the aliphatic fraction (EC12 to EC35), aromatic fraction (EC8 to EC21) and the chemical substances associated with Anthracene and Phenanthrene compounds (PAH). These chemical properties and toxicity values were loaded in the RICS-5 software taken from the application of TPHCWG and U.S EPA (RISC-5, 2011). Figure D.7.21 in appendix-D shows the specified plant uptake data for the Trapp and Matthies plant uptake model.

Table 7.10. The selected exposure routes for HHRA in RISC-5 model based on the hydrocarbon contamination located in the site.

Exposure Routes of Contamination Located at Unsaturated Zone Soil Pathway Selected for Human Health Risk Assessment (HHRA)	
Pathways Selected for Unsaturated Soil Zone	**Routes Selected in this Study**
Surface soil Pathways	Ingestion of soil
	Dermal contact
	Ingestion of homegrown vegetables
Air Exposure Routes	Inhalation of outdoor air (from volatiles)
	Inhalation of particulates

Table 7.11. Site specific parameters data measured and information of the assumed pathway.

Input parameter based on unsaturated zone soil pathway selected in RISC-5 modeling.							
a. Box Data for Outdoor Air Model Parameters		b. Particulates Parameters (defaults values suggested in the RISC-5 software)		c. Source Geometry Parameters		d. Unsaturated Zone Parameters	
Non-soil-specific parameter	Input Value	Non-soil-Specific parameters	Input Value	Non-Soil-Specific parameters	Input Value	Parameters with defaults values available from sand parameters database:	Input Value
Height of Box*	2 m	Particulate emission rate (sub 10 micron)*	6.9 E-14	Depth to top of contamination (may be zero)****	0 m	a.Total porosity*	0.375 cm3/cm3
Width of Box*	10 m	Fraction of site with building or vegetation*	0	Length of source area****	100 m	b. Residual water content*	0.053 cm3/cm3
Length of Box*	10 m	Equivalent threshold value of wind speed at 7m*	11.32 m/s	Width of Source area****	100 m	c. Fraction organic carbon*	0.002 goc/gsoil
Wind speed***	4.8 m/s	$^{(*1)}$ Mean annual wind speed (Um)*	6.16 m/s	Thickness of contamination****	0.5 m	d. soil bulk density**	1.68 g/cm3
		Wind speed distribution function (F(X))*	0.194	Distance from bottom of source to groundwater****	10 m	e. saturated conductivity of the vadose zone*	6.4 m/d
						f. Value of Van Genuchten N*	2.68
						g. Thickness of lens*	2.0m

Note:*: it means all the these defaults values suggested by U.S EPA in the RISC-5 software which are used as assumption in this study site in Kuwait because there is no accredited values related to these parameter approved by Kuwait government or found in literature.

**: it used the sandy soil bulk density of Burgan Oil Field in Kuwait as parameter value (Al-Sarawi et al., 1998b).

***: it used the average wind speed in Kuwait as parameter value (Al-Ajmi, 1994).

****: it used the parameters values as assumption related to the site investigation for the dry oil lake site in Kuwait (Al-Magwa area).

Table 7.12. The properties of the chemical substances of concern as assumed in RISC-5 software for contaminated located at unsaturated zone soil pathway.

Chemical Name	**Estimated Properties**									
	Molecular weight (g/mol)	*Solubility (mg/L)*	*Henry's law constant (no NDs)*	*Koc (ND for inorganics) (ml/g)*	*Kd (soil partition coeff.) (ml/g)*	***Log Kow — octanol/water partition coeff. (L/kg)	*Diffusion coefficient in air (cm^2/s)*	*Diffusion coefficient in water (cm^2/s)*	**Reference concentration (RfC) mg/m^3**	**Unit risk factor µg/m^3**
Anthracene	178.2	0.0434	0.00267	29500	*ND	4.55	0.0324	7.74E-06	*ND	*ND
Phenanthrene	178.2	1.15	0.00148	22900	*ND	4.46	0.0517	5.9E-06	*ND	
Aliphatic EC12 - EC16	200	0.00076	540	5010000	*ND	6.84	0.1	1E-05	1	
Aliphatic EC16 - EC35	270	1.3E-06	6400	1000000000	*ND	8.91	0.1	1E-05	**NA	
Aromatic EC8 - EC10	120	65	0.49	1580	*ND	3.14	0.1	1E-05	0.2	
Aromatic EC10 - EC12	130	25	0.14	2510	*ND	3.45	0.1	1E-05	0.2	
Aromatic EC12 - EC16	150	5.8	0.054	5010	*ND	3.93	0.1	1E-05	0.2	
Aromatic EC16 - EC21	190	0.51	0.013	15800	*ND	4.72	0.1	1E-05	**NA	

Table 7.12. Continued.

Chemical Name	Estimated Properties				
	Reference dose (RfD) oral mg/kg-d	Gastro-intestinal absorption factor (dimensionless)	Absorption adjustment factor: dermal-soil (dimensionless)	Uptake factor for plants (L/kg)	Slope factor oral 1/(mg/kg-d)
Anthracene	0.3	1	0.13	***Use Kow	*ND
phenanthrene	*ND	1	0.1		
Aliphatic EC12 - EC16	0.1	1	1		
Aliphatic EC16 - EC35	2	1	1		
Aromatic EC8 - EC10	0.04	1	1		
Aromatic EC10 - EC12	0.04	1	1		
Aromatic EC12 - EC16	0.04	1	1		
Aromatic EC16 - EC21	0.03	1	1		

Note: *ND: It means not detected with Petrol.
*****NA: It means not available.***
******Use Kow: The RISC-5 software recommended to use Kow values.***

7.5.3.2 Future Resident Receptor Parameters (Child and Adult)

For this present study, children (both male and female) and adults (both male and female) are considered to be the potential receptors (future residents) to be evaluated for risk assessment. Risk Evaluation on the receptors (children and adults) was assumed to be upper percentile exposure defaults as for the “Reasonable Maximum Exposure” (RME).

To evaluate the risks (carcinogenic and non-carcinogenic) on human health of the receptors from the studied site, the exposure parameter factors used were the default values as recognised in the RISC-5 model. For instance, the average exposure time for carcinogenic parameters for both receptors (child and adult) is 70 years. On the other hand, residential children’s time outdoors (hours/days) parameter was taken as an assumption of a 12 hour day rather than a 24 hour day. This was due to the 12 hours spent by child receptors between sleeping time and school time; the remaining 12 hours were taken to be spent in the garden. Table 7.13 below tabulates all the exposure parameter values for upcoming residents.

Contaminant Intake Rate

This present study shows the impact of carcinogenic and non-carcinogenic risks to human health as related to ingestion of soil, dermal contact, ingestion of home grown vegetables, inhalation of outdoor air and inhalation of particulates to aliphatic (EC12 to EC35); also aromatic (EC8 to EC21) fractions in the shallow ground were assessed and calculated. The risk calculation was performed in accordance with RISC-5 (2011) to ascertain the estimated rate of intake for each chemical concerned from each exposure route. This Intake Rate, commonly known as a Dose, is expressed in milligrams per day of chemicals absorbed into the body per unit of body weight (mg/kg-d). As mentioned in the RISC-5 (2011), the EPA's Risk Assessment Guidance for Superfund (RAGS) Manual (EPA, 1989a) suggests that within the evaluation of longer-term exposure to non-carcinogenic toxicants, the intake should be computed by averaging the intake over the exposure period (or averaging time). The final result is termed as Chronic Average Daily Dose (CADD) and is employed in determining the HQ from each route as estimated in the studied area by comparing against a safe *Reference Dose* (RfD). In other words, the HQ is equivalent to the Chronic Average Daily Dose (CADD) for each route estimated at the studied site divided by the Reference Dose (RfD) of that particular chemical. For carcinogenic risks computed, the Lifetime Averaged Daily Dose (LADD) was employed in estimating the Incremental Excess Lifetime Cancer Risk (IELCR) by multiplying the LADD with a toxicity factor (Slope Factor (SF)). This means that the slope factors are used to measure potential human carcinogenic risks. A slope factor is an upper-bound lifetime probability which assumes that exposure to any quantity of a carcinogen will potentially raise the risk of cancer. The confidence limit of a slope factor is approximately 95 %. The rise in the risk of cancer is usually expressed in units of proportional influenced per mg of substance/kg bodyweight-day. This potential human carcinogenic risk is normally kept for use in the 'low-dose area' of the 'dose- response' relationship for exposure corresponding to a risk of less than 1 in 100. A slope factor should reflect the pathway of intake, e.g., inhalation, ingestion, or dermal absorption. Unfortunately, toxicological data is not always shown for each pathway, therefore, pathway-to-pathway extrapolations must be completed (U.S. EPA, 2016; RISC-5, 2011).

As such, the intake rate of aliphatic and aromatic fraction and chemicals linked to Anthracene and Phenanthrene (PAH) from the above mentioned assumed pathways in the area of study were computed by means of specific equations which are displayed in Tables D.7.3 to D.7.11 of Appendix-D.

Table 7.13. Assumed specify exposure parameters of the future resident such as Child and Adult receptors.

Exposure Parameters	**Future Residents**	
	Child-95 % Upper Percentile of the Mean	***Adult-95 % Upper Percentile of the Mean***
Averaging time for carcinogens (yr)*	70	70
Body weight (kg)*	15	70
Exposure duration (yr)*	6	24
Exposure frequency for soil (events/yr)*	350	350
Skin surface area exposed to soil (cm^2)*	2190	5300
Soil/skin adherence factor (mg/cm^2)	0.2	0.07
Ingestion rate for soil (mg/d)*	200	100
Exposure frequency for vegetable intake (events/ yr)*	350	350
Ingestion rate for above ground vegetables (g/d)*	55.8	127
Ingestion rate for root vegetables (g/d)*	48.5	87.5
Fraction of vegetables grown in contaminated soil (dimensionless)	0.25	0.25
Exposure frequency for outdoor air (events/ yr)*	350	350
Inhalation rate outdoors (m^3/ hr)*	1.2	1.6
Time outdoors (hr/ d)*[1]	12	2.5

Note; ***: *All the Exposure parameters used as defults values from RISC-5 software.***

*[1]: ***The values of time outdoor for the children receptor was used as assumed for Kuwaiti life style.***

7.5.4 Risk Evaluation (phase 2b)

7.5.4.1 Human Health Carcinogenic Risks

As revealed from the cancer risk values by the RICS-5 software and exhibited in tables D.7.3 to D.7.11 of Appendix D, the human health (child and adult) cumulative cancer risk caused by hydrocarbon contamination from sources such as TPH fractions (aliphatic and aromatic) and the detected chemicals associated with Anthracene and Phenanathrene (belonging to PAH) from the exposure into the above assumed pathways were concluded as *Not Detected* (ND).

7.5.4.2 Human Health Non- Carcinogenic Risks

The effects of the non-carcinogenic risks on human health caused by the Anthracene and Phenanathrene (PAH) and TPH fraction (aliphatic and aromatic) contamination through the same above assumed pathways at the site under consideration, are shown in Tables (7.14 and 7.15) and Figures (7.15 and 7.16). These Tables and Figures, show that the total HQ were 2.7 for children and 1.03 for adults. In other words, HQ was > 1 which means a potential risk.

7.5.4.3 Site Specific Clean-up Level

The Site Specific Target Level (SSTLs) was calculated from the assumed parameters (related to the dry *oil lake* site) which entered into the modelling software as shown in Tables (7.10) and (7.11).

The outcome of the Site-Specific Target Levels (SSTLs) was obtained from the RISC-5 software by using the individual constituent levels option, i.e. for each contaminated hydrocarbon substance of concern; and each cumulative risk selection, i.e. risks are added for all related TPH fractions. The risks' clean-up level exposed to the hydrocarbon contamination in the soil via the assumed pathways at the dry *oil lake* site (Al-Magwa area) are demonstrated in Table 7.16.

The entire simulation process, including the results obtained from the modelling (RICS-5), are as indicated in figures D.7.22 to D.7.37 and Tables D.7.12 to D.7.19 in appendix D.

The following table 7.16 demonstrates that the site specific target levels (SSTLs - clean up levels) values were compared with the concentration of hydrocarbon soil contaminants discovered at the site under study. The findings clearly demonstrate that the hydrocarbon contamination concentrations, i.e Anthracene, Phenanthrene, aliphatic (EC12 - EC16), aliphatic (EC16 - EC35), aromatic (EC8 - EC10), aromatic (EC10 - EC12), aromatic (EC12 - EC16) and aromatic (EC21 - EC35) are below the SSTLs. However, the tested concentrations of the aromatic (EC16 - EC21) hydrocarbon are 2.48 times greater than the calculated SSTLs for these specific hydrocarbons. Additionally, the total of TPH concentration of the site is higher than the value of SSTLs with a different value of 295.9 mg/kg.

The results from the health risk assessment performed in the area of study are generally consistent with a similar exercise undertaken by Pinedo *et al*. (2012) who carried out research which included undertaking site specific risk assessment for TPH fractions distribution and concentration utilising the RBCA framework. Two contamination routes were investigated; each route considered one distinct pathway, for example Volatilization and Particulates to Outdoor Air Inhalation (through ambient air volatilization of contaminants from affected soils and small particles of superficial affected soil) and Surface Soil (through direct ingestion, dermal contact and inhalation).

They found that the Outdoor Air pathway has a lower risk, as shown in the HQ values (HQ – 0 m = 0.863, HQ – 50 m = 0.42 and HQ – 100 m = 0.138), which are lower than the upper limit of 1.0. However, the soil risks for each fraction are also less than the HQ limit and the cumulative risk is above the limit by nearly 1.6. This cumulative risk is primarily attributed to the aromatic EC16 - EC21 fraction, which accounts for nearly half of the total risk. The total TPH is found only in superficial soil, with a value equivalent of 1.6 times greater than the Site-Specific Target Levels (SSTLs). Further, Study by Hua *et al*. (2012) - whose work also revolved around health risk assessments as a result of exposure to organic contaminated soil at an oil refinery.

They found that the concentration of benzene, benzo(a)pyrene and benzo(a)anthracene within the soil obtained from the site were higher than their respective risk screening values, with the pollutants mainly concentrated within 0.1 to 5.5 m below the ground surface. They considered three major exposure pathways, namely oral digestion, skin contact and air inhalation. Their results showed that the three major pathways were capable of indicating carcinogenic risk (CR) and non-carcinogenic HQ of the contaminated soil reaching 9.59×10^{-5} and 15.46, respectively; these were significantly higher than the acceptable threshold values of 10^{-5} and 1.

As with the above study, Pinedo *et al*. (2012) showed that the HQ value of the Outdoor Air pathway through exposure to the TPH fraction contamination was lower than the upper limit of 1.0. However, the cumulative risk (total HQ) was an unacceptable risk value (HQ > 1) (Pinedo *et al*., 2012). These values are in line with the findings of the HQ through the only outdoor air pathway of the current study. On the other hand, the HQ value of ingestion of vegetables for adults and child receptors was more than 1 (potential risk > 1) for the current study. Additionally, total HQ values were found to be higher than 1 which is similar to the current study. All total TPH values for both previous studies (Pinedo *et al*., 2012 and the current study) were found to be greater than the SSTLs.

On the other hand, the study by Hua *et al*. (2012) found that the carcinogenic risk (CR) value of contaminated soil (benzene, benzo(a)pyrene and benzo(a)anthracene) was higher than the acceptable threshold values via oral digestion, skin contact and air inhalation. These results interfered with the values of the current study due to the following reasons:

- Hua *et al*. (2012) detected concentrations of Benzene and benzo(a)pyrene (related to PAH) and benzo(a)anthracene (related to PAH) substances at their contamination site which were considered to be carcinogenic substances in accordance with TPHCWH (1998), as opposed to the current study which detected concentrations of TPH fractions after more than two decades at the dry *oil lake* site in Kuwait's hot climate.

Table 7.14. Summaries the non-carcinogenic risk (HQ) results for child resident from the contamination site (dry *oil lake*) based on pathways assumed in the study site.

Receptor 1: Child Resident-Upper Percentile						
Chemicals of Concern	**Routes Assumed in the Study Site**					**Total (HQ)**
	Ingestion of Soil	***Dermal Contact with Soil***	***Ingestion of homegrown Vegetables***	***Inhalation of Outdoor air***	***Inhalation of Particulates***	
Anthracene	**0.0015	**0.00042	**0.013	*ND	*ND	**0.015
phenanthrene	*ND	*ND	*ND	*ND	*ND	*ND
Aliphatic C12-C16	**0.00023	**0.0005	**0.002	**0.000051	**6.2E-19	**0.0025
Aliphatic C16-C35	**0.002	**0.0044	**0.0072	*ND	*ND	**0.014
Aromatic C8-C10	**0.00005	**0.0001	**0.0004	**0.000085	**3.0E-19	**0.0006
Aromatic C10-C12	**0.0007	**0.0014	**0.0062	**0.00042	**4.0E-18	**0.009
Aromatic C12-C16	**0.0082	**0.018	**0.11	**0.00084	**4.4E-17	**0.13
Aromatic C16-C21	**0.093	**0.20	***2.2	*ND	*ND	***2.5
Total (HQ)	**0.11	**0.23	***2.34	**0.0014	**5.0E-17	***2.7

Note: *ND: it means not detected with carcinogenic risk.

**Green colour used for marginally values (< 0.5).

***Brown Colure used for Potential risk values (> 1.0).

Table 7.15. Summaries of non-carcinogenic risk (HQ) results for adult resident from the contamination site (dry *oil lake*) based on pathways assumed in the study site.

Receptor 2: Adults Resident-Upper Percentile						
Chemicals of Concern	**Routes Assumed in the Study Site**					**Total (HQ)**
	Ingestion of Soil	***Dermal Contact with Soil***	***Ingestion of homegrown Vegetables***	***Inhalation of Outdoor air***	***Inhalation of Particulates***	
Anthracene	**0.0002	**0.00008	**0.02	*ND	*ND	**0.02
phenanthrene	*ND	*ND	*ND	*ND	*ND	*ND
Aliphatic C12-C16	**0.000021	**0.00008	**0.001	**0.00001	**1.1E-19	**0.0011
Aliphatic C16-C35	**0.00022	**0.0008	**0.005	*ND	*ND	**0.006
Aromatic C8-C10	**0.0000044	**0.000016	**0.0005	**0.00002	**2.6E-20	**0.00054
Aromatic C10-C12	**0.000061	**0.0004	**0.005	**0.00008	**6.4E-19	**0.0055
Aromatic C12-C16	**0.0008	**0.003	**0.04	**0.0003	**8.1E-18	**0.044
Aromatic C16-C21	**0.011	**0.04	***0.90	*ND	*ND	***0.95
Total (HQ)	**0.011	**0.045	***0.97	**0.0004	**9.0E-18	****1.03

Note: *ND: it means not detected with* carcinogenic *risk.

*****Green colour used for marginally values (< 0.5).***

******Orange Colour used for the values close to the potentially risk value (HQ=1) (≥ 0.5 <1.0)***

*******Brown Colure used for Potential risk values (> 1.0).***

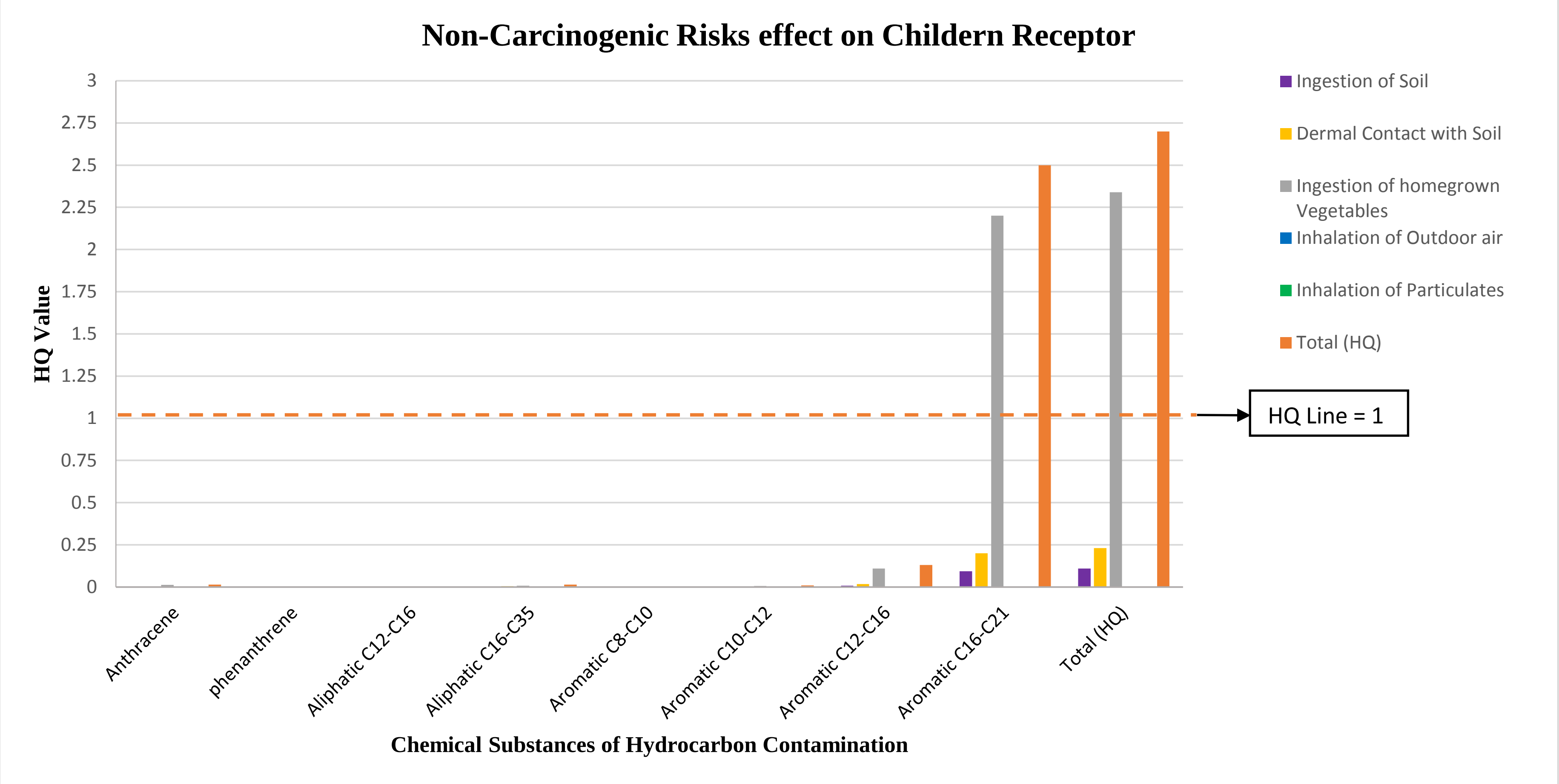


Figure 7.15. The effect of the non-carcinogenic risks (HQ) on the children receptor through exposure to hydrocarbon contamination via the assumed routes in the study site.

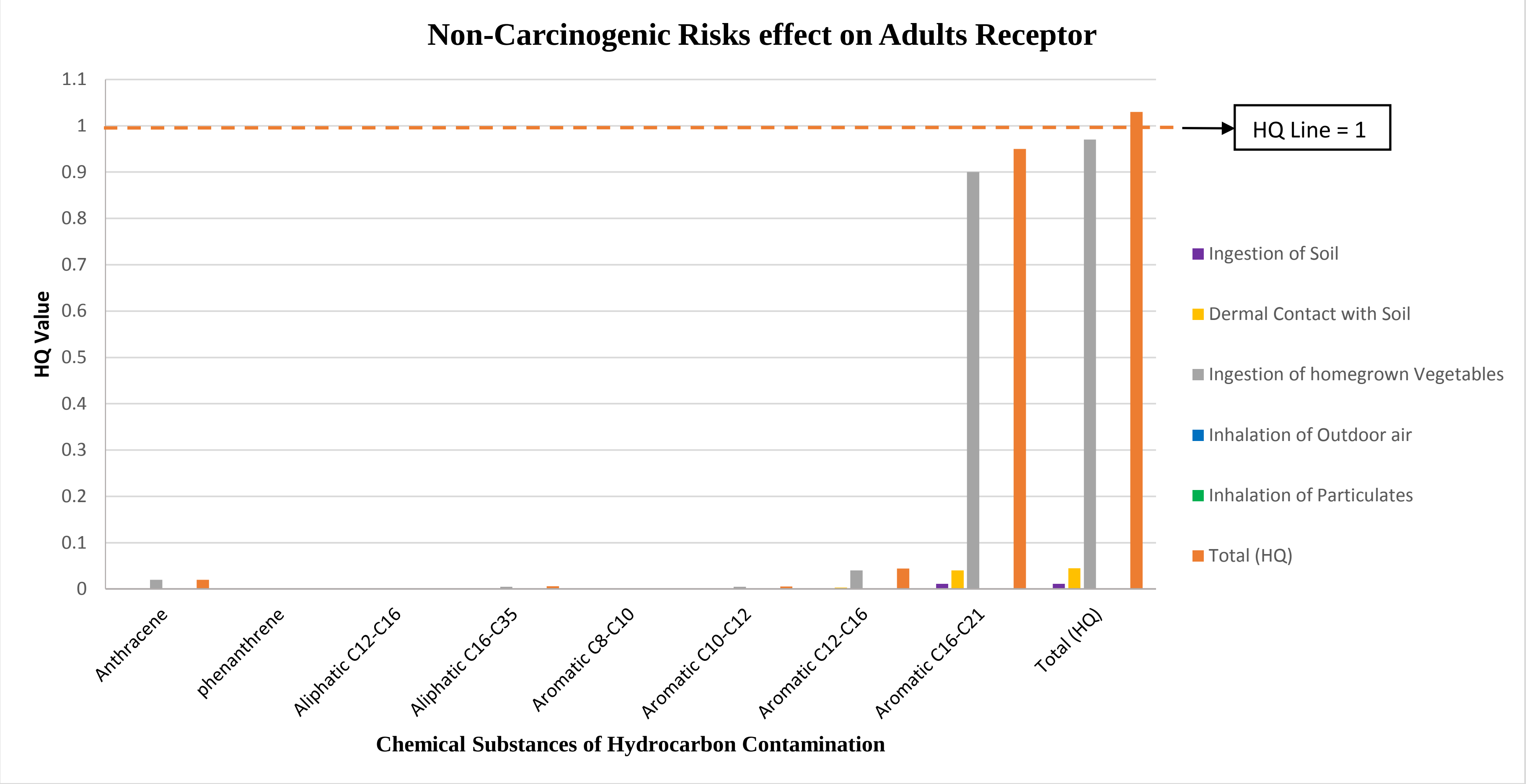


Figure 7.16. The effect of the non-carcinogenic risks (HQ) on the adult receptor through exposure to hydrocarbon contamination via the assumed routes in the study site.

Table 7.16. Comparing between the SSTLs (i.e. clean up levels) values and the concentrations for the chemicals of concern detected in the site (Greater Burgan Oil Field- Al Magwa area).

<table>
<tr><th colspan="3"><i>Individual Constituent Clean up Levels of Hydrocarbon Contamination Substances related to PAH Detected at the Site</i></th></tr>
<tr><th>Hydrocarbon Chemical Substances of Concern</th><th>SSTLs (i.e. Clean up Levels) (mg/kg)</th><th>Soil contamination concentration (95% UCL of the mean) in the site (mg/kg)</th></tr>
<tr><td><i>Anthracene</i></td><td>2400</td><td>*35.44</td></tr>
<tr><td><i>Phenanthrene</i></td><td>100000</td><td>*38.51</td></tr>
<tr><th colspan="3"><i>Individual Constituent Clean up Levels of TPH Fractions Contamination Detected at the Site</i></th></tr>
<tr><th>TPH Fractions of Concern</th><th>SSTLs (i.e. Clean up Levels) (mg/kg)</th><th>Soil contamination concentration (95% UCL of the mean) in the site (mg/kg)</th></tr>
<tr><td><i>Aliphatic EC12 - EC16</i></td><td>870</td><td>*23.23</td></tr>
<tr><td><i>Aliphatic EC16 - EC35</i></td><td>23000</td><td>*323.7</td></tr>
<tr><td><i>Aromatic EC8 - EC10</i></td><td>2600</td><td>*7.845</td></tr>
<tr><td><i>Aromatic EC10 - EC12</i></td><td>850</td><td>*39.53</td></tr>
<tr><td><i>Aromatic EC12 - EC16</i></td><td>290</td><td>*83.98</td></tr>
<tr><td><i>Aromatic EC16 - EC21</i></td><td>91</td><td>**225.6</td></tr>
<tr><th colspan="3"><i>Cumulative Clean up Level of the Total of TPH Contamination Detected at the Site</i></th></tr>
<tr><th>TPH Fractions of Concern</th><th>SSTLs (i.e. Clean up Levels) (mg/kg)</th><th>Soil contamination concentration (95% UCL of the mean) in the site (mg/kg)</th></tr>
<tr><td><i>Total of TPH fractions</i></td><td>292.8</td><td>**588.7</td></tr>
</table>

Note:***Hydrocarbon contamination concentrations less than the SSTLs (i.e. clean up levels) are illustrated in green colour.***

*****Hydrocarbon contamination concentrations more than the SSTLs (i.e. Clean up levels) are displayed in brown colour.***

7.6 Summary

This Chapter outlines the HHRA scenarios used for the contaminated site (dry *oil lake* at Al-Magwa area), including: (1a) Hazard Identification; (1b) Hazard Assessment; (2a) Risk Estimation; and (2b) Risk Evaluation. The HHRA scenarios followed in this study in order to evaluate the carcinogenic and non-carcinogenic risks to human health and to calculate clean-up levels needed for the identified locations-specifically for the safety of inhabitants who may wish to reside in these area in the future. This Risk Evaluation was analysed by means of RISC-5 modelling software. The following conclusions were drawn from these analyses:

- The human health (child and adult) carcinogenic risks caused by TPH fractions (aliphatic and aromatic) and the chemicals associated with Anthracene and Phenanathrene from the exposure into the assumed pathways at the site were concluded as *Not Detected* (ND).
- The influence of the non-carcinogenic risks on human health caused by the Anthracene and Phenanathrene (PAH) and TPH fraction (aliphatic and aromatic) contamination through the same assumed pathways show that the total HQ were 2.7 for children and 1.03 for adults, concluding that the HQ was > 1 which means a potential risk.
- The SSTLs, i.e. clean up levels' values were compared with the concentration of hydrocarbon soil contaminants discovered at the site under study. The findings clearly demonstrate that the detected contamination concentrations of the aromatic (EC16 - EC21) hydrocarbon are greater than the calculated SSTLs. The total TPH concentration of the site is also higher than the value of SSTLs, meaning that there is a potential need for risk management measures.

8. DISCUSSION OF DEVELOPED SITE MODEL

8.1 Introduction

This chapter presents a discussion and interpretation of the correlation between the geotechnical and geochemical characteristics of the hydrocarbon contaminated soil (see Chapters 5 and 6). It also compares the relationship between the geotechnical and geochemical properties of the hydrocarbon contaminated soil to the non-contaminated (control) soil. A statistical analysis was conducted on the results of the laboratory data. The analysis (in general) showed no appreciable changes to the characteristics of soil.

The Human Health Risk Assessment (HHRA) regarding the hydrocarbon contamination in the soil (dry *oil lake*) in terms of non-carcinogenic risk values via the assumed pathways are also discussed and evaluated. Additionally, the screening level values of the dry *oil lake* site are compared with hydrocarbon concentrations and estimated for any site designated for future development. This chapter also considers how Kuwaiti's human health has been affected by hydrocarbon contaminations since the Iraqi invasion of 1991.To the best of the writer's knowledge no previous studies have been carried out to research this relationship with soil contaminated with crude oil after a long drying-out period (as in this study).

8.2 Geotechnical Properties

The effects of the hydrocarbon contamination on the geotechnical properties and the interrelationship between these properties are discussed in this section.

8.2.1 Effect on Grain Size Distribution

As explained in section 5.3, hydrocarbon contamination of the silty sand soil in the dry *oil lake* altered the grain size constituents of the original soil. It has led to an increase in the percentage of large particles (more than 2.0 mm). This was clearly seen in samples taken from the top soil where hydrocarbon contamination was found to be higher. However, contamination was found to be decreasing at depths of approximately zero at 2.0 m from the ground surface. Changes (see section 5.3) were attributed to the binding effect of the dry *oil lake* residue on soil particles to cause an aggregation of several particles forming one large particle during the sieving operation. This was clearer at the top soil level (0.0 m depth).

The above phenomenon was justified from SEM photographs (Figures 5.14 to 5.16) for samples taken from the top soil as further investigation of the grain size distribution took place. An increase in the percentage of fine particles (less than 0.063 mm) was attributed to the asphaltane particles left after drying of the *oil lake* residue. Statistical analysis proved that contamination have significantly changed most of the grain size constituent percentages. Such PSD variations seem to extend the soil away from being well graded, in other words, the soil became closer to the uniformly or poorly graded.

The change to poorer gradation in the contaminated area was proved from statistical results of Cc and Cu values (Section 5.3.2). The increase in the percentages of fine particles (less than 0.063 mm) is in line with the study of Jia *et al*. (2011), who found higher clay particles in severely polluted oil contamination (Section 3.3.1).

8.2.2 Effect on Permeability

As was clear from sections 5.3 and 5.4, contamination was high at shallow depths which may have clogged some of the voids in soil at 0.25 m depth. However, at 0.0 m depth, where the hydrocarbon contamination was higher it was expected to have been subjected to a higher extent of drying than that of the 0.25 m depth leading to aggregations of some particles (as shown in Figures 5.17 and 5.19) leading to coarser PSD; therefore, the permeability at 0.0 m depth was higher than that at 0.25 m. This phenomenon was noticed during the sampling process.

8.2.3 Reduction in Angle of Internal Friction (φ)

Referring to table 5.8 and figure 5.22, the angle of internal friction (φ) at the contaminated site was shown to have been steadily decreased due to hydrocarbon contamination in all samples. However, the decrease in internal friction angle (φ) due to hydrocarbon contamination was generally lower as the depths increased. Statistical analysis proved that the angle of internal friction (φ) was significantly increased with an increase in depth at the contaminated area. However, in the non-contaminated area, there was no significant change with depth (Figure 5.23). This phenomenon may be related to the reduced soil contamination at greater depths.

As mentioned in section 5.6, the decrease of angle of internal friction (φ) in contaminated soil may be related to hydrocarbon contamination changes to the PSD of soil to a poorer grade. Although the reduction in the angle of friction does not appear to be high, (in this study) due to contamination, it does cause an appreciable decrease in the angle of internal friction of the soil.

8.3 Geochemical Properties

Clarification of the effects of oil contamination in the geochemical characterisation found in the results of this study, i.e. changes in the acidity, chloride, sulphate, elementals, and hydrocarbon contamination, will be provided in this section.

8.3.1 Change in the Acidity

For soils obtained from both contaminated and non-contaminated sites, it was found that the contamination significantly increased the range between the maximum and minimum pH values particularly at the top layer (which was expected to have higher contamination) down to a depth of slightly more than 0.5 m. It was also found that the pH minimum values of samples taken from the contaminated sites were significantly lower than for those from the non-contaminated sites at all depths. This signifies that the hydrocarbon contamination increases soil acidity. Although, this increase in acidity does not cause the soil to be unsuitable for plant growth, it does, however, decrease its availability for agricultural activities.

8.3.2 Effect on Chloride and Sulphate Content

As seen from the results in section 6.3, it is evident that the contamination of the chloride has taken place through the whole 2.0 m investigated depth in the contaminated area. The chloride content for the top layer of this area was found to be very high. Concentration subsequently decreases with depth down 0.25 m below ground level, whereas, after the 0.25 m depth, it reaches an approximately constant value down to 2.0 m. At the non-contaminated site, however, the chloride concentration was almost negligible. This characteristic was proved statistically (see Figure 6.8) after deleting the outlier values. The presence of high concentrations of chloride at the upper layer of the contaminated site could be due to the higher hydrocarbon oil contamination.

Figures 6.5 and 6.6 in section 6.3 show that originally the soils had an appreciable sulphate content (both SO_3 and SO_4). These contents were approximately constant at all depths in the non-contaminated site. The figures also show that the sulphate contents of the very top layer of the contaminated site were higher than that of the non-contaminated site. They then drop down suddenly through the depths to become lower than that in the non-contaminated site. Statistical analysis after deleting the outlier values proved this phenomenon (see Figures 6.9 and 6.10). The lower content of SO_3 and SO_4 at depths lower than the top layer may be attributed to the following interpretations:

- A drop had taken place in the original sulphate (SO_3 and SO_4) of the soil before its contamination which may be attributed to the proper action of water in extinguishing the fires (Section 6.3).

- The high concentration of sulphate still in the top layer comes from high hydrocarbon contamination. However, during fire extinguishing these sulphates may have been dissolved by the runoff from the fire fighting materials and transported either vertically or horizontally through the soil. Furthermore, statistical analysis showed that the depth does not predict the concentration of sulphate (SO_3 and SO_4) at either site.

8.3.3 Changes in the Carbon and Hydrocarbon Contamination with Depth

With the increase in depth, the mean values of carbon content (C %) in the contaminated site was decreased considerably at depths down to 0.5 m; after that they drop to nearly negligible values. However, in the non-contaminated area the carbon contents (C %) can be considered as negligible at all depths (see Table 6.9 and Figure 6.16 shows C % values after deleting outliers).

The above trend of relationships between the TPH concentrations with depths at the contaminated site is noted. Statistical analysis proved that the TPH concentration at the top layer was significantly higher than that at depths of 0.25 m and 0.5 m. TPH was not encountered at lower depths (see Table 6.16).

8.4 Correlations in the Changes between Geotechnical and Geochemical Properties

- Table (8.1) was prepared for the purpose of comparing changes between the geotechnical and geochemical properties of the soil due to contamination. The table displays multiple linear regression analysis using the backward elimination technique which was performed on the TPH concentration data for the contaminated site, to determine whether four predictors (fine sand, curvature coefficient, angle of internal friction, and SO_4 at T.P.C. (50 m, 50 m) predict TPH concentration. Results revealed that in the original program, model 1 of four predictors had no significant impact on TPH, R2 = 0.992, F (4, 1) = 29.32, *p*= 0.138. The final model 4 included only that the angle of internal friction was approaching significance, i.e. (B = -54.487, SEB = 20.090, Beta = -0.805, *p*= 0.05).

  From the above, it can be concluded that the angle of internal friction was the best predictor in this model for TPH concentration. For every one unit increase in angle of internal friction, the TPH concentration decreased by 54.487 (mg / kg) units. On average, the R Square value of 0.648 indicates that the correlation between angle of internal friction and TPH concentration is approximately 64.8 %.

- Furthermore, there was virtually no (or very slight) changes in the above characteristics below the 2.0 m depth (from the ground level). This indicates that no crude oil residue contamination was taking place under this layer and as such there is no concern regarding contamination to the ground water, since the water table depth is more than 10 m below the ground level.

Table 8.1. Multiple regression (Backward elimination technique) predicting TPH concentration (mg/kg) from fine sand %, curvature coefficient (Cc), angle of internal friction (φ) and SO_4 (mg/kg) at T.P.C. (50 m, 50 m).

Model (Notes)	Variable	Unstandardized Coefficients		Standardized Coefficients	t-value	p-value
		B	**SE.B**	**Beta**		
1 (All four predictors to predict TPH)	***(Constant)***	3517.42	445.39		7.89	0.08
	Fine Sand %	15.35	2.93	0.92	5.23	0.12
	Curvature coefficient (Cc) %	-458.09	72.32	-1.34	-6.33	0.10
	Angle of Internal Friction (φ)	-120.60	13.45	-1.78	-8.96	0.07
	SO_4 concentrations (mg/kg)	0.10	0.04	0.36	2.21	0.27
2 (SO_4 is excluded in Model 2 as it was the least significant predictor in Model 1)	***(Constant)***	3918.85	699.24		5.60	0.03
	Fine Sand %	11.59	4.11	0.70	2.81	0.10
	Curvature coefficient (Cc) %	-393.86	113.86	-1.15	-3.45	0.07
	Angle of Internal Friction (φ)	-124.74	22.89	-1.84	-5.44	0.03
3 (Fine sand % is excluded in Model 3 as it was the least significant predictor in Model 2)	***(Constant)***	2646.99	972.64		2.72	0.07
	Curvature coefficient (Cc) %	-155.77	139.03	-0.45	-1.12	0.34
	Angle of Internal Friction (φ)	-76.31	27.55	-1.12	-2.77	0.07
4 (Only Angle of Internal Friction is included in final Model 4, as the best predictor of TPH)	***(Constant)***	1811.80	644.44		2.81	0.04
	Angle of Internal Friction (φ)	-54.48	20.09	-0.80	-2.71	*0.05

Note: -Dependent Variable: TPH Concentration.

-Coarse Sand, Medium Sand, and Exact Soil Passing number 230 predictor variables were excluded from this backward elimination model. Linear regression found neither Coarse sand (B=-32.88, SEB=31.80, Beta=-.459, p=.360), Medium Sand (B=10.294, SEB=8.757, Beta=0.507, p=0.305) and Exact Soil Passing No.230 (B=-17.037, SEB=31.223, Beta=-0.263, p=0.614) predicted TPH concentration.

*******indicates to the significant relationship between independent and dependent varaibles.*

8.5 Human Health Risk Assessment (HHRA)

The investigation on geotechnical and geochemical properties detected hydrocarbon concentrations on the site under investigation. Future expansion of Kuwait city is likely to require development of these areas; as such a Human Health Risk Assessment (HHRA) of the site has been carried out.

Thus, (in this section) the non-carcinogenic adverse impacts of the toxicity of hydrocarbon contamination on human health through assumed pathways at the site were examined; the clean-up level values for the contaminated site are also discussed in this section.

8.5.1 Non- Carcinogenic Risks through Investigated Pathways

Tables (7.14 & 7.15) and figures (7.16 & 7.17) show that the HQ is more than 1 for both resident children and adults, which means that there is a potential health risk. Furthermore, it can be clearly seen that a significant risk comes from the hydrocarbons through ingestion of home-grown vegetables; this ingestion alone generates a HQ = 2.7 for child residents (male and female) and 1.03 for adults (male and female). Therefore, if the home-grown vegetables' pathway is removed in the area through the prohibition of such activities then the human health risk will subsequently reduce as demonstrated by recalculated HQ of 0.34 for child (male and female) and 0.05 for adults (male and female) as such, there would be no risk from the non-carcinogenic areas.

8.5.2 Estimation of Clean-up Levels for the Dry Oil Lake

Table 7.16 show that the aromatic EC16-EC21 and the total of TPH concentrations in the site are higher than the site specific target levels (SSTLs). These values (above the SSTLs) are justified as follows:

- As principle deriving risk to the health of child and adult residents (both male and female) was constituted through the aromatic (EC16 - EC21) hydrocarbons.
- The TPH fractions' concentrations of HQ < 1 are considered to be acceptable. However, it is evident that the total of these TPH fraction concentrations for the whole site will constitute a potential risk to the health of both children and adult residents (male and female) in the future (HQ >1) (Tables 7.14 and 7.15).

The results indicate that there is need for risk management measures for not only home-grown vegetables but also other agricultural activities in the dry *oil lake* site (al-Magwa area) for the protection of future residents.

9. FINAL CONCLUSIONS

9.1 General Overview

Following the Gulf War in 1990 and the extinguishing of the oil fires on the Greater Burgan Oil Field (Al-Magwa area), the resulting dry *oil lakes* were left untouched for 23 years. During this time changes to the geotechnical and geochemical properties of the near surface soil found in these lakes occurred. In particular, the level of detectable hydrocarbons and their subsequent effects on the soil at ground surface were found to have decreased to very low levels at typical normal building foundation depths. As such, it can be assumed that there has been no subsequent contamination of the ground water from this dry *oil lake*, as the ground water level is typically found at around 10 m below ground level.

This study has also clearly shown that hydrocarbons exist in the upper soil layer (0.0 m - 0.5 m depth), despite having been exposed to a hot arid environment since the initial polluting events of the Gulf War in 1990.

9.2 Geotechnical Properties

This study has shown that the hydrocarbon contamination in a dry *oil lake* influences the particle size distribution (PSD) and decreases the shear strength of the soil and has complicated effects on permeability in the upper soil layer. In particular:

- **Effect on grain size distribution:** Hydrocarbon contamination aggregates the grains at the upper soil layer, increasing the percentages of gravel size particles (more than 2.0 mm). The overall effect was change in the soil gradation to a poorer one.

- **Mechanism of change in permeability:** The permeability was significantly decreased to depth 0.25 m although it was not affected to any considerable extent (at depth 0.0 m due to contamination) (this phenomenon is discussed in section 8.2.2), because of the complication of clogging with some of the voids by the dried oil and changes in the PSD to poorer grade.
- **Reduction in Angle of Internal Friction:** This reduction has been shown to be related to the aggregation of the soil particles in the upper soil layer, leading to poorer PSD. The overall effect being shown to decrease linearly with depth (Figures 5.20 & 5.22).

9.3 Geochemical Properties

This study has shown that the hydrocarbon contamination in a dry *oil lake* causes alteration in the acidity, the soluble chloride and the soluble sulphate contents at varying depths in the near ground surface soil layers. In particular:

- **Change in the Acidity:** Hydrocarbon contamination causes an increase in the acidity of the soil. The increase in acidity, however, was not so great as to lower the soil cultivation activity to unsuitable, whereas the minimum pH values of the soil samples for the contaminated site was classified in the range of neutral values (6.6 - 7.3) (Horneck *et al*., 2011).

- **Effect on the chloride and sulphate content:** It appears that hydrocarbon contamination results in a very high chloride content particularly of the upper soil layer.

  High soluble sulphate content has also been detected, at the top layer (0.0 m), however, it decreased to a lower value than that at the non-contaminated site which may have been the result of runoff from the firefighting process. This runoff may have further dissolved the sulphate contents in the original soil (prior to hydrocarbon contamination). A decrease in both the soluble chloride and sulphate content at depth have been shown to occur at the contaminated site.

- **Hydrocarbon content**: The hydrocarbon content of the upper soil layer has been shown to decrease with depth (0.0 m - 0.5 m), until negligible at a depth of 1.0 m.

9.4 Human Health Risk Assessment (HHRA)

The Human Health Risk Assessment has given the following results:

- The largest influencing pathway is the ingestion of home-grown vegetables. Consequently, if this pathway is removed from the area through the prohibition of such home-grown vegetable production and agricultural activities then the human health risk will be reduced (HQ < 1), therefore, there would be no health risk from the non-carcinogenic areas for residents, i.e. child and adults (see Tables 7.14 & 7.15 in section 7.5.4).

- The key hydrocarbon contaminant of concern was identified as aromatic EC16 - EC21 hydrocarbons.

- The total of TPH concentration (mg/kg) at the site (Al-Magwa area) exceeds the calculated SSTL value (mg/kg).

- Any future development of dry *oil lake* sites should include relevant risk management measures for home-grown vegetables and other agricultural activities to remove the potential ingestion pathway.

10. FINAL RECOMMENDATIONS FOR FURTHER WORK

As mentioned by North (2000), cancer and respiratory related diseases have multiplied substantially in Kuwait since the Iraqi invasion of the 1990s. It has been suggested that the increase in these illnesses may be attributed to the following factors:

- The presence of hydrocarbon contamination for the last 25 years (currently being studied) in open spaces which have had no remediation; this has seriously affected the whole area.

- The rapid rise in the population of Kuwait since 1991, which has led to an increase in residential development and subsequently slow encroachment onto the 'dry *oil lakes*'.

- The hot and arid climate of Kuwait caused high evaporation rates from the abandoned hydrocarbon *oil lakes* into the atmosphere thus potentially directly affecting Kuwaiti residents. Dr. Al-Ghanim (HICT, 2011) mentioned that a large proportion of asthmatic sufferers come from the southern area of Kuwait which is close to the Greater Burgan Oil Field (current study).

Therefore, in respect of future plans of the Kuwaiti Government to expand the residential area near the Greater Burgan Oil Field, further studies are recommended as shown below:

- Implementation of similar studies are recommended for nearby *oil lakes* to consider the full extent of hydrocarbon contamination at depth.
- Investigation into probable hydrocarbon contamination of the ground water would be beneficial.
- Development of a wider ground model of the long term migratory behavior of hydrocarbons from the dry *oil lakes.*
- Application of RISC-5 software or other suitable software to develop lateral vapor and particulates' models suitable to the ground conditions encountered at the study site.
- Further investigation into changes to the angle of internal friction related to contact with the hydrocarbon residue.
- Investigation into the effects of the measured chloride and sulphate contents on likely concrete foundations.

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Two, 6, 10-Trimethylpentadecane. (n.d.). *ChemSpider: Search and share chemistry database*. Retrieved from http://www.chemspider.com/Chemical-Structure.18627.html

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APPENDIX A

4. GREATER BURGAN OIL FIELD INVESTIGATION.

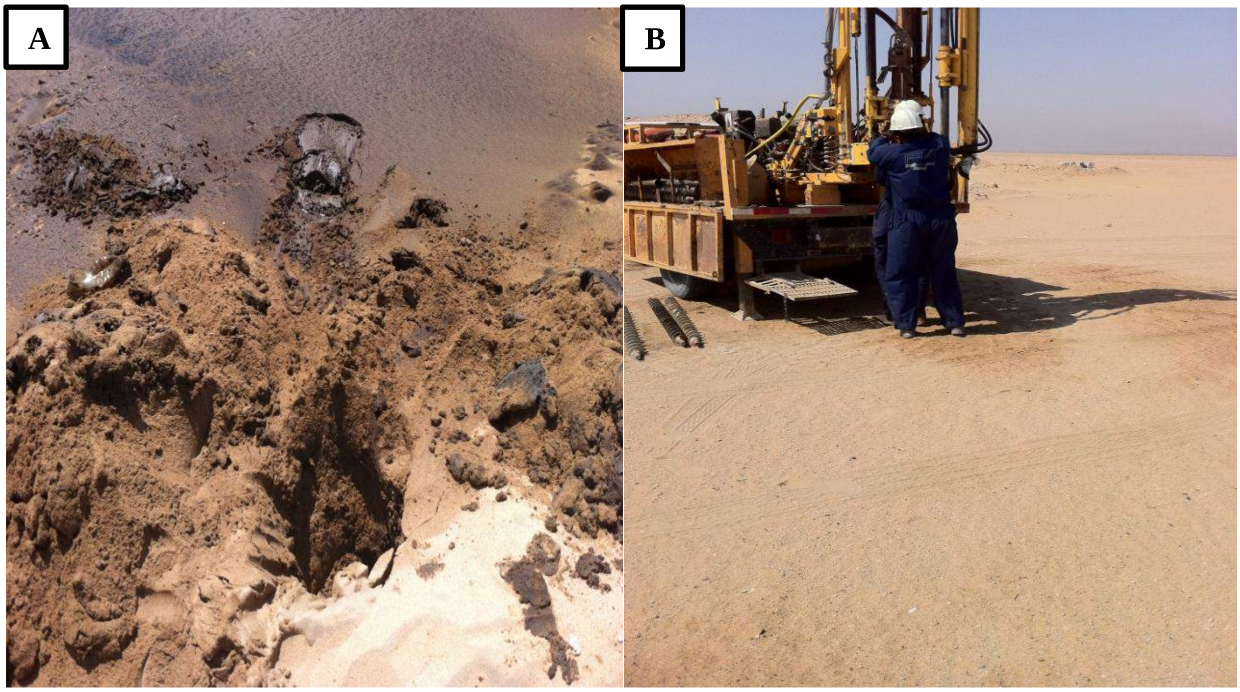


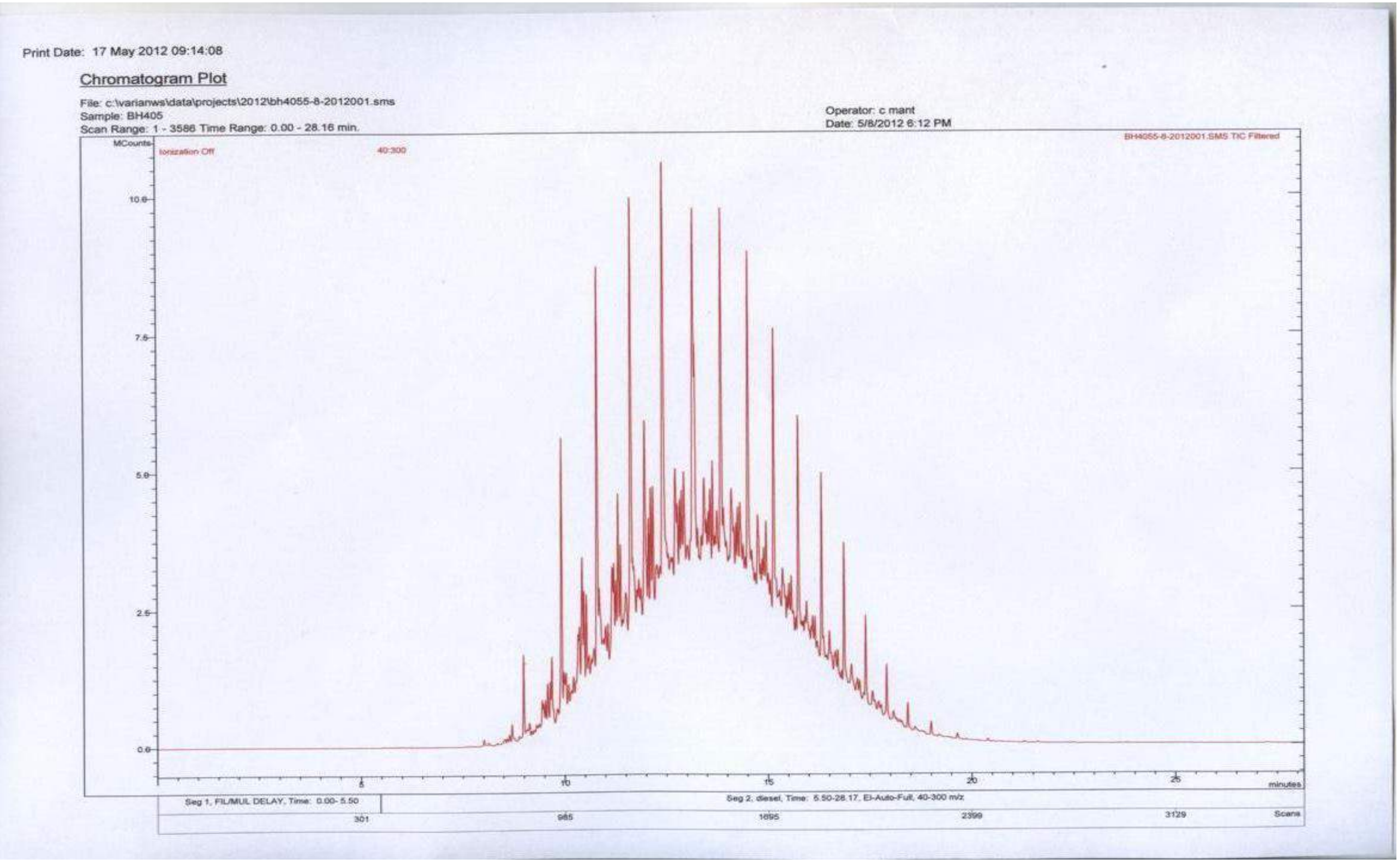
Plate A.4.1. Shows the disturbed contaminated soil sample at depth (0.5 m) in Greater Burgan oil field (A) and the uncontaminated soil samples obtained by borehole truck at depths (0.5 m, 1.0 m, 2.0 m & 4.0 m) in Greater Burgan oil field (al-Magwa Area) (B).

Table A.4.1. Shows the TPH concentration of the soil sample at contaminated site (Greater Burgan oil field-Al Magwa Area).

Trial Pit -Shovel		
Depth (m)	**Soil Weight (g)**	**TPH (mg/kg)**
0.5	1.005	18683.37

Table A.4.2. Shows the TPH concentration of the soil samples at uncontaminated site (Greater Burgan oil field-Al Magwa Area).

Depth (m)	Soil Weight (g)	TPH (µg/g)
Borehole 1		
0.5	10.00	0.00879
1.0	10.00	1.0297
2.0	10.01	0.5161
4.0	10.00	37.72



Print Date: 17 May 2012 09:14:08

Chromatogram Plot

File: c:\varianws\data\projects\2012\bh4055-8-2012001.sms
Sample: BH405
Scan Range: 1 - 3586 Time Range: 0.00 - 28.16 min.

Operator: c mant
Date: 5/8/2012 6:12 PM

Figure A.4.1. Shows TPH concentration for one soil sample at contaminated site (wet oil lake) at depth (0.5 m) at Greater Burgan oil field (Al-Magwa Area).

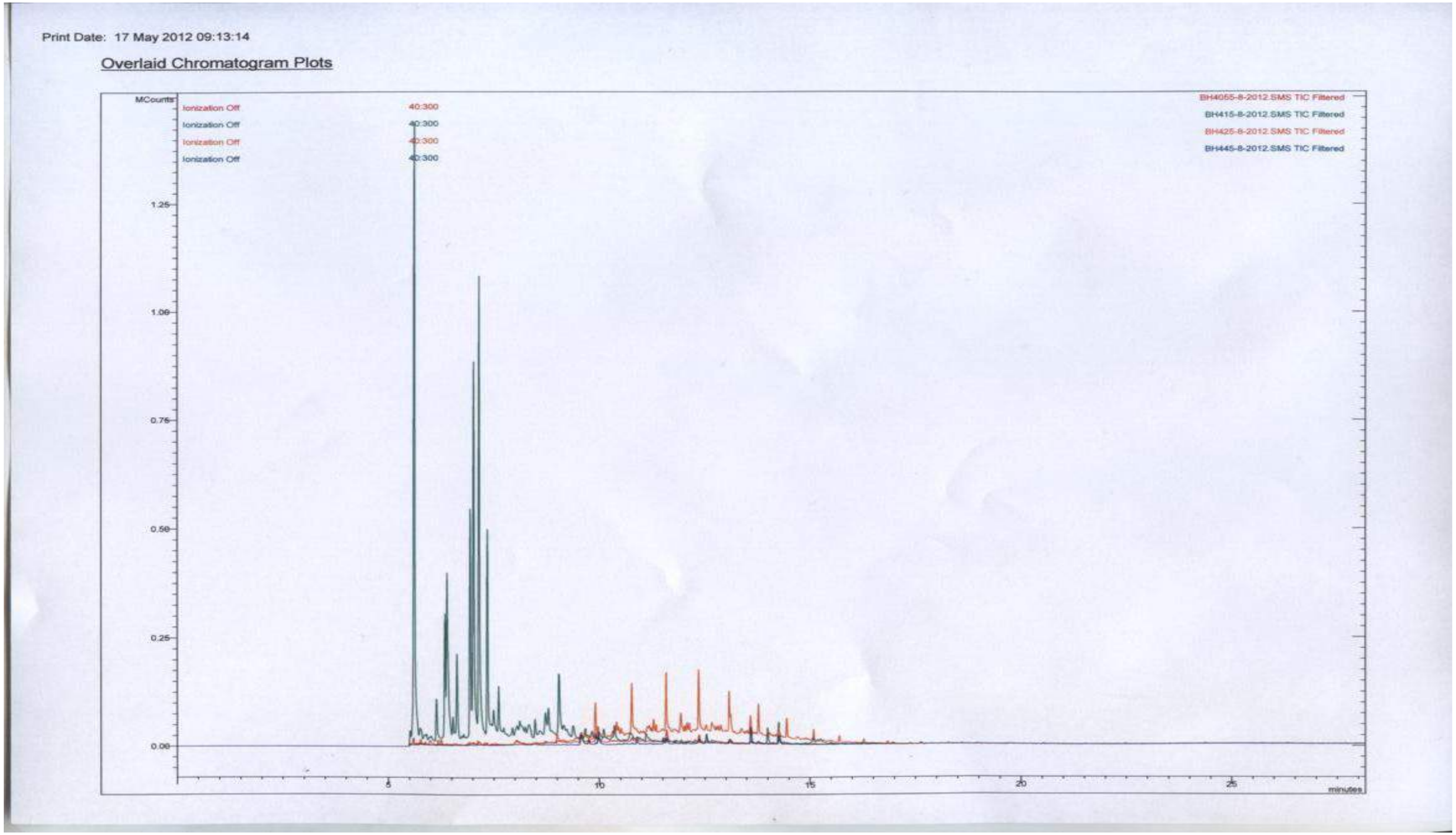
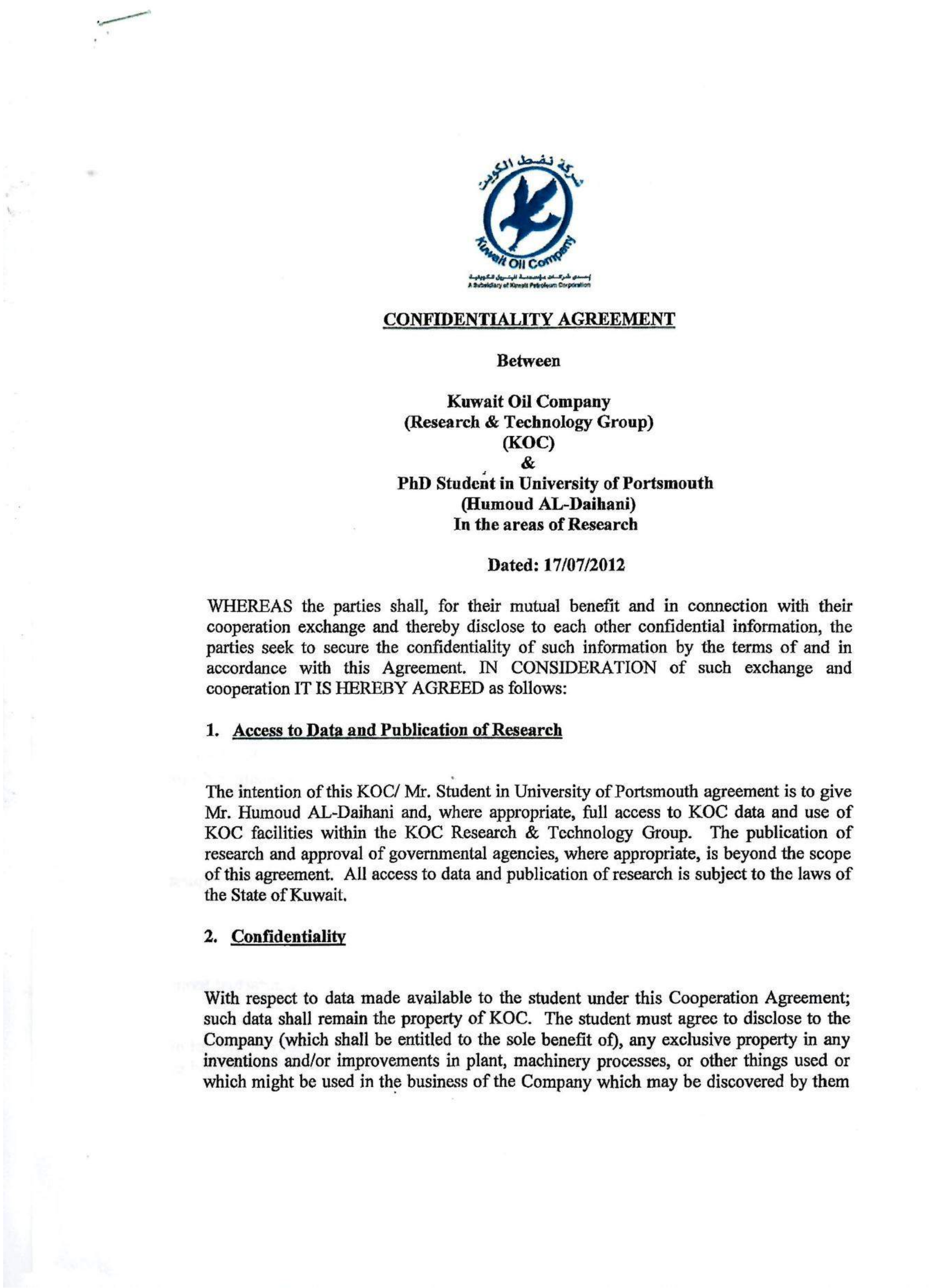


Figure A.4.2. Shows the TPH concentration for the four soil samples at uncontaminated site at different depths (0.5 m, 1.0 m, 2.0 m & 4.0 m) in Greater Burgan oil field (Al-Magwa Area).



CONFIDENTIALITY AGREEMENT

Between

Kuwait Oil Company
(Research & Technology Group)
(KOC)
&
PhD Student in University of Portsmouth
(Humoud AL-Daihani)
In the areas of Research

Dated: 17/07/2012

WHEREAS the parties shall, for their mutual benefit and in connection with their cooperation exchange and thereby disclose to each other confidential information, the parties seek to secure the confidentiality of such information by the terms of and in accordance with this Agreement. IN CONSIDERATION of such exchange and cooperation IT IS HEREBY AGREED as follows:

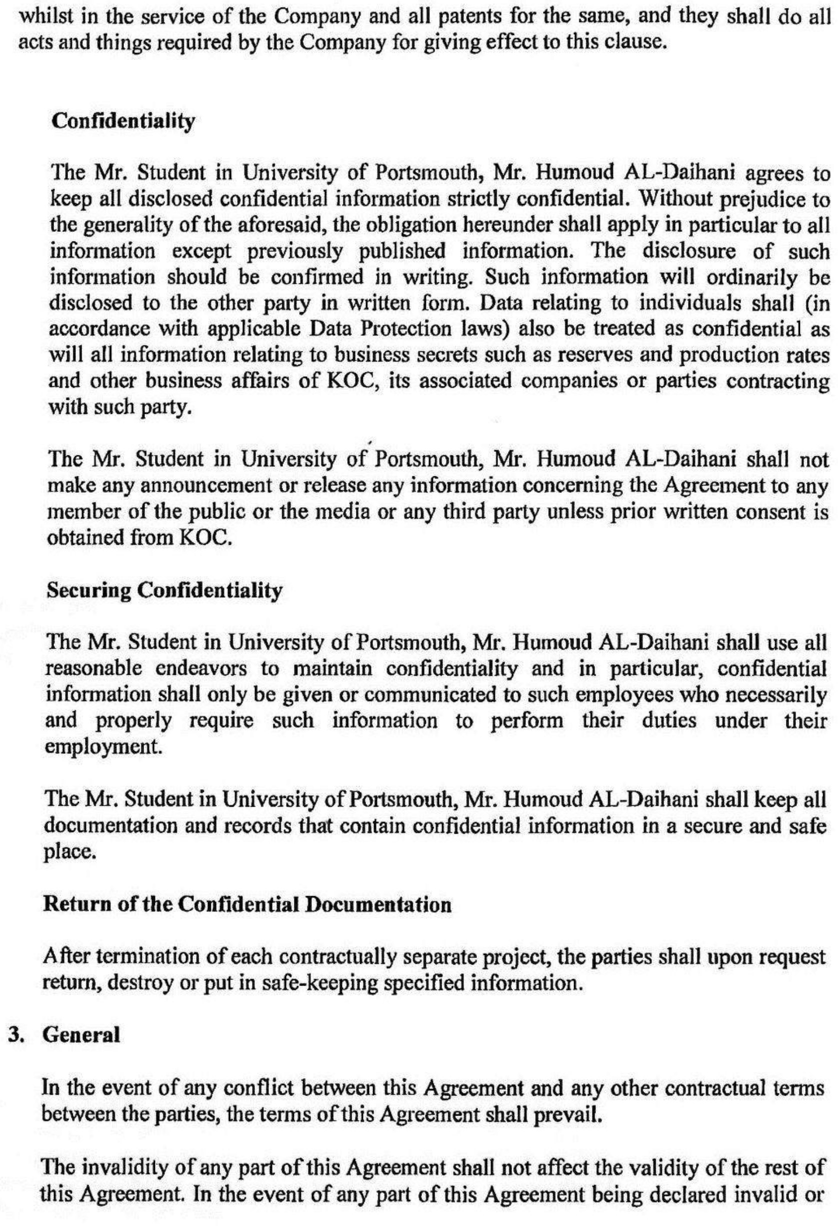
1. Access to Data and Publication of Research

The intention of this KOC/ Mr. Student in University of Portsmouth agreement is to give Mr. Humoud AL-Daihani and, where appropriate, full access to KOC data and use of KOC facilities within the KOC Research & Technology Group. The publication of research and approval of governmental agencies, where appropriate, is beyond the scope of this agreement. All access to data and publication of research is subject to the laws of the State of Kuwait.

2. Confidentiality

With respect to data made available to the student under this Cooperation Agreement; such data shall remain the property of KOC. The student must agree to disclose to the Company (which shall be entitled to the sole benefit of), any exclusive property in any inventions and/or improvements in plant, machinery processes, or other things used or which might be used in the business of the Company which may be discovered by them

Figure A.4.3a. Shows the confidentially agreement between Kuwait Oil Company (KOC) and University of Portsmouth.



whilst in the service of the Company and all patents for the same, and they shall do all acts and things required by the Company for giving effect to this clause.

Confidentiality

The Mr. Student in University of Portsmouth, Mr. Humoud AL-Daihani agrees to keep all disclosed confidential information strictly confidential. Without prejudice to the generality of the aforesaid, the obligation hereunder shall apply in particular to all information except previously published information. The disclosure of such information should be confirmed in writing. Such information will ordinarily be disclosed to the other party in written form. Data relating to individuals shall (in accordance with applicable Data Protection laws) also be treated as confidential as will all information relating to business secrets such as reserves and production rates and other business affairs of KOC, its associated companies or parties contracting with such party.

The Mr. Student in University of Portsmouth, Mr. Humoud AL-Daihani shall not make any announcement or release any information concerning the Agreement to any member of the public or the media or any third party unless prior written consent is obtained from KOC.

Securing Confidentiality

The Mr. Student in University of Portsmouth, Mr. Humoud AL-Daihani shall use all reasonable endeavors to maintain confidentiality and in particular, confidential information shall only be given or communicated to such employees who necessarily and properly require such information to perform their duties under their employment.

The Mr. Student in University of Portsmouth, Mr. Humoud AL-Daihani shall keep all documentation and records that contain confidential information in a secure and safe place.

Return of the Confidential Documentation

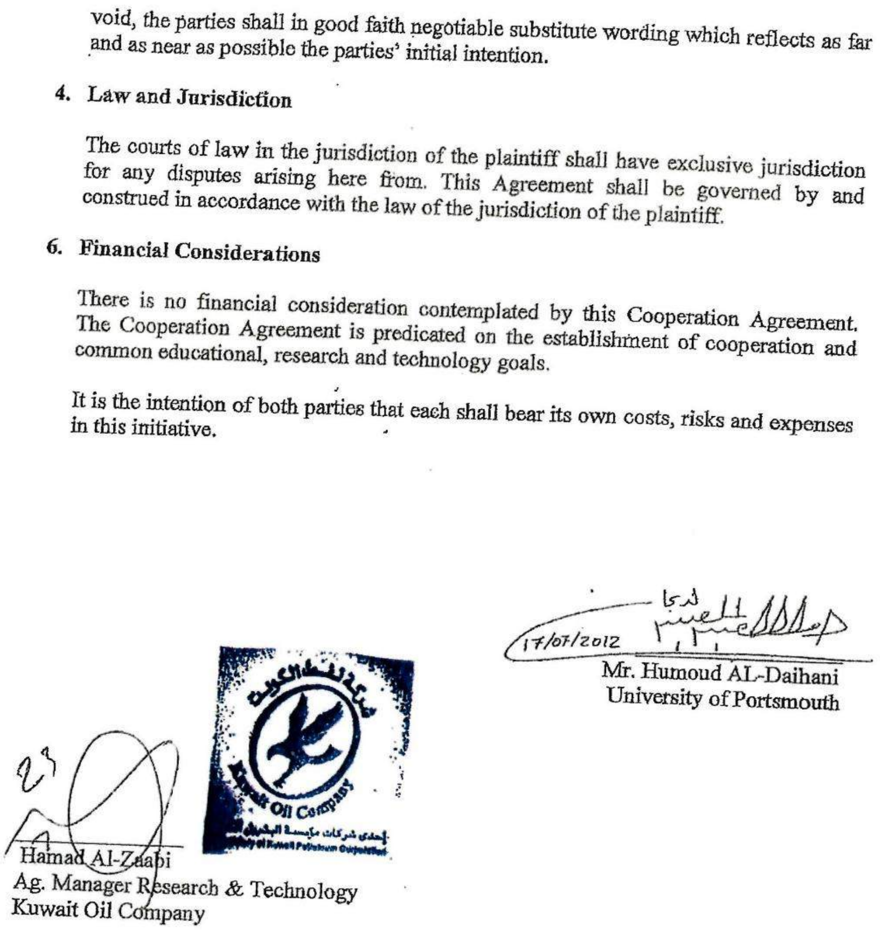
After termination of each contractually separate project, the parties shall upon request return, destroy or put in safe-keeping specified information.

3. **General**

In the event of any conflict between this Agreement and any other contractual terms between the parties, the terms of this Agreement shall prevail.

The invalidity of any part of this Agreement shall not affect the validity of the rest of this Agreement. In the event of any part of this Agreement being declared invalid or

Figure A.4.3b. Shows the confidentially agreement between Kuwait Oil Company (KOC) and University of Portsmouth.



void, the parties shall in good faith negotiable substitute wording which reflects as far and as near as possible the parties' initial intention.

4. Law and Jurisdiction

The courts of law in the jurisdiction of the plaintiff shall have exclusive jurisdiction for any disputes arising here from. This Agreement shall be governed by and construed in accordance with the law of the jurisdiction of the plaintiff.

6. Financial Considerations

There is no financial consideration contemplated by this Cooperation Agreement. The Cooperation Agreement is predicated on the establishment of cooperation and common educational, research and technology goals.

It is the intention of both parties that each shall bear its own costs, risks and expenses in this initiative.

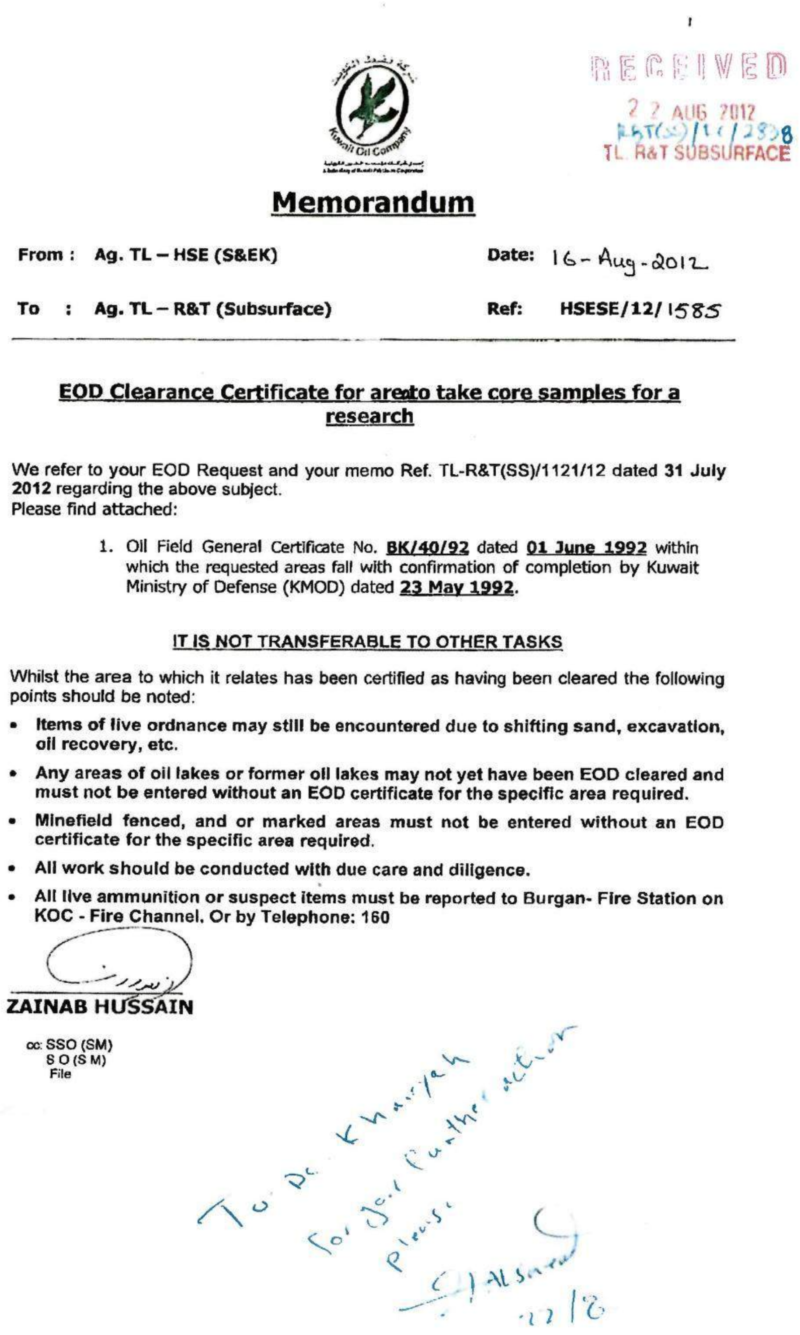
17/07/2012

Mr. Humoud AL-Daihani
University of Portsmouth

23

Hamad Al-Zaabi
Ag. Manager Research & Technology
Kuwait Oil Company

Figure A.4.3c. Shows the confidentially agreement between Kuwait Oil Company (KOC) and University of Portsmouth.



Kuwait Oil Company

RECEIVED
22 AUG 2012
R&T(SS)/11/2838
TL. R&T SUBSURFACE

Memorandum

From : **Ag. TL – HSE (S&EK)** **Date:** 16-Aug-2012

To : **Ag. TL – R&T (Subsurface)** **Ref:** **HSESE/12/**1585

EOD Clearance Certificate for area to take core samples for a research

We refer to your EOD Request and your memo Ref. TL-R&T(SS)/1121/12 dated **31 July 2012** regarding the above subject.
Please find attached:

1. Oil Field General Certificate No. **BK/40/92** dated **01 June 1992** within which the requested areas fall with confirmation of completion by Kuwait Ministry of Defense (KMOD) dated **23 May 1992**.

IT IS NOT TRANSFERABLE TO OTHER TASKS

Whilst the area to which it relates has been certified as having been cleared the following points should be noted:

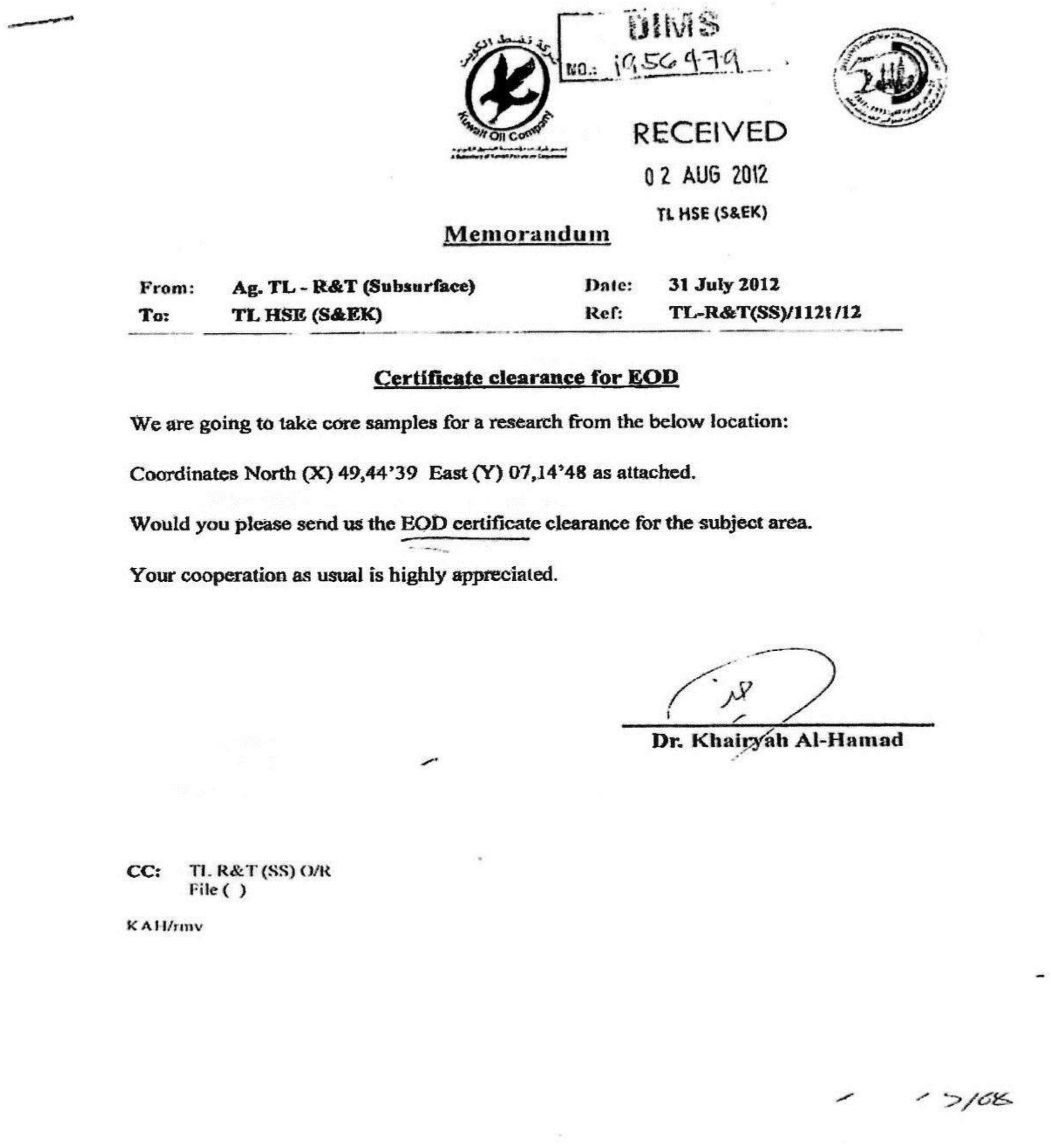
- **Items of live ordnance may still be encountered due to shifting sand, excavation, oil recovery, etc.**
- **Any areas of oil lakes or former oil lakes may not yet have been EOD cleared and must not be entered without an EOD certificate for the specific area required.**
- **Minefield fenced, and or marked areas must not be entered without an EOD certificate for the specific area required.**
- **All work should be conducted with due care and diligence.**
- **All live ammunition or suspect items must be reported to Burgan- Fire Station on KOC - Fire Channel. Or by Telephone: 160**

ZAINAB HUSSAIN

cc: SSO (SM)
S O (S M)
File

To Dr. Khariyah
for your further action
please
Al Sanad
22/8

Figure A.4.4a. Shows the EoD Clearance certificate for contamination contamination site.



DIMS
NO.: 1956479

RECEIVED
02 AUG 2012
TL HSE (S&EK)

Memorandum

From:	**Ag. TL - R&T (Subsurface)**	**Date:**	**31 July 2012**
To:	**TL HSE (S&EK)**	**Ref:**	**TL-R&T(SS)/112t/12**

Certificate clearance for EOD

We are going to take core samples for a research from the below location:

Coordinates North (X) 49,44'39 East (Y) 07,14'48 as attached.

Would you please send us the EOD certificate clearance for the subject area.

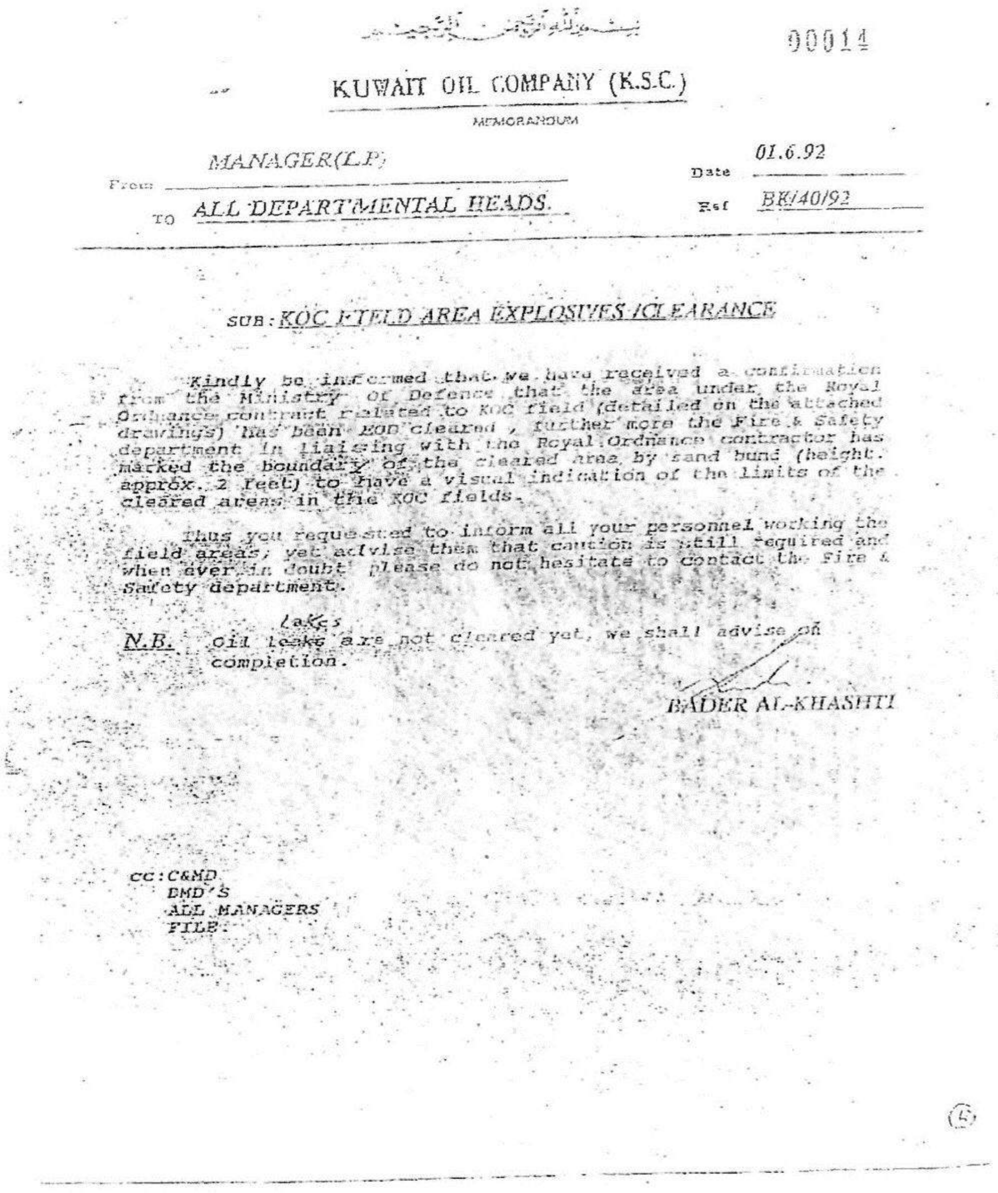
Your cooperation as usual is highly appreciated.

Dr. Khairyah Al-Hamad

CC: TL R&T (SS) O/R
File ( )

KAH/rmv

Figure A.4.4b. Shows the EoD Clearance certificate for contamination contamination site.



بسم الله الرحمن الرحيم

00014

KUWAIT OIL COMPANY (K.S.C.)

MEMORANDUM

From MANAGER(L.P.)
TO ALL DEPARTMENTAL HEADS.
Date 01.6.92
Ref BK/40/92

SUB: KOC FIELD AREA EXPLOSIVES/CLEARANCE

Kindly be informed that we have received a confirmation from the Ministry of Defence that the area under the Royal Ordnance contract related to KOC field (detailed on the attached drawings) has been EOD cleared, further more the Fire & Safety department in liaising with the Royal Ordnance contractor has marked the boundary of the cleared area by sand bund (height. approx. 2 feet) to have a visual indication of the limits of the cleared areas in the KOC fields.

Thus you requested to inform all your personnel working the field areas; yet advise them that caution is still required and when ever in doubt please do not hesitate to contact the Fire & Safety department.

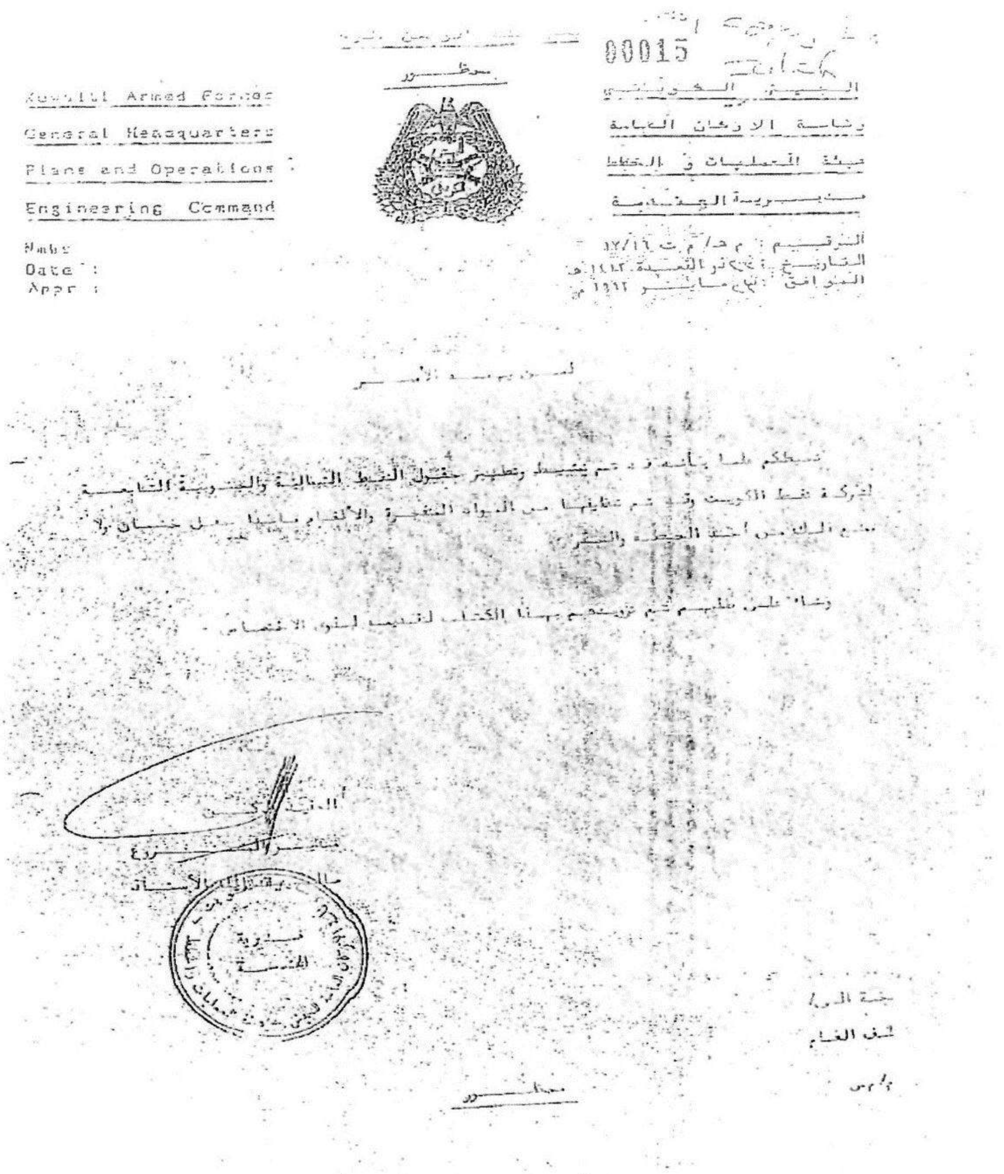
lakes
N.B. oil leaks are not cleared yet, we shall advise on completion.

BADER AL-KHASHTI

cc: C&MD
DMD'S
ALL MANAGERS
FILE.

(5)

Figure A.4.4c. Shows the EoD Clearance certificate for contamination contamination site.



00015

محظور

Kuwaiti Armed Forces
General Headquarters
Plans and Operations
Engineering Command

Numb:
Date :
Appr :

الجيش الكويتي
رئاسة الأركان العامة
هيئة العمليات و الخطط
مديرية الهندسة

الترقيم : [illegible]
التاريخ : [illegible] ذو القعدة [illegible] هـ
الموافق : [illegible] مايو [illegible] م

لمن يهمه الأمر

نحيطكم علما بأنه قد تم تمشيط وتطهير حقول النفط الشمالية والجنوبية التابعة لشركة نفط الكويت وقد تم تطهيرها من المواد المتفجرة والألغام [illegible] من أخطار [illegible]

وبناء على طلبهم تم تزويدهم بهذا الكتاب لتقديمه لذوي الاختصاص .

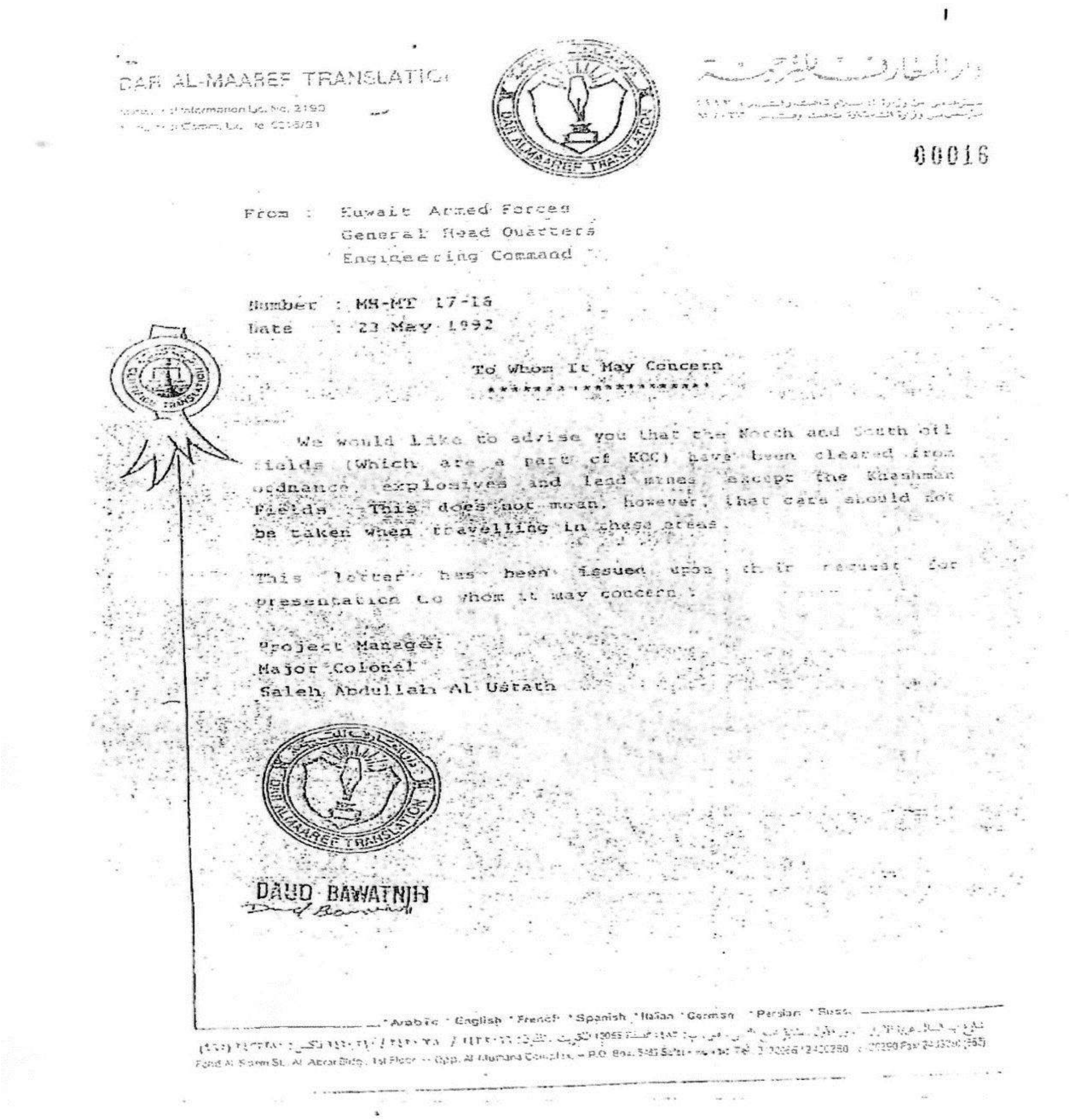
[illegible]

مديرية الهندسة

نسخة إلى
ملف العام

محظور

Figure A.4.4d. Shows the EoD Clearance certificate for contamination contamination site.



DAR AL-MAAREF TRANSLATION
[illegible] Information Lic. No. 2190
[illegible] Comm. Lic. No. [illegible]

00016

From : Kuwait Armed Forces
General Head Quarters
Engineering Command

Number : MR-MT 17-16
Date : 23 May 1992

To Whom It May Concern

We would like to advise you that the North and South oil fields (Which are a part of KOC) have been cleared from ordnance, explosives and land mines, except the Khashman Fields. This does not mean, however, that care should not be taken when travelling in these areas.

This letter has been issued upon their request for presentation to whom it may concern.

Project Manager
Major Colonel
Saleh Abdullah Al Ustath

DAUD BAWATNJH

Arabic • English • French • Spanish • Italian • German • Persian • Russ[illegible]

Figure A.4.4e. Shows the EoD Clearance certificate for contamination contamination site.

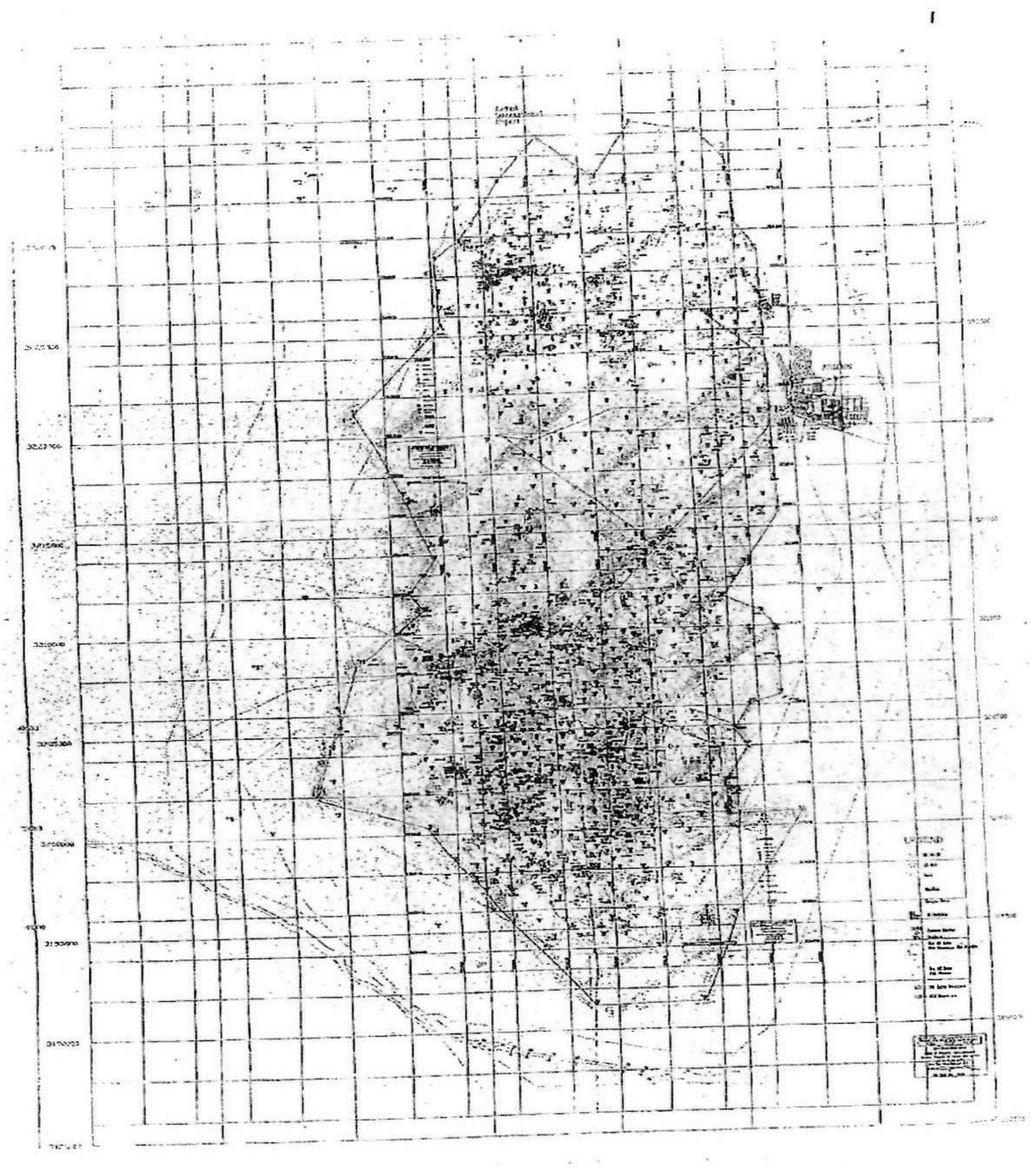
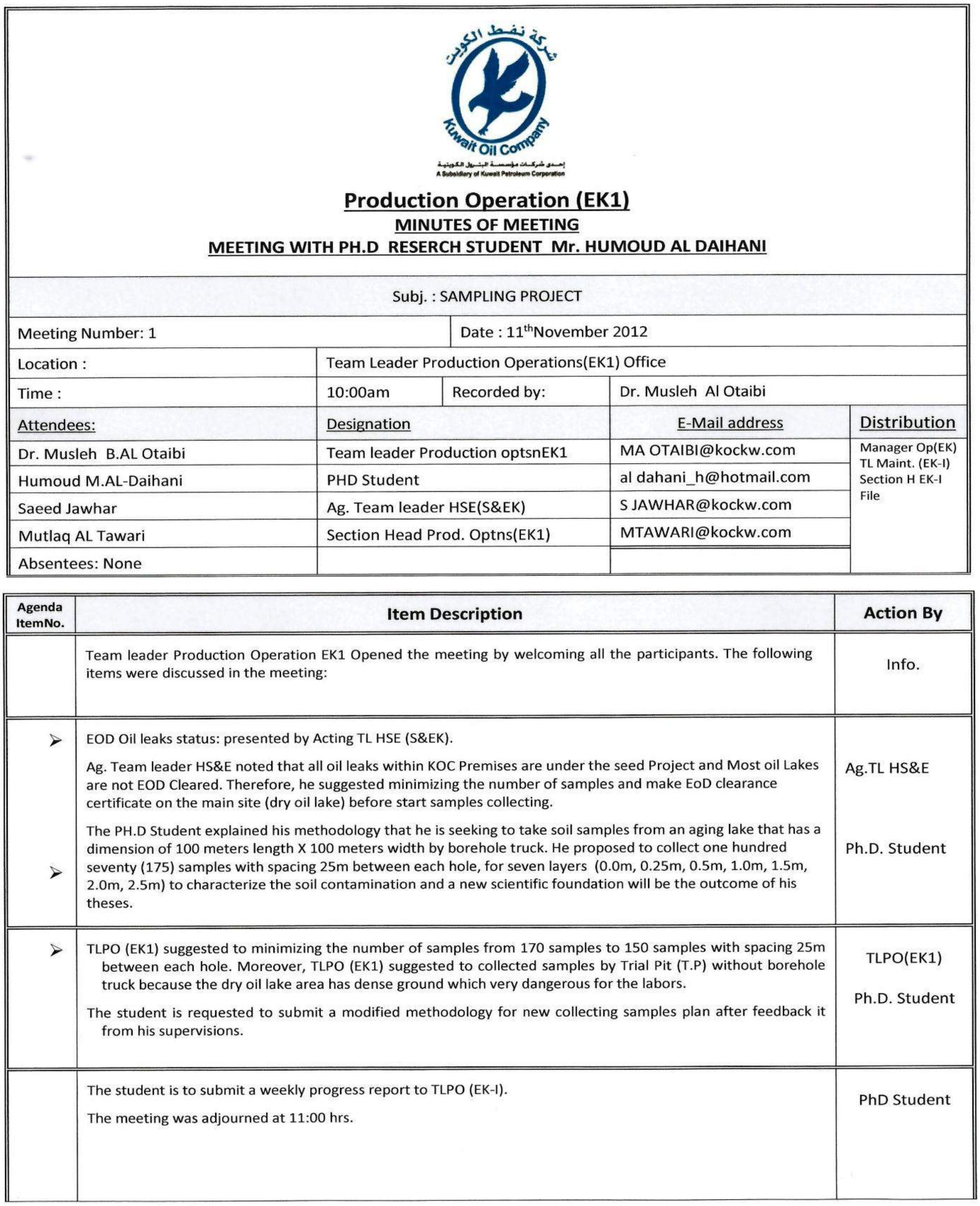


Figure A.4.4f. Shows the EoD Clearance certificate for contamination contamination site.



A Subsidiary of Kuwait Petroleum Corporation

Production Operation (EK1)

MINUTES OF MEETING

MEETING WITH PH.D RESERCH STUDENT Mr. HUMOUD AL DAIHANI

Subj. : SAMPLING PROJECT

Meeting Number: 1

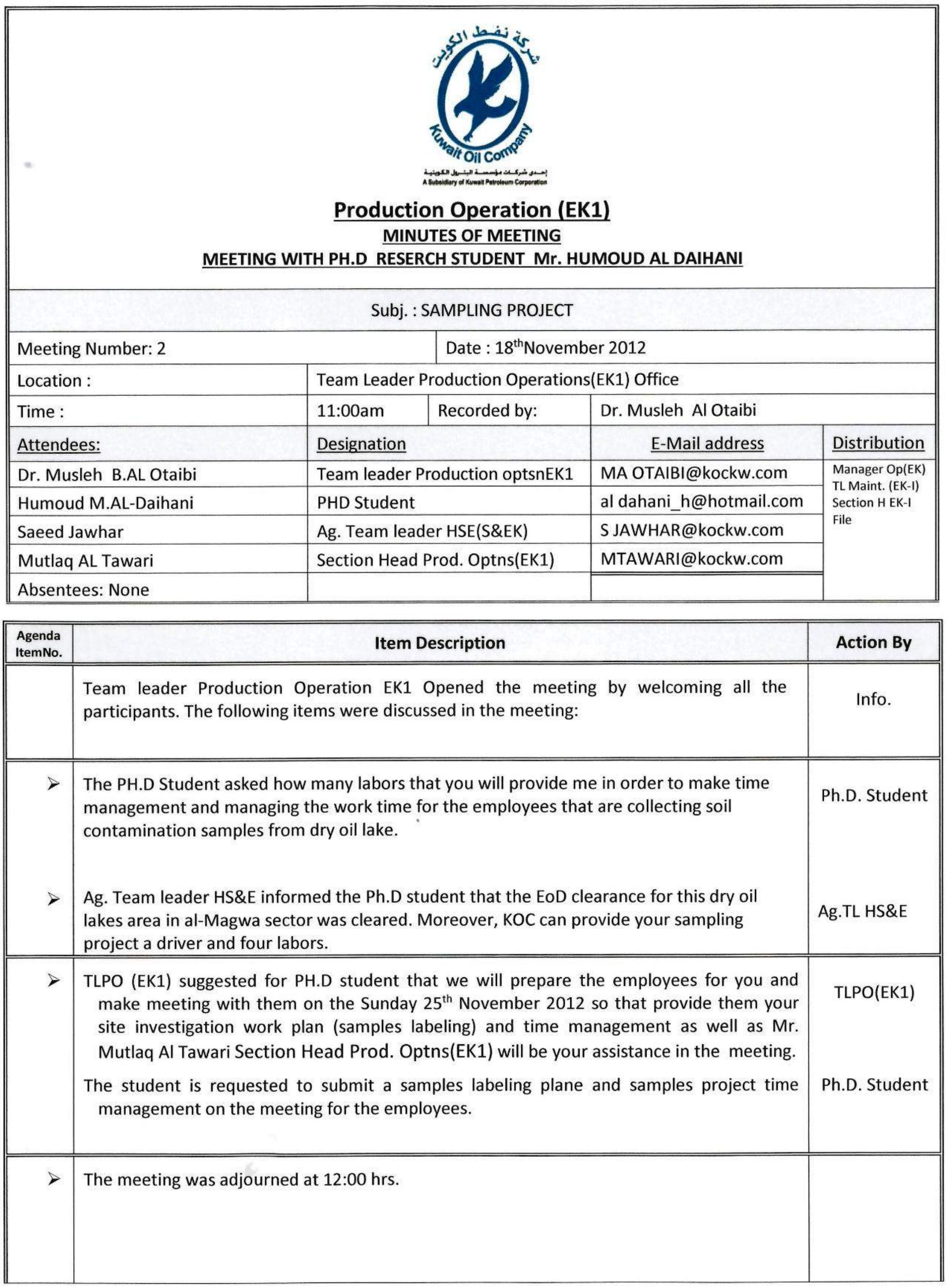
Date : 11th November 2012

Location :	Team Leader Production Operations(EK1) Office		
Time :	10:00am	Recorded by:	Dr. Musleh Al Otaibi

Attendees:	Designation	E-Mail address	Distribution
Dr. Musleh B.AL Otaibi	Team leader Production optsnEK1	MA OTAIBI@kockw.com	Manager Op(EK) TL Maint. (EK-I) Section H EK-I File
Humoud M.AL-Daihani	PHD Student	al dahani_h@hotmail.com	
Saeed Jawhar	Ag. Team leader HSE(S&EK)	S JAWHAR@kockw.com	
Mutlaq AL Tawari	Section Head Prod. Optns(EK1)	MTAWARI@kockw.com	
Absentees: None			

Agenda ItemNo.	Item Description	Action By
	Team leader Production Operation EK1 Opened the meeting by welcoming all the participants. The following items were discussed in the meeting:	Info.
➢	EOD Oil leaks status: presented by Acting TL HSE (S&EK). Ag. Team leader HS&E noted that all oil leaks within KOC Premises are under the seed Project and Most oil Lakes are not EOD Cleared. Therefore, he suggested minimizing the number of samples and make EoD clearance certificate on the main site (dry oil lake) before start samples collecting.	Ag.TL HS&E
➢	The PH.D Student explained his methodology that he is seeking to take soil samples from an aging lake that has a dimension of 100 meters length X 100 meters width by borehole truck. He proposed to collect one hundred seventy (175) samples with spacing 25m between each hole, for seven layers (0.0m, 0.25m, 0.5m, 1.0m, 1.5m, 2.0m, 2.5m) to characterize the soil contamination and a new scientific foundation will be the outcome of his theses.	Ph.D. Student
➢	TLPO (EK1) suggested to minimizing the number of samples from 170 samples to 150 samples with spacing 25m between each hole. Moreover, TLPO (EK1) suggested to collected samples by Trial Pit (T.P) without borehole truck because the dry oil lake area has dense ground which very dangerous for the labors. The student is requested to submit a modified methodology for new collecting samples plan after feedback it from his supervisions.	TLPO(EK1) Ph.D. Student
	The student is to submit a weekly progress report to TLPO (EK-I). The meeting was adjourned at 11:00 hrs.	PhD Student

Figure A.4.5. Shows the the meeting one form with KOC expert staff concerning with sampling project.



شركة نفط الكويت
Kuwait Oil Company
إحدى شركات مؤسسة البترول الكويتية
A Subsidiary of Kuwait Petroleum Corporation

Production Operation (EK1)

MINUTES OF MEETING

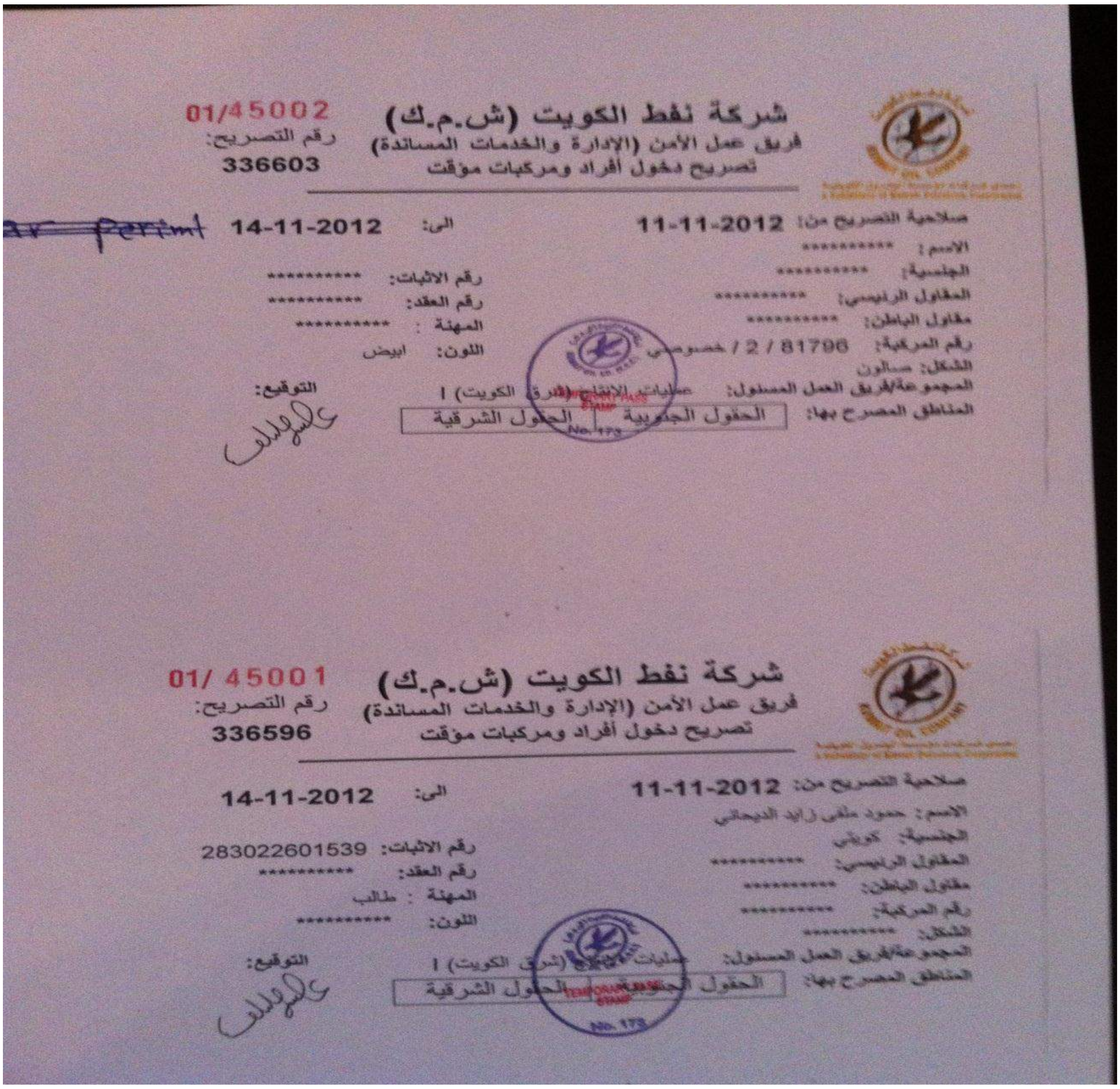
MEETING WITH PH.D RESERCH STUDENT Mr. HUMOUD AL DAIHANI

Subj. : SAMPLING PROJECT			
Meeting Number: 2		Date : 18thNovember 2012	
Location :	Team Leader Production Operations(EK1) Office		
Time :	11:00am	Recorded by:	Dr. Musleh Al Otaibi

Attendees:	Designation	E-Mail address	Distribution
Dr. Musleh B.AL Otaibi	Team leader Production optsnEK1	MA OTAIBI@kockw.com	Manager Op(EK) TL Maint. (EK-I) Section H EK-I File
Humoud M.AL-Daihani	PHD Student	al dahani_h@hotmail.com	
Saeed Jawhar	Ag. Team leader HSE(S&EK)	S JAWHAR@kockw.com	
Mutlaq AL Tawari	Section Head Prod. Optns(EK1)	MTAWARI@kockw.com	
Absentees: None			

Agenda ItemNo.	Item Description	Action By
	Team leader Production Operation EK1 Opened the meeting by welcoming all the participants. The following items were discussed in the meeting:	Info.
➢	The PH.D Student asked how many labors that you will provide me in order to make time management and managing the work time for the employees that are collecting soil contamination samples from dry oil lake.	Ph.D. Student
➢	Ag. Team leader HS&E informed the Ph.D student that the EoD clearance for this dry oil lakes area in al-Magwa sector was cleared. Moreover, KOC can provide your sampling project a driver and four labors.	Ag.TL HS&E
➢	TLPO (EK1) suggested for PH.D student that we will prepare the employees for you and make meeting with them on the Sunday 25th November 2012 so that provide them your site investigation work plan (samples labeling) and time management as well as Mr. Mutlaq Al Tawari Section Head Prod. Optns(EK1) will be your assistance in the meeting.	TLPO(EK1)
	The student is requested to submit a samples labeling plane and samples project time management on the meeting for the employees.	Ph.D. Student
➢	The meeting was adjourned at 12:00 hrs.	

Figure A.4.6. Shows the the meeting two form with KOC expert staff concerning with sampling project.



01/45002
رقم التصريح:
336603

شركة نفط الكويت (ش.م.ك)
فريق عمل الأمن (الإدارة والخدمات المساندة)
تصريح دخول أفراد ومركبات مؤقت

صلاحية التصريح من: 11-11-2012 الى: 14-11-2012 ~~ar Perimt~~
الاسم: **********
الجنسية: **********
المقاول الرئيسي: **********
مقاول الباطن: **********
رقم المركبة: 81796 / 2 / خصوصي
الشكل: صالون
رقم الاثبات: **********
رقم العقد: **********
المهنة : **********
اللون: ابيض
المجموعة/فريق العمل المسئول: عمليات الانتاج (شرق الكويت) ا
المناطق المصرح بها: الحقول الجنوبية | الحقول الشرقية
التوقيع:

TEMPORARY PASS STAMP
No. 173

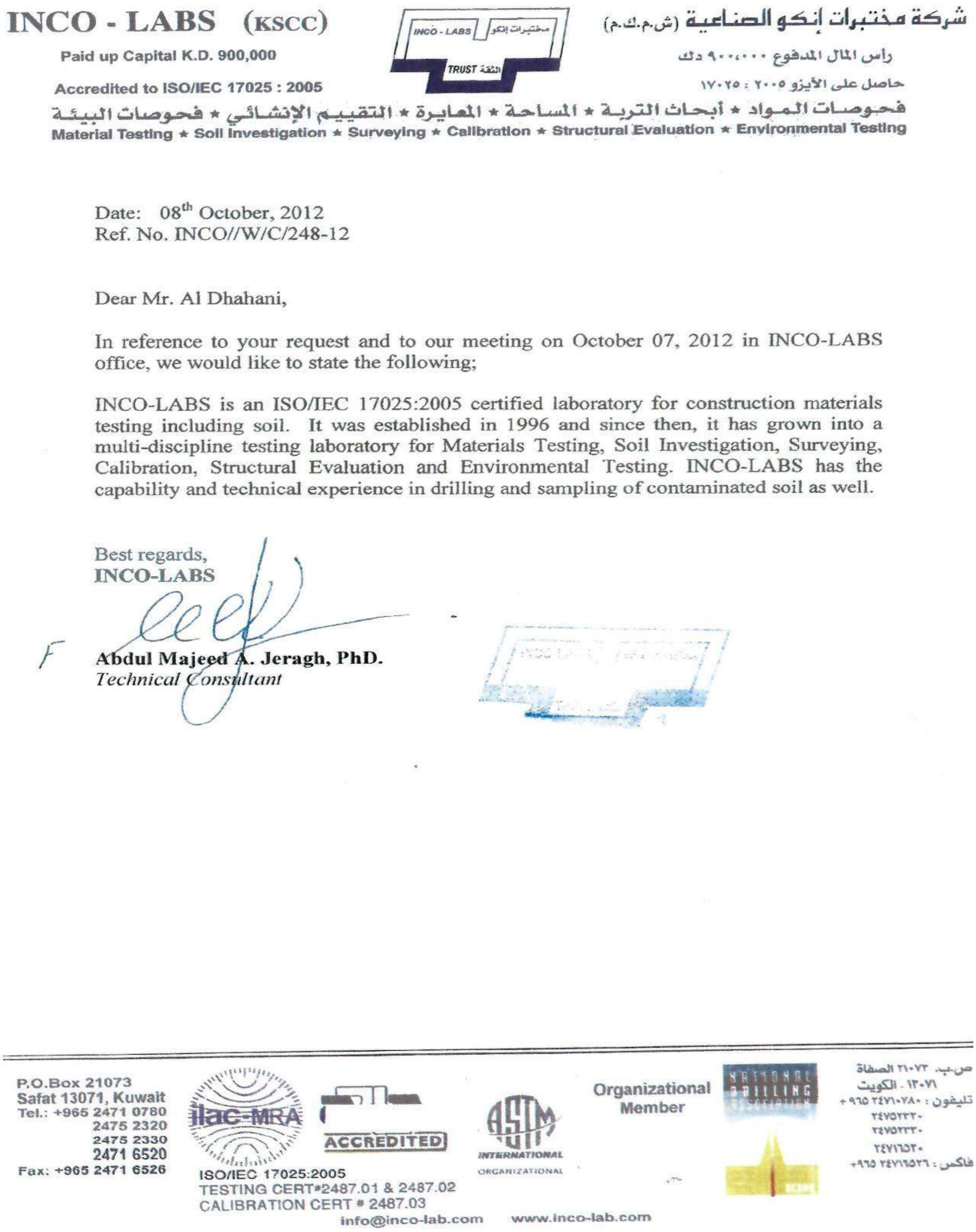
01/ 45001
رقم التصريح:
336596

شركة نفط الكويت (ش.م.ك)
فريق عمل الأمن (الإدارة والخدمات المساندة)
تصريح دخول أفراد ومركبات مؤقت

صلاحية التصريح من: 11-11-2012 الى: 14-11-2012
الاسم: حمود ملفي زايد الديحاني
الجنسية: كويتي
المقاول الرئيسي: **********
مقاول الباطن: **********
رقم المركبة: **********
الشكل: **********
رقم الاثبات: 283022601539
رقم العقد: **********
المهنة : طالب
اللون: **********
المجموعة/فريق العمل المسئول: عمليات الانتاج (شرق الكويت) ا
المناطق المصرح بها: الحقول الجنوبية | الحقول الشرقية
التوقيع:

TEMPORARY PASS STAMP
No. 173

Figure A.4.7. Shows the temporary entry permit card.



INCO - LABS (KSCC)
Paid up Capital K.D. 900,000
Accredited to ISO/IEC 17025 : 2005

شركة مختبرات إنكو الصناعية (ش.م.ك.م)
راس المال المدفوع ٩٠٠،٠٠٠ دك
حاصل على الأيزو ٢٠٠٥ : ١٧٠٢٥

فحوصات المواد ★ أبحاث التربة ★ المساحة ★ المعايرة ★ التقييم الإنشائي ★ فحوصات البيئة
Material Testing ★ Soil Investigation ★ Surveying ★ Calibration ★ Structural Evaluation ★ Environmental Testing

Date: 08th October, 2012
Ref. No. INCO//W/C/248-12

Dear Mr. Al Dhahani,

In reference to your request and to our meeting on October 07, 2012 in INCO-LABS office, we would like to state the following;

INCO-LABS is an ISO/IEC 17025:2005 certified laboratory for construction materials testing including soil. It was established in 1996 and since then, it has grown into a multi-discipline testing laboratory for Materials Testing, Soil Investigation, Surveying, Calibration, Structural Evaluation and Environmental Testing. INCO-LABS has the capability and technical experience in drilling and sampling of contaminated soil as well.

Best regards,
INCO-LABS

F
Abdul Majeed A. Jeragh, PhD.
Technical Consultant

P.O.Box 21073
Safat 13071, Kuwait
Tel.: +965 2471 0780
2475 2320
2475 2330
2471 6520
Fax: +965 2471 6526

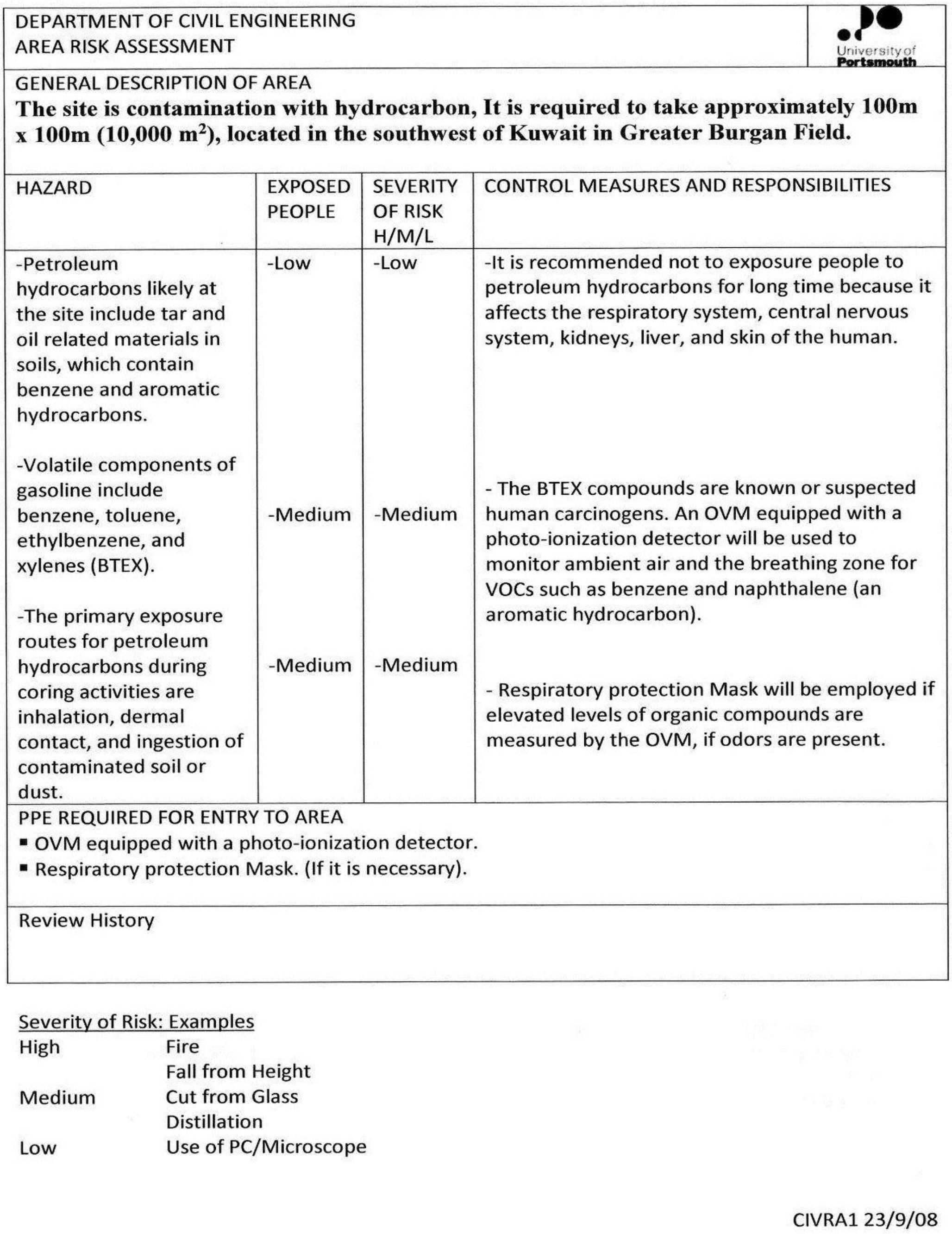
ISO/IEC 17025:2005
TESTING CERT#2487.01 & 2487.02
CALIBRATION CERT # 2487.03

Organizational Member

ص.ب. ٢١٠٧٣ الصفاة
١٣٠٧١ - الكويت
تليفون : ٢٤٧١٠٧٨٠ ٩٦٥+
٢٤٧٥٢٣٢٠
٢٤٧٥٢٣٣٠
٢٤٧١٦٥٢٠
فاكس: ٢٤٧١٦٥٢٦ ٩٦٥+

info@inco-lab.com www.inco-lab.com

Figure A.4.8. Shows the Inco lab letter.



DEPARTMENT OF CIVIL ENGINEERING
AREA RISK ASSESSMENT

GENERAL DESCRIPTION OF AREA

The site is contamination with hydrocarbon, It is required to take approximately 100m x 100m (10,000 m^2), located in the southwest of Kuwait in Greater Burgan Field.

HAZARD	EXPOSED PEOPLE	SEVERITY OF RISK H/M/L	CONTROL MEASURES AND RESPONSIBILITIES
-Petroleum hydrocarbons likely at the site include tar and oil related materials in soils, which contain benzene and aromatic hydrocarbons.	-Low	-Low	-It is recommended not to exposure people to petroleum hydrocarbons for long time because it affects the respiratory system, central nervous system, kidneys, liver, and skin of the human.
-Volatile components of gasoline include benzene, toluene, ethylbenzene, and xylenes (BTEX).	-Medium	-Medium	- The BTEX compounds are known or suspected human carcinogens. An OVM equipped with a photo-ionization detector will be used to monitor ambient air and the breathing zone for VOCs such as benzene and naphthalene (an aromatic hydrocarbon).
-The primary exposure routes for petroleum hydrocarbons during coring activities are inhalation, dermal contact, and ingestion of contaminated soil or dust.	-Medium	-Medium	- Respiratory protection Mask will be employed if elevated levels of organic compounds are measured by the OVM, if odors are present.

PPE REQUIRED FOR ENTRY TO AREA

- OVM equipped with a photo-ionization detector.
- Respiratory protection Mask. (If it is necessary).

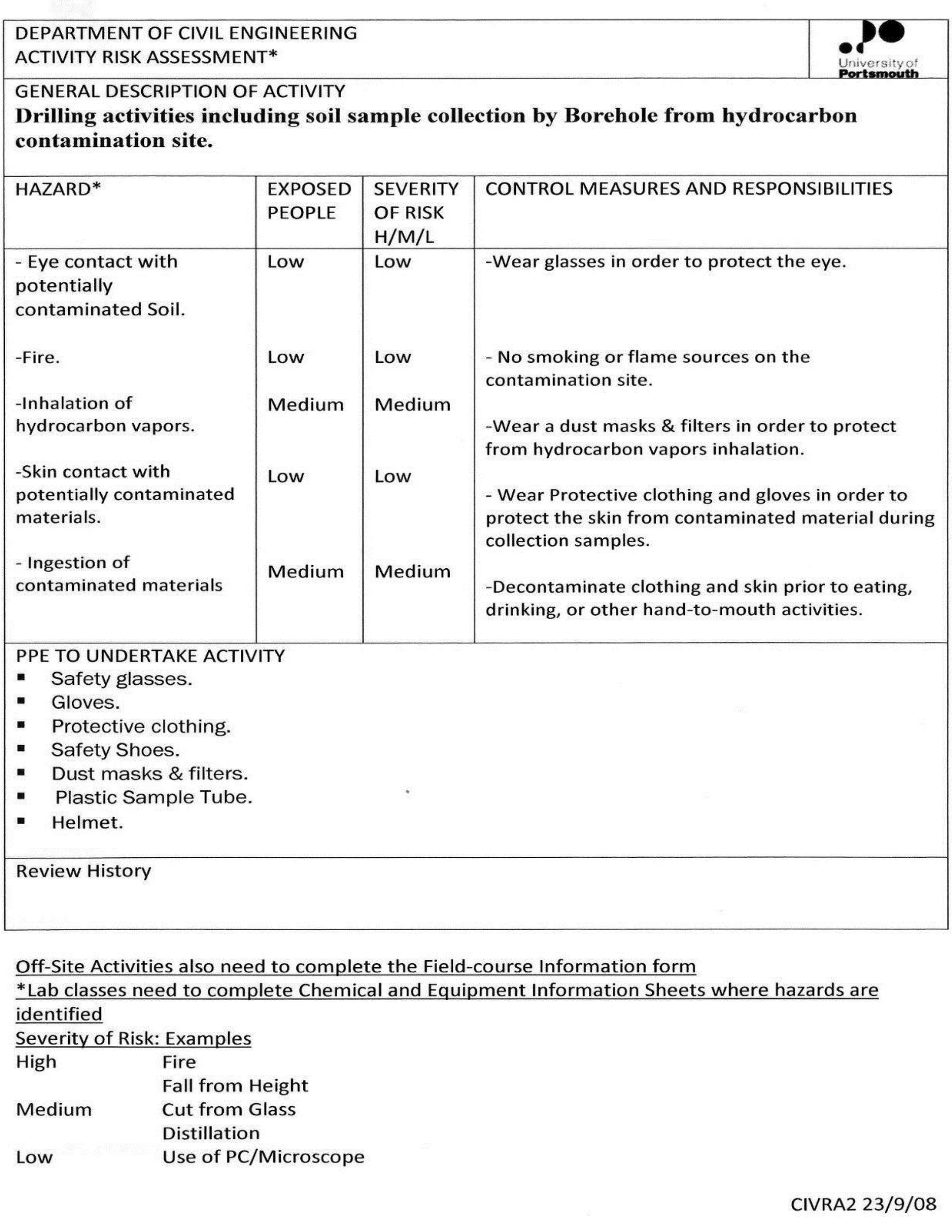
Review History

Severity of Risk: Examples

High	Fire Fall from Height
Medium	Cut from Glass Distillation
Low	Use of PC/Microscope

CIVRA1 23/9/08

Figure A.4.9a. Shows the Area Risk Assessment Form from University of Portsmouth.



DEPARTMENT OF CIVIL ENGINEERING
ACTIVITY RISK ASSESSMENT*

University of Portsmouth

GENERAL DESCRIPTION OF ACTIVITY

Drilling activities including soil sample collection by Borehole from hydrocarbon contamination site.

HAZARD*	EXPOSED PEOPLE	SEVERITY OF RISK H/M/L	CONTROL MEASURES AND RESPONSIBILITIES
- Eye contact with potentially contaminated Soil.	Low	Low	-Wear glasses in order to protect the eye.
-Fire.	Low	Low	- No smoking or flame sources on the contamination site.
-Inhalation of hydrocarbon vapors.	Medium	Medium	-Wear a dust masks & filters in order to protect from hydrocarbon vapors inhalation.
-Skin contact with potentially contaminated materials.	Low	Low	- Wear Protective clothing and gloves in order to protect the skin from contaminated material during collection samples.
- Ingestion of contaminated materials	Medium	Medium	-Decontaminate clothing and skin prior to eating, drinking, or other hand-to-mouth activities.

PPE TO UNDERTAKE ACTIVITY

- Safety glasses.
- Gloves.
- Protective clothing.
- Safety Shoes.
- Dust masks & filters.
- Plastic Sample Tube.
- Helmet.

Review History

Off-Site Activities also need to complete the Field-course Information form

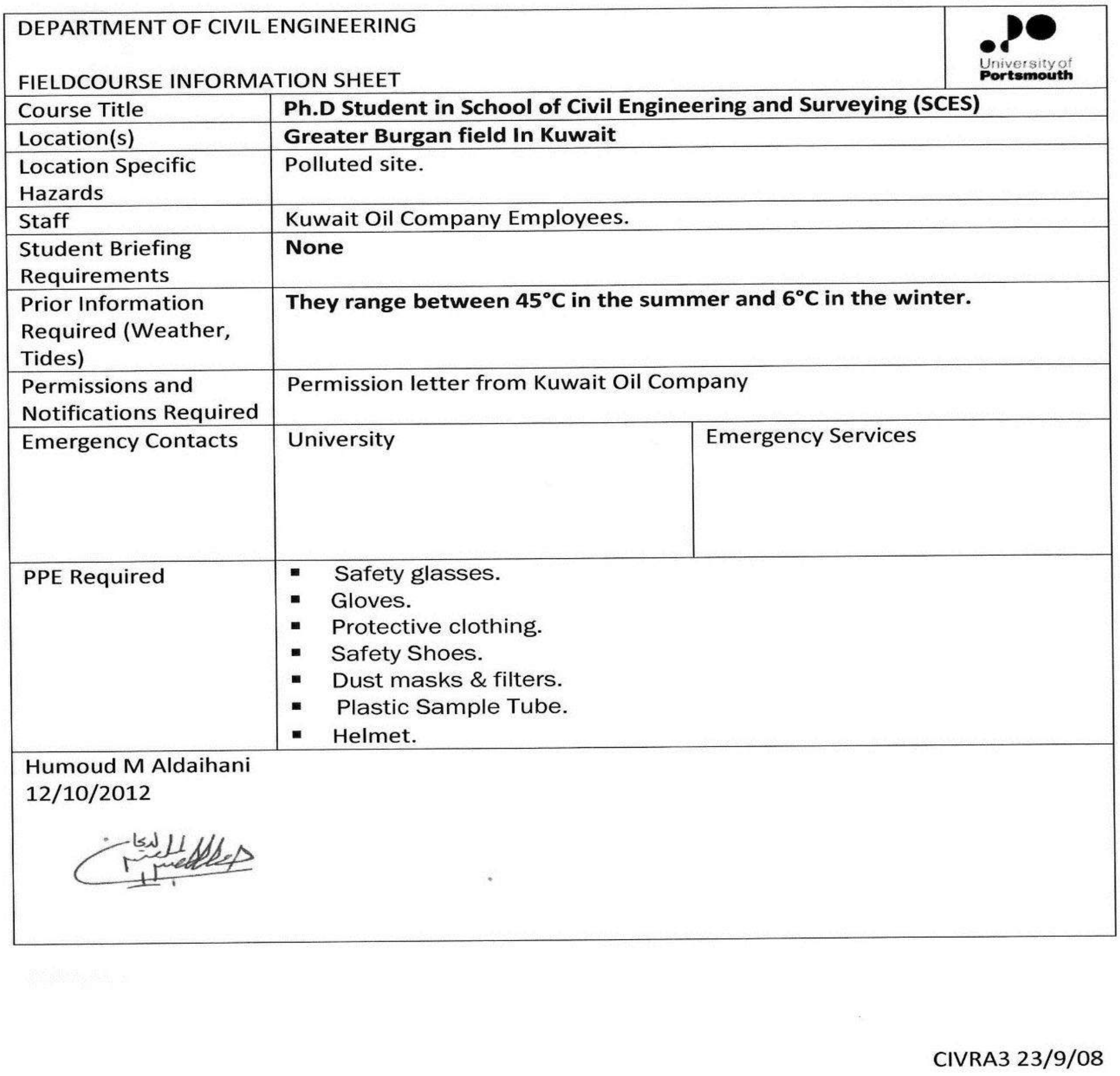
*Lab classes need to complete Chemical and Equipment Information Sheets where hazards are identified

Severity of Risk: Examples

High	Fire Fall from Height
Medium	Cut from Glass Distillation
Low	Use of PC/Microscope

CIVRA2 23/9/08

Figure A.4.9b. Shows the Area Risk Assessment Form from University of Portsmouth.



DEPARTMENT OF CIVIL ENGINEERING

FIELDCOURSE INFORMATION SHEET

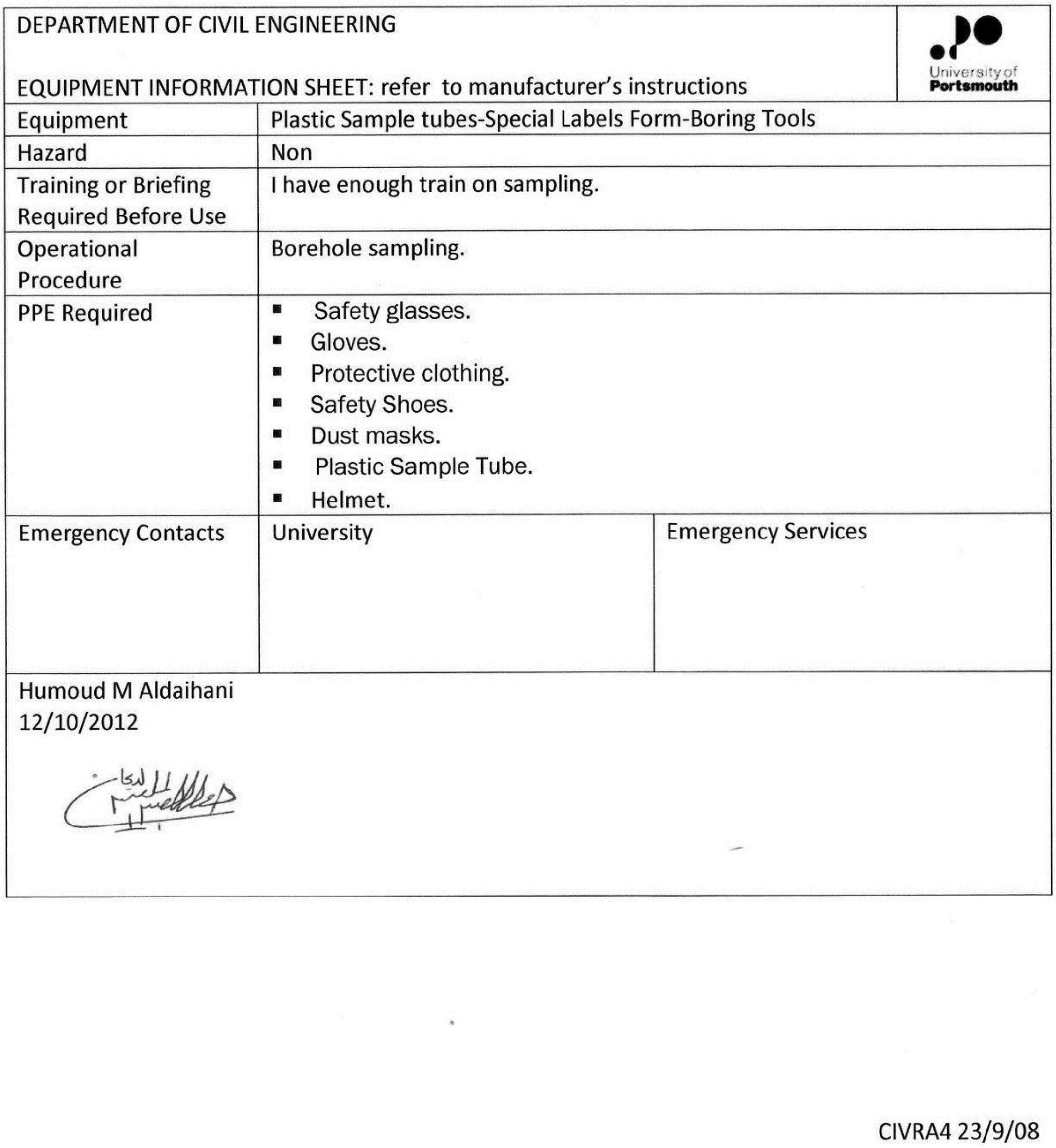
University of Portsmouth

Course Title	**Ph.D Student in School of Civil Engineering and Surveying (SCES)**	
Location(s)	**Greater Burgan field In Kuwait**	
Location Specific Hazards	Polluted site.	
Staff	Kuwait Oil Company Employees.	
Student Briefing Requirements	**None**	
Prior Information Required (Weather, Tides)	**They range between 45°C in the summer and 6°C in the winter.**	
Permissions and Notifications Required	Permission letter from Kuwait Oil Company	
Emergency Contacts	University	Emergency Services
PPE Required	▪ Safety glasses. ▪ Gloves. ▪ Protective clothing. ▪ Safety Shoes. ▪ Dust masks & filters. ▪ Plastic Sample Tube. ▪ Helmet.	

Humoud M Aldaihani
12/10/2012

CIVRA3 23/9/08

Figure A.4.9c. Shows the Area risk Assessment Form from University of Portsmouth.



DEPARTMENT OF CIVIL ENGINEERING

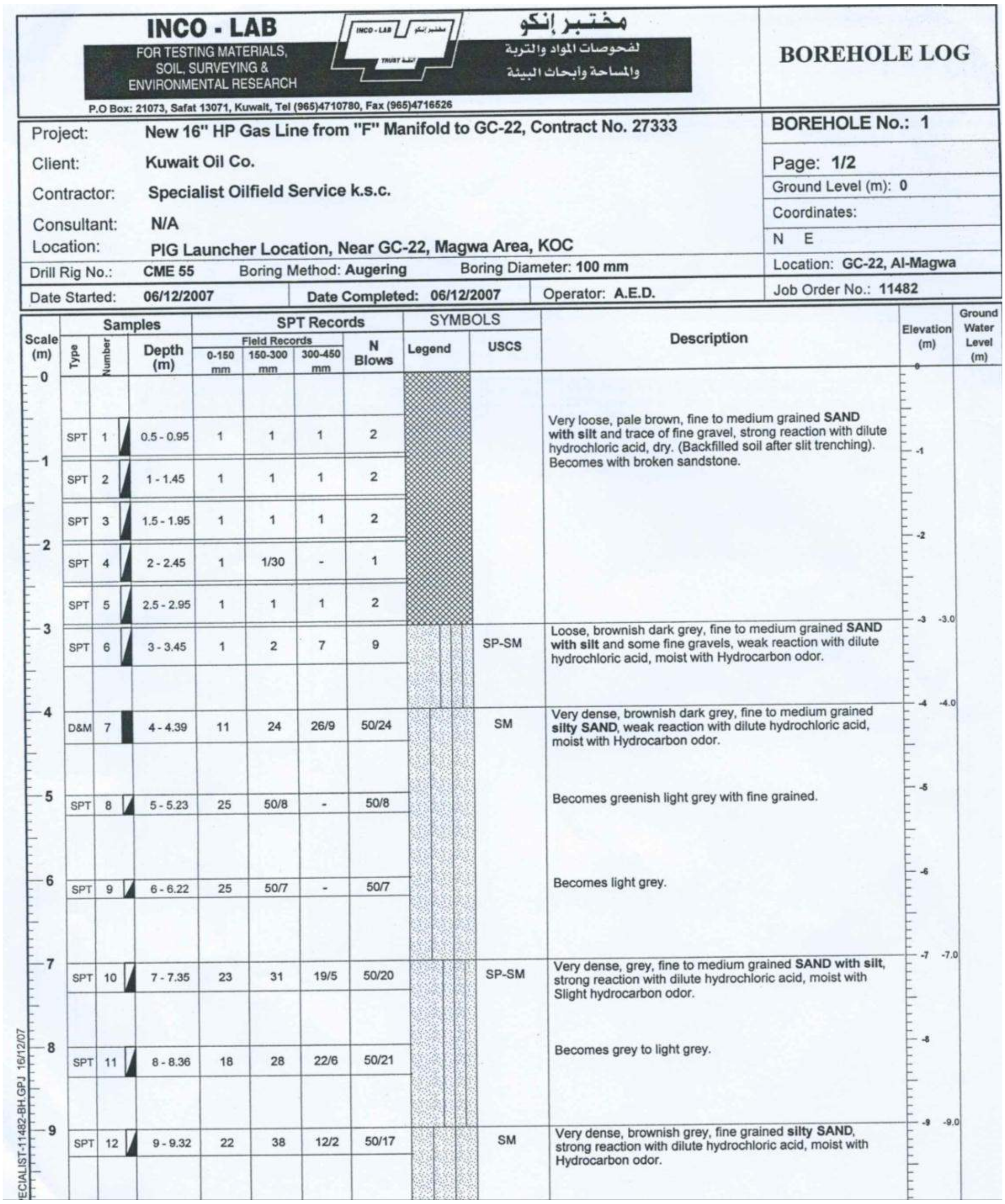
EQUIPMENT INFORMATION SHEET: refer to manufacturer's instructions

University of Portsmouth

Equipment	Plastic Sample tubes-Special Labels Form-Boring Tools	
Hazard	Non	
Training or Briefing Required Before Use	I have enough train on sampling.	
Operational Procedure	Borehole sampling.	
PPE Required	▪ Safety glasses. ▪ Gloves. ▪ Protective clothing. ▪ Safety Shoes. ▪ Dust masks. ▪ Plastic Sample Tube. ▪ Helmet.	
Emergency Contacts	University	Emergency Services
Humoud M Aldaihani 12/10/2012		

CIVRA4 23/9/08

Figure A.4.9d. Shows the Area Risk Assessment Form from University of Portsmouth.



INCO - LAB
FOR TESTING MATERIALS,
SOIL, SURVEYING &
ENVIRONMENTAL RESEARCH

مختبر إنكو
لفحوصات المواد والتربة
والمساحة وأبحاث البيئة

P.O Box: 21073, Safat 13071, Kuwait, Tel (965)4710780, Fax (965)4716526

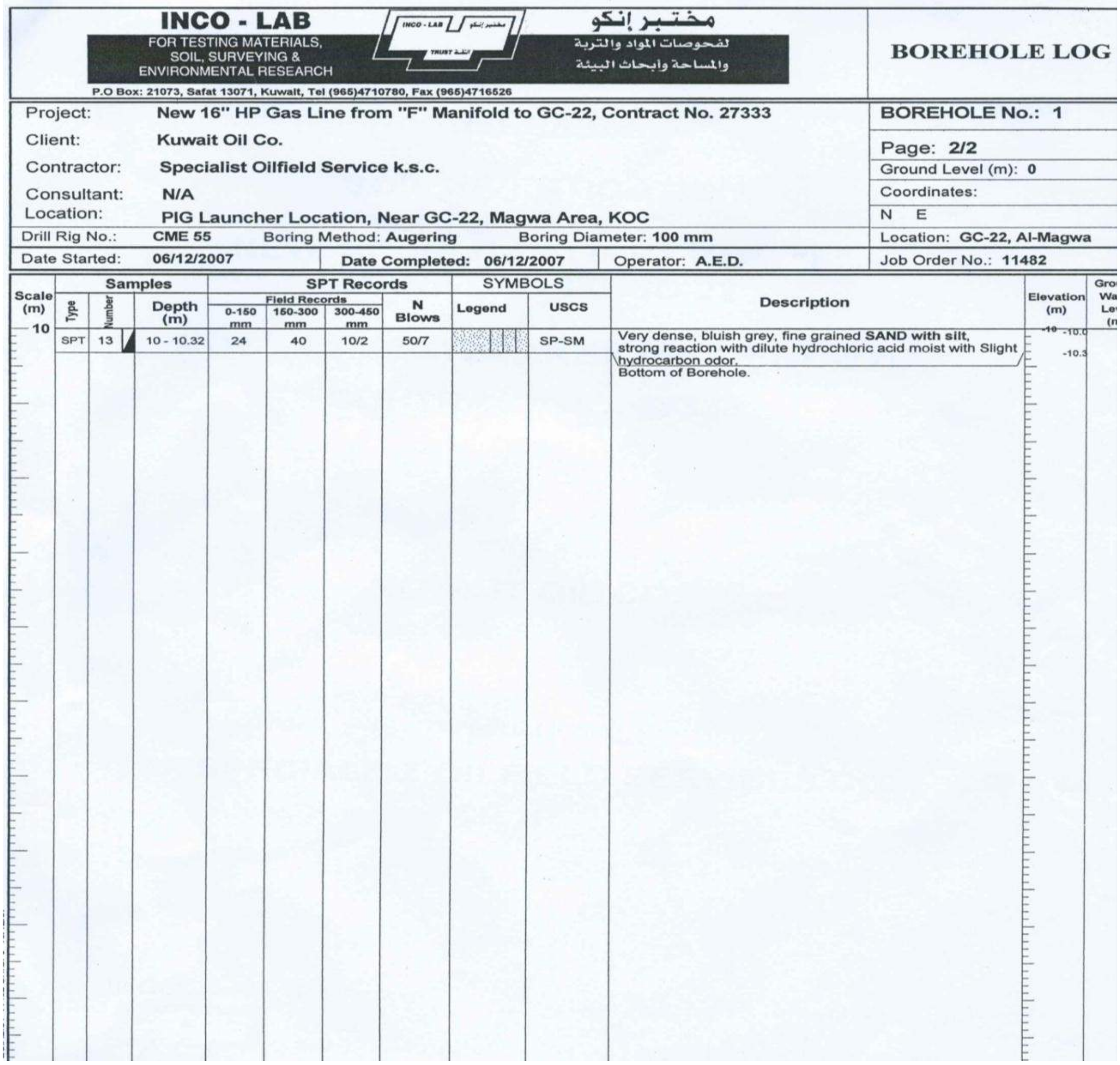
BOREHOLE LOG

Project:	**New 16" HP Gas Line from "F" Manifold to GC-22, Contract No. 27333**
Client:	**Kuwait Oil Co.**
Contractor:	**Specialist Oilfield Service k.s.c.**
Consultant:	**N/A**
Location:	**PIG Launcher Location, Near GC-22, Magwa Area, KOC**
Drill Rig No.:	**CME 55**
Boring Method:	**Augering**
Boring Diameter:	**100 mm**
Date Started:	**06/12/2007**
Date Completed:	**06/12/2007**
Operator:	**A.E.D.**
BOREHOLE No.:	**1**
Page:	**1/2**
Ground Level (m):	**0**
Coordinates:	
N E	
Location:	**GC-22, Al-Magwa**
Job Order No.:	**11482**

Scale (m)	Samples			SPT Records				SYMBOLS		Description	Elevation (m)	Ground Water Level (m)
	Type	Number	Depth (m)	Field Records 0-150 mm	150-300 mm	300-450 mm	N Blows	Legend	USCS			
0											0	
	SPT	1	0.5 - 0.95	1	1	1	2			Very loose, pale brown, fine to medium grained **SAND with silt** and trace of fine gravel, strong reaction with dilute hydrochloric acid, dry. (Backfilled soil after slit trenching). Becomes with broken sandstone.		
1	SPT	2	1 - 1.45	1	1	1	2				-1	
	SPT	3	1.5 - 1.95	1	1	1	2					
2	SPT	4	2 - 2.45	1	1/30	-	1				-2	
	SPT	5	2.5 - 2.95	1	1	1	2					
3	SPT	6	3 - 3.45	1	2	7	9		SP-SM	Loose, brownish dark grey, fine to medium grained **SAND with silt** and some fine gravels, weak reaction with dilute hydrochloric acid, moist with Hydrocarbon odor.	-3	-3.0
4	D&M	7	4 - 4.39	11	24	26/9	50/24		SM	Very dense, brownish dark grey, fine to medium grained **silty SAND**, weak reaction with dilute hydrochloric acid, moist with Hydrocarbon odor.	-4	-4.0
5	SPT	8	5 - 5.23	25	50/8	-	50/8			Becomes greenish light grey with fine grained.	-5	
6	SPT	9	6 - 6.22	25	50/7	-	50/7			Becomes light grey.	-6	
7	SPT	10	7 - 7.35	23	31	19/5	50/20		SP-SM	Very dense, grey, fine to medium grained **SAND with silt**, strong reaction with dilute hydrochloric acid, moist with Slight hydrocarbon odor.	-7	-7.0
8	SPT	11	8 - 8.36	18	28	22/6	50/21			Becomes grey to light grey.	-8	
9	SPT	12	9 - 9.32	22	38	12/2	50/17		SM	Very dense, brownish grey, fine grained **silty SAND**, strong reaction with dilute hydrochloric acid, moist with Hydrocarbon odor.	-9	-9.0

ECIALIST-11482-BH.GPJ 16/12/07

Figure A.4.10a. Shows the borehole log made by INCO company at the same study location in Al- Magwa Area (INCO, 2007).



INCO - LAB

FOR TESTING MATERIALS,
SOIL, SURVEYING &
ENVIRONMENTAL RESEARCH

مختبر إنكو

لفحوصات المواد والتربة
والمساحة وأبحاث البيئة

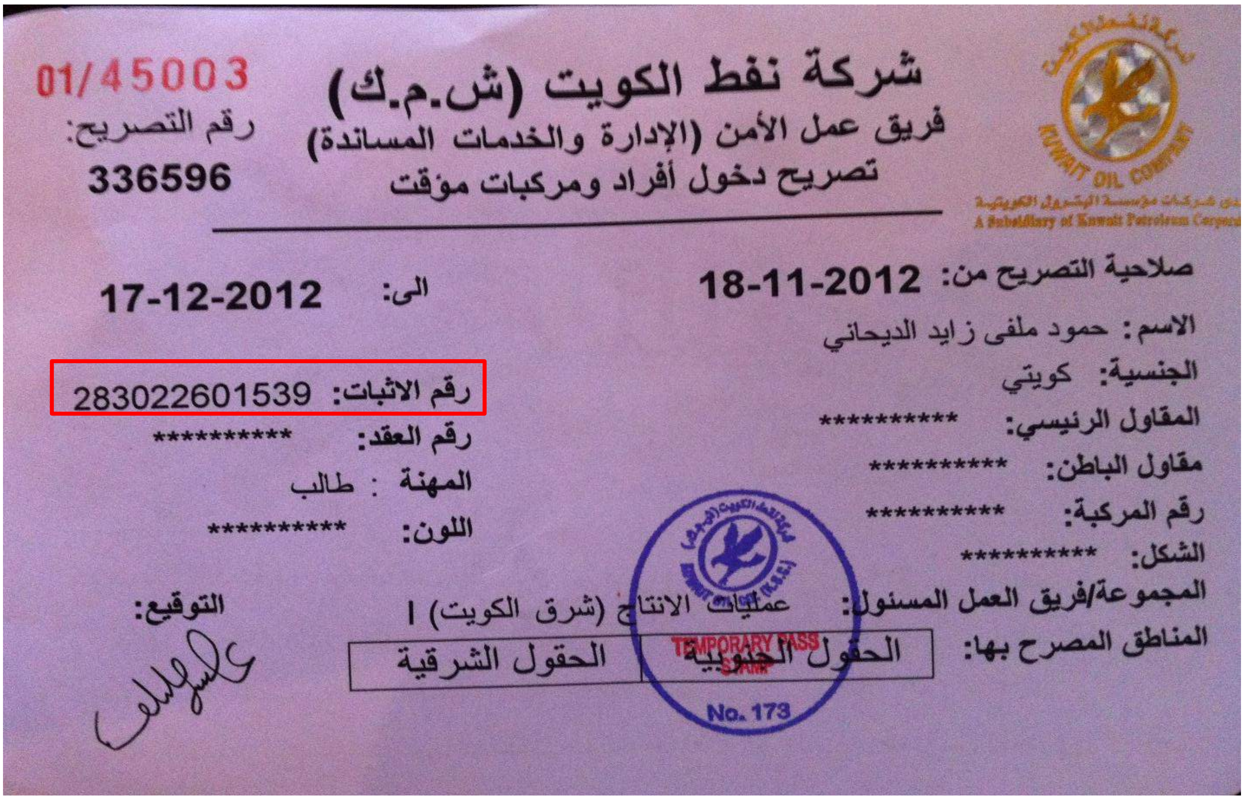
P.O Box: 21073, Safat 13071, Kuwait, Tel (965)4710780, Fax (965)4716526

BOREHOLE LOG

Project:	**New 16" HP Gas Line from "F" Manifold to GC-22, Contract No. 27333**		BOREHOLE No.: **1**
Client:	**Kuwait Oil Co.**		Page: **2/2**
Contractor:	**Specialist Oilfield Service k.s.c.**		Ground Level (m): **0**
Consultant:	**N/A**		Coordinates:
Location:	**PIG Launcher Location, Near GC-22, Magwa Area, KOC**		N E
Drill Rig No.: **CME 55**	Boring Method: **Augering**	Boring Diameter: **100 mm**	Location: **GC-22, Al-Magwa**
Date Started: **06/12/2007**	Date Completed: **06/12/2007**	Operator: **A.E.D.**	Job Order No.: **11482**

Scale (m)	Samples			SPT Records				SYMBOLS		Description	Elevation (m)	Gro Wa Le (n
	Type	Number	Depth (m)	Field Records 0-150 mm	150-300 mm	300-450 mm	N Blows	Legend	USCS			
10	SPT	13	10 - 10.32	24	40	10/2	50/7	▨	SP-SM	Very dense, bluish grey, fine grained **SAND with silt**, strong reaction with dilute hydrochloric acid moist with Slight hydrocarbon odor. Bottom of Borehole.	-10 -10.0 -10.3	

Figure A.4.10b. Continuing (INCO, 2007).



01/45003

رقم التصريح:

336596

شركة نفط الكويت (ش.م.ك)

فريق عمل الأمن (الإدارة والخدمات المساندة)

تصريح دخول أفراد ومركبات مؤقت

صلاحية التصريح من: 18-11-2012 الى: 17-12-2012

الاسم: حمود ملفى زايد الديحاني

الجنسية: كويتي

المقاول الرئيسي: **********

مقاول الباطن: **********

رقم المركبة: **********

الشكل: **********

رقم الاثبات: 283022601539

رقم العقد: **********

المهنة : طالب

اللون: **********

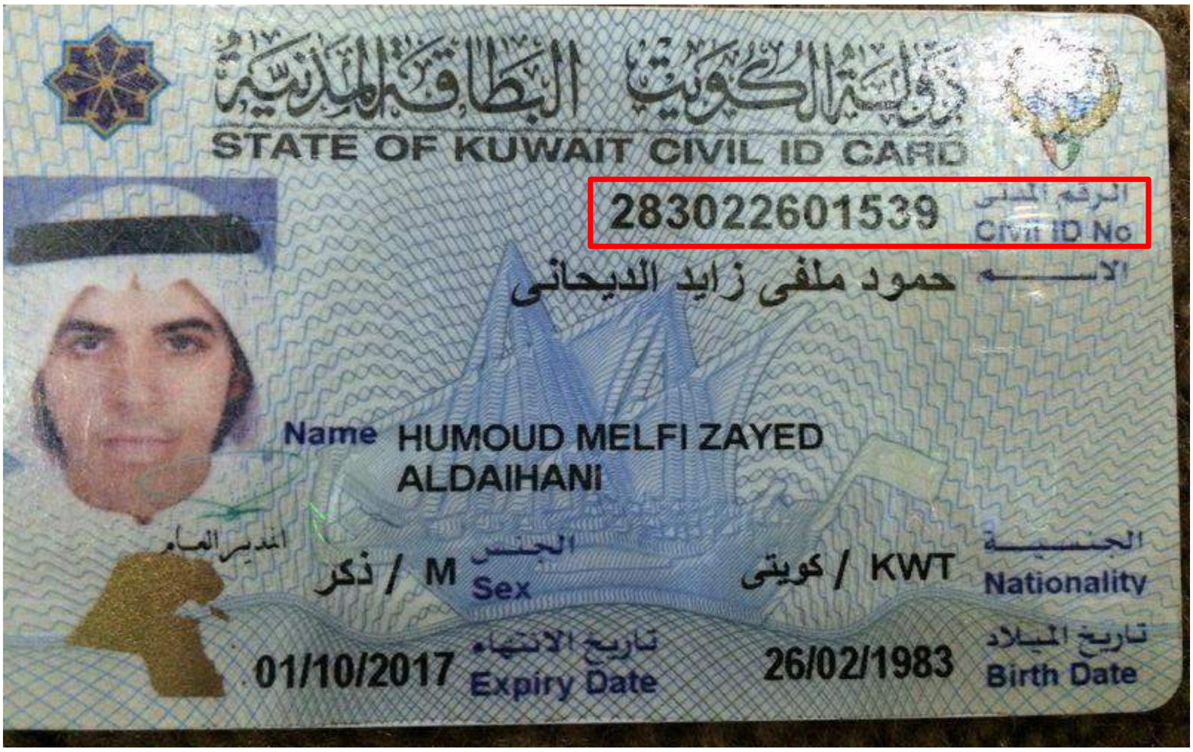
المجموعة/فريق العمل المسئول: عمليات الانتاج (شرق الكويت) ا

المناطق المصرح بها: الحقول الجنوبية | الحقول الشرقية

التوقيع:

TEMPORARY PASS STAMP No. 173

Figure A.4.11. Shows permitting card for the researcher from KOC in order to collect the main soil samples from Greater Burgan field for the project.



دولة الكويت البطاقة المدنية

STATE OF KUWAIT CIVIL ID CARD

الرقم المدني Civil ID No 283022601539

الاسـم حمود ملفى زايد الديحانى

Name HUMOUD MELFI ZAYED ALDAIHANI

الجنسية Nationality كويتى / KWT

الجنس Sex ذكر / M

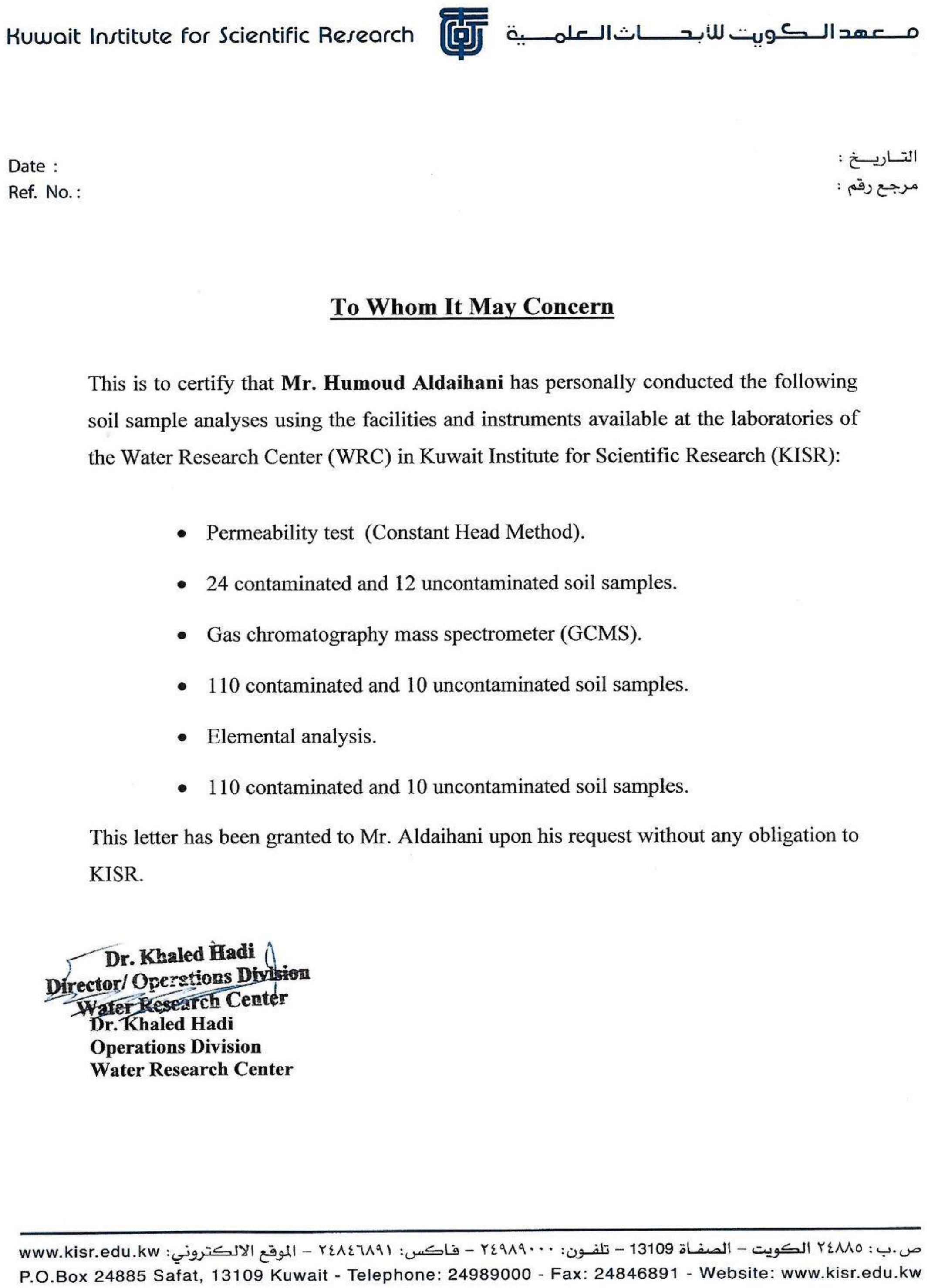
تاريخ الميلاد Birth Date 26/02/1983

تاريخ الانتهاء Expiry Date 01/10/2017

المدير العام

Figure A.4.12. Shows my Kuwaiti Civil ID number which is matching with KOC passing gate card for the Greater Burgan oil field (Al-Magwa Area).

Plate A.4.2. Shows the Gas center (GC-09) close to the dry crude oil lake belong to Kuwait Oil Company (KOC) at Greater Burgan oil field (Al-Magwa Area) south west of Kuwait (A). Also, the contaminated site that is prepared with small flag in order to collect soil samples (B) as well as it shows the undisturbed contaminated soil samples for direct shear test (C) and the undisturbed contaminated soil samples for permeability test (D).



Kuwait Institute for Scientific Research
معهد الكويت للأبحاث العلمية

Date :
Ref. No. :

التاريخ :
مرجع رقم :

To Whom It May Concern

This is to certify that **Mr. Humoud Aldaihani** has personally conducted the following soil sample analyses using the facilities and instruments available at the laboratories of the Water Research Center (WRC) in Kuwait Institute for Scientific Research (KISR):

- Permeability test (Constant Head Method).
- 24 contaminated and 12 uncontaminated soil samples.
- Gas chromatography mass spectrometer (GCMS).
- 110 contaminated and 10 uncontaminated soil samples.
- Elemental analysis.
- 110 contaminated and 10 uncontaminated soil samples.

This letter has been granted to Mr. Aldaihani upon his request without any obligation to KISR.

Dr. Khaled Hadi
Director/ Operations Division
Water Research Center

Dr. Khaled Hadi
Operations Division
Water Research Center

www.kisr.edu.kw :ص.ب : ٢٤٨٨٥ الكويت – الصفاة 13109 – تلفون: ٢٤٩٨٩٠٠٠ – فاكس: ٢٤٨٤٦٨٩١ – الموقع الالكتروني
P.O.Box 24885 Safat, 13109 Kuwait - Telephone: 24989000 - Fax: 24846891 - Website: www.kisr.edu.kw

Figure A.4.13. Shows a letter from KISR and SMATCO labs concerning with samples testing.

SEMATCO
SOIL & ENGINEERING MATERIAL TESTING CO. (W.L.L.)
SEMATCO
شركة سيماتكو
لفحص التربة والمواد الهندسية (ذ.م.م)

Date: 25/04/2015

To Whom It May Concern

This is to certify that Mr. Humoud Aldaihani has personally conducted soil sample testing byusing Direct Shear Test. The samples numbers were tested as following:

- 42 undisturbed contaminated soil samples.
- 18 undisturbed non-contaminated soil samples.

This letter has been granted to Mr. Aldaihani upon his requested without any obligation to SEMATCO Lab.

Best Regards,

General Manger

سيماتكو
الكويت
KUWAIT
SEMATCO

تلفون : ٢٤٧٣٩٤٦٣/ ٥/ ٦ - فاكس : ٢٤٧٣٩٤٦١ - ص.ب : ٢١١٨٥ الصفاة - ١٣٠٧٢ الكويت

Figure A.4.13. Contiuned.

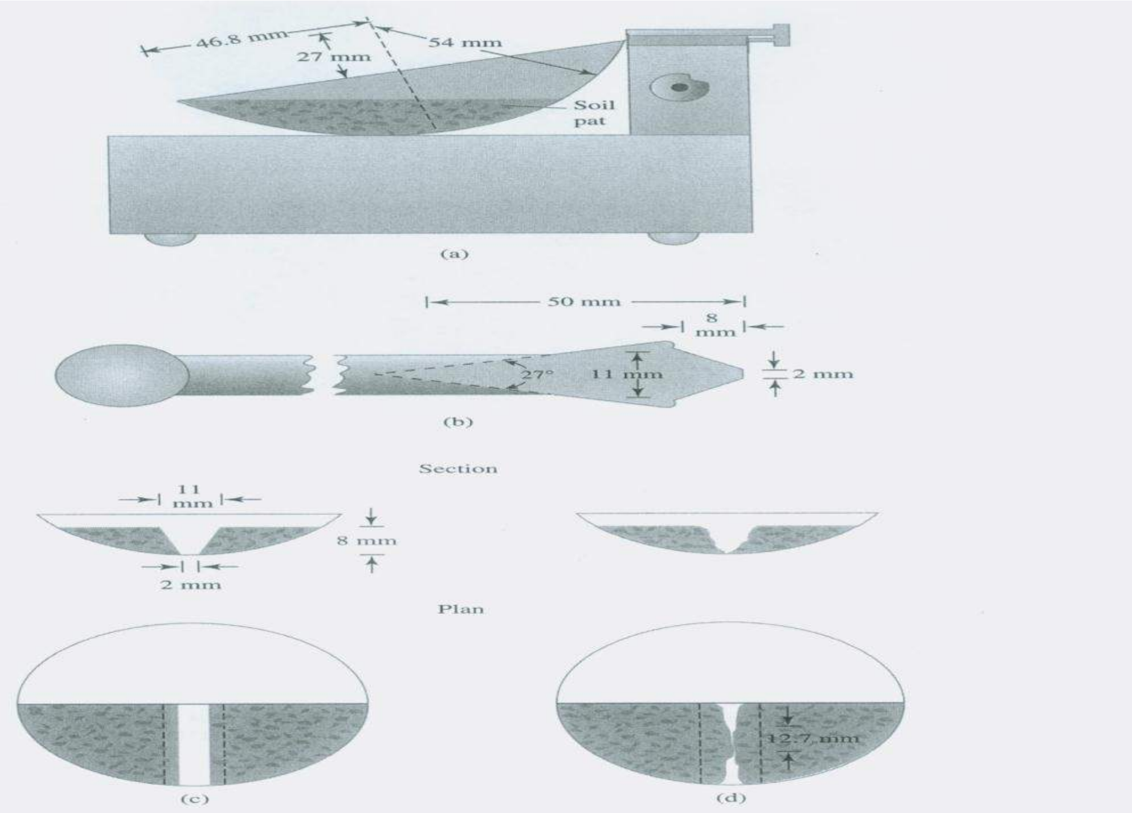


Figure A.4.14. The test of Liquid Limit: (a) liquid limit device; (b) grooving tool; (c) soil pat before test; (d) soil pat after test. (Das, 2002).

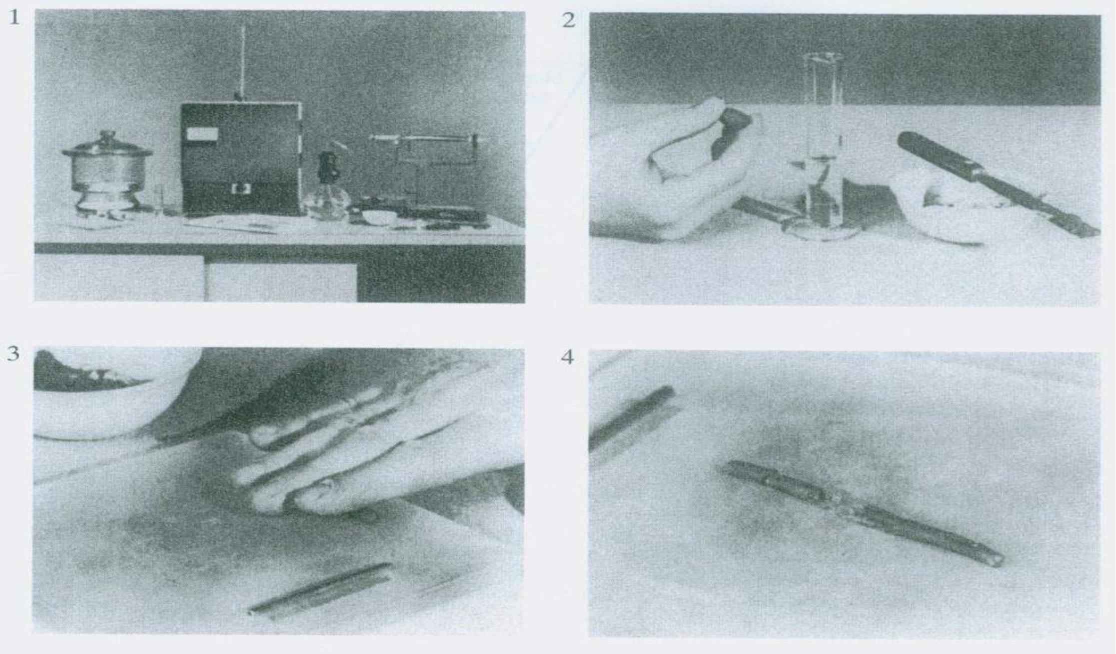


Figure A.4.15. Plastic Limit test: (1) equipment; (2) beginning of test; (3) thread being rolled; (4) crumbled soil. (Das, 2002).

a. **Shows the soil samples in tare in order to put in the oven for 24hrs.**

b. **Shows the soil sample kibbled like powder.**

c. **Shows the soil samples put it in sieve 425 µm in order to test the retained soil for liquid limit test.**

d. **Show the retained soil from sieve 425 µm and mixed by distilled water.**

e. **Shows the mixed soil sample placed in the Cup of Casagrande apparatus resting on the base.**

f. **Shows the soil has rolled the thread between the fingers from finger-tip to the second joint of one hand and the surface of the glass rolling plate.**

Plate A.4.3. Shows the Atterberg Limit test in INCO lab in Kuwait.

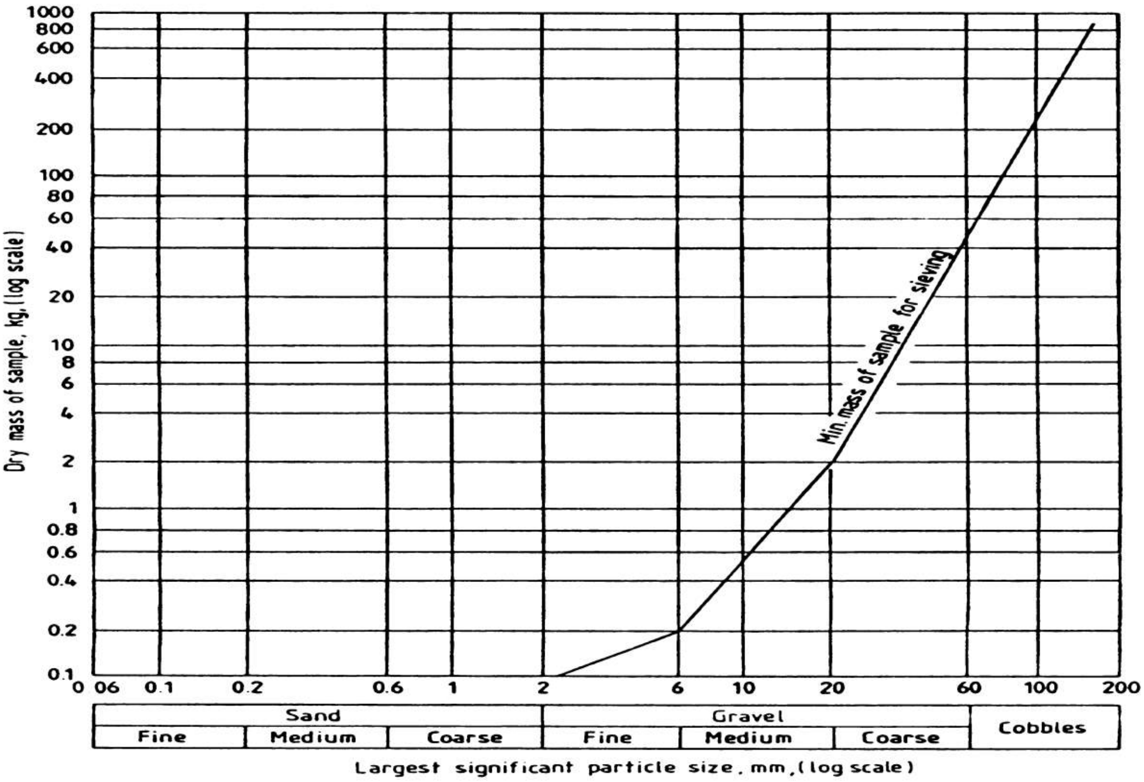
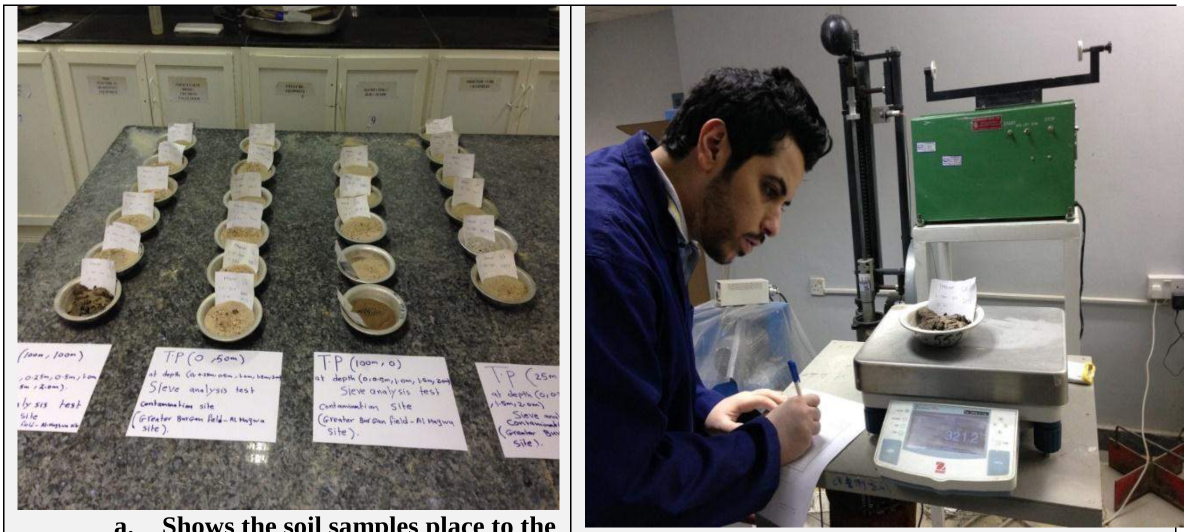


Figure A.4.16. Shows the Particles Size Distribution (PSD) curve for soil classification (BS-1377-part 2, 1990).



a. Shows the soil samples place to the tare

b. Shows the sample weight by scale weight.

c. Shows some sample place in the oven.

d. Shows the sample wash by distilled water.

e. Shows the automatically sieve machine in order to classify the soils

Plate A.4.4. Shows Sieve Analysis test in INCO lab in Kuwait.

Figure A.4.17. Shows a typical SEM instrument which including the electron column, sample chamber, EDS detector, electronics console, and visual display monitors. (GIA, 2014).

Table A.4.3. Shows the Permeability test (constant head method) procedures in accordance with International Organization for Standardization-Part 11 (ISO/TS 17892-11: 2013).

Permeability Test Procedures Numbers (No.)	Permeability Test (constant head method) in Accordance with BS 1377-5:1990
1	Placing the ring samples in the ring holders.
2	Allow the water to fill the permeater container.
3	Wait until the water level inside the sample container and water bath reach the same level.
4	Place the bridge in sample holder to lower the water in the sample.
5	Wait until the water start to pass throw burret.
6	With help of Burret measure volume of the water passing throw the sample in certain time.
7	Determine constant head with help of water level indicator for each sample.
8	8-Insert all observe parameter such as (v), (L), (A), (t) & (h) in the following equation.

The following equation was used to determine coefficient of permeability following constant head method:

$$K= \frac{V \times L}{A \times t \times h}$$

Whereas

K= coefficient of permeability,

V= volume of water,

L= length of soil sample,

A= cross-section surface of the sample,

t = time,

h= calculate with the water levels measured with the water level meter.

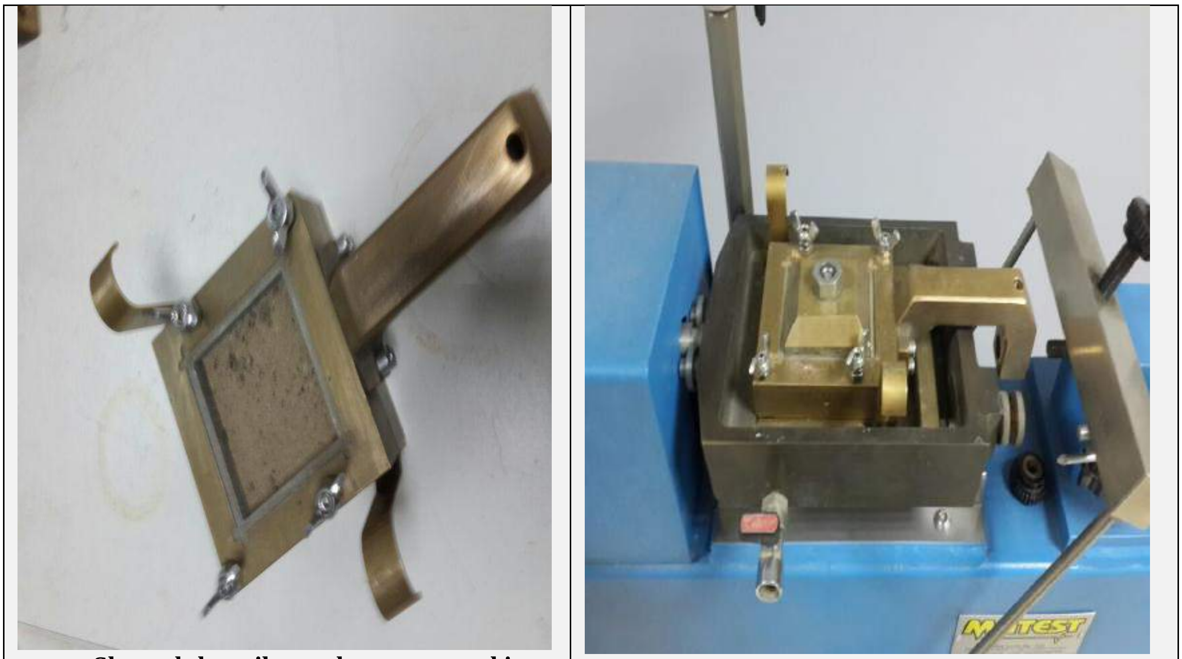
a. Collected soil samples in sampling rings.

b. **Eijkelkamp permeameter apparatus.**

c. Soil samples the permeameter during testing.

d. Measurement of volume of water during testing.

Plate A.4.5. Shows the Permeability lab in Kuwait Institution Scientific Research (KISR) at Shuwaikh-branch.



a. Showed the soil sample was tamped in the shear box (60mm square X 20 thick).

b. Shows the shear box placed in the carriage in order to apply the vertical and horizontal forces.

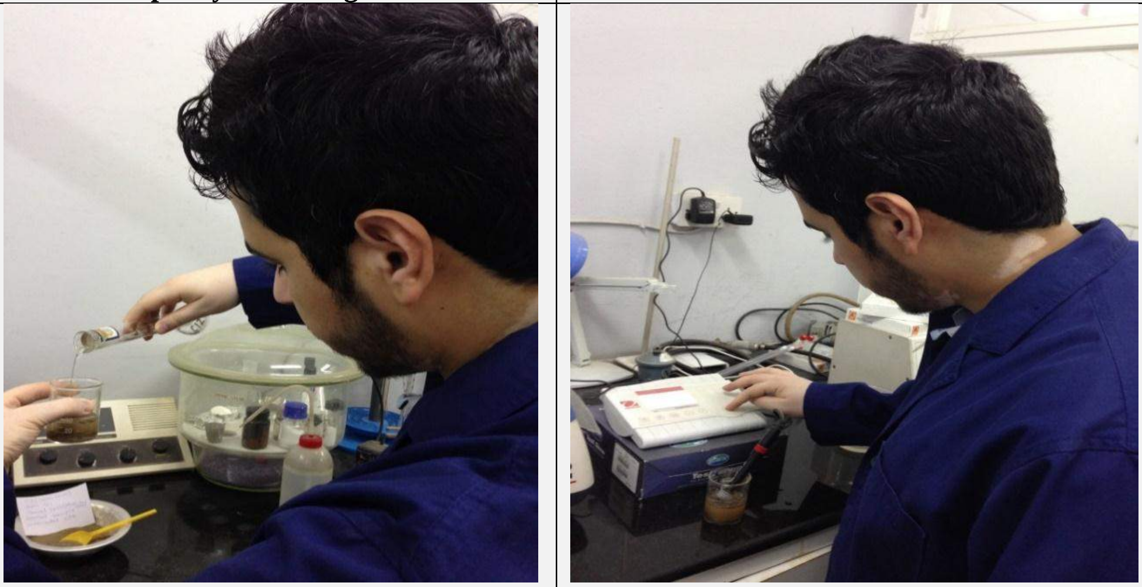
c. The Vertical load is applied and the horizontal gauge displacement is set.

d. Showed the reading of the vertical forces and displacement.

Plate A.4.6. Shows the Direct Shear test in SAMTCO lab in Kuwait.

a. **Shows the 30g weight of dry soil sample by scale weight.**

b. **Shows the 75mL of distilled water.**



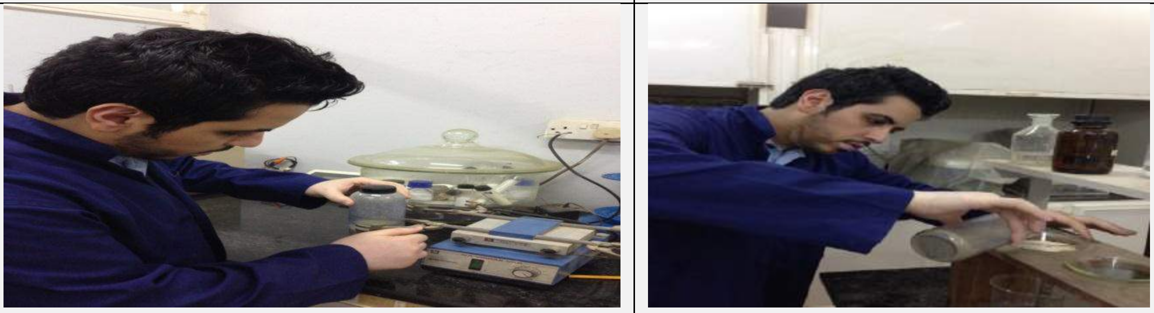
c. **Shows the distil water mixing with dry soil sample.**

d. **Shows the reading of pH meter.**

Plate A.4.7. Shows the pH test in INCO lab in Kuwait.

a. Shows the 100g of the dried powdered sample into a clean dry 500ml bottle with screw cap.

b. Shows the 200ml of distilled water placed into the bottle containing soil and close the bottle.



c. Shows the Shake the bottle on a shaker for 16 hours.

d. Shows the filter of the extract through a dry 42 grade filter paper into a clean dry beaker.

e. Take 50ml from filtrate

f. Boilng

g. Adding Barium chloride.

Plate A.4.8. Shows the Water Soluble Chloride (Cl-) and Sulphates (i.e. SO_3 & SO_4) tests in INCO lab in Kuwait.

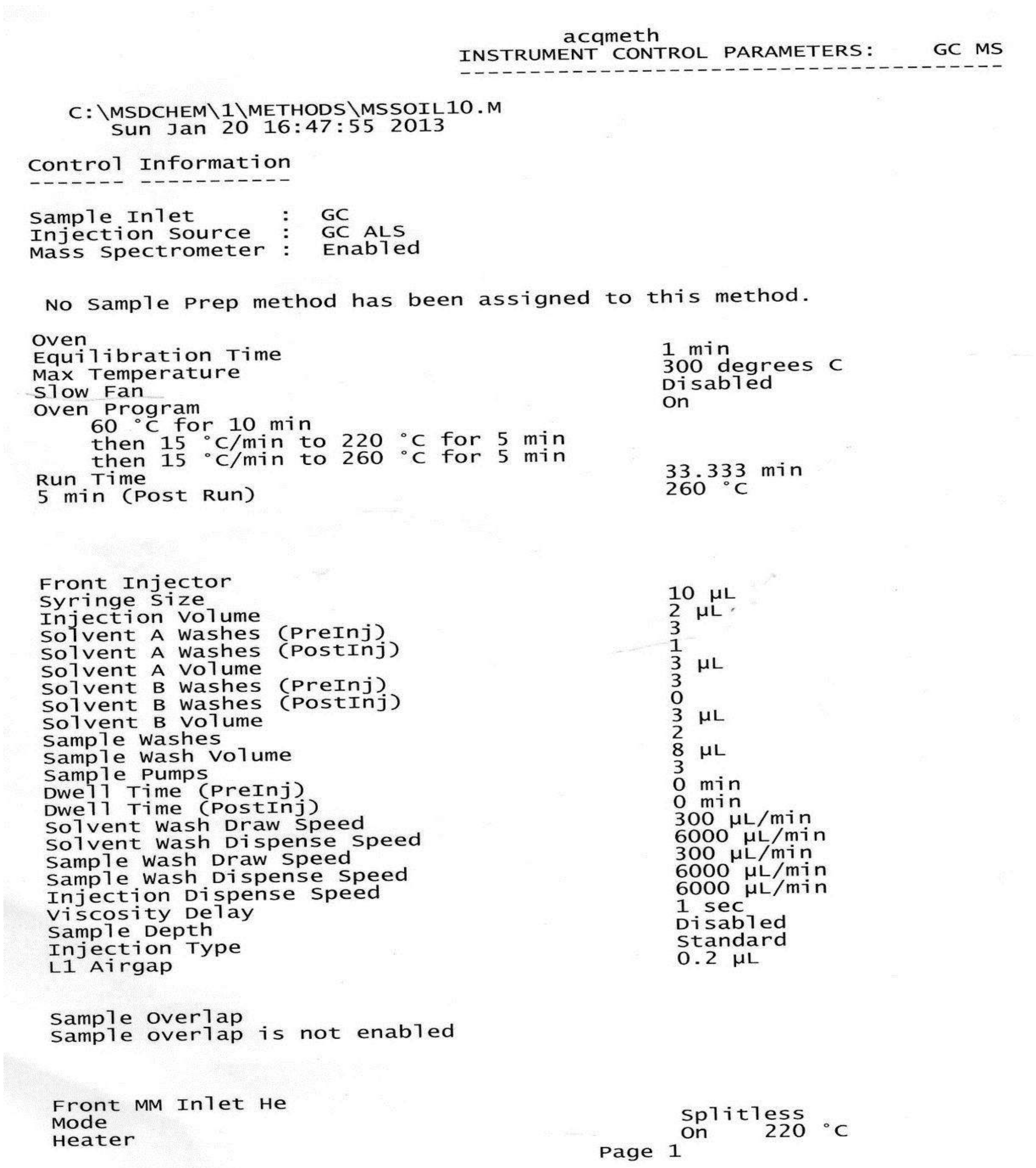
a. **Shows that the preparation of the soil samples in order to wrap it by tin foil.**

b. **Shows the sample was packed in tin foil in order to weight it with specific weight (45mg).**

c. **Shows the preparation of the electronic scale weight in order to make sure that the sample weight within range from 40 to 45 mg.**

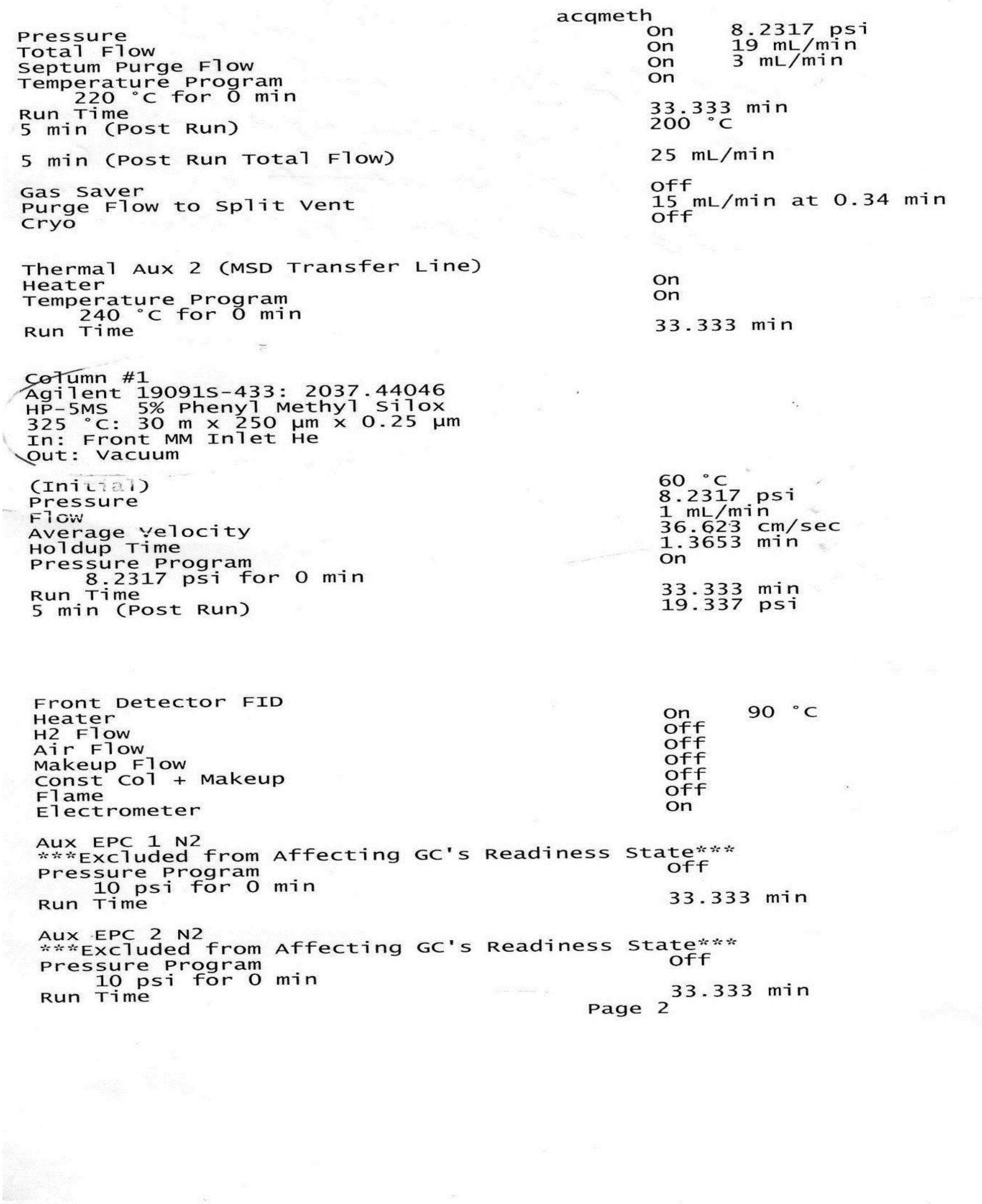
d. **Shows the packed tin foil sample placed into the carousel of the automatic sample feeder in order to detect the total content of C%, N%, H% & S% as percentages.**

Plate A.4.9. Shows the Elemental Analyser test (Vario MACRO) in KISR lab-Ahamdai branch in Kuwait.



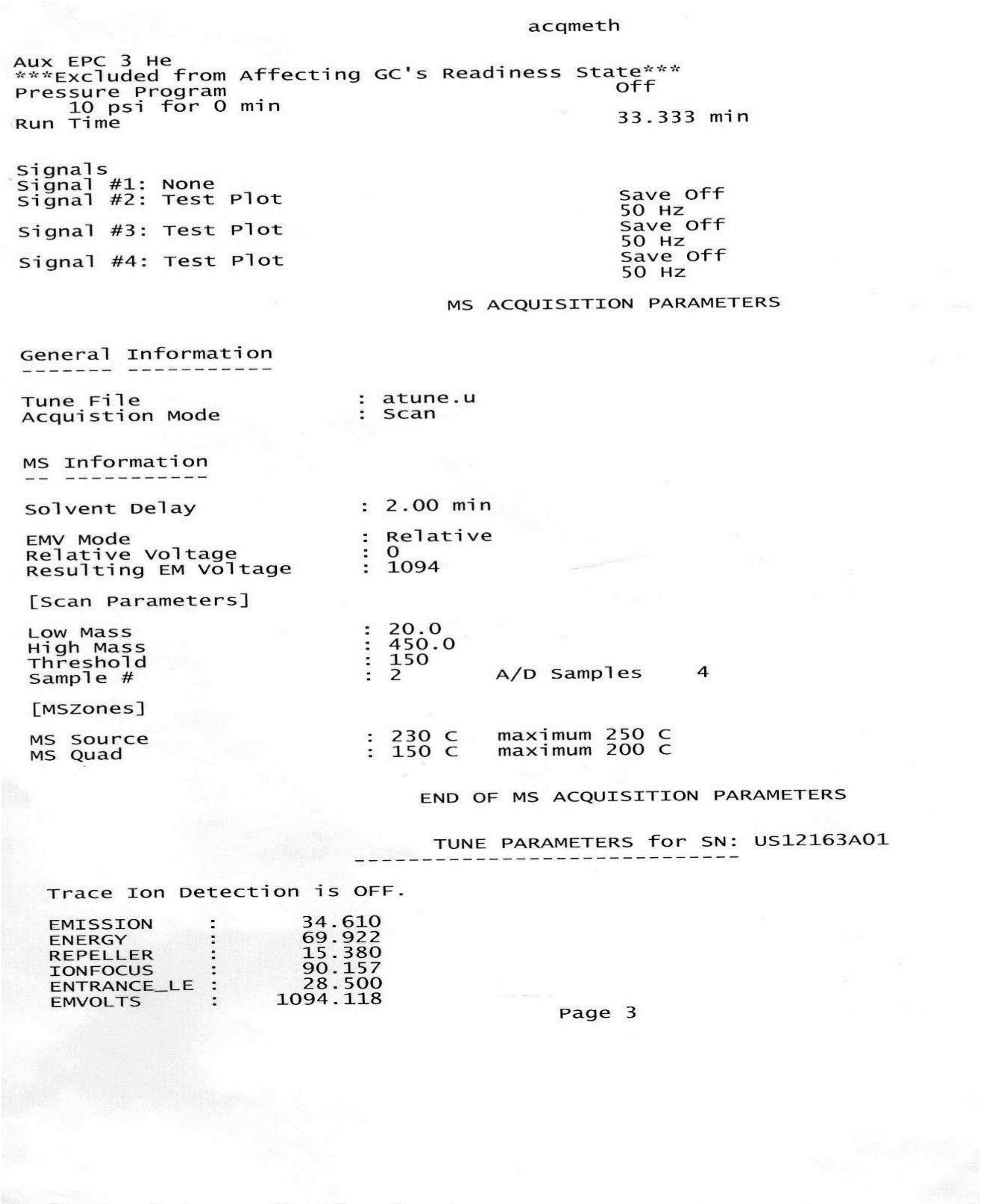
```
                                           acqmeth
                                  INSTRUMENT CONTROL PARAMETERS:     GC MS
                                  ----------------------------------------

    C:\MSDCHEM\1\METHODS\MSSOIL10.M
        Sun Jan 20 16:47:55 2013

  Control Information
  ------- -----------

  Sample Inlet        :   GC
  Injection Source    :   GC ALS
  Mass Spectrometer   :   Enabled

   No Sample Prep method has been assigned to this method.

  Oven
  Equilibration Time                                       1 min
  Max Temperature                                          300 degrees C
  Slow Fan                                                 Disabled
  Oven Program                                             On
       60 °C for 10 min
       then 15 °C/min to 220 °C for 5 min
       then 15 °C/min to 260 °C for 5 min
  Run Time                                                 33.333 min
  5 min (Post Run)                                         260 °C



  Front Injector
  Syringe Size                                             10 µL
  Injection Volume                                         2 µL
  Solvent A Washes (PreInj)                                3
  Solvent A Washes (PostInj)                               1
  Solvent A Volume                                         3 µL
  Solvent B Washes (PreInj)                                3
  Solvent B Washes (PostInj)                               0
  Solvent B Volume                                         3 µL
  Sample Washes                                            2
  Sample Wash Volume                                       8 µL
  Sample Pumps                                             3
  Dwell Time (PreInj)                                      0 min
  Dwell Time (PostInj)                                     0 min
  Solvent Wash Draw Speed                                  300 µL/min
  Solvent Wash Dispense Speed                              6000 µL/min
  Sample Wash Draw Speed                                   300 µL/min
  Sample Wash Dispense Speed                               6000 µL/min
  Injection Dispense Speed                                 6000 µL/min
  Viscosity Delay                                          1 sec
  Sample Depth                                             Disabled
  Injection Type                                           Standard
  L1 Airgap                                                0.2 µL

  Sample Overlap
  Sample overlap is not enabled


  Front MM Inlet He
  Mode                                                     Splitless
  Heater                                                   On     220 °C
                                                   Page 1
```

Figure A.4.18. Shows the GC-MS method that used during soil samples testing.



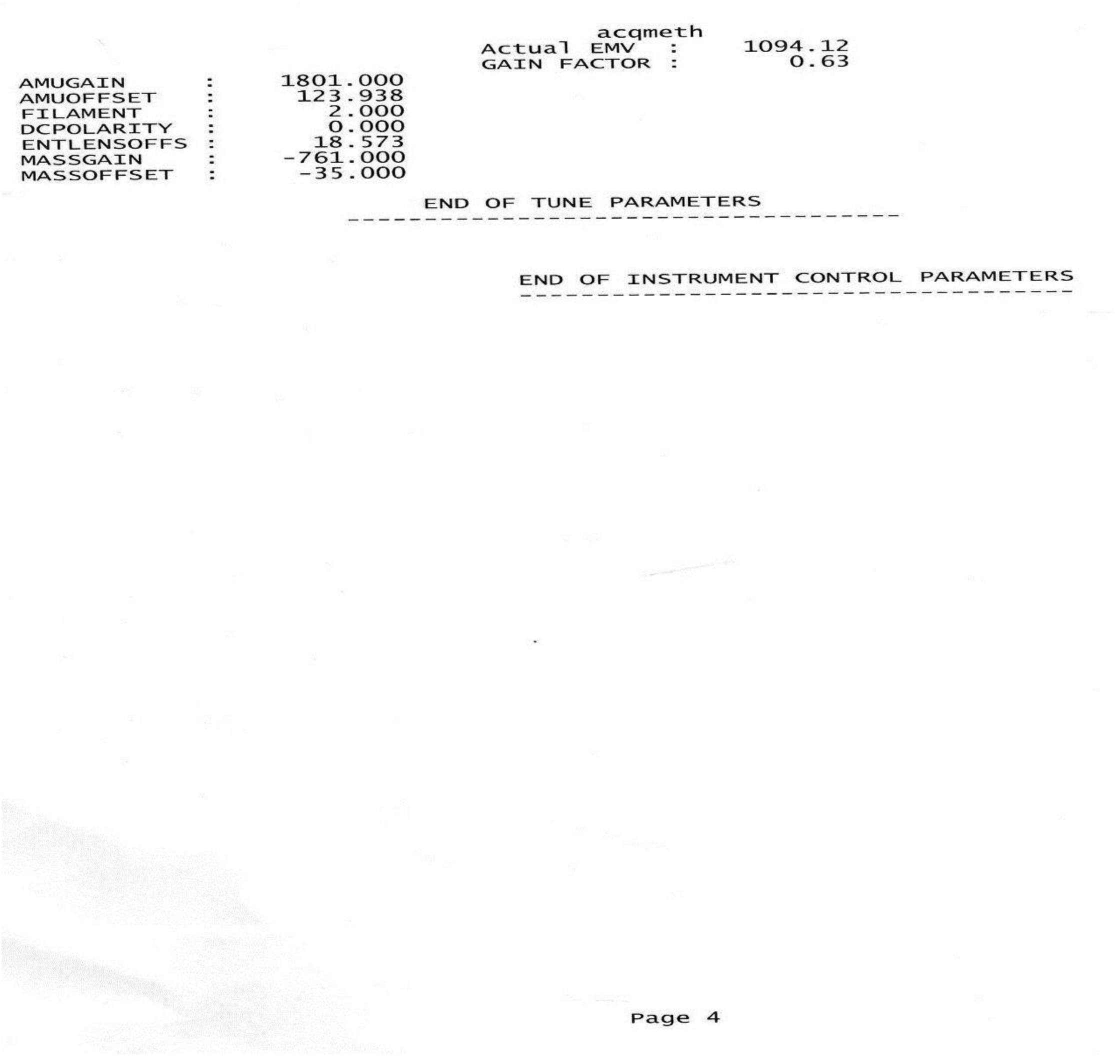
```
                                                  acqmeth
Pressure                                                On      8.2317 psi
Total Flow                                              On      19 mL/min
Septum Purge Flow                                       On      3 mL/min
Temperature Program                                     On
    220 °C for 0 min
Run Time                                                33.333 min
5 min (Post Run)                                        200 °C

5 min (Post Run Total Flow)                             25 mL/min

Gas Saver                                               Off
Purge Flow to Split Vent                                15 mL/min at 0.34 min
Cryo                                                    Off


Thermal Aux 2 (MSD Transfer Line)
Heater                                                  On
Temperature Program                                     On
    240 °C for 0 min
Run Time                                                33.333 min


Column #1
Agilent 19091S-433: 2037.44046
HP-5MS  5% Phenyl Methyl Silox
325 °C: 30 m x 250 µm x 0.25 µm
In: Front MM Inlet He
Out: Vacuum

(Initial)                                               60 °C
Pressure                                                8.2317 psi
Flow                                                    1 mL/min
Average Velocity                                        36.623 cm/sec
Holdup Time                                             1.3653 min
Pressure Program                                        On
    8.2317 psi for 0 min
Run Time                                                33.333 min
5 min (Post Run)                                        19.337 psi



Front Detector FID
Heater                                                  On      90 °C
H2 Flow                                                 Off
Air Flow                                                Off
Makeup Flow                                             Off
Const Col + Makeup                                      Off
Flame                                                   Off
Electrometer                                            On

Aux EPC 1 N2
***Excluded from Affecting GC's Readiness State***
Pressure Program                                        Off
    10 psi for 0 min
Run Time                                                33.333 min

Aux EPC 2 N2
***Excluded from Affecting GC's Readiness State***
Pressure Program                                        Off
    10 psi for 0 min
Run Time                                                33.333 min
                                                Page 2
```

Figure A.4.18. Contiuned.



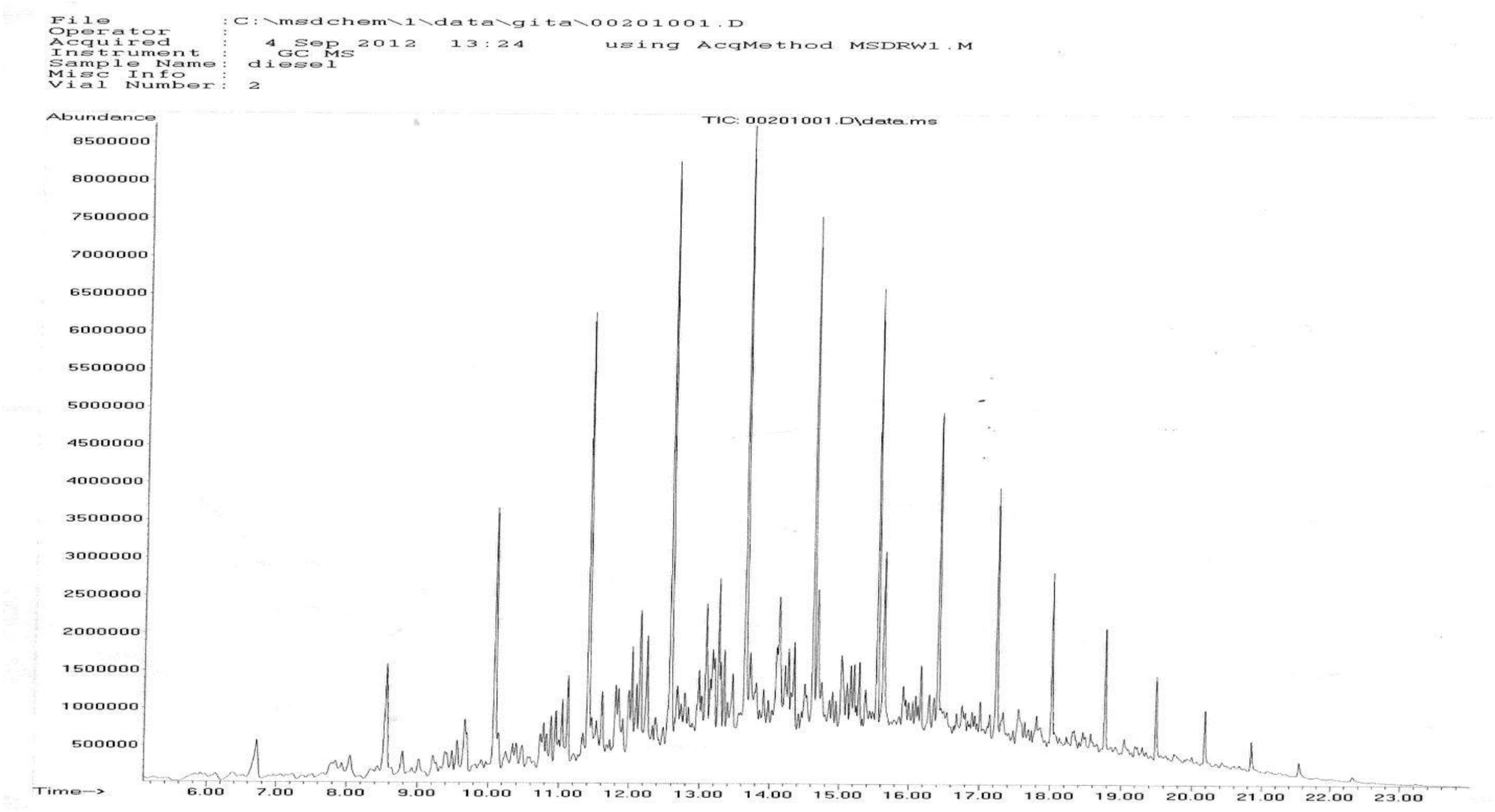
```
                                        acqmeth

Aux EPC 3 He
***Excluded from Affecting GC's Readiness State***
Pressure Program                               Off
   10 psi for 0 min
Run Time                                       33.333 min


Signals
Signal #1: None
Signal #2: Test Plot                           Save Off
                                               50 Hz
Signal #3: Test Plot                           Save Off
                                               50 Hz
Signal #4: Test Plot                           Save Off
                                               50 Hz
                                    MS ACQUISITION PARAMETERS


General Information
------- -----------

Tune File                  : atune.u
Acquistion Mode            : Scan


MS Information
-- -----------

Solvent Delay              : 2.00 min

EMV Mode                   : Relative
Relative Voltage           : 0
Resulting EM Voltage       : 1094

[Scan Parameters]

Low Mass                   : 20.0
High Mass                  : 450.0
Threshold                  : 150
Sample #                   : 2       A/D Samples    4

[MSZones]

MS Source                  : 230 C   maximum 250 C
MS Quad                    : 150 C   maximum 200 C

                                   END OF MS ACQUISITION PARAMETERS


                                    TUNE PARAMETERS for SN: US12163A01
                            -----------------------------

 Trace Ion Detection is OFF.

 EMISSION      :       34.610
 ENERGY        :       69.922
 REPELLER      :       15.380
 IONFOCUS      :       90.157
 ENTRANCE_LE   :       28.500
 EMVOLTS       :     1094.118
                                         Page 3
```

Figure A.4.18. Contiuned.



```
                                    acqmeth
                            Actual EMV  :      1094.12
                            GAIN FACTOR :         0.63
AMUGAIN       :     1801.000
AMUOFFSET     :      123.938
FILAMENT      :        2.000
DCPOLARITY    :        0.000
ENTLENSOFFS   :       18.573
MASSGAIN      :     -761.000
MASSOFFSET    :      -35.000
                         END OF TUNE PARAMETERS
                  ------------------------------------

                              END OF INSTRUMENT CONTROL PARAMETERS
                              ------------------------------------

                                        Page 4
```

Figure A.4.18. Contiuned.



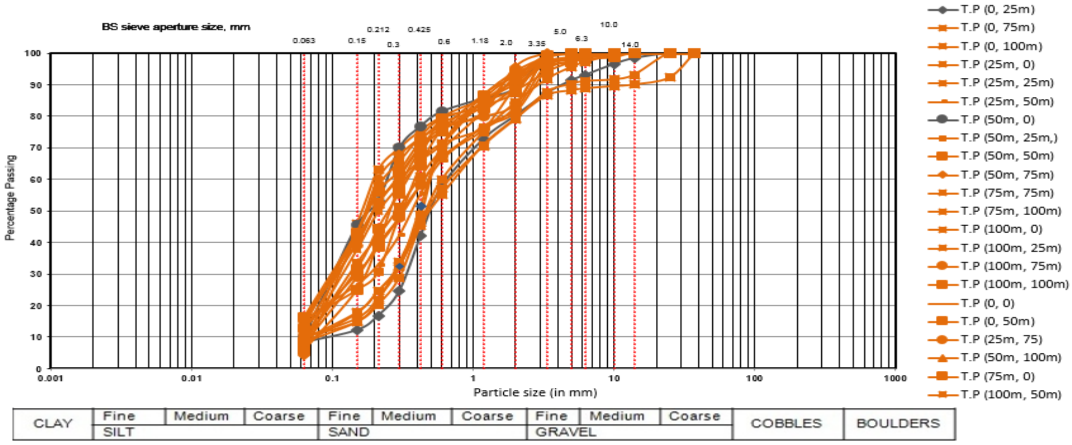
```
File        :C:\msdchem\1\data\gita\00201001.D
Operator    :
Acquired    :   4 Sep 2012   13:24      using AcqMethod MSDRW1.M
Instrument  :    GC MS
Sample Name: diesel
Misc Info   :
Vial Number:  2
```

Figure A.4.18. Contiuned.

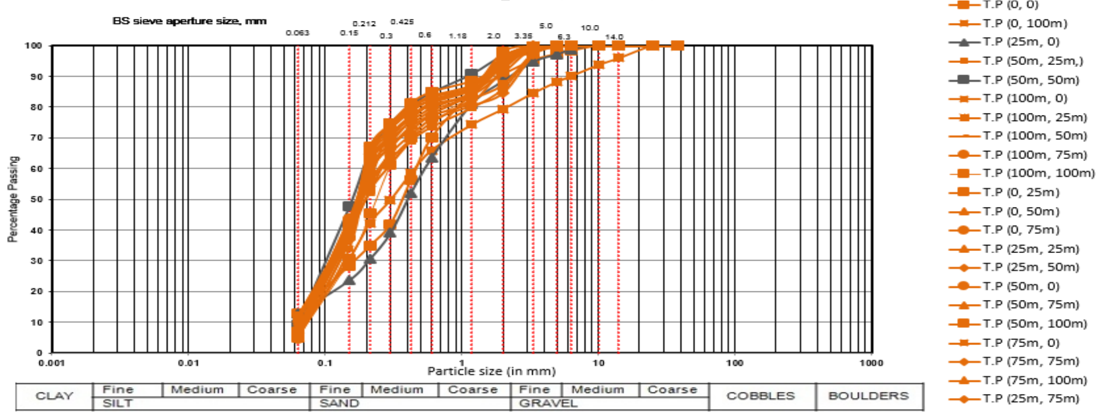
APPENDIX B

5. GEOTECHNICAL CHARACTERISATION.

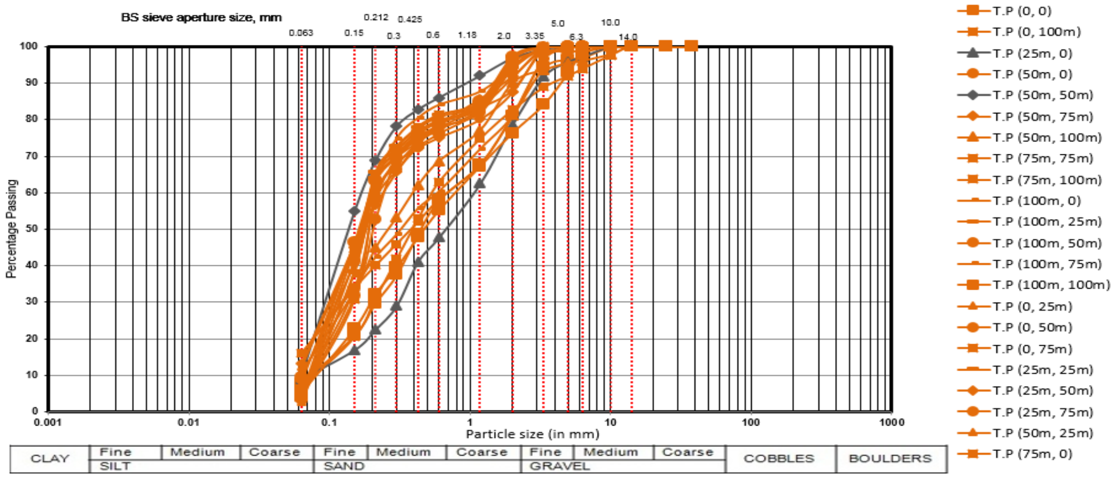
Particle Size Distribution (PSD)



At Depth (0.25 m)

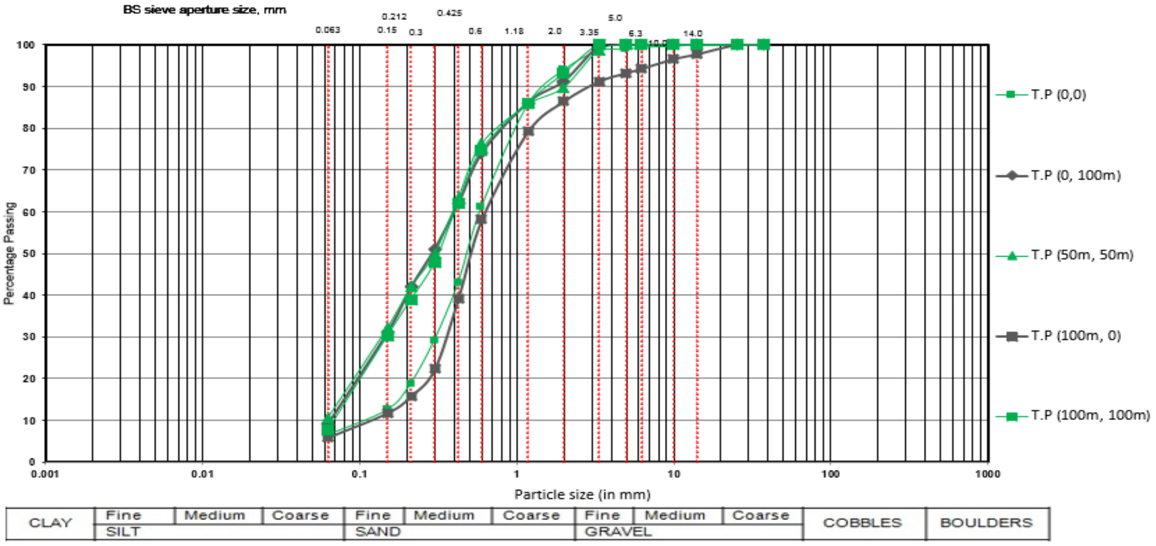


At Depth (1.0 m)

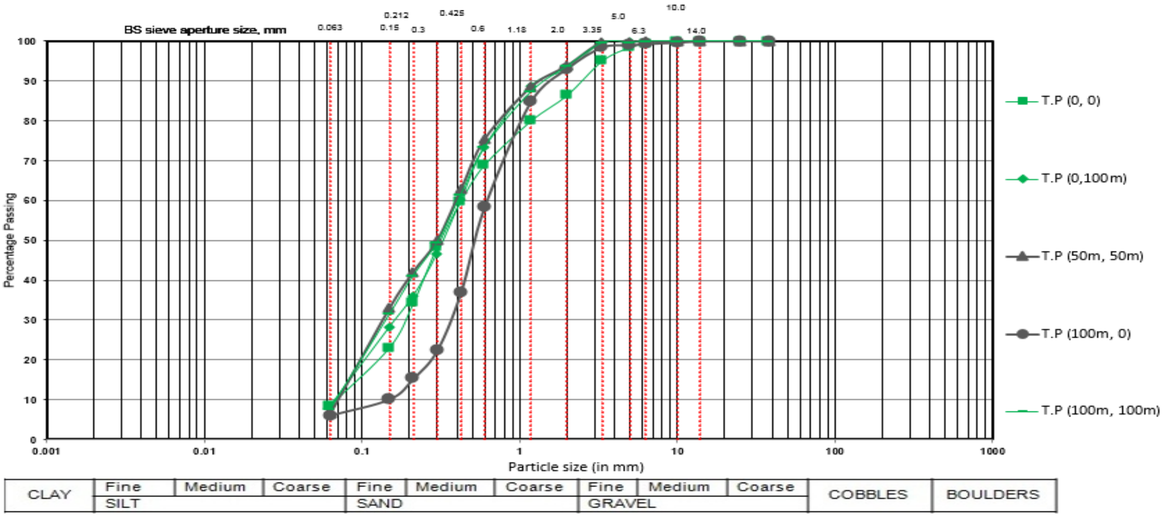


At Depth (1.5 m)

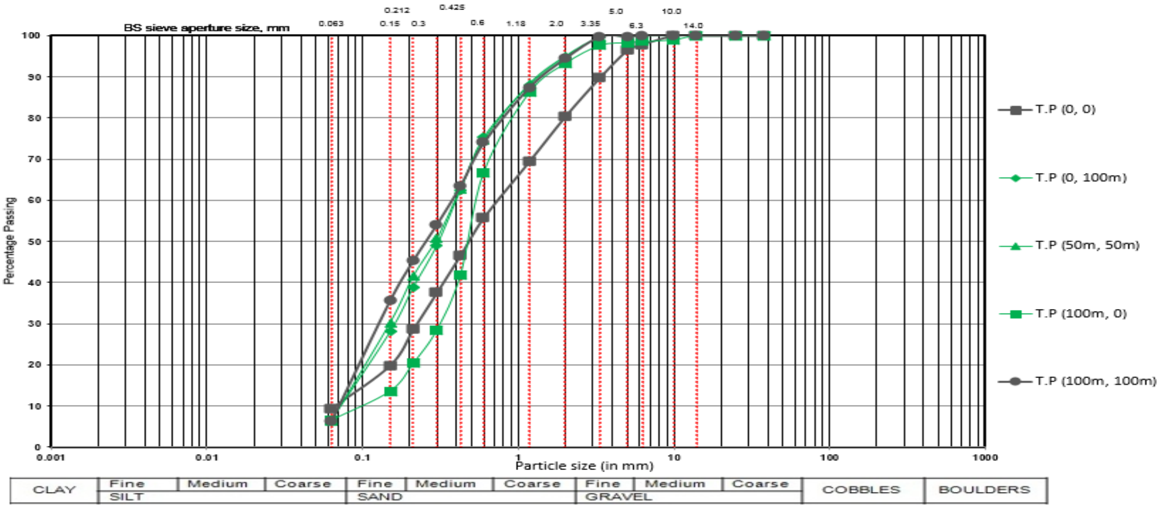
Figure B.5.1. Shows the PSD Curves for contaminated samples at depths (0.25 m, 1.0 m & 1.5 m).



At depth (0.25m)



At depth (1.0m)



At depth (1.5m)

Figure B.5.2. Shows the PSD Curves for non-contaminated samples at depth (0.25 m, 1.0 m & 1.5 m).

Table B.5.1. Shows the soil description results for contaminated samples at depth (0.0 m) in Greater Burgan oil field (Al-Magwa Area).

Trial Pits Coordinates. (T.P.Cs)	**Proportions of Soil Class Percent (%)**					**Silty/clay Passing Percentages % (B.S. SIEVE No.#230)**	**Soil Classification**
	Silty/Clay%	**Fine Sand %**	**Medium Sand %**	**Coarse Sand %**	**Gravel %**		
(0 m, 0 m)	11	7	34	22	15	11.3	Silty sand (S-M)
(25 m, 0 m)	8	10	34	26	14	7.8	Silty sand (S-M)
(50 m, 0 m)	5	51	24	11	4	5.0	Sand (SP)
(75 m, 0 m)	16	25	23	15	5	16.4	Very silty Sand (S-M)
(100 m, 0 m)	11	10	27	28	14	10.6	Silty Sand (S-M)
(0 m , 25m)	5	24	39	25	2	5.2	Silty sand (S-M)
(25 m, 25 m)	11	31	30	14	3	10.9	Silty sand (S-M)
(50 m, 25 m)	15	28	21	12	9	15.2	Very silty sand (SM)
(100 m, 25 m)	16	35	20	12	1	16.2	Very Silty Sand (S-M)
(0 m, 50 m)	13	28	20	17	9	12.8	Silty sand (S-M)
(25 m, 50 m)	15	28	20	11	11	15.2	Very silty sand (SM)
(50 m, 50 m)	7	38	33	11	4	7.4	Silty Sand (S-M)
(100 m, 50 m)	8	29	36	19	0	8	Silty Sand (S-M)
(0 m, 75 m)	9	14	37	26	5	9.5	Silty Sand (S-M)
(25 m, 75 m)	11	35	24	18	1	11.4	Silty sand (S-M)
(50 m, 75 m)	12	54	13	9	1	11.9	Silty Sand (S-M)
(75 m, 75 m)	10	42	25	12	1	10.3	Silty sand (S-M)
(100 m, 75 m)	13	30	30	13	1	13.5	Silty Sand (S-M)
(0 m, 100 m)	1	1	4	9	83	1.5	Sand (SP)
(50 m, 100 m)	9	35	25	14	8	9	Silty sand (S-M)
(75 m, 100 m)	8	31	32	20	1	8.3	Silty Sand (S-M)
(100 m,100 m)	3	17	17	12	49	2.7	Sand (SP)
Min. Value	1	1	4	9	1	2.7	-------
Max. Value	16	54	39	28	83	16.4	-------
Mean Value	10	28	25	17	11	9.7	Silty Sand (S-M)
Standard Deviation Value	4.08	13.49	8.51	5.95	19.16	4.11	-------

Table B.5.2. Shows the soil description results for contaminated samples at depth (0.25 m) in Greater Burgan oil field (Al-Magwa Area).

Trial Pits Coordinates (T.P.Cs)	Proportions of Soil Class Percent (%)					Silty/clay Passing Percentages % (B.S. SIEVE No.#230)	Soil Classification
	Silty/Clay%	Fine Sand %	Medium Sand %	Coarse Sand %	Gravel %		
(0 m , 0 m)	10	12	43	23	2	10.1	Silty sand (S-M)
(25 m, 0 m)	10	12	43	22	3	10.1	Silty sand (S-M)
(50 m, 0 m)	10	43	29	7	1	10.1	Silty sand (S-M)
(75 m, 0 m)	16	31	22	14	1	16.3	Silty sand (S-M)
(100 m, 0 m)	8	17	33	22	12	8	Silty Sand (S-M)
(0 m , 25 m)	8	8	41	22	13	8.3	Silty sand (S-M)
(25 m, 25 m)	6	56	17	14	1	6.5	Silty sand (S-M)
(50 m, 25 m)	15	15	36	14	5	15.4	Very silty sand (SM)
(100 m, 25 m)	14	38	21	12	1	13.8	Silty Sand (S-M)
(0 m, 50 m)	13	18	35	19	2	13	Silty sand (S-M)
(25 m, 50 m)	15	18	33	16	3	15.4	Very silty sand (SM)
(50 m, 50 m)	6	34	36	13	6	5.9	Silty Sand (S-M)
(100 m, 50 m)	9	40	21	20	1	9.4	Silty Sand (S-M)
(0 m, 75 m)	9	15	35	24	8	9.2	Silty Sand (S-M)
(25 m, 75 m)	8	32	28	22	3	7.7	Silty sand (S-M)
(50 m, 75 m)	4	56	17	19	0	4.3	Sand (SP)
(75 m, 75 m)	8	34	27	20	3	8.5	Silty sand (S-M)
(100 m, 75 m)	15	37	24	8	1	15.3	Very silty sand (SM)
(0 m, 100 m)	8	12	35	24	13	8.3	Silty Sand (S-M)
(50 m, 100 m)	12	40	23	12	1	11.9	Silty sand (S-M)
(75 m, 100 m)	16	37	18	12	1	15.8	Very silty sand (SM)
(100 m,100 m)	9	36	35	11	1	8.6	Silty Sand (S-M)
Min. Value	4	8	17	7	0	4.3	--------
Max. Value	15	56	43	24	13	16.3	--------
Mean Value	11	30	30	17	4	10.5	Silty Sand (S-M)
Standard Deviation Value	3.54	14.31	8.31	5.32	4.10	3.53	--------

Table B.5.3. Shows the soil description results for contaminated samples at depth (0.5 m) in Greater Burgan oil field (Al-Magwa Area).

Trial Pits Coordinates. (T.P.Cs)	Proportions of Soil Class Percent (%)					Silty/clay Passing Percentages % (B.S. SIEVE No.#230)	Soil Classification
	Silty/Clay%	Fine Sand %	Medium Sand %	Coarse Sand %	Gravel %		
(0 m , 0 m)	10	14	38	23	5	9.6	Silty sand (S-M)
(25 m, 0 m)	11	13	35	24	6	11.3	Silty sand (S-M)
(50 m, 0 m)	3	39	37	15	3	3.4	Sand (SP)
(75 m, 0 m)	8	52	19	14	0	7.5	Silty sand (S-M)
(100 m, 0 m)	10	10	36	24	11	9.9	Silty Sand (S-M)
(0 m, 25 m)	7	55	19	11	1	7.5	Silty sand (S-M)
(25 m, 25 m)	12	42	19	14	1	12	Silty sand (S-M)
(50 m, 25 m)	12	42	16	15	3	12.5	Silty sand (S-M)
(100 m, 25 m)	9	46	21	14	1	9	Silty Sand (S-M)
(0 m, 50 m)	9	49	19	12	2	8.6	Silty sand (S-M)
(25 m, 50 m)	14	40	19	12	2	13.9	Silty sand (S-M)
(50 m, 50 m)	8	50	18	16	1	7	Silty Sand (S-M)
(100 m, 50 m)	8	43	23	18	0	8.5	Silty Sand (S-M)
(0 m, 75 m)	11	45	22	10	1	11.4	Silty Sand (S-M)
(25 m, 75 m)	11	45	21	13	0	10.9	Silty sand (S-M)
(50 m, 75 m)	5	56	18	16	0	5.2	Silty sand (S-M)
(75 m, 75 m)	12	44	21	10	1	12.1	Silty sand (S-M)
(100 m, 75 m)	9	44	24	14	0	8.8	Silty Sand (S-M)
(0 m, 100 m)	9	12	33	21	16	9	Silty Sand (S-M)
(50 m, 100 m)	10	40	22	18	0	10.4	Silty sand (S-M)
(75 m, 100 m)	11	42	23	13	0	11.2	Silty Sand (S-M)
(100 m,100 m)	11	33	26	17	3	10.0	Silty Sand (S-M)
Min. Value	3	12	16	10	0	3.4	------
Max. Value	14	56	38	24	16	13.9	------
Mean Value	9	40	25	16	3	9.5	Silty Sand (S-M)
Standard Deviation Value	2.4	13.9	6.9	4.2	3.9	2.4	------

Table B.5.4. Shows the soil description results for contaminated samples at depth (1.0 m) in Greater Burgan oil field (Al-Magwa Area).

Trial Pits Coordinates. (T.P.Cs)	**Proportions of Soil Class Percent (%)**					**Silty/clay Passing Percentages % (B.S. SIEVE No.#230)**	**Soil Classification**
	Silty/Clay%	**Fine Sand %**	**Medium Sand %**	**Coarse Sand %**	**Gravel %**		
(0 m , 0 m)	13	14	35	20	5	12.8	Silty sand (S-M)
(25 m, 0 m)	13	14	33	22	5	13.0	Silty sand (S-M)
(50 m, 0 m)	6	48	26	12	2	5.7	Silty sand (S-M)
(75 m, 0 m)	5	59	18	13	0	4.9	Sand (SP)
(100 m, 0 m)	11	44	20	12	2	11.4	Silty Sand (S-M)
(0 m, 25 m)	7	60	18	8	0	7	Silty sand (S-M)
(25 m, 25 m)	6	58	19	11	0	6	Silty sand (S-M)
(50 m, 25 m)	12	41	21	12	2	12.4	Silty sand (S-M)
(100 m, 25 m)	5	61	17	12	0	5.2	Silty Sand (S-M)
(0 m, 50 m)	8	53	18	12	1	7.8	Silty sand (S-M)
(25 m, 50 m)	12	44	20	9	3	12.1	Silty sand (S-M)
(50 m, 50 m)	9	51	19	12	0	9.2	Silty Sand (S-M)
(100 m, 50 m)	7	49	19	18	0	7	Silty Sand (S-M)
(0 m, 75 m)	5	62	17	12	0	4.6	Sand (SP)
(25 m, 75 m)	5	60	17	14	0	4.9	Sand (SP)
(50 m, 75 m)	10	42	26	12	0	10.3	Silty sand (S-M)
(75 m, 75 m)	7	56	18	13	0	6.7	Silty sand (S-M)
(100 m, 75 m)	8	54	17	14	0	7.6	Silty Sand (S-M)
(0 m, 100 m)	6	36	24	13	15	6.2	Silty Sand (S-M)
(50 m, 100 m)	5	55	18	17	0	5.1	Silty sand (S-M)
(75 m, 100 m)	8	52	18	15	0	7.6	Silty Sand (S-M)
(100 m,100 m)	6	39	30	19	0	5.6	Silty Sand (S-M)
Min. Value	5	14	17	8	0	4.6	------
Max. Value	13	62	35	22	15	12.8	------
Mean Value	8	49	21	14	2	7.9	Silty Sand (S-M)
Standard Deviation Value	2.7	13.3	5.39	3.48	1.59	2.8	------

Table B.5.5. Shows the soil description results for contaminated samples at depth (1.5 m) in Greater Burgan oil field (Al-Magwa Area).

Trial Pits Coordinates (T.P.Cs)	Proportions of Soil Class Percent (%)					Silty/clay Passing Percentages % (B.S. SIEVE No.#230)	Soil Classification
	Silty/Clay%	Fine Sand %	Medium Sand %	Coarse Sand %	Gravel %		
(0 m, 0 m)	8	28	28	23	6	7.9	Silty sand (S-M)
(25 m, 0 m)	9	18	25	31	8	9	Silty sand (S-M)
(50 m, 0 m)	5	45	27	17	1	4.7	Sand (SP)
(75 m, 0 m)	4	56	17	19	0	4.1	Sand (SP)
(100 m, 0 m)	6	56	22	10	0	6.4	Silty Sand (S-M)
(0 m, 25 m)	3	60	17	18	0	2.7	Sand (SP)
(25 m, 25 m)	3	61	16	17	0	3.1	Sand (SP)
(50 m, 25 m)	12	51	14	10	1	12.4	Silty sand (S-M)
(100 m, 25 m)	4	62	16	13	1	3.8	Sand (SP)
(0 m, 50 m)	5	62	15	13	0	5.4	Silty sand (S-M)
(25 m, 50 m)	13	47	14	12	0	13.2	Silty sand (S-M)
(50 m, 50 m)	10	51	17	11	1	10	Silty Sand (S-M)
(100 m, 50 m)	10	42	18	20	1	9.6	Silty Sand (S-M)
(0 m, 75 m)	4	62	16	15	0	3.6	Sand (SP)
(25 m, 75 m)	5	59	15	17	0	4.6	Sand (SP)
(50 m, 75 m)	8	48	22	13	1	8.4	Silty sand (S-M)
(75 m, 75 m)	8	57	17	11	0	7.5	Silty sand (S-M)
(100 m, 75m)	16	26	18	21	3	16.1	Very silty sand (SM)
(0 m, 100 m)	7	24	32	20	11	6.7	Silty Sand (S-M)
(50 m, 100 m)	11	30	21	21	6	10.9	Silty sand (S-M)
(75 m, 100 m)	16	24	18	23	3	16	Very Silty Sand (SM)
(100 m,100 m)	5	27	23	24	16	5.3	Silty Sand (S-M)
Min. Value	3	18	14	10	0	2.7	------
Max. Value	16	62	32	31	16	16.1	------
Mean Value	8	45	20	17	3	7.8	Silty Sand (S-M)
Standard Deviation Value	3.9	15.1	4.9	5.4	4.2	4.0	------

Table B.5.6. Shows the soil description results for contaminated samples at depth (2.0 m) in Greater Burgan oil field (Al-Magwa Area).

Trial Pits Coordinates. (T.P.Cs)	Proportions of Soil Class Percent (%)					Silty/clay Passing Percentages % (B.S. SIEVE No.#230)	Soil Classification
	Silty/Clay%	Fine Sand %	Medium Sand %	Coarse Sand %	Gravel %		
(0 m, 0 m)	5	52	21	17	0	5.3	Silty sand (S-M)
(25 m, 0 m)	11	48	17	12	1	11.8	Silty sand (S-M)
(50 m, 0 m)	5	37	33	19	1	5.4	Silty sand (S-M)
(75 m, 0 m)	4	61	15	16	0	4.0	Sand (SP)
(100 m, 0 m)	12	36	25	14	1	12.4	Silty Sand (S-M)
(0 m, 25 m)	3	60	19	15	0	3.2	Sand (SP)
(25 m, 25 m)	3	58	16	21	0	2.7	Sand (SP)
(50 m, 25 m)	7	49	17	19	1	7.4	Silty sand (S-M)
(100 m, 25 m)	4	51	25	17	0	3	Sand (SP)
(0 m, 50 m)	6	55	17	16	0	6	Silty sand (S-M)
(25 m, 50 m)	9	47	19	16	2	8.5	Silty sand (S-M)
(50 m, 50 m)	12	28	25	16	6	13	Silty Sand (S-M)
(100 m, 50 m)	13	34	18	17	5	13.1	Silty Sand (S-M)
(0 m, 75 m)	2	53	18	25	0	2.2	Sand (SP)
(25 m, 75 m)	10	46	20	14	1	9.6	Sand (SP)
(50 m, 75 m)	11	45	22	18	1	11	Silty sand (S-M)
(75 m, 75 m)	16	27	25	13	3	16	Very silty sand (SM)
(100 m, 75 m)	9	47	20	14	1	9.1	Silty Sand (S-M)
(0 m, 100 m)	3	49	23	19	3	2.8	Sand (SP)
(50 m, 100 m)	9	23	20	17	22	9.2	Silty sand (S-M)
(75 m, 100 m)	10	46	18	15	1	10.4	Silty Sand (S-M)
(100 m, 100 m)	6	27	26	26	9	6.5	Silty Sand (S-M)
Min. Value	2	23	16	12	0	2.2	------
Max. Value	13	61	33	26	22	13.1	------
Mean Value	8	46	21	17	3	7.8	Silty Sand (S-M)
Standard Deviation Value	3.8	11.1	4.2	3.4	4.8	4.0	------

Table B.5.7. Shows the soil description results for control samples at depth (0.0 m) in Greater Burgan oil field (Al-Magwa Area).

Trial Pits Coordinates (T.P.Cs)	Proportions of Soil Class Percent (%)					Silty/clay Passing Percentages % (B.S. SIEVE No.#230)	Soil Classification
	Silty/Clay %	Fine Sand %	Medium Sand %	Coarse Sand %	Gravel %		
(0 m, 0 m)	7	19	38	27	2	7.3	Silty sand (S-M)
(100 m, 0 m)	2	17	48	29	2	2.1	Sand (SP)
(50 m, 50 m)	9	24	36	23	0	8.6	Silty sand (S-M)
(0 m, 100 m)	6	28	43	17	0	6.3	Silty sand (S-M)
(100 m, 100 m)	9	22	37	22	1	9.0	Silty Sand (S-M)
Min. Value	2	17	36	17	0	2.1	--------
Max. Value	9	28	48	29	2	9	--------
Mean Value	7	22	40	24	1	6.6	Silty sand (S-M)
Standard Deviation Value	2.8	4.3	5.0	4.6	1.0	2.7	--------

Table B.5.8. Shows the soil description results for control samples at depth (0.25 m) in Greater Burgan oil field (Al-Magwa Area).

Trial Pits Coordinates (T.P.Cs)	Proportions of Soil Class Percent (%)					Silty/clay Passing Percentages % (B.S. SIEVE No.#230)	Soil Classification
	Silty/Clay %	Fine sand %	Medium Sand %	Coarse Sand %	Gravel %		
(0 m, 0 m)	6	12	42	33	1	6.5	Silty sand (S-M)
(100 m, 0 m)	6	10	42	28	9	5.9	Silty Sand (S-M)
(50 m, 50 m)	11	31	34	13	1	10.7	Silty sand (S-M)
(0 m, 100 m)	9	33	32	17	0	9.2	Silty Sand (S-M)
(100 m, 100 m)	8	31	36	18	0	7.9	Silty sand (S-M)
Min. Value	6	10	32	13	0	5.9	-------
Max. Value	11	33	42	33	9	10.7	-------
Mean Value	8	23	37	22	2	8	Silty sand (S-M)
Standard Deviation Value	2.1	11.3	4.6	8.3	3.8	1.9	-------

Table B.5.9. Shows the soil description results for control samples at depth (0.5 m) in Greater Burgan oil field (Al-Magwa Area).

Trial Pits Coordinates. (T.P.Cs)	Proportions of Soil Class Percent (%)					Silty/clay Passing Percentages % (B.S. SIEVE No.#230)	Soil Classification
	Silty/Clay %	Fine Sand %	Medium Sand %	Coarse Sand %	Gravel %		
(0 m, 0 m)	6	12	43	23	11	5.6	Silty sand (S-M)
(100 m, 0 m)	5	20	45	22	3	5.3	Silty Sand (S-M)
(50 m, 50 m)	11	30	32	17	0	10.6	Silty sand (S-M)
(0 m, 100 m)	10	26	41	13	0	10.5	Silty sand (S-M)
(100 m, 100 m)	9	25	36	22	0	8.7	Silty Sand (S-M)
Min. Value	5	12	32	13	0	5.3	-------
Max. Value	11	30	45	23	11	10.6	-------
Mean Value	8	23	39	20	3	8.2	Silty Sand (S-M)
Standard Deviation Value	2.5	6.9	5.3	4.2	4.7	2.5	-------

Table B.5.10. Shows the soil description results for control samples at depth (1.0 m) in Greater Burgan oil field (Al-Magwa Area).

Trial Pits Coordinates (T.P.Cs)	Proportions of Soil Class Percent (%)					Silty/clay Passing Percentages % (B.S. SIEVE No.#230)	Soil Classification
	Silty/Clay%	Fine Sand %	Medium Sand %	Coarse Sand %	Gravel %		
(0 m , 0 m)	8	26	35	18	5	8.5	Silty sand (S-M)
(100 m, 0 m)	6	9	43	35	1	6.1	Silty Sand (S-M)
(50 m, 50 m)	7	36	33	18	0	6.6	Silty sand (S-M)
(0 m, 100 m)	8	28	37	19	0	8.4	Silty sand (S-M)
(100 m, 100 m)	7	34	32	20	0	7.4	Silty Sand (S-M)
Min. Value	6	9	32	18	0	6.1	-------
Max. Value	8	36	43	35	5	8.5	-------
Mean Value	7	26	36	22	1	7.4	Silty Sand (S-M)
Standard Deviation Value	0.8	10.6	4.3	7.3	2.1	1.0	-------

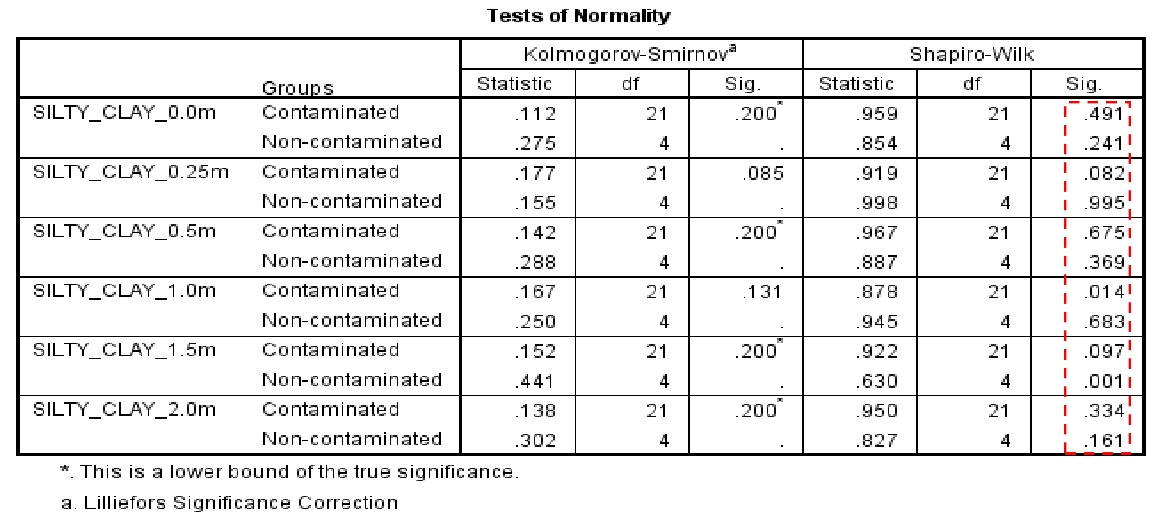
Table B.5.11. Shows the soil description results for control samples at depth (1.5 m) in Greater Burgan oil field (Al-Magwa Area).

Trial Pits Coordinates. (T.P.Cs)	Proportions of Soil Class Percent (%)					Silty/clay Passing Percentages % (B.S. SIEVE No.#230)	Soil Classification
	Silty/Clay %	Fine Sand %	Medium Sand %	Coarse Sand %	Gravel %		
(0 m, 0 m)	9	19	27	25	10	9.4	Silty sand (S-M)
(100 m, 0 m)	6	14	46	26	2	6.5	Silty Sand (S-M)
(50 m, 50 m)	6	35	33	20	0	6.3	Silty sand (S-M)
(0 m, 100 m)	7	32	36	19	0	6.5	Silty sand (S-M)
(100 m, 100 m)	6	39	29	20	0	6.4	Silty Sand (S-M)
Min. Value	6	14	27	19	0	6.3	-------
Max. Value	9	39	46	26	10	9.4	-------
Mean Value	7	28	34	22	3	7	Silty Sand (S-M)
Standard Deviation Value	1.3	10.7	7.4	3.2	4.3	1.3	-------

Table B.5.12. Shows the soil description results for control samples at depth (2.0 m) in Greater Burgan oil field (Al-Magwa Area).

Trial Pits Coordinates (T.P.Cs)	Proportions of Soil Class Percent (%)					Silty/clay Passing Percentages % (B.S. SIEVE No.#230)	Soil Classification
	Silty/Clay %	Fine Sand %	Medium Sand %	Coarse Sand %	Gravel %		
(0 m, 0 m)	5	52	19	17	2	5.3	Silty sand (S-M)
(100 m, 0 m)	5	10	49	28	3	5.2	Silty Sand (S-M)
(50 m, 50 m)	9	23	42	16	1	9.3	Silty sand (S-M)
(100 m, 100 m)	8	22	44	17	1	5.3	Silty Sand (S-M)
(0 m, 100 m)	5	29	44	16	1	8.1	Silty sand (S-M)
Min. Value	5	10	19	16	1	5.2	--------
Max. Value	9	52	49	28	3	9.3	--------
Mean Value	7	27	40	19	2	6.6	Silty Sand (S-M)
Standard Deviation Value	1.9	15.4	11.8	5.1	0.8	1.9	--------

Table B.5.13. The significant p-values via normality Shapiro-Wilk test indicate that the soil constituents data (i.e. silty/clay %, fine sand %, medium sand %, Coarse Sand % and exact soil passing No. 230) at contaminated and non-contaminated sites follow normal distribution.

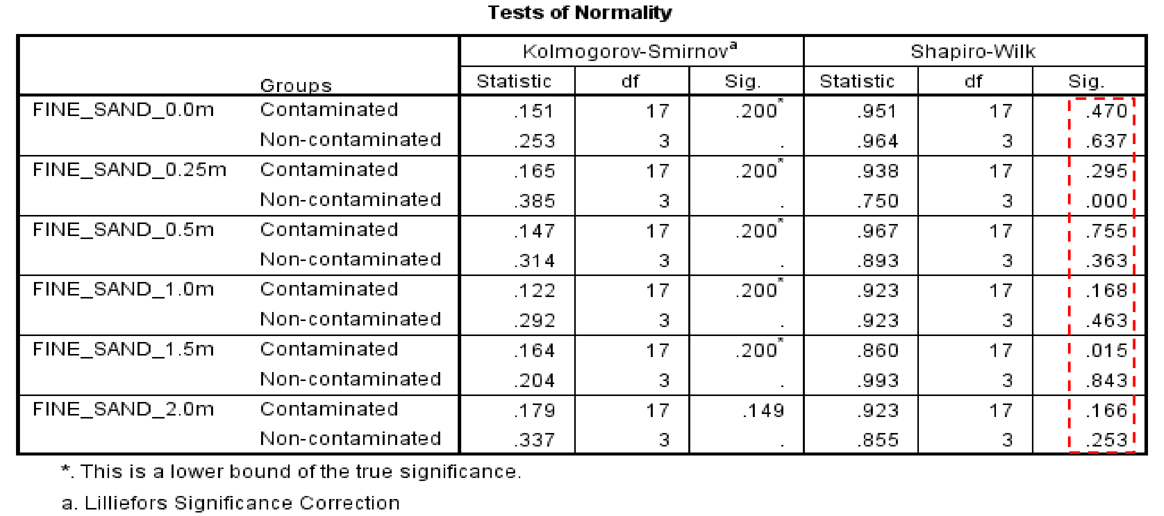


Tests of Normality

		Kolmogorov-Smirnov^{a}			Shapiro-Wilk		
	Groups	Statistic	df	Sig.	Statistic	df	Sig.
SILTY_CLAY_0.0m	Contaminated	.112	21	.200*	.959	21	.491
	Non-contaminated	.275	4	.	.854	4	.241
SILTY_CLAY_0.25m	Contaminated	.177	21	.085	.919	21	.082
	Non-contaminated	.155	4	.	.998	4	.995
SILTY_CLAY_0.5m	Contaminated	.142	21	.200*	.967	21	.675
	Non-contaminated	.288	4	.	.887	4	.369
SILTY_CLAY_1.0m	Contaminated	.167	21	.131	.878	21	.014
	Non-contaminated	.250	4	.	.945	4	.683
SILTY_CLAY_1.5m	Contaminated	.152	21	.200*	.922	21	.097
	Non-contaminated	.441	4	.	.630	4	.001
SILTY_CLAY_2.0m	Contaminated	.138	21	.200*	.950	21	.334
	Non-contaminated	.302	4	.	.827	4	.161

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

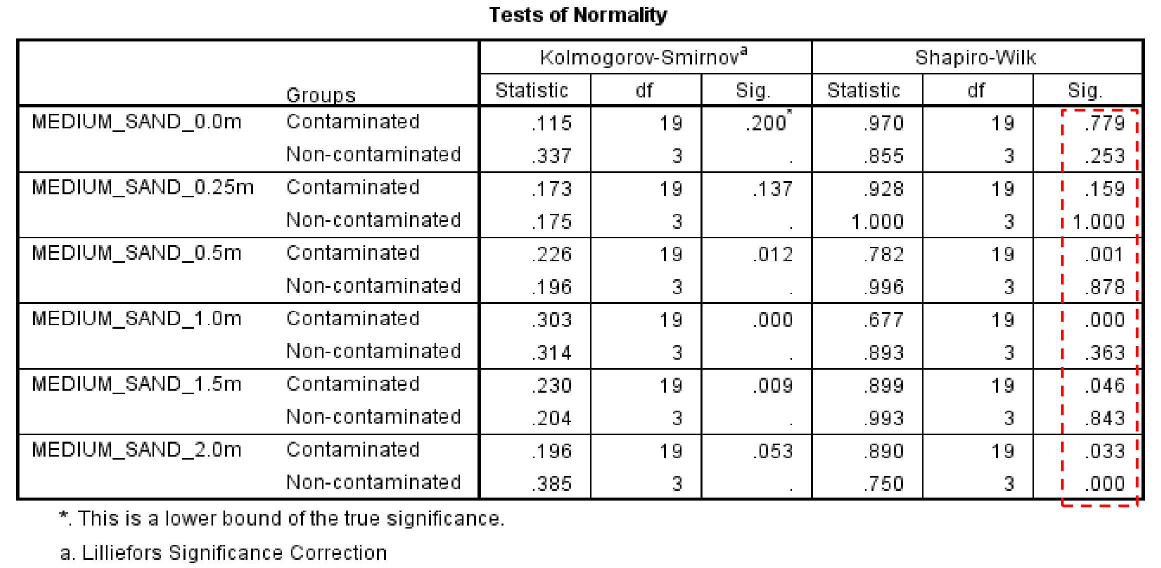


Tests of Normality

		Kolmogorov-Smirnov^{a}			Shapiro-Wilk		
	Groups	Statistic	df	Sig.	Statistic	df	Sig.
FINE_SAND_0.0m	Contaminated	.151	17	.200*	.951	17	.470
	Non-contaminated	.253	3	.	.964	3	.637
FINE_SAND_0.25m	Contaminated	.165	17	.200*	.938	17	.295
	Non-contaminated	.385	3	.	.750	3	.000
FINE_SAND_0.5m	Contaminated	.147	17	.200*	.967	17	.755
	Non-contaminated	.314	3	.	.893	3	.363
FINE_SAND_1.0m	Contaminated	.122	17	.200*	.923	17	.168
	Non-contaminated	.292	3	.	.923	3	.463
FINE_SAND_1.5m	Contaminated	.164	17	.200*	.860	17	.015
	Non-contaminated	.204	3	.	.993	3	.843
FINE_SAND_2.0m	Contaminated	.179	17	.149	.923	17	.166
	Non-contaminated	.337	3	.	.855	3	.253

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction



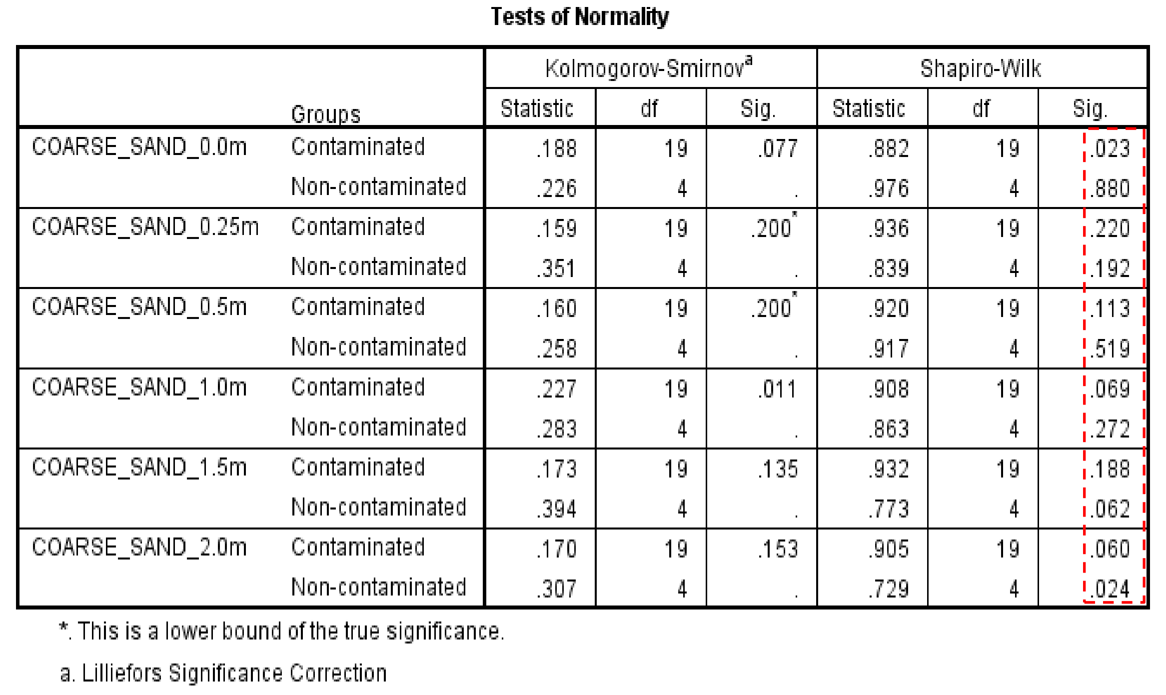
Tests of Normality

		Kolmogorov-Smirnov^{a}			Shapiro-Wilk		
	Groups	Statistic	df	Sig.	Statistic	df	Sig.
MEDIUM_SAND_0.0m	Contaminated	.115	19	.200*	.970	19	.779
	Non-contaminated	.337	3	.	.855	3	.253
MEDIUM_SAND_0.25m	Contaminated	.173	19	.137	.928	19	.159
	Non-contaminated	.175	3	.	1.000	3	1.000
MEDIUM_SAND_0.5m	Contaminated	.226	19	.012	.782	19	.001
	Non-contaminated	.196	3	.	.996	3	.878
MEDIUM_SAND_1.0m	Contaminated	.303	19	.000	.677	19	.000
	Non-contaminated	.314	3	.	.893	3	.363
MEDIUM_SAND_1.5m	Contaminated	.230	19	.009	.899	19	.046
	Non-contaminated	.204	3	.	.993	3	.843
MEDIUM_SAND_2.0m	Contaminated	.196	19	.053	.890	19	.033
	Non-contaminated	.385	3	.	.750	3	.000

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Table B.5.13. continuous.

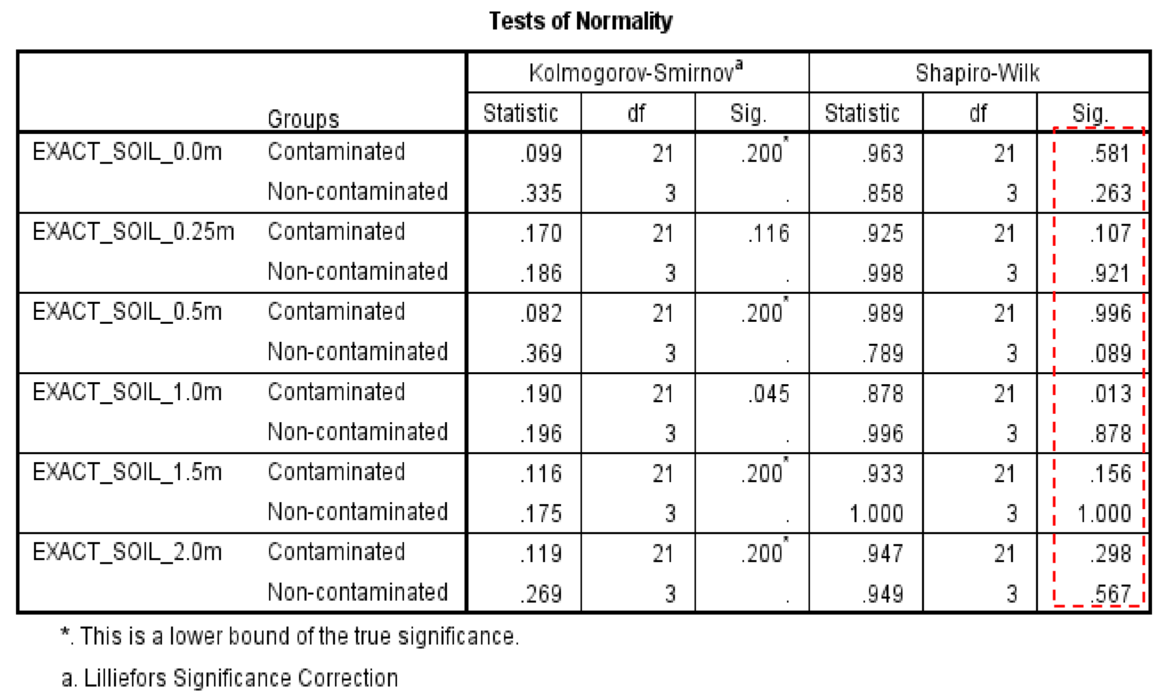


Tests of Normality

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Groups	Statistic	df	Sig.	Statistic	df	Sig.
COARSE_SAND_0.0m	Contaminated	.188	19	.077	.882	19	.023
	Non-contaminated	.226	4	.	.976	4	.880
COARSE_SAND_0.25m	Contaminated	.159	19	.200*	.936	19	.220
	Non-contaminated	.351	4	.	.839	4	.192
COARSE_SAND_0.5m	Contaminated	.160	19	.200*	.920	19	.113
	Non-contaminated	.258	4	.	.917	4	.519
COARSE_SAND_1.0m	Contaminated	.227	19	.011	.908	19	.069
	Non-contaminated	.283	4	.	.863	4	.272
COARSE_SAND_1.5m	Contaminated	.173	19	.135	.932	19	.188
	Non-contaminated	.394	4	.	.773	4	.062
COARSE_SAND_2.0m	Contaminated	.170	19	.153	.905	19	.060
	Non-contaminated	.307	4	.	.729	4	.024

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction



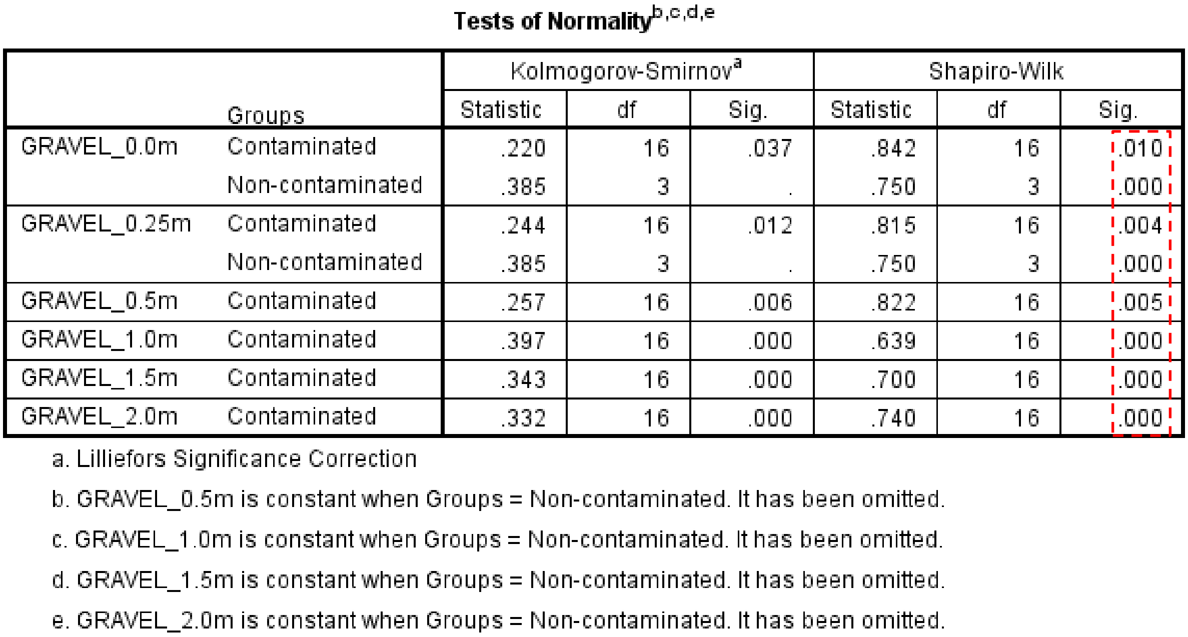
Tests of Normality

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Groups	Statistic	df	Sig.	Statistic	df	Sig.
EXACT_SOIL_0.0m	Contaminated	.099	21	.200*	.963	21	.581
	Non-contaminated	.335	3	.	.858	3	.263
EXACT_SOIL_0.25m	Contaminated	.170	21	.116	.925	21	.107
	Non-contaminated	.186	3	.	.998	3	.921
EXACT_SOIL_0.5m	Contaminated	.082	21	.200*	.989	21	.996
	Non-contaminated	.369	3	.	.789	3	.089
EXACT_SOIL_1.0m	Contaminated	.190	21	.045	.878	21	.013
	Non-contaminated	.196	3	.	.996	3	.878
EXACT_SOIL_1.5m	Contaminated	.116	21	.200*	.933	21	.156
	Non-contaminated	.175	3	.	1.000	3	1.000
EXACT_SOIL_2.0m	Contaminated	.119	21	.200*	.947	21	.298
	Non-contaminated	.269	3	.	.949	3	.567

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Table B.5.14. The significant p-values via normality Shapiro-Wilk test indicate that the soil constituent data (i.e. Gravel %) at contaminated and non-contaminated sites follows non-normal distribution.



Tests of Normality^{b,c,d,e}

	Groups	Kolmogorov-Smirnov^{a}			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
GRAVEL_0.0m	Contaminated	.220	16	.037	.842	16	.010
	Non-contaminated	.385	3	.	.750	3	.000
GRAVEL_0.25m	Contaminated	.244	16	.012	.815	16	.004
	Non-contaminated	.385	3	.	.750	3	.000
GRAVEL_0.5m	Contaminated	.257	16	.006	.822	16	.005
GRAVEL_1.0m	Contaminated	.397	16	.000	.639	16	.000
GRAVEL_1.5m	Contaminated	.343	16	.000	.700	16	.000
GRAVEL_2.0m	Contaminated	.332	16	.000	.740	16	.000

a. Lilliefors Significance Correction

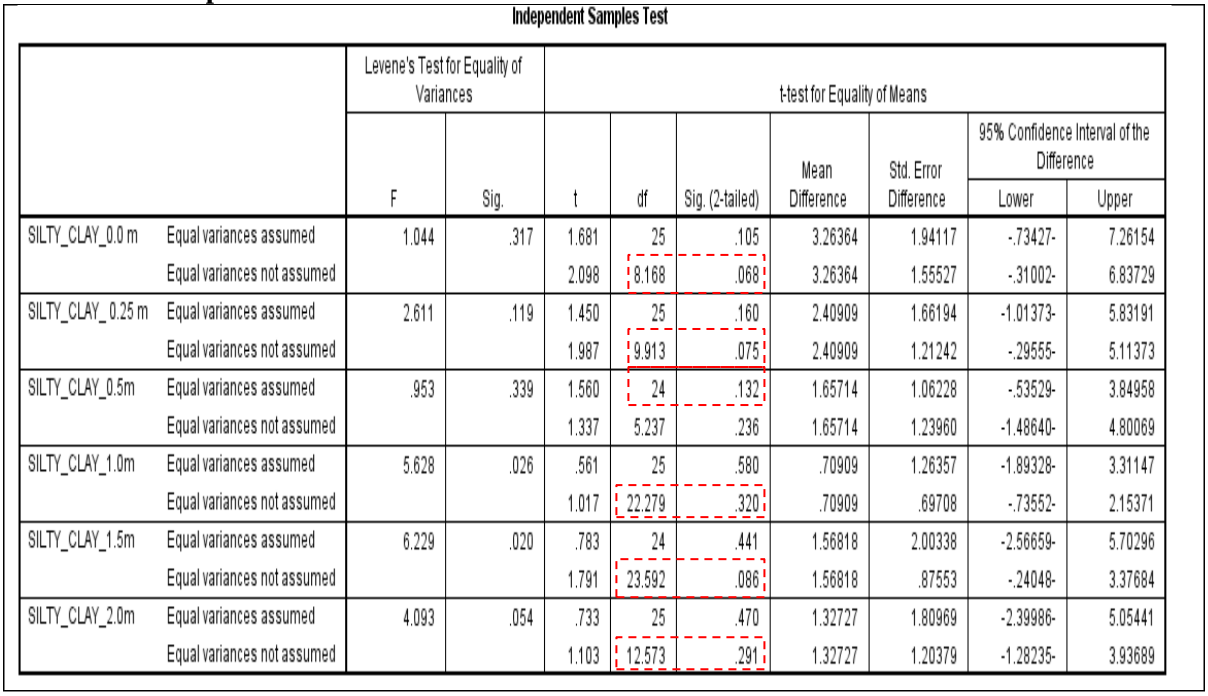
b. GRAVEL_0.5m is constant when Groups = Non-contaminated. It has been omitted.

c. GRAVEL_1.0m is constant when Groups = Non-contaminated. It has been omitted.

d. GRAVEL_1.5m is constant when Groups = Non-contaminated. It has been omitted.

e. GRAVEL_2.0m is constant when Groups = Non-contaminated. It has been omitted.

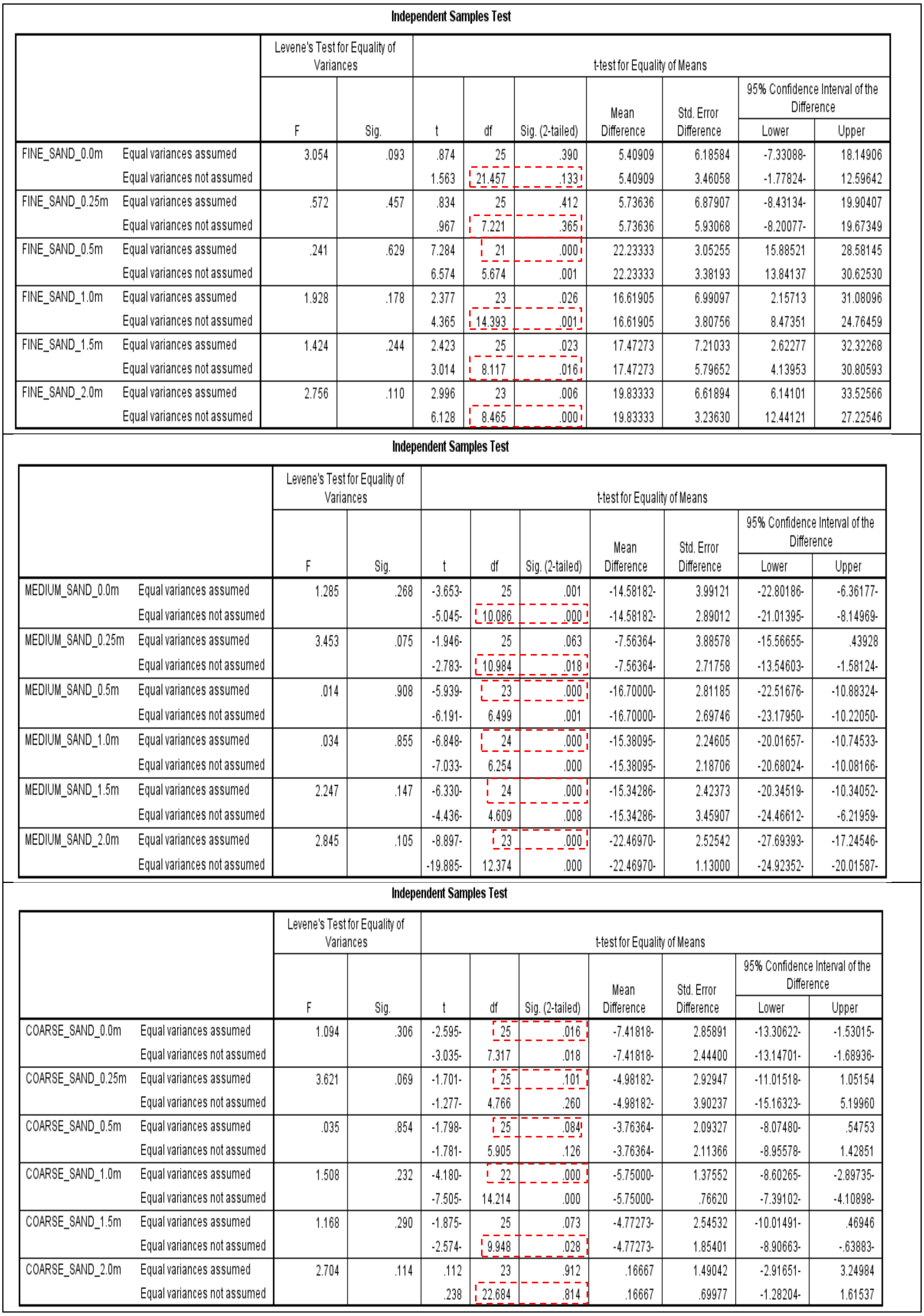
Table B.5.15. Indicates the significant differences of soil classification constitutes (i.e. silty/clay %, fine sand %, medium sand %, coarse Sand % and exact soil passing No. 230) at six different depths between contaminated and non-contaminated sites.



Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
SILTY_CLAY_0.0 m	Equal variances assumed	1.044	.317	1.681	25	.105	3.26364	1.94117	-.73427-	7.26154
	Equal variances not assumed			2.098	8.168	.068	3.26364	1.55527	-.31002-	6.83729
SILTY_CLAY_ 0.25 m	Equal variances assumed	2.611	.119	1.450	25	.160	2.40909	1.66194	-1.01373-	5.83191
	Equal variances not assumed			1.987	9.913	.075	2.40909	1.21242	-.29555-	5.11373
SILTY_CLAY_0.5m	Equal variances assumed	.953	.339	1.560	24	.132	1.65714	1.06228	-.53529-	3.84958
	Equal variances not assumed			1.337	5.237	.236	1.65714	1.23960	-1.48640-	4.80069
SILTY_CLAY_1.0m	Equal variances assumed	5.628	.026	.561	25	.580	.70909	1.26357	-1.89328-	3.31147
	Equal variances not assumed			1.017	22.279	.320	.70909	.69708	-.73552-	2.15371
SILTY_CLAY_1.5m	Equal variances assumed	6.229	.020	.783	24	.441	1.56818	2.00338	-2.56659-	5.70296
	Equal variances not assumed			1.791	23.592	.086	1.56818	.87553	-.24048-	3.37684
SILTY_CLAY_2.0m	Equal variances assumed	4.093	.054	.733	25	.470	1.32727	1.80969	-2.39986-	5.05441
	Equal variances not assumed			1.103	12.573	.291	1.32727	1.20379	-1.28235-	3.93689

Table B.5.15. Continuous.



Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
FINE_SAND_0.0m	Equal variances assumed	3.054	.093	.874	25	.390	5.40909	6.18584	-7.33088-	18.14906
	Equal variances not assumed			1.563	21.457	.133	5.40909	3.46058	-1.77824-	12.59642
FINE_SAND_0.25m	Equal variances assumed	.572	.457	.834	25	.412	5.73636	6.87907	-8.43134-	19.90407
	Equal variances not assumed			.967	7.221	.365	5.73636	5.93068	-8.20077-	19.67349
FINE_SAND_0.5m	Equal variances assumed	.241	.629	7.284	21	.000	22.23333	3.05255	15.88521	28.58145
	Equal variances not assumed			6.574	5.674	.001	22.23333	3.38193	13.84137	30.62530
FINE_SAND_1.0m	Equal variances assumed	1.928	.178	2.377	23	.026	16.61905	6.99097	2.15713	31.08096
	Equal variances not assumed			4.365	14.393	.001	16.61905	3.80756	8.47351	24.76459
FINE_SAND_1.5m	Equal variances assumed	1.424	.244	2.423	25	.023	17.47273	7.21033	2.62277	32.32268
	Equal variances not assumed			3.014	8.117	.016	17.47273	5.79652	4.13953	30.80593
FINE_SAND_2.0m	Equal variances assumed	2.756	.110	2.996	23	.006	19.83333	6.61894	6.14101	33.52566
	Equal variances not assumed			6.128	8.465	.000	19.83333	3.23630	12.44121	27.22546

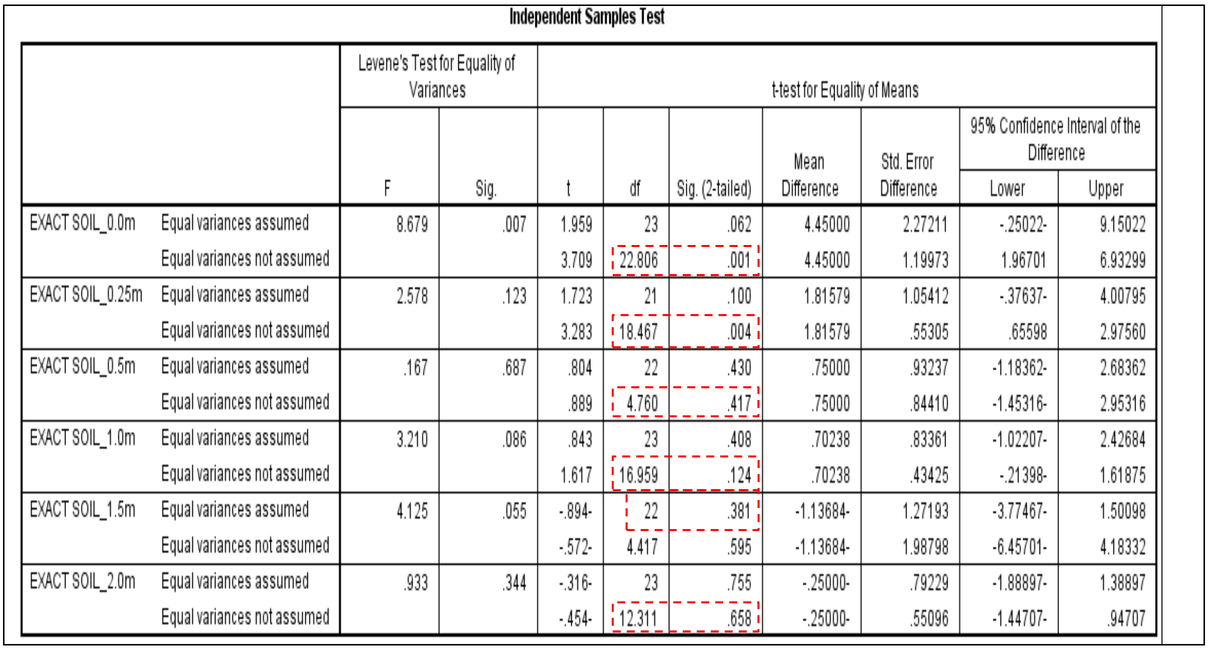
Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
MEDIUM_SAND_0.0m	Equal variances assumed	1.285	.268	-3.653-	25	.001	-14.58182-	3.99121	-22.80186-	-6.36177-
	Equal variances not assumed			-5.045-	10.086	.000	-14.58182-	2.89012	-21.01395-	-8.14969-
MEDIUM_SAND_0.25m	Equal variances assumed	3.453	.075	-1.946-	25	.063	-7.56364-	3.88578	-15.56655-	.43928
	Equal variances not assumed			-2.783-	10.984	.018	-7.56364-	2.71758	-13.54603-	-1.58124-
MEDIUM_SAND_0.5m	Equal variances assumed	.014	.908	-5.939-	23	.000	-16.70000-	2.81185	-22.51676-	-10.88324-
	Equal variances not assumed			-6.191-	6.499	.001	-16.70000-	2.69746	-23.17950-	-10.22050-
MEDIUM_SAND_1.0m	Equal variances assumed	.034	.855	-6.848-	24	.000	-15.38095-	2.24605	-20.01657-	-10.74533-
	Equal variances not assumed			-7.033-	6.254	.000	-15.38095-	2.18706	-20.68024-	-10.08166-
MEDIUM_SAND_1.5m	Equal variances assumed	2.247	.147	-6.330-	24	.000	-15.34286-	2.42373	-20.34519-	-10.34052-
	Equal variances not assumed			-4.436-	4.609	.008	-15.34286-	3.45907	-24.46612-	-6.21959-
MEDIUM_SAND_2.0m	Equal variances assumed	2.845	.105	-8.897-	23	.000	-22.46970-	2.52542	-27.69393-	-17.24546-
	Equal variances not assumed			-19.885-	12.374	.000	-22.46970-	1.13000	-24.92352-	-20.01587-

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
COARSE_SAND_0.0m	Equal variances assumed	1.094	.306	-2.595-	25	.016	-7.41818-	2.85891	-13.30622-	-1.53015-
	Equal variances not assumed			-3.035-	7.317	.018	-7.41818-	2.44400	-13.14701-	-1.68936-
COARSE_SAND_0.25m	Equal variances assumed	3.621	.069	-1.701-	25	.101	-4.98182-	2.92947	-11.01518-	1.05154
	Equal variances not assumed			-1.277-	4.766	.260	-4.98182-	3.90237	-15.16323-	5.19960
COARSE_SAND_0.5m	Equal variances assumed	.035	.854	-1.798-	25	.084	-3.76364-	2.09327	-8.07480-	.54753
	Equal variances not assumed			-1.781-	5.905	.126	-3.76364-	2.11366	-8.95578-	1.42851
COARSE_SAND_1.0m	Equal variances assumed	1.508	.232	-4.180-	22	.000	-5.75000-	1.37552	-8.60265-	-2.89735-
	Equal variances not assumed			-7.505-	14.214	.000	-5.75000-	.76620	-7.39102-	-4.10898-
COARSE_SAND_1.5m	Equal variances assumed	1.168	.290	-1.875-	25	.073	-4.77273-	2.54532	-10.01491-	.46946
	Equal variances not assumed			-2.574-	9.948	.028	-4.77273-	1.85401	-8.90663-	-.63883-
COARSE_SAND_2.0m	Equal variances assumed	2.704	.114	.112	23	.912	.16667	1.49042	-2.91651-	3.24984
	Equal variances not assumed			.238	22.684	.814	.16667	.69977	-1.28204-	1.61537

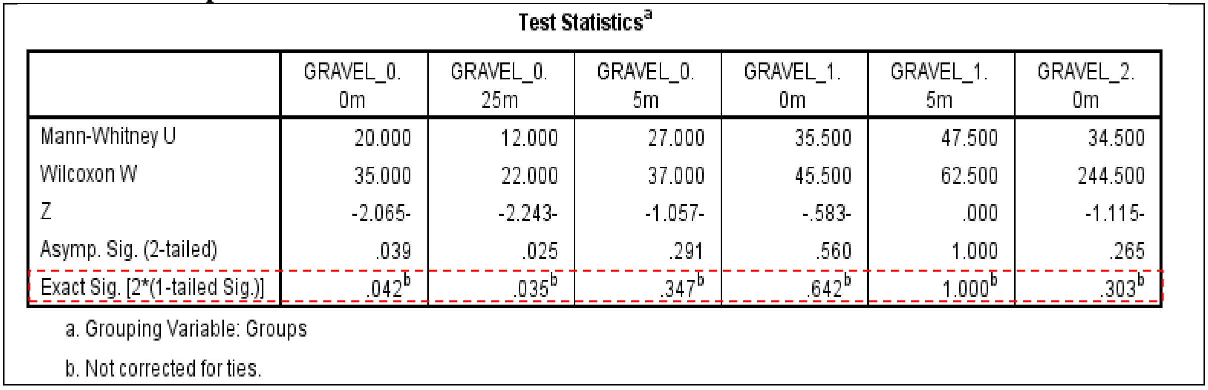
Table B.5.15. Continuous.



Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
EXACT SOIL_0.0m	Equal variances assumed	8.679	.007	1.959	23	.062	4.45000	2.27211	-.25022-	9.15022
	Equal variances not assumed			3.709	22.806	.001	4.45000	1.19973	1.96701	6.93299
EXACT SOIL_0.25m	Equal variances assumed	2.578	.123	1.723	21	.100	1.81579	1.05412	-.37637-	4.00795
	Equal variances not assumed			3.283	18.467	.004	1.81579	.55305	.65598	2.97560
EXACT SOIL_0.5m	Equal variances assumed	.167	.687	.804	22	.430	.75000	.93237	-1.18362-	2.68362
	Equal variances not assumed			.889	4.760	.417	.75000	.84410	-1.45316-	2.95316
EXACT SOIL_1.0m	Equal variances assumed	3.210	.086	.843	23	.408	.70238	.83361	-1.02207-	2.42684
	Equal variances not assumed			1.617	16.959	.124	.70238	.43425	-.21398-	1.61875
EXACT SOIL_1.5m	Equal variances assumed	4.125	.055	-.894-	22	.381	-1.13684-	1.27193	-3.77467-	1.50098
	Equal variances not assumed			-.572-	4.417	.595	-1.13684-	1.98798	-6.45701-	4.18332
EXACT SOIL_2.0m	Equal variances assumed	.933	.344	-.316-	23	.755	-.25000-	.79229	-1.88897-	1.38897
	Equal variances not assumed			-.454-	12.311	.658	-.25000-	.55096	-1.44707-	.94707

Table 5.16. Indicates the significant differences of soil classification constitutes (i.e. gravel) at six different depths between contaminated and non-contaminated sites.



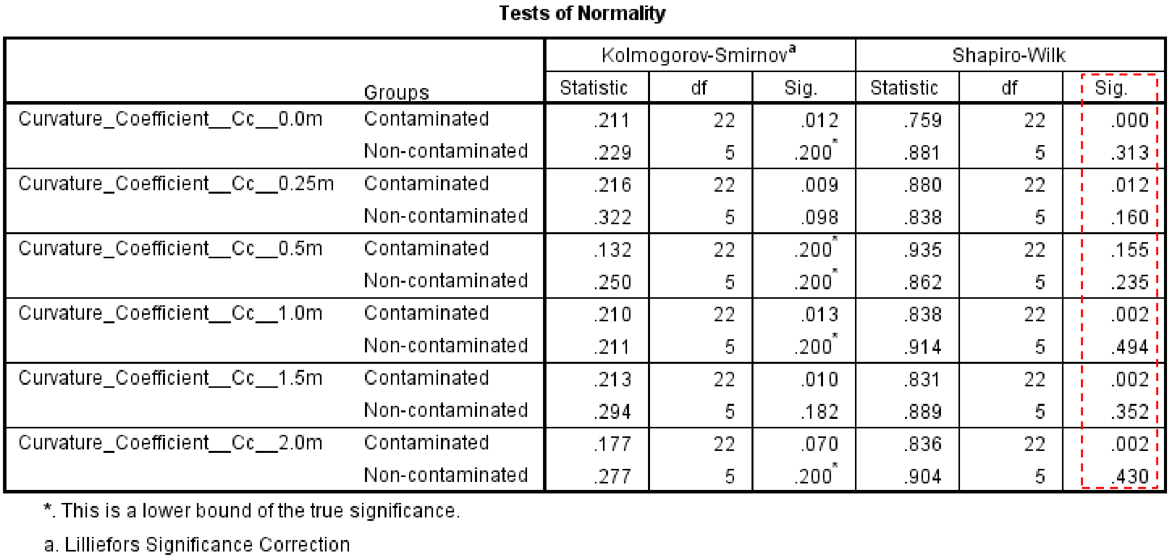
Test Statistics[a]

	GRAVEL_0.0m	GRAVEL_0.25m	GRAVEL_0.5m	GRAVEL_1.0m	GRAVEL_1.5m	GRAVEL_2.0m
Mann-Whitney U	20.000	12.000	27.000	35.500	47.500	34.500
Wilcoxon W	35.000	22.000	37.000	45.500	62.500	244.500
Z	-2.065-	-2.243-	-1.057-	-.583-	.000	-1.115-
Asymp. Sig. (2-tailed)	.039	.025	.291	.560	1.000	.265
Exact Sig. [2*(1-tailed Sig.)]	.042[b]	.035[b]	.347[b]	.642[b]	1.000[b]	.303[b]

a. Grouping Variable: Groups

b. Not corrected for ties.

Table B.5.17. The significant p-values via normality Shapiro-Wilk test indicate that the curvature coefficient (Cc) data of the soil classification at contaminated and non-contaminated sites follows normal distribution.



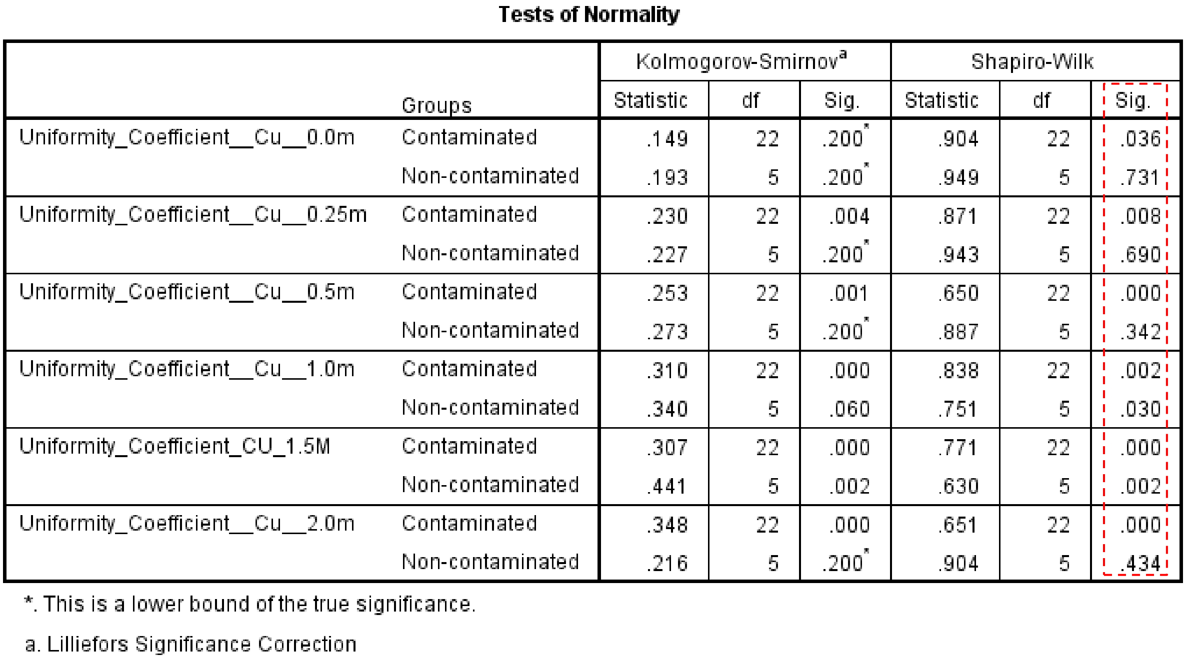
Tests of Normality

	Groups	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Curvature_Coefficient__Cc__0.0m	Contaminated	.211	22	.012	.759	22	.000
	Non-contaminated	.229	5	.200*	.881	5	.313
Curvature_Coefficient__Cc__0.25m	Contaminated	.216	22	.009	.880	22	.012
	Non-contaminated	.322	5	.098	.838	5	.160
Curvature_Coefficient__Cc__0.5m	Contaminated	.132	22	.200*	.935	22	.155
	Non-contaminated	.250	5	.200*	.862	5	.235
Curvature_Coefficient__Cc__1.0m	Contaminated	.210	22	.013	.838	22	.002
	Non-contaminated	.211	5	.200*	.914	5	.494
Curvature_Coefficient__Cc__1.5m	Contaminated	.213	22	.010	.831	22	.002
	Non-contaminated	.294	5	.182	.889	5	.352
Curvature_Coefficient__Cc__2.0m	Contaminated	.177	22	.070	.836	22	.002
	Non-contaminated	.277	5	.200*	.904	5	.430

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Table B.5.18. The significant p-values via normality Shapiro-Wilk test indicate that the uniformity coefficient (Cu) data of the soil classification at contaminated and non-contaminated sites follows non-normal distribution.



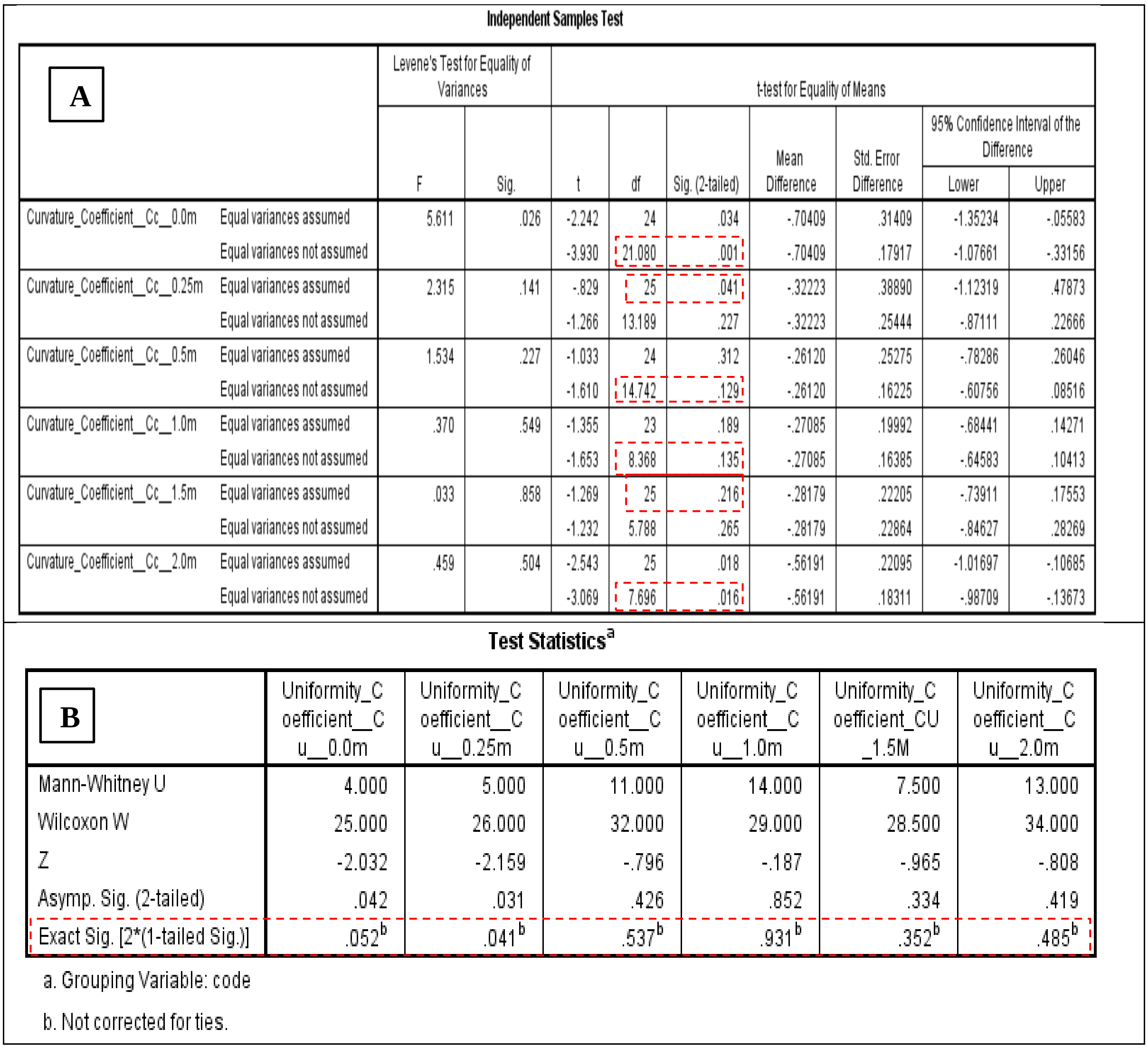
Tests of Normality

	Groups	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Uniformity_Coefficient__Cu__0.0m	Contaminated	.149	22	.200*	.904	22	.036
	Non-contaminated	.193	5	.200*	.949	5	.731
Uniformity_Coefficient__Cu__0.25m	Contaminated	.230	22	.004	.871	22	.008
	Non-contaminated	.227	5	.200*	.943	5	.690
Uniformity_Coefficient__Cu__0.5m	Contaminated	.253	22	.001	.650	22	.000
	Non-contaminated	.273	5	.200*	.887	5	.342
Uniformity_Coefficient__Cu__1.0m	Contaminated	.310	22	.000	.838	22	.002
	Non-contaminated	.340	5	.060	.751	5	.030
Uniformity_Coefficient_CU_1.5M	Contaminated	.307	22	.000	.771	22	.000
	Non-contaminated	.441	5	.002	.630	5	.002
Uniformity_Coefficient__Cu__2.0m	Contaminated	.348	22	.000	.651	22	.000
	Non-contaminated	.216	5	.200*	.904	5	.434

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Table B.5.19. Indicates the significant differences of curvature coefficient (Cc) (A) and uniformity coefficient (Cu) (B) variables of the soil at six different depths between contaminated and non-contaminated sites.



Independent Samples Test

A

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Curvature_Coefficient__Cc__0.0m	Equal variances assumed	5.611	.026	-2.242	24	.034	-.70409	.31409	-1.35234	-.05583
	Equal variances not assumed			-3.930	21.080	.001	-.70409	.17917	-1.07661	-.33156
Curvature_Coefficient__Cc__0.25m	Equal variances assumed	2.315	.141	-.829	25	.041	-.32223	.38890	-1.12319	.47873
	Equal variances not assumed			-1.266	13.189	.227	-.32223	.25444	-.87111	.22666
Curvature_Coefficient__Cc__0.5m	Equal variances assumed	1.534	.227	-1.033	24	.312	-.26120	.25275	-.78286	.26046
	Equal variances not assumed			-1.610	14.742	.129	-.26120	.16225	-.60756	.08516
Curvature_Coefficient__Cc__1.0m	Equal variances assumed	.370	.549	-1.355	23	.189	-.27085	.19992	-.68441	.14271
	Equal variances not assumed			-1.653	8.368	.135	-.27085	.16385	-.64583	.10413
Curvature_Coefficient__Cc__1.5m	Equal variances assumed	.033	.858	-1.269	25	.216	-.28179	.22205	-.73911	.17553
	Equal variances not assumed			-1.232	5.788	.265	-.28179	.22864	-.84627	.28269
Curvature_Coefficient__Cc__2.0m	Equal variances assumed	.459	.504	-2.543	25	.018	-.56191	.22095	-1.01697	-.10685
	Equal variances not assumed			-3.069	7.696	.016	-.56191	.18311	-.98709	-.13673

Test Statistics[a]

B	Uniformity_Coefficient__Cu__0.0m	Uniformity_Coefficient__Cu__0.25m	Uniformity_Coefficient__Cu__0.5m	Uniformity_Coefficient__Cu__1.0m	Uniformity_Coefficient_CU_1.5M	Uniformity_Coefficient__Cu__2.0m
Mann-Whitney U	4.000	5.000	11.000	14.000	7.500	13.000
Wilcoxon W	25.000	26.000	32.000	29.000	28.500	34.000
Z	-2.032	-2.159	-.796	-.187	-.965	-.808
Asymp. Sig. (2-tailed)	.042	.031	.426	.852	.334	.419
Exact Sig. [2*(1-tailed Sig.)]	.052[b]	.041[b]	.537[b]	.931[b]	.352[b]	.485[b]

a. Grouping Variable: code

b. Not corrected for ties.

Permeability (Hydraulic Conductivity)

Table B.5.20. Coefficient of Permeability results for contaminated samples at six different depths of 0.0 m, 0.25 m, 0.5 m, 1.0 m, 1.5 m and 2.0 m.

Trial Pits Coordinates (T.P.Cs)	Permeability coefficient Results (m/sec)	Soil Classification
At Depth (0.0 m)		
(50 m, 0 m)	2.06x10^{-5}	Sand (SP)
(100 m, 0 m)	1.53x10^{-5}	Silty Sand (S-M)
(50 m, 50 m)	2.33x10^{-5}	Silty Sand (S-M)
(100 m, 50 m)	4.79x10^{-5}	Silty sand (S-M)
Min. value	1.53x10^{-5}	-
Max. value	4.79x10^{-5}	-
Mean Value	2.67x10^{-5}	-
standard deviation value	1.44 X10^{-5}	-
At Depth (0.25 m)		
(50 m, 0 m)	*Nil	Silty Sand (S-M)
(100 m, 0 m)	*Nil	Silty Sand (S-M)
(50 m, 50 m)	1.78x 10^{-5}	Silty Sand (S-M)
(100 m, 50 m)	6.59x 10^{-6}	Silty Sand (S-M)
Min. value	6.59x 10^{-6}	-
Max. value	1.78x 10^{-5}	-
Mean Value	6.1x 10^{-6}	-
standard deviation value	7.92x10^{-6}	-
At Depth (0.5 m)		
(50 m, 0 m)	*Nil	Sand (SP)
(100 m, 0 m)	1.07x10^{-5}	Silty Sand (S-M)
(50 m, 50 m)	*Nil	Silty Sand (S-M)
(100 m, 50 m)	8.56x10^{-6}	Sand with silt (S-M)
Min. value	8.56x10^{-6}	-
Max. value	1.07x10^{-5}	-
Mean Value	4.81 x 10^{-6}	-
standard deviation value	1.51x 10^{-6}	-
At Depth (1.0 m)		
(50 m, 0 m)	3.25x10^{-5}	Silty Sand (S-M)
(100 m, 0 m)	4.64x10^{-5}	Silty Sand (S-M)
(50 m, 50 m)	2.19x10^{-5}	Silty Sand (S-M)
(100 m, 50 m)	2.66x10^{-5}	Silty Sand (S-M)
Min. value	2.19x10^{-5}	-
Max. value	4.64x10^{-5}	-
Mean Value	3.18x10^{-5}	-
standard deviation value	1.06x10^{-5}	-

Table B.5.20. Continues.

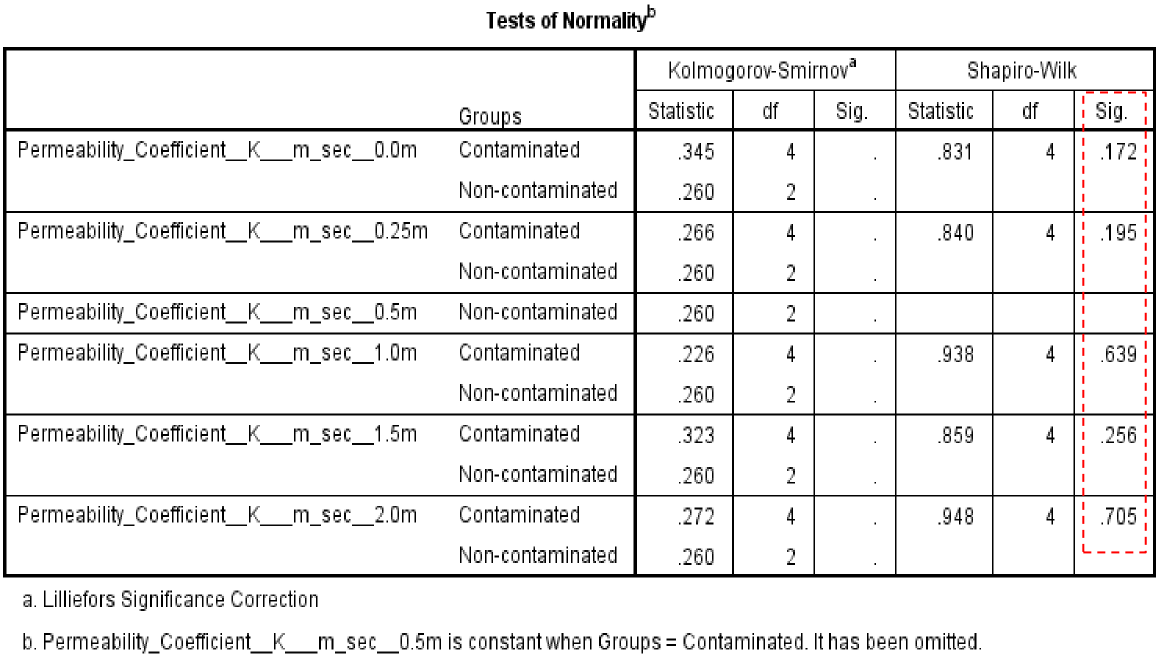
Trial Pits Coordinates (T.P.Cs)	Permeability coefficient Results (m/sec)	Soil Classification
At Depth (1.5 m)		
(50 m, 0 m)	$4.93x10^{-5}$	Sand (SP)
(100 m, 0 m)	$4.02x10^{-5}$	Silty Sand (S-M)
(50 m, 50 m)	$4.37x10^{-5}$	Silty Sand (S-M)
(100 m, 50 m)	$1.72x10^{-5}$	Silty Sand (S-M)
Min. value	$1.72x10^{-5}$	-
Max. value	$4.93x10^{-5}$	-
Mean Value	$3.76x10^{-5}$	-
standard deviation value	$1.41x10^{-5}$	-
At Depth (2.0 m)		
(50 m, 0 m)	$3.83x10^{-5}$	Silty Sand (S-M)
(100 m, 0 m)	$5.81x10^{-5}$	Silty Sand (S-M)
(50 m, 50 m)	$4.01x10^{-5}$	Silty sand (S-M)
(100 m, 50 m)	$2.67x10^{-5}$	Silty Sand (S-M)
Min. value	$2.67x10^{-5}$	-
Max. value	$5.81x10^{-5}$	-
Mean Value	$4.08x10^{-5}$	-
standard deviation value	$1.29x10^{-5}$	-

Note: *Nil: it means the cylinder samples were destroyed in the lab.

Table B.5.21. Coefficient of permeability results for non-contaminated samples at six different depths of 0.0 m, 0.25 m, 0.5 m and 1.0 m, 1.5 m and 2.0 m.

Trial Pits Coordinates (T.P.Cs)	**Permeability Coefficient Results (m/sec)**	**Soil Classification**
At Depth (0.0 m)		
(0 m, 0 m)	$3.05x10^{-5}$	silty SAND (S-M).
(50 m, 50 m)	$1.14x10^{-5}$	silty SAND (S-M).
Min. value	$1.14x10^{-5}$	-
Max. value	$3.05x10^{-5}$	-
Mean Value	$2.09x10^{-5}$	-
standard deviation value	$1.35x10^{-5}$	-
At Depth (0.25 m)		
(0 m, 0 m)	$7.69x10^{-5}$	silty SAND (S-M).
(50 m, 50 m)	$1.34x10^{-4}$	silty SAND (S-M).
Min. value	$7.69x10^{-5}$	-
Max. value	$1.34x10^{-4}$	-
Mean Value	$1.05x10^{-4}$	-
standard deviation value	$4.03x10^{-5}$	-
At Depth (0.5 m)		
(0 m, 0 m)	$9.58x10^{-5}$	silty sand (S-M)
(50 m, 50 m)	$7.63x10^{-6}$	silty SAND (S-M).
Min. value	$7.63x10^{-6}$	-
Max. value	$9.58x10^{-5}$	-
Mean Value	$5.17x10^{-5}$	-
standard deviation value	$6.23x10^{-5}$	-
At Depth (1.0 m)		
(0 m, 0 m)	$4.82x10^{-5}$	Very silty SAND (SM).
(50 m, 50 m)	$1.03x10^{-6}$	silty SAND (S-M).
Min. value	$1.03x10^{-6}$	-
Max. value	$4.82x10^{-5}$	-
Mean Value	$2.46x10^{-5}$	-
standard deviation value	$3.33x10^{-5}$	-
At Depth (1.5 m)		
(0 m, 0 m)	$3.49x10^{-5}$	Silty Sand (S-M)
(50 m, 50 m)	$1.63x10^{-5}$	Silty Sand (S-M)
Min. value	$1.63x10^{-5}$	-
Max. value	$3.49x10^{-5}$	-
Mean Value	$2.56x10^{-5}$	-
standard deviation value	$1.31x10^{-5}$	-
At Depth (2.0 m)		
(0 m, 0 m)	$3.12x10^{-6}$	Silty Sand (S-M)
(50 m, 50 m)	$2.23x10^{-5}$	Silty Sand (S-M)
Min. value	$3.12x10^{-6}$	-
Max. value	$2.23x10^{-5}$	-
Mean Value	$1.27x10^{-5}$	-
standard deviation value	$1.35x10^{-5}$	-

Table B.5.22. The significant p-values via normality Shapiro-Wilk test indicate that the permeability coefficient (m/s) values of the soil at contaminated and non-contaminated sites follow normal distribution.



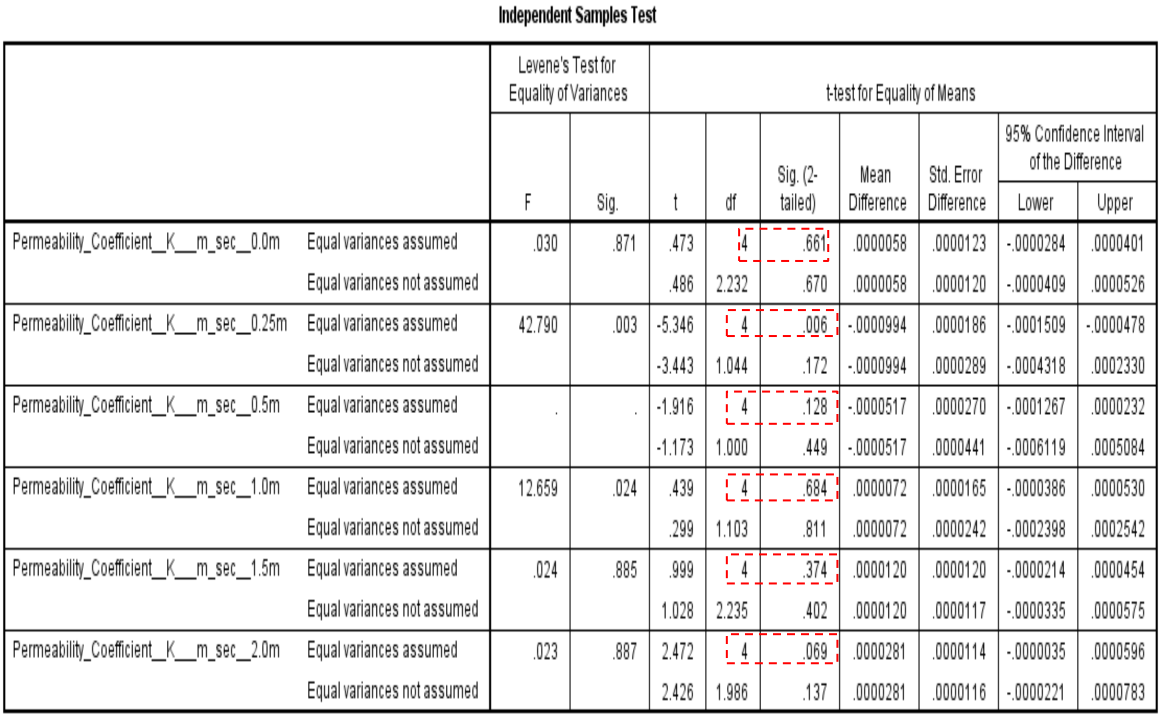
Tests of Normality[b]

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Groups	Statistic	df	Sig.	Statistic	df	Sig.
Permeability_Coefficient__K___m_sec__0.0m	Contaminated	.345	4	.	.831	4	.172
	Non-contaminated	.260	2	.			
Permeability_Coefficient__K___m_sec__0.25m	Contaminated	.266	4	.	.840	4	.195
	Non-contaminated	.260	2	.			
Permeability_Coefficient__K___m_sec__0.5m	Non-contaminated	.260	2	.			
Permeability_Coefficient__K___m_sec__1.0m	Contaminated	.226	4	.	.938	4	.639
	Non-contaminated	.260	2	.			
Permeability_Coefficient__K___m_sec__1.5m	Contaminated	.323	4	.	.859	4	.256
	Non-contaminated	.260	2	.			
Permeability_Coefficient__K___m_sec__2.0m	Contaminated	.272	4	.	.948	4	.705
	Non-contaminated	.260	2	.			

a. Lilliefors Significance Correction

b. Permeability_Coefficient__K___m_sec__0.5m is constant when Groups = Contaminated. It has been omitted.

Table B.5.23. Indicates the significant differences of the permeability coefficient (m/s) in the soil at six different depths between contaminated and non-contaminated sites.



Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Permeability_Coefficient__K___m_sec__0.0m	Equal variances assumed	.030	.871	.473	4	.661	.0000058	.0000123	-.0000284	.0000401
	Equal variances not assumed			.486	2.232	.670	.0000058	.0000120	-.0000409	.0000526
Permeability_Coefficient__K___m_sec__0.25m	Equal variances assumed	42.790	.003	-5.346	4	.006	-.0000994	.0000186	-.0001509	-.0000478
	Equal variances not assumed			-3.443	1.044	.172	-.0000994	.0000289	-.0004318	.0002330
Permeability_Coefficient__K___m_sec__0.5m	Equal variances assumed	.	.	-1.916	4	.128	-.0000517	.0000270	-.0001267	.0000232
	Equal variances not assumed			-1.173	1.000	.449	-.0000517	.0000441	-.0006119	.0005084
Permeability_Coefficient__K___m_sec__1.0m	Equal variances assumed	12.659	.024	.439	4	.684	.0000072	.0000165	-.0000386	.0000530
	Equal variances not assumed			.299	1.103	.811	.0000072	.0000242	-.0002398	.0002542
Permeability_Coefficient__K___m_sec__1.5m	Equal variances assumed	.024	.885	.999	4	.374	.0000120	.0000120	-.0000214	.0000454
	Equal variances not assumed			1.028	2.235	.402	.0000120	.0000117	-.0000335	.0000575
Permeability_Coefficient__K___m_sec__2.0m	Equal variances assumed	.023	.887	2.472	4	.069	.0000281	.0000114	-.0000035	.0000596
	Equal variances not assumed			2.426	1.986	.137	.0000281	.0000116	-.0000221	.0000783

Direct Shear test

Table B.5.24. Angle of internal friction (φ) results for contaminated soil samples at six different depths of 0.0 m, 0.25 m, 0.5 m, 1.0 m, 1.5 m and 2.0 m.

Trial Pits Coordinates (T.P.Cs)	Strength Parameters (φ) Angle of Internal Friction (φ)
At Depth (0.0 m)	
(0 m, 0 m)	33
(50 m, 0 m)	32
(0 m, 50 m)	35
(50 m, 50 m)	28
(100 m, 50 m)	29
(50 m, 100 m)	29
(100 m, 100 m)	30
Min. Value	28
Max. Value	35
Mean Value	30.8
Standard deviation value	2.5
At Depth (0.25 m)	
(0 m, 0 m)	34
(50 m, 0 m)	31
(0 m, 50 m)	32
(50 m, 50 m)	30
(100 m, 50 m)	34
(50 m, 100 m)	33
(100 m, 100 m)	33
Min. Value	30
Max. Value	34
Mean Value	32
Standard deviation value	1.5
At Depth (0.5 m)	
(0 m, 0 m)	34
(50 m, 0 m)	33
(0 m, 50 m)	31
(50 m, 50 m)	33
(100 m, 50 m)	33
(50 m, 100 m)	34
(100 m, 100 m)	32
Min. Value	31
Max. Value	34
Mean Value	32.8
Standard deviation value	1.06
At Depth (1.0 m)	
(0 m, 0 m)	34
(50 m, 0 m)	31
(0 m, 50 m)	34
(50 m, 50 m)	33
(100 m, 50 m)	33
(50 m, 100 m)	34
(100 m, 100 m)	32
Min. Value	31
Max. Value	34
Mean Value	33
Standard deviation value	1.15

Table B.5.24. Continued.

Trial Pits Coordinates (T.P.Cs)	Strength Parameters (φ)
	Angle of Internal Friction (φ)
At Depth (1.5 m)	
(0 m, 0 m)	32
(50 m, 0 m)	31
(0 m, 50 m)	34
(50 m, 50 m)	34
(100 m, 50 m)	32
(50 m, 100 m)	34
(100 m, 100 m)	34
Min. Value	31
Max. Value	34
Mean Value	33
Standard deviation value	1.29
At Depth (2.0 m)	
(0 m, 0 m)	33
(50 m, 0 m)	33
(0 m, 50 m)	32
(50 m, 50 m)	34
(100 m, 50 m)	34
(50 m, 100 m)	35
(100 m, 100 m)	34
Min. Value	32
Max. Value	35
Mean Value	33.6
Standard deviation value	0.97

Table B.5.25. Angle of internal friction (φ) results for the non-contaminated soil samples at six different depths of 0.0 m, 0.25 m, 0.5 m, 1.0 m, 1.5 m and 2.0 m.

Trial Pits Coordinates (T.P.Cs)	**Strength Parameters (φ)**
	Angle of Internal Friction (φ)
At Depth (0.0 m)	
(0 m, 0 m)	37
(50 m, 50 m)	37.5
(100 m, 100 m)	37
Min. Value	37
Max. Value	37.5
Mean Value	37.16
Standard deviation value	0.28
At Depth (0.25 m)	
(0 m, 0 m)	34
(50 m, 50 m)	37.5
(100 m, 100 m)	36.5
Min. Value	34
Max. Value	37.5
Mean Value	36
Standard deviation value	1.80
At Depth (0.5 m)	
(0 m, 0 m)	38.4
(50 m, 50 m)	39.3
(100 m, 100 m)	40.2
Min. Value	39.3
Max. Value	40.2
Mean Value	39.3
Standard deviation value	0.9
At Depth (1.0 m)	
(0 m, 0 m)	37
(50 m, 50 m)	40.7
(100 m, 100 m)	36
Min. Value	36
Max. Value	40.7
Mean Value	37.9
Standard deviation value	2.47
At Depth (1.5 m)	
(0 m, 0 m)	37.9
(50 m, 50 m)	38
(100 m, 100 m)	35.5
Min. Value	35.5
Max. Value	38
Mean Value	37.13
Standard deviation value	1.41
At Depth (2.0 m)	
(0 m, 0 m)	38.4
(50 m, 50 m)	37.5
(100 m, 100 m)	34
Min. Value	34
Max. Value	38.4
Mean Value	36.63
Standard deviation value	2.32

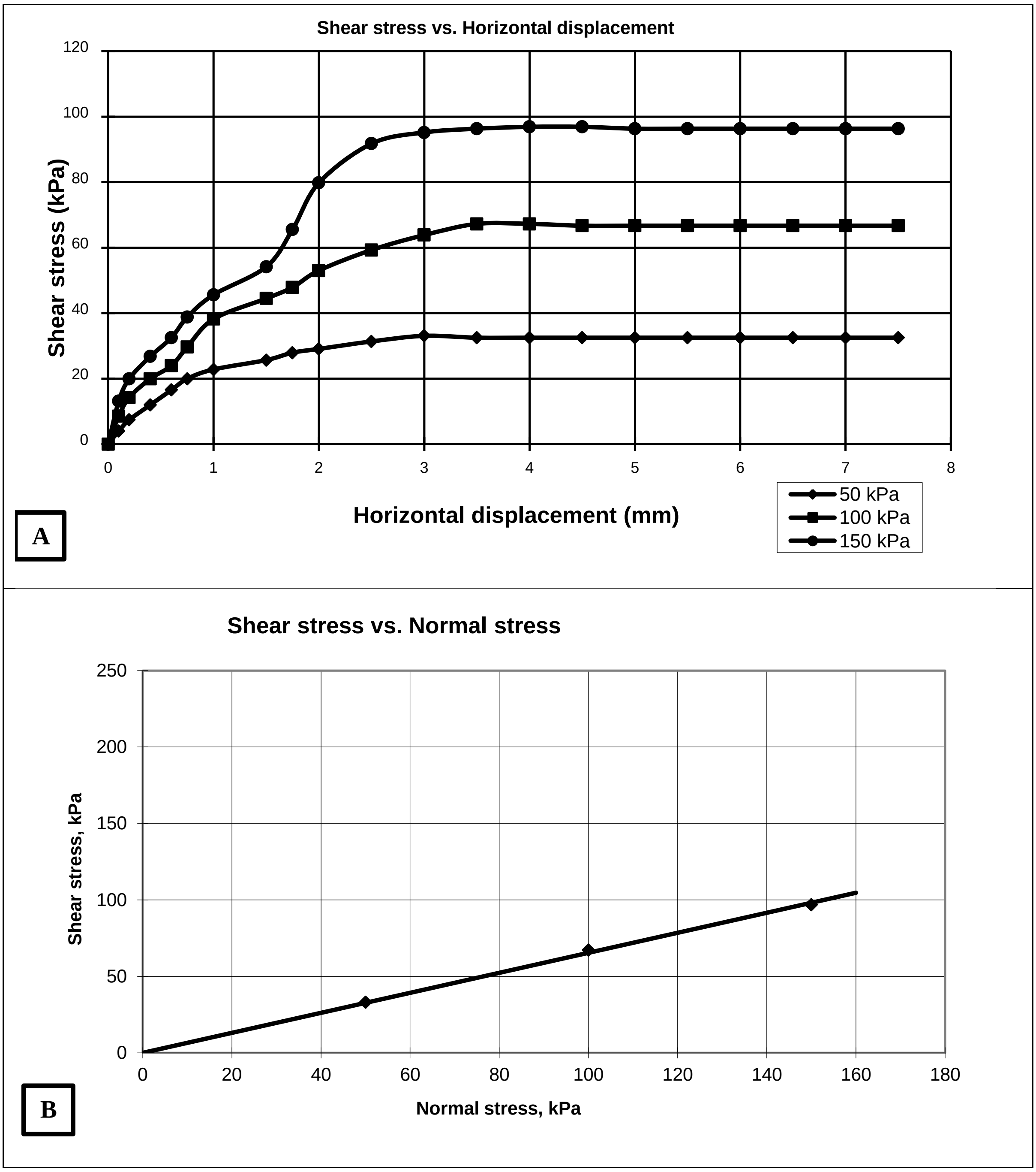


Figure B.5.3. Shows the relationship between the horizontal displacement (mm) & Shear stress (kPa) (A) and relationship between the Normal stress (kPa) & Shear stress (kPa) by Direct shear test for contaminated sample T.P.C (0 m, 0 m) at depth (0.0 m) (B).

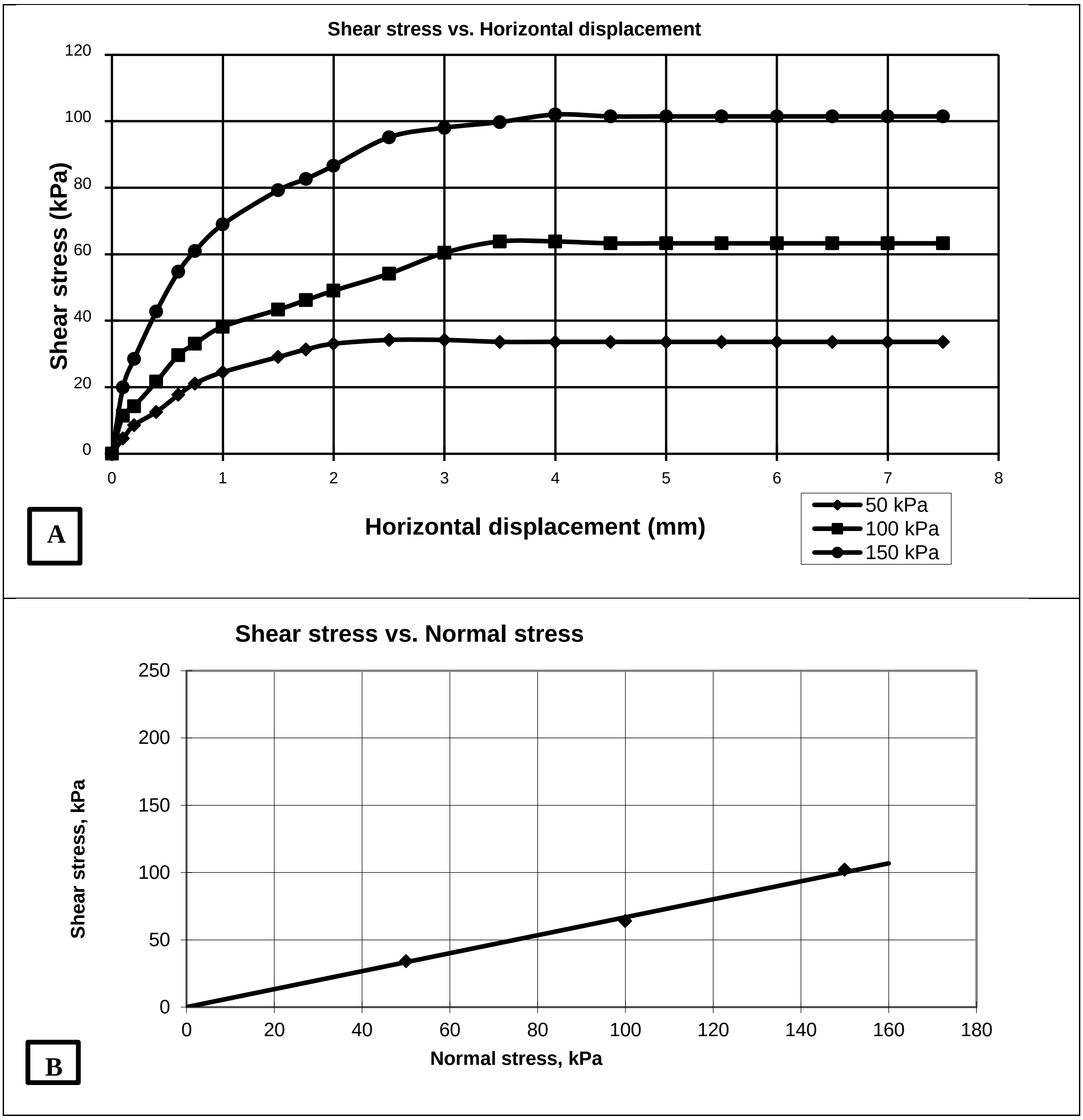


Figure B.5.4. Shows the relationship between the horizontal displacement (mm) & Shear stress (kPa) (A) and relationship between the Normal stress (kPa) & Shear stress (kPa) by Direct Shear test for contaminated sample T.P.Cs (0 m, 0 m) at depth (0.25 m) (B).

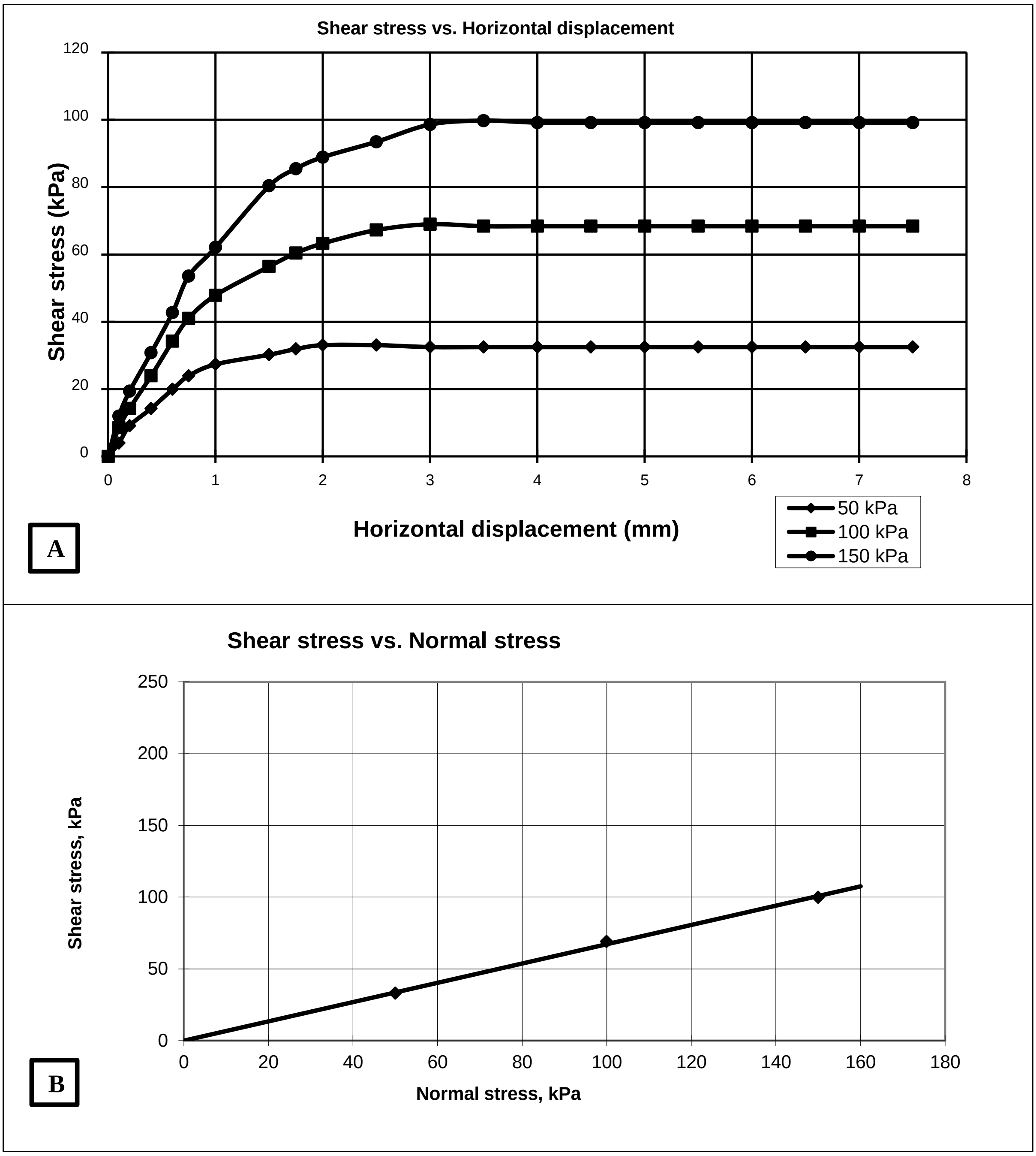


Figure B.5.5. Shows the relationship between the horizontal displacement (mm) & Shear stress (kPa) (A) and relationship between the Normal stress (kPa) & Shear stress (kPa) by Direct Shear test for contaminated sample T.P.Cs (0 m, 0 m) at depth (0.5 m) (B).

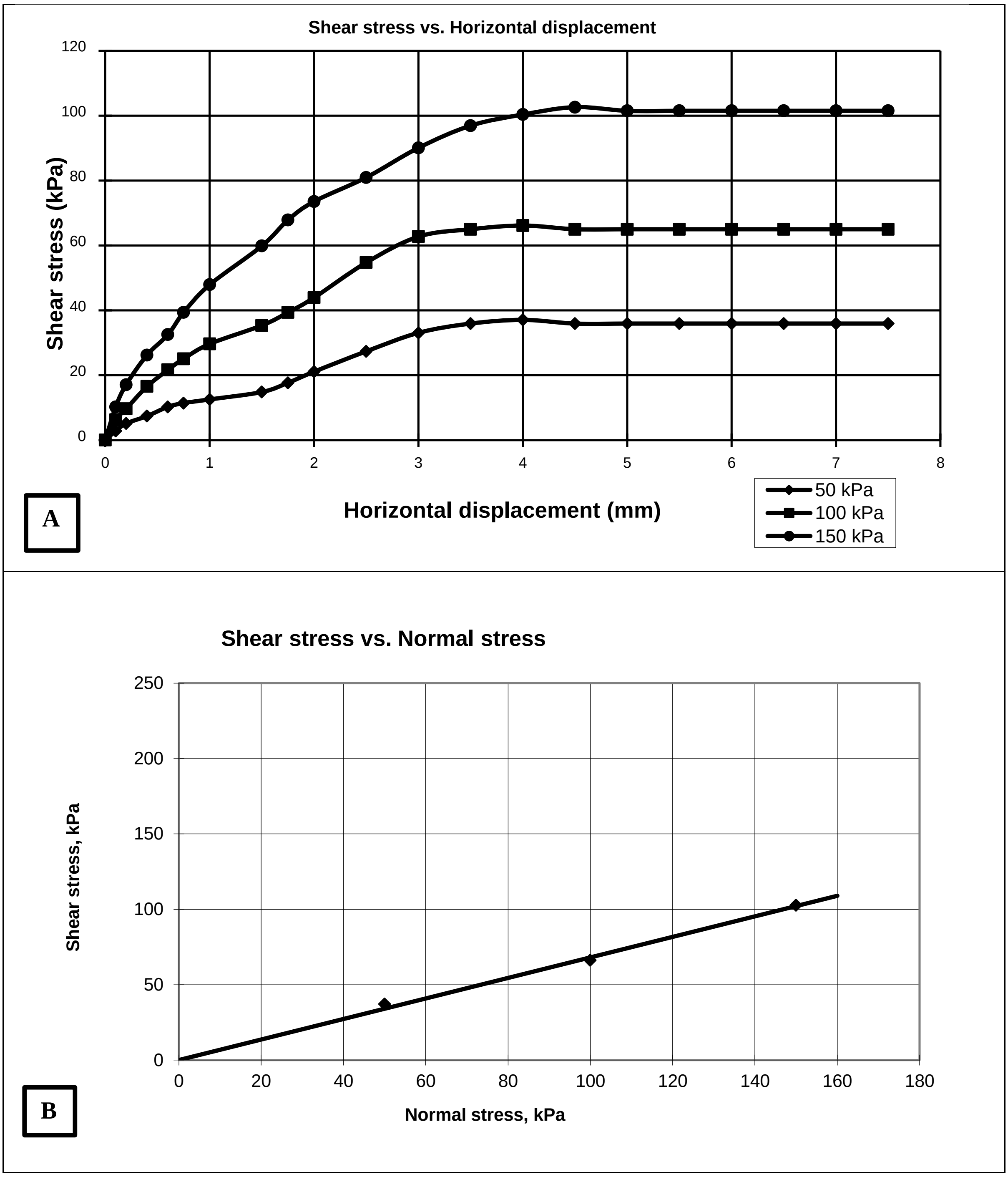


Figure B.5.6. Shows the relationship between the horizontal displacement (mm) & Shear stress (kPa) (A) and relationship between the Normal stress (kPa) & Shear stress (kPa) by Direct Shear test for contaminated sample T.P.Cs (0 m, 0 m) at depth (1.0 m) (B).

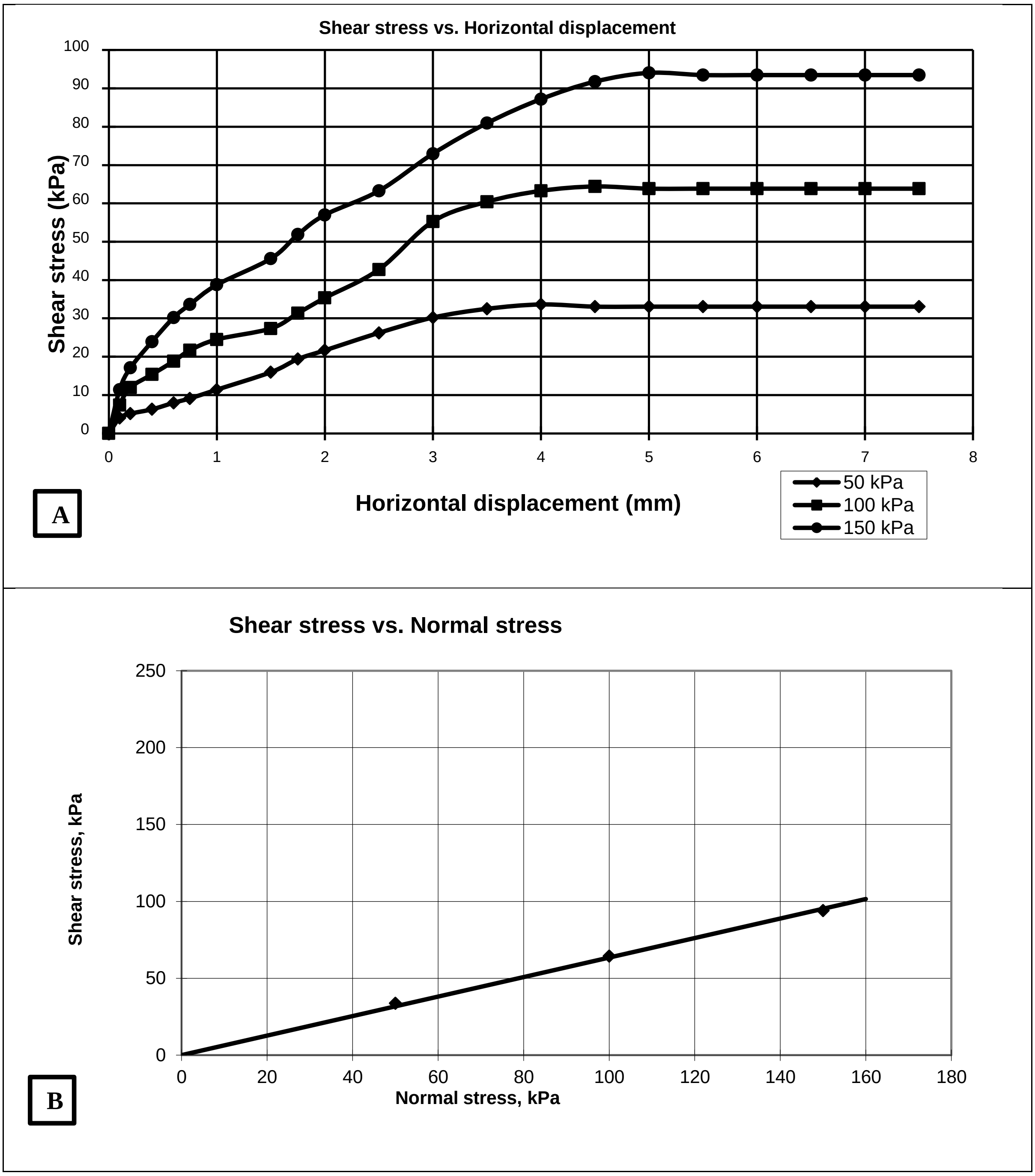


Figure B.5.7. Shows the relationship between the horizontal displacement (mm) & Shear stress (kPa) (A) and relationship between the Normal stress (kPa) & Shear stress (kPa) by Direct Shear test for contaminated sample T.P.Cs (0 m, 0 m) at depth (1.5 m) (B).

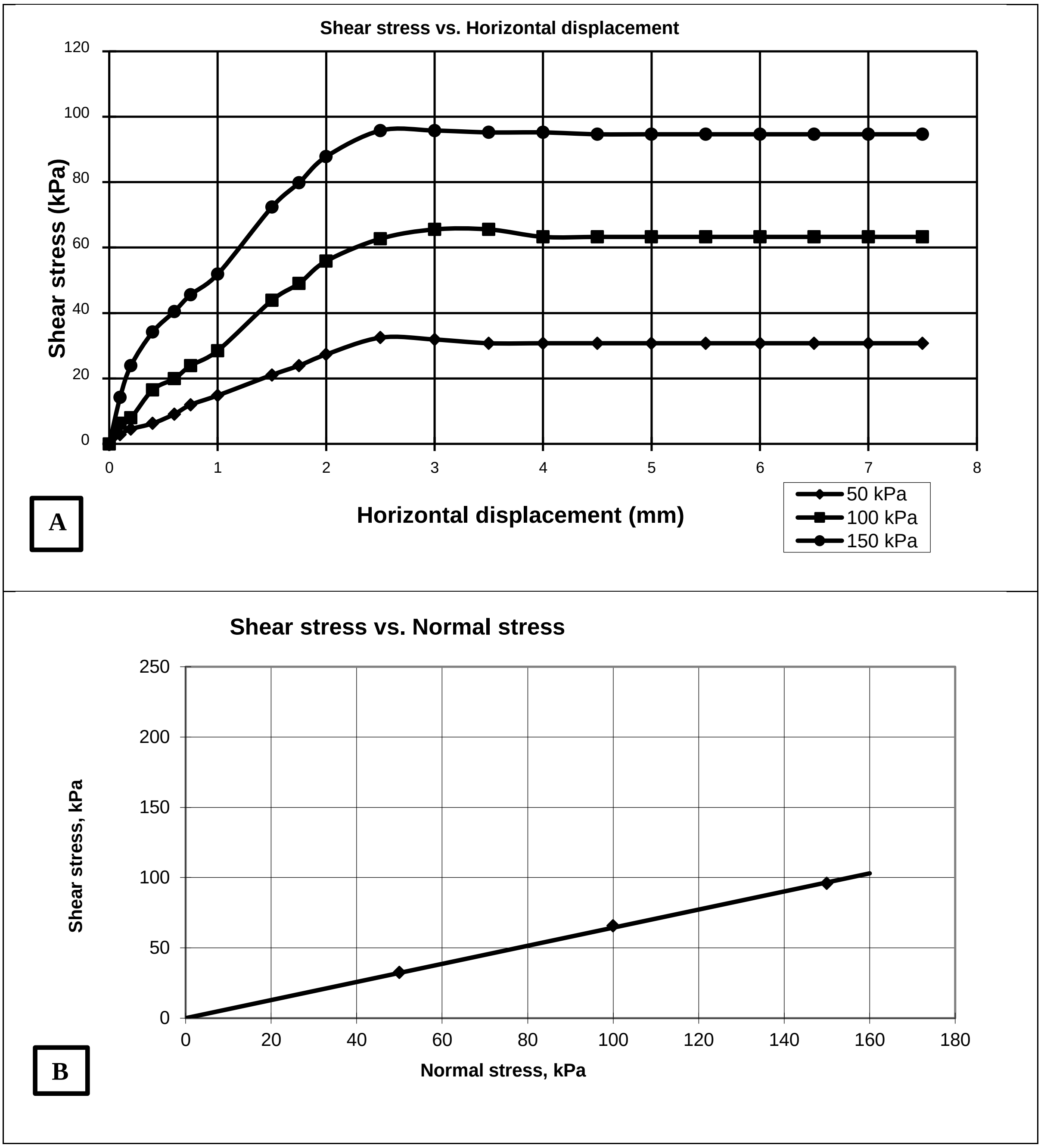


Figure B.5.8. Shows the relationship between the horizontal displacement (mm) & Shear stress (kPa) (A) and relationship between the Normal stress (kPa) & Shear stress (kPa) by Direct Shear test for contaminated sample T.P.Cs (0 m, 0 m) at depth (2.0 m) (B).

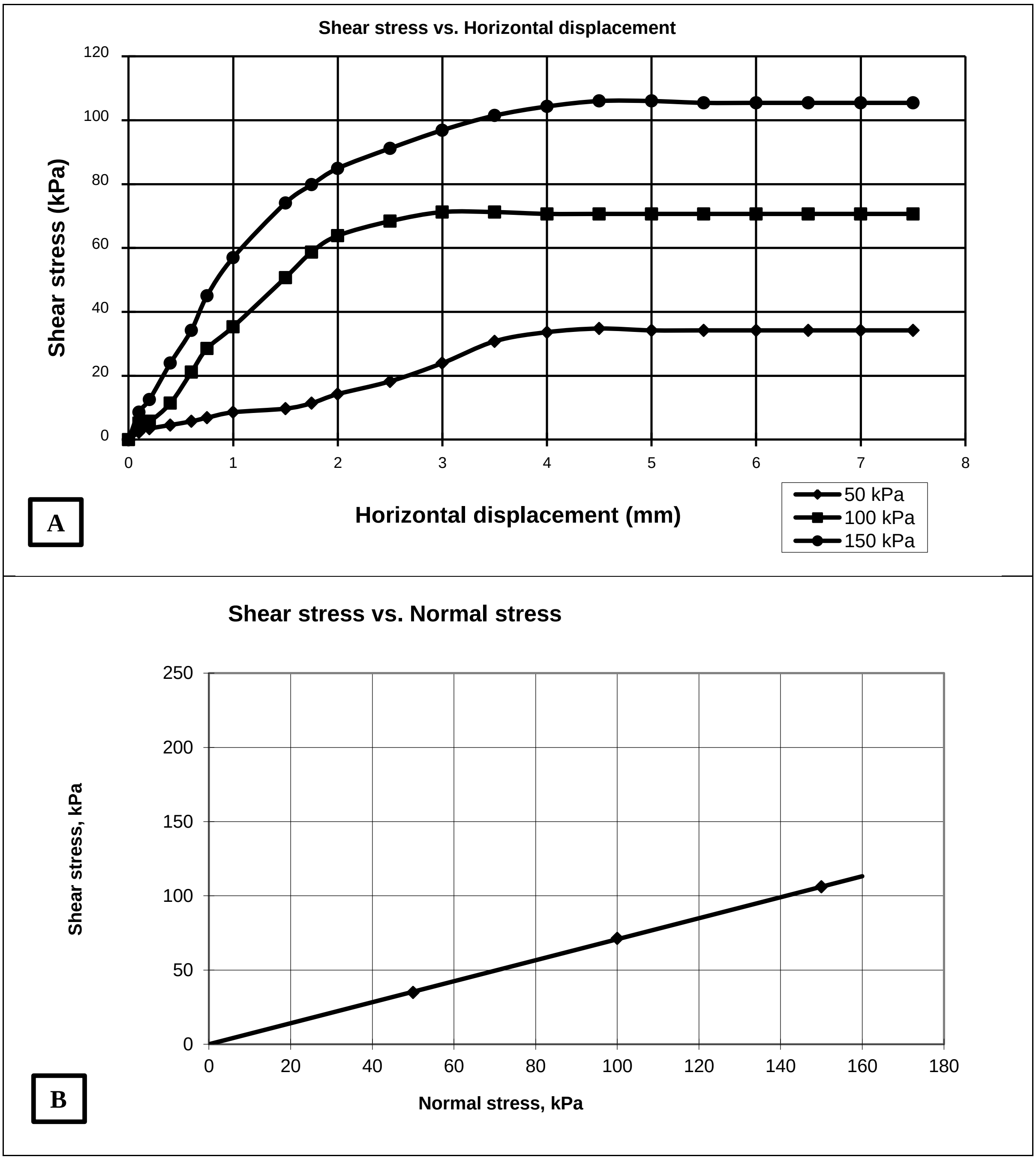


Figure B.5.9. Shows the relationship between the horizontal displacement (mm) & Shear stress (kPa) (A) and relationship between the Normal stress (kPa) & Shear stress (kPa) by Direct Shear test for contaminated sample T.P.Cs (0 m, 50 m) at depth (0.0 m) (B).

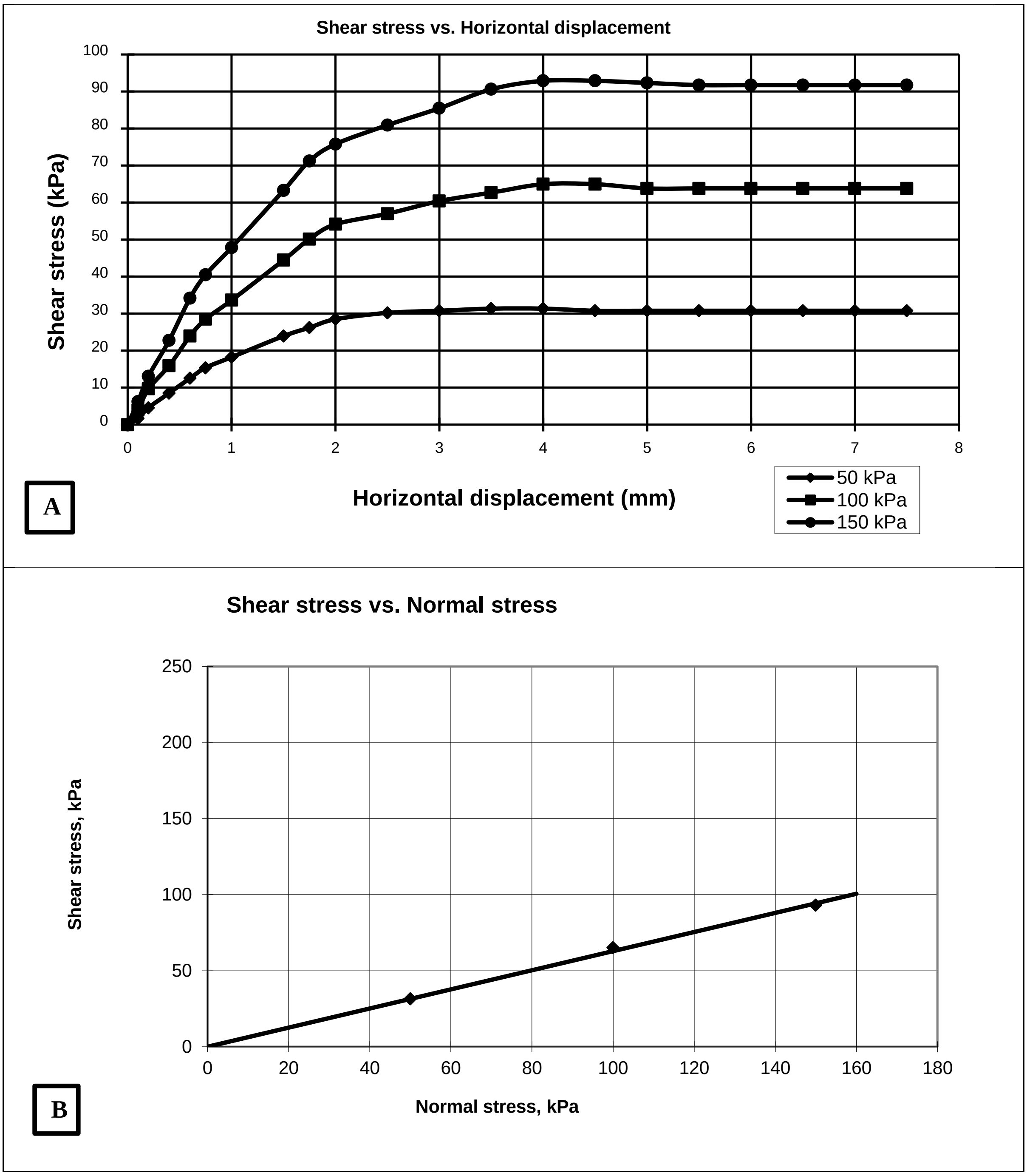


Figure B.5.10. Shows the relationship between the horizontal displacement (mm) & Shear stress (kPa) (A) and relationship between the Normal stress (kPa) & Shear stress (kPa) by Direct Shear test for contaminated sample T.P.Cs (0 m, 50 m) at depth (0.25 m) (B).

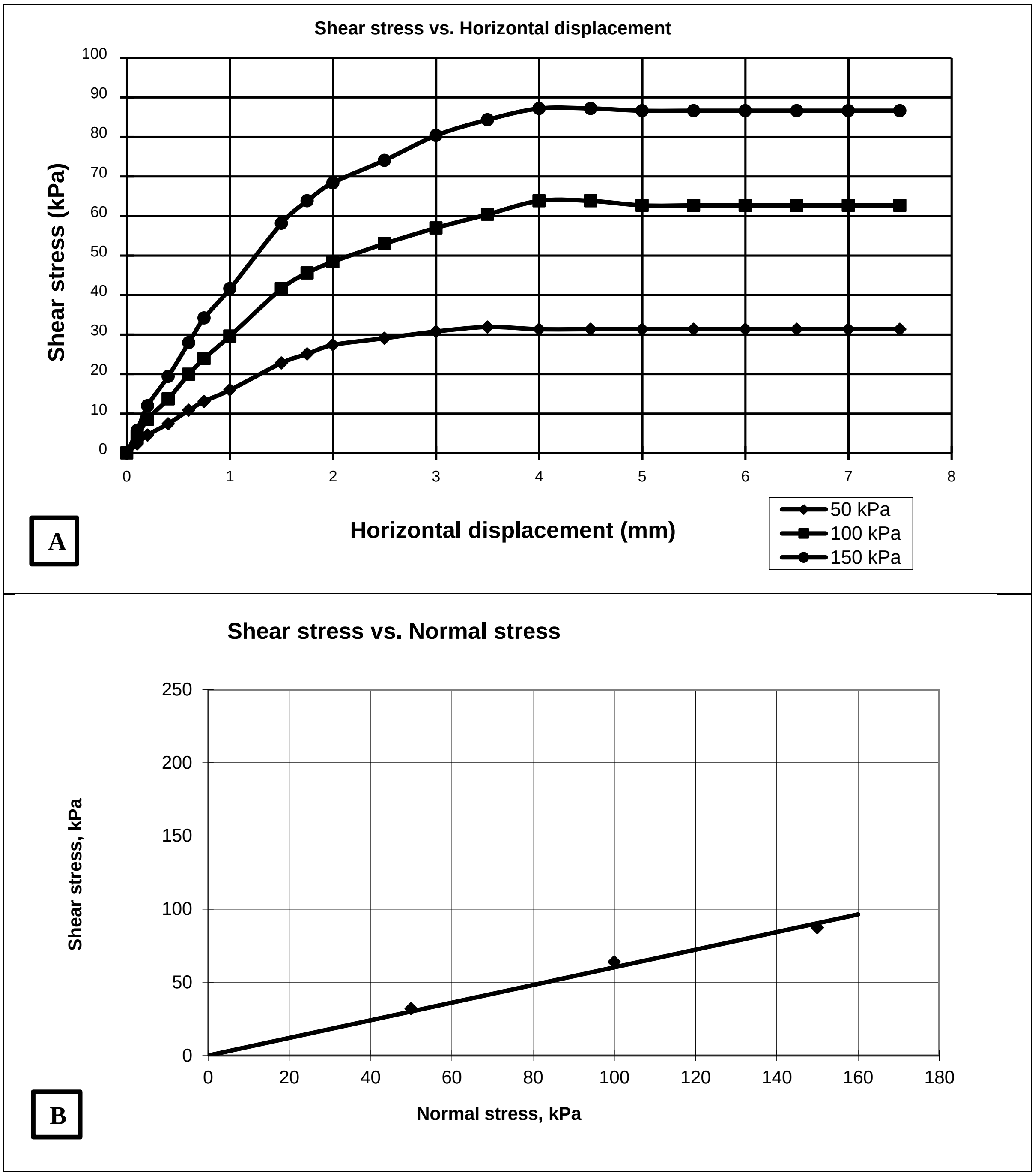


Figure B.5.11. Shows the relationship between the horizontal displacement (mm) & Shear stress (kPa) (A) and relationship between the Normal stress (kPa) & Shear stress (kPa) by Direct Shear test for contaminated sample T.P.Cs (0 m, 50 m) at depth (0.5 m) (B).

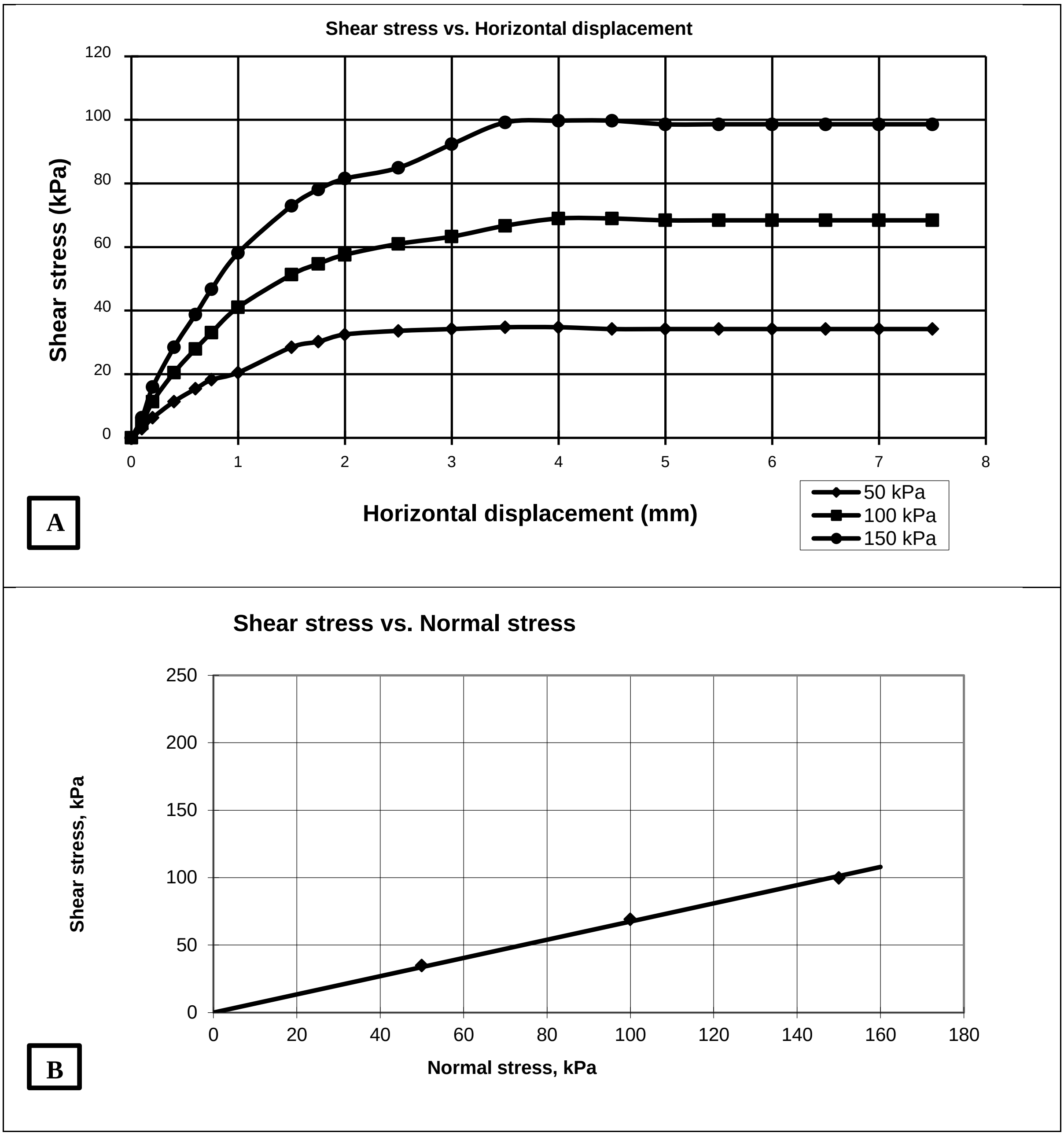


Figure B.5.12. Shows the relationship between the horizontal displacement (mm) & Shear stress (kPa) (A) and relationship between the Normal stress (kPa) & Shear stress (kPa) by Direct Shear test for contaminated sample T.P.Cs (0 m, 50 m) at depth (1.0 m) (B).

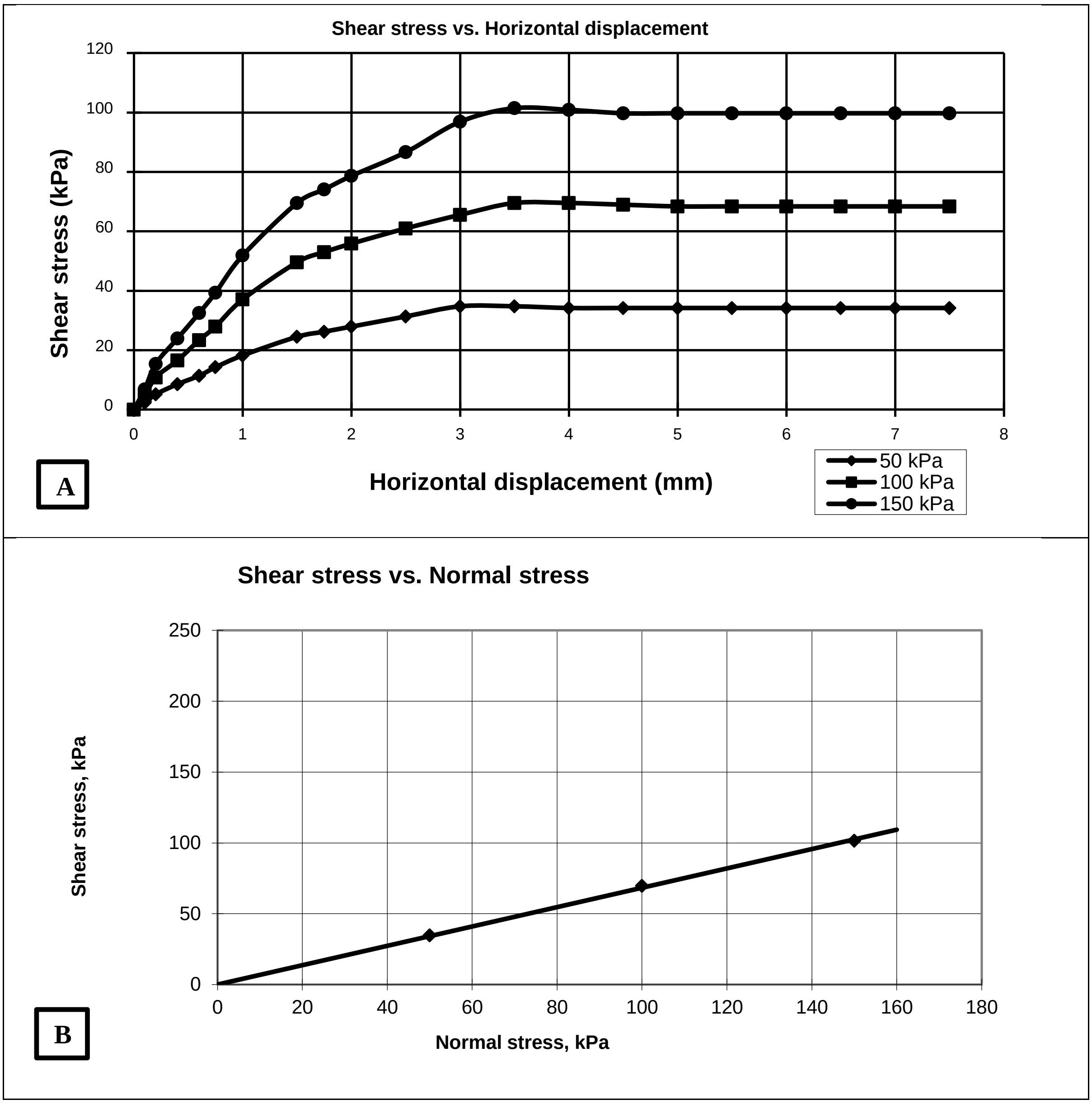


Figure B.5.13. Shows the relationship between the horizontal displacement (mm) & Shear stress (kPa) (A) and relationship between the Normal stress (kPa) & Shear stress (kPa) by Direct Shear test for contaminated sample T.P.Cs (0 m, 50 m) at depth (1.5 m) (B).

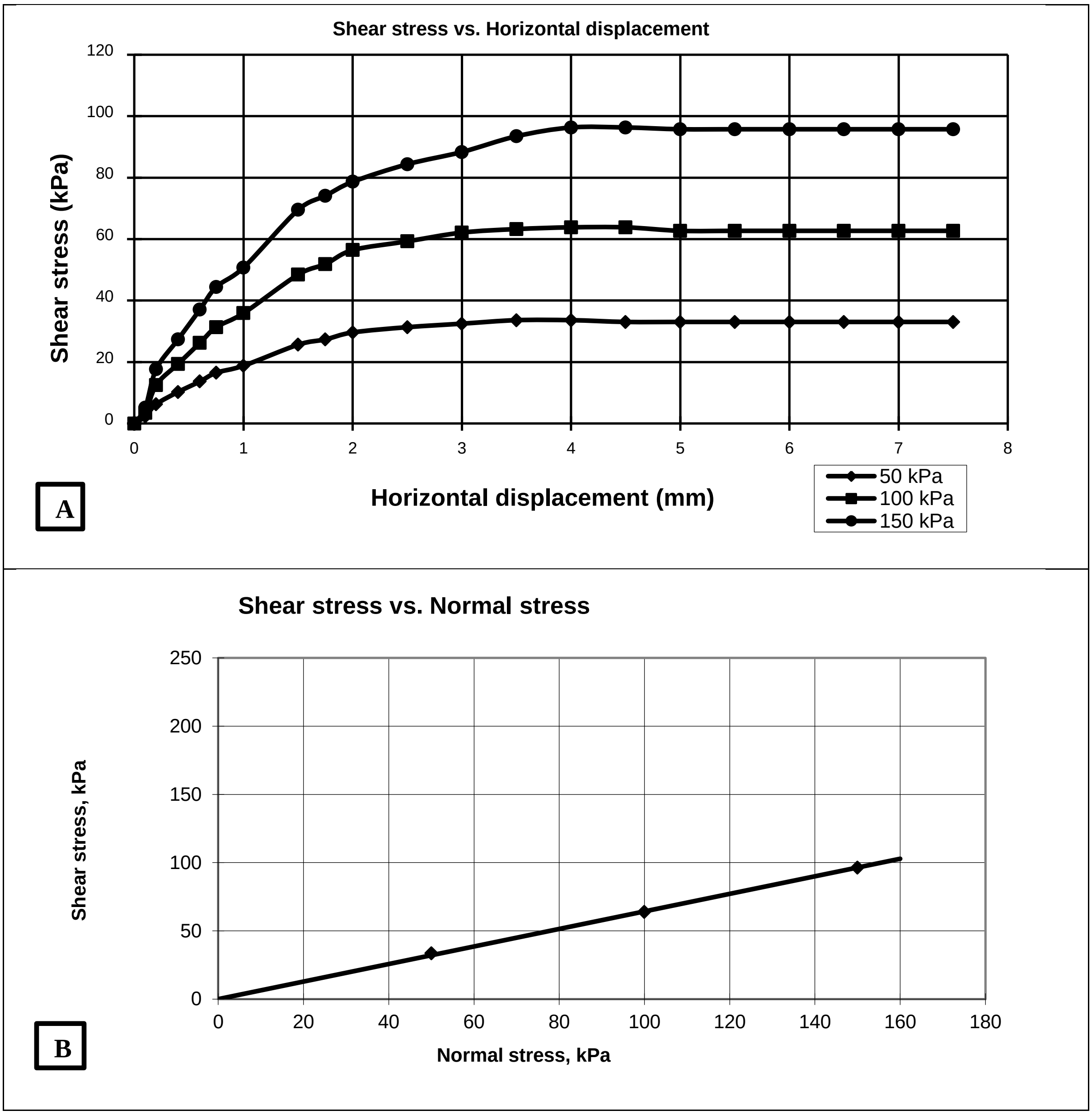


Figure B.5.14. Shows the relationship between the horizontal displacement (mm) & Shear stress (kPa) (A) and relationship between the Normal stress (kPa) & Shear stress (kPa) by Direct Shear test for contaminated sample T.P.Cs (0 m, 50 m) at depth (2.0 m) (B).

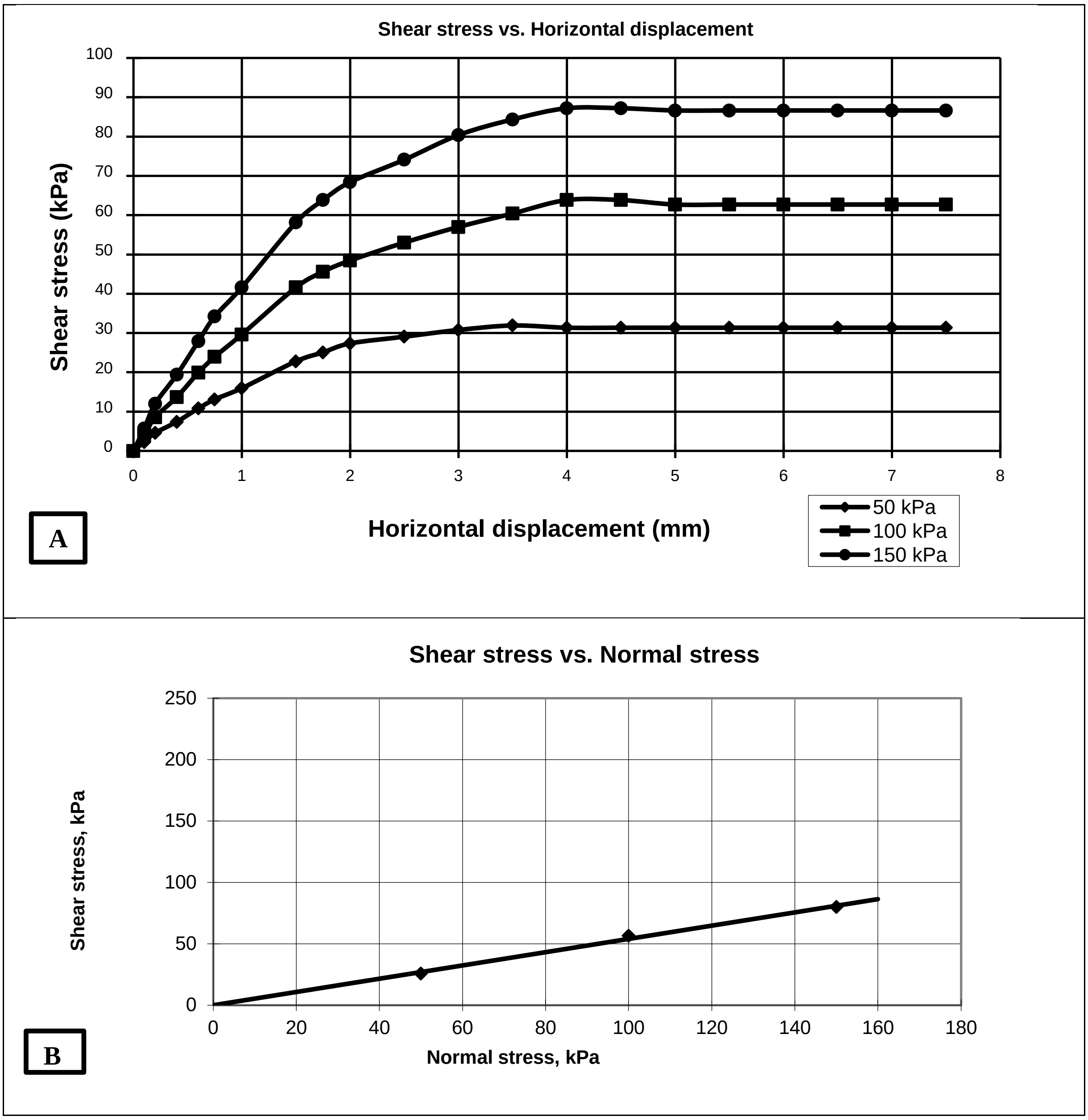


Figure B.5.15. Shows the relationship between the horizontal displacement (mm) & Shear stress (kPa) (A) and relationship between the Normal stress (kPa) & Shear stress (kPa) by Direct Shear test for contaminated sample T.P.Cs (50 m, 50 m) at depth (0.0 m) (B).

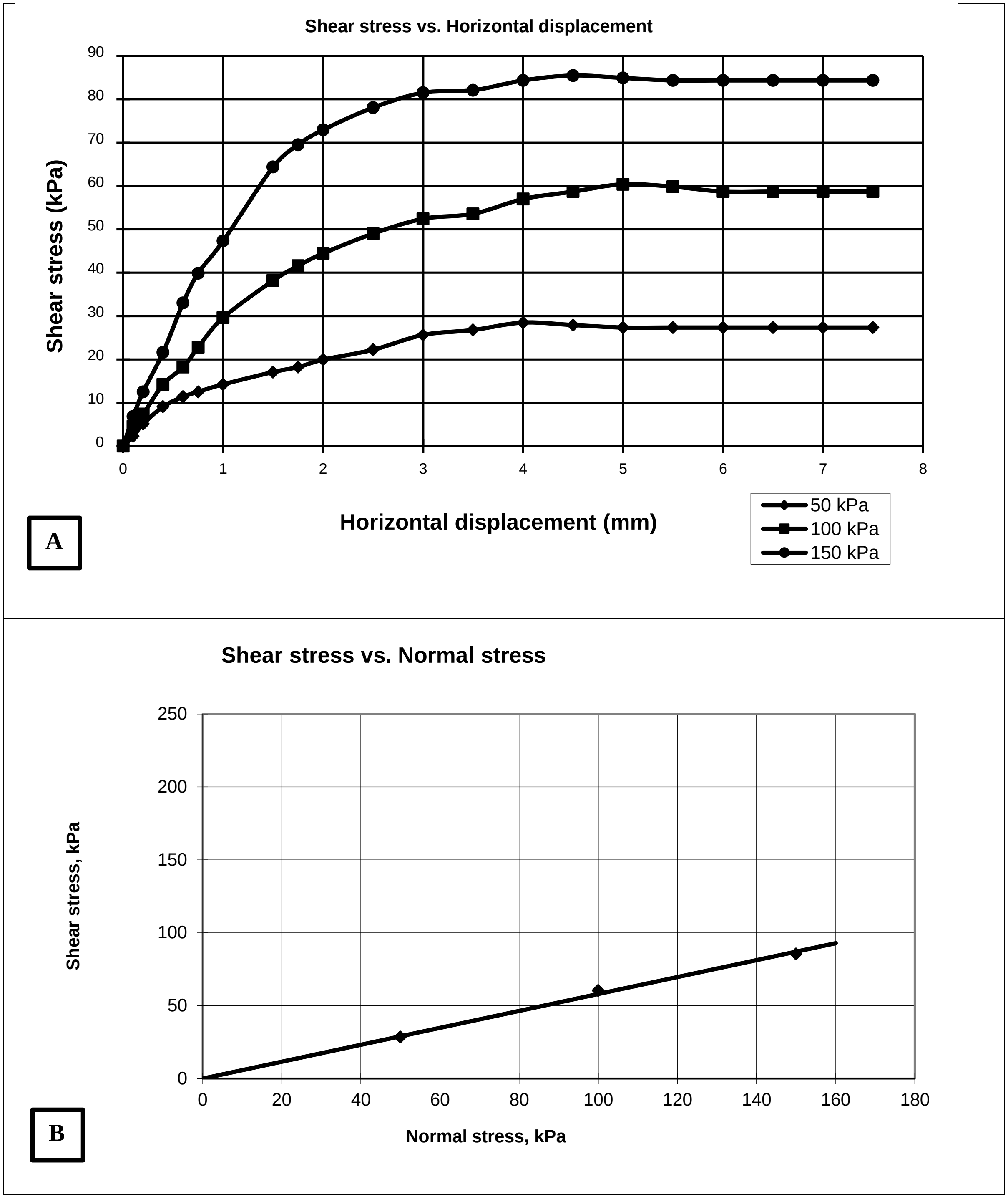


Figure B.5.16. Shows the relationship between the horizontal displacement (mm) & Shear stress (kPa) (A) and relationship between the Normal stress (kPa) & Shear stress (kPa) by Direct Shear test for contaminated sample T.P.Cs (50 m, 50 m) at depth (0.25 m) (B).

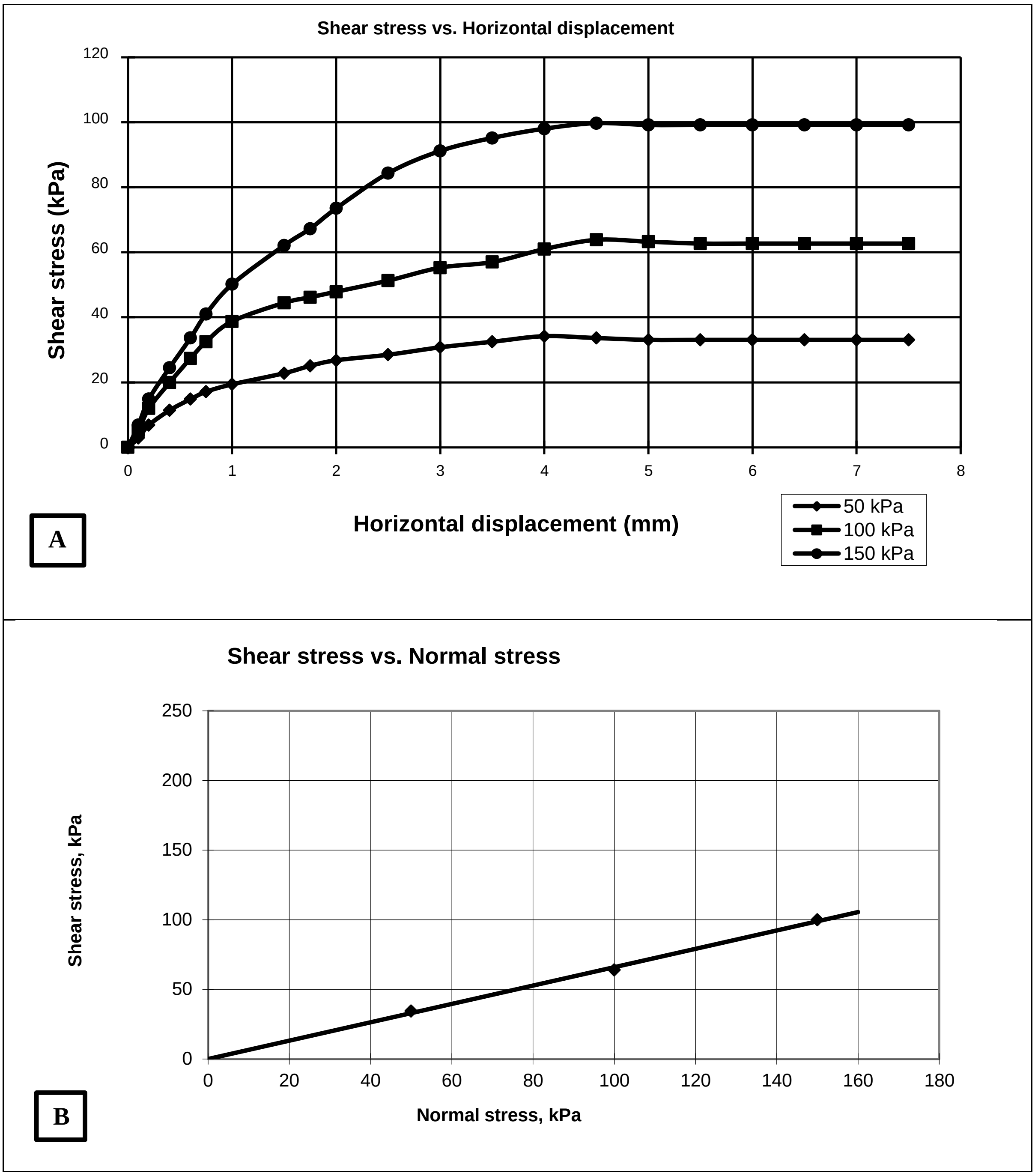


Figure B.5.17. Shows the relationship between the horizontal displacement (mm) & Shear stress (kPa) (A) and relationship between the Normal stress (kPa) & Shear stress (kPa) by Direct Shear test for contaminated sample T.P.Cs (50 m, 50 m) at depth (0.5 m) (B).

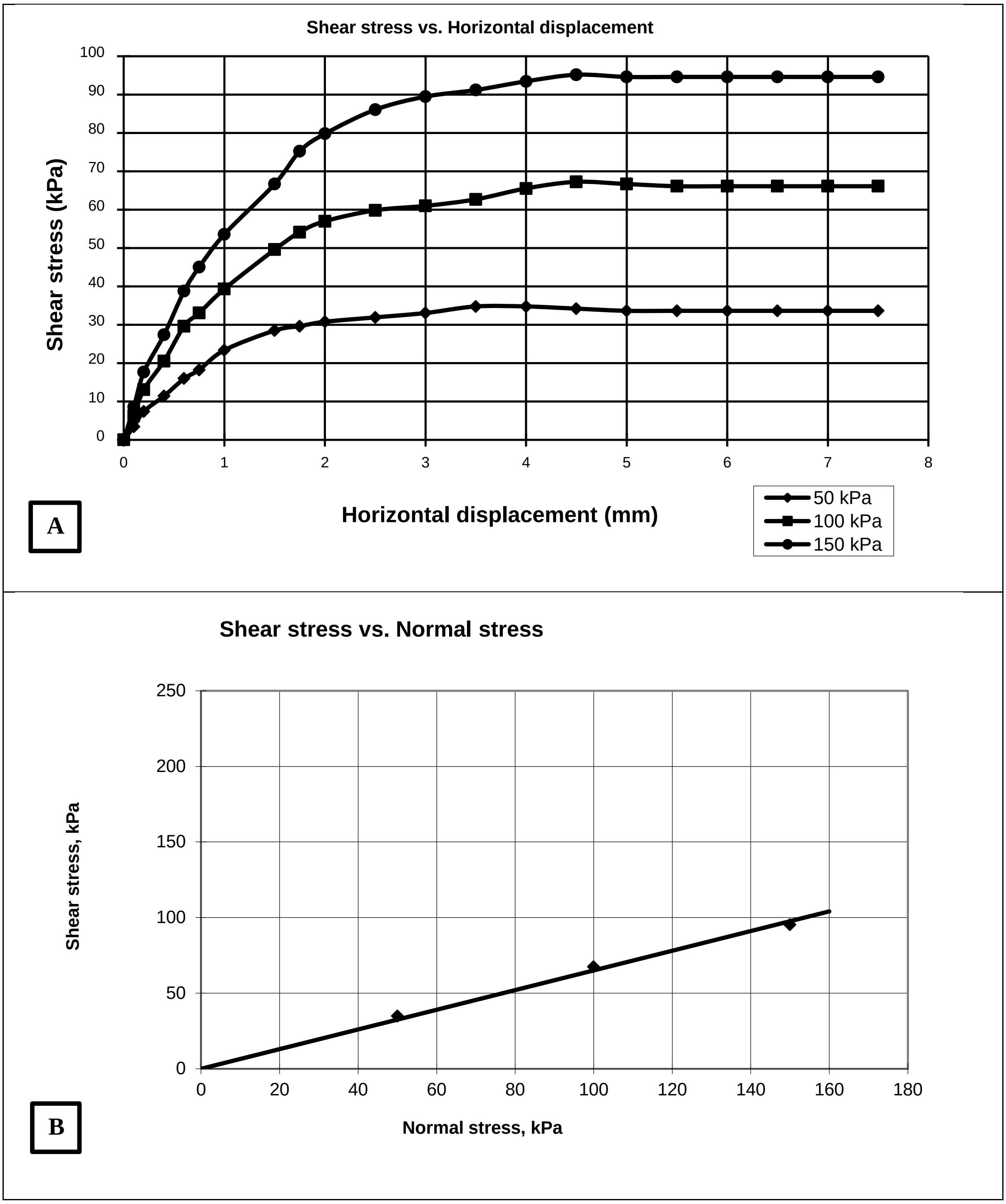


Figure B.5.18. Shows the relationship between the horizontal displacement (mm) & Shear stress (kPa) (A) and relationship between the Normal stress (kPa) & Shear stress (kPa) by Direct Shear test for contaminated sample T.P.Cs (50 m, 50 m) at depth (1.0 m) (B).

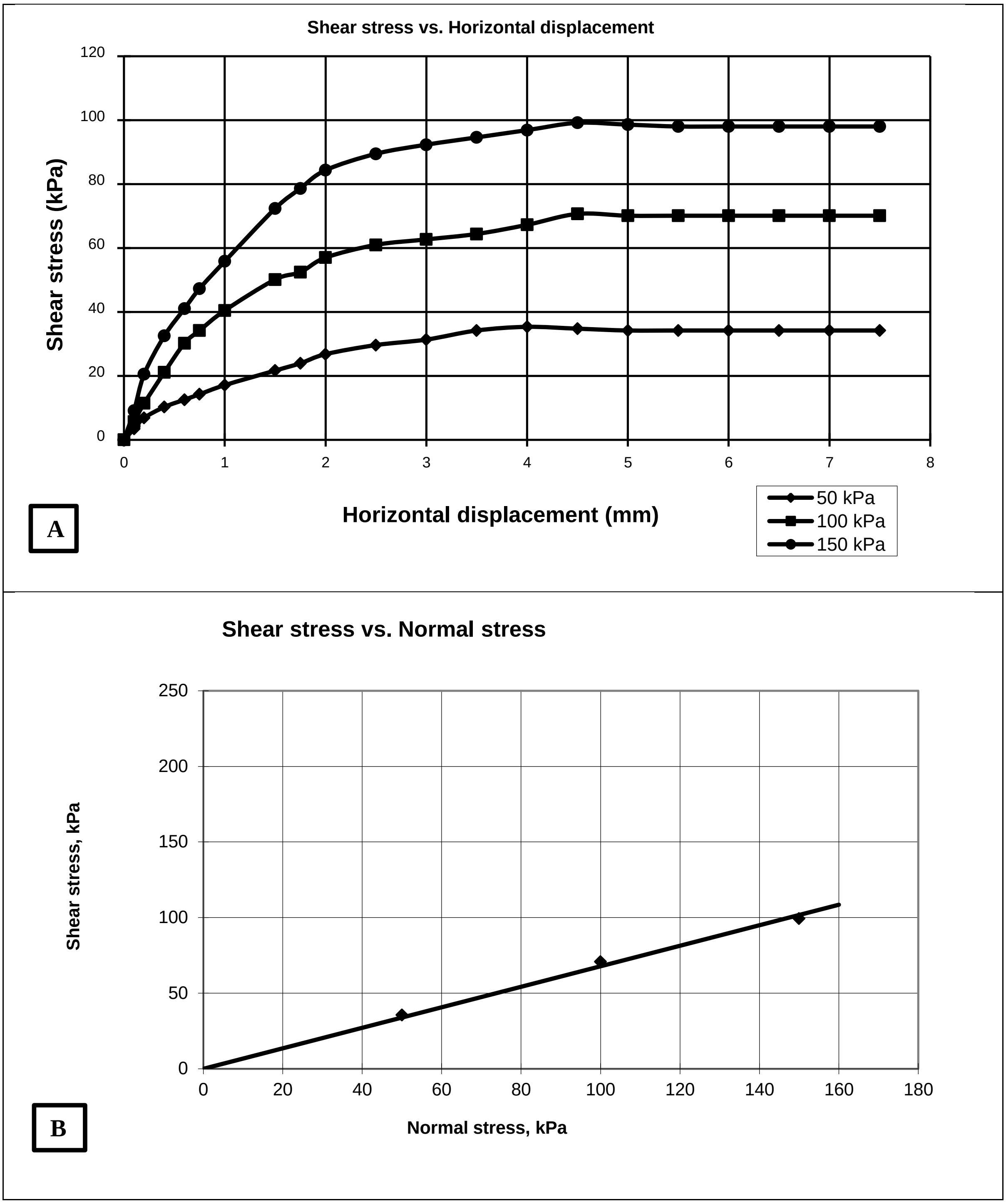


Figure B.5.19. Shows the relationship between the horizontal displacement (mm) & Shear stress (kPa) (A) and relationship between the Normal stress (kPa) & Shear stress (kPa) by Direct Shear test for contaminated sample T.P.Cs (50 m, 50 m) at depth (1.5 m) (B).

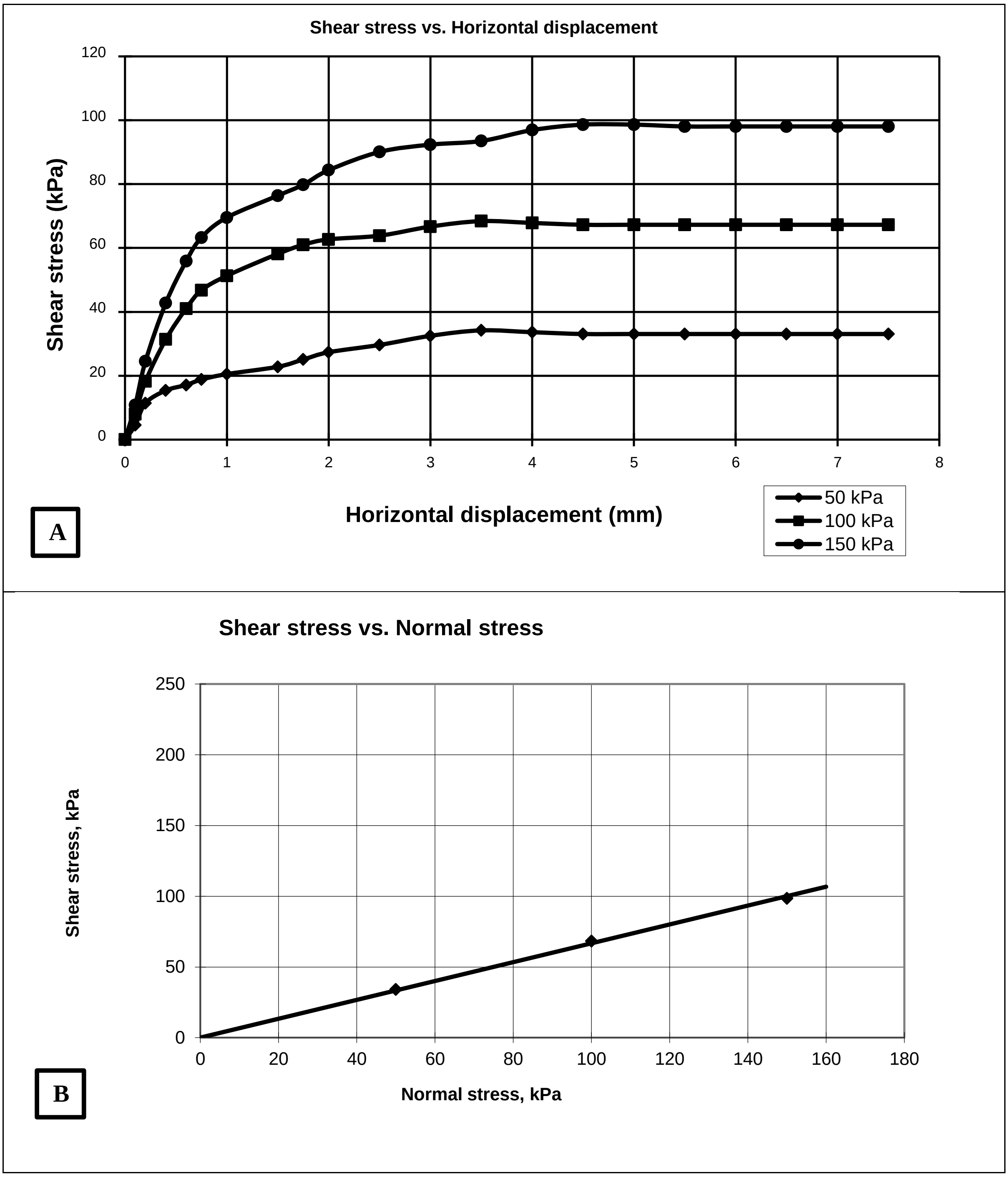


Figure B.5.20. Shows the relationship between the horizontal displacement (mm) & Shear stress (kPa) (A) and relationship between the Normal stress (kPa) & Shear stress (kPa) by Direct Shear test for contaminated sample T.P.Cs (50 m, 50 m) at depth (2.0 m) (B).

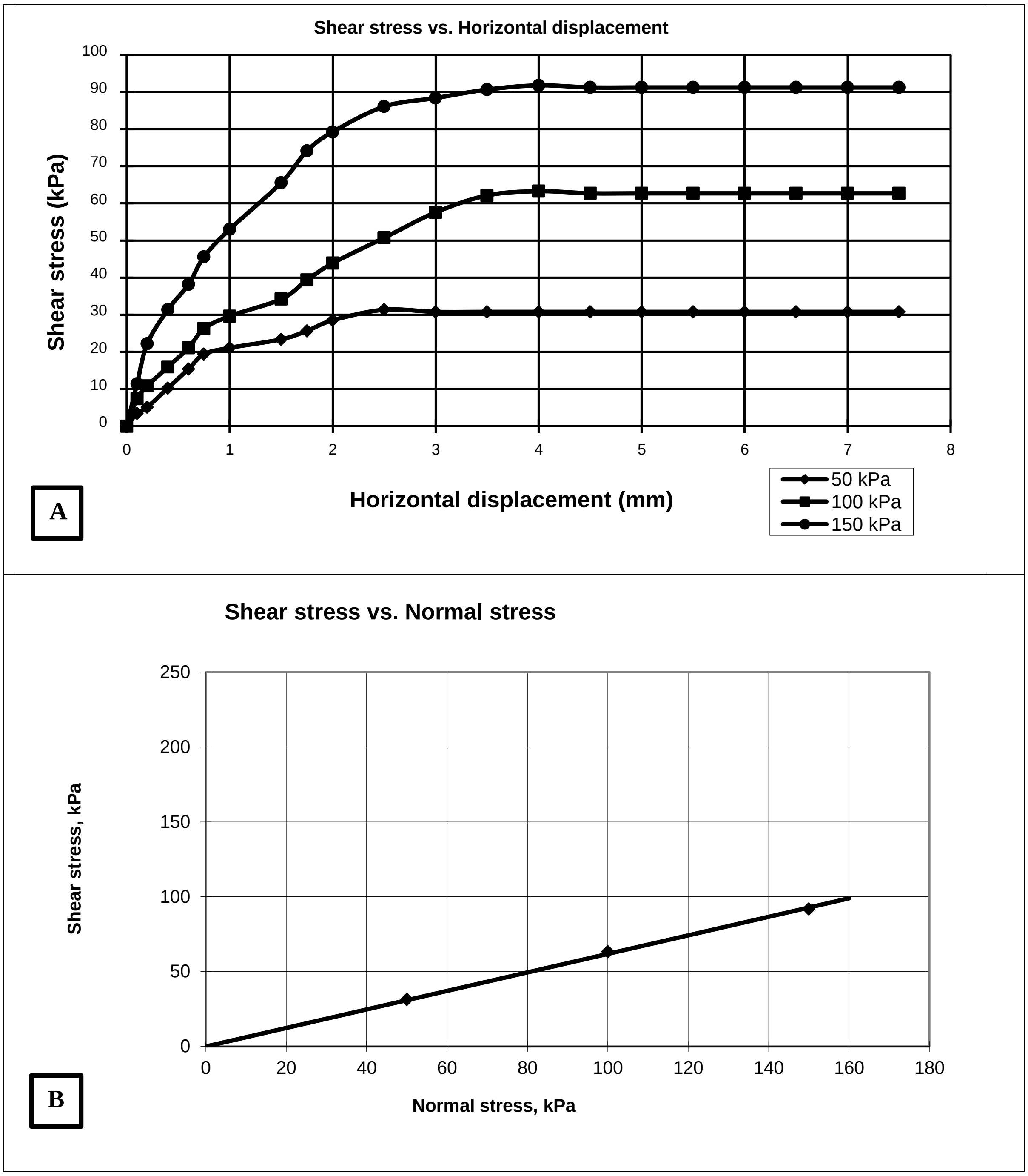


Figure B.5.21. Shows the relationship between the horizontal displacement (mm) & Shear stress (kPa) (A) and relationship between the Normal stress (kPa) & Shear stress (kPa) by Direct Shear test for contaminated sample T.P.Cs (50 m, 0 m) at depth (0.0 m) (B).

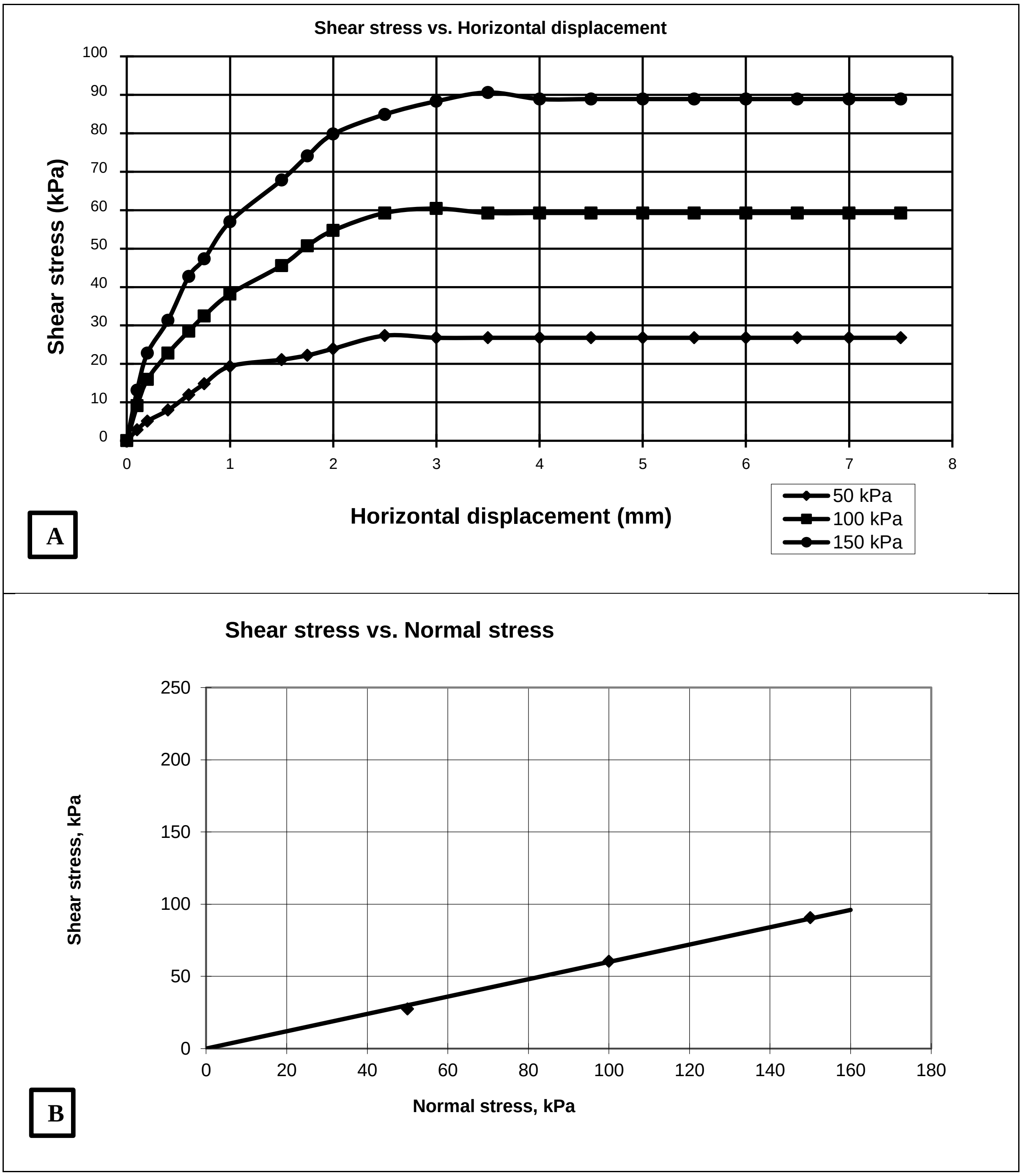


Figure B.5.22. Shows the relationship between the horizontal displacement (mm) & Shear stress (kPa) (A) and relationship between the Normal stress (kPa) & Shear stress (kPa) by Direct Shear test for contaminated sample T.P.Cs (50 m, 0 m) at depth (0.25 m) (B).

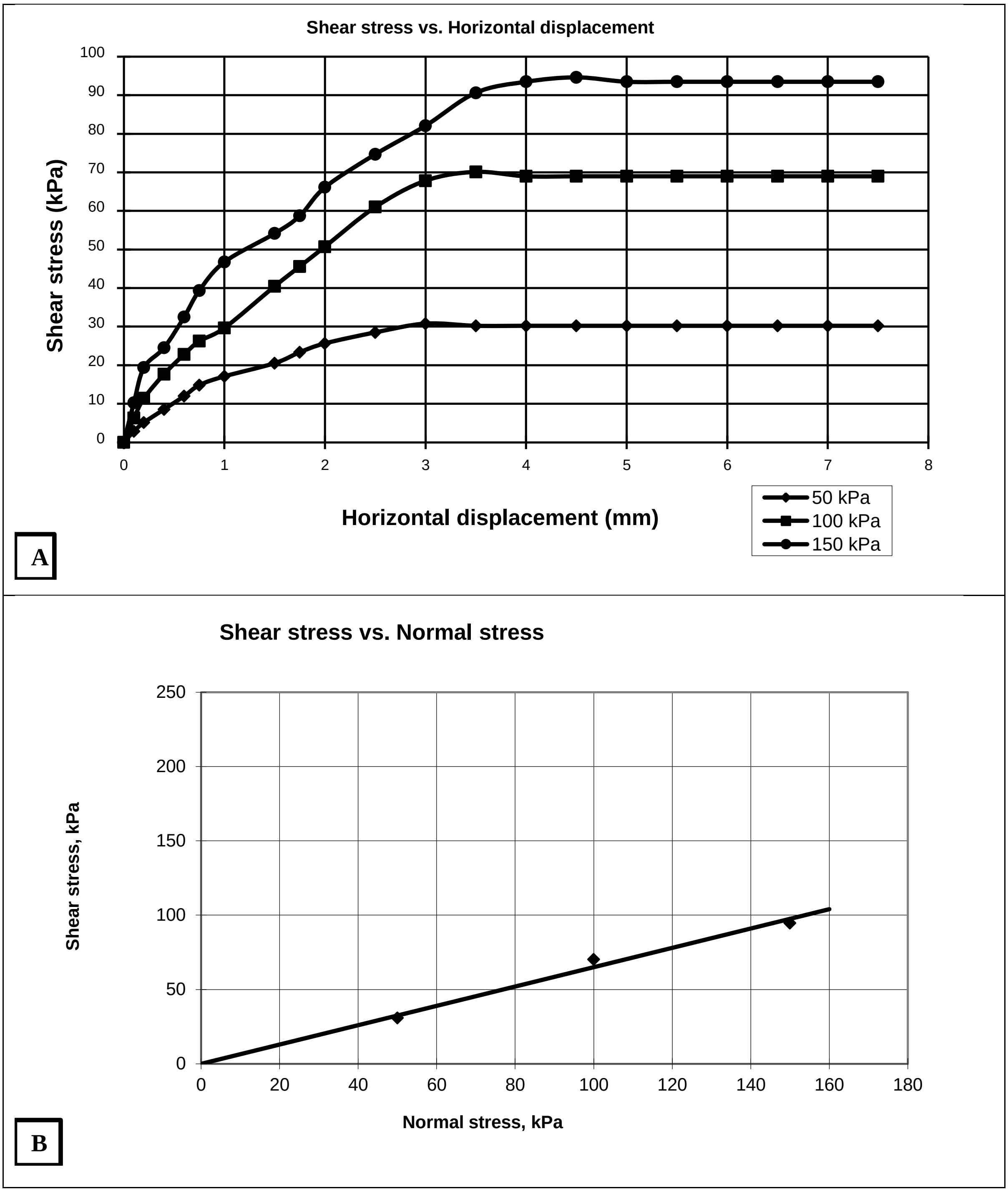


Figure B.5.23. Shows the relationship between the horizontal displacement (mm) & Shear stress (kPa) (A) and relationship between the Normal stress (kPa) & Shear stress (kPa) by Direct Shear test for contaminated sample T.P.Cs (50 m, 0 m) at depth (0.5 m) (B).

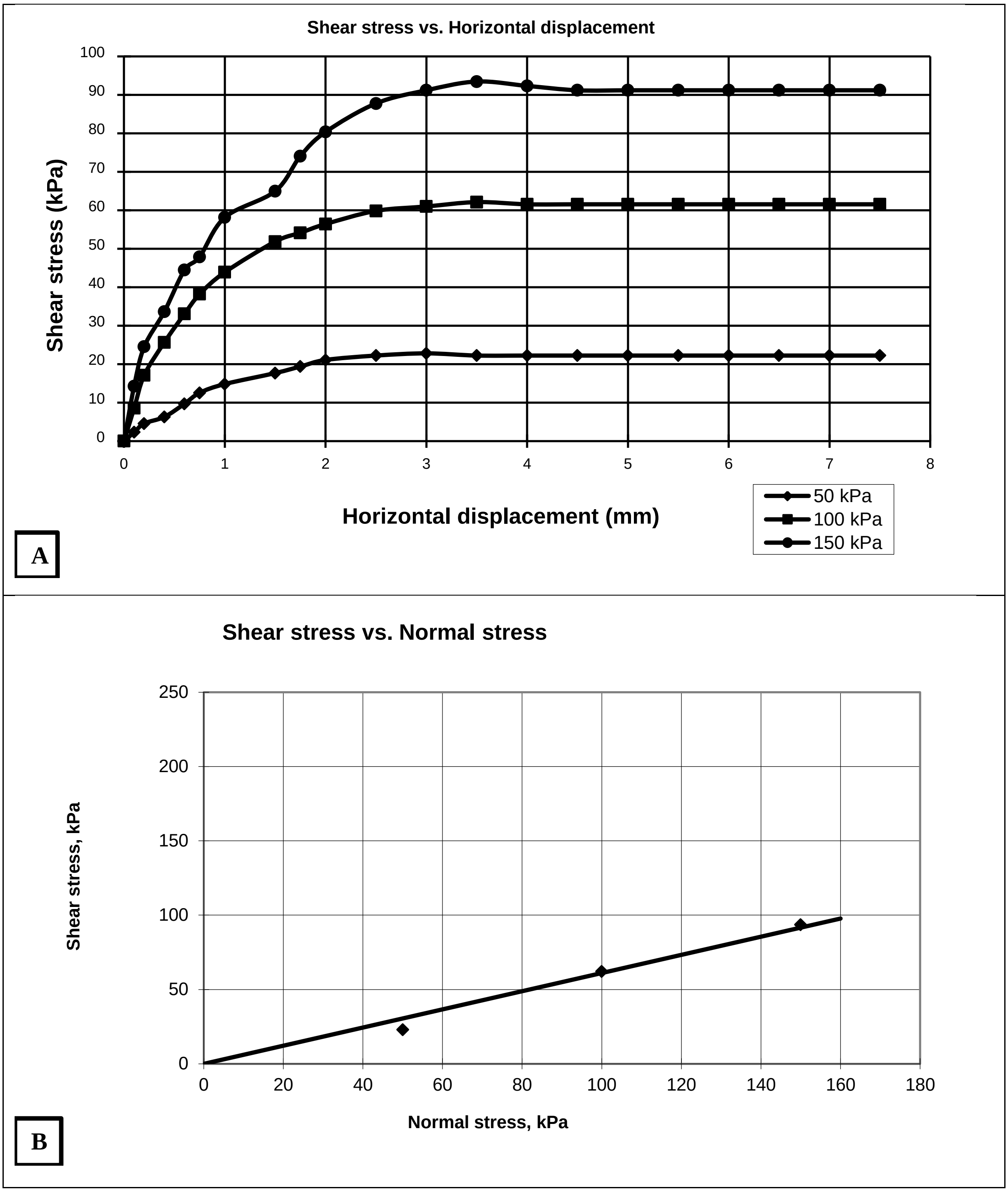


Figure B.5.24. Shows the relationship between the horizontal displacement (mm) & Shear stress (kPa) (A) and relationship between the Normal stress (kPa) & Shear stress (kPa) by Direct Shear test for contaminated sample T.P.Cs (50 m, 0 m) at depth (1.0 m) (B).

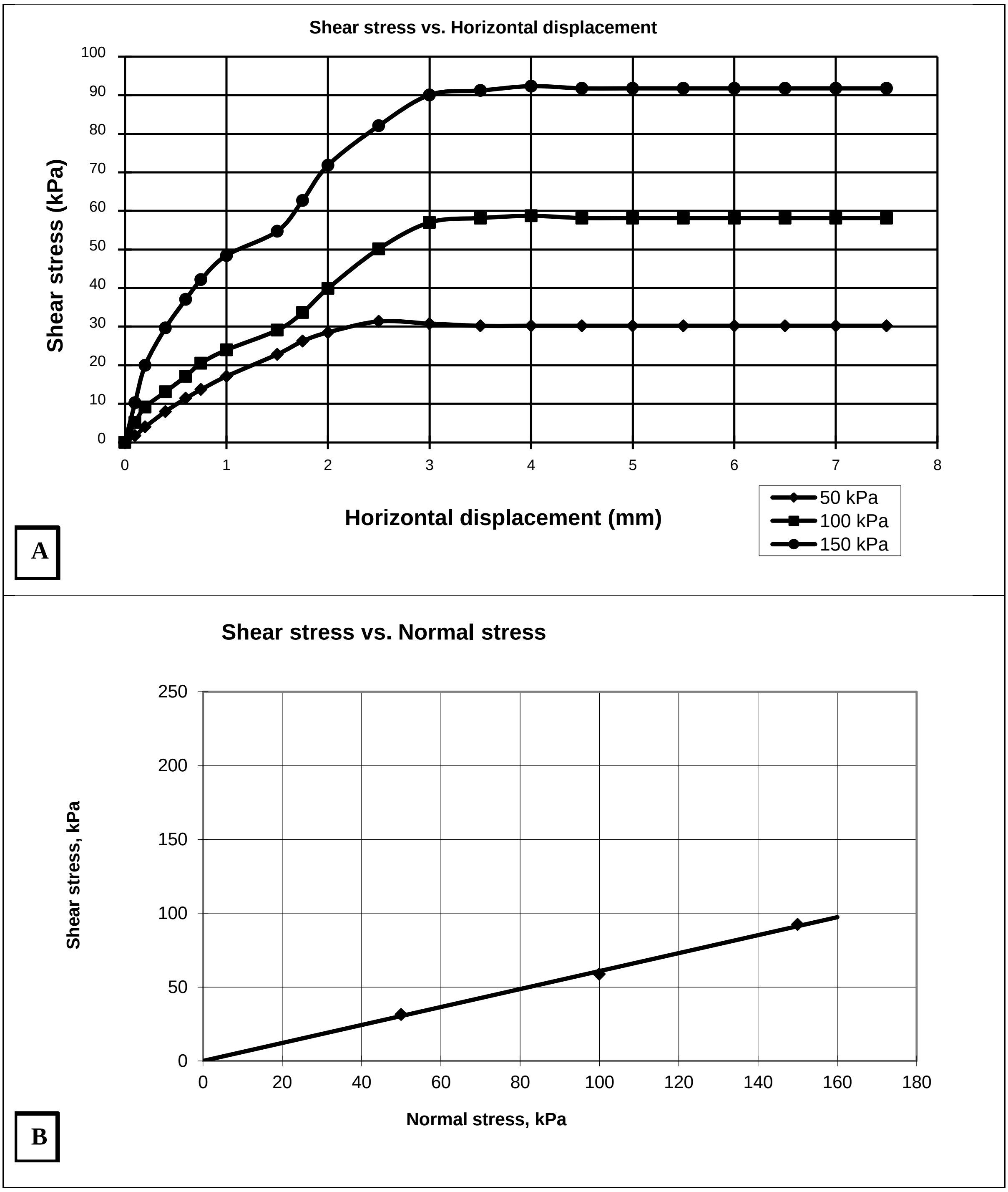


Figure B.5.25. Shows the relationship between the horizontal displacement (mm) & Shear stress (kPa) (A) and relationship between the Normal stress (kPa) & Shear stress (kPa) by Direct Shear test for contaminated sample T.P.Cs (50 m, 0 m) at depth (1.5 m) (B).

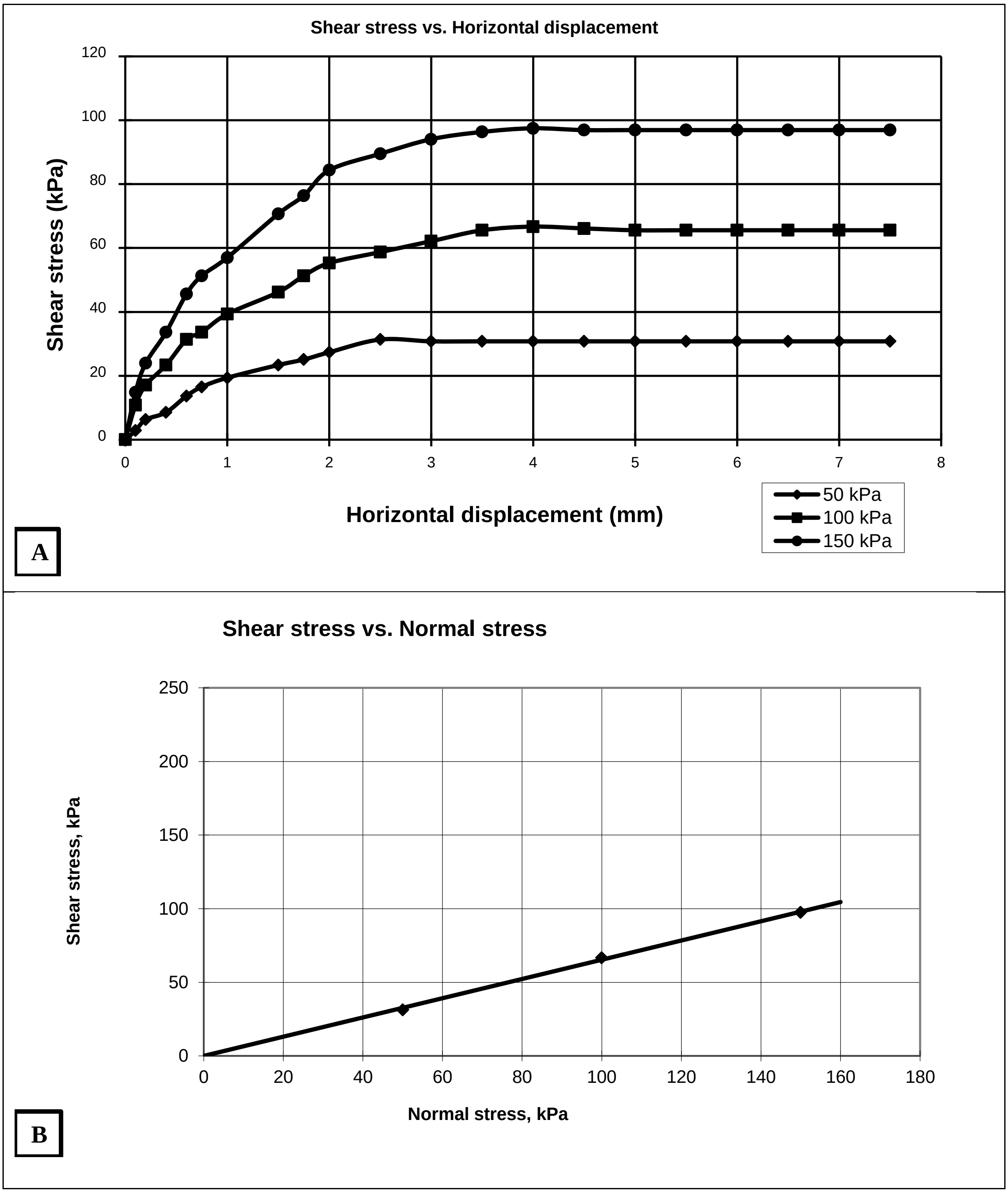


Figure B.5.26. Shows the relationship between the horizontal displacement (mm) & Shear stress (kPa) (A) and relationship between the Normal stress (kPa) & Shear stress (kPa) by Direct Shear test for contaminated sample T.P.Cs (50 m, 0 m) at depth (2.0 m) (B).

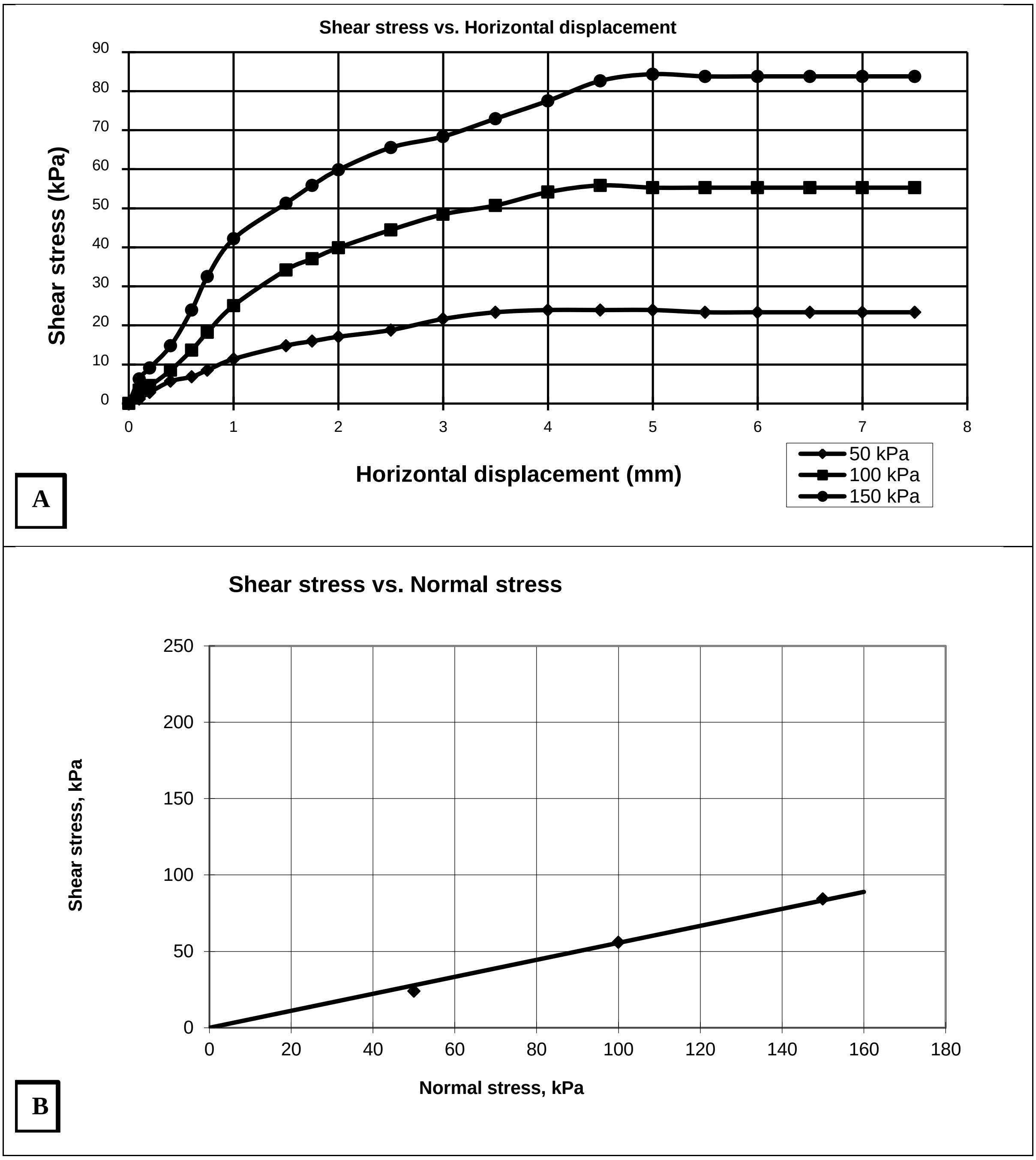


Figure B.5.27. Shows the relationship between the horizontal displacement (mm) & Shear stress (kPa) (A) and relationship between the Normal stress (kPa) & Shear stress (kPa) by Direct Shear test for contaminated sample T.P.Cs (50 m, 100 m) at depth (0.0 m) (B).

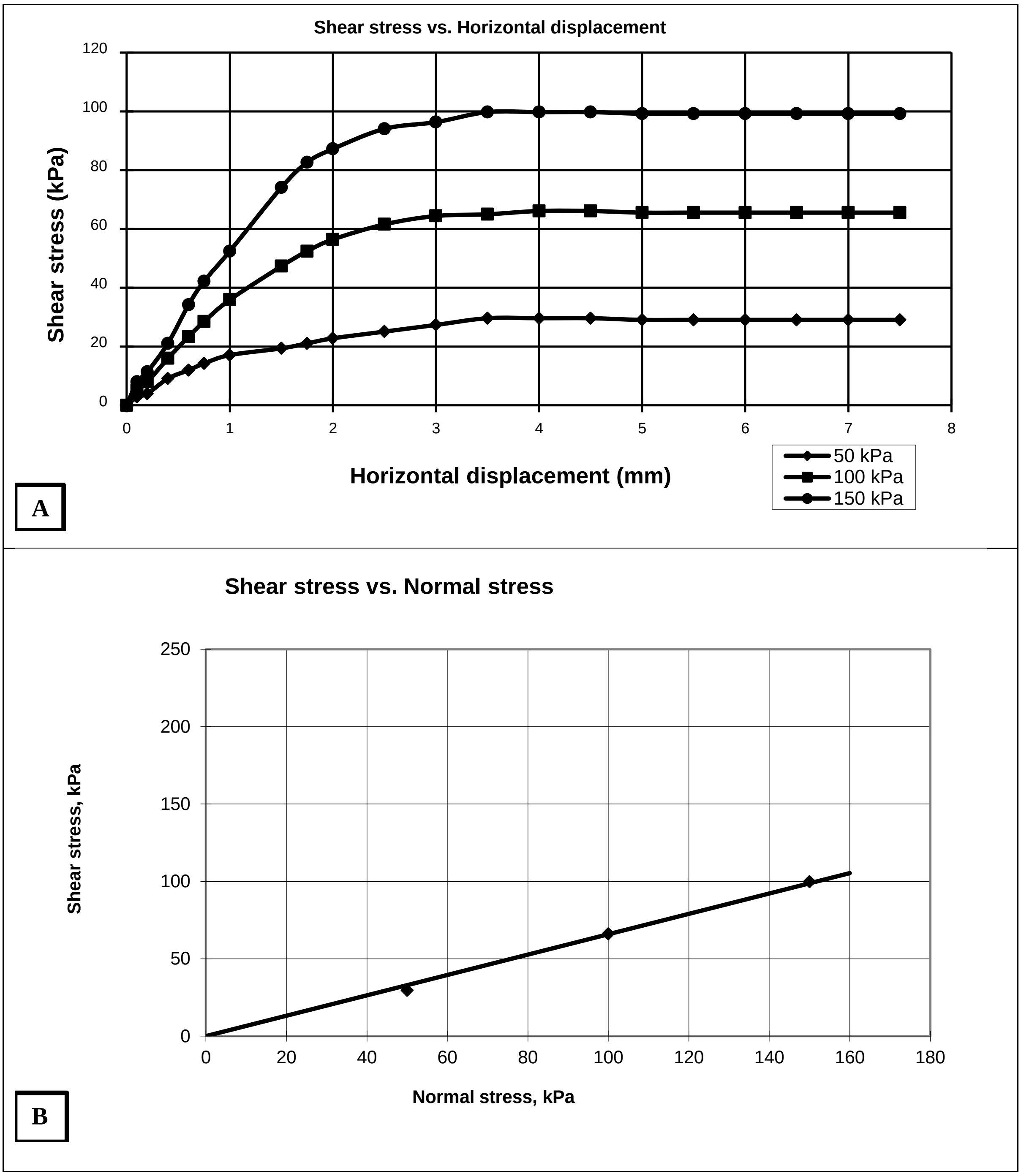


Figure B.5.28. Shows the relationship between the horizontal displacement (mm) & Shear stress (kPa) (A) and relationship between the Normal stress (kPa) & Shear stress (kPa) by Direct Shear test for contaminated sample T.P.Cs (50 m, 100 m) at depth (0.25 m) (B).

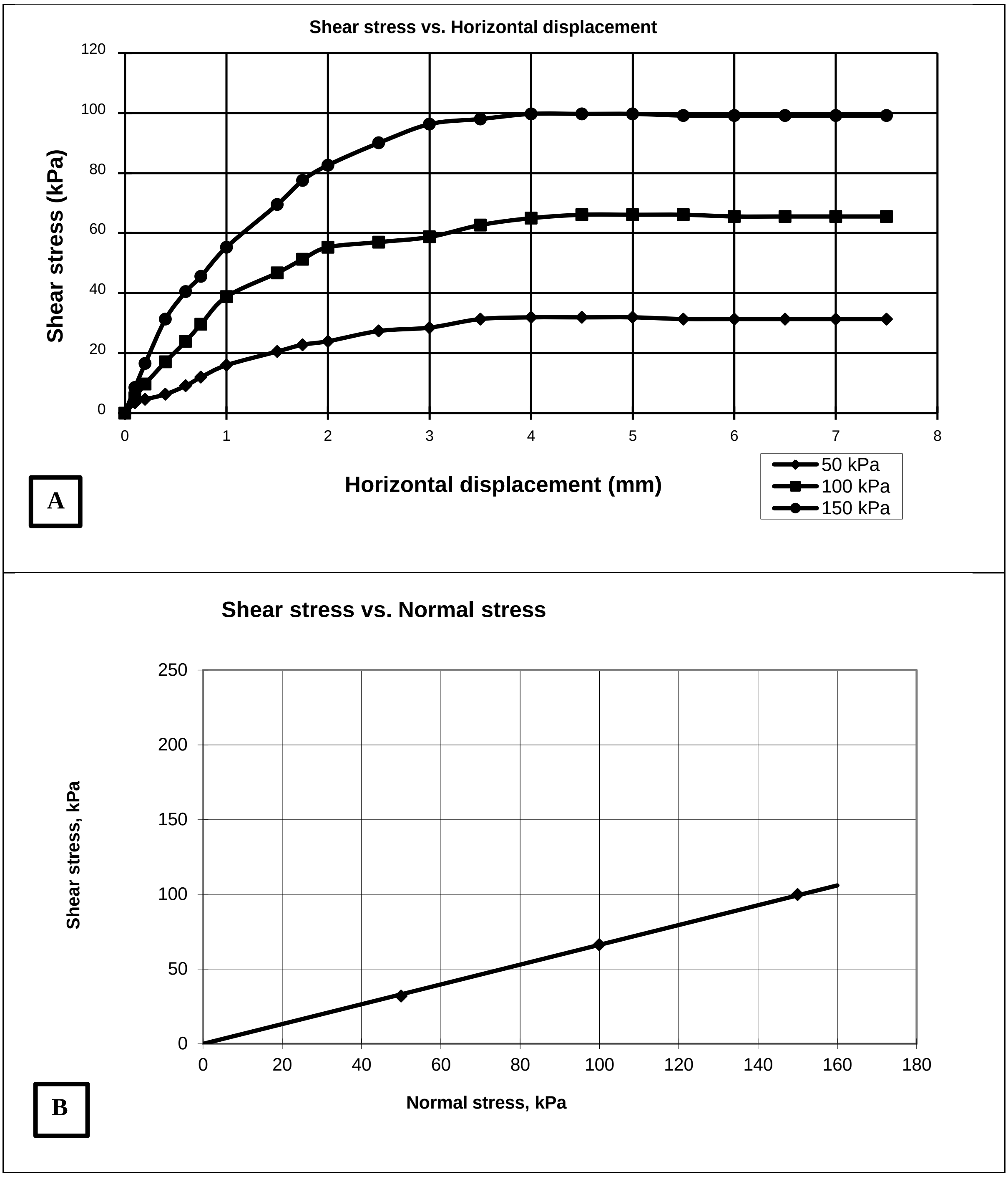


Figure B.5.29. Shows the relationship between the horizontal displacement (mm) & Shear stress (kPa) (A) and relationship between the Normal stress (kPa) & Shear stress (kPa) by Direct Shear test for contaminated sample T.P.Cs (50 m, 100 m) at depth (0.5 m) (B).

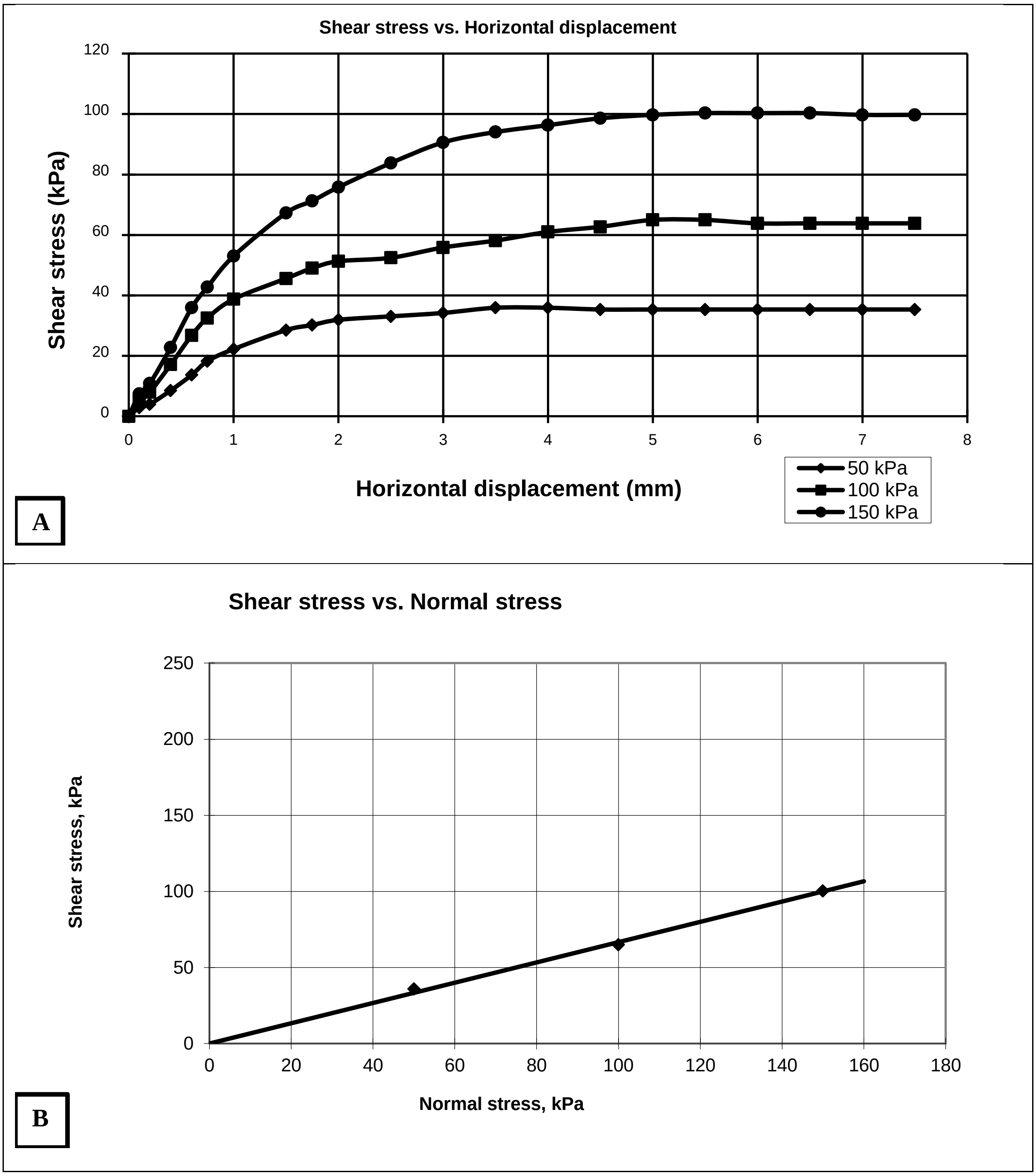


Figure B.5.30. Shows the relationship between the horizontal displacement (mm) & Shear stress (kPa) (A) and relationship between the Normal stress (kPa) & Shear stress (kPa) by Direct Shear test for contaminated sample T.P.Cs (50 m, 100 m) at depth (1.0 m) (B).

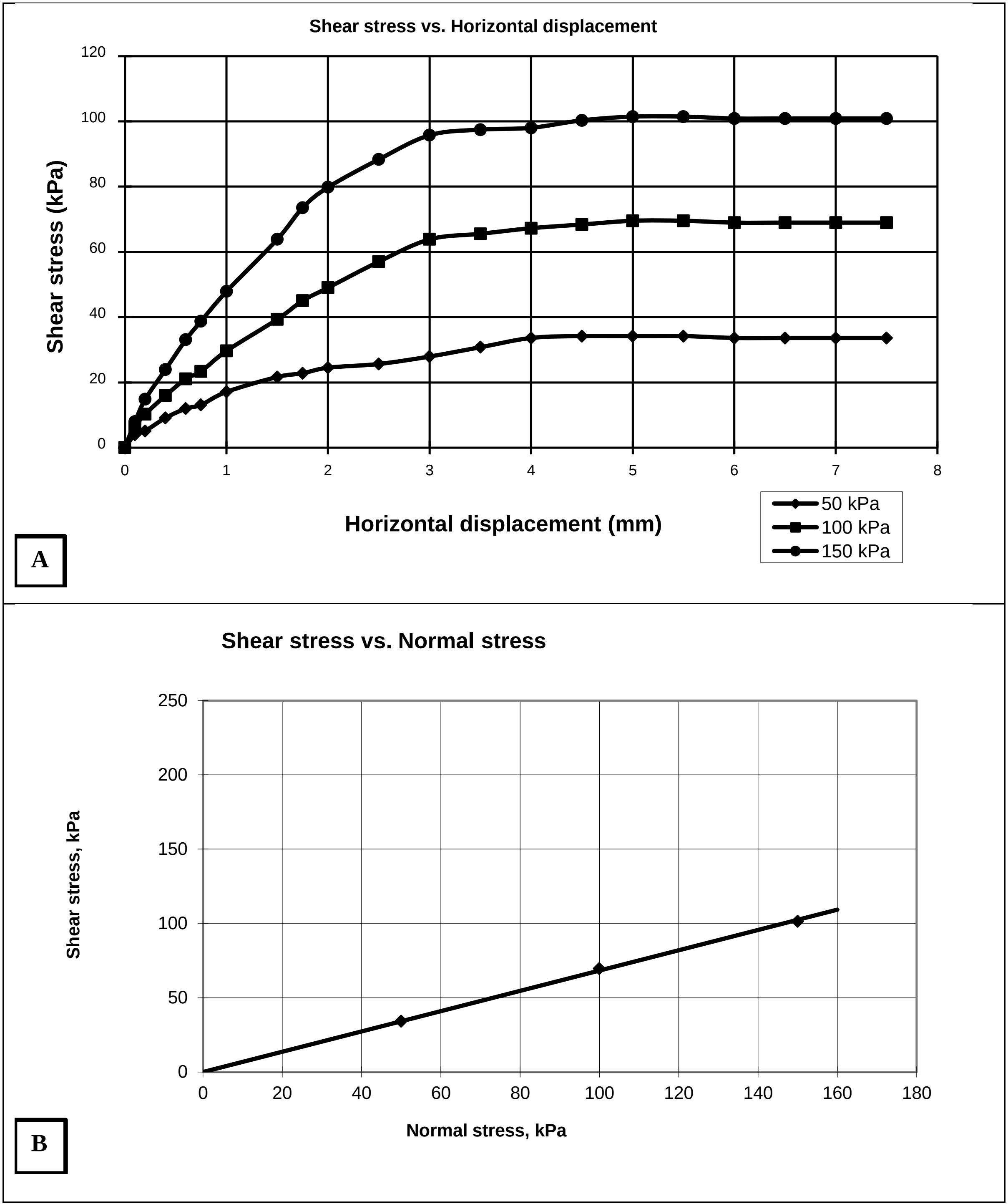


Figure B.5.31. Shows the relationship between the horizontal displacement (mm) & Shear stress (kPa) (A) and relationship between the Normal stress (kPa) & Shear stress (kPa) by Direct Shear test for contaminated sample T.P.Cs (50 m, 100 m) at depth (1.5 m) (B).

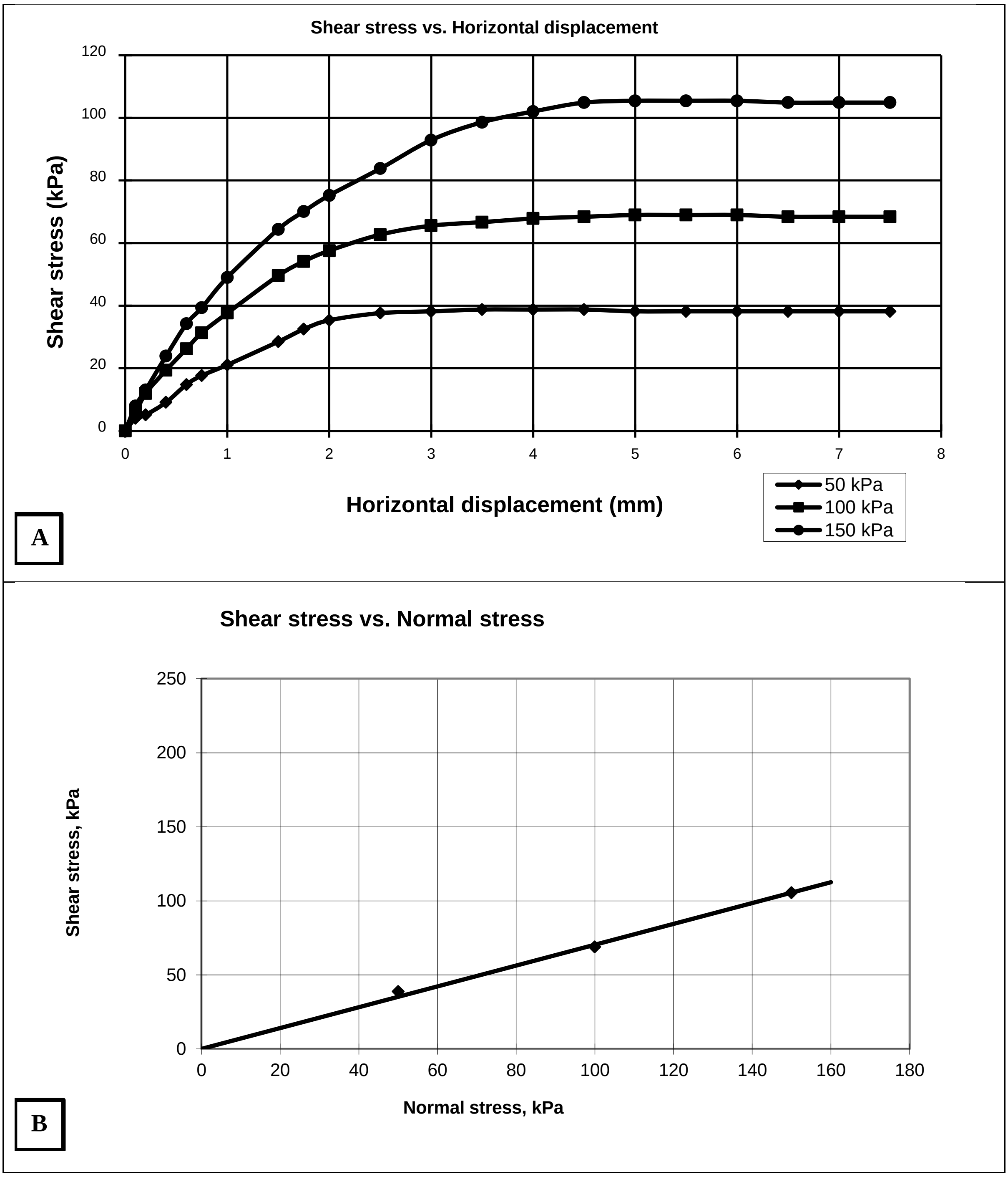


Figure B.5.32. Shows the relationship between the horizontal displacement (mm) & Shear stress (kPa) (A) and relationship between the Normal stress (kPa) & Shear stress (kPa) by Direct Shear test for contaminated sample T.P.Cs (50 m, 100 m) at depth (2.0 m) (B).

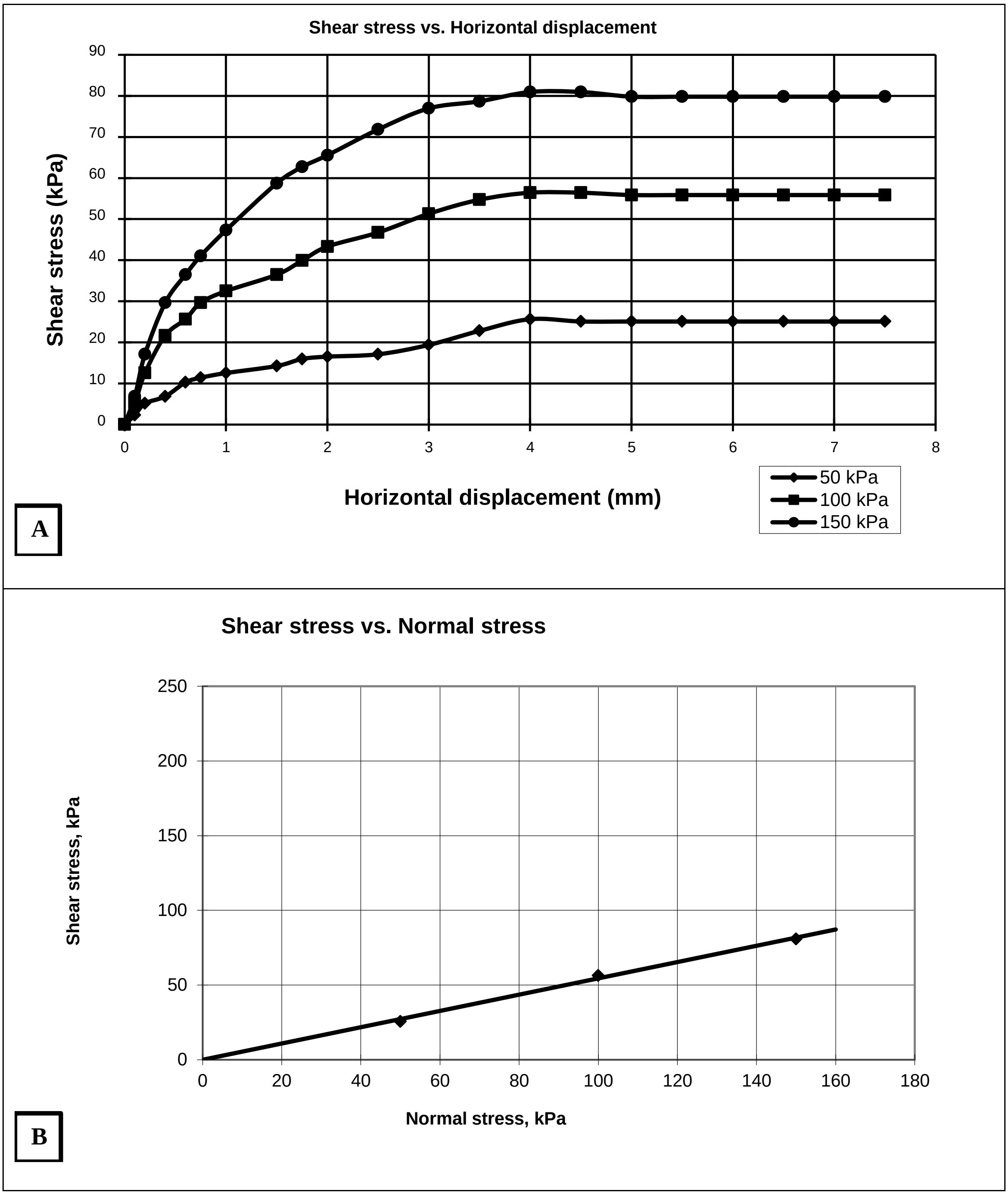


Figure B.5.33. Shows the relationship between the horizontal displacement (mm) & Shear stress (kPa) (A) and relationship between the Normal stress (kPa) & Shear stress (kPa) by Direct shear test for contaminated sample T.P.Cs (100 m, 50 m) at depth (0.0 m) (B).

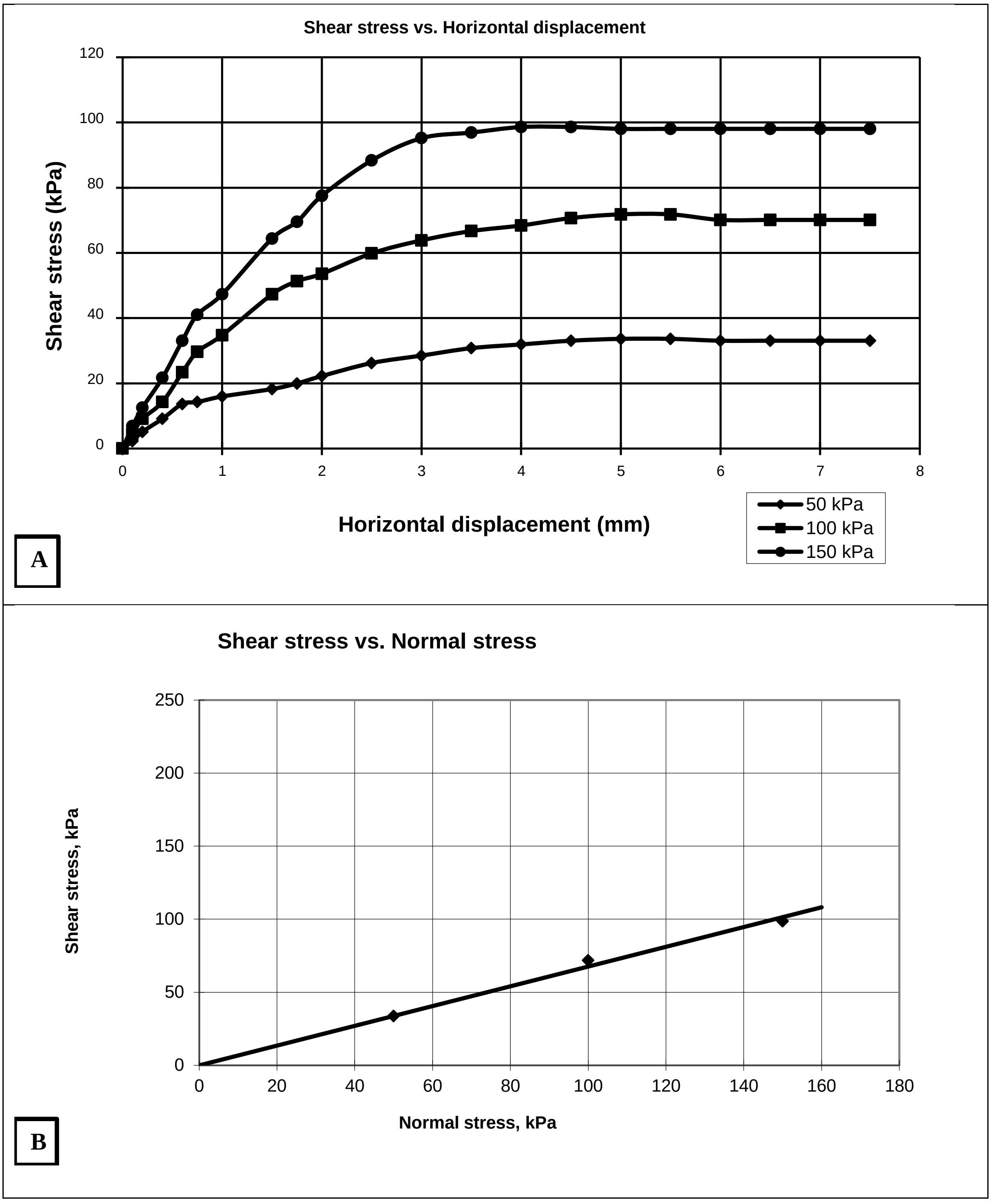


Figure B.5.34. Shows the relationship between the horizontal displacement (mm) & Shear stress (kPa) (A) and relationship between the Normal stress (kPa) & Shear stress (kPa) by Direct Shear test for contaminated sample T.P.Cs (100 m, 50 m) at depth (0.25 m) (B).

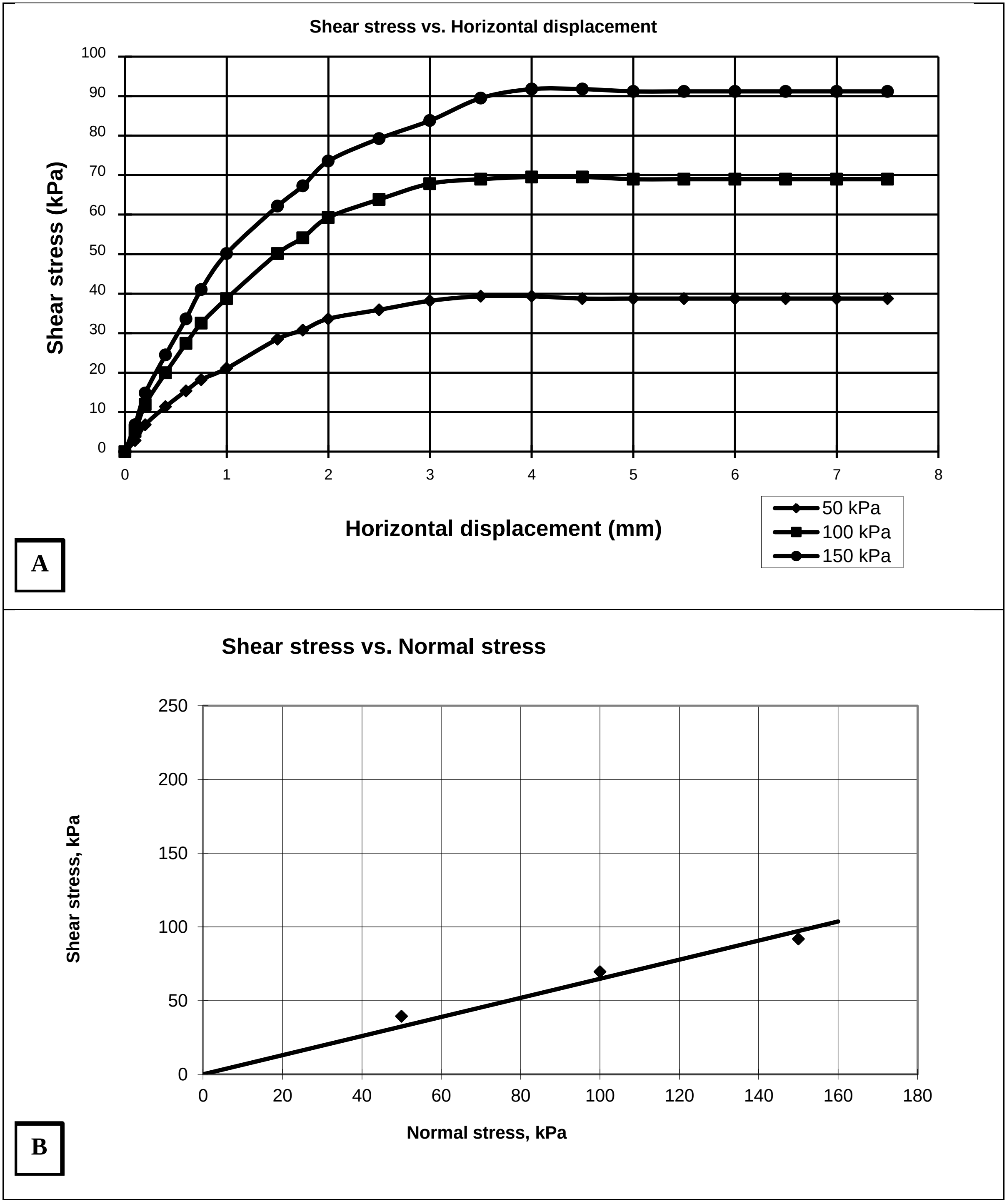


Figure B.5.35. Shows the relationship between the horizontal displacement (mm) & Shear stress (kPa) (A) and relationship between the Normal stress (kPa) & Shear stress (kPa) by Direct Shear test for contaminated sample T.P.Cs (100 m, 50 m) at depth (0.5 m) (B).

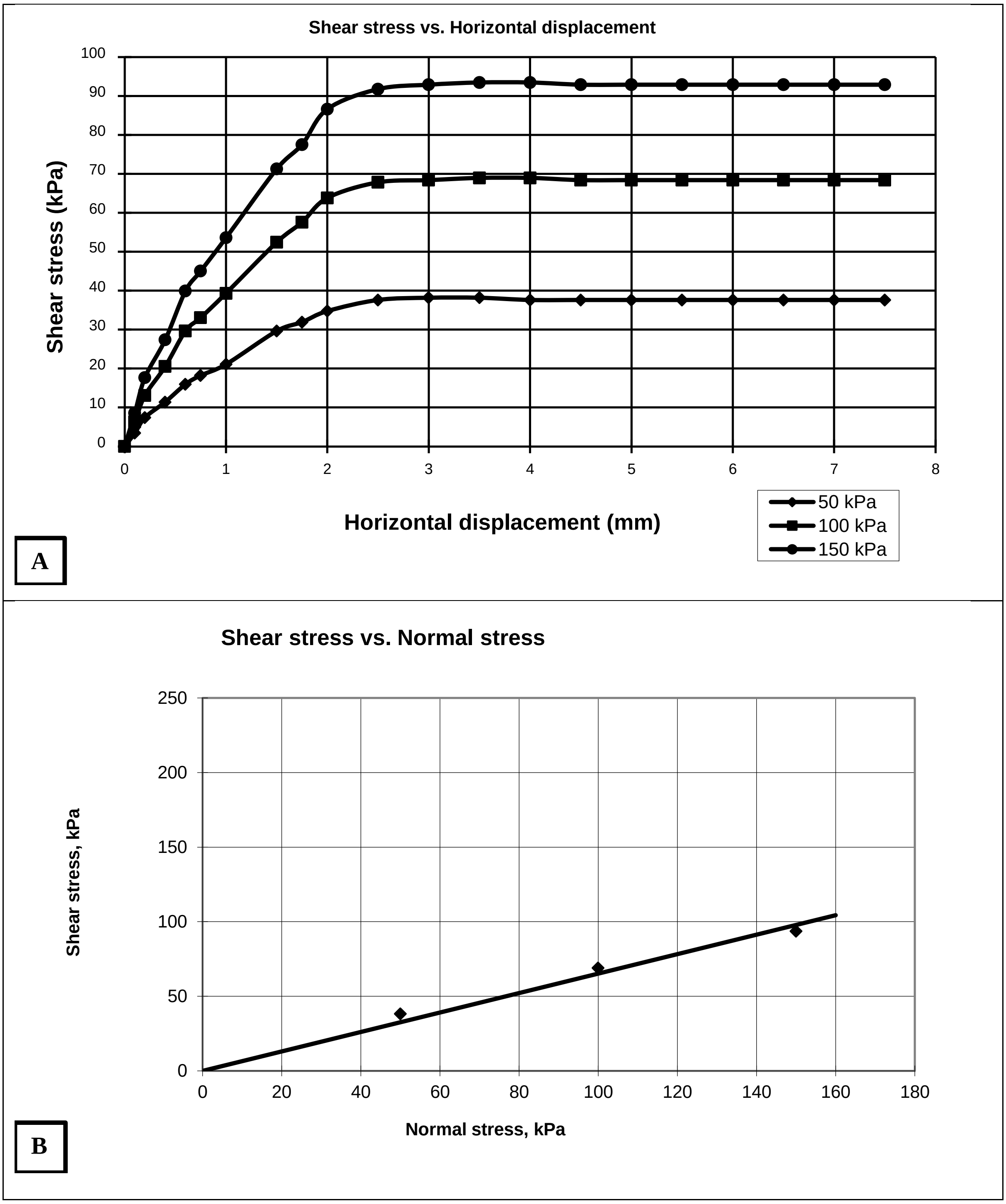


Figure B.5.36. Shows the relationship between the horizontal displacement (mm) & Shear stress (kPa) (A) and relationship between the Normal stress (kPa) & Shear stress (kPa) by Direct Shear test for contaminated sample T.P.Cs (100 m, 50 m) at depth (1.0 m) (B).

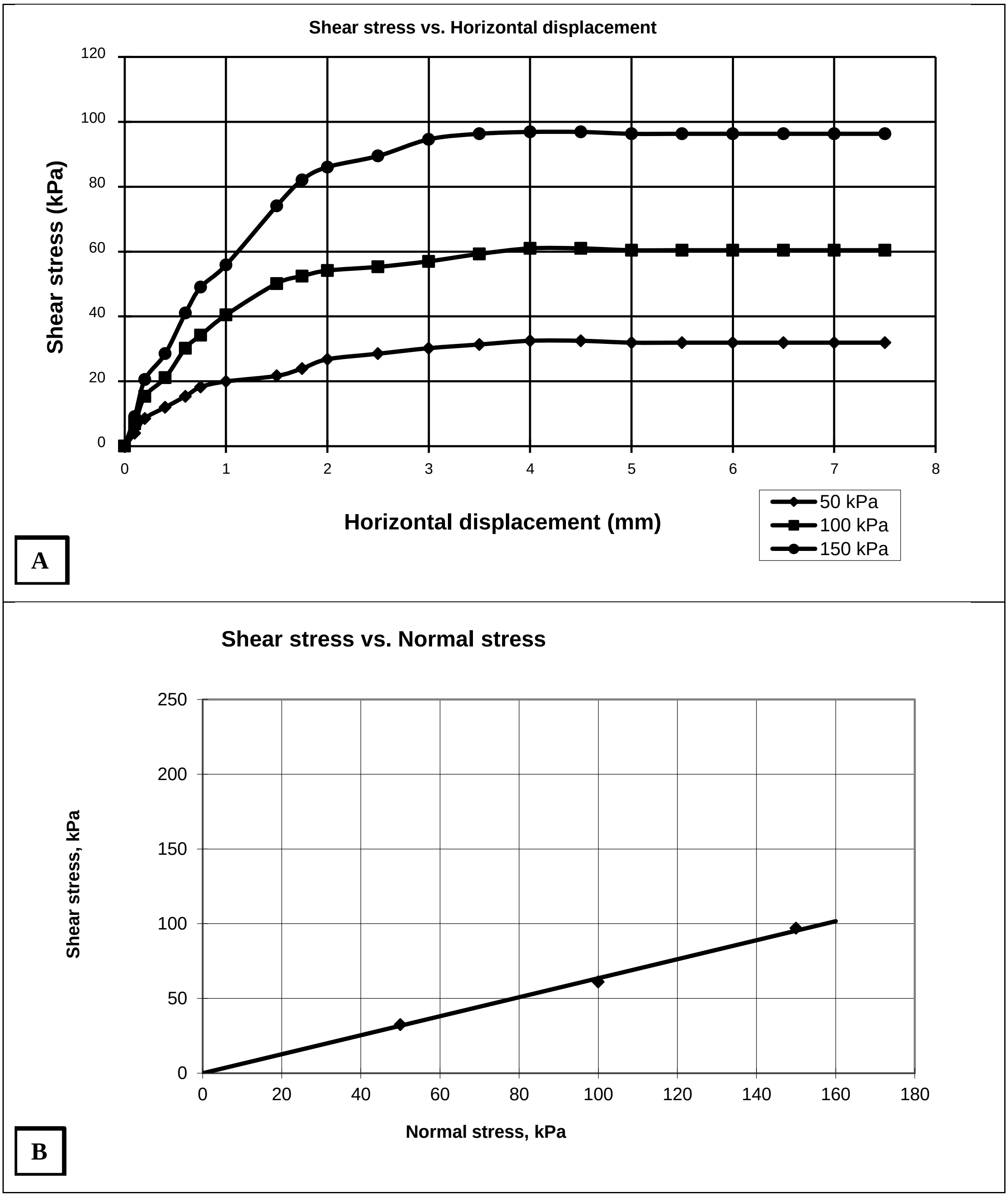


Figure B.5.37. Shows the relationship between the horizontal displacement (mm) & Shear stress (kPa) (A) and relationship between the Normal stress (kPa) & Shear stress (kPa) by Direct Shear test for contaminated sample T.P.Cs (100 m, 50 m) at depth (1.5 m) (B).

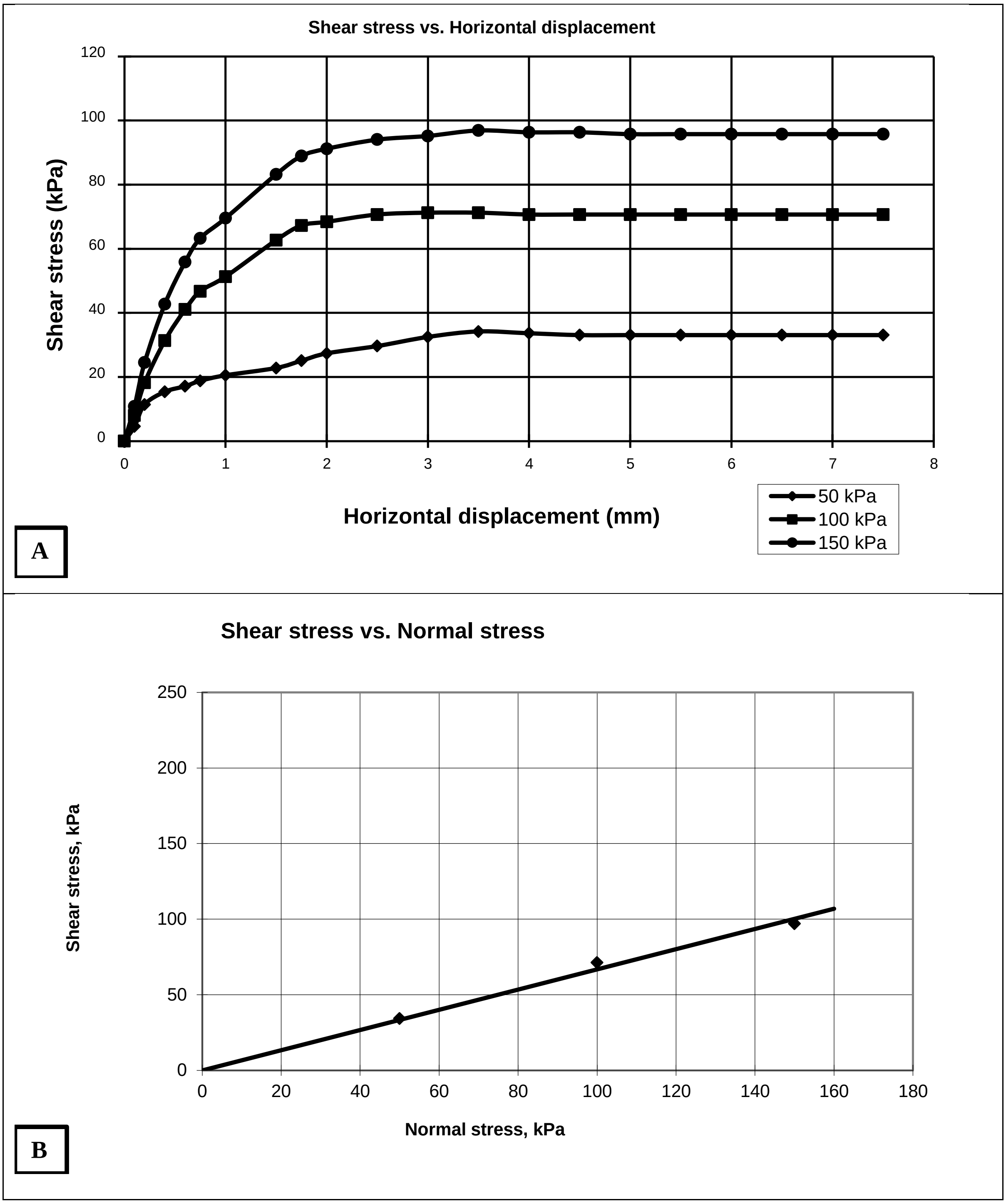


Figure B.5.38. Shows the relationship between the horizontal displacement (mm) & Shear stress (kPa) (A) and relationship between the Normal stress (kPa) & Shear stress (kPa) by Direct Shear test for contaminated sample T.P.Cs (100 m, 50 m) at depth (2.0 m) (B).

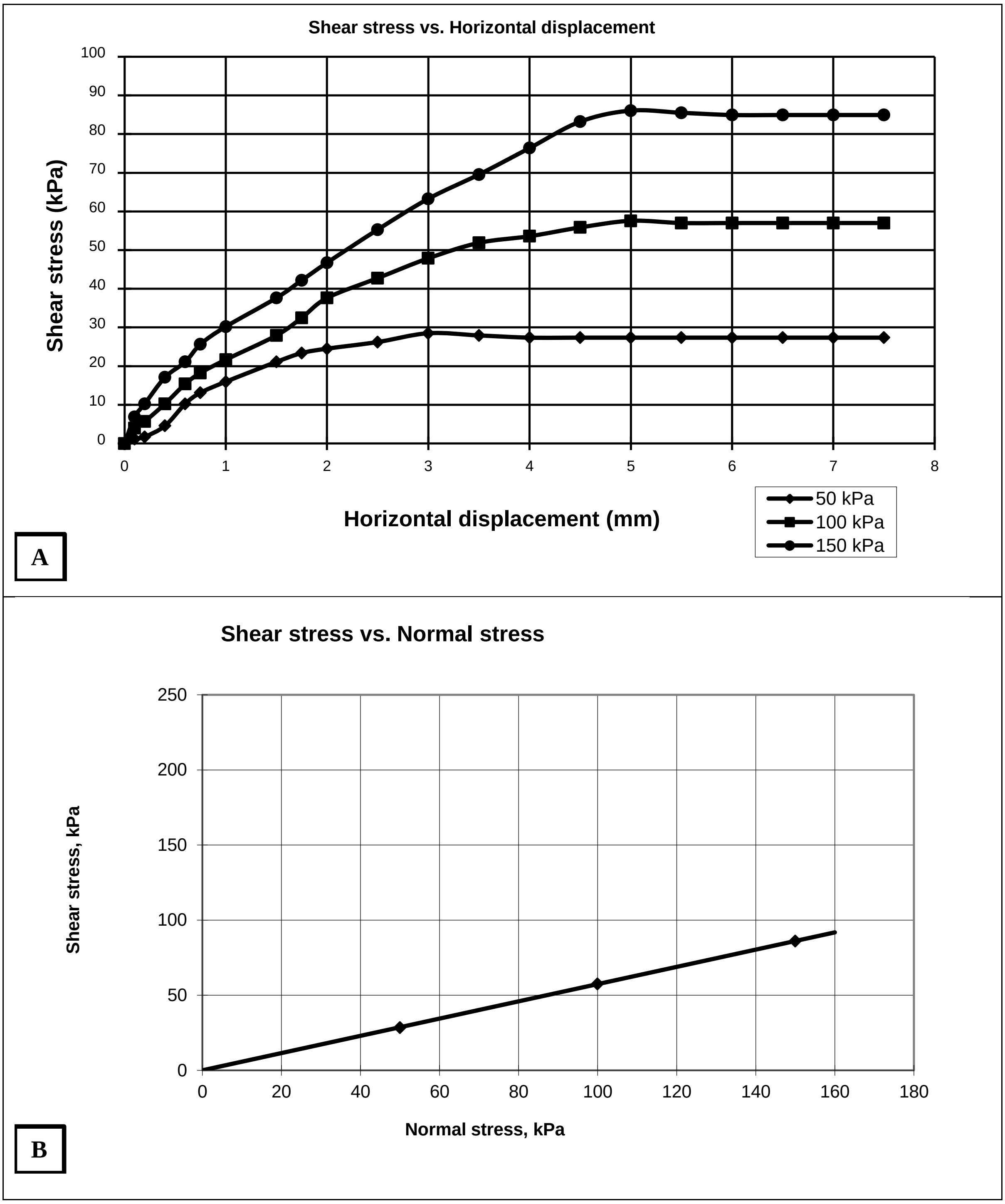


Figure B.5.39. Shows the relationship between the horizontal displacement (mm) & Shear stress (kPa) (A) and relationship between the Normal stress (kPa) & Shear stress (kPa) by Direct Shear test for contaminated sample T.P.Cs (100 m, 100 m) at depth (0.0 m) (B).

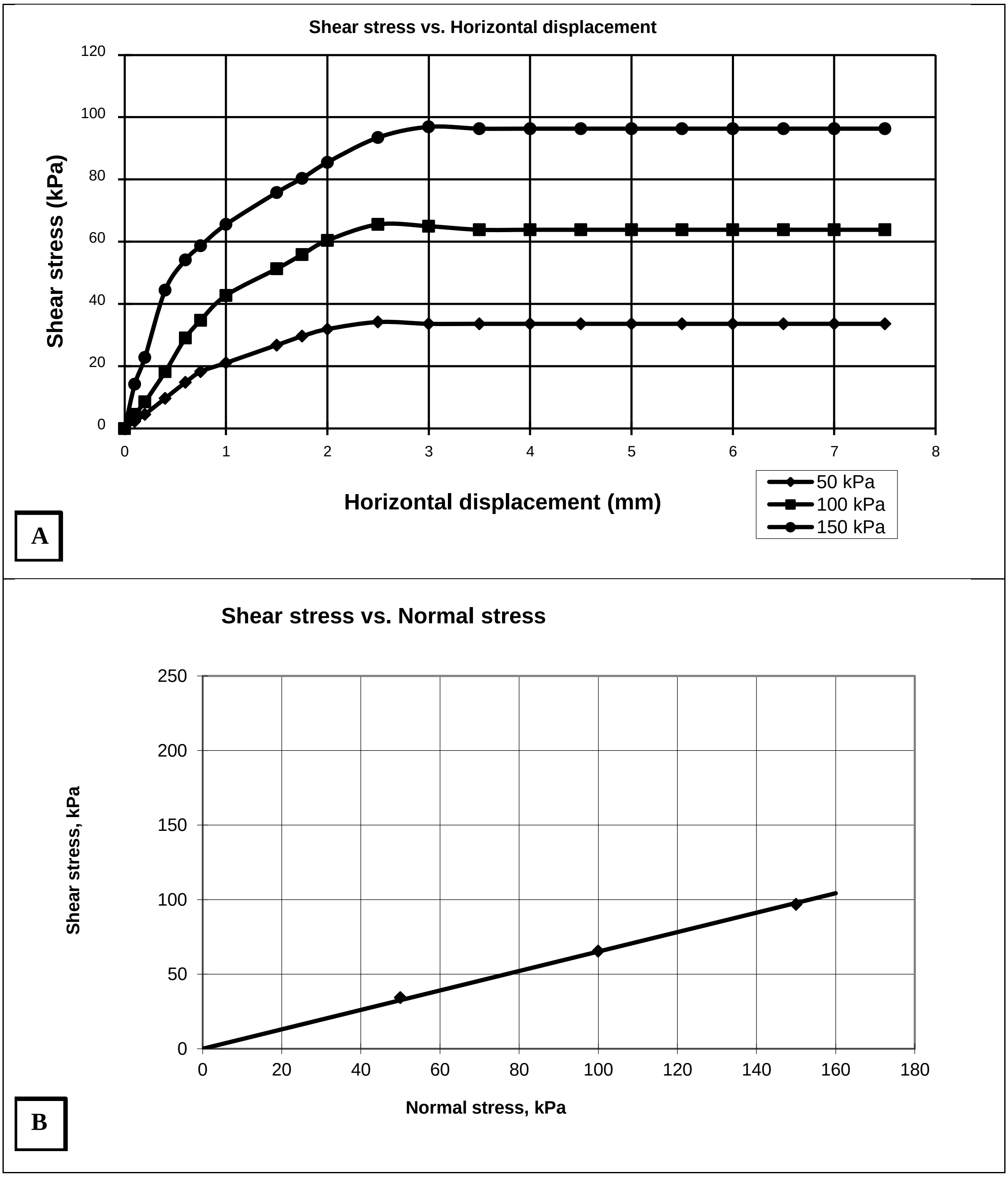


Figure B.5.40. Shows the relationship between the horizontal displacement (mm) & Shear stress (kPa) (A) and relationship between the Normal stress (kPa) & Shear stress (kPa) by Direct Shear test for contaminated sample T.P.Cs (100 m, 100 m) at depth (0.25 m) (B).

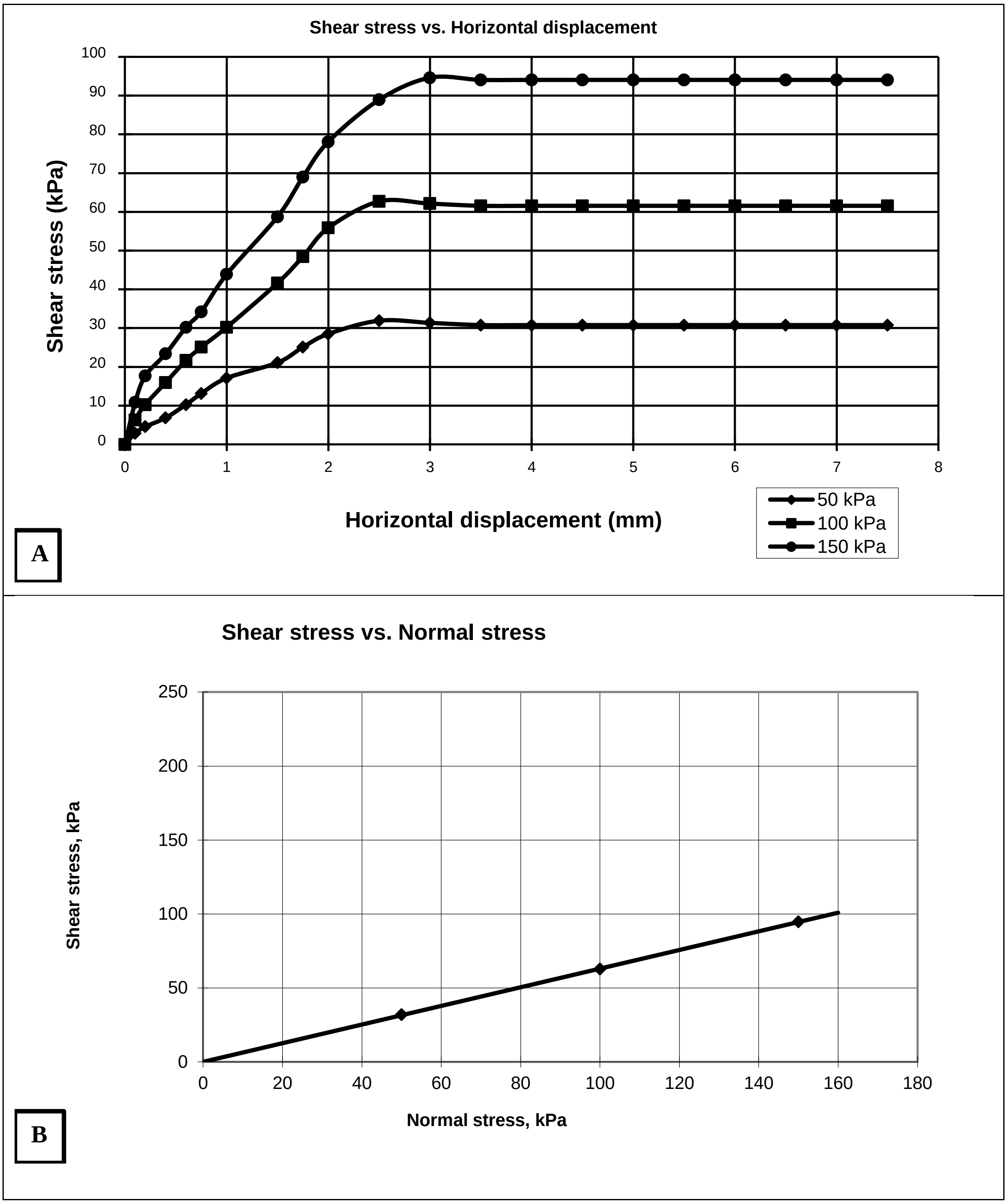


Figure B.5.41. Shows the relationship between the horizontal displacement (mm) & Shear stress (kPa) (A) and relationship between the Normal stress (kPa) & Shear stress (kPa) by Direct Shear test for contaminated sample T.P.Cs (100 m, 100 m) at depth (0.5 m) (B).

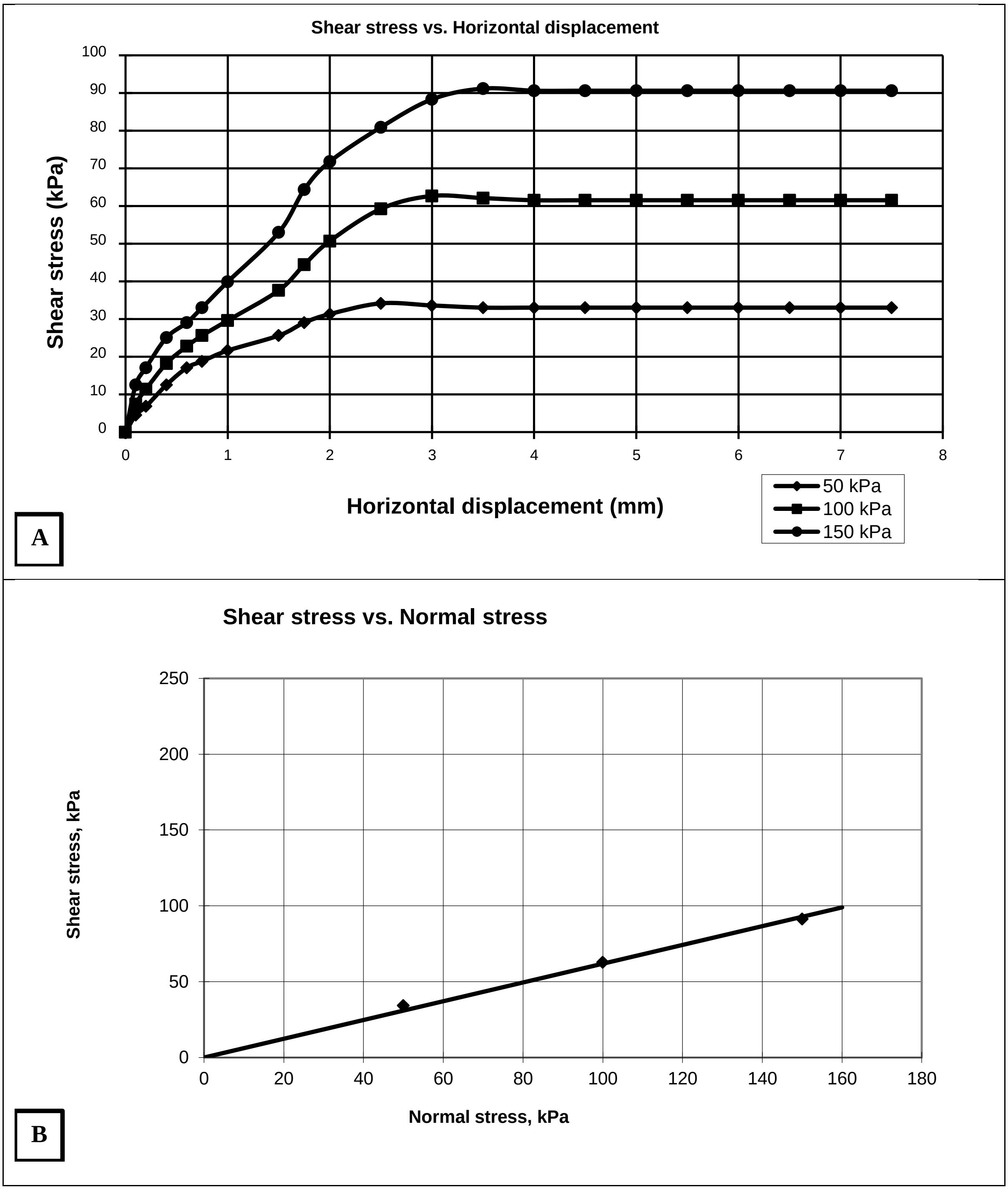


Figure B.5.42. Shows the relationship between the horizontal displacement (mm) & Shear stress (kPa) (A) and relationship between the Normal stress (kPa) & Shear stress (kPa) by Direct Shear test for contaminated sample T.P.Cs (100 m, 100 m) at depth (1.0 m) (B).

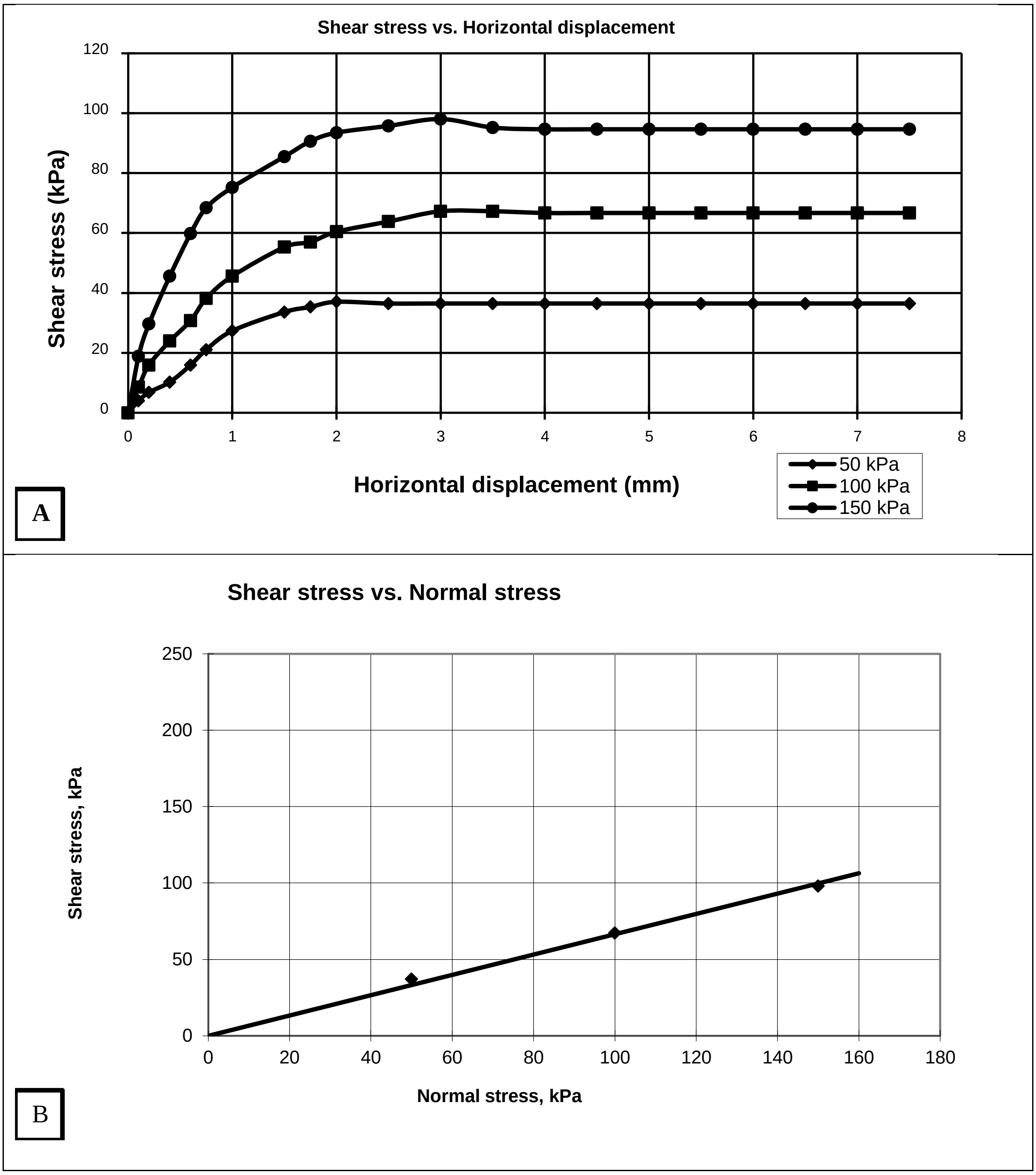


Figure B.5.43. Shows the relationship between the horizontal displacement (mm) & Shear stress (kPa) (A) and relationship between the Normal stress (kPa) & Shear stress (kPa) by Direct Shear test for contaminated sample T.P.Cs (100 m, 100 m) at depth (1.5 m) (B).

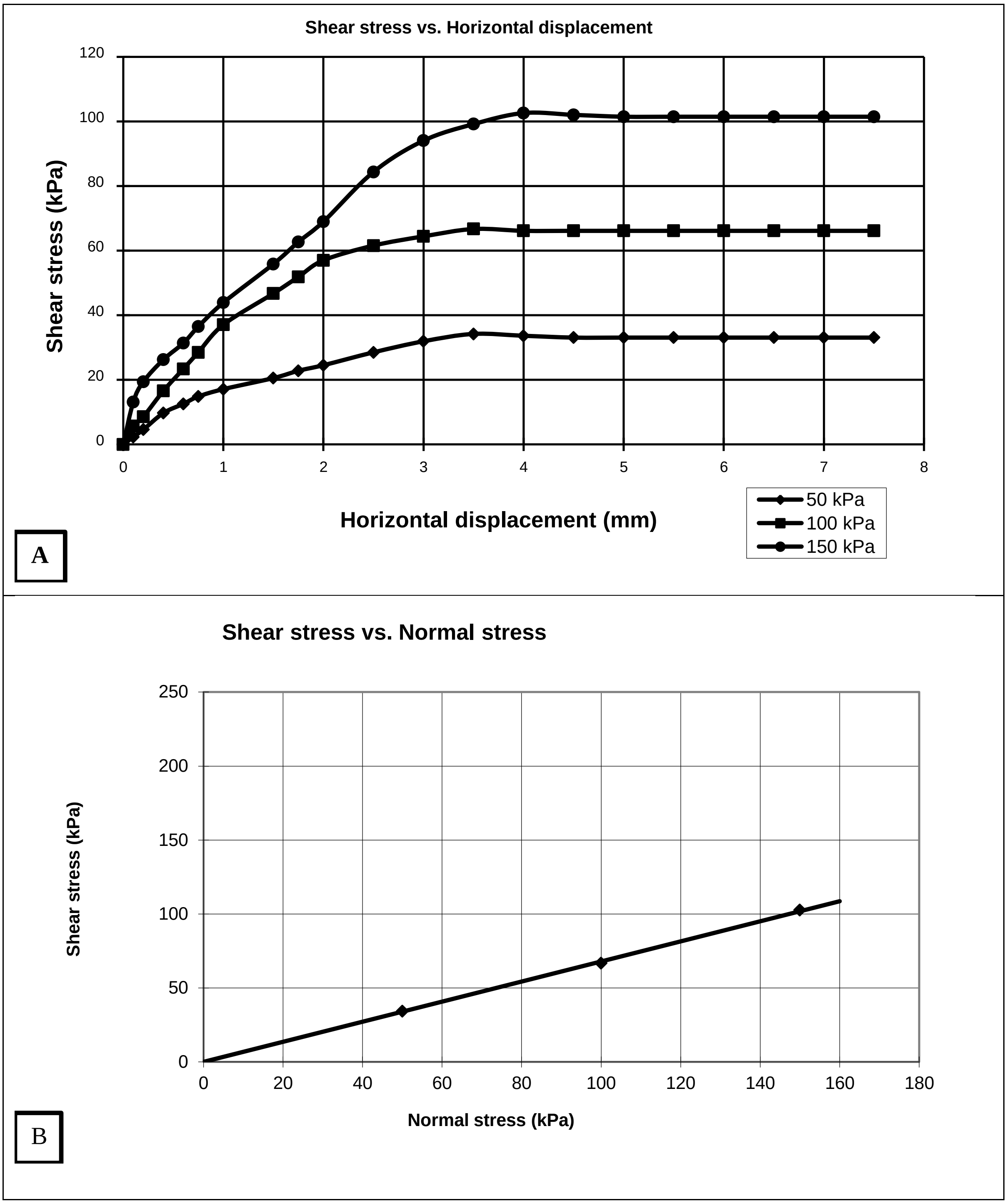


Figure B.5.44. Shows the relationship between the horizontal displacement (mm) & Shear stress (kPa) (A) and relationship between the Normal stress (kPa) & Shear stress (kPa) by Direct Shear test for contaminated sample T.P.Cs (100 m, 100 m) at depth (2.0 m) (B).

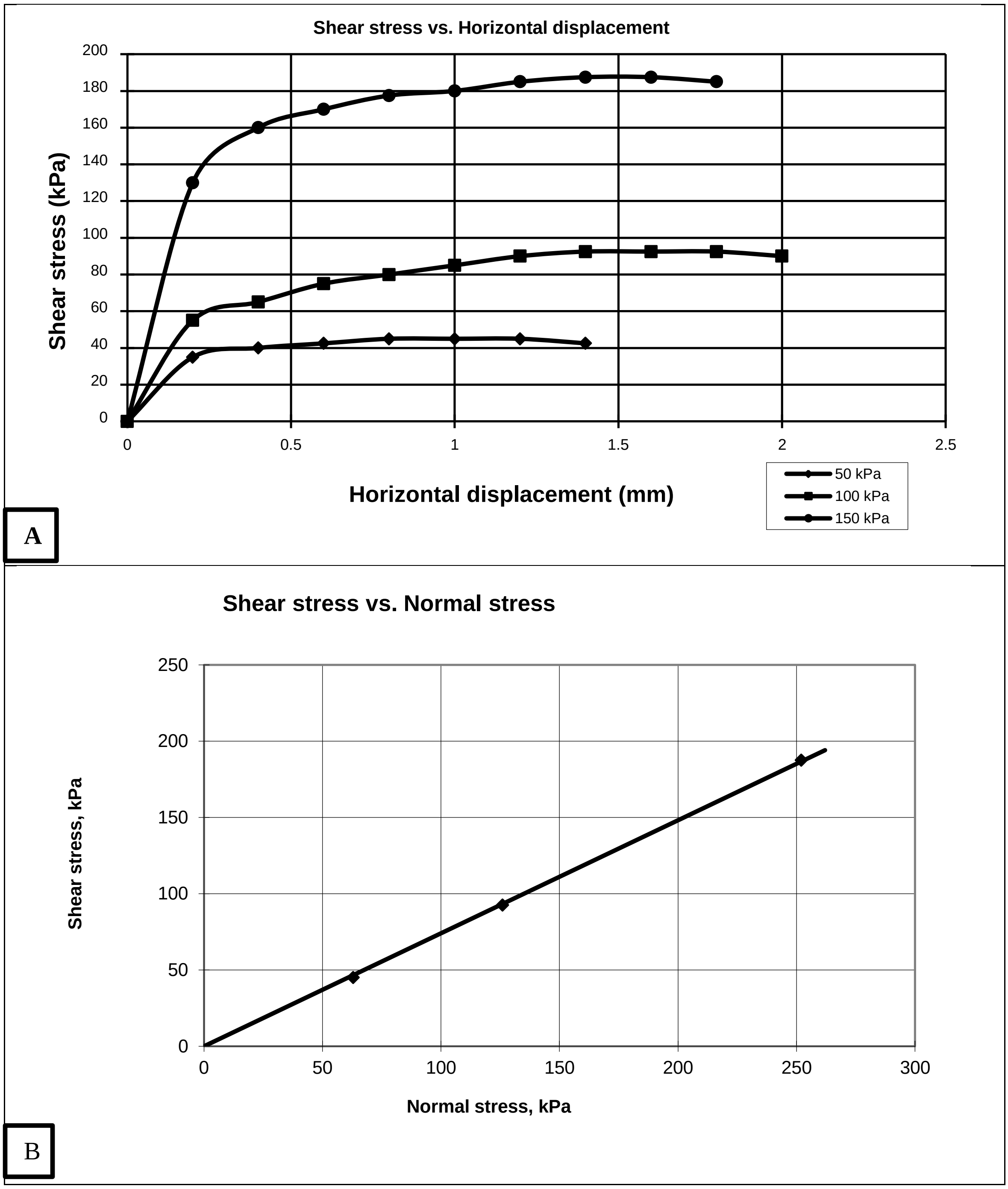


Figure B.5.45. Shows the relationship between the horizontal displacement (mm) & Shear stress (kPa) (A) and relationship between the Normal stress (kPa) & Shear stress (kPa) by Direct Shear test for non-contaminated sample T.P.Cs (0 m, 0 m) at depth (0.0 m) (B).

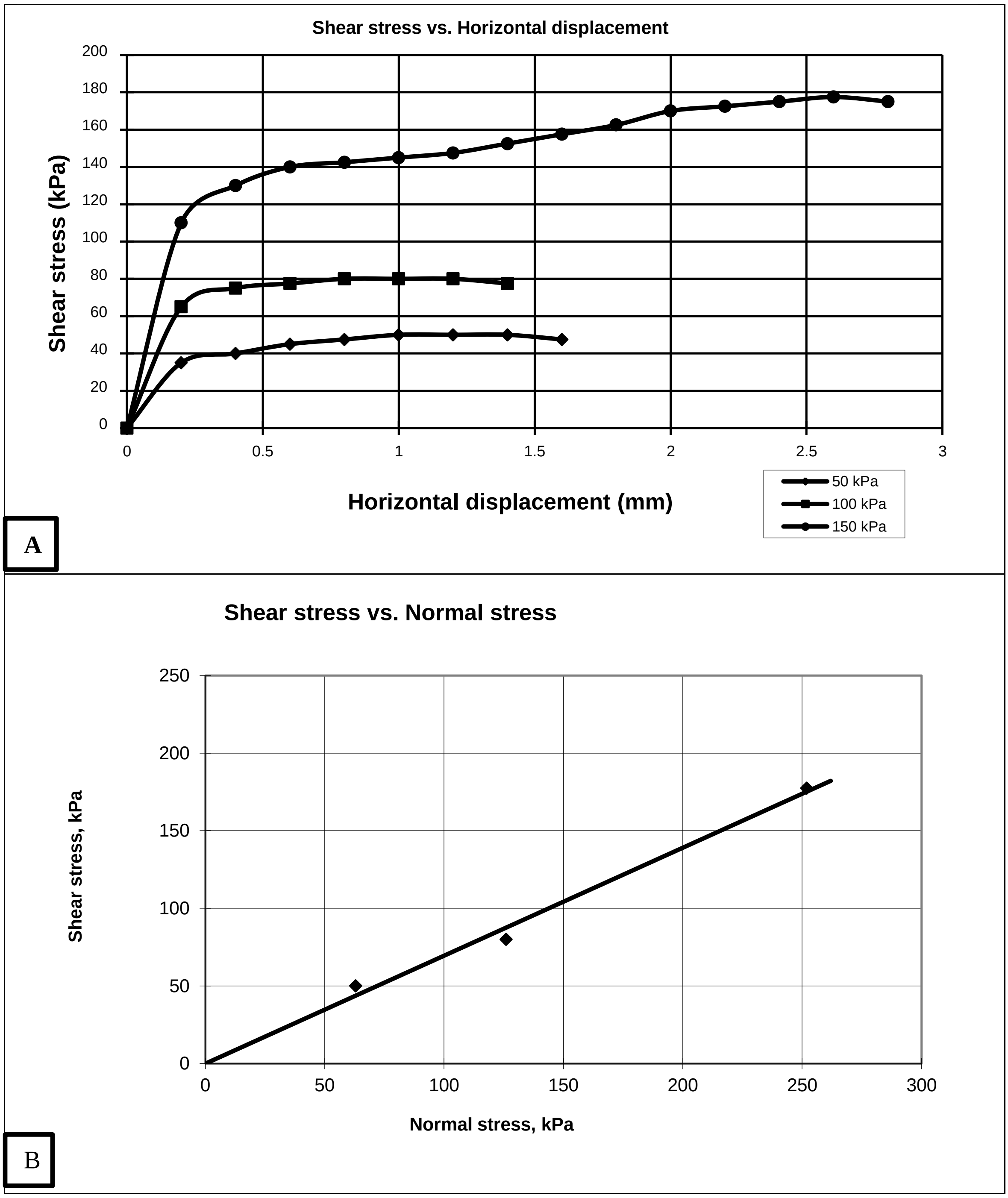


Figure B.5.46. Shows the relationship between the horizontal displacement (mm) & Shear stress (kPa) (A) and relationship between the Normal stress (kPa) & Shear stress (kPa) by Direct Shear test for non-contaminated sample T.P.Cs (0 m, 0 m) at depth (0.25 m) (B).

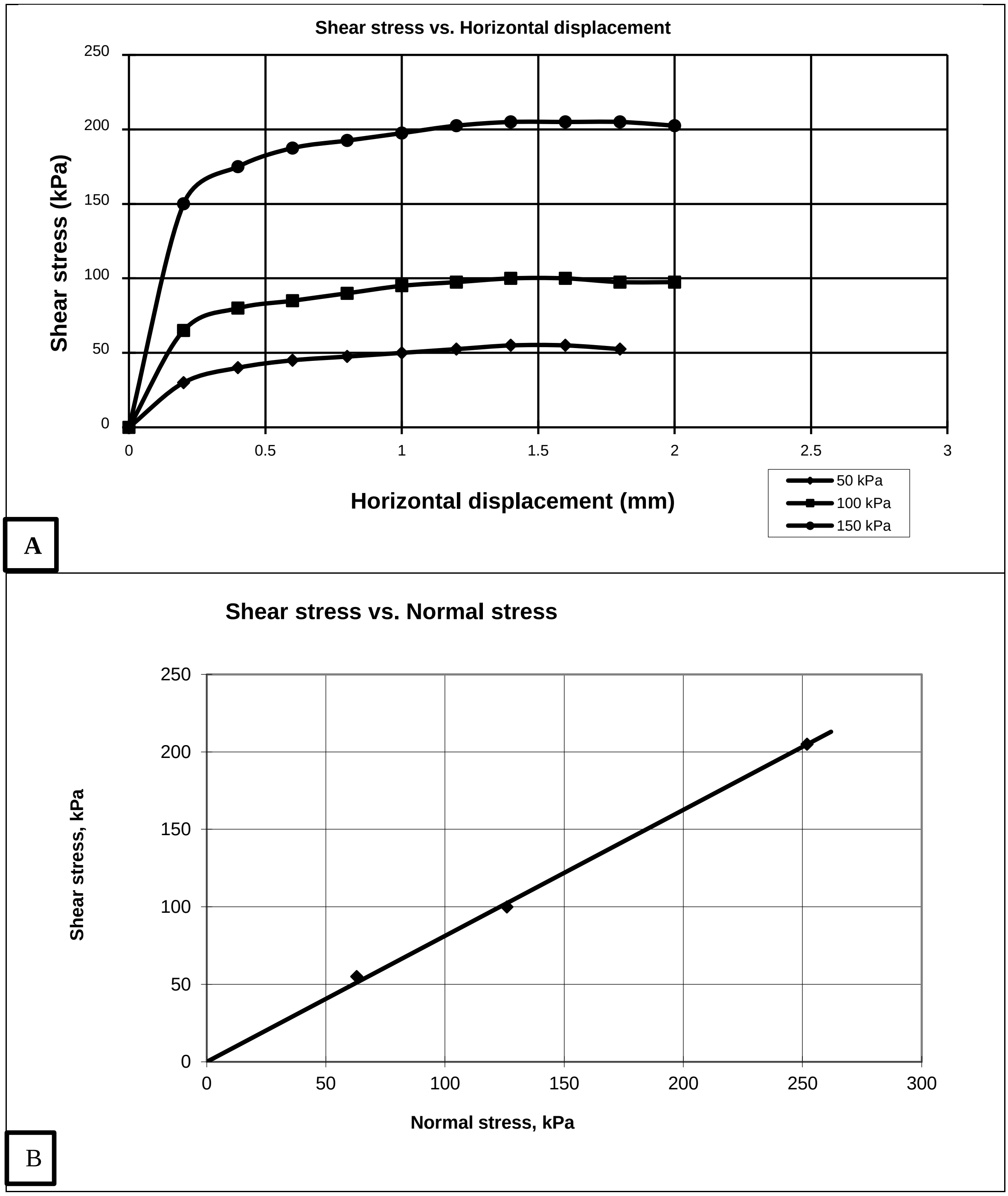


Figure B.5.47. Shows the relationship between the horizontal displacement (mm) & Shear stress (kPa) (A) and relationship between the Normal stress (kPa) & Shear stress (kPa) by Direct Shear test for non-contaminated sample T.P.Cs (0 m, 0 m) at depth (0.5 m) (B).

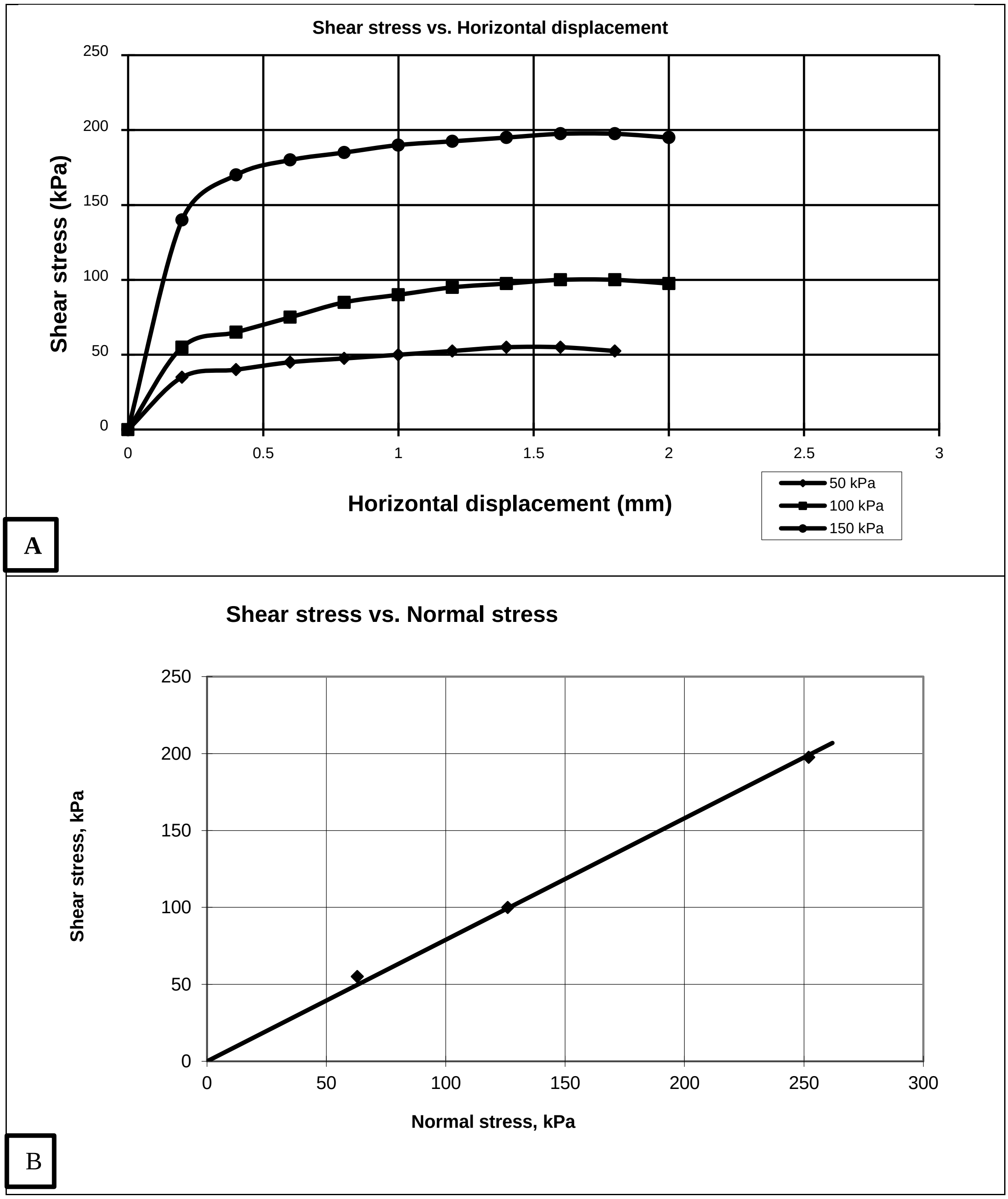


Figure B.5.48. Shows the relationship between the horizontal displacement (mm) & Shear stress (kPa) (A) and relationship between the Normal stress (kPa) & Shear stress (kPa) by Direct Shear test for non-contaminated sample T.P.Cs (0 m, 0 m) at depth (1.0 m) (B).

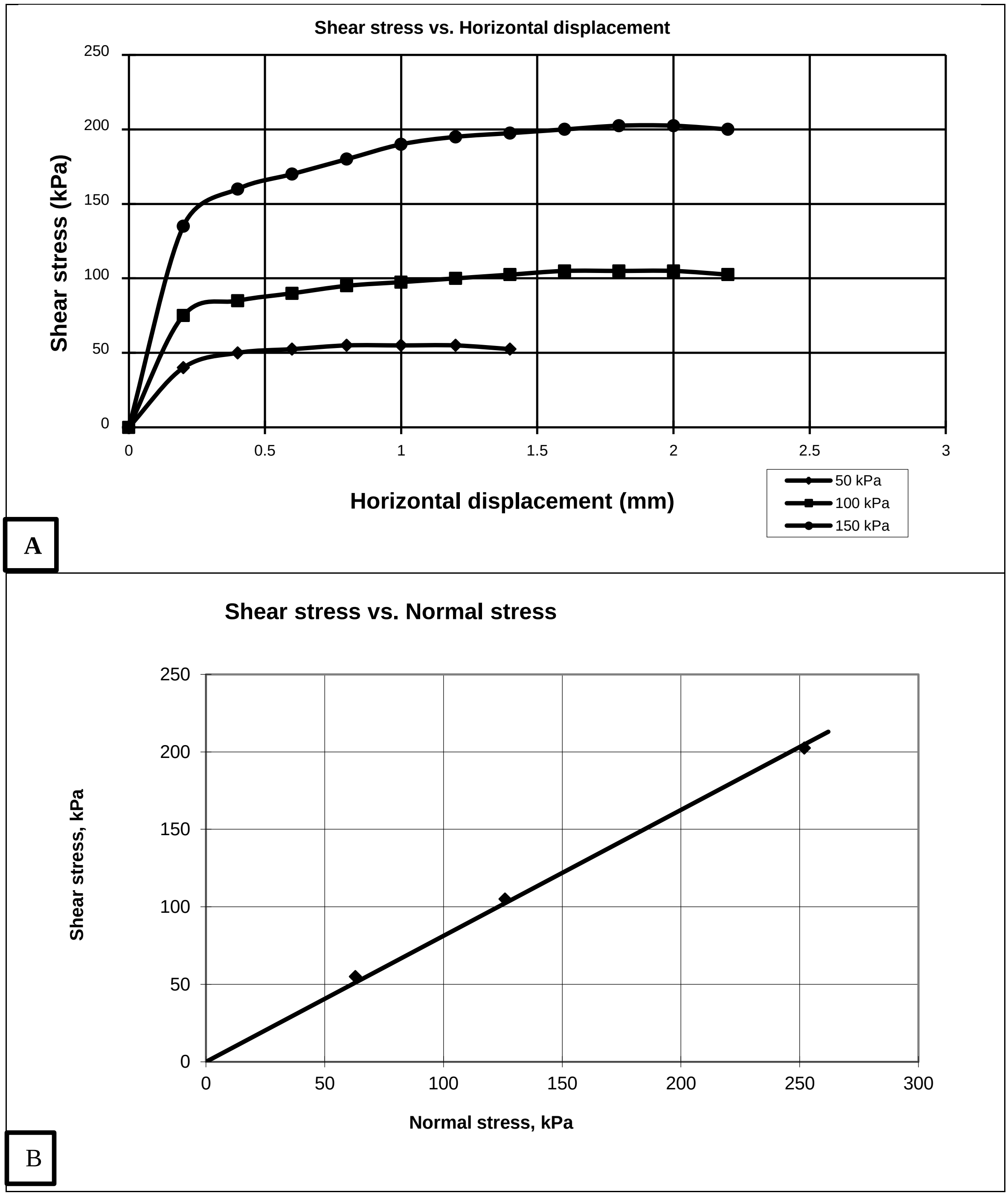


Figure B.5.49. Shows the relationship between the horizontal displacement (mm) & Shear stress (kPa) (A) and relationship between the Normal stress (kPa) & Shear stress (kPa) by Direct Shear test for non-contaminated sample T.P.Cs (0 m, 0 m) at depth (1.5 m) (B).

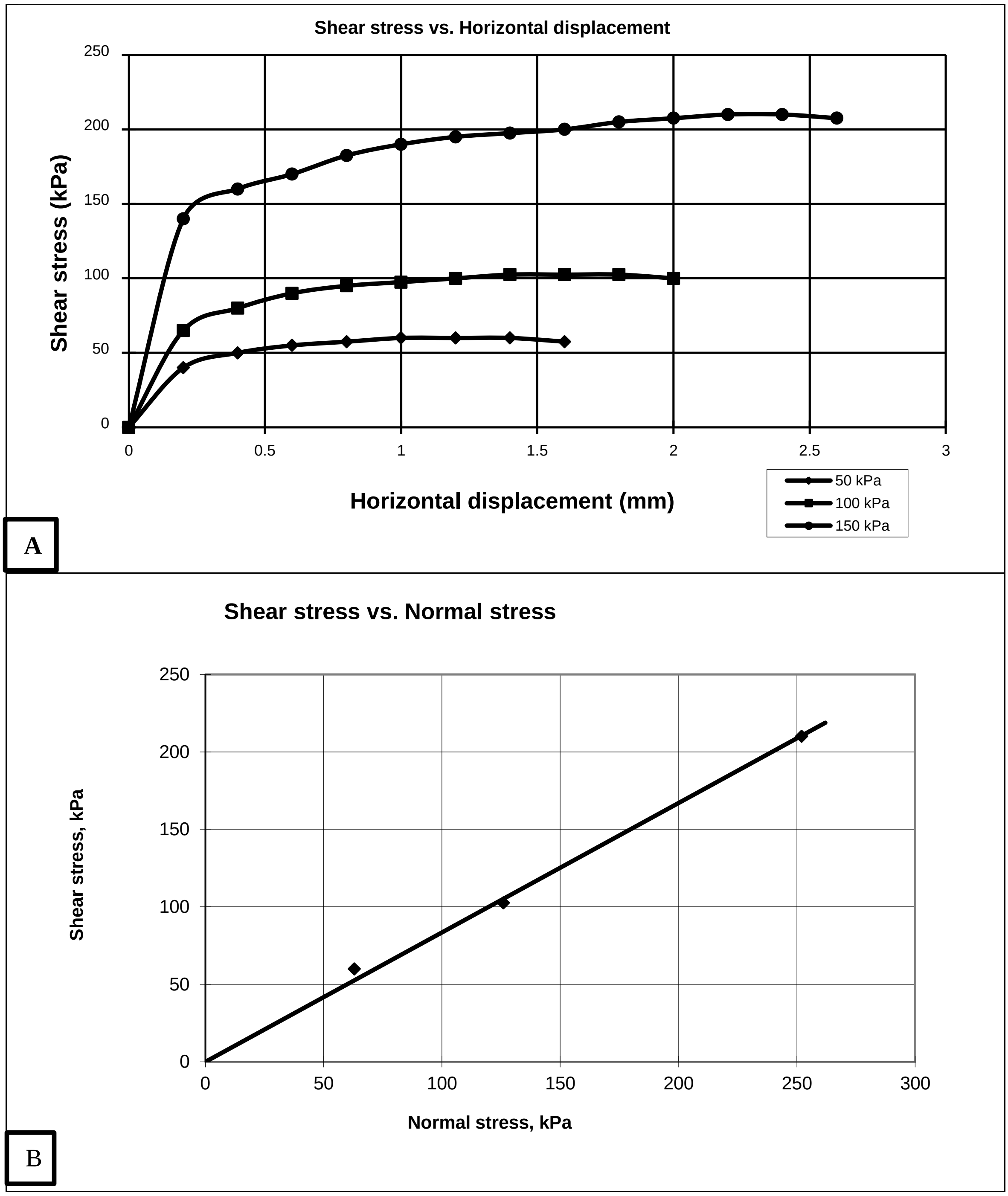


Figure B.5.50. Shows the relationship between the horizontal displacement (mm) & Shear stress (kPa) (A) and relationship between the Normal stress (kPa) & Shear stress (kPa) by Direct Shear test for non-contaminated sample T.P.Cs (0 m, 0 m) at depth (2.0 m) (B).

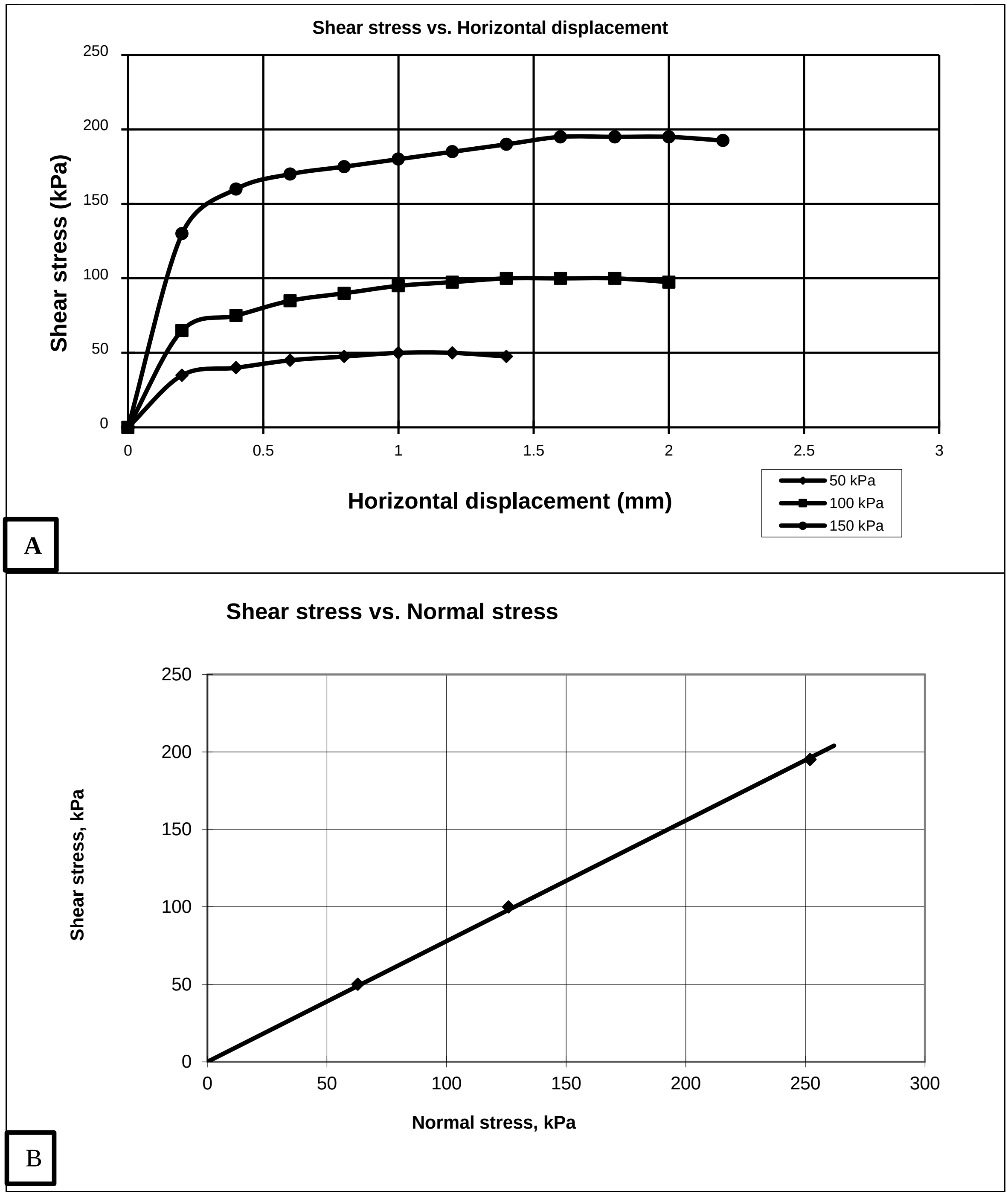


Figure B.5.51. Shows the relationship between the horizontal displacement (mm) & Shear stress (kPa) (A) and relationship between the Normal stress (kPa) & Shear stress (kPa) by Direct Shear test for non-contaminated sample T.P.Cs (50 m, 50 m) at depth (0.0 m) (B).

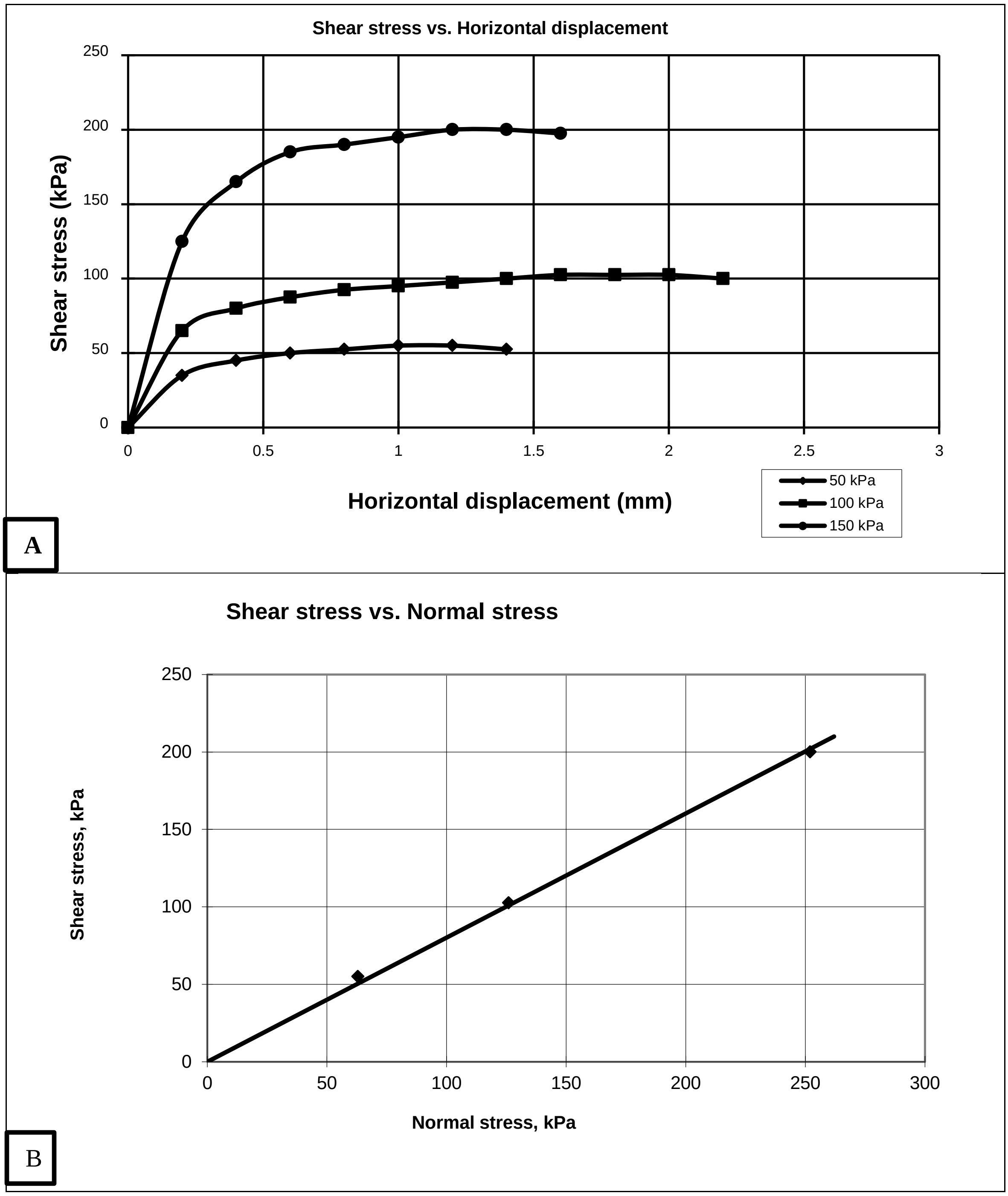


Figure B.5.52. Shows the relationship between the horizontal displacement (mm) & Shear stress (kPa) (A) and relationship between the Normal stress (kPa) & Shear stress (kPa) by Direct Shear test for non-contaminated sample T.P.Cs (50 m, 50 m) at depth (0.25 m) (B).

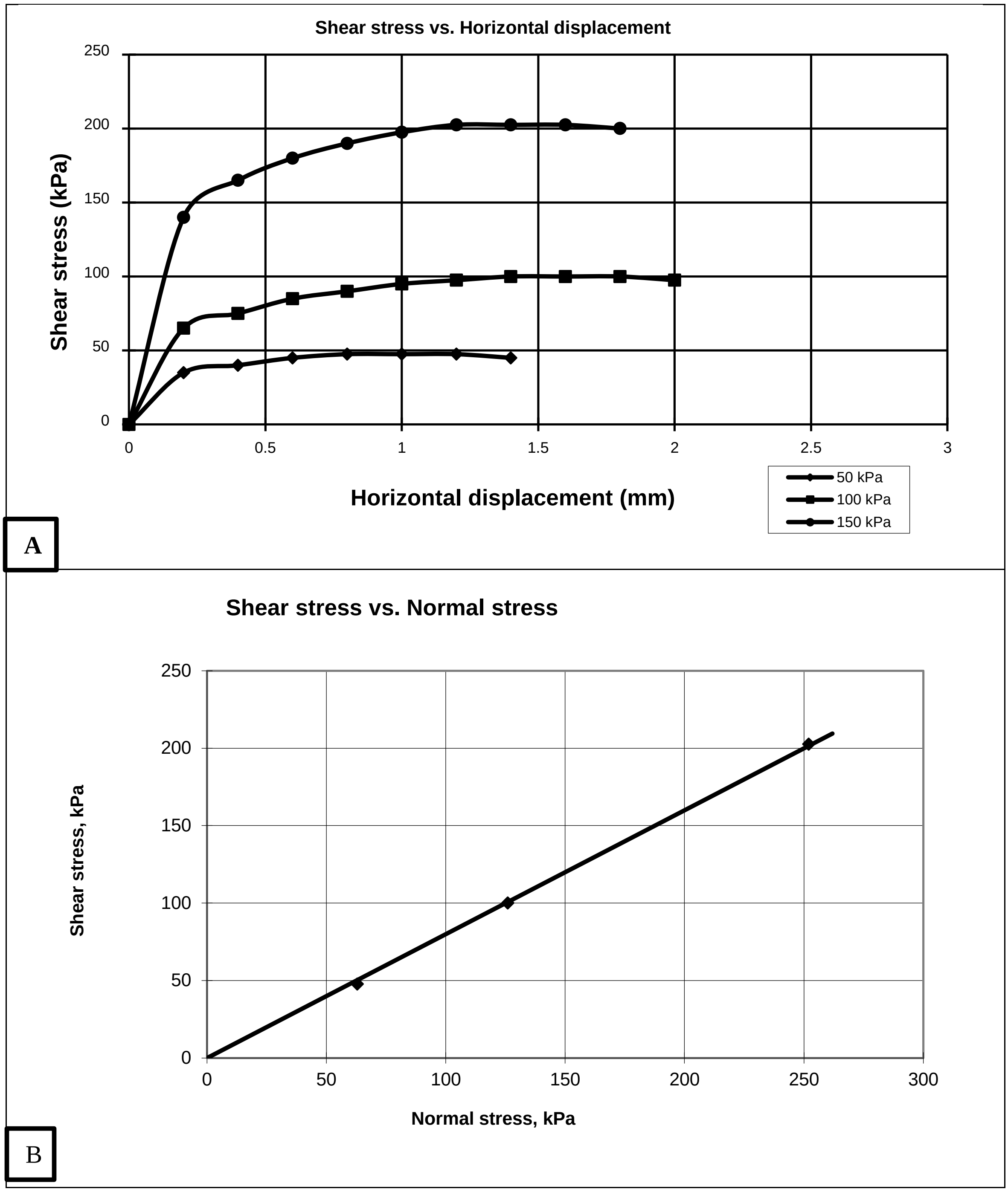


Figure B.5.53. Shows the relationship between the horizontal displacement (mm) & Shear stress (kPa) (A) and relationship between the Normal stress (kPa) & Shear stress (kPa) by Direct Shear test for non-contaminated sample T.P.Cs (50 m, 50 m) at depth (0.5 m) (B).

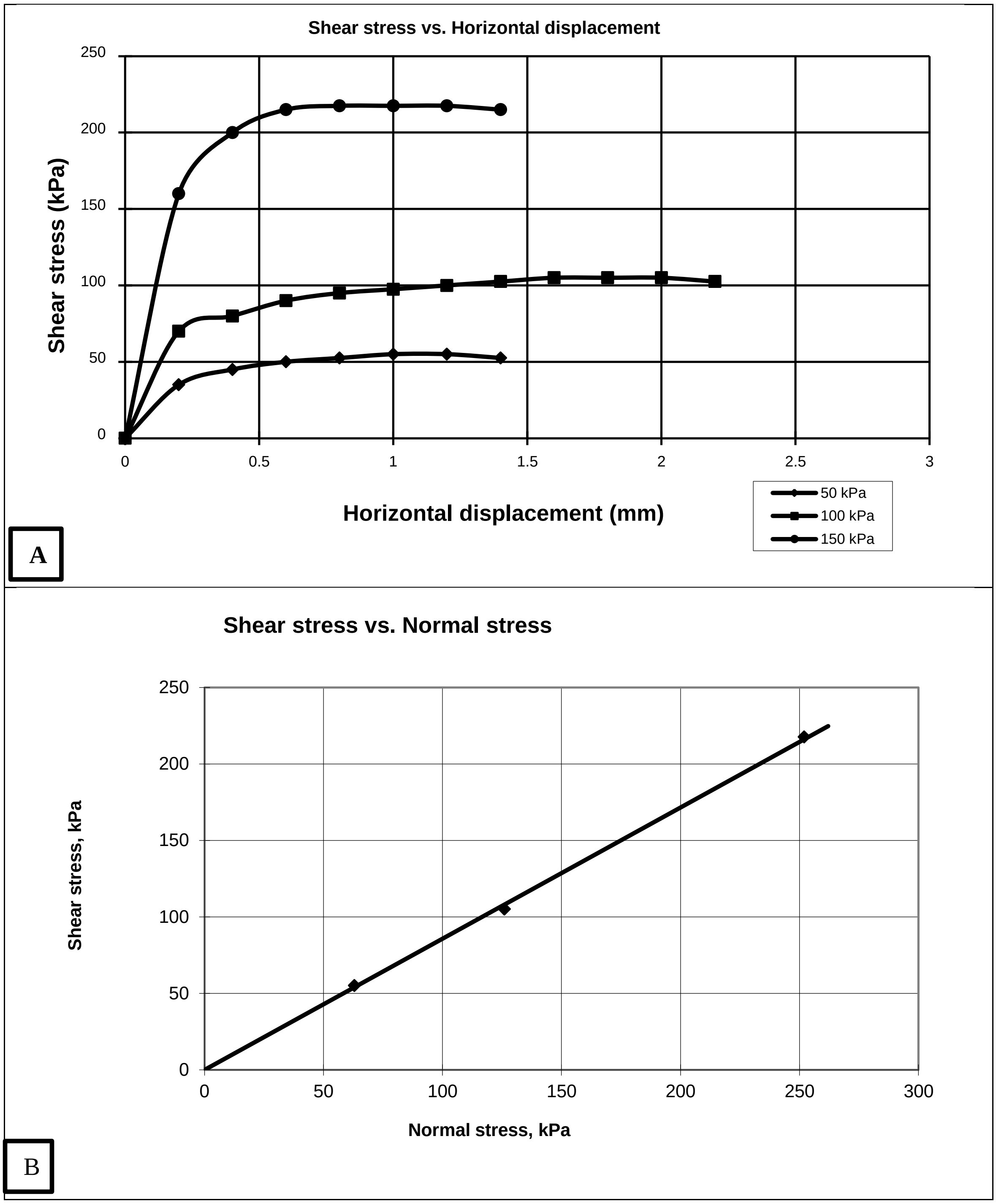


Figure B.5.54. Shows the relationship between the horizontal displacement (mm) & Shear stress (kPa) (A) and relationship between the Normal stress (kPa) & Shear stress (kPa) by Direct Shear test for non-contaminated sample T.P.Cs (50 m, 50 m) at depth (1.0 m) (B).

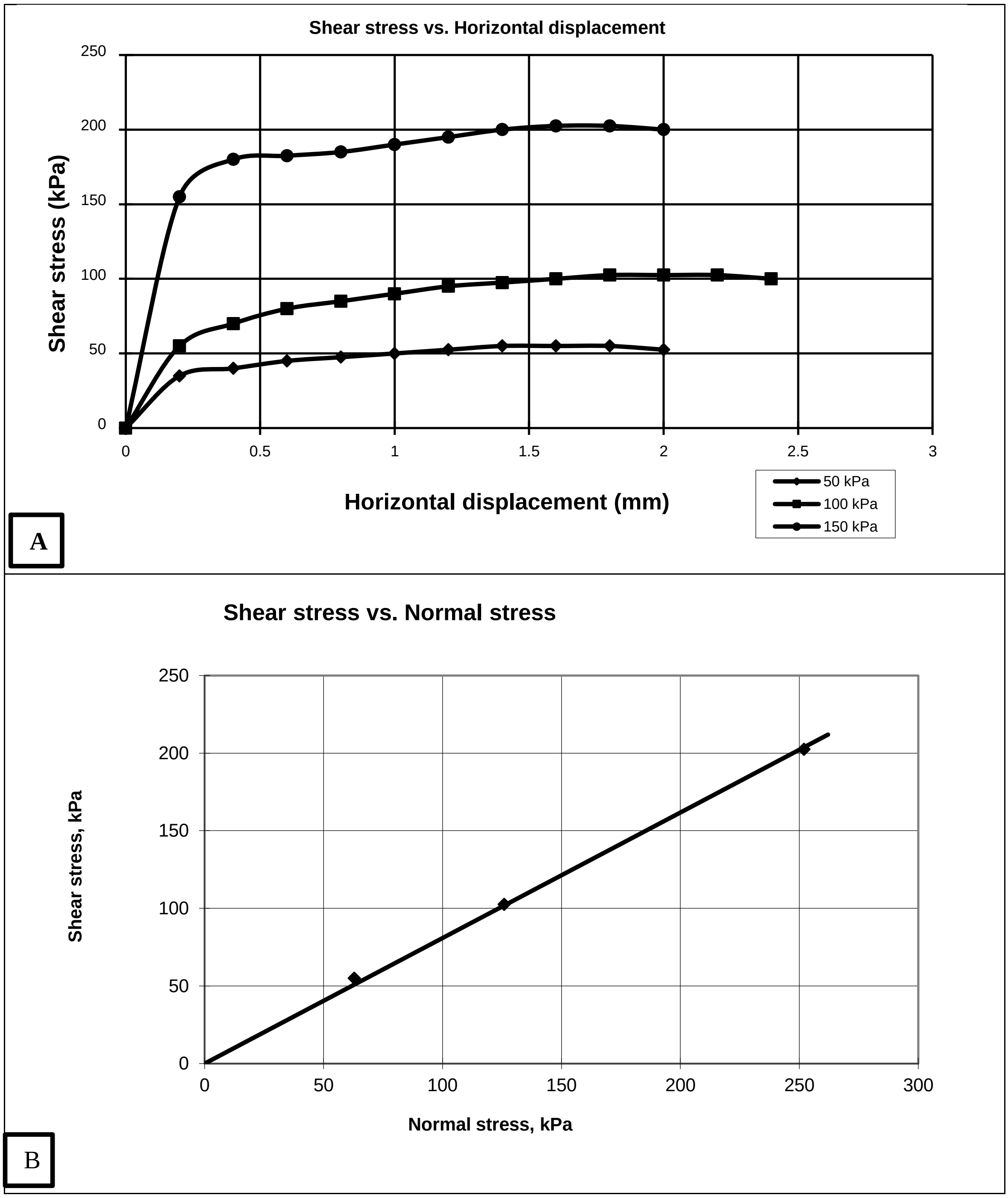


Figure B.5.55. Shows the relationship between the horizontal displacement (mm) & Shear stress (kPa) (A) and relationship between the Normal stress (kPa) & Shear stress (kPa) by Direct Shear test for non-contaminated sample T.P.Cs (50 m, 50 m) at depth (1.5 m) (B).

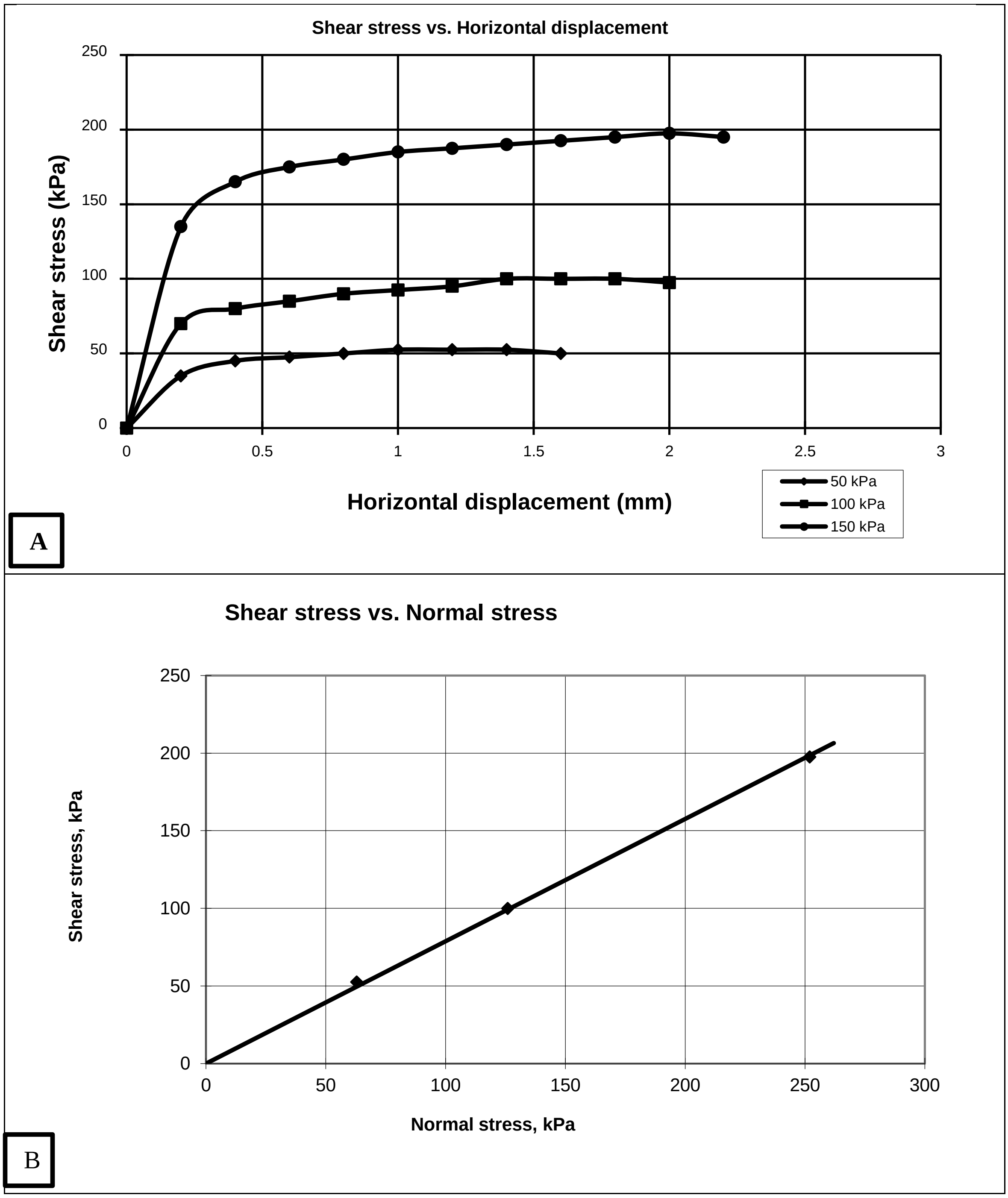


Figure B.5.56. Shows the relationship between the horizontal displacement (mm) & Shear stress (kPa) (A) and relationship between the Normal stress (kPa) & Shear stress (kPa) by Direct Shear test for non-contaminated sample T.P.Cs (50 m, 50 m) at depth (2.0 m) (B).

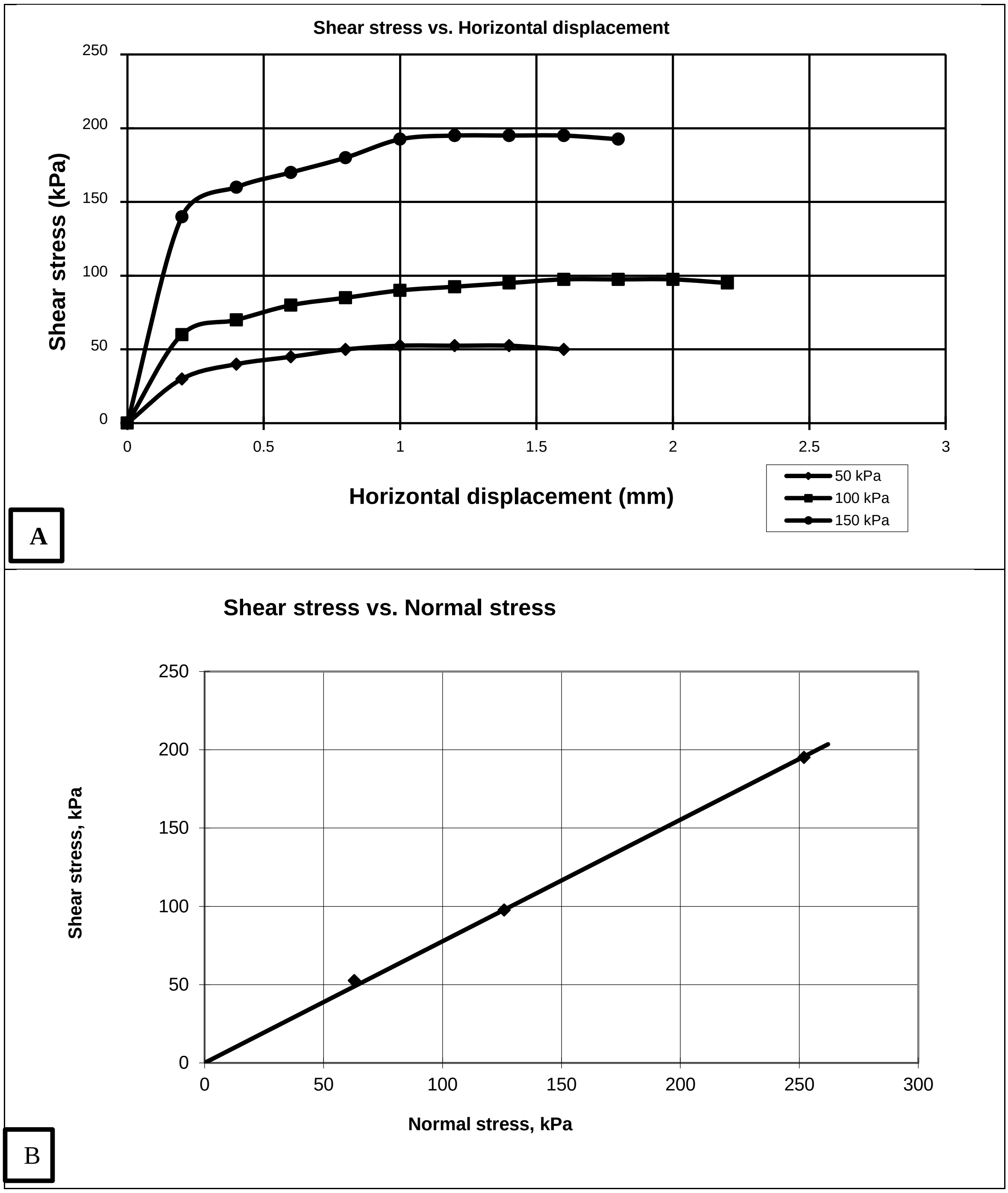


Figure B.5.57. Shows the relationship between the horizontal displacement (mm) & Shear stress (kPa) (A) and relationship between the Normal stress (kPa) & Shear stress (kPa) by Direct Shear test for non-contaminated sample T.P.Cs (100 m, 100 m) at depth (0.0 m) (B).

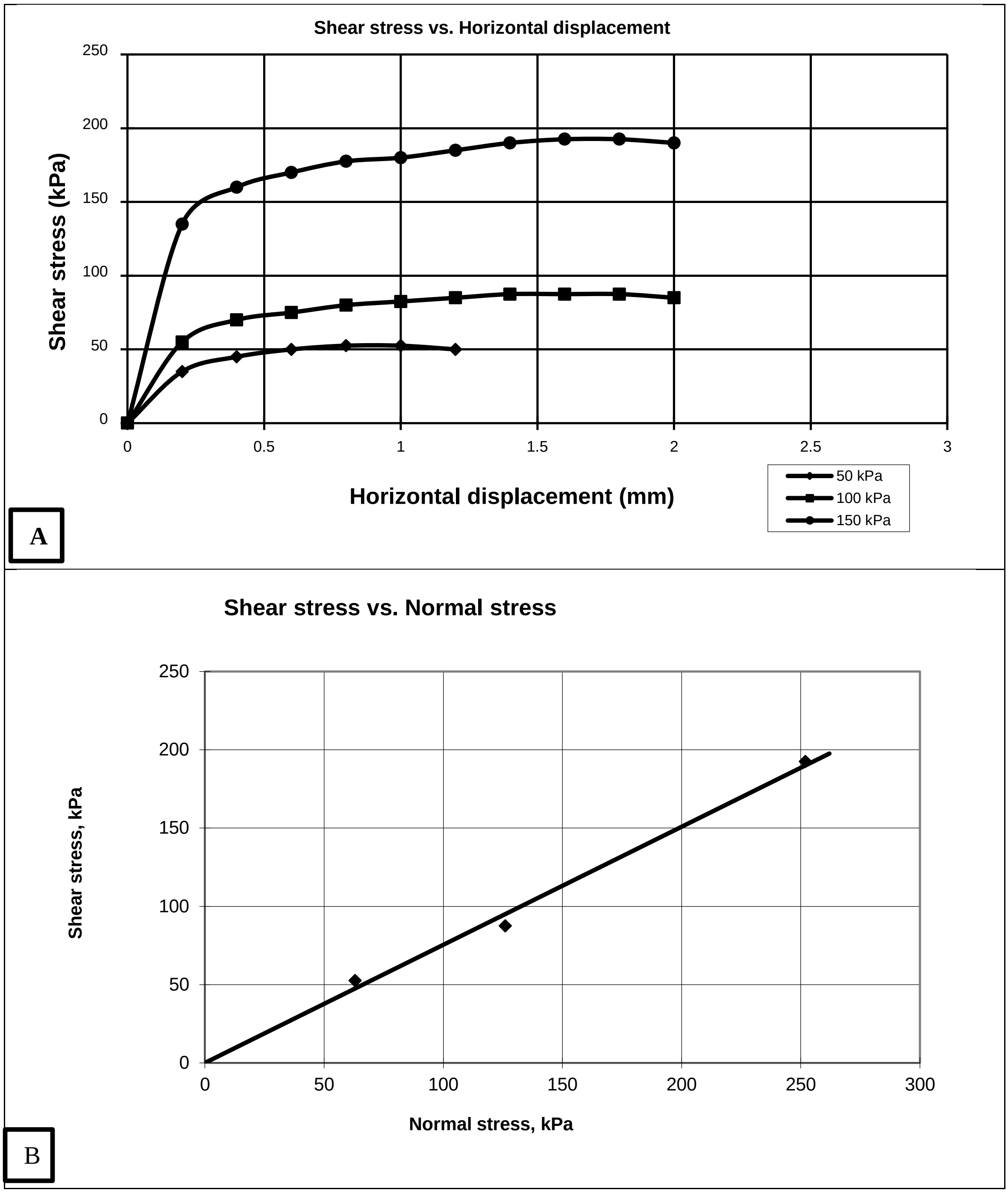


Figure B.5.58. Shows the relationship between the horizontal displacement (mm) & Shear stress (kPa) (A) and relationship between the Normal stress (kPa) & Shear stress (kPa) by Direct Shear test for non-contaminated sample T.P.Cs (100 m, 100 m) at depth (0.25 m) (B).

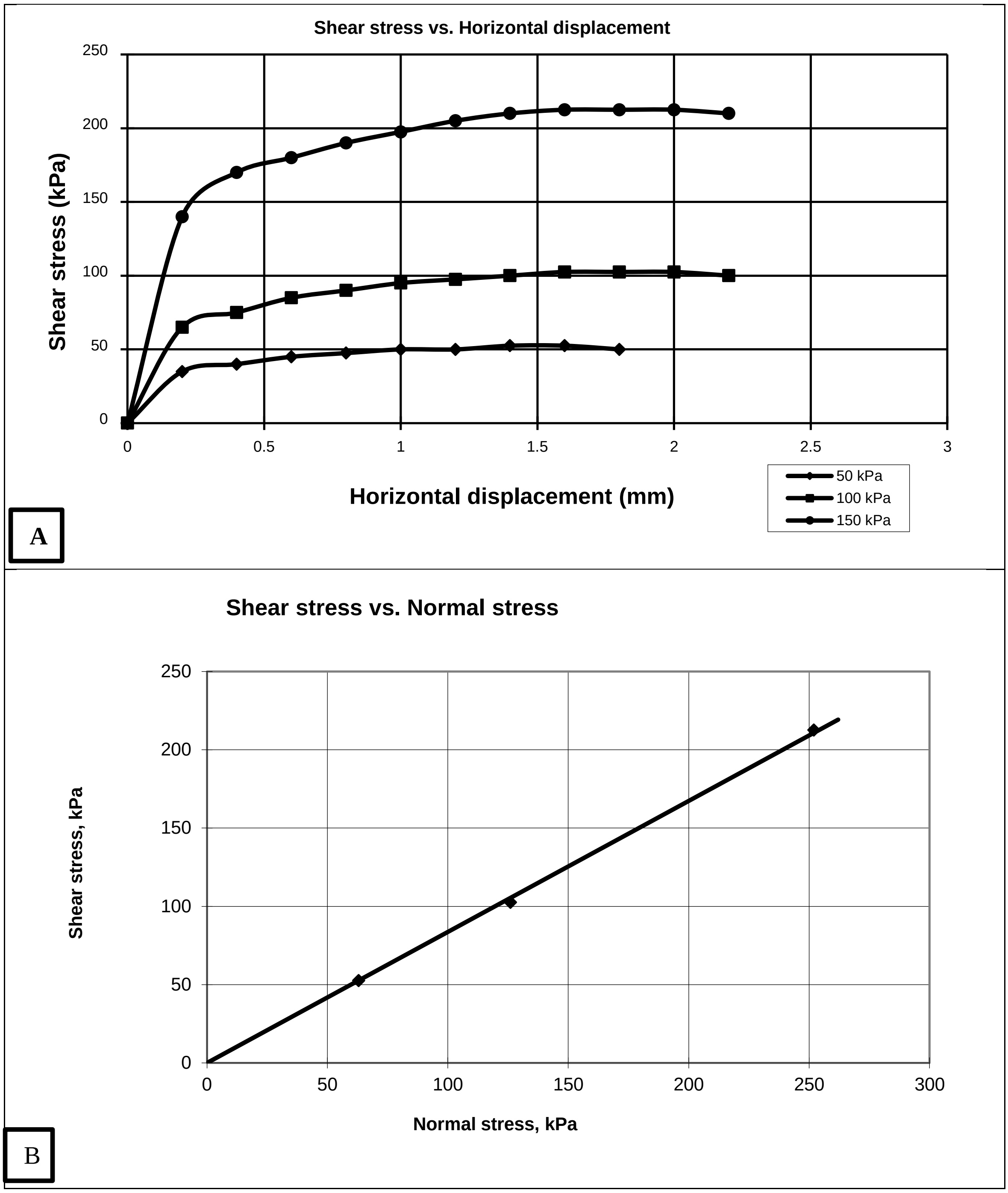


Figure B.5.59. Shows the relationship between the horizontal displacement (mm) & Shear stress (kPa) (A) and relationship between the Normal stress (kPa) & Shear stress (kPa) by Direct Shear test for non-contaminated sample T.P.Cs (100 m, 100 m) at depth (0.5 m) (B).

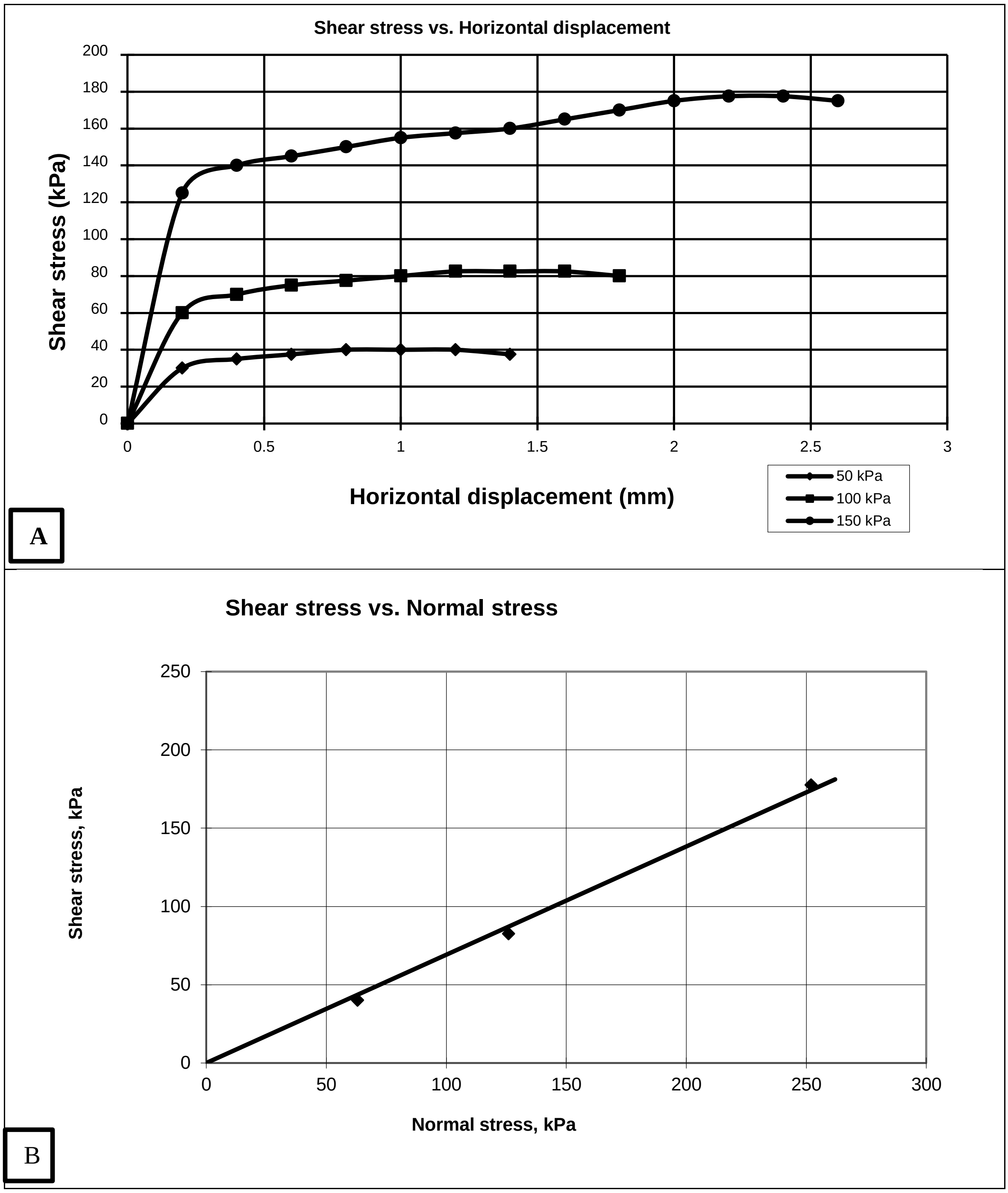


Figure B.5.60. Shows the relationship between the horizontal displacement (mm) & Shear stress (kPa) (A) and relationship between the Normal stress (kPa) & Shear stress (kPa) by Direct Shear test for non-contaminated sample T.P.Cs (100 m, 100 m) at depth (1.0 m) (B).

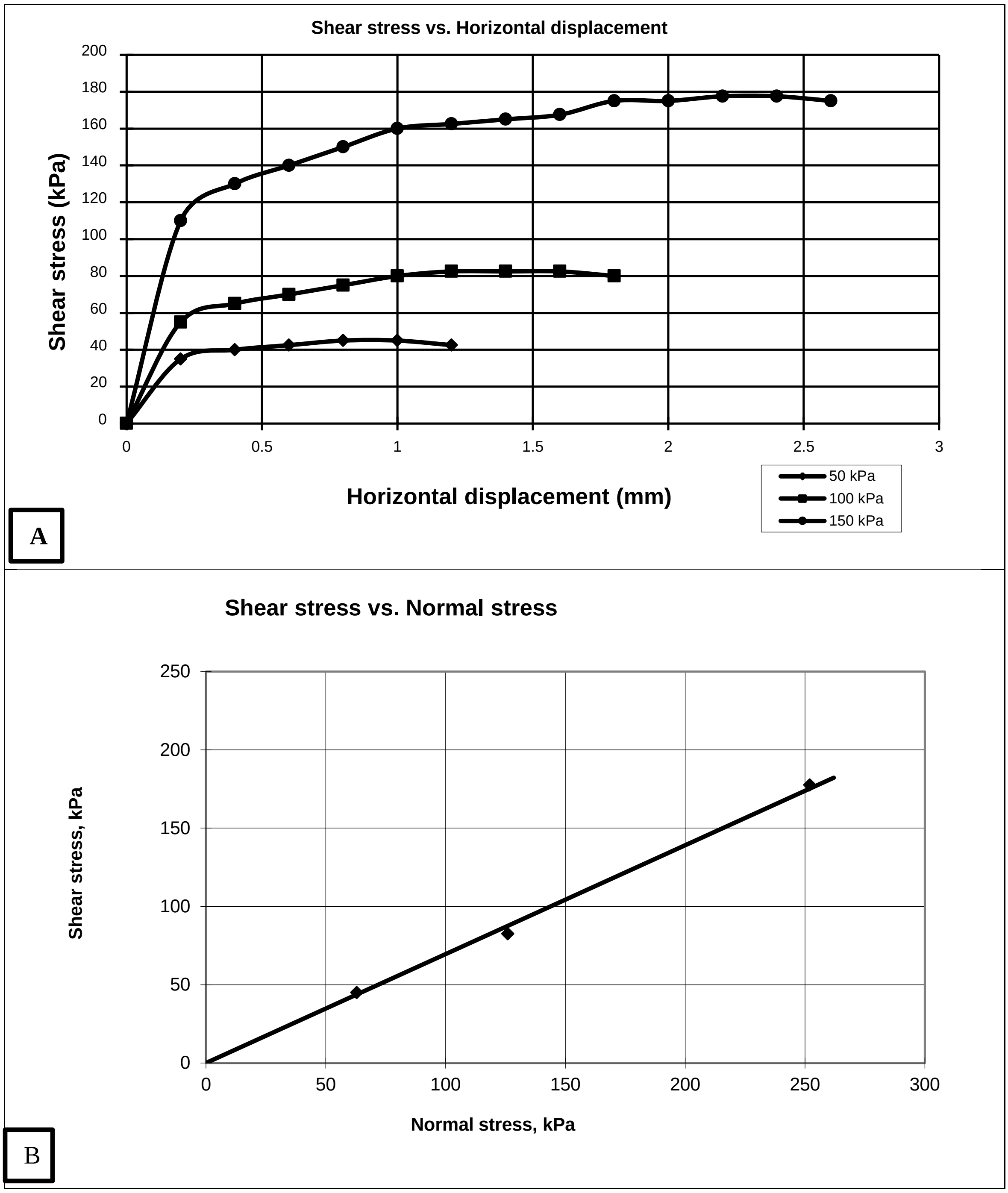


Figure B.5.61. Shows the relationship between the horizontal displacement (mm) & Shear stress (kPa) (A) and relationship between the Normal stress (kPa) & Shear stress (kPa) by Direct Shear test for non-contaminated sample T.P.Cs (100 m, 100 m) at depth (1.5 m) (B).

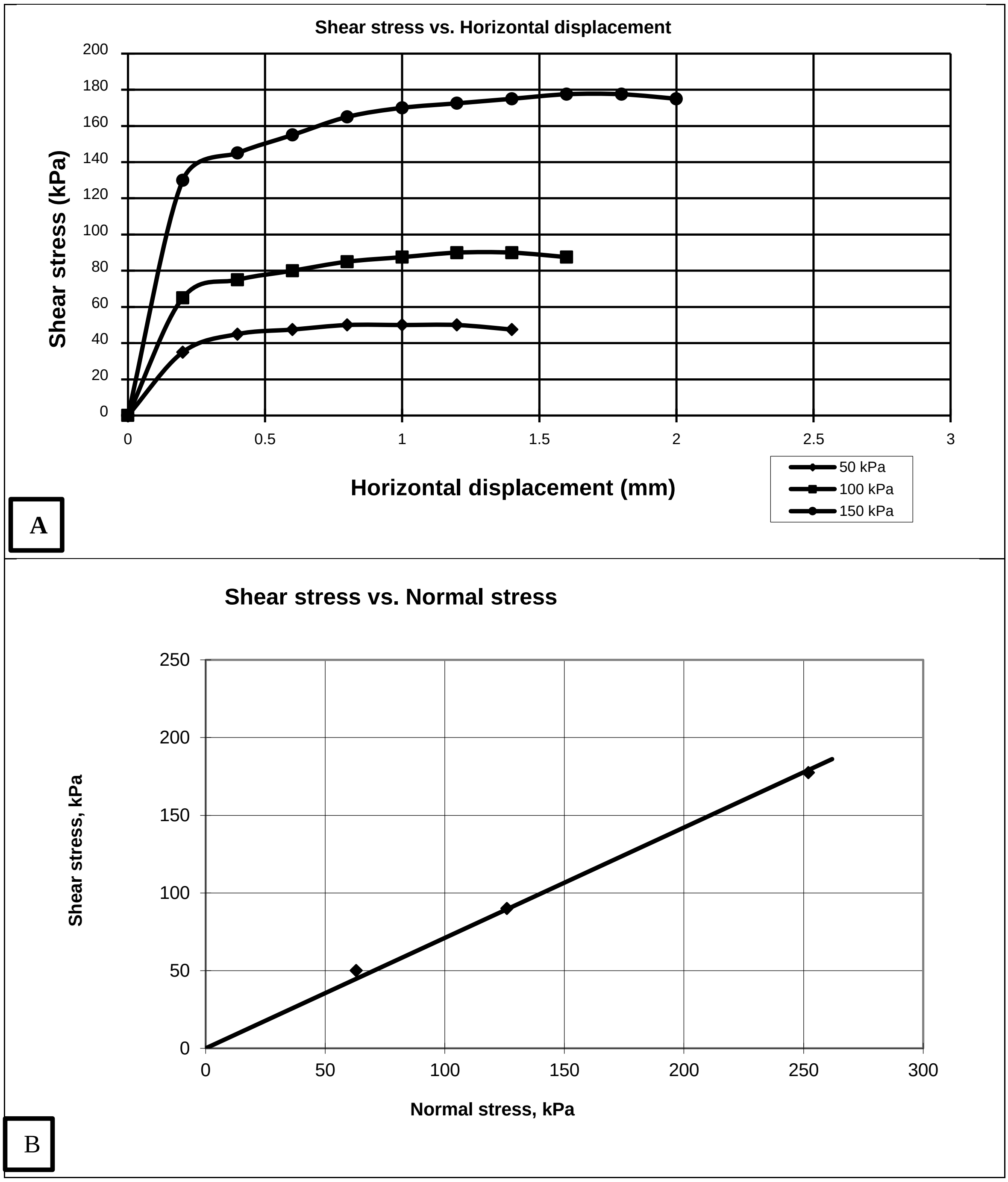
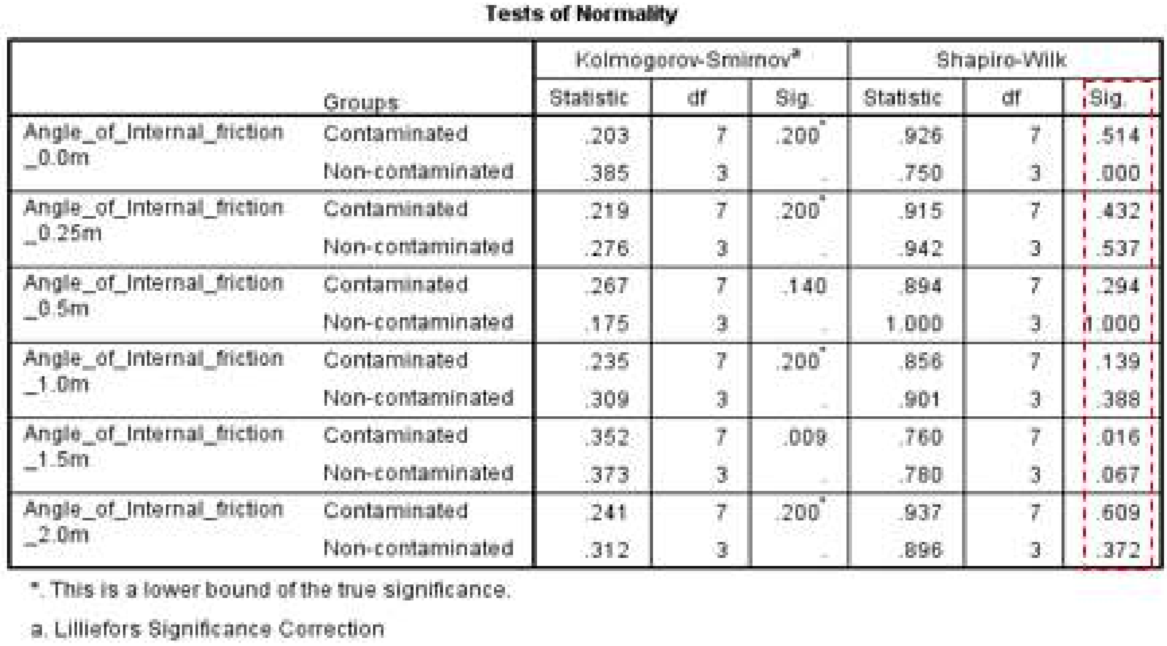


Figure B.5.62. Shows the relationship between the horizontal displacement (mm) & Shear stress (kPa) (A) and relationship between the Normal stress (kPa) & Shear stress (kPa) by Direct Shear test for non-contaminated sample T.P.Cs (100 m, 100 m) at depth (2.0 m) (B).

Table B.5.26. The significant p-values via normality Shapiro-Wilk test indicate that the angle of internal friction (φ) values of the soil at contaminated and non-contaminated sites follow normal distribution.



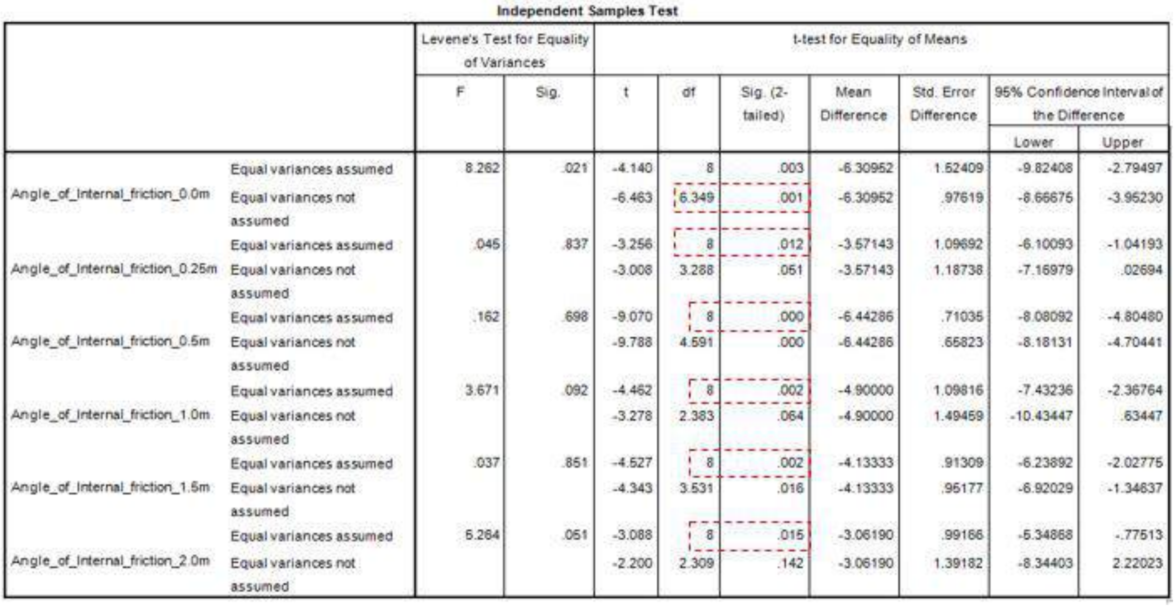
Tests of Normality

	Groups	Kolmogorov-Smirnov[a] Statistic	df	Sig.	Shapiro-Wilk Statistic	df	Sig.
Angle_of_Internal_friction_0.0m	Contaminated	.203	7	.200*	.926	7	.514
	Non-contaminated	.385	3	.	.750	3	.000
Angle_of_Internal_friction_0.25m	Contaminated	.219	7	.200*	.915	7	.432
	Non-contaminated	.276	3	.	.942	3	.537
Angle_of_Internal_friction_0.5m	Contaminated	.267	7	.140	.894	7	.294
	Non-contaminated	.175	3	.	1.000	3	1.000
Angle_of_Internal_friction_1.0m	Contaminated	.235	7	.200*	.856	7	.139
	Non-contaminated	.309	3	.	.901	3	.388
Angle_of_Internal_friction_1.5m	Contaminated	.352	7	.009	.760	7	.016
	Non-contaminated	.373	3	.	.780	3	.067
Angle_of_Internal_friction_2.0m	Contaminated	.241	7	.200*	.937	7	.609
	Non-contaminated	.312	3	.	.896	3	.372

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Table B.5.27. Indicates the significant differences of the angle of internal friction (φ) variable in the soil at six different depths between contaminated and non-contaminated sites.



Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference Lower	Upper
Angle_of_Internal_friction_0.0m	Equal variances assumed	8.262	.021	-4.140	8	.003	-6.30952	1.52409	-9.82408	-2.79497
	Equal variances not assumed			-6.463	6.349	.001	-6.30952	.97619	-8.66675	-3.95230
Angle_of_Internal_friction_0.25m	Equal variances assumed	.045	.837	-3.256	8	.012	-3.57143	1.09692	-6.10093	-1.04193
	Equal variances not assumed			-3.008	3.288	.051	-3.57143	1.18738	-7.16979	.02694
Angle_of_Internal_friction_0.5m	Equal variances assumed	.162	.698	-9.070	8	.000	-6.44286	.71035	-8.08092	-4.80480
	Equal variances not assumed			-9.788	4.591	.000	-6.44286	.65823	-8.18131	-4.70441
Angle_of_Internal_friction_1.0m	Equal variances assumed	3.671	.092	-4.462	8	.002	-4.90000	1.09816	-7.43236	-2.36764
	Equal variances not assumed			-3.278	2.383	.064	-4.90000	1.49459	-10.43447	.63447
Angle_of_Internal_friction_1.5m	Equal variances assumed	.037	.851	-4.527	8	.002	-4.13333	.91309	-6.23892	-2.02775
	Equal variances not assumed			-4.343	3.531	.016	-4.13333	.95177	-6.92029	-1.34637
Angle_of_Internal_friction_2.0m	Equal variances assumed	5.264	.051	-3.088	8	.015	-3.06190	.99166	-5.34868	-.77513
	Equal variances not assumed			-2.200	2.309	.142	-3.06190	1.39182	-8.34403	2.22023

APPENDIX C

6. GEOCHEMICAL CHARACTERISATION.

Water soluble chloride (Cl-) and sulphates (SO_3 & SO_4)

Table C.6.1. Water soluble Chloride (Cl-) and Sulphates (SO_3 & SO_4) content (mg/kg) for contaminated samples at depth (0.0 m).

Trial Pit Coordinates (T.P.Cs)	**Water Soluble Chloride (Cl-)**		**Water Soluble Sulphates**			
	%	**PPM**	**as SO_3**		**as SO_4**	
			%	**PPM**	**%**	**PPM**
(0 m, 0 m)	0.539	5390	0.1457	1457	0.1748	1748
(25 m, 0 m)	1.6312	16312	0.3455	3455	0.4145	4145
(50 m, 0 m)	1.0638	10638	0.3342	3342	0.401	4010
(75 m, 0 m)	1.0638	10638	0.3342	3342	0.401	4010
(100 m, 0 m)	1.1347	11347	0.4303	4303	0.5162	5162
(0 m, 25 m)	1.1773	11773	0.0546	546	0.0655	655
(25 m, 25 m)	1.929	19290	0.2653	2653	0.3183	3183
(50 m, 25 m)	1.0638	10638	0.0541	541	0.0649	649
(100 m, 25 m)	2.695	26950	0.2437	2437	0.2923	2923
(0 m, 50 m)	1.9432	19432	0.2634	2634	0.316	3160
(25 m, 50 m)	0.7574	7574	0.6262	6262	0.7512	7512
(50 m, 50 m)	0.539	5390	0.1875	1875	0.225	2250
(100 m, 50 m)	0.6383	6383	0.2511	2511	0.3012	3012
(0 m, 75 m)	1.9148	19148	0.1279	1279	0.1534	1535
(25 m, 75 m)	0.7801	7801	0.2686	2686	0.3223	3223
(50 m, 75 m)	6.0991	60991	0.2039	2039	0.2446	2446
(75 m, 75 m)	0.1418	1418	0.0713	713	0.0856	856
(100 m, 75 m)	0.0425	425	0.2055	2055	0.243	2430
(0 m, 100 m)	0.0624	624	0.2442	2442	0.293	2930
(50 m, 100 m)	0.872	8720	0.2875	2875	0.345	3450
(75 m, 100 m)	2.0212	20212	0.3361	3361	0.4033	4033
(100 m, 100 m)	0.0255	255	0.1852	1852	0.2222	2222
Min. value	0.0425	425	0.0541	541	0.0649	649
Max. value	6.0991	60991	0.6262	6262	0.7512	7512
Mean value	1.27	12788.59	0.25	2484.54	0.30	2979.27
Standard deviation value	1.30	12986.65	0.12	1297.29	0.15	1556.85

Table C.6.2. Water soluble Chloride (Cl-) and Sulphates (SO_3 & SO_4) content (mg/kg) for contaminated samples at depth (0.25 m).

Trial Pit Coordinates (T.P.Cs)	Water Soluble Chloride (Cl-)		Water Soluble Sulphates			
	%	PPM	as SO_3		as SO_4	
			%	PPM	%	PPM
(0 m, 0 m)	0.0851	851	0.0568	568	0.0681	681
(25 m, 0 m)	0.5674	5674	0.1583	1583	0.1899	1899
(50 m, 0 m)	0.2837	2837	0.0527	527	0.0632	632
(75 m, 0 m)	1.5248	15248	0.1026	1026	0.1231	1231
(100 m, 0 m)	0.1986	1986	0.0156	156	0.0188	188
(0 m, 25 m)	0.5674	5674	0.2733	2733	0.3279	3279
(25 m, 25 m)	0.2695	2695	0.0211	211	0.0253	253
(50 m, 25 m)	0.2128	2128	0.0206	206	0.0247	247
(100 m, 25 m)	0.6737	6737	0.0288	288	0.0346	346
(0 m, 50 m)	3.8297	38297	0.2629	2629	0.3154	3154
(25 m, 50 m)	0.8794	8794	0.261	2610	0.3131	3131
(50 m, 50 m)	0.539	5390	0.1875	1875	0.225	2250
(100 m, 50 m)	0.0709	709	0.0615	615	0.0737	737
(0 m, 75 m)	3.9006	39006	0.0129	129	0.0155	155
(25 m, 75 m)	0.4964	4964	0.1196	1196	0.1435	1435
(50 m, 75 m)	0.3546	3546	0.0617	617	0.0741	741
(75 m, 75 m)	0.695	6950	0.197	1970	0.2364	2364
(100 m, 75 m)	0.0055	55	0.189	1890	0.2268	2268
(0 m, 100 m)	0.0975	975	0.1207	1207	0.1448	1448
(50 m, 100 m)	0.1418	1418	0.0847	847	0.1017	1017
(75 m, 100 m)	4.0779	40779	0.2582	2582	0.3098	3098
(100 m, 100 m)	0.0043	43	0.2009	2009	0.241	2410
Min. value	0.0043	43	0.0129	129	0.0155	155
Max. value	4.077	40779	0.2733	2733	0.3279	3279
Mean value	0.885	8852.545	0.1248	1248.818	0.1498	1498.363
Standard deviation value	1.288	12889.877	0.090	907.319	0.1088	1088.522

Table C.6.3. Water soluble Chloride (Cl-) and Sulphates (SO_3 & SO_4) content (mg/kg) for contaminated samples at depth (0.5 m).

Trial Pit Coordinates (T.P.Cs)	Water Soluble Chloride (Cl-)		Water Soluble Sulphates			
	%	PPM	as SO_3		as SO_4	
			%	PPM	%	PPM
(0 m, 0 m)	0.0426	426	0.084	840	0.1007	1007
(25 m, 0 m)	0.2695	2695	0.0255	255	0.0306	306
(50 m, 0 m)	0.2837	2837	0.0104	104	0.0125	125
(75 m, 0 m)	0.2837	2837	0.0104	104	0.0125	125
(100 m, 0 m)	0.0284	284	0.0154	154	0.0184	184
(0 m, 25 m)	2.0567	20567	0.1583	1583	0.1899	1899
(25 m, 25 m)	0.0709	709	0.0436	436	0.0523	523
(50 m, 25 m)	0.0851	851	0.0184	184	0.0221	221
(100 m, 25 m)	0.3262	3262	0.0104	104	0.0125	125
(0 m, 50 m)	0.4681	4681	0.022	220	0.0263	263
(25 m, 50 m)	0.2553	2553	0.0132	131	0.0158	158
(50 m, 50 m)	0.0552	552	0.0971	971	0.1165	1165
(100 m, 50 m)	0.4964	4964	0.1117	1117	0.134	1340
(0 m, 75 m)	2.5531	25531	0.0198	198	0.0237	237
(25 m, 75 m)	0.2837	2837	0.1767	1767	0.212	212
(50 m, 75 m)	0.3546	3546	0.2187	2187	0.2624	2624
(75 m, 75 m)	0.1418	1418	0.0252	252	0.0303	303
(100 m, 75 m)	0.0085	85	0.1876	1876	0.2251	2251
(0 m, 100 m)	0.0283	283	0.2025	2025	0.243	2430
(50 m, 100 m)	0.0082	82	0.1033	1033	0.124	1240
(75 m, 100 m)	0.7518	7518	0.0255	255	0.0306	306
(100 m, 100 m)	0.0043	43	0.1583	1583	0.1899	1899
Min. value	0.0082	82	0.0104	104	0.0125	125
Max. value	2.553	25531	0.2187	2187	0.262	2624
Mean value	0.402	4025.5	0.079	789.95	0.094	861.045
Standard deviation value	0.649	6497.054	0.073	735.17	0.088	854.701

Table C.6.4. Water soluble Chloride (Cl-) and Sulphates (SO_3 & SO_4) content for contaminated samples at depth (1.0 m).

Trial Pit Coordinates (T.P.Cs)	Water Soluble Chloride (Cl-)		Water Soluble Sulphates			
	%	PPM	as SO_3		as SO_4	
			%	PPM	%	PPM
(0 m, 0 m)	0.3972	3972	0.0768	768	0.0922	922
(25 m, 0 m)	0.2269	2269	0.0184	184	0.0221	221
(50 m, 0 m)	0.4397	4397	0.0096	96	0.0115	115
(75 m, 0 m)	0.4397	4397	0.0096	96	0.0115	115
(100 m, 0 m)	0.1135	1135	0.0115	115	0.0138	138
(0 m, 25 m)	1.4184	14184	0.1106	1106	0.1327	1327
(25 m, 25 m)	0.1277	1277	0.0392	392	0.0471	471
(50 m, 25 m)	0.0993	993	0.0091	91	0.0109	109
(100 m, 25 m)	0.1702	1702	0.0195	195	0.0234	234
(0 m, 50 m)	0.6525	6525	0.022	220	0.0263	263
(25 m, 50 m)	0.1986	1986	0.0027	27	0.0033	33
(50 m, 50 m)	0.1037	1037	0.067	670	0.0804	804
(100 m, 50 m)	0.1475	1475	0.2247	2247	0.2696	2696
(0 m, 75 m)	0.922	9220	0.1495	1495	0.1794	1795
(25 m, 75 m)	0.1844	1844	0.0519	519	0.0622	622
(50 m, 75 m)	0.3546	3546	0.1841	1841	0.2209	2209
(75 m, 75 m)	0.1986	1986	0.1402	1402	0.1682	1682
(100 m, 75 m)	0.0556	556	0.088	880	0.1056	1056
(0 m, 100 m)	0.1673	1673	0.0274	274	0.0329	329
(50 m, 100 m)	0.0237	237	0.0567	567	0.068	680
(75 m, 100 m)	1.078	10780	0.0541	541	0.0649	649
(100 m, 100 m)	0.0085	85	0.0291	291	0.0349	349
Min. value	0.008	85	0.0027	27	0.0033	33
Max. value	1.418	14184	0.224	2247	0.2696	2696
Mean value	0.342	3421.636	0.0637	637.136	0.076	764.5
Standard deviation value	0.367	3678.060	0.062	621.152	0.074	745.37

Table C.6.5. Water soluble Chloride (Cl-) and Sulphates (SO_3 & SO_4) content (mg/kg) for contaminated samples at depth (1.5 m).

Trial Pit Coordinates (T.P.Cs)	Water Soluble Chloride (Cl-)		Water Soluble Sulphates			
	%	PPM	as SO_3		as SO_4	
			%	PPM	%	PPM
(0 m, 0 m)	0.3404	3404	0.045	450	0.054	540
(25 m, 0 m)	0.1277	1277	0.0085	85	0.0102	102
(50 m, 0 m)	0.1702	1702	0.0134	134	0.0161	161
(75 m, 0 m)	0.1702	1702	0.0134	134	0.0161	161
(100 m, 0 m)	0.1702	1702	0.0107	107	0.0128	128
(0 m, 25 m)	0.9929	9929	0.0702	702	0.0843	843
(25 m, 25 m)	0.1418	1418	0.0239	239	0.0286	286
(50 m, 25 m)	0.1277	1277	0.0104	104	0.0125	125
(100 m, 25 m)	0.2411	2411	0.0184	184	0.0221	221
(0 m, 50 m)	0.2553	2553	0.0121	121	0.0145	145
(25 m, 50 m)	0.2128	2128	0.0005	5	0.0007	7
(50 m, 50 m)	0.023	230	0.1422	1422	0.1706	1706
(100 m, 50 m)	0.4255	4255	0.0154	154	0.0184	184
(0 m, 75 m)	0.851	8510	0.053	530	0.0635	635
(25 m, 75 m)	0.312	3120	0.0214	214	0.0257	257
(50 m, 75 m)	0.3546	3546	0.1841	1841	0.2209	2209
(75 m, 75 m)	0.2695	2695	0.0228	228	0.0273	273
(100 m, 75 m)	0.0228	228	0.029	290	0.0348	348
(0 m, 100 m)	0.0936	936	0.1009	1009	0.1211	1211
(50 m, 100 m)	0.0208	208	0.145	1450	0.174	1740
(75 m, 100 m)	0.1986	1986	0.0524	524	0.0629	629
(100 m, 100 m)	0.0085	85	0.0656	656	0.0787	787
Min. value	0.008	85	0.0005	5	0.0007	7
Max. value	0.992	9929	0.184	1841	0.220	2209
Mean value	0.251	2513.727	0.048	481.04	0.057	577.181
Standard deviation value	0.245	2459.695	0.05	511.71	0.061	614.009

Table C.6.6. Water soluble Chloride (Cl-) and Sulphates (SO_3 & SO_4) content (mg/kg) for contaminated samples at depth (2.0 m).

Trial Pit Coordinates (T.P.Cs)	Water Soluble Chloride (Cl-)		Water Soluble Sulphates			
	%	PPM	as SO_3		as SO_4	
			%	PPM	%	PPM
(0 m, 0 m)	0.4397	4397	0.0324	324	0.0388	388
(25 m, 0 m)	0.1277	1277	0.0102	102	0.0122	122
(50 m, 0 m)	0.1277	1277	0.0145	145	0.0174	174
(75 m, 0 m)	0.1277	1277	0.0145	145	0.0174	174
(100 m, 0 m)	0.2411	2411	0.0209	209	0.025	250
(0 m, 25 m)	0.922	9220	0.0944	944	0.1132	1132
(25 m, 25 m)	0.1702	1702	0.0252	252	0.0303	303
(50 m, 25 m)	0.1986	1986	0.0156	156	0.0188	188
(100 m, 25 m)	0.2411	2411	0.0071	71	0.0086	86
(0 m, 50 m)	0.4255	4255	0.1045	1045	0.1254	1254
(25 m, 50 m)	0.2128	2128	0.0291	291	0.0349	349
(50 m, 50 m)	0.1554	1554	0.122	1220	0.1464	1464
(100 m, 50 m)	0.8794	8794	0.152	1520	0.1824	1824
(0 m, 75 m)	0.7801	7801	0.0456	456	0.0546	546
(25 m, 75 m)	0.4823	4823	0.0247	247	0.0296	296
(50 m, 75 m)	0.4681	4681	0.1243	1243	0.1491	1491
(75 m, 75 m)	0.6383	6383	0.0206	206	0.0247	247
(100 m, 75 m)	0.1875	1875	0.0885	885	0.1062	1062
(0 m, 100 m)	0.5106	5106	0.1012	1012	0.1214	1214
(50 m, 100 m)	0.0154	154	0.1872	1872	0.2246	2246
(75 m, 100 m)	0.0794	794	0.0214	214	0.0257	257
(100 m, 100 m)	0.0057	57	0.0381	381	0.0458	458
Min. value	0.0057	57	0.0071	71	0.0086	86
Max. value	0.922	9220	0.187	1872	0.224	2246
Mean value	0.338	3380.136	0.058	588.18	0.070	705.681
Standard deviation value	0.272	2723.288	0.053	530.44	0.063	636.40

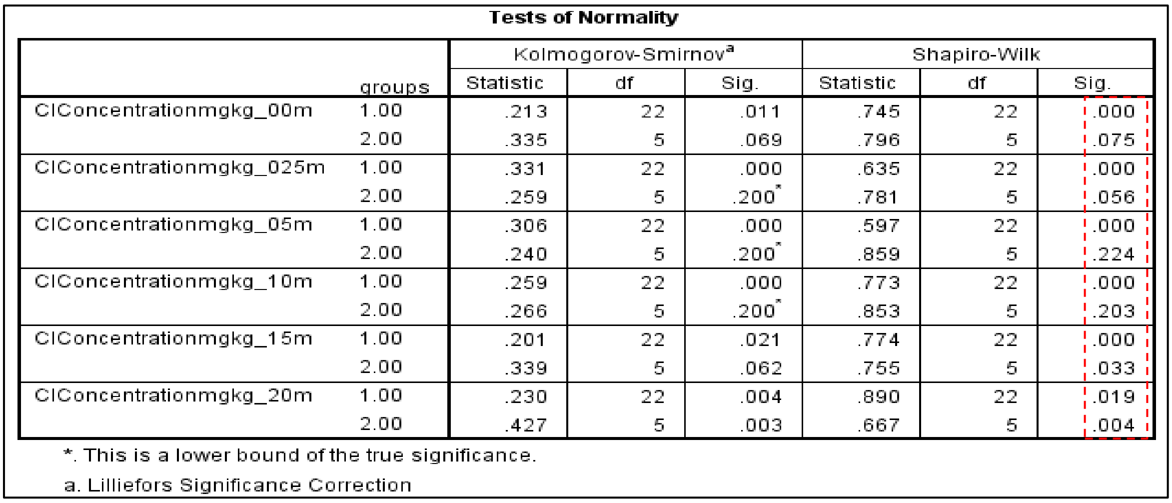
Table C.6.7. Water soluble Chloride (Cl-) and Sulphates (SO_3 & SO_4) content (mg/kg) for non-contaminated samples at depth (0.0 m, 0.25 m, 0.5 m, 1.0 m, 1.5 m and 2.0 m).

Trial Pit Coordinates (T.P.Cs)	**Water Soluble Chloride (Cl-)**		**Water Soluble Sulphates**			
			as SO_3		**as SO_4**	
	%	**PPM**	**%**	**PPM**	**%**	**PPM**
At Depth (0.0 m)						
(0 m, 0 m)	0.0042	42	0.1304	1304	0.1563	1563
(100 m, 0 m)	0.0170	170	0.2450	2450	0.2939	2939
(50 m, 50 m)	0.0042	42	0.1503	1503	0.1804	1804
(0 m, 100 m)	0.0170	170	0.1204	1204	0.1445	1445
(100 m, 100 m)	0.0510	510	0.2310	2310	0.2771	2771
Min. Value	0.0042	42	0.1204	1204	0.1445	1445
Max. Value	0.051	510	0.245	2450	0.2939	2939
Mean Value	0.0187	186.8	0.17542	1754.2	0.2104	2104.4
Standard deviation value	0.01916	191.6	0.05834	583.4	0.06998	699.8
At Depth (0.25 m)						
(0 m, 0 m)	0.0028	28	0.1761	1761	0.2113	2113
(100 m, 0 m)	0.0141	141	0.2623	2623	0.3147	3147
(50 m, 50 m)	0.0028	28	0.1901	1901	0.2281	2281
(0 m, 100 m)	0.0113	113	0.1561	1561	0.1873	1873
(100 m, 100 m)	0.0141	141	0.1731	1731	0.2077	2077
Min. Value	0.0028	28	0.1561	1561	0.1873	1873
Max. Value	0.0141	141	0.2623	2623	0.3147	3147
Mean Value	0.00902	90.2	0.19154	1915.4	0.22982	2298.2
Standard deviation value	0.00579	57.9	0.04136	413.6	0.04961	496.1
At Depth (0.5 m)						
(0 m, 0 m)	0.0042	42	0.1953	1953	0.2343	2343
(100 m, 0 m)	0.0170	170	0.2554	2554	0.3064	3064
(50 m, 50 m)	0.0028	28	0.2126	2126	0.2551	2551
(0 m, 100 m)	0.0085	85	0.1251	1251	0.1511	1511
(100 m, 100 m)	0.0056	56	0.1196	1196	0.1435	1435
Min. Value	0.0028	28	0.1196	1196	0.1435	1435
Max. Value	0.017	170	0.2554	2554	0.3064	3064
Mean Value	0.00762	76.2	0.1816	1816	0.21808	2180.8
Standard deviation value	0.00565	56.5	0.05837	583.7	0.06978	697.8
At Depth (1.0 m)						
(0 m, 0 m)	0.0056	56	0.1876	1876	0.2251	2251
(100 m, 0 m)	0.0255	255	0.2036	2036	0.2442	2442
(50 m, 50 m)	0.0425	425	0.1487	1487	0.1784	1784
(0 m, 100 m)	0.0056	56	0.1978	1978	0.2373	2373
(100 m, 100 m)	0.0113	113	0.1304	1304	0.1563	1563
Min. Value	0.0056	56	0.1304	1304	0.1563	1563
Max. Value	0.0425	425	0.2036	2036	0.2442	2442
Mean Value	0.0181	181	0.17362	1736.2	0.20826	2082.6
Standard deviation value	0.01588	158.8	0.03227	322.7	0.03876	387.6

Table C.6.7. Continued.

Trial Pits Coordinates (T.P.Cs)	Water Soluble Chloride (Cl-)		Water Soluble Sulphates			
			as SO_3		as SO_4	
	%	PPM	%	PPM	%	PPM
At Depth (1.5 m)						
(0 m, 0 m)	0.0056	56	0.2014	2014	0.2416	2416
(100 m, 0 m)	0.0113	113	0.1489	1489	0.1787	1787
(50 m, 50 m)	0.0056	56	0.1865	1865	0.2238	2238
(0 m, 100m)	0.0198	198	0.1704	1704	0.2044	2044
(100 m, 100 m)	0.0056	56	0.1067	1067	0.1280	1280
Min. Value	0.0056	56	0.1067	1067	0.128	1280
Max. Value	0.0198	198	0.2014	2014	0.2416	2416
Mean Value	0.00958	95.8	0.16278	1627.8	0.1953	1953
Standard deviation value	0.00622	62.2	0.03691	369.1	0.04428	442.8
At Depth (2.0 m)						
(0 m, 0 m)	0.0042	42	0.1841	1841	0.2208	2208
(100 m, 0 m)	0.0085	85	0.1874	1874	0.2248	2248
(50 m, 50 m)	0.0056	56	0.1396	1396	0.1675	1675
(0 m, 100 m)	0.0397	397	0.1753	1753	0.2103	2103
(100 m, 100 m)	0.0085	85	0.1256	1256	0.1507	1507
Min. Value	0.0042	42	0.1256	1256	0.1507	1507
Max. Value	0.0397	397	0.1874	1874	0.2248	2248
Mean Value	0.0133	133	0.1624	1624	0.19482	1948.2
Standard deviation value	0.01487	148.7	0.028001	280.01	0.03356	335.6

Table C.6.8. The significant p-values via normality Shapiro-Wilk test indicate that the Cl-values (mg/kg) of the soil at contaminated and non-contaminated sites follow non-normal distribution.



Tests of Normality

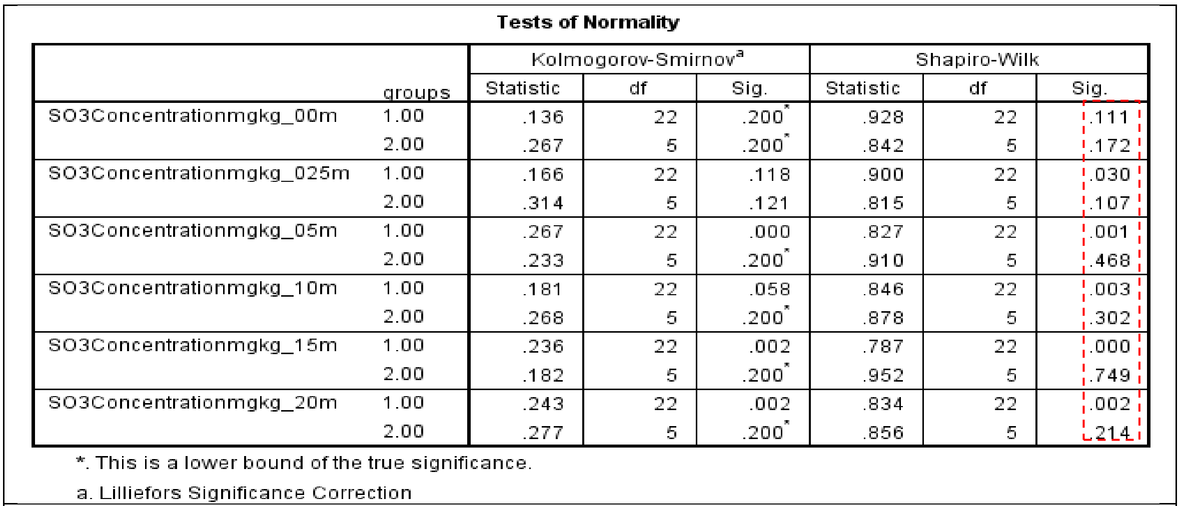
	groups	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
ClConcentrationmgkg_00m	1.00	.213	22	.011	.745	22	.000
	2.00	.335	5	.069	.796	5	.075
ClConcentrationmgkg_025m	1.00	.331	22	.000	.635	22	.000
	2.00	.259	5	.200*	.781	5	.056
ClConcentrationmgkg_05m	1.00	.306	22	.000	.597	22	.000
	2.00	.240	5	.200*	.859	5	.224
ClConcentrationmgkg_10m	1.00	.259	22	.000	.773	22	.000
	2.00	.266	5	.200*	.853	5	.203
ClConcentrationmgkg_15m	1.00	.201	22	.021	.774	22	.000
	2.00	.339	5	.062	.755	5	.033
ClConcentrationmgkg_20m	1.00	.230	22	.004	.890	22	.019
	2.00	.427	5	.003	.667	5	.004

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Note: groups 1.00 = contaminated samples, 2.00 = non-contaminated samples.

Table C.6.9. The significant p-values via normality Shapiro-Wilk test indicate that the SO_3 and SO_4 values of the soil at contaminated and non-contaminated sites follow normal distribution.

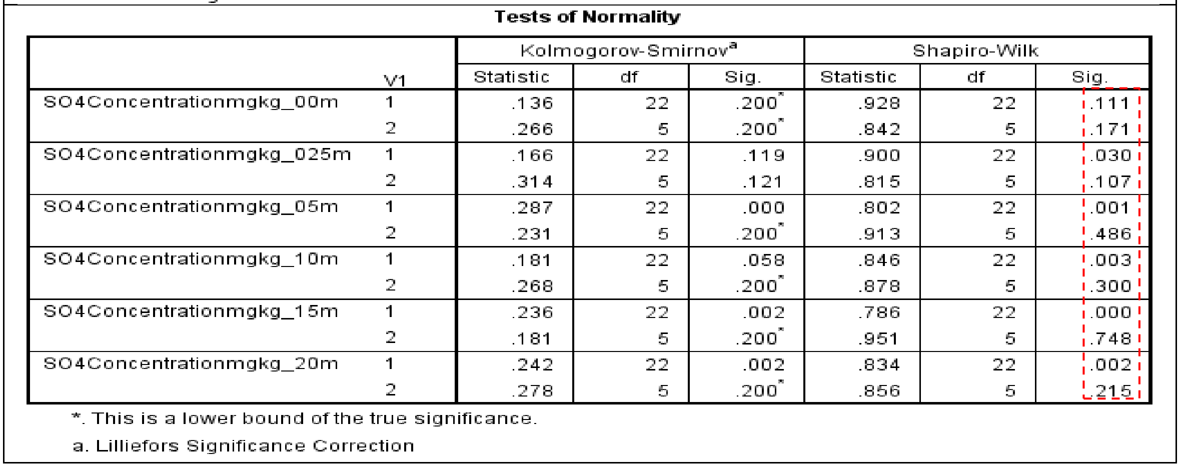


Tests of Normality

	groups	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
SO3Concentrationmgkg_00m	1.00	.136	22	.200*	.928	22	.111
	2.00	.267	5	.200*	.842	5	.172
SO3Concentrationmgkg_025m	1.00	.166	22	.118	.900	22	.030
	2.00	.314	5	.121	.815	5	.107
SO3Concentrationmgkg_05m	1.00	.267	22	.000	.827	22	.001
	2.00	.233	5	.200*	.910	5	.468
SO3Concentrationmgkg_10m	1.00	.181	22	.058	.846	22	.003
	2.00	.268	5	.200*	.878	5	.302
SO3Concentrationmgkg_15m	1.00	.236	22	.002	.787	22	.000
	2.00	.182	5	.200*	.952	5	.749
SO3Concentrationmgkg_20m	1.00	.243	22	.002	.834	22	.002
	2.00	.277	5	.200*	.856	5	.214

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction



Tests of Normality

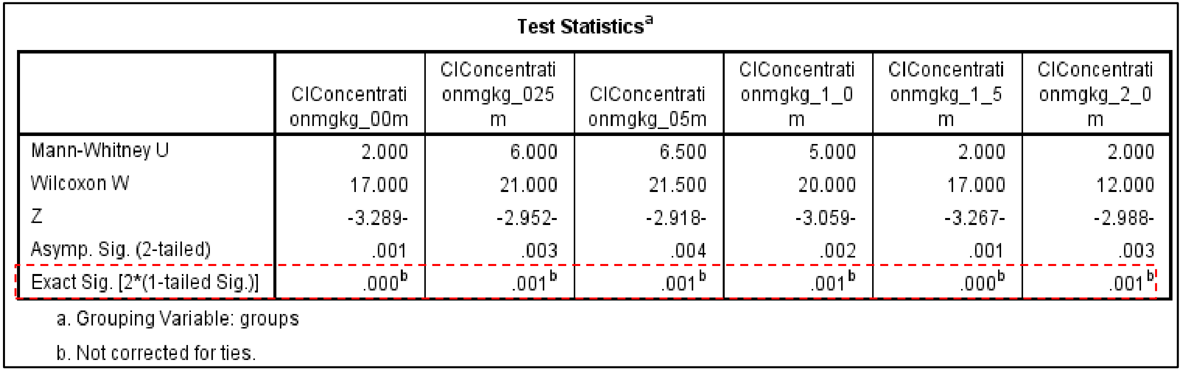
	V1	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
SO4Concentrationmgkg_00m	1	.136	22	.200*	.928	22	.111
	2	.266	5	.200*	.842	5	.171
SO4Concentrationmgkg_025m	1	.166	22	.119	.900	22	.030
	2	.314	5	.121	.815	5	.107
SO4Concentrationmgkg_05m	1	.287	22	.000	.802	22	.001
	2	.231	5	.200*	.913	5	.486
SO4Concentrationmgkg_10m	1	.181	22	.058	.846	22	.003
	2	.268	5	.200*	.878	5	.300
SO4Concentrationmgkg_15m	1	.236	22	.002	.786	22	.000
	2	.181	5	.200*	.951	5	.748
SO4Concentrationmgkg_20m	1	.242	22	.002	.834	22	.002
	2	.278	5	.200*	.856	5	.215

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Note: groups 1.00 = contaminated samples, 2.00 = non-contaminated samples.

Table C.6.10. Indicates the significant differences of the Cl- (mg/kg) variable in the soil at six different depths between contaminated and non-contaminated sites.



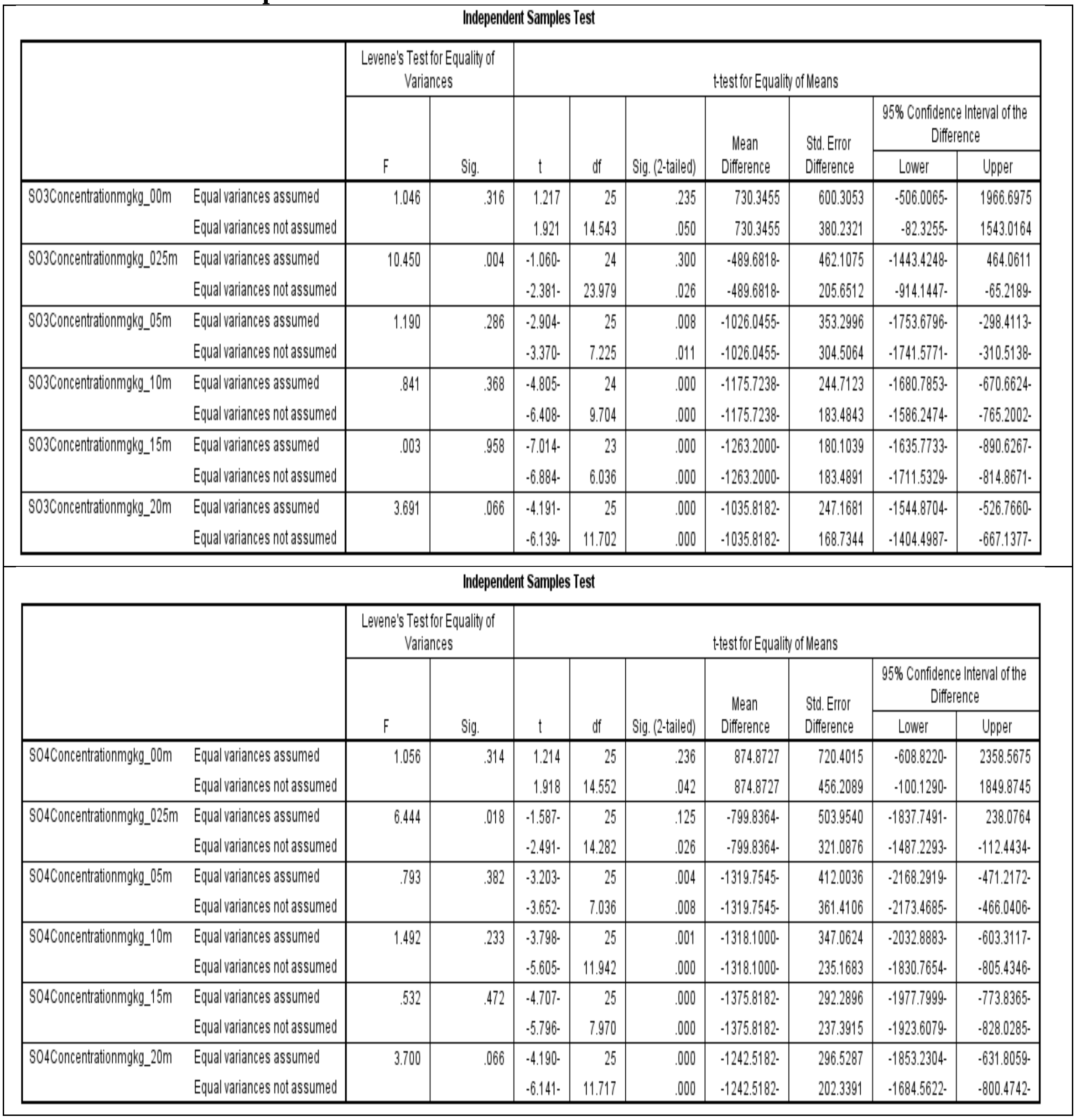
Test Statistics[a]

	ClConcentrationmgkg_00m	ClConcentrationmgkg_025m	ClConcentrationmgkg_05m	ClConcentrationmgkg_1_0m	ClConcentrationmgkg_1_5m	ClConcentrationmgkg_2_0m
Mann-Whitney U	2.000	6.000	6.500	5.000	2.000	2.000
Wilcoxon W	17.000	21.000	21.500	20.000	17.000	12.000
Z	-3.289-	-2.952-	-2.918-	-3.059-	-3.267-	-2.988-
Asymp. Sig. (2-tailed)	.001	.003	.004	.002	.001	.003
Exact Sig. [2*(1-tailed Sig.)]	.000[b]	.001[b]	.001[b]	.001[b]	.000[b]	.001[b]

a. Grouping Variable: groups

b. Not corrected for ties.

Table C.6.11. Indicates the significant differences of the SO_3 and SO_4 (mg/kg) variables in the soil at six different depths between contaminated and non-contaminated sites.



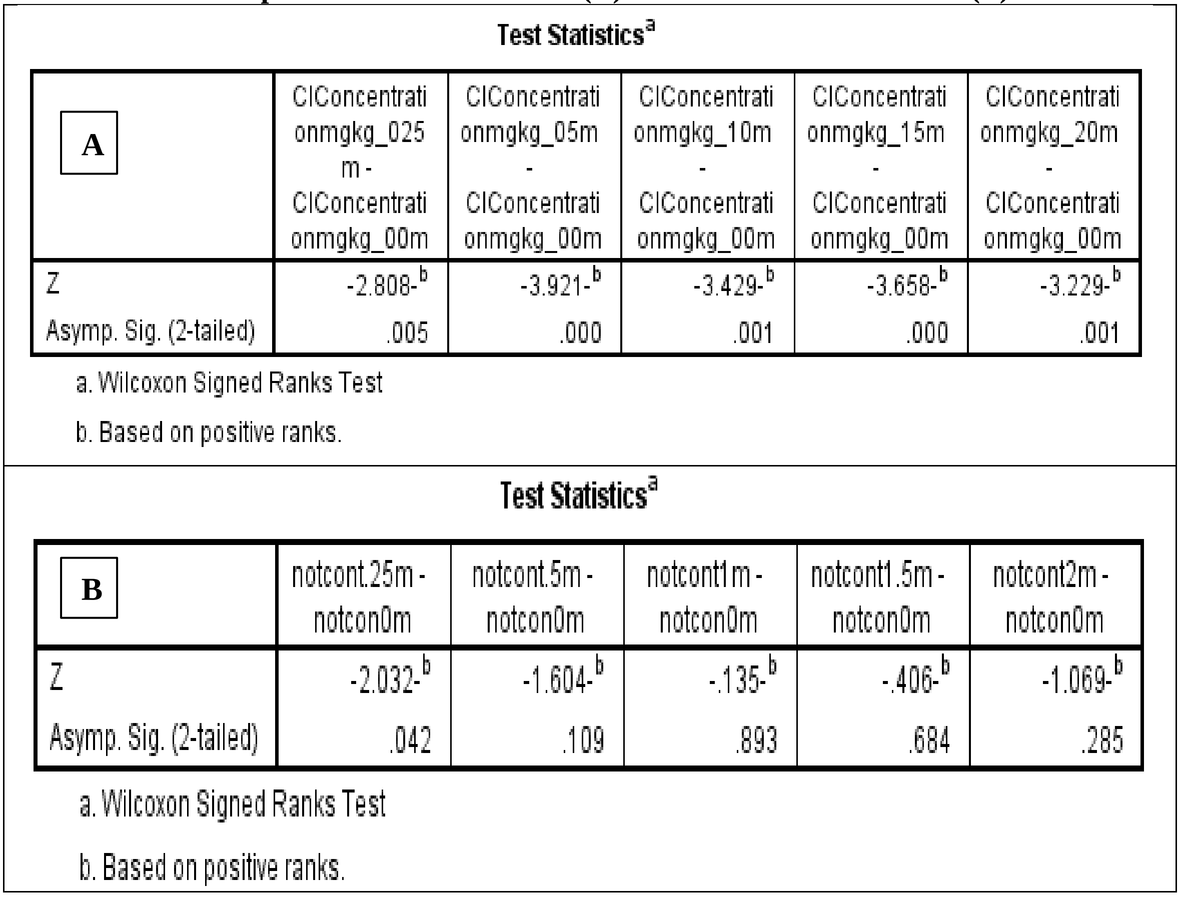
Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
SO3Concentrationmgkg_00m	Equal variances assumed	1.046	.316	1.217	25	.235	730.3455	600.3053	-506.0065-	1966.6975
	Equal variances not assumed			1.921	14.543	.050	730.3455	380.2321	-82.3255-	1543.0164
SO3Concentrationmgkg_025m	Equal variances assumed	10.450	.004	-1.060-	24	.300	-489.6818-	462.1075	-1443.4248-	464.0611
	Equal variances not assumed			-2.381-	23.979	.026	-489.6818-	205.6512	-914.1447-	-65.2189-
SO3Concentrationmgkg_05m	Equal variances assumed	1.190	.286	-2.904-	25	.008	-1026.0455-	353.2996	-1753.6796-	-298.4113-
	Equal variances not assumed			-3.370-	7.225	.011	-1026.0455-	304.5064	-1741.5771-	-310.5138-
SO3Concentrationmgkg_10m	Equal variances assumed	.841	.368	-4.805-	24	.000	-1175.7238-	244.7123	-1680.7853-	-670.6624-
	Equal variances not assumed			-6.408-	9.704	.000	-1175.7238-	183.4843	-1586.2474-	-765.2002-
SO3Concentrationmgkg_15m	Equal variances assumed	.003	.958	-7.014-	23	.000	-1263.2000-	180.1039	-1635.7733-	-890.6267-
	Equal variances not assumed			-6.884-	6.036	.000	-1263.2000-	183.4891	-1711.5329-	-814.8671-
SO3Concentrationmgkg_20m	Equal variances assumed	3.691	.066	-4.191-	25	.000	-1035.8182-	247.1681	-1544.8704-	-526.7660-
	Equal variances not assumed			-6.139-	11.702	.000	-1035.8182-	168.7344	-1404.4987-	-667.1377-

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
SO4Concentrationmgkg_00m	Equal variances assumed	1.056	.314	1.214	25	.236	874.8727	720.4015	-608.8220-	2358.5675
	Equal variances not assumed			1.918	14.552	.042	874.8727	456.2089	-100.1290-	1849.8745
SO4Concentrationmgkg_025m	Equal variances assumed	6.444	.018	-1.587-	25	.125	-799.8364-	503.9540	-1837.7491-	238.0764
	Equal variances not assumed			-2.491-	14.282	.026	-799.8364-	321.0876	-1487.2293-	-112.4434-
SO4Concentrationmgkg_05m	Equal variances assumed	.793	.382	-3.203-	25	.004	-1319.7545-	412.0036	-2168.2919-	-471.2172-
	Equal variances not assumed			-3.652-	7.036	.008	-1319.7545-	361.4106	-2173.4685-	-466.0406-
SO4Concentrationmgkg_10m	Equal variances assumed	1.492	.233	-3.798-	25	.001	-1318.1000-	347.0624	-2032.8883-	-603.3117-
	Equal variances not assumed			-5.605-	11.942	.000	-1318.1000-	235.1683	-1830.7654-	-805.4346-
SO4Concentrationmgkg_15m	Equal variances assumed	.532	.472	-4.707-	25	.000	-1375.8182-	292.2896	-1977.7999-	-773.8365-
	Equal variances not assumed			-5.796-	7.970	.000	-1375.8182-	237.3915	-1923.6079-	-828.0285-
SO4Concentrationmgkg_20m	Equal variances assumed	3.700	.066	-4.190-	25	.000	-1242.5182-	296.5287	-1853.2304-	-631.8059-
	Equal variances not assumed			-6.141-	11.717	.000	-1242.5182-	202.3391	-1684.5622-	-800.4742-

Table C.6.12. Indicates the significant difference between the Cl- (mg/kg) variable in the soil and six different depths at contaminated site (A) and non-contaminated site (B).



Test Statistics[a]

A	ClConcentrationmgkg_025m - ClConcentrationmgkg_00m	ClConcentrationmgkg_05m - ClConcentrationmgkg_00m	ClConcentrationmgkg_10m - ClConcentrationmgkg_00m	ClConcentrationmgkg_15m - ClConcentrationmgkg_00m	ClConcentrationmgkg_20m - ClConcentrationmgkg_00m
Z	-2.808-[b]	-3.921-[b]	-3.429-[b]	-3.658-[b]	-3.229-[b]
Asymp. Sig. (2-tailed)	.005	.000	.001	.000	.001

a. Wilcoxon Signed Ranks Test

b. Based on positive ranks.

Test Statistics[a]

B	notcont.25m - notcon0m	notcont.5m - notcon0m	notcont1m - notcon0m	notcont1.5m - notcon0m	notcont2m - notcon0m
Z	-2.032-[b]	-1.604-[b]	-.135-[b]	-.406-[b]	-1.069-[b]
Asymp. Sig. (2-tailed)	.042	.109	.893	.684	.285

a. Wilcoxon Signed Ranks Test

b. Based on positive ranks.

Elemental Analysis (EA)

Table C.6.13. The percentages (%) results of Nitrogen, Carbon, Sulphur and Hydrogen for contaminated samples at depth (0.0 m).

Trial Pits coordinates. (T.P.Cs)	Sample Weight (g)	Content of N, C, S & H (%) by elemental analysis			
		Nitrogen N%	Carbon C%	Sulphur S%	Hydrogen H%
(0, 0)	45.8	0.537	23.41	1.771	3.008
(25m, 0)	46.93	0.494	17.17	1.419	2.14
(50m, 0)	44.81	0.52	17.61	1.591	2.385
(75m, 0)	45.72	0.446	8.03	0.495	0.945
(100m, 0)	45.49	0.456	9.37	0.695	1.12
(0, 25m)	45.68	0.512	8.864	0.658	1.023
(25m, 25m)	45.28	0.598	28.42	1.859	3.338
(50m, 25m)	46.39	0.496	13.98	1.003	1.597
(100m, 25m)	46.26	0.401	4.058	0.637	0.373
(0, 50m)	44.59	0.628	25.54	1.382	2.983
(25m, 50m)	45.84	0.588	23.82	5.085	4.303
(50m, 50m)	46.96	0.547	15.83	3.242	2.197
(100m, 50m)	44.81	0.442	6.394	0.688	0.821
(0, 75m)	45.21	0.652	37.58	3.267	3.587
(25m, 75m)	47.67	0.573	35.53	3.956	5.198
(50m, 75m)	44.2	0.627	26.68	3.436	3.182
(75m, 75m)	44.54	0.585	31.89	2.407	4.431
(100m, 75m)	45.02	0.649	26.01	4.255	3.522
(0, 100m)	45.64	0.588	29.21	2.816	3.871
(50m, 100m)	41.67	0.59	23.14	3.737	3.155
(75m, 100m)	45.19	0.537	24.44	3.944	3.283
(100m, 100m)	45.18	0.528	22.15	5.154	3.47
Min. Value	44.2	0.401	4.058	0.495	0.373
Max. Value	47.67	0.652	35.53	5.154	4.431
Mean Value	45.403	0.545	20.869	2.431	2.724
Standard deviation Value	1.194	0.070	9.485	1.518	1.305

Table C.6.14. The percentages (%) results of Nitrogen, Carbon, Sulphur and Hydrogen for contaminated samples at depth (0.25 m).

Trial Pits coordinates. (T.P.Cs)	Sample Weight (g)	Content of N, C, S & H (%) by elemental analysis			
		Nitrogen N%	Carbon C%	Sulphur S%	Hydrogen H%
(0, 0)	45.49	0.465	6.665	0.479	0.627
(25m, 0)	45.64	0.453	10.36	0.867	1.309
(50m, 0)	45.39	0.444	7.519	0.892	0.962
(75m, 0)	46.38	0.432	8.372	0.47	0.926
(100m, 0)	43.58	0.498	12.46	1.157	1.681
(0, 25m)	45.64	0.495	1.772	0.377	0.527
(25m, 25m)	46.56	0.531	20.33	3.038	2.915
(50m, 25m)	47.26	0.476	7.937	1.154	1.935
(100m, 25m)	45.87	0.437	7.142	0.814	0.686
(0, 50m)	44.8	0.415	0.516	0.173	0.039
(25m, 50m)	45.69	0.396	1.837	0.354	0.241
(50m, 50m)	47.58	0.393	1.434	0.254	0.093
(100m, 50m)	45.39	0.547	26.55	2.374	3.655
(0, 75m)	46.22	0.556	30.77	2.29	4.136
(25m, 75m)	46.19	0.402	1.684	0.22	0.13
(50m, 75m)	46.48	0.435	5.534	0.658	0.612
(75m, 75m)	46.7	0.387	1.826	0.32	0.212
(100m, 75m)	45.66	0.404	2.574	0.391	0.2
(0, 100m)	45.16	0.415	0.904	0.221	0.052
(50m, 100m)	46.3	0.41	3.42	0.436	0.335
(75m, 100m)	44.9	0.5	17	3.617	2.378
(100m, 100m)	48.22	0.426	6.731	0.812	0.731
Min. Value	43.58	0.387	0.516	0.173	0.039
Max. Value	48.22	0.556	30.77	2.374	4.136
Mean Value	45.959	0.450	8.333	0.971	1.108
Standard deviation Value	1.00	0.051	8.405	0.970	1.195

Table C.6.15. The percentages (%) results of Nitrogen, Carbon, Sulphur and Hydrogen for contaminated samples at depth (0.5 m).

Trial Pits coordinates. (T.P.Cs)	Sample Weight (g)	Content of N, C, S & H (%) by elemental analysis			
		Nitrogen N%	Carbon C%	Sulphur S%	Hydrogen H%
(0, 0)	44.33	0.259	2.669	0.141	0.023
(25m, 0)	44.2	0.256	2.362	0.053	0.022
(50m, 0)	44.7	0.26	2.376	0.102	0.026
(75m, 0)	44.17	0.252	1.905	0.077	0.021
(100m, 0)	44.35	0.271	0.546	0.126	0.002
(0, 25m)	44.94	0.269	2.33	0.054	0.019
(25m, 25m)	44.73	0.259	2.294	0.063	0.022
(50m, 25m)	44.54	0.253	2.275	0.064	0.021
(100m, 25m)	44.33	0.266	2.077	0.06	0.021
(0, 50m)	44.82	0.265	2.471	0.126	0.027
(25m, 50m)	44.61	0.264	2.275	0.056	0.023
(50m, 50m)	44.99	0.277	2.434	0.057	0.019
(100m, 50m)	44.7	0.259	2.174	0.071	0.025
(0, 75m)	44.77	0.266	2.029	0.346	0.055
(25m, 75m)	44.11	0.248	2.152	0.102	0.025
(50m, 75m)	44.49	0.264	2.224	0.058	0.021
(75m, 75m)	44.86	0.251	2.419	0.059	0.022
(100m, 75m)	44.53	0.266	1.552	0.088	0.023
(0, 100m)	44.51	0.261	2.328	0.186	0.032
(50m, 100m)	44.7	0.271	1.932	0.059	0.022
(75m, 100m)	44.34	0.269	2.429	0.071	0.018
(100m, 100m)	44.68	0.233	1.586	0.062	0.022
Min. Value	44.11	0.248	1.552	0.053	0.002
Max. Value	44.99	0.277	2.669	0.346	0.055
Mean Value	44.563	0.260	2.129	0.094	0.023
Standard deviation Value	0.251	0.009	0.446	0.066	0.008

Table C.6.16. The percentages (%) results of Nitrogen, Carbon, Sulphur and Hydrogen for contaminated samples at depth (1.0 m).

Trial Pits coordinates. (T.P.Cs)	Sample Weight (g)	Content of N, C, S & H (%) by elemental analysis			
		Nitrogen N%	Carbon C%	Sulphur S%	Hydrogen H%
(0, 0)	44.27	0.246	1.593	0.054	0.017
(25m, 0)	45.6	0.397	1.981	0.143	0.056
(50m, 0)	45.29	0.425	2.247	0.074	0.046
(75m, 0)	46.13	0.425	2.121	0.081	0.088
(100m, 0)	45.95	0.384	2.196	0.076	0.249
(0, 25m)	44.94	0.269	2.33	0.054	0.019
(25m, 25m)	45.97	0.431	2.119	0.134	0.07
(50m, 25m)	45.52	0.427	1.906	0.066	0.049
(100m, 25m)	44.4	0.519	2.227	0.204	0.066
(0, 50m)	45.13	0.495	2.271	0.155	0.053
(25m, 50m)	44.74	0.498	2.094	0.168	0.056
(50m, 50m)	45.48	0.256	2.221	0.053	0.018
(100m, 50m)	45.29	0.236	2.217	0.053	0.021
(0, 75m)	46.65	0.434	2.358	0.254	0.087
(25m, 75m)	44.79	0.46	2.159	0.125	0.072
(50m, 75m)	44.98	0.425	2.046	0.091	0.096
(75m, 75m)	47.34	0.426	2.543	0. 197	0.264
(100m, 75m)	43.89	0.51	2.221	0.191	0.107
(0, 100m)	44.72	0.266	2.553	0.059	0.019
(50m, 100m)	46.96	0.408	1.78	0.045	0.044
(75m, 100m)	45.24	0.418	1.674	0.038	0.024
(100m, 100m)	47.51	0.414	1.877	0.041	0.043
Min. Value	44.27	0.246	1.593	0.038	0.017
Max. Value	47.51	0.519	2.553	0.254	0.264
Mean Value	45.490	0.398	2.124	0.102	0.071
Standard deviation Value	0.965	0.087	0.246	0.062	0.065

Table C.6.17. The percentages (%) results of Nitrogen, Carbon, Sulphur and Hydrogen for contaminated samples at depth (1.5 m).

Trial Pits coordinates. (T.P.Cs)	Sample Weight (g)	Content of N, C, S & H (%) by elemental analysis			
		Nitrogen N%	Carbon C%	Sulphur S%	Hydrogen H%
(0, 0)	44.24	0.253	2.382	0.088	0.023
(25m, 0)	45.64	0.256	2.538	0.475	0.056
(50m, 0)	45.15	0.189	1.567	0.053	0.035
(75m, 0)	46.11	0.198	1.365	0.051	0.014
(100m, 0)	44.25	0.265	2.251	0.176	0.03
(0, 25m)	46.02	0.236	1.791	0.047	0.014
(25m, 25m)	46.01	0.194	1.421	0.026	0.019
(50m, 25m)	44.62	0.178	0.953	0.035	0.02
(100m, 25m)	45.07	0.175	1.427	0.038	0.013
(0, 50m)	44.65	0.215	1.113	0.105	0.032
(25m, 50m)	45.93	0.173	1.734	0.042	0.017
(50m, 50m)	44.04	0.241	1.873	0.07	0.021
(100m, 50m)	45.15	0.255	1.827	0.063	0.02
(0, 75m)	44.25	0.217	1.289	0.121	0.034
(25m, 75m)	44.19	0.221	1.568	0.953	0.015
(50m, 75m)	45.17	0.185	1.381	0.029	0.015
(75m, 75m)	44.19	0.254	1.593	0.054	0.018
(100m, 75m)	45.15	0.182	1.734	0.121	0.073
(0, 100m)	44.72	0.266	2.553	0.059	0.019
(50m, 100m)	44.62	0.137	0.825	0.028	0.034
(75m, 100m)	44.19	0.212	1.142	0.026	0.013
(100m, 100m)	45.34	0.141	0.753	0.027	0.022
Min. Value	44.04	0.137	0.753	0.026	0.013
Max. Value	46.11	0.266	2.553	0.475	0.073
Mean Value	44.940	0.211	1.594	0.122	0.025
Standard deviation Value	0.682	0.038	0.510	0.208	0.014

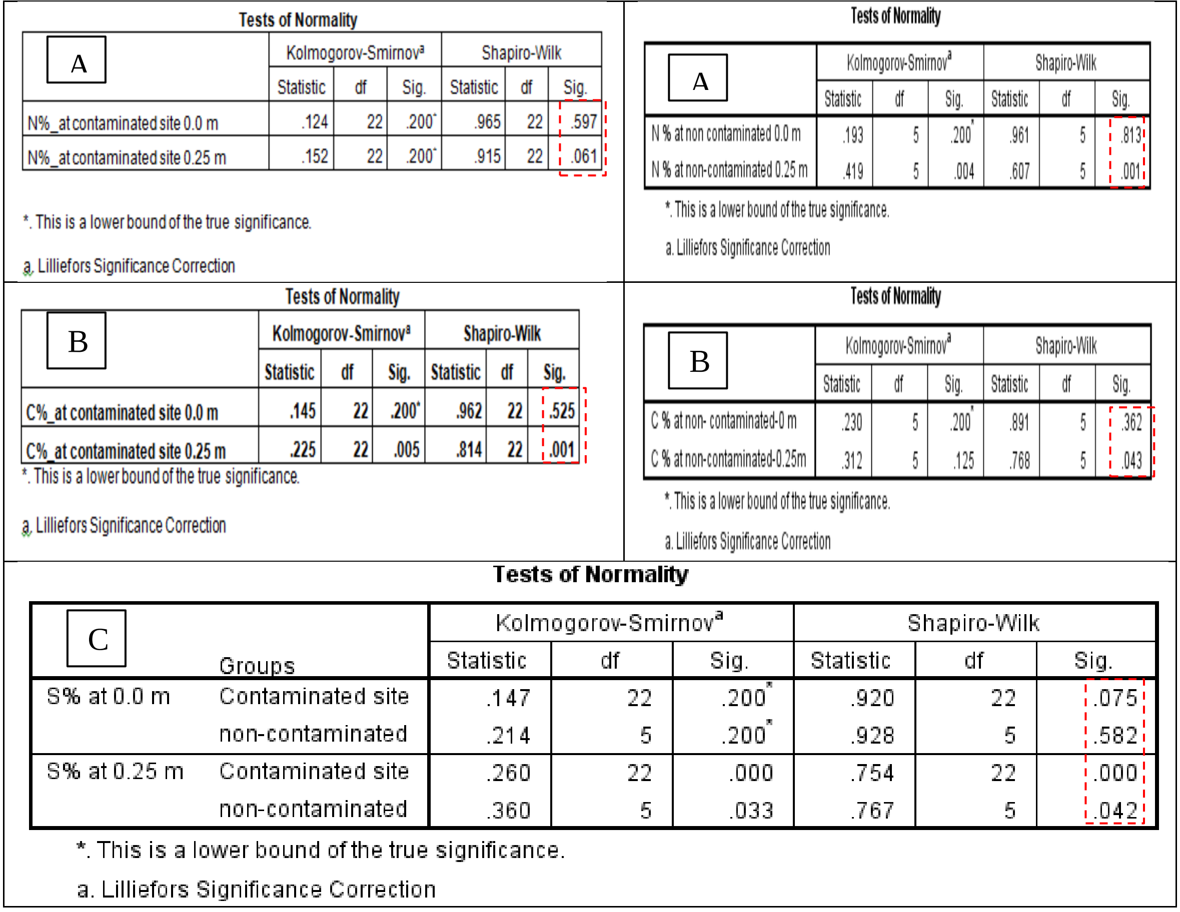
Table C.6.18. The percentages (%) results of Nitrogen, Carbon, Sulphur and Hydrogen for contaminated samples at depth (2.0 m).

Trial Pits coordinates. (T.P.Cs)	Sample Weight (g)	Content of N, C, S & H (%) by elemental analysis			
		Nitrogen N%	Carbon C%	Sulphur S%	Hydrogen H%
(0, 0)	45.09	0.146	0.824	0.054	0.018
(25m, 0)	45.63	0.205	0.518	0.289	0.031
(50m, 0)	44.22	0.114	0.934	0.023	0.015
(75m, 0)	45.38	0.115	0.328	0.034	0.009
(100m, 0)	45.1	0.243	0.981	0.031	0.015
(0, 25m)	45.05	0.082	0.657	0.031	0.009
(25m, 25m)	45.48	0.133	0.825	0.017	0.01
(50m, 25m)	44.67	0.149	0.453	0.021	0.07
(100m, 25m)	45.39	0.101	0.037	0.025	0.01
(0, 50m)	44.28	0.184	0.754	0.085	0.012
(25m, 50m)	45.38	0.125	0.291	0.019	0.006
(50m, 50m)	44.52	0.208	0.781	0.045	0.014
(100m, 50m)	44.22	0.155	0.751	0.025	0.012
(0, 75m)	45.1	0.161	0.702	0.054	0.01
(25m, 75m)	45.12	0.145	0.506	0.435	0.004
(50m, 75m)	45.62	0.069	0.092	0.011	0.003
(75m, 75m)	45.12	0.183	0.867	0.039	0.005
(100m, 75m)	45.45	0.109	0.868	0.805	0.058
(0, 100m)	45.1	0.128	1.145	0.032	0.008
(50m, 100m)	44.67	0.121	0.428	0.018	0.012
(75m, 100m)	45.12	0.095	0.76	0.014	0.007
(100m, 100m)	45.62	0.125	0.326	0.019	0.013
Min. Value	44.22	0.069	0.037	0.011	0.003
Max. Value	45.63	0.243	1.145	0.805	0.058
Mean Value	45.060	0.140	0.628	0.096	0.015
Standard deviation Value	0.448	0.043	0.291	0.187	0.016

Table C.6.19. The percentages (%) results of Nitrogen, Carbon, Sulphur and Hydrogen for non-contaminated samples at depths (0.0 m, 0.25 m).

Trial Pits Coordinates. (T.P.Cs)	**Sample Weight (g)**	**Content of N, C, S & H (%) by elemental analysis**			
		Nitrogen N%	**Carbon C%**	**Sulphur S%**	**Hydrogen H%**
At Depth (0.0 m)					
(0 m, 0 m)	45.940	0.0030	0.011	0.013	0.0052
(100 m, 0 m)	45.160	0.0015	0.021	0.014	0.010
(50 m, 50 m)	44.300	0.0025	0.036	0.004	0.003
(0 m, 100 m)	44.260	0.0029	0.080	0.008	0.0028
(100 m, 100 m)	4.290	0.0037	0.092	0.001	0.0062
Min. value	44.26	0.0015	0.011	0.001	0.0028
Max. value	45.94	0.0037	0.092	0.014	0.01
Mean value	36.79	0.002	0.048	0.008	0.005
Standard deviation value	18.181	0.0008	0.036	0.005	0.002
At Depth (0.25 m)					
(0 m, 0 m)	44.130	0.0012	0.001	0.000	0.0001
(100 m, 0 m)	44.810	0.0001	0.000	0.003	0.001
(50 m, 50 m)	44.410	0.000	0.0011	0.000	0.0021
(0 m, 100 m)	45.290	0.000	0.0012	0.002	0.0017
(100 m, 100 m)	46.190	0.000	0.000	0.000	0.0010
Min. value	44.13	0	0	0	0.0001
Max. value	44.81	0.0012	0.0012	0.003	0.0021
Mean value	44.966	0.0002	0.0006	0.001	0.0011
Standard deviation value	0.811	0.0005	0.0006	0.0014	0.0007

Table C.6.20. The significant p-values via normality Shapiro-Wilk test indicate that the elemental analysis (i.e. N % (A), C % (B) & S % (C)) values of the soil at contaminated and non-contaminated sites at two different depths (0.0 m & 0.25 m) follow normal distribution.



Tests of Normality

A	Kolmogorov-Smirnov^{a}			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
N%_at contaminated site 0.0 m	.124	22	.200*	.965	22	.597
N%_at contaminated site 0.25 m	.152	22	.200*	.915	22	.061

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Tests of Normality

A	Kolmogorov-Smirnov^{a}			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
N % at non contaminated 0.0 m	.193	5	.200*	.961	5	.813
N % at non-contaminated 0.25 m	.419	5	.004	.607	5	.001

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Tests of Normality

B	Kolmogorov-Smirnov^{a}			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
C%_at contaminated site 0.0 m	.145	22	.200*	.962	22	.525
C%_at contaminated site 0.25 m	.225	22	.005	.814	22	.001

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Tests of Normality

B	Kolmogorov-Smirnov^{a}			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
C % at non- contaminated-0 m	.230	5	.200*	.891	5	.362
C % at non-contaminated-0.25m	.312	5	.125	.768	5	.043

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

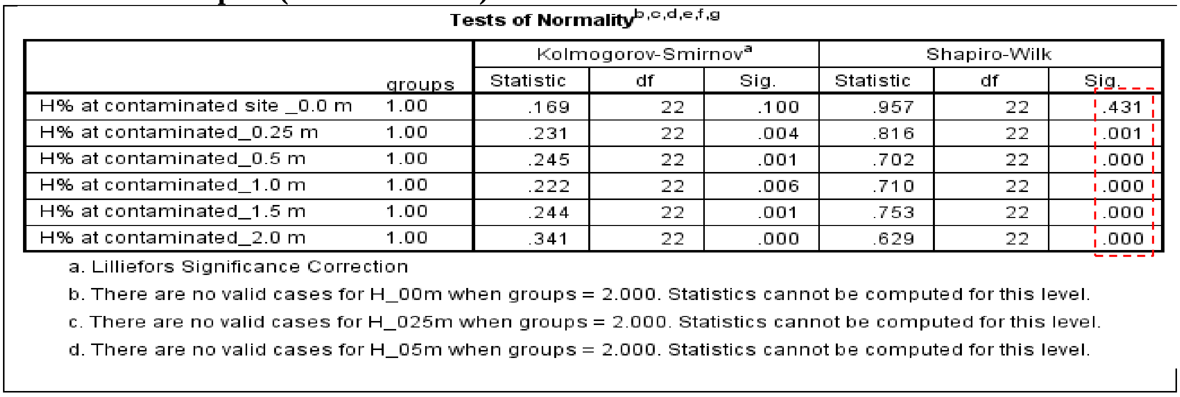
Tests of Normality

C	Groups	Kolmogorov-Smirnov^{a}			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
S% at 0.0 m	Contaminated site	.147	22	.200*	.920	22	.075
	non-contaminated	.214	5	.200*	.928	5	.582
S% at 0.25 m	Contaminated site	.260	22	.000	.754	22	.000
	non-contaminated	.360	5	.033	.767	5	.042

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Table C.6.21. The significant p-values via normality Shapiro-Wilk test indicate that the elemental analysis (i.e. H %) values of the soil at contaminated and non-contaminated sites at two different depths (0.0 m & 0.25 m) follow non-normal distribution.



Tests of Normality^{b,c,d,e,f,g}

	groups	Kolmogorov-Smirnov^{a}			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
H% at contaminated site _0.0 m	1.00	.169	22	.100	.957	22	.431
H% at contaminated_0.25 m	1.00	.231	22	.004	.816	22	.001
H% at contaminated_0.5 m	1.00	.245	22	.001	.702	22	.000
H% at contaminated_1.0 m	1.00	.222	22	.006	.710	22	.000
H% at contaminated_1.5 m	1.00	.244	22	.001	.753	22	.000
H% at contaminated_2.0 m	1.00	.341	22	.000	.629	22	.000

a. Lilliefors Significance Correction

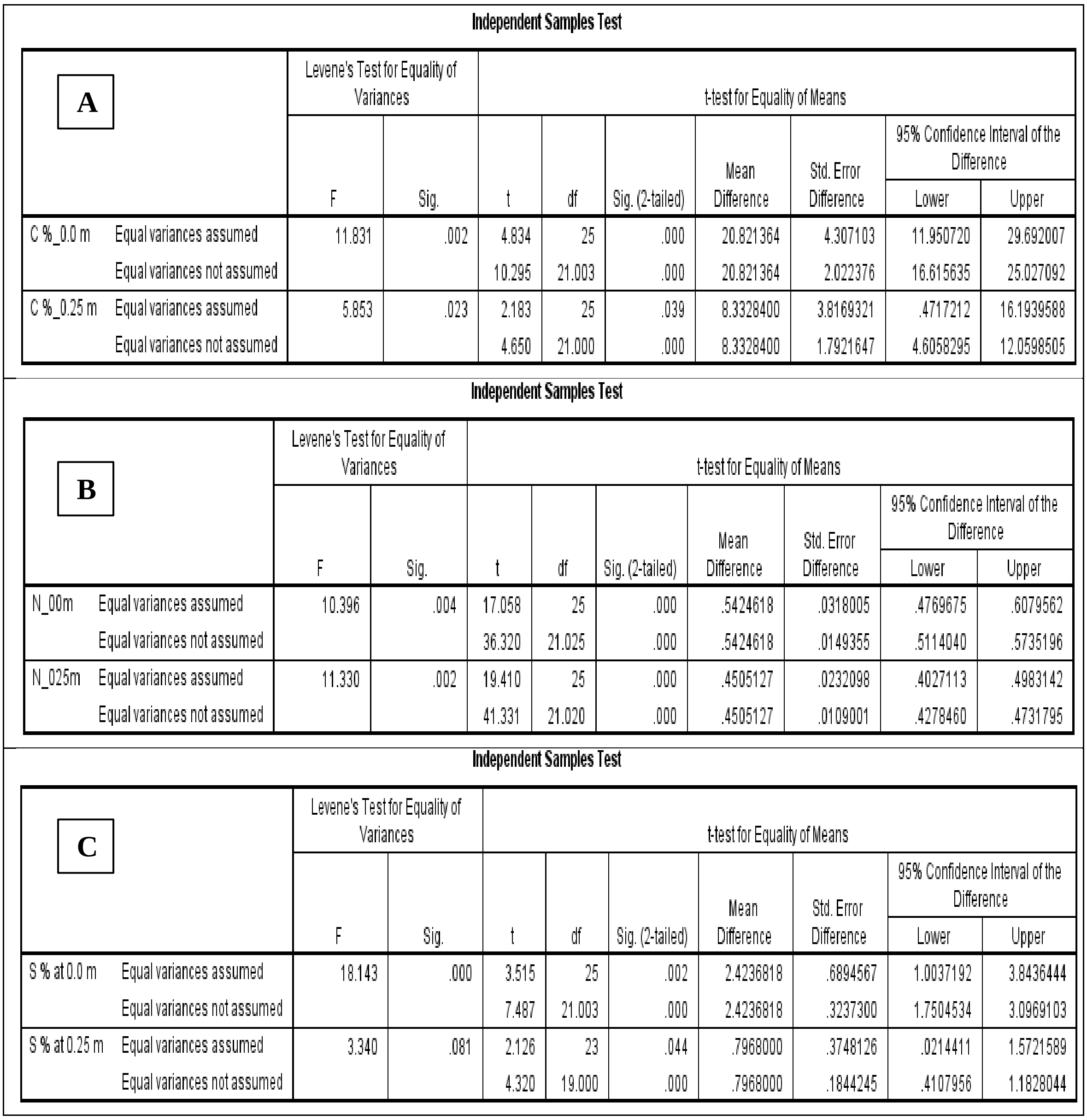
b. There are no valid cases for H_00m when groups = 2.000. Statistics cannot be computed for this level.

c. There are no valid cases for H_025m when groups = 2.000. Statistics cannot be computed for this level.

d. There are no valid cases for H_05m when groups = 2.000. Statistics cannot be computed for this level.

Note: the H % values at non-contaminated site (group = 2.0) were found to be close to zero.

Table C.6.22. Indicates the significant differences of the elemental analysis (i.e. N % (A), C % (B) & S % (C)) variables in the soil at two different depths between contaminated and non-contaminated sites.



Independent Samples Test

A		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
C %_0.0 m	Equal variances assumed	11.831	.002	4.834	25	.000	20.821364	4.307103	11.950720	29.692007
	Equal variances not assumed			10.295	21.003	.000	20.821364	2.022376	16.615635	25.027092
C %_0.25 m	Equal variances assumed	5.853	.023	2.183	25	.039	8.3328400	3.8169321	.4717212	16.1939588
	Equal variances not assumed			4.650	21.000	.000	8.3328400	1.7921647	4.6058295	12.0598505

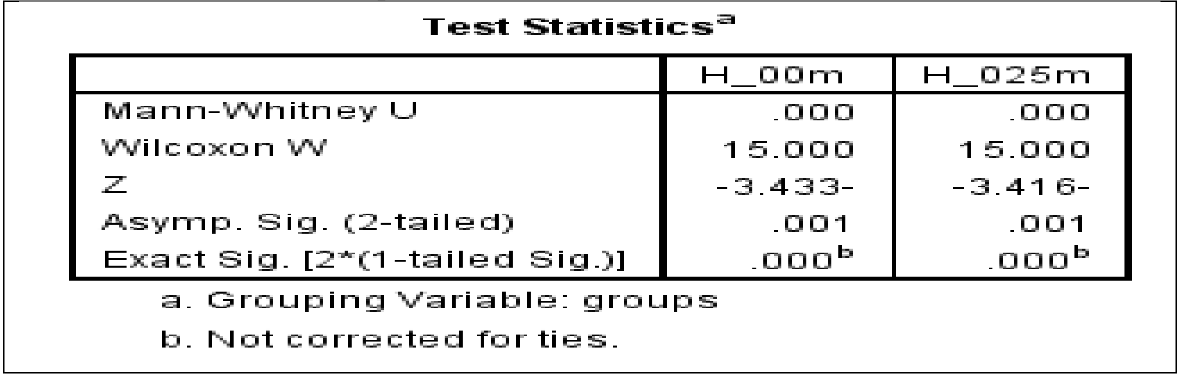
Independent Samples Test

B		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
N_00m	Equal variances assumed	10.396	.004	17.058	25	.000	.5424618	.0318005	.4769675	.6079562
	Equal variances not assumed			36.320	21.025	.000	.5424618	.0149355	.5114040	.5735196
N_025m	Equal variances assumed	11.330	.002	19.410	25	.000	.4505127	.0232098	.4027113	.4983142
	Equal variances not assumed			41.331	21.020	.000	.4505127	.0109001	.4278460	.4731795

Independent Samples Test

C		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
S % at 0.0 m	Equal variances assumed	18.143	.000	3.515	25	.002	2.4236818	.6894567	1.0037192	3.8436444
	Equal variances not assumed			7.487	21.003	.000	2.4236818	.3237300	1.7504534	3.0969103
S % at 0.25 m	Equal variances assumed	3.340	.081	2.126	23	.044	.7968000	.3748126	.0214411	1.5721589
	Equal variances not assumed			4.320	19.000	.000	.7968000	.1844245	.4107956	1.1828044

Table C.6.23. Indicates the significant differences of the elemental analysis (i.e. H %) variable in the soil at two different depths between contaminated and non-contaminated sites.



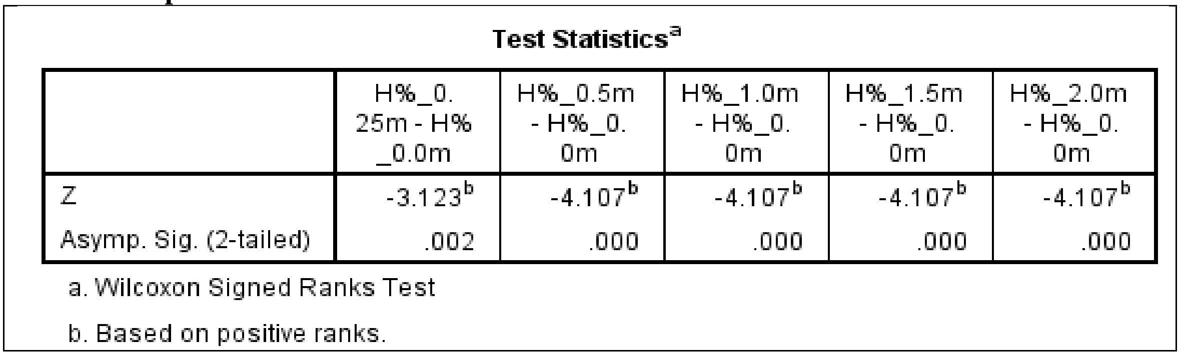
Test Statistics[a]

	H_00m	H_025m
Mann-Whitney U	.000	.000
Wilcoxon W	15.000	15.000
Z	-3.433-	-3.416-
Asymp. Sig. (2-tailed)	.001	.001
Exact Sig. [2*(1-tailed Sig.)]	.000[b]	.000[b]

a. Grouping Variable: groups

b. Not corrected for ties.

Table C.6.24. Indicates the significant difference between the H % variable in the soil and six different depths at contaminated site.



Test Statistics[a]

	H%_0.25m - H%_0.0m	H%_0.5m - H%_0.0m	H%_1.0m - H%_0.0m	H%_1.5m - H%_0.0m	H%_2.0m - H%_0.0m
Z	-3.123[b]	-4.107[b]	-4.107[b]	-4.107[b]	-4.107[b]
Asymp. Sig. (2-tailed)	.002	.000	.000	.000	.000

a. Wilcoxon Signed Ranks Test

b. Based on positive ranks.

GC-MS Results

Table C.6.25. The results of detected soil sample with TPH which tested by GC-MS instrument for T.P.C. (75 m, 0 m) at depth (0.0 m) of contaminated site (Al-Magwa Area).

Peak	Ret. Time	Chemical Composition of the TPH in the Contaminated Soil Sample	Area Under the Curve (m2)	Chemical Composition Formula	Classification of the TPH based on Aliphatic and Aromatic	Concentration of each TPH Chemical Composition Detected in the Contaminated Soil Sample (µg/ml)	Concentration of each TPH Chemical Composition Detected in the Contaminated Soil Sample (mg/kg)	Total Concentration of the Total TPH Compositions Detected in the Contaminated Soil Sample (mg/kg)	References
*1	3.118 BV	Dihydroxydimethylsilane	-39496627	$C_2H_8O_2$	-------	0	0	53.02	(Dimethylsilanediol, n.d.)
**2	19.564 BV	BHT	5772938	$C_{15}H_{24}$	Aromatic EC12 - EC16	48.131	16.043		(BHT, n.d.)
***3	22.458 PV	------	3018562	------	---------	12.462	4.154		---------
**4	22.575 VV	Dihydro indol-2-one	4227389	C_8H_7NO	Aromatic EC8 - EC10	28.116	9.372		(Oxindole, n.d.)
***5	22.901 VV	------	2078641	------	-------	0.290	0.096		---------
**6	23.077 VV	9,10-Dimethylanthracene	4000251	$C_{16}H_{14}$	Aromatic EC16- EC21	25.175	8.391		(Nine, 10-dimethylanthracene, n.d.)
**7	23.191 VV	1,7-Dimethylphenanthrene	5289993	$C_{16}H_{14}$	Aromatic EC16- EC21	41.877	13.959		(One, 7-Dimethylphenanthrene, n.d.)
**8	23.337 VV	14β-pregnane	2164912	$C_{21}H_{36}$	Aliphatic EC16 - EC35	1.407	0.469		((14β)-Pregnane, n.d.)
**9	23.696 PV	Isopentyltrimethyl benezene	3164712	$C_{14}H_{22}$	Aromatic EC12 - EC16	14.355	4.785		(One-Isopentyl-2,3,5-trimethylbenzene, n.d.)

Notes: * Greeen colure clarify the solvent compound came from the column bleeding during soil sample analysis by GC-MS test.

*****Brown colour clarify the hydrocarbon compounds and their concentrations detected in soil sample.***

******Blue Colure clarify the unknown chemical compounds and their concentrations (not identify by diesel standard) detected in soil sample which are excluded from the total concentration of the TPH.***

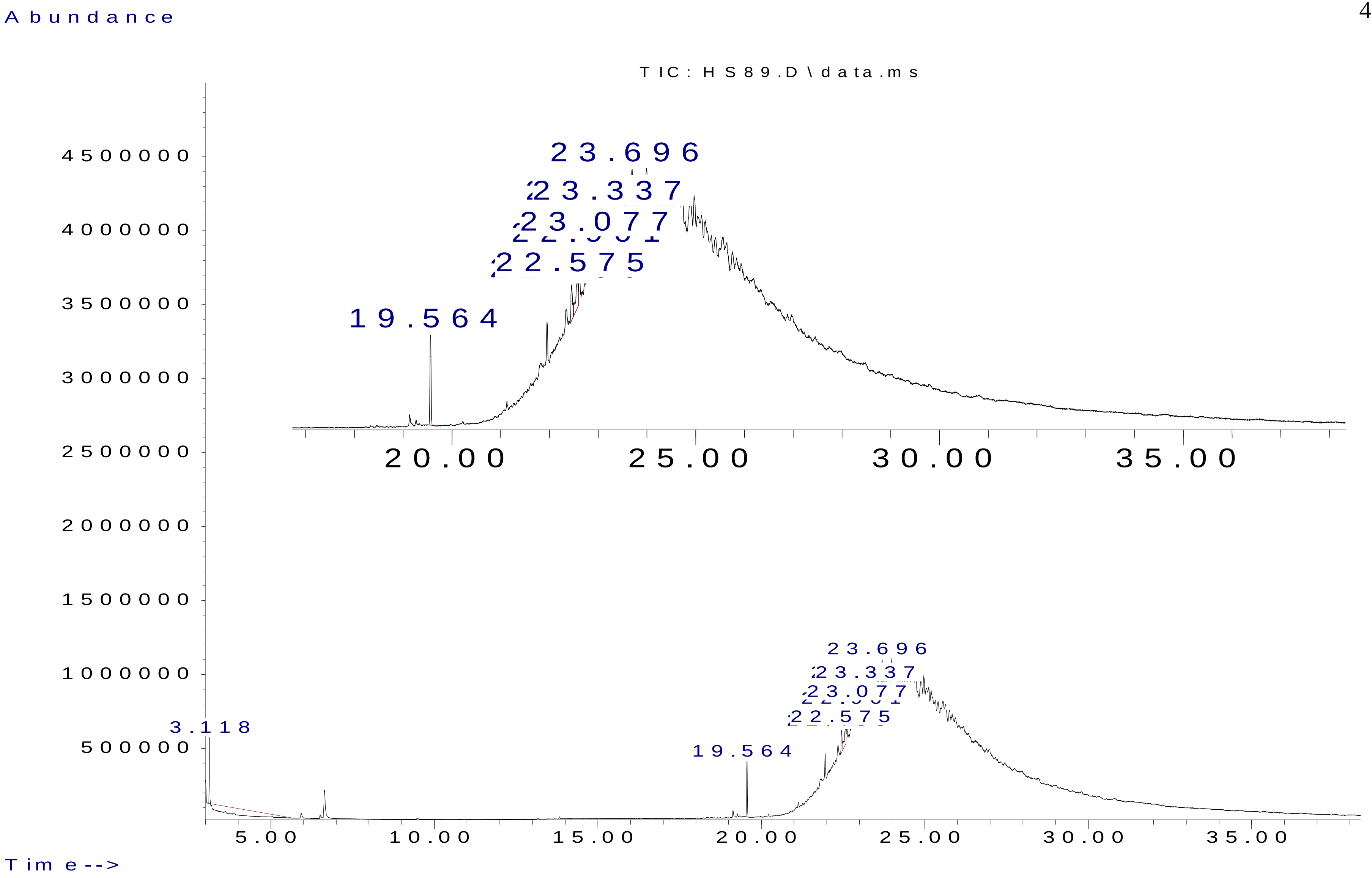


Figure C.6.1. The Total Ion Chromatograms (TIC) of detected soil sample with TPH for T.P.C. (75 m, 0 m) at depth (0.0 m), at contaminated site (Al-Magwa Area).

Table C.6.26. The results of detected soil sample with TPH which tested by GC-MS instrument for T.P.C. (100 m, 0 m) at depth (0.0 m) of contaminated site (Al-Magwa Area).

Peak	Ret. Time	Chemical Composition of the TPH in the Contaminated Soil Sample	Area Under the Curve (m^2)	Chemical Composition Formula	Classification of the TPH based on Aliphatic and Aromatic	Concentration of each TPH Chemical Composition Detected in the Contaminated Soil Sample (µg/ml)	Concentration of each TPH Chemical Composition Detected in the Contaminated Soil Sample (mg/kg)	Total Concentration of the Total TPH Compositions Detected in the Contaminated Soil Sample (mg/kg)	References
1	18.866 BV	BHT	4978660	$C_{15}H_{24}$	Aromatic EC12-EC16	37.845	12.615	17.801	(BHT, n.d.)
2	21.067 VV	Tetramethylhexadecane	3257709	$C_{20}H_{42}$	Aliphatic EC16-EC35	15.559	5.186		(Two, 6, 10, 14-tetramethylhexadecane, n.d.)

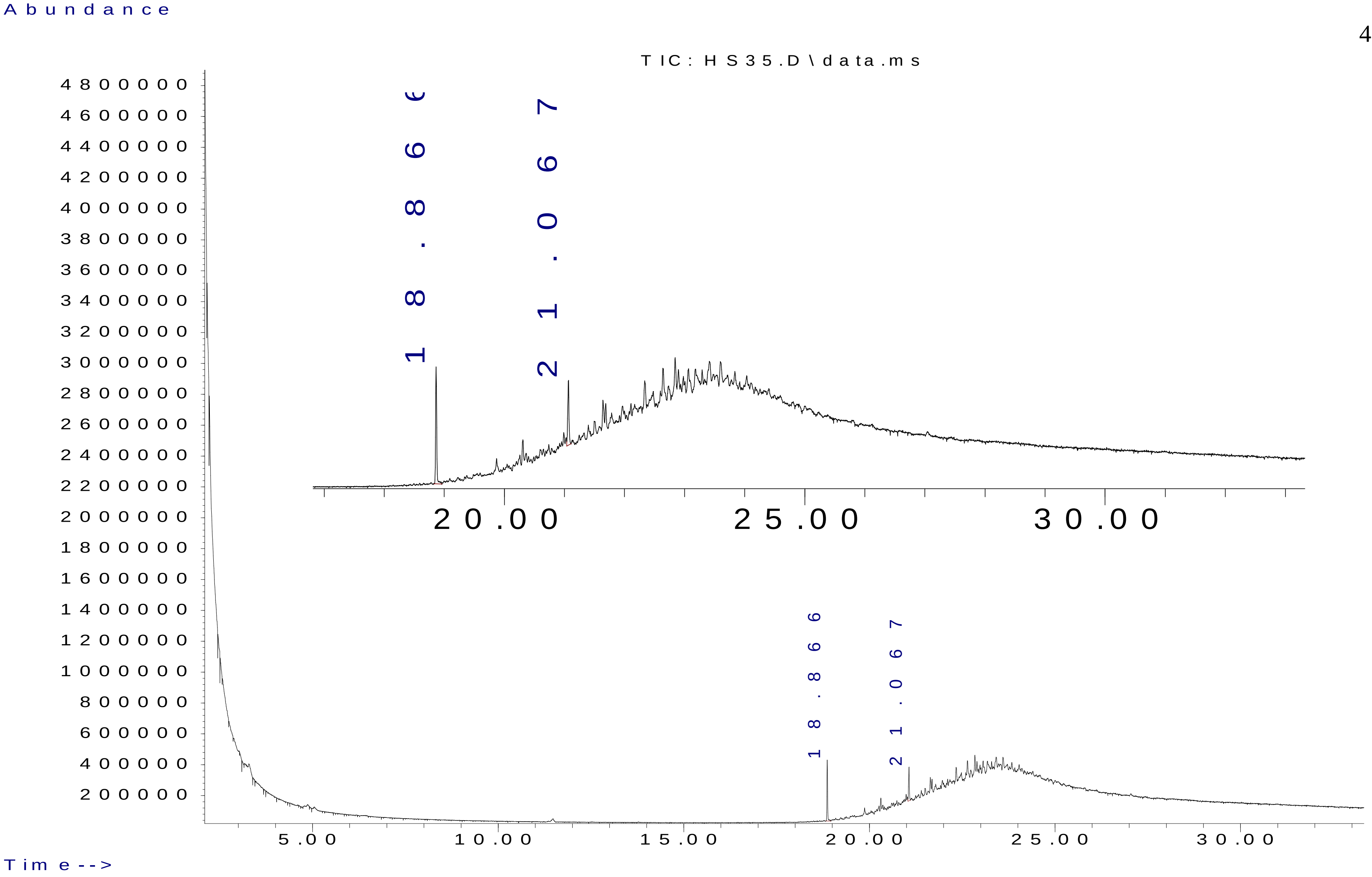


Figure C.6.2. The Total Ion Chromatograms (TIC) of detected soil sample with TPH for T.P.C. (100 m, 0 m) at depth (0.0 m), at contaminated site (Al-Magwa Area).

Table C.6.27. Shows the results of detected sample with TPH which tested by GC-MS instrument for T.P.C. (25 m, 25 m) at depth (0.0 m) of contaminated site (Al-Magwa Area).

Peak	Ret. Time	Chemical Composition of the TPH in the Contaminated Soil Sample	Area Under the Curve (m2)	Chemical Composition Formula	Classification of the TPH based on Aliphatic and Aromatic	Concentration of each TPH Chemical Composition Detected in the Contaminated Soil Sample (μg/ml)	Concentration of each TPH Chemical Composition Detected in the Contaminated Soil Sample (mg/kg)	Total Concentration of the Total TPH Compositions Detected in the Contaminated Soil Sample (mg/kg)	References
1	18.868 BB	BHT	3667821	$C_{15}H_{24}$	Aromatic EC12 - EC16	20.870	6.956	43.167	(BHT, n.d.)
2	21.068 VV	9,10-Dimethylanthracene	5627746	$C_{16}H_{14}$	Aromatic EC16 – EC21	46.251	15.417		(Nine, 10-dimethylanthracene, n.d.)
3	21.645 PV	2-Methylheptadecane	4263025	$C_{18}H_{38}$	Aliphatic EC16 - EC35	28.578	9.526		(Two-methylheptadecane, n.d.)
4	22.345 VV	Eicosane	1795104	$C_{20}H_{42}$	Aliphatic EC16 - EC35	0	0		(Icosane, n.d.)
5	22.643 VV	2,7-Dimethyldibenzothiophene	3789062	$C_{14}H_{12}S$	Aromatic EC12 - EC16	22.440	7.48		(Three, 8-dimethyldibenzothiophene, n.d.)
6	22.845 PV	9,10-Dimethylanthracene	2933586	$C_{16}H_{14}$	Aromatic EC16 - EC21	11.362	3.787		(Nine, 10-dimethylanthracene, n.d.)

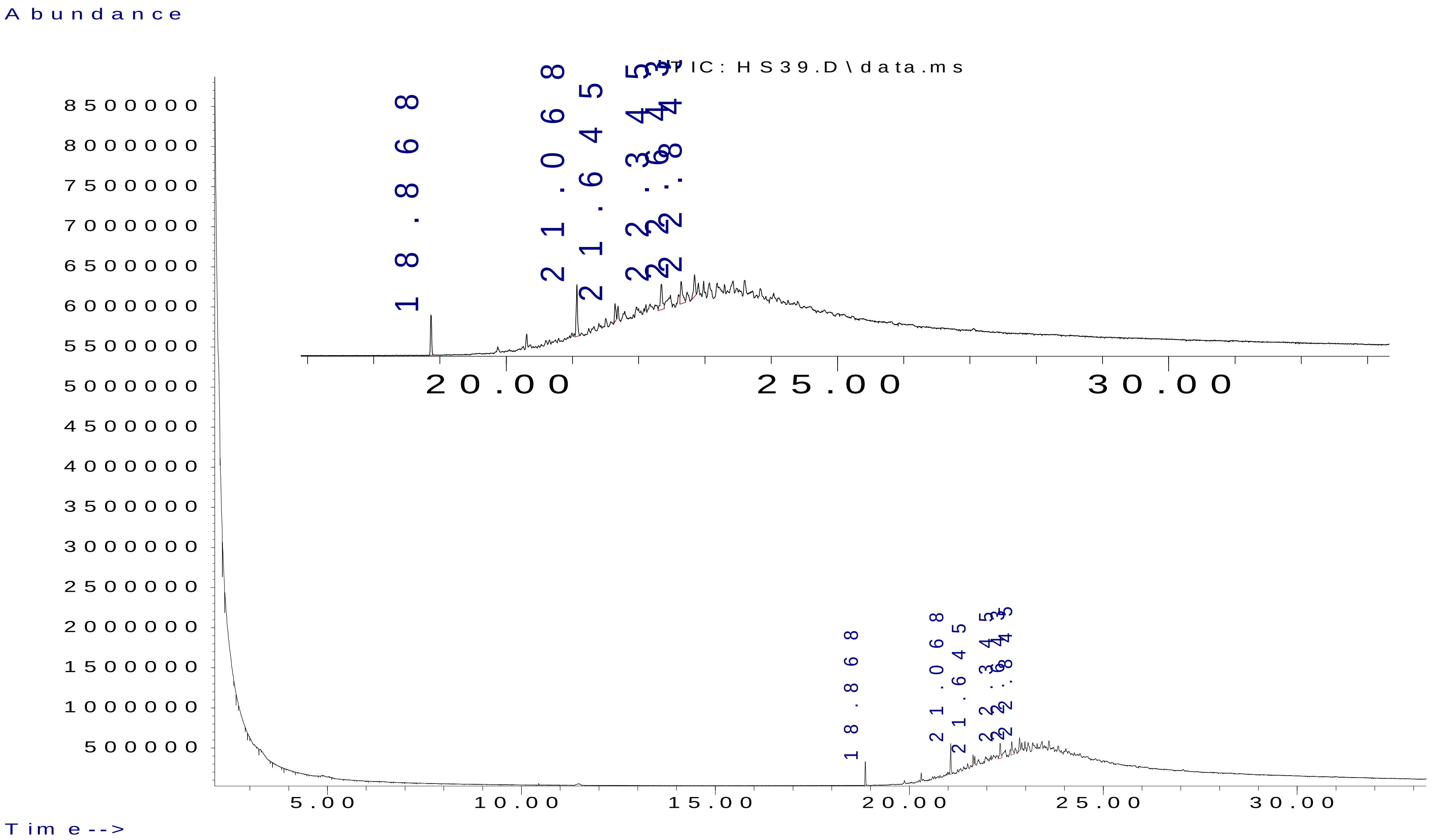


Figure C.6.3. The Total Ion Chromatograms (TIC) of detected soil sample with TPH for T.P.C. (25 m, 25 m) at depth (0.0 m), at contaminated site (Al-Magwa Area).

Table C.6.28. The results of detected soil sample with TPH which tested by GC-MS instrument for T.P.C. (100 m, 25 m) at depth (0.0 m) of contaminated site (Al-Magwa Area).

Peak	Ret. Time	Chemical Composition of the TPH in the Contaminated Soil Sample	Area Under the Curve (m2)	Chemical Composition Formula	Classification of the TPH based on Aliphatic and Aromatic	Concentration of each TPH Chemical Composition Detected in the Contaminated Soil Sample (µg/ml)	Concentration of each TPH Chemical Composition Detected in the Contaminated Soil Sample (mg/kg)	Total Concentration of the Total TPH Compositions Detected in the Contaminated Soil Sample (mg/kg)	References
1	19.562 BV	BHT	14342521	$C_{15}H_{24}$	Aromatic EC12 - EC16	159.107	53.035	324.203	(BHT, n.d.)
2	21.952 VV	9,10-Dimethylanthracene	4894895	$C_{16}H_{14}$	Aromatic EC16 – EC21	36.760	12.253		(Nine, 10-dimethylanthracene, n.d.)
3	22.622 VV	Tetradecane	3789302	$C_{14}H_{30}$	Aliphatic EC12 - EC16	22.443	7.481		(Tetradecane, n.d.)
4	23.337 BV	Eicosane	6805533	$C_{20}H_{42}$	Aliphatic EC16 - EC35	61.503	20.501		(Icosane, n.d.)
5	23.754 VV	4,6-dimethyldibenzothiophene	7276403	$C_{14}H_{12}S$	Aromatic EC12 - EC16	67.601	22.533		(Four, 6-dimethyldibenzothiophene, n.d.)
6	23.895 VV	1,7-Dimethylphenanthrene	11051878	$C_{16}H_{14}$	Aromatic EC16 – EC21	116.493	38.831		(One, 7-Dimethylphenanthrene, n.d.)
7	23.988 VV	10-Methylanthracene-9-carboxaldehyde	6844176	$C_{16}H_{12}O$	Aromatic EC16 – EC21	62.004	20.668		(Ten-Methyl-9-anthracenecarbaldehyde, n.d.)
8	24.063 VV	Hexadecane	12459108	$C_{16}H_{34}$	Aliphatic EC16 - EC35	134.717	44.905		(Hexadecane, n.d.)
9	24.253 VV	3-(2,5-Dimethyl-1H-pyrrole-3-yl)-1,3-dihydro-indol-2-one	11312542	$C_{15}H_{14}$	Aromatic EC12 - EC16	119.869	39.956		(Semaxanib, n.d.)
10	24.706 VV	Iso-hexadecane	11253535	$C_{16}H_{34}$	Aliphatic EC16 - EC35	119.105	39.701		(Iso hexadecane, n.d.)
11	24.858 VV	Pregnenone	7694044	$C_{21}H_{36}$	Aliphatic EC16 - EC35	73.009	24.336		(Pregnane, n.d.)

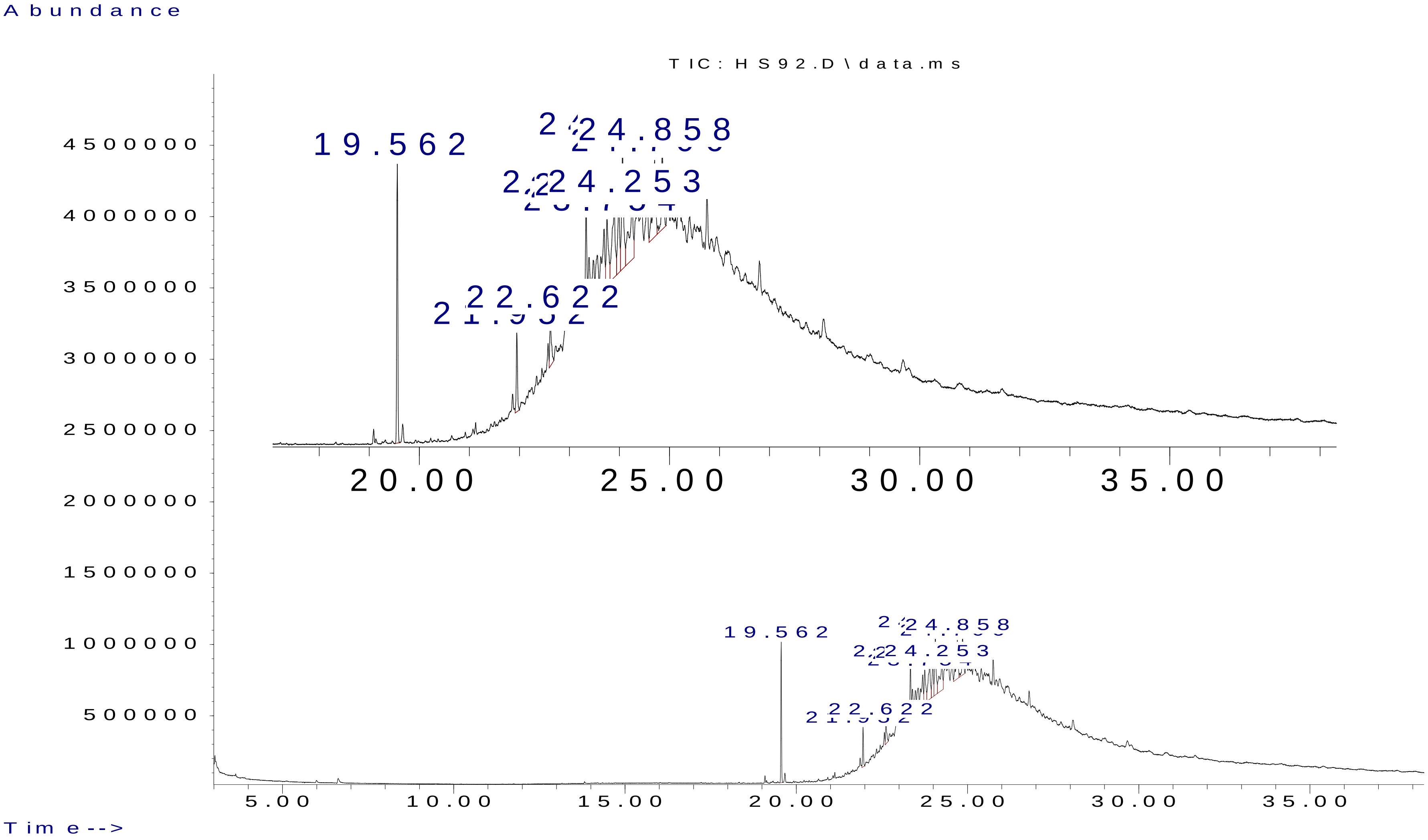


Figure C.6.4. The Total Ion Chromatograms (TIC) of detected soil sample with TPH for T.P.C. (100 m, 25 m) at depth (0.0 m), at contaminated site (Al-Magwa Area).

Table C.6.29. The results of detected soil sample with TPH which tested by GC-MS instrument for T.P.C. (25 m, 50 m) at depth (0.0 m) of contaminated site (Al-Magwa Area).

Peak	Ret. Time	Chemical Composition of the TPH in the Contaminated Soil Sample	Area Under the Curve (m^2)	Chemical Composition Formula	Classification of the TPH based on Aliphatic and Aromatic	Concentration of each TPH Chemical Composition Detected in the Contaminated Soil Sample (µg/ml)	Concentration of each TPH Chemical Composition Detected in the Contaminated Soil Sample (mg/kg)	Total Concentration of the Total TPH Compositions Detected in the Contaminated Soil Sample (mg/kg)	References
1	3.036 BV	Methyldimethoxysilane	4110314	$C_3H_{10}O_2Si$	--------	26.600	8.866	113.93	(Methyldimethoxysilane, n.d.)
2	19.563 BV	BHT	9167184	$C_{15}H_{24}$	Aromatic EC12 - EC16	92.087	30.695		(BHT, n.d.)
3	22.347 VV	1-allyl-methylindole carbaldehyde	4519003	$C_{13}H_{13}NO$	Aromatic EC12 - EC16	31.893	10.631		(One-Allyl-2-methyl-1H-indole-3-carbaldehyde, n.d.)
4	22.456 PV	Eicosane	6269607	$C_{20}H_{42}$	Aliphatic EC16 - EC35	54.563	18.187		(Icosane, n.d.)
5	22.562 VV	10-Methylanthracene-9-carboxaldehyde	3046984	$C_{16}H_{12}O$	Aromatic EC16 – EC21	12.830	4.276		(Ten-Methyl-9-anthracenecarbaldehyde, n.d.)
6	22.615 VV	1-allyl-3-methyl carbaldehyde	2624307	$C_{13}H_{13}NO$	Aromatic EC12 - EC16	7.356	2.452		(One-Allyl-2-methyl-1H-indole-3-carbaldehyde, n.d.)
7	22.896 VV	2-methyl dihydrobenzofuran	3496372	$C_9H_{10}O$	Aromatic EC8 - EC10	18.650	18.65		(Two-Methyl-2,3-dihydro-1-benzofuran, n.d.)
8	23.085 VV	β-pregnane	3772225	$C_{21}H_{36}$	Aliphatic EC16 - EC35	22.222	7.407		(Pregnane, n.d.)
9	23.189 VV	-----	5389259	------	------	43.163	14.387		--------
10	23.695 PV	4-allyl phenol	5472877	$C_9H_{10}O$	Aromatic EC8 - EC10	44.245	14.748		(Chavicol, n.d.)
11	23.994 BV	1-octadecanol	3659348	$C_{18}H_{38}O$	Aliphatic EC16 - EC35	20.760	6.92		(Octadecan-1-ol, n.d.)

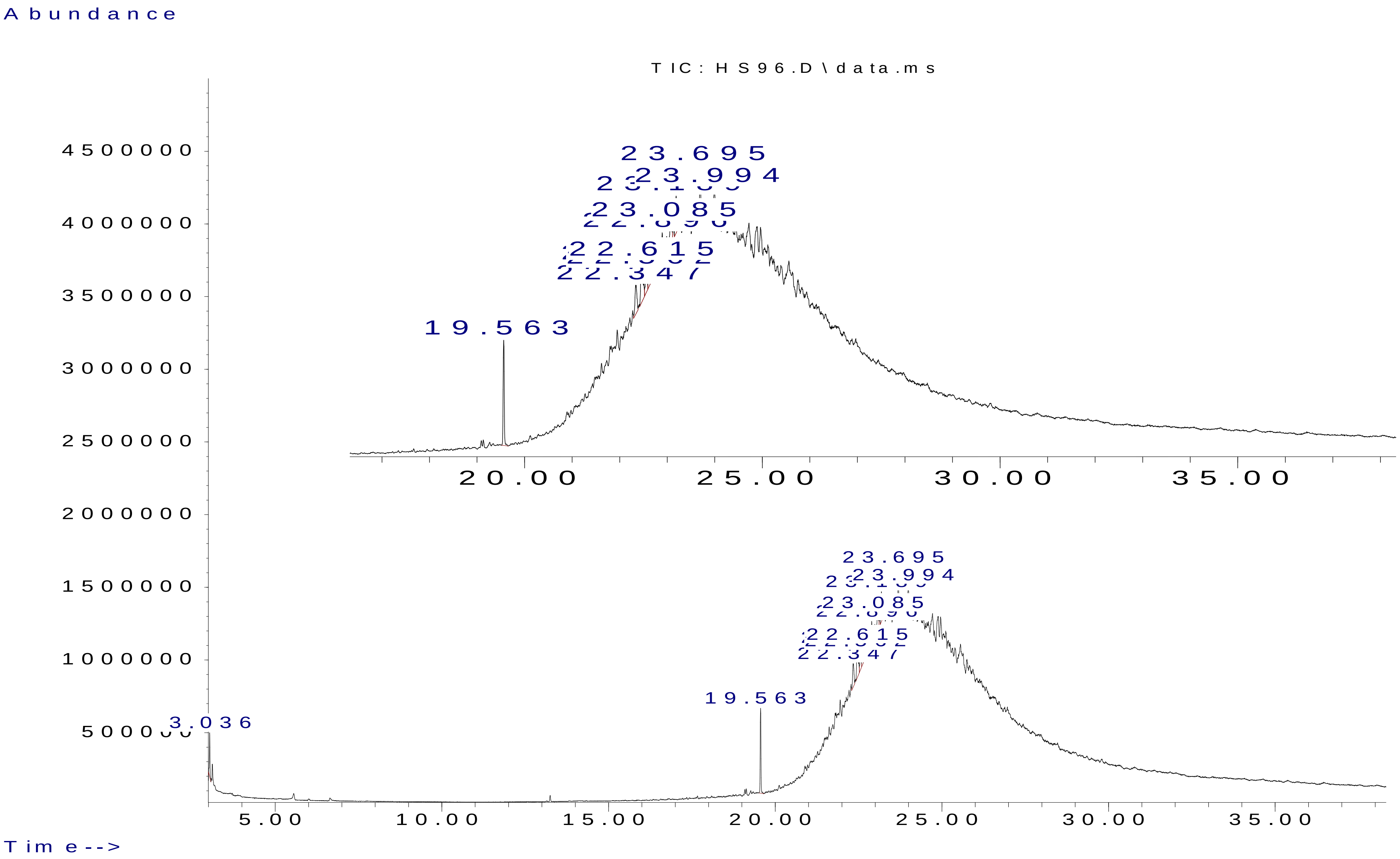


Figure C.6.5. The Total Ion Chromatograms (TIC) of detected soil sample with TPH for T.P.C. (25 m, 50 m) at depth (0.0 m), at contaminated site (Al-Magwa Area).

Table C.6.30. The results of detected soil sample with TPH which tested by GC-MS instrument for T.P.C. (50 m, 50 m) at depth (0.0 m) of contaminated site (Al-Magwa Area).

Peak	Ret. Time	Chemical Composition of the TPH in the Contaminated Soil Sample	Area Under the Curve (m2)	Chemical Composition Formula	Classification of the TPH based on Aliphatic and Aromatic	Concentration of each TPH Chemical Composition Detected in the Contaminated Soil Sample (µg/ml)	Concentration of each TPH Chemical Composition Detected in the Contaminated Soil Sample (mg/kg)	Total Concentration of the Total TPH Compositions Detected in the Contaminated Soil Sample (mg/kg)	References
1	21.128 VV	9,10-Dimethylanthracene	3628926	$C_{16}H_{14}$	Aromatic EC16 – EC21	20.366	6.788	406.83	(Nine, 10-dimethylanthracene, n.d.)
2	21.869 VV	Octadecane	9887139	$C_{18}H_{38}$	Aliphatic E C16 - EC35	101.410	33.803		(Octadecane, n.d.)
3	21.953 VV	1,7-Dimethylphenanthrene	14187940	$C_{16}H_{14}$	Aromatic EC16 – EC21	157.106	52.368		(One, 7-Dimethylphenanthrene, n.d.)
4	22.624 VV	Nonadecane	15838452	$C_{19}H_{40}$	Aliphatic EC16 - EC35	178.480	59.493		(Nonadecane, n.d.)
5	23.340 VV	Eicosane	26132682	$C_{20}H_{42}$	Aliphatic EC16 - EC35	311.790	103.93		(Icosane, n.d.)
6	23.758 VV	Dimethylbenzothiophene	12877854	$C_{10}H_{10}S$	Aromatic EC10 - EC12	140.140	46.713		(Dimethylbenzothiophene, 2016)
7	24.065 VV	Heneicosane	20139838	$C_{21}H_{44}$	Aliphatic EC16 - EC35	234.183	78.061		(Heneicosane, n.d.)
8	24.856 PV	------	14353698	------	-------	159.252	53.084		-------
9	25.750 VV	Ethyloctadecane	8010651	$C_{20}H_{42}$	Aliphatic EC16 - EC35	77.110	25.703		(Three-Ethyloctadecane, n.d.)

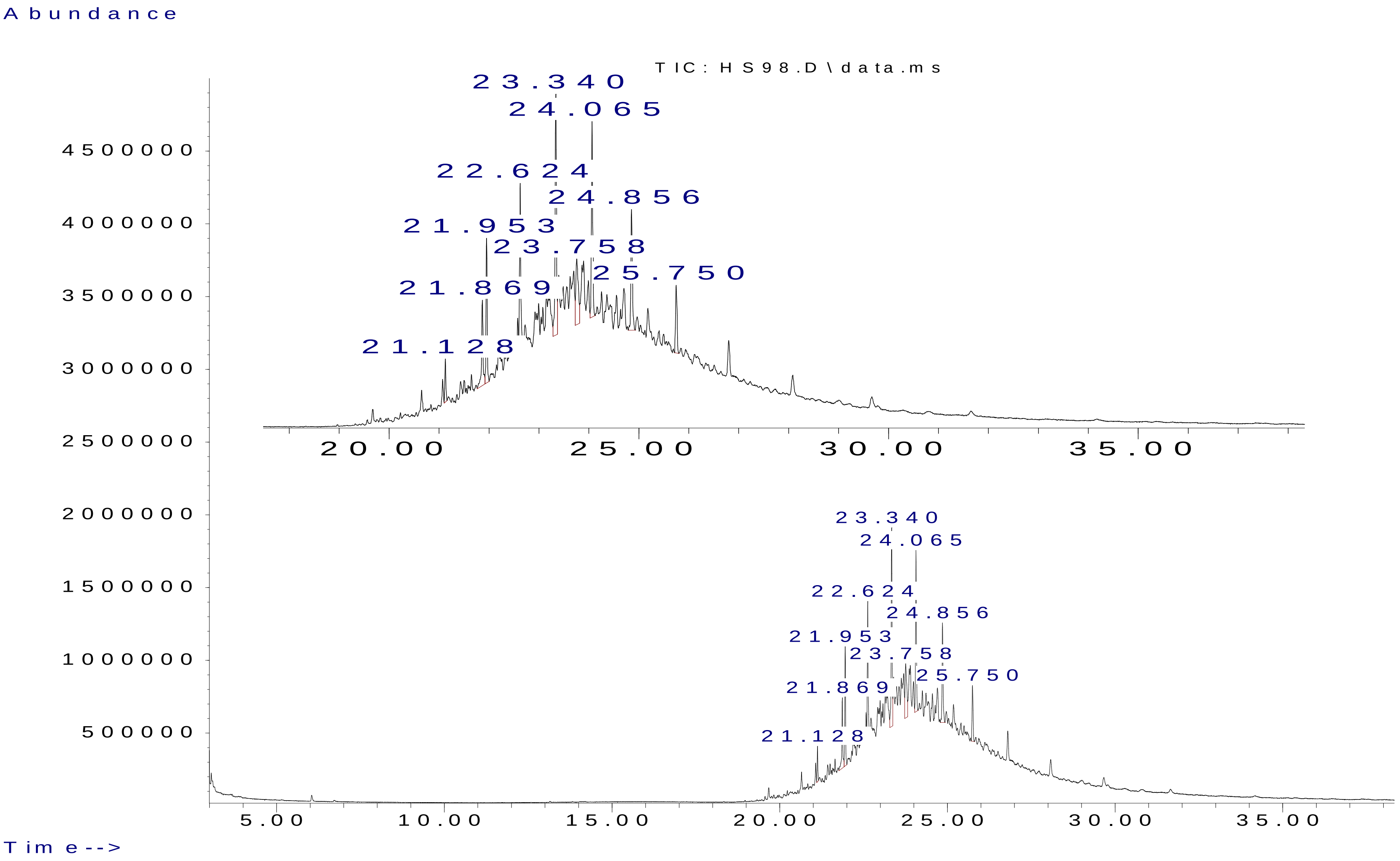


Figure C.6.6. The Total Ion Chromatograms (TIC) of detected soil sample with TPH for T.P.C. (50 m, 50 m) at depth (0.0 m), at contaminated site (Al-Magwa Area).

Table C.6.31. The results of detected soil sample with TPH which tested by GC-MS instrument for T.P.C. (100 m, 50 m) at depth (0.0 m) of contaminated site (Al-Magwa Area).

Peak	Ret. Time	Chemical Composition of the TPH in the Contaminated Soil Sample	Area Under the Curve (m2)	Chemical Composition Formula	Classification of the TPH based on Aliphatic and Aromatic	Concentration of each TPH Chemical Composition Detected in the Contaminated Soil Sample (µg/ml)	Concentration of each TPH Chemical Composition Detected in the Contaminated Soil Sample (mg/kg)	Total Concentration of the Total TPH Compositions Detected in the Contaminated Soil Sample (mg/kg)	References
1	20.654 PV	Tridecane	10156854	$C_{13}H_{28}$	Aliphatic EC12 - EC16	104.903	34.967	1330.087	(Tridecane, n.d.)
2	21.076 VV	Heptadecane	8793615	$C_{17}H_{36}$	Aliphatic EC16 - EC35	87.249	29.083		(Heptadecane, n.d.)
3	21.129 VV	9,10-Dimethylanthracene	14433039	$C_{16}H_{14}$	Aromatic EC16 – EC21	160.280	53.42667		(Nine, 10-dimethylanthracene, n.d.)
4	21.871 VV	Octadecane	19056122	$C_{18}H_{38}$	Aliphatic EC16 - EC35	220.149	73.383		(Octadecane, n.d.)
5	21.956 VV	10-Methylanthracene-9-carboxaldehyde	42016744	$C_{16}H_{12}O$	Aromatic EC16 – EC21	517.489	172.4963		(Ten-Methyl-9-anthracenecarbaldehyde, n.d.)
6	22.579 VV	Nonadecane	15866535	$C_{19}H_{40}$	Aliphatic E C16 - EC35	178.843	59.61433		(Nonadecane, n.d.)
7	22.626 VV	Eicosane	28371208	$C_{20}H_{42}$	Aliphatic EC16 - EC35	340.779	113.593		(Icosane, n.d.)
8	23.153 VV	β-Pregnane	18690622	$C_{21}H_{36}$	Aliphatic EC16 - EC35	215.415	71.805		(Pregnane, n.d.)
9	23.341 VV	Eicosane	41694327	$C_{20}H_{42}$	Aliphatic EC16 - EC35	513.314	171.1047		(Icosane, n.d.)
10	23.700 VV	------	30075439	------	------	362.849	120.9497		------
11	23.761 VV	2,7 Dimethylbenzothiophene	34948916	$C_{10}H_{10}S$	Aromatic EC10 - EC12	425.960	141.9867		(Dimethylbenzothiophene, n.d.)
12	23.899 VV	Di-p-tolylacetylene	47199387	$C_{16}H_{14}$	Aromatic EC16 – EC21	584.604	194.868		(Di-p-Tolylacetylene, n.d.)
13	24.067 VV	n-Cetane	38843678	$C_{16}H_{34}$	Aliphatic EC16 - EC35	476.398	158.7993		(Hexadecane, n.d.)
14	24.858 VV	n-Cetane	14790650	$C_{16}H_{34}$	Aliphatic EC16 - EC35	164.911	54.97033		

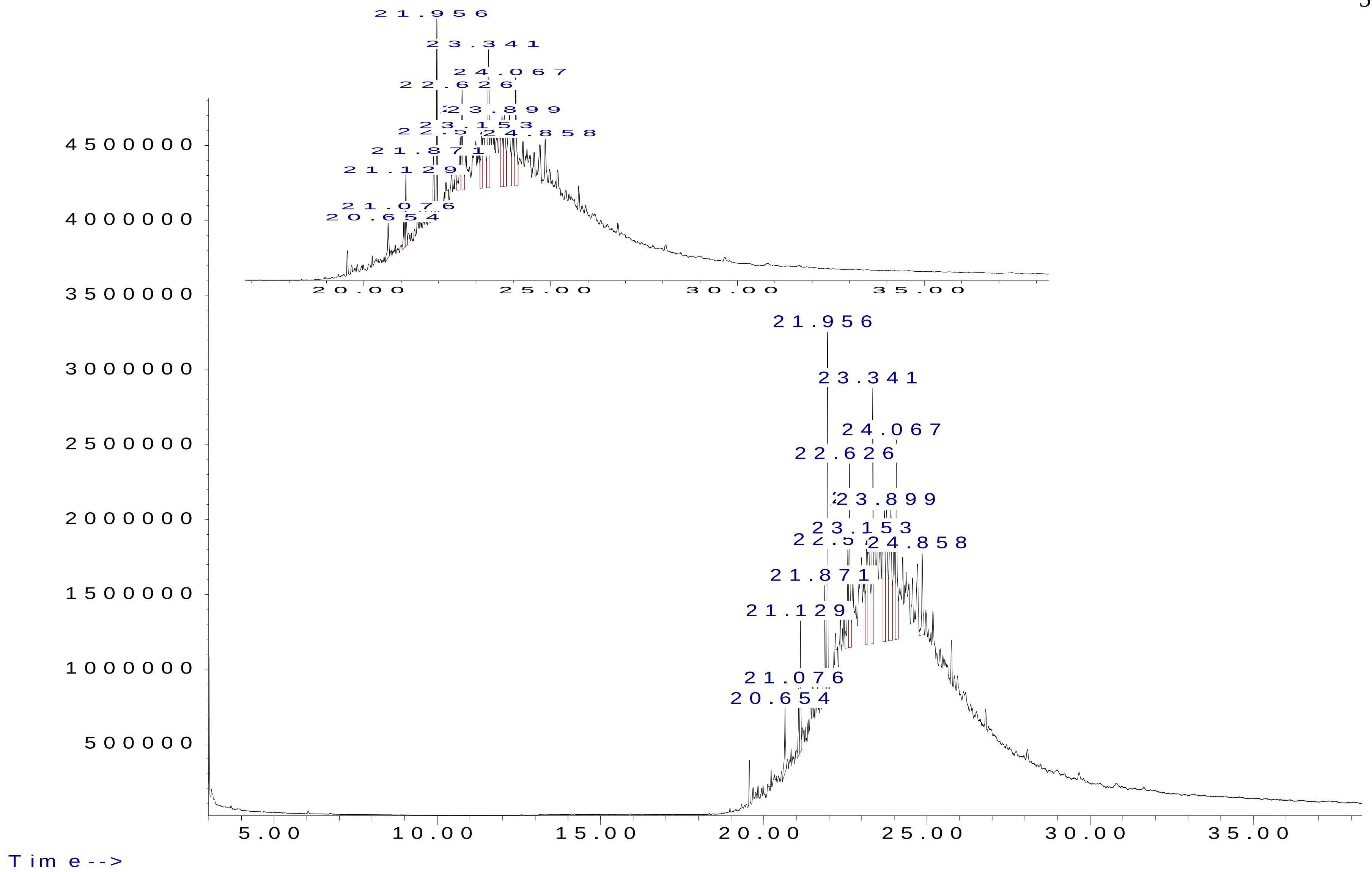


Figure C.6.7. The Total Ion Chromatograms (TIC) of detected soil sample with TPH for T.P.C. (100 m, 50 m) at depth (0.0 m), at contaminated site (Al-Magwa Area).

Table C.6.32. The results of detected soil sample with TPH which tested by GC-MS instrument for T.P.C. (0 m, 75 m) at depth (0.0 m) of contaminated site (Al-Magwa Area).

Peak	Ret. Time	Chemical Composition of the TPH in the Contaminated Soil Sample	Area Under the Curve (m2)	Chemical Composition Formula	Classification of the TPH based on Aliphatic and Aromatic	Concentration of each TPH Chemical Composition Detected in the Contaminated Soil Sample (µg/ml)	Concentration of each TPH Chemical Composition Detected in the Contaminated Soil Sample (mg/kg)	Total Concentration of the Total TPH Compositions Detected in the Contaminated Soil Sample (mg/kg)	References
1	21.072 VV	Tetramethylhexadecane	7244593	$C_{20}H_{42}$	Aliphatic EC16 - EC35	68.18	22.7	332.497	(Two, 6, 10, 14-tetramethylhexadecane, n.d.)
2	21.650 VV	Tetradecane	5395889	$C_{14}H_{30}$	Aliphatic EC12 - EC16	44.24	14.7		(Tetradecane, n.d.)
3	21.692 VV	Nonadecane	4230522	$C_{19}H_{40}$	Aliphatic EC16 - EC35	30.15	10.05		(Nonadecane, n.d.)
4	21.970 VV	Tri indane	6482805	C_9H_{10}	Aromatic EC8 - EC10	58.32	19.44		(Indane, n.d.)
5	22.111 VV	Methylanthracene	4387001	$C_{15}H_{12}$	Aromatic EC12 - EC16	33.18	11.06		(Methylanthracene, n.d.)
6	22.344 VV	Eicosane	10362137	$C_{20}H_{42}$	Aliphatic EC16 - EC35	109.561	36.52		(Icosane, n.d.)
7	22.483 VV	2,7-dimethyldibenzothiophene	9539441	$C_{14}H_{12}S$	Aromatic EC12 - EC16	99.1	33.03		(Three, 8-dimethyldibenzothiophene, n.d.)
8	22.649 VV	4,6-dimethyldibenzothiophene	11694599	$C_{14}H_{12}S$	Aromatic EC12 - EC16	126.3	42.0		(Four, 6-dimethyldibenzothiophene, n.d.)
9	22.851 VV	9,10-dimethylanthracene	10893429	$C_{16}H_{14}$	Aromatic EC16 - EC21	119.4	40.0		(Nine, 10-dimethylanthracene, n.d.)
10	22.907 VV	Substituted phenol	7032856	C_7H_8O	Aromatic	68.447	22.815		(Two-Methylphenol, n.d.)
11	23.069 VV	2-Methylthioxanthone	10530817	$C_{14}H_{10}OS$	Aromatic EC12 - EC16	109.746	36.582		(Two-Methylthioxanthone, n.d.)
12	23.299 VV	--------	5700373	------	----------	47.191	15.730		---------
13	23.420 VV	Heneicosane	9364575	$C_{21}H_{44}$	Aliphatic EC16 - EC35	98.64	33.0		(Heneicosane, n.d.)
14	23.606 PV	Hexadecane	4272533	$C_{16}H_{34}$	Aliphatic EC16 - EC35	31.701	10.567		(Hexadecane, n.d.)

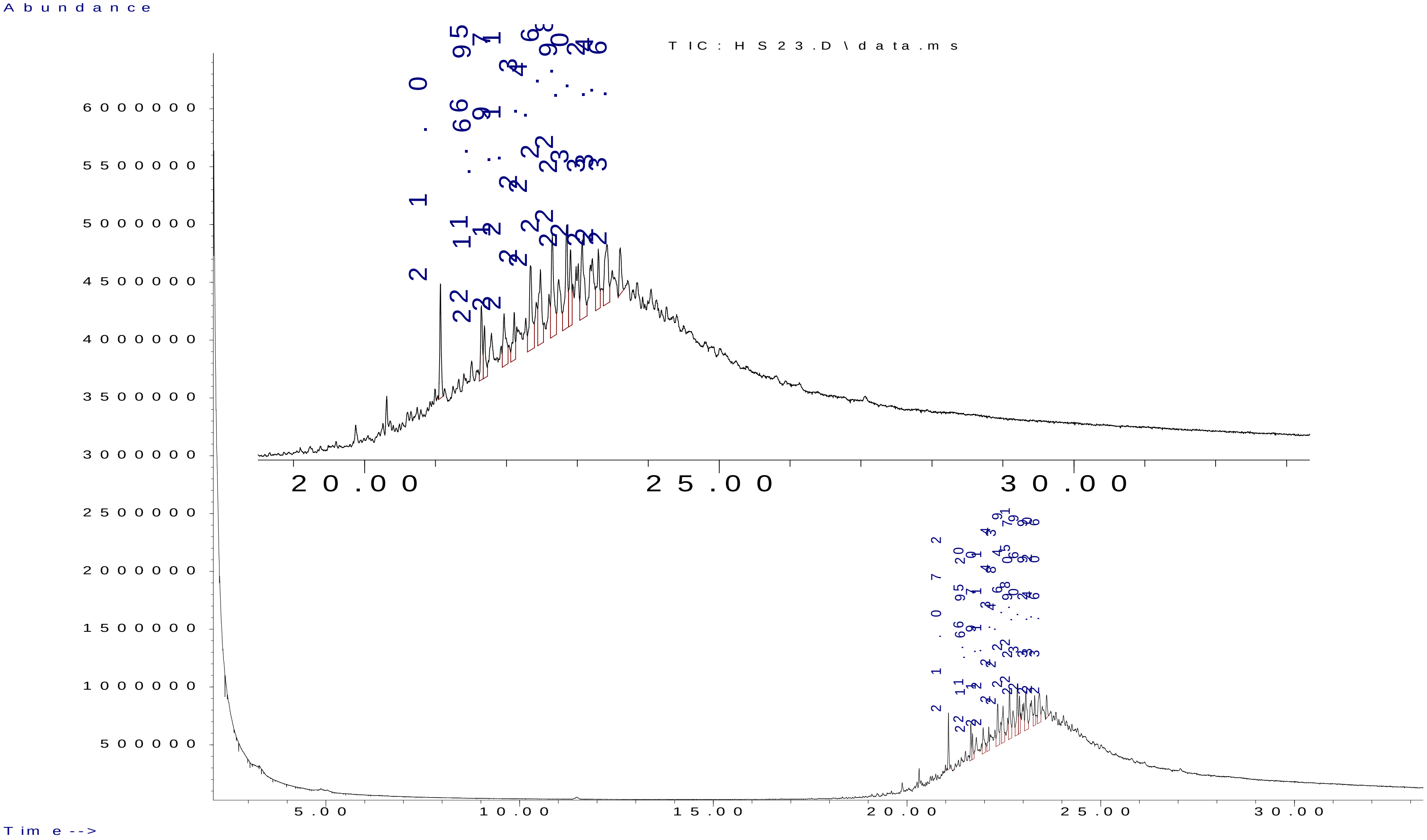


Figure C.6.8. The Total Ion Chromatograms (TIC) of detected soil sample with TPH for T.P.C. (0 m, 75 m) at depth (0.0 m), at contaminated site (Al-Magwa Area).

Table C.6.33. The results of detected sample with TPH which tested by GC-MS instrument for T.P.C. (25 m, 75 m) at depth (0.0 m) of contaminated site (Al-Magwa Area).

Peak	Ret.Time	Chemical Composition of the TPH in the Contaminated Soil Sample	Area Under the Curve (m2)	Chemical Composition Formula	Classification of the TPH based on Aliphatic and Aromatic	Concentration of each TPH Chemical Composition Detected in the Contaminated Soil Sample (µg/ml)	Concentration of each TPH Chemical Composition Detected in the Contaminated Soil Sample (mg/kg)	Total Concentration of the Total TPH Compositions Detected in the Contaminated Soil Sample (mg/kg)	References
1	**18.869 BV**	**BHT**	**6230423**	$C_{15}H_{24}$	**Aromatic EC12 - EC16**	**54.056**	**18.018**	**35.866**	**(BHT, n.d.)**
2	**22.648 VV**	**Tetrahydro 9,10-anthracenedione**	**2179310**	$C_{14}H_{12}O_2$	**Aromatic EC12 - EC16**	**1.594**	**0.531**		**(Anthraquinone, 1,2,3,4-tetrahydro-, n.d.)**
3	**22.850 PV**	**Dimethylanthracene**	**3688128**	$C_{16}H_{14}$	**Aromatic EC16 - EC21**	**21.133**	**7.044**		**(Dimethylanthracene, 2016)**
4	**22.903 VV**	**dimethylphenantrene**	**2375333**	$C_{16}H_{14}$	**Aromatic EC16 - EC21**	**4.132**	**1.377**		
5	**23.422 VV**	**2-Methylheptadecane**	**3860314**	$C_{18}H_{38}$	**Aliphatic EC16 - EC35**	**23.363**	**7.787**		**(Two-methylheptadecane, n.d.)**
6	**23.609 VV**	**Pyrolidene derivative**	**2312732**	C_4H_9N	**Aliphatic C4**	**3.3219**	**1.107**		**(Pyrrolidine, n.d.)**

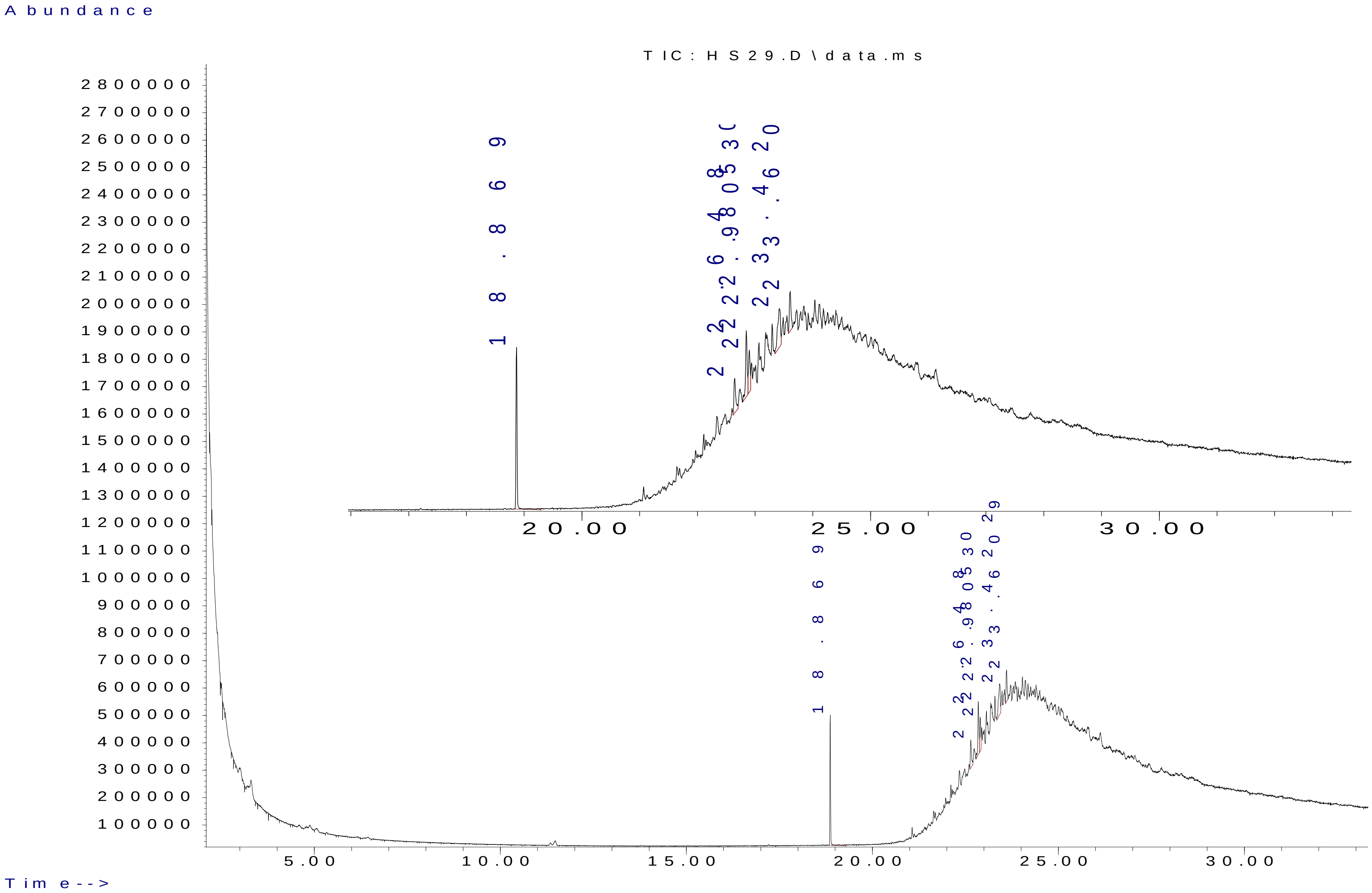


Figure C.6.9. The Total Ion Chromatograms (TIC) of detected soil sample with TPH for T.P.C. (25 m, 75 m) at depth (0.0 m), at contaminated site (Al-Magwa Area).

Table C.6.34. The results of detected soil sample with TPH which tested by GC-MS instrument for T.P.C. (50 m, 75 m) at depth (0.0 m) of contaminated site (Al-Magwa Area).

Peak	Ret. Time	Chemical Composition of the TPH in the Contaminated Soil Sample	Area Under the Curve (m2)	Chemical Composition Formula	Classification of the TPH based on Aliphatic and Aromatic	Concentration of each TPH Chemical Composition Detected in the Contaminated Soil Sample (µg/ml)	Concentration of each TPH Chemical Composition Detected in the Contaminated Soil Sample (mg/kg)	Total Concentration of the Total TPH Compositions Detected in the Contaminated Soil Sample (mg/kg)	References
1	3.028 BV	Methyldimethoxysilane	6453289	$C_3H_{10}O_2Si$	--------	56.942	18.980	865.223	(Methyldimethoxysilane, n.d.)
2	21.869 BV	Octadecane	10700879	$C_{18}H_{38}$	Aliphatic EC16 - EC35	111.948	37.316		(Octadecane, n.d.)
3	21.953 VV	Di-p-tolylacetylene	21365693	$C_{16}H_{14}$	Aromatic EC16 – EC21	250.058	83.352		(Di-p-Tolylacetylene, n.d.)
4	22.577 VV	Eicosane	8918550	$C_{20}H_{42}$	Aliphatic EC16 - EC35	88.867	29.622		(Icosane, n.d.)
5	22.625 VV	Nonadecane	25281416	$C_{19}H_{40}$	Aliphatic EC16 - EC35	300.766	100.255		(Nonadecane, n.d.)
6	22.995 VV	10-Methylanthracene-9-carboxaldehyde	16162900	$C_{16}H_{12}O$	Aromatic EC16 – EC21	182.681	60.893		(Ten-Methyl-9-anthracenecarbaldehyde, n.d.)
7	23.151 VV	1-Methylphenanthrene	12251310	$C_{15}H_{12}$	Aromatic EC12 - EC16	132.026	44.008		(Methylphenanthrene, n.d.)
8	23.340 VV	Eicosane	31256101	$C_{20}H_{42}$	Aliphatic EC16 - EC35	378.138	126.046		(Icosane, n.d.)
9	23.398 VV	2,7-Dimethylbenzothiophene	17564077	$C_{10}H_{10}S$	Aromatic EC10 - EC12	200.827	66.942		(Dimethylbenzothiophene, 2016)
10	23.760 VV	Di-p-tolylacetylene	21851494	$C_{16}H_{14}$	Aromatic EC16 – EC21	256.349	85.449		(Di-p-Tolylacetylene, n.d.)
11	23.896 VV	2-Methylheptadecane	25899580	$C_{18}H_{38}$	Aliphatic EC16 - EC35	308.771	102.923		(Two-methylheptadecane, n.d.)
12	24.065 VV	n-Heneicosane	20970757	$C_{21}H_{44}$	Aliphatic EC16 - EC35	244.943	81.647		(Heneicosane, n.d.)
13	24.855 PV	Docosane	12891156	$C_{22}H_{46}$	Aliphatic EC16 - EC35	140.312	46.770		(Docosane, n.d.)

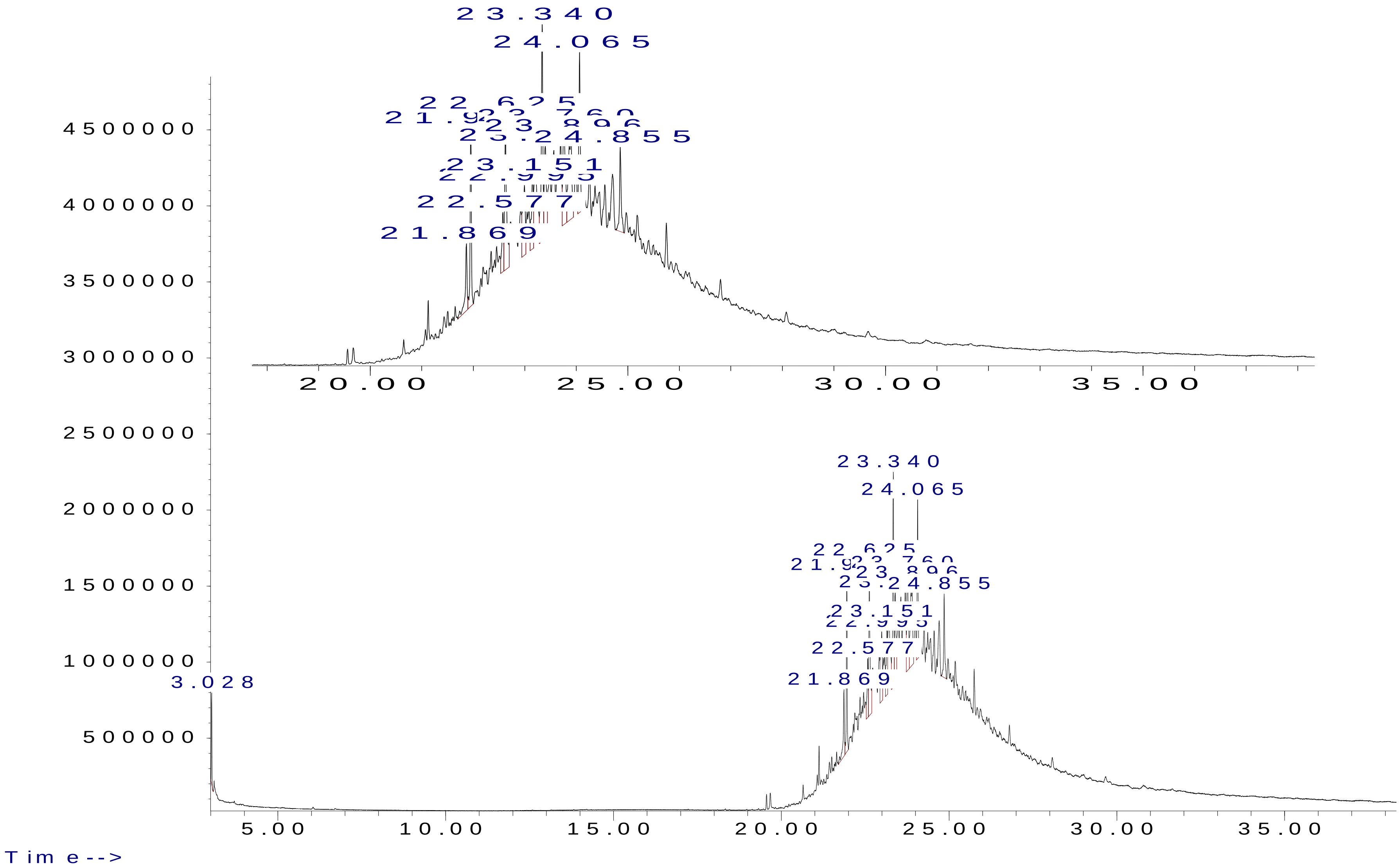


Figure C.6.10. The Total Ion Chromatograms (TIC) of detected soil sample with TPH for T.P.C. (50 m, 75 m) at depth (0.0 m), at contaminated site (Al-Magwa Area).

Table C.6.35. The results of detected soil sample with TPH which tested by GC-MS instrument for T.P.C. (75 m, 75 m) at depth (0.0 m) of contaminated site (Al-Magwa Area).

Peak	Ret. Time	Chemical Composition of the TPH in the Contaminated Soil Sample	Area Under the Curve (m2)	Chemical Composition Formula	Classification of the TPH based on Aliphatic and Aromatic	Concentration of each TPH Chemical Composition Detected in the Contaminated Soil Sample (μg/ml)	Concentration of each TPH Chemical Composition Detected in the Contaminated Soil Sample (mg/kg)	Total Concentration of the Total TPH Compositions Detected in the Contaminated Soil Sample (mg/kg)	References
1	3.012 BV	Methyldimethoxysilane	7292440	$C_3H_{10}O_2Si$	--------	67.809	22.603	567.336	(Methyldimethoxysilane, n.d.)
2	21.953 VV	9,10-Dimethylanthracene	13623920	$C_{16}H_{14}$	Aromatic EC16 – EC21	149.801	49.933		(Nine, 10-dimethylanthracene, n.d.)
3	22.577 VV	Heneicosane	12600015	$C_{21}H_{44}$	Aliphatic EC16- EC35	136.542	45.514		(Heneicosane, n.d.)
4	22.625 VV	Nonadecane	18699504	$C_{19}H_{40}$	Aliphatic EC16 - EC35	215.530	71.843		(Nonadecane, n.d.)
5	23.339 VV	Eicosane	9001903	$C_{20}H_{42}$	Aliphatic EC16 - EC35	89.947	29.982		(Icosane, n.d.)
6	23.397 VV	2,7-Dimethyldibenzothiophene	17362242	$C_{14}H_{12}S$	Aromatic EC12 - EC16	198.213	66.071		(Three, 8-dimethyldibenzothiophene, n.d.)
7	23.562 VV	1,7-Dimethyldibenzothiophene	14249069	$C_{14}H_{12}S$	Aromatic EC12 - EC16	157.897	52.632		(One, 7-Dimethyldibenzothiophene, n.d.)
8	23.697 VV	Di-p-tolylacetylene	11635172	$C_{16}H_{14}$	Aromatic EC16 – EC21	124.047	41.349		(Di-p-Tolylacetylene, n.d.)
9	23.759 VV	-------	13006757	-------	-------	141.809	47.269		-----------
10	23.895 VV	Pentadecane	11052537	$C_{15}H_{32}$	Aliphatic EC12 - EC16	116.502	38.834		(Pentadecane, n.d.)
11	23.991 VV	1,7-Dimethylphenanthrene	18253314	$C_{16}H_{14}$	Aromatic EC16 - EC21	209.752	69.917		(One, 7-Dimethylphenanthrene, n.d.)
12	24.065 VV	Cetane	10216906	$C_{16}H_{34}$	Aliphatic EC16 - EC35	105.681	35.227		(Hexadecane, n.d.)
13	24.706 VV	β-Pregnane	14583468	$C_{21}H_{36}$	Aliphatic EC16 - EC35	162.228	54.076		(Pregnane, 2016)
14	24.856 PV	Docosane	4204300	$C_{22}H_{46}$	Aliphatic EC16 - EC35	27.817	9.272		(Docosane, n.d.)
15	25.750 PV	Pregenone	2678578	$C_{21}H_{36}$	Aliphatic EC16 - EC35	8.0596	2.686		(Pregnane, 2016)

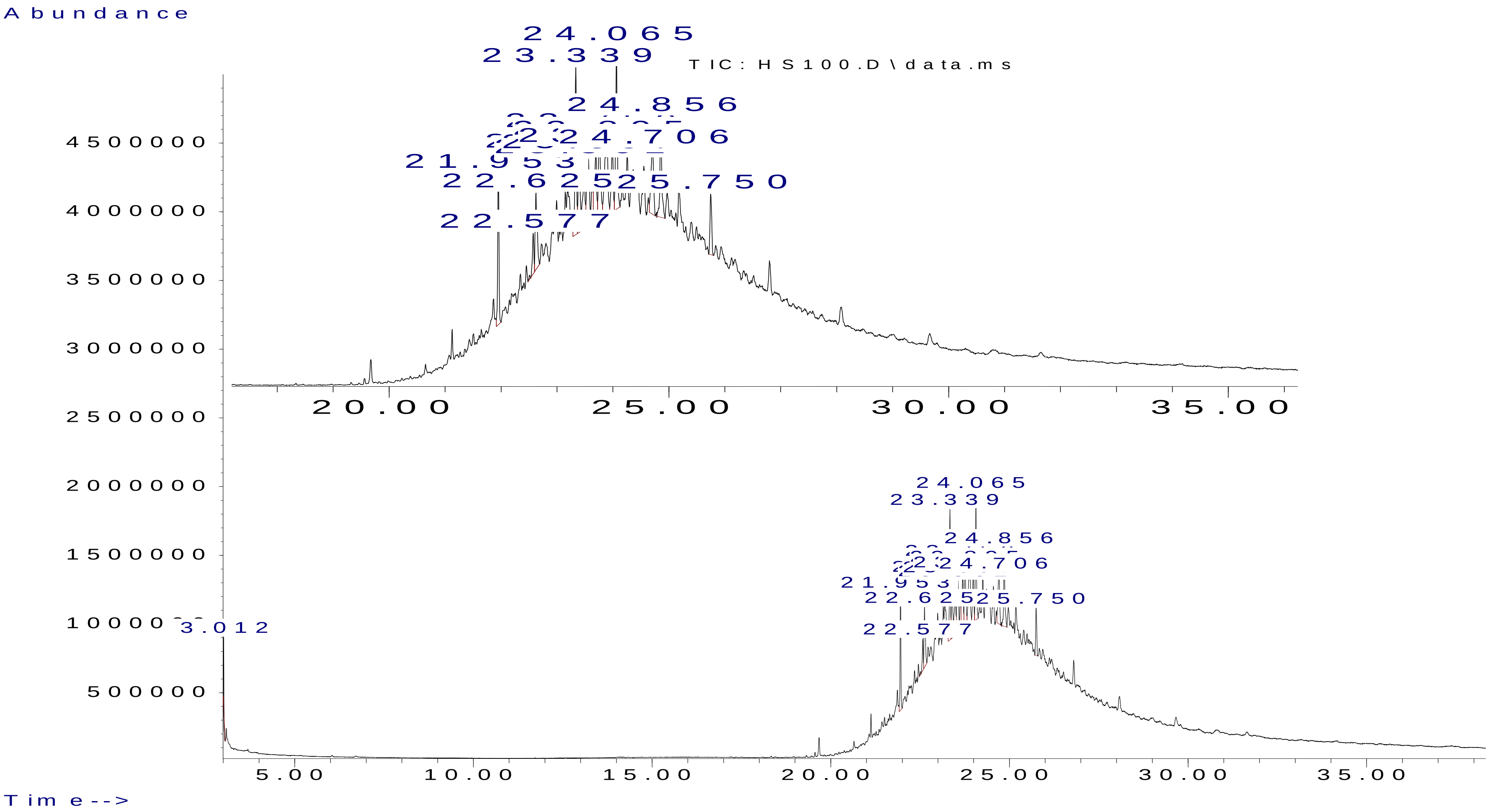


Figure C.6.11. The Total Ion Chromatograms (TIC) of detected soil sample with TPH for T.P.C. (75 m, 75 m) at depth (0.0 m), at contaminated site (Al-Magwa Area).

Table C.6.36. The results of detected soil sample with TPH which tested by GC-MS instrument for T.P.C. (0 m, 100 m) at depth (0.0 m) of contaminated site (Al-Magwa Area).

Peak	Ret. Time	Chemical Composition of the TPH in the Contaminated Soil Sample	Area Under the Curve (m2)	Chemical Composition Formula	Classification of the TPH based on Aliphatic and Aromatic	Concentration of each TPH Chemical Composition Detected in the Contaminated Soil Sample (µg/ml)	Concentration of each TPH Chemical Composition Detected in the Contaminated Soil Sample (mg/kg)	Total Concentration of the Total TPH Compositions Detected in the Contaminated Soil Sample (mg/kg)	References
1	2.226 PV	--------	-8114817	--------	--------	0	0	1.36	--------
2	18.870 BV	Butylhydroxytoluene (BHT)	1805862	$C_{15}H_{24}$	Aromatic EC12 - EC16	0	0		(BHT, n.d.)
3	21.072 PV	Trimethyltetradecane	1119095	$C_{17}H_{36}$	Aliphatic EC16 - EC35	0	0		(Two, 2-Dimethylpentadecane, n.d.)
4	22.351 VV	Eicosane	2371834	$C_{20}H_{42}$	Aliphatic EC16 - EC35	4.10	1.36		(Icosane, n.d.)
5	22.651 VV	Dimethyldibenzothiophene	1936669	$C_{14}H_{12}S$	Aromatic EC12 - EC16	0	0		(Dimethyldibenzothiophene, n.d.)
6	22.849 PV	Dimethylanthracene	1649924	$C_{16}H_{14}$	Aromatic EC16 - EC21	0	0		(Dimethylanthracene, n.d.)
7	22.986 PV	n-Heneicosane	1332478	$C_{21}H_{44}$	Aliphatic EC16 - EC35	0	0		(Heneicosane, n.d.)
8	23.012 VV	β-Pregnane	1137540	$C_{21}H_{36}$	Aliphatic EC16 - EC35	0	0		(Pregnane, n.d.)
9	23.601 BV	Hexadecane	1651013	$C_{16}H_{34}$	Aliphatic EC16 - EC35	0	0		(Hexadecane, n.d.)

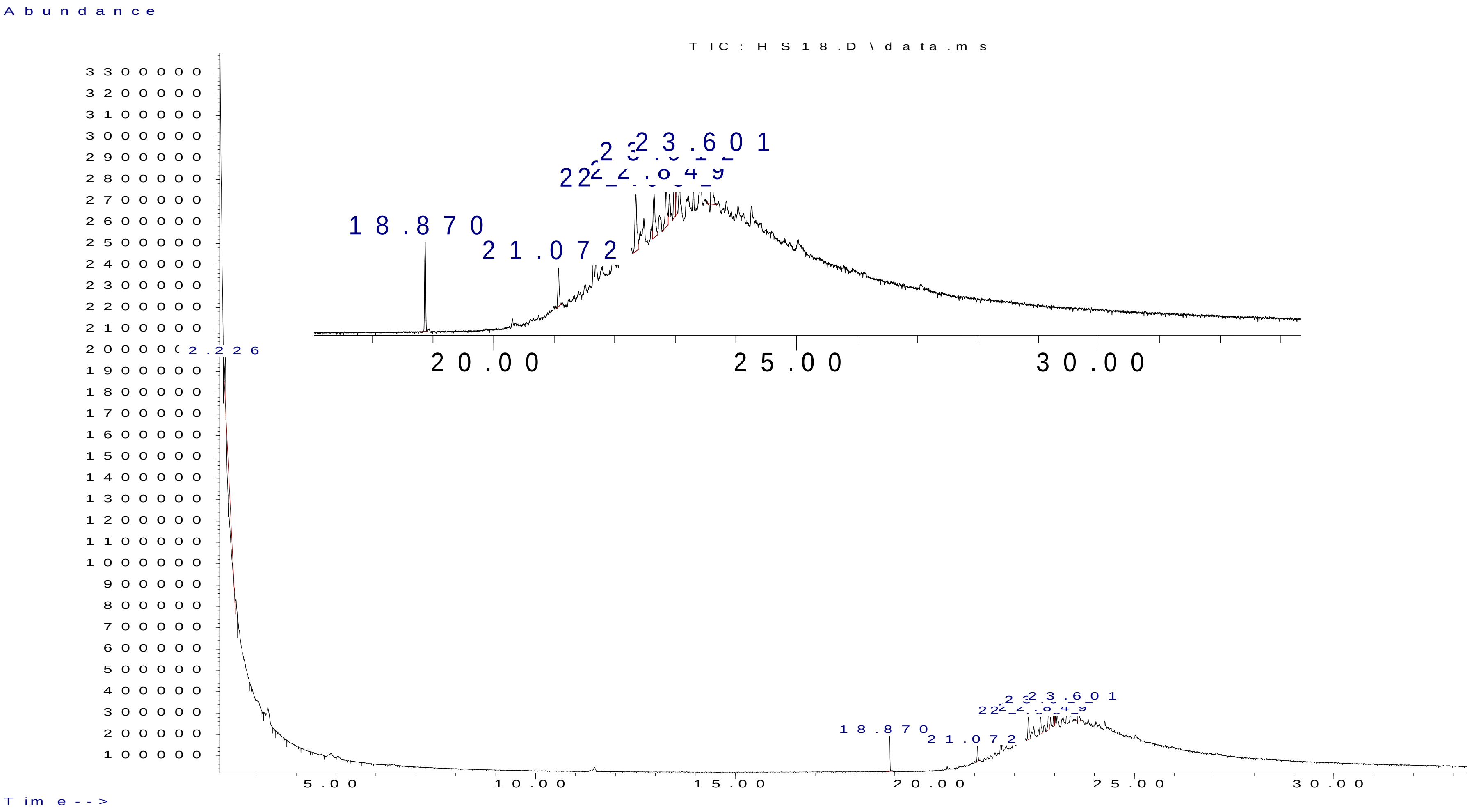


Figure C.6.12. The Total Ion Chromatograms (TIC) of detected soil sample with TPH for T.P.C. (0 m, 100 m) at depth (0.0 m), at contaminated site (Al-Magwa Area).

Table C.6.37. The results of detected soil sample with TPH which tested by GC-MS instrument for T.P.C. (50 m, 100 m) at depth (0.0 m) of contaminated site (Al-Magwa Area).

Peak	Ret. Time	Chemical Composition of the TPH in the Contaminated Soil Sample	Area Under the Curve (m2)	Chemical Composition Formula	Classification of the TPH based on Aliphatic and Aromatic	Concentration of each TPH Chemical Composition Detected in the Contaminated Soil Sample (μg/ml)	Concentration of each TPH Chemical Composition Detected in the Contaminated Soil Sample (mg/kg)	Total Concentration of the Total TPH Compositions Detected in the Contaminated Soil Sample (mg/kg)	References
1	3.021 BV	Methyldimethoxysilane	5273877	$C_3H_{10}O_2Si$	--------	41.668	13.889	331.608	(Methyldimethoxysilane, n.d.)
2	19.563 BV	BHT	10720157	$C_{15}H_{24}$	Aromatic EC12 - EC16	112.198	37.399		(BHT, n.d.)
3	21.827 VV	Dimethyldibenzothiophene	21607799	$C_{14}H_{12}S$	Aromatic EC12 - EC16	253.193	84.397		(Dimethyldibenzothiophene, n.d.)
4	21.955 VV	Di-p-tolylacetylene	24292193	$C_{16}H_{14}$	Aromatic EC16 – EC21	287.956	95.985		(Di-p-Tolylacetylene, n.d.)
5	22.348 VV	------	12565267	------	------	136.092	45.364		--------
6	22.457 PV	2-Methylanthracene	17447535	$C_{15}H_{12}$	Aromatic EC12 - EC16	199.317	66.439		(Two-Methylanthracene, n.d.)
7	22.576 VV	------	11107486	------	------	117.214	39.071		--------
8	22.621 VV	------	6635929	------	------	59.307	19.769		--------
9	23.698 VV	4-allyl phenol	7616082	$C_9H_{10}O$	Aromatic EC8 - EC10	72.000	24		(Chavicol, n.d.)
10	23.996 PV	9,10-dimethylanthracene	7474390	$C_{16}H_{14}$	Aromatic EC16 - EC21	70.165	23.388		(Nine,10-Dimethylanthracene, n.d.)

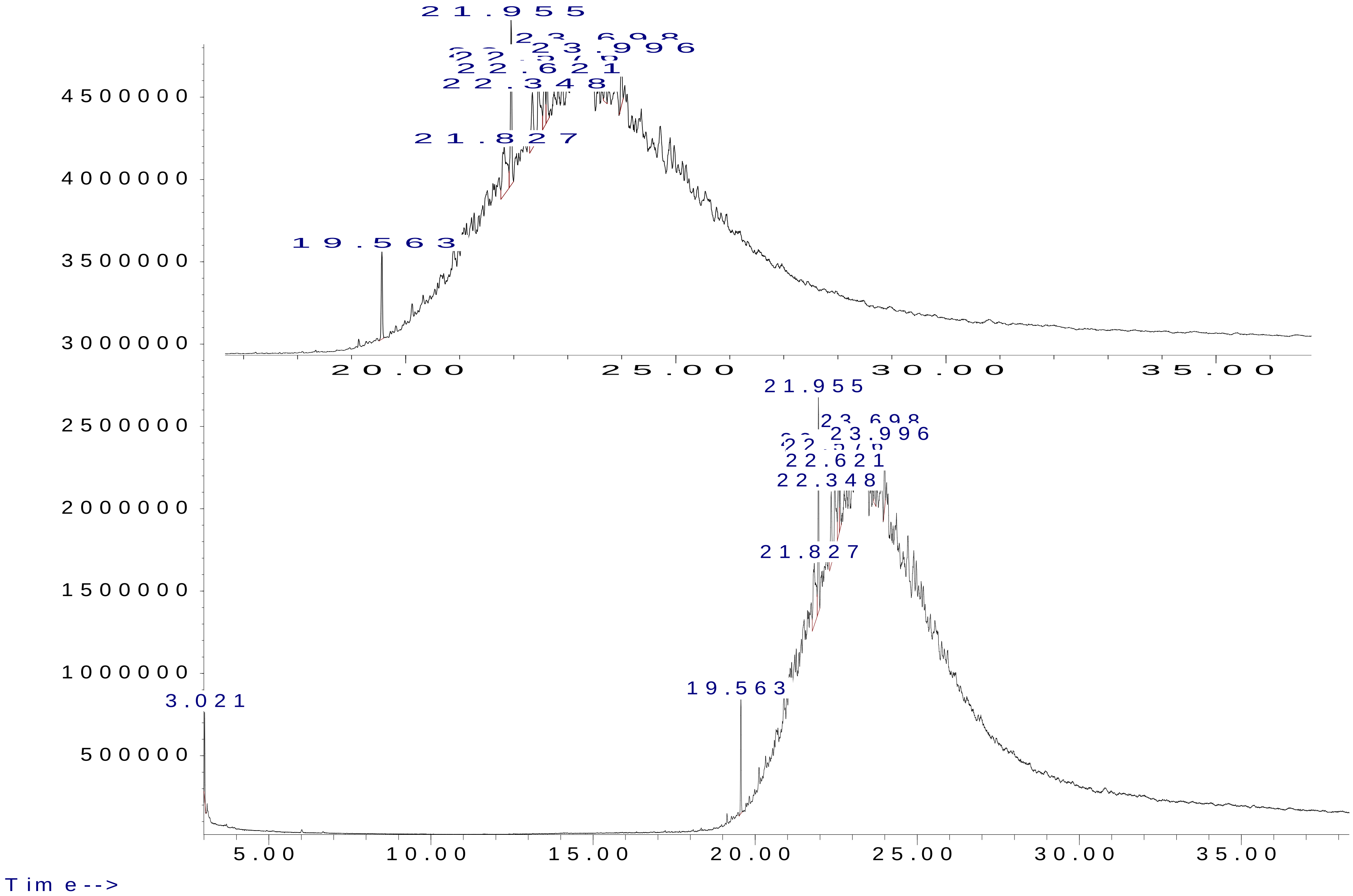


Figure C.6.13. The Total Ion Chromatograms (TIC) of detected soil sample with TPH for T.P.C. (50 m, 100 m) at depth (0.0 m), at contaminated site (Al-Magwa Area).

Table C.6.38. The results of detected soil sample with TPH which tested by GC-MS instrument for T.P.C. (75 m, 100 m) at depth (0.0 m) of contaminated site (Al-Magwa Area).

Peak	Ret. Time	Chemical Composition of the TPH in the Contaminated Soil Sample	Area Under the Curve (m2)	Chemical Composition Formula	Classification of the TPH based on Aliphatic and Aromatic	Concentration of each TPH Chemical Composition Detected in the Contaminated Soil Sample (µg/ml)	Concentration of each TPH Chemical Composition Detected in the Contaminated Soil Sample (mg/kg)	Total Concentration of the Total TPH Compositions Detected in the Contaminated Soil Sample (mg/kg)	References
1	19.562 BV	BHT	6952430	$C_{15}H_{24}$	Aromatic EC12 - EC16	63.406	21.13533	667.249	(BHT, n.d.)
2	21.129 VV	9,10-Dimethylanthracene	11412030	$C_{16}H_{14}$	Aromatic EC16 – EC21	121.157	40.38567		(Nine, 10-dimethylanthracene, n.d.)
3	21.957 VV	Di-p-tolylacetylene	43584983	$C_{16}H_{14}$	Aromatic EC16 – EC21	537.798	179.266		(Di-p-Tolylacetylene, n.d.)
4	22.458 VV	β-Pregnane	17165339	$C_{21}H_{36}$	Aliphatic EC16 - EC35	195.663	65.221		(Pregnane, n.d.)
5	22.578 VV	1,7-Dimethylphenanthrene	22691463	$C_{16}H_{14}$	Aromatic EC16 – EC21	267.226	89.07533		(One, 7-Dimethylphenanthrene, n.d.)
6	23.337 VV	10-Methylanthracene-9-carboxaldehyde	24932773	$C_{16}H_{12}O$	Aromatic EC16 – EC21	296.251	98.75033		(Ten-Methyl-9-anthracenecarbaldehyde, n.d.)
7	23.900 VV	Di-p-tolylacetylene	29131559	$C_{16}H_{14}$	Aromatic EC16 – EC21	350.626	116.8753		(Di-p-Tolylacetylene, n.d.)
8	24.064 VV	n-cetane	15154283	$C_{16}H_{34}$	Aliphatic EC16 - EC35	169.620	56.54		(Hexadecane, n.d.)

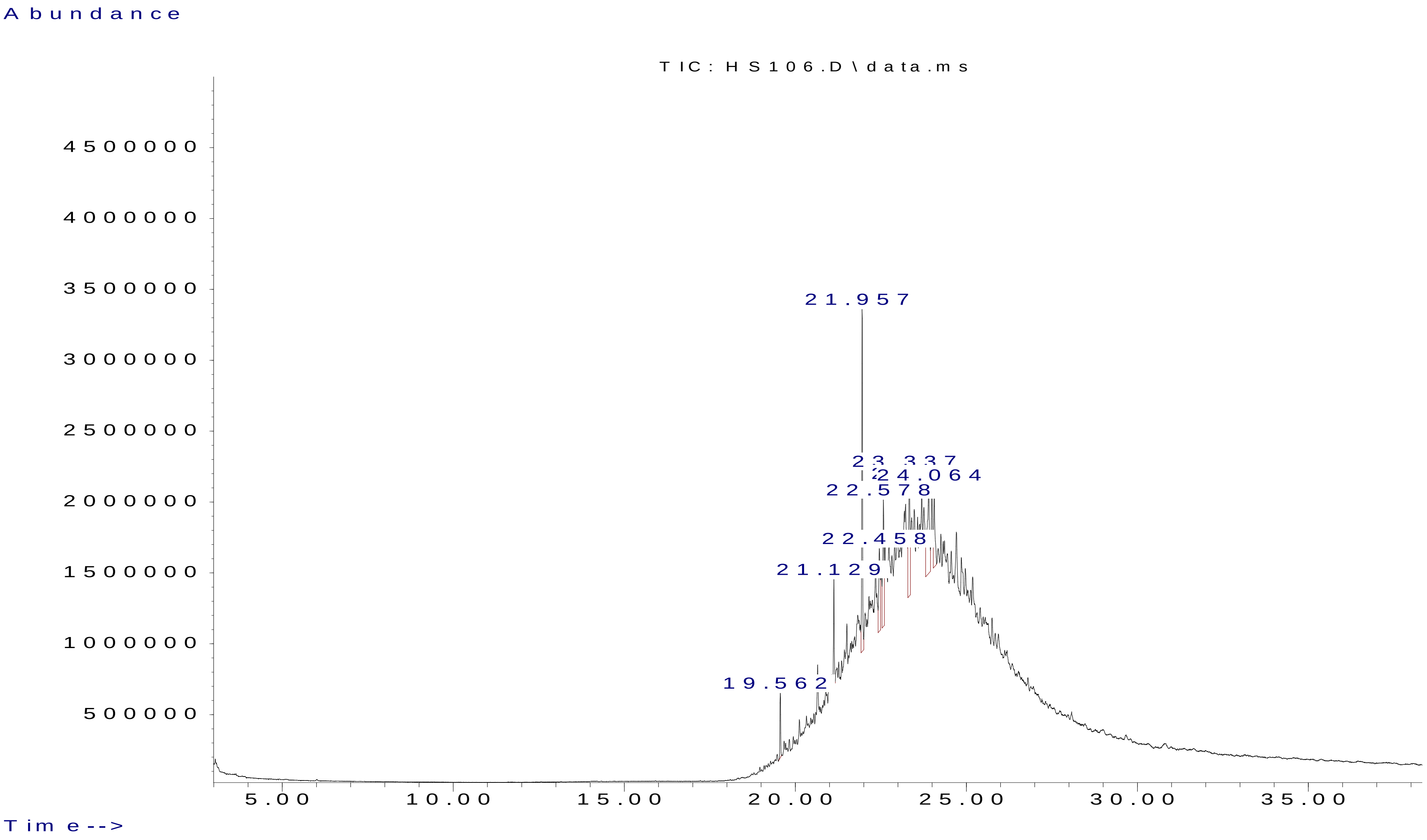


Figure C.6.14. The Total Ion Chromatograms (TIC) of detected soil sample with TPH for T.P.C. (75 m, 100 m) at depth (0.0 m), at contaminated site (Al-Magwa Area).

Table C.6.39. The results of detected soil sample with TPH which tested by GC-MS instrument for T.P.C. (100 m, 100 m) at depth (0.0 m) of contaminated site (Al-Magwa Area).

Peak	Ret. Time	Chemical Composition of the TPH in the Contaminated Soil Sample	Area Under the Curve (m2)	Chemical Composition Formula	Classification of the TPH based on Aliphatic and Aromatic	Concentration of each TPH Chemical Composition Detected in the Contaminated Soil Sample (µg/ml)	Concentration of each TPH Chemical Composition Detected in the Contaminated Soil Sample (mg/kg)	Total Concentration of the Total TPH Compositions Detected in the Contaminated Soil Sample (mg/kg)	References
1	3.013 BV	Methyldimethoxysilane	3652984	$C_3H_{10}O_2Si$	--------	20.678	6.892	214.805	(Methyldimethoxysilane, n.d.)
2	21.128 VV	9,10-Dimethylanthracene	6834824	$C_{16}H_{14}$	Aromatic EC16 – EC21	61.883	20.627		(Nine, 10-dimethylanthracene, n.d.)
3	21.827 VV	-------	10164575	------	------	105.003	35.001		------
4	21.955 VV	Di-p-tolylacetylene	27604520	$C_{16}H_{14}$	Aromatic EC16 – EC21	330.850	110.283		(Di-p-Tolylacetylene, n.d.)
5	22.458 PV	------	7519001	------	------	70.743	23.581		------
6	22.576 PV	Hexadecane	6268648	$C_{16}H_{34}$	Aliphatic EC16 - EC35	54.551	18.183		(Hexadecane, n.d.)
7	23.185 VV	10-Methylanthracene-9-carboxaldehyde	13425434	$C_{16}H_{12}O$	Aromatic EC16 – EC21	147.231	49.077		(Ten-Methyl-9-anthracenecarbaldehyde, n.d.)
8	23.695 VV	------	8532810	------	------	83.872	27.957		------
9	23.993 PV	Di-p-tolylacetylene	5909975	$C_{16}H_{14}$	Aromatic EC16 - EC21	49.906	16.635		(Di-p-Tolylacetylene, n.d.)

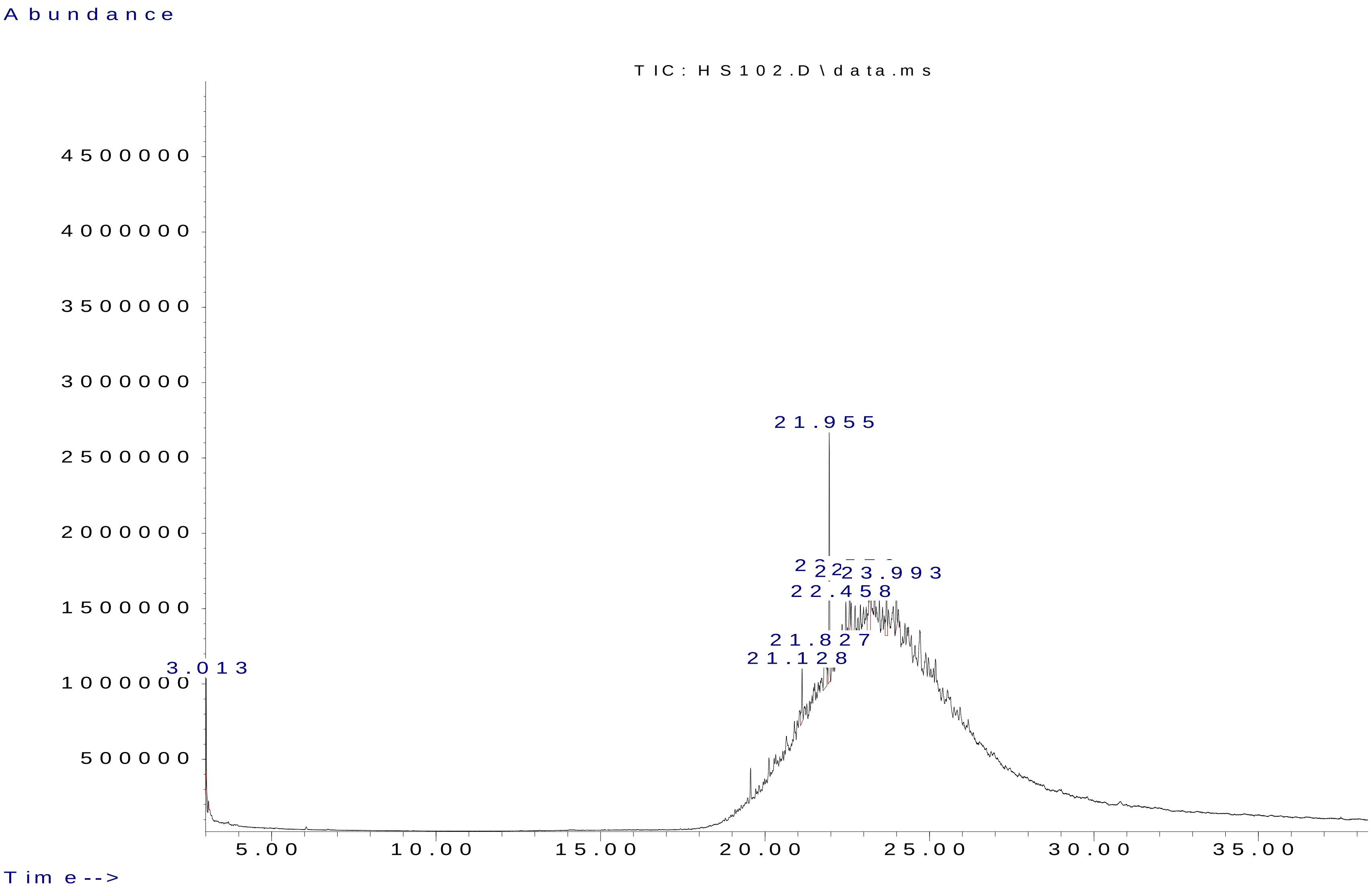


Figure C.6.15. The Total Ion Chromatograms (TIC) of detected soil sample with TPH for T.P.C. (100 m, 100 m) at depth (0.0 m), at contaminated site (Al-Magwa Area).

At depth (0.25 m) at contaminated site

Table C.6.40. The results of detected soil sample with TPH which tested by GC-MS instrument for T.P.C. (100 m, 0 m) at depth (0.25 m) of contaminated site (Al-Magwa Area).

Peak	Ret. Time	Chemical Composition of the TPH in the Contaminated Soil Sample	Area Under the Curve (m2)	Chemical Composition Formula	Classification of the TPH based on Aliphatic and Aromatic	Concentration of each TPH Chemical Composition Detected in the Contaminated Soil Sample (µg/ml)	Concentration of each TPH Chemical Composition Detected in the Contaminated Soil Sample (mg/kg)	Total Concentration of the Total TPH Compositions Detected in the Contaminated Soil Sample (mg/kg)	References
1	18.867 BB	BHT	2642984	$C_{15}H_{24}$	Aromatic EC12 - EC16	7.598	2.532	2.532	(BHT, n.d.)

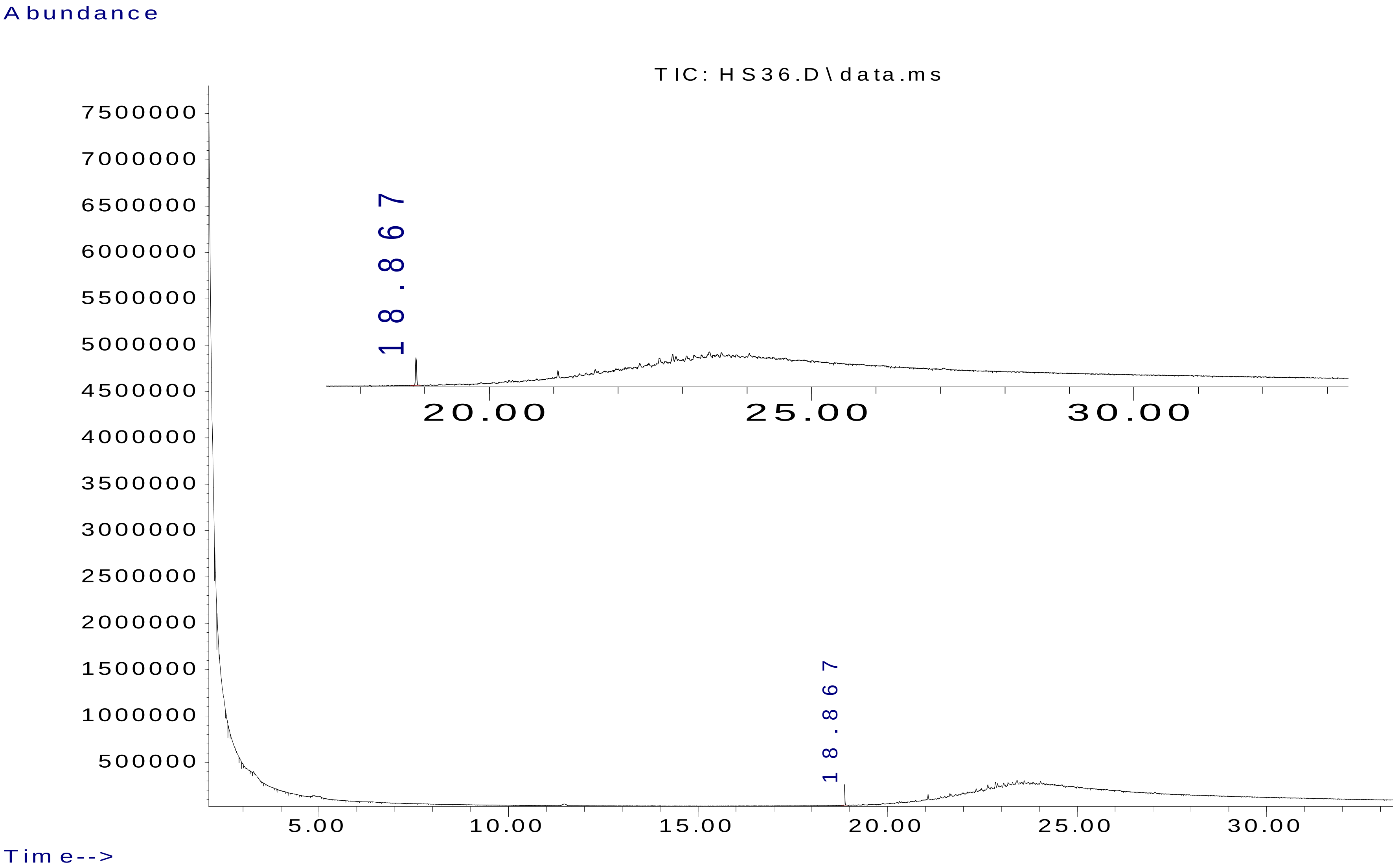


Figure C.6.16. The Total Ion Chromatograms (TIC) of detected soil sample for T.P.C. (100 m, 0 m) at depth (0.25 m), at contaminated site (Al-Magwa Area).

Table C.6.41. The results of detected soil sample with TPH which tested by GC-MS instrument for T.P.C. (0 m, 25 m) at depth (0.25 m) of contaminated site (Al-Magwa Area).

Peak	Ret. Time	Chemical Composition of the TPH in the Contaminated Soil Sample	Area Under the Curve (m2)	Chemical Composition Formula	Classification of the TPH based on Aliphatic and Aromatic	Concentration of each TPH Chemical Composition Detected in the Contaminated Soil Sample (µg/ml)	Concentration of each TPH Chemical Composition Detected in the Contaminated Soil Sample (mg/kg)	Total Concentration of the Total TPH Compositions Detected in the Contaminated Soil Sample (mg/kg)	References
1	20.262 VV	Heptadecane	3083330	$C_{17}H_{36}$	Aliphatic EC16 - EC35	13.30	4.433	42.3	(Heptadecane, n.d.)
2	20.993 PV	Octadecane	1801359	$C_{18}H_{38}$	Aliphatic EC16 - EC35	0	0		(Octadecane, n.d.)
3	21.689 VV	Hexadecane	3026865	$C_{16}H_{34}$	Aliphatic EC16 - EC35	12.569	4.189		(Hexadecane, n.d.)
4	22.346 PV	pentadecane	4112831	$C_{15}H_{32}$	Aliphatic EC12 - EC16	26.633	8.877		(Pentadecane, n.d.)
5	22.644 VV	4,6-Dimethyldibenzothiophene	4652408	$C_{14}H_{12}S$	Aromatic EC12 - EC16	33.620	11.206		(Four, 6-dimethyldibenzothiophene, n.d.)
6	22.848 VV	9,10-Dimethylanthracene	3941521	$C_{16}H_{14}$	Aromatic EC16 - EC21	24.414	8.138		(Nine, 10-dimethylanthracene, n.d.)
7	23.598 PV	10-Methylanthracene-9-carboxaldehyde	3320329	$C_{16}H_{12}O$	Aromatic EC16 - EC21	16.370	5.456		(Ten-Methyl-9-anthracenecarbaldehyde, n.d.)

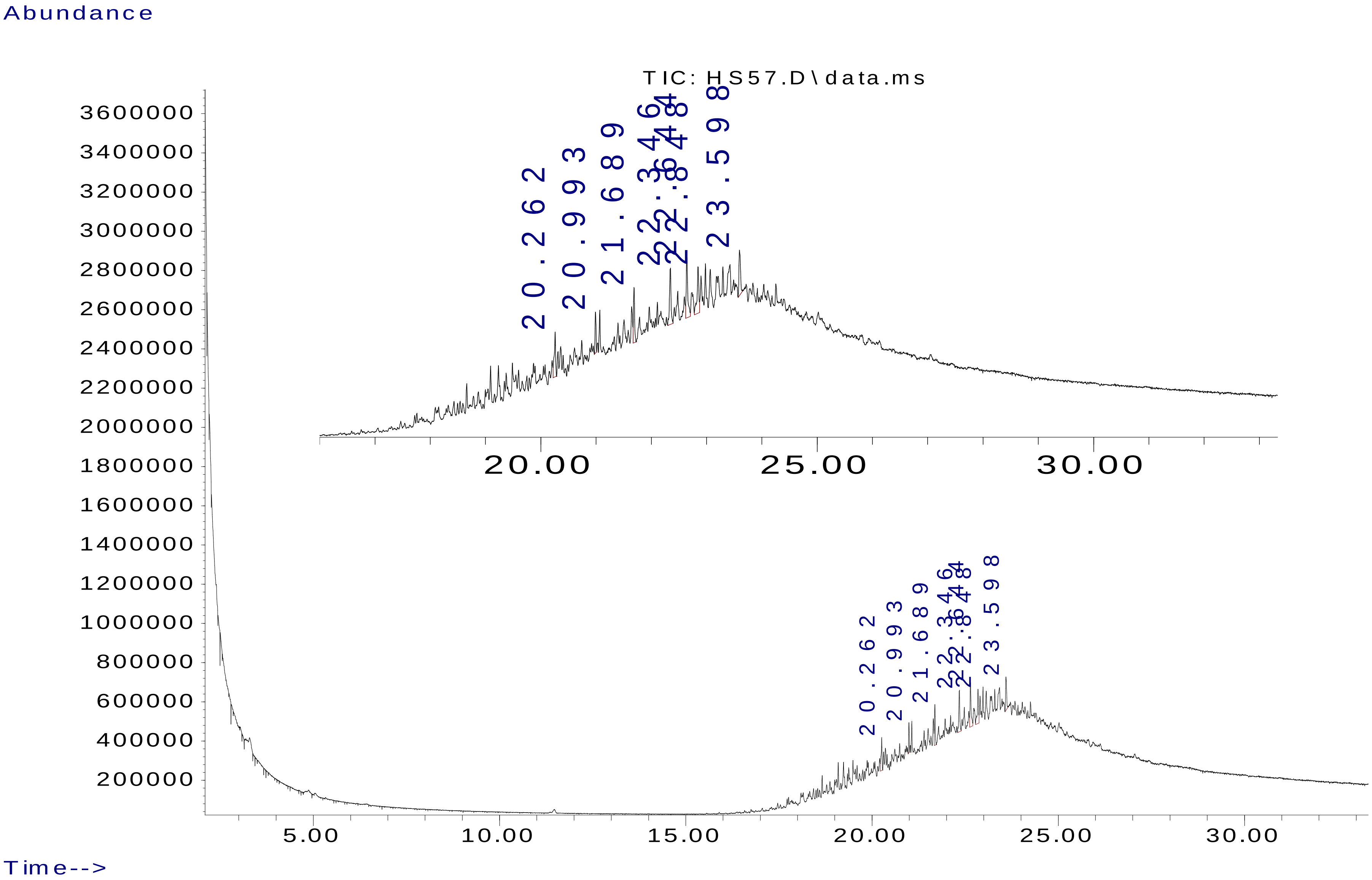


Figure C.6.17. The Total Ion Chromatograms (TIC) of detected soil sample for T.P.C. (0 m, 25 m) at depth (0.25 m), at contaminated site (Al-Magwa Area).

Table C.6.42. The results of detected soil sample with TPH which tested by GC-MS instrument for T.P.C. (25 m, 50 m) at depth (0.25 m) of contaminated site (Al-Magwa Area).

Peak	Ret. Time	Chemical Composition of the TPH in the Contaminated Soil Sample	Area Under the Curve (m2)	Chemical Composition Formula	Classification of the TPH based on Aliphatic and Aromatic	Concentration of each TPH Chemical Composition Detected in the Contaminated Soil Sample (µg/ml)	Concentration of each TPH Chemical Composition Detected in the Contaminated Soil Sample (mg/kg)	Total Concentration of the Total TPH Compositions Detected in the Contaminated Soil Sample (mg/kg)	References
1	3.074 BV	Methyldimethoxysilane	7766120	$C_3H_{10}O_2Si$	--------	0	0	31.529	(Methyldimethoxysilane, n.d.)
2	3.188 VV	dimethysilanediol	-1584033	$C_2H_8O_2$	--------	0	0		(Dimethysilanediol, n.d.)
3	19.560 BV	BHT	6701257	$C_{15}H_{24}$	Aromatic EC12- EC16	60.153	20.05		(BHT, n.d.)
4	21.860 PV	tetramethylhexadecane	2101955	$C_{20}H_{42}$	Aliphatic EC16- EC35	0.592	0.197		(Two, 6, 10, 14-tetramethylhexadecane, n.d.)
5	21.951 VV	Di-p-tolylacetylene	4669878	$C_{16}H_{14}$	Aromatic EC16- EC21	33.847	11.282		(Di-p-Tolylacetylene, n.d.)
6	23.189 VV	-----------	4183295	-------	--------		--------		--------

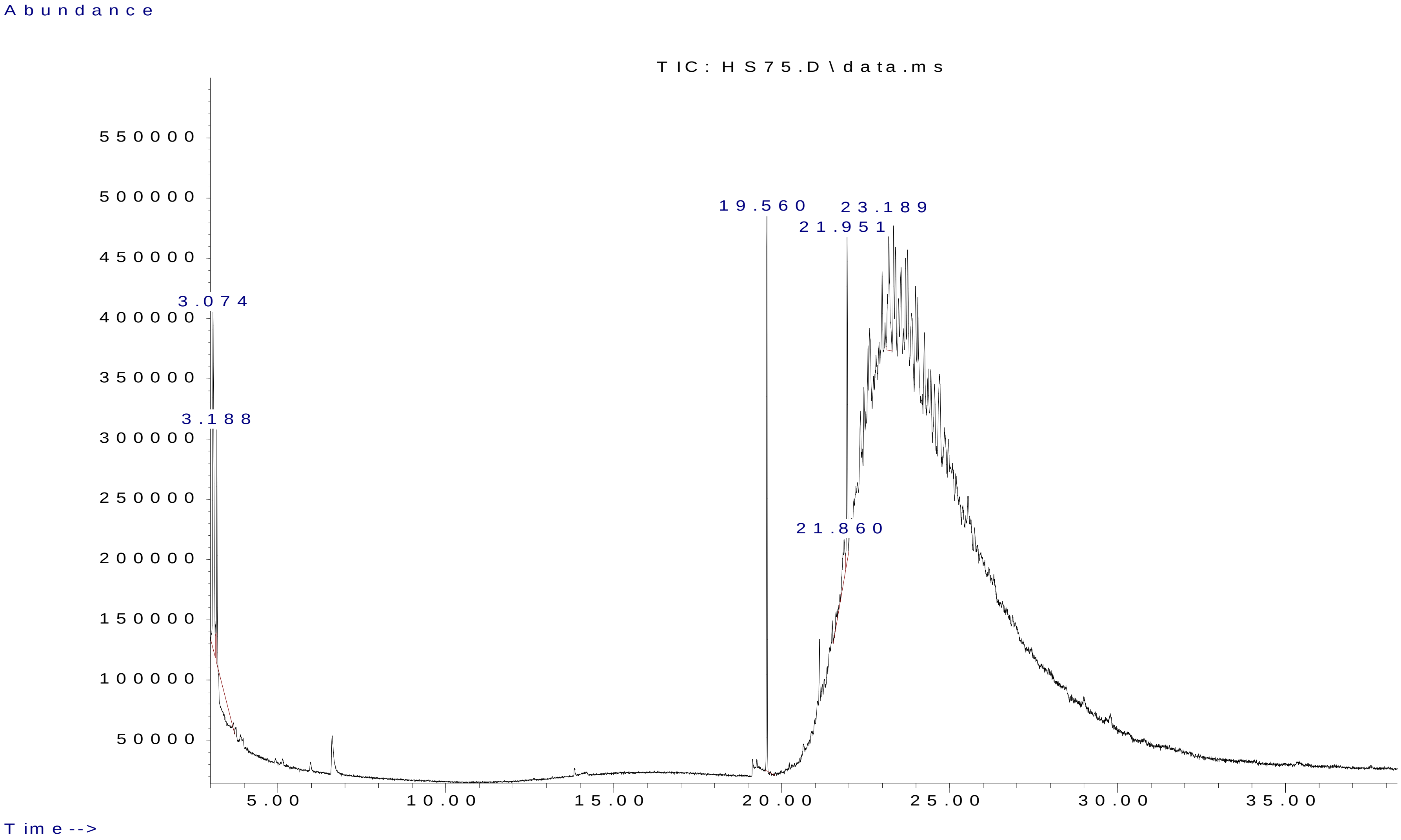


Figure C.6.18. The Total Ion Chromatograms (TIC) of detected soil sample for T.P.C. (25 m, 50 m) at depth (0.25 m), at contaminated site (Al-Magwa Area).

Table C.6.43. The results of detected sample with TPH which tested by GC-MS instrument for T.P.C. (50 m, 50 m) at depth (0.25 m) of contaminated site (Al-Magwa Area).

Peak	Ret. Time	Chemical Composition of the TPH in the Contaminated Soil Sample	Area Under the Curve (m2)	Chemical Composition Formula	Classification of the TPH based on Aliphatic and Aromatic	Concentration of each TPH Chemical Composition Detected in the Contaminated Soil Sample (µg/ml)	Concentration of each TPH Chemical Composition Detected in the Contaminated Soil Sample (mg/kg)	Total Concentration of the Total TPH Compositions Detected in the Contaminated Soil Sample (mg/kg)	References
1	5.451 BV	Dihydroxydimethylsilane	15785244	$C_2H_8O_2$	-------	177.791	59.263	3.506	(Dimethylsilanediol, n.d.)
2	13.276 BV	C12H32O6Si3 Hexamethylhexaoxatrisilapentadecane	2868478	C12	Aromatic EC12 - EC16	10.518	3.506		(SCHEMBL2956430, n.d.)

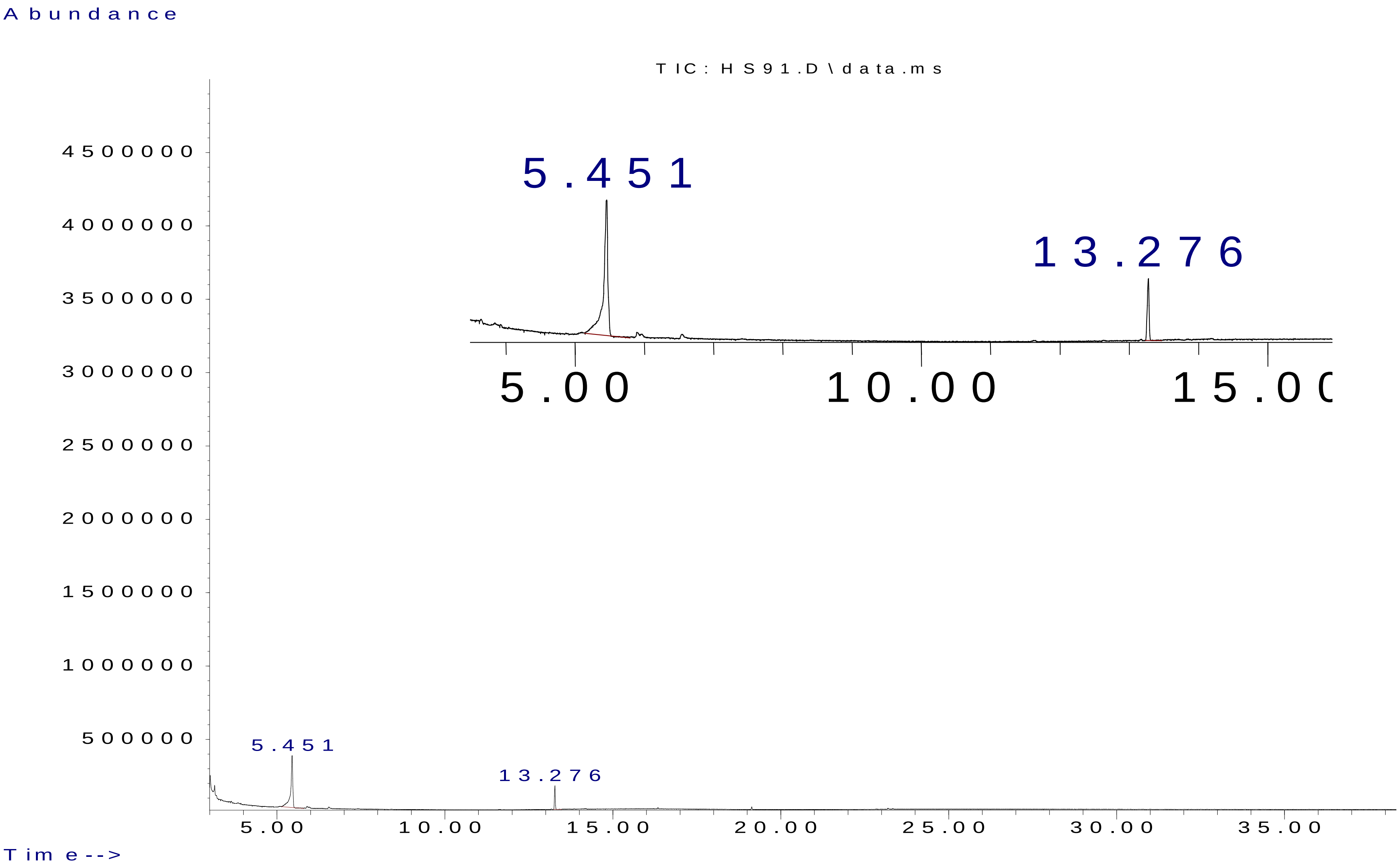


Figure C.6.19. The Total Ion Chromatograms (TIC) of detected soil sample for T.P.C. (50 m, 50 m) at depth (0.25 m), at contaminated site (Al-Magwa Area).

Table C.6.44. The results of detected soil sample with TPH which tested by GC-MS instrument for T.P.C. (0 m, 75 m) at depth (0.25 m) of contaminated site (Al-Magwa Area).

Peak	Ret. Time	Chemical Composition of the TPH in the Contaminated Soil Sample	Area Under the Curve (m2)	Chemical Composition Formula	Classification of the TPH based on Aliphatic and Aromatic	Concentration of each TPH Chemical Composition Detected in the Contaminated Soil Sample (μg/ml)	Concentration of each TPH Chemical Composition Detected in the Contaminated Soil Sample (mg/kg)	Total Concentration of the Total TPH Compositions Detected in the Contaminated Soil Sample (mg/kg)	References
1	18.663 PV	pentadecane	3907621	$C_{15}H_{32}$	Aliphatic EC12 - EC16	23.97	7.99	225.1	(Pentadecane, n.d.)
2	19.490 BV	Hexadecane	5137019	$C_{16}H_{34}$	Aliphatic EC16 - EC35	39.896	13.298		(Hexadecane, n.d.)
3	19.874 PV	Tridecane	6492353	$C_{13}H_{28}$	Aliphatic EC12 - EC16	57.448	19.149		(Tridecane, n.d.)
4	20.263 VV	Heptadecane	6613165	$C_{17}H_{36}$	Aliphatic EC16 - EC35	59.012	19.670		(Heptadecane, n.d.)
5	20.311 PV	Tetramethylpentadecane	3479945	$C_{19}H_{40}$	Aliphatic EC16 - EC35	18.437	6.145		(Pristane, n.d.)
6	20.995 VV	Octadecane	6264583	$C_{18}H_{38}$	Aliphatic EC16 - EC35	54.498	18.166		(Octadecane, n.d.)
7	21.069 VV	Tetramethylhexadecane	7623443	$C_{20}H_{42}$	Aliphatic EC16 - EC35	72.095	24.031		(Two, 6, 10, 14-tetramethylhexadecane, n.d.)
8	21.648 PV	Tetradecanoicacid ester	3560588	$C_{28}H_{56}O_2$	Aliphatic EC16 - EC35	19.481	6.493		(Tetradecyl myristate, n.d.)
9	21.689 VV	Nonadecane	7171546	$C_{19}H_{40}$	Aliphatic EC16 - EC35	66.243	22.081		(Nonadecane, n.d.)
10	22.350 VV	Eicosane	8988373	$C_{20}H_{42}$	Aliphatic EC16 - EC35	89.771	29.923		(Icosane, n.d.)
11	22.647 VV	Dimethyldibenzothiophene	5629771	$C_{14}H_{12}S$	Aromatic EC12 - EC16	46.277	15.425		(Dimethyldibenzothiophene, n.d.)
12	22.848 VV	9,10-dimethylanthracene	5432648	$C_{16}H_{14}$	Aromatic EC16 - EC21	43.724	14.574		(Nine, 10-dimethylanthracene, n.d.)
13	22.983 VV	Heneicosane	5772541	$C_{21}H_{44}$	Aliphatic EC16 - EC35	48.126	16.042		(Heneicosane, n.d.)
14	23.598 PV	Heptadecane	4862296	$C_{17}H_{36}$	Aliphatic EC16 - EC35	36.338	12.112		(Heptadecane, n.d.)

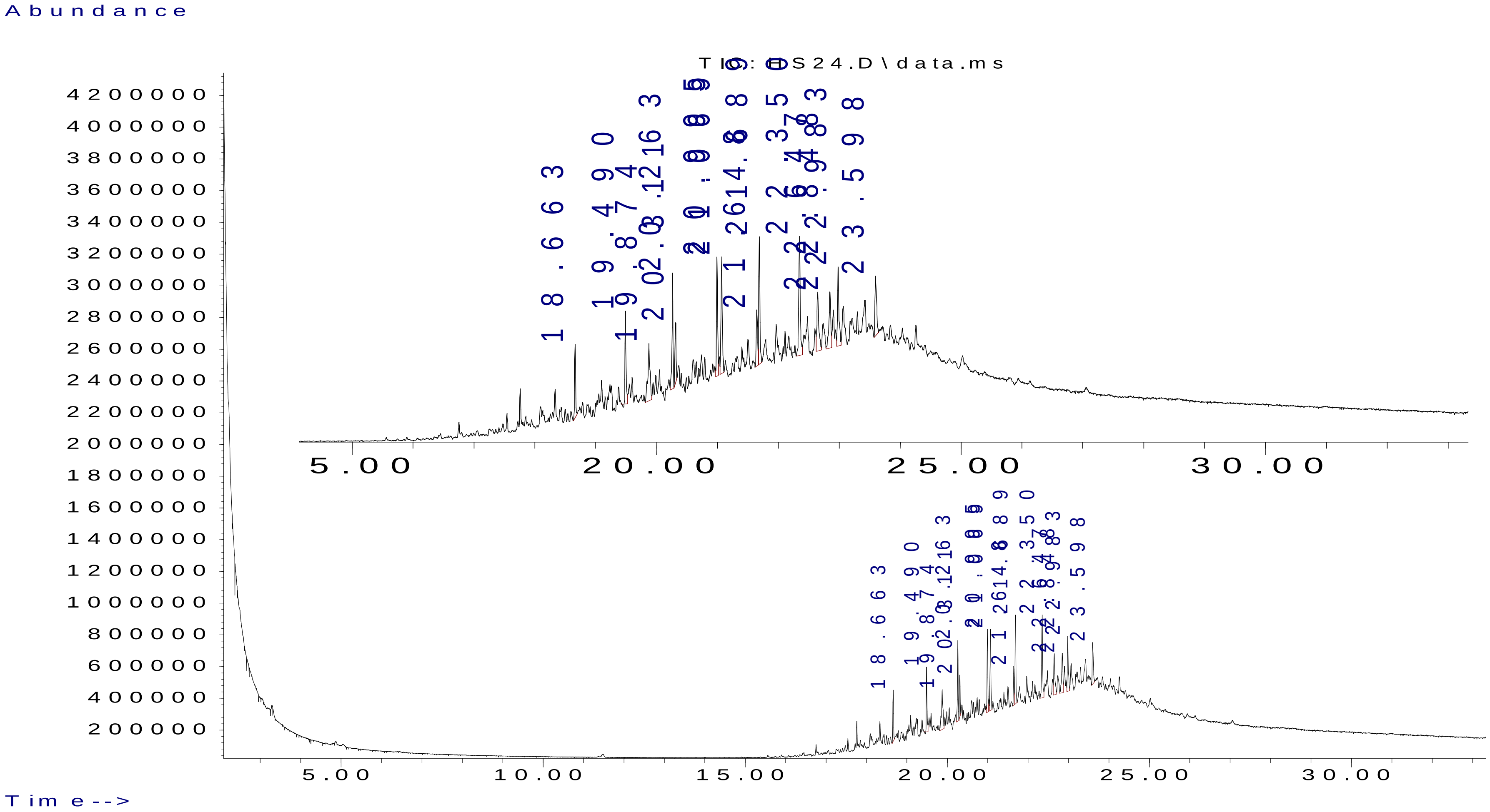


Figure C.6.20. The Total Ion Chromatograms (TIC) of detected soil sample for T.P.C. (0 m, 75 m) at depth (0.25 m), at contaminated site (Al-Magwa Area).

Table C.6.45. The results of detected soil sample with TPH which tested by GC-MS instrument for T.P.C. (100 m, 75 m) at depth (0.25 m) of contaminated site (Al-Magwa Area).

Peak	Ret. Time	Chemical Composition of the TPH in the Contaminated Soil Sample	Area Under the Curve (m2)	Chemical Composition Formula	Classification of the TPH based on Aliphatic and Aromatic	Concentration of each TPH Chemical Composition Detected in the Contaminated Soil Sample (µg/ml)	Concentration of each TPH Chemical Composition Detected in the Contaminated Soil Sample (mg/kg)	Total Concentration of the Total TPH Compositions Detected in the Contaminated Soil Sample (mg/kg)	References
1	**20.654 PV**	**Trimethylpentadecane**	**12963837**	$C_{18}H_{38}$	**Aliphatic EC16 - EC35**	**141.253**	**47.08433**	**1271.038**	**(Two, 6, 10-Trimethylpentadecane, n.d.)**
2	**21.075 VV**	**Tridecane**	**9065115**	$C_{13}H_{28}$	**Aliphatic EC12 - EC16**	**90.765**	**30.255**		**(Tridecane, n.d.)**
3	**21.129 VV**	**Di-p-tolylacetylene**	**15615129**	$C_{16}H_{14}$	**Aromatic EC16 – EC21**	**175.588**	**58.52933**		**(Di-p-Tolylacetylene, n.d.)**
4	**21.870 VV**	**Octadecane**	**23651142**	$C_{18}H_{38}$	**Aliphatic EC16 - EC35**	**279.654**	**93.218**		**(Octadecane, n.d.)**
5	**21.956 VV**	**Di-p-tolylacetylene**	**42350166**	$C_{16}H_{14}$	**Aromatic EC16 – EC21**	**521.807**	**173.9357**		**(Di-p-Tolylacetylene, n.d.)**
6	**22.627 VV**	**Nonadecane**	**26768203**	$C_{19}H_{40}$	**Aliphatic EC16 - EC35**	**320.020**	**106.6733**		**(Nonadecane, n.d.)**
7	**22.997 VV**	**1-methylphenanthrene**	**13197525**	$C_{15}H_{12}$	**Aromatic EC12 - EC16**	**144.280**	**48.09333**		**(Methylphenanthrene, n.d.)**
8	**23.153 VV**	**2-Methylanthracene**	**14894942**	$C_{15}H_{12}$	**Aromatic EC12 - EC16**	**166.261**	**55.42033**		**(Two-Methylanthracene, n.d.)**
9	**23.340 VV**	**n-Eicosane**	**30374049**	$C_{20}H_{42}$	**Aliphatic EC16 - EC35**	**366.716**	**122.2387**		**(Icosane, n.d.)**
10	**23.399 VV**	**2,7-Dimethylbenzothiophene**	**21000368**	$C_{10}H_{10}S$	**Aromatic EC10 - EC12**	**245.327**	**81.77567**		**(Dimethylbenzothiophene, 2016)**
11	**23.565 VV**	**1,7-Dimethylbenzothiophene**	**26261193**	$C_{10}H_{10}S$	**Aromatic EC10 - EC12**	**313.454**	**104.4847**		**(Dimethylbenzothiophene, 2016)**
12	**23.701 VV**	**Dimethylbenzothiopehene**	**22899828**	$C_{10}H_{10}S$	**Aromatic EC10 - EC12**	**269.925**	**89.975**		**(Dimethylbenzothiophene, 2016)**
13	**23.763 VV**	**3,7-Dimethylbenzothiophene**	**28309191**	$C_{10}H_{10}S$	**Aromatic EC10 - EC12**	**339.976**	**113.3253**		**(Dimethylbenzothiophene, 2016)**
14	**23.897 VV**	**----------**	**33219713**	**------**	**---------**	**403.567**	**134.5223**		**---------**
15	**24.067 VV**	**n-Cetane**	**24617097**	$C_{16}H_{34}$	**Aliphatic EC16 - EC35**	**292.163**	**97.38767**		**(Hexadecane, n.d.)**
16	**24.857 BV**	**Docosane**	**13324585**	$C_{22}H_{46}$	**Aliphatic EC16 - EC35**	**145.925**	**48.64167**		**(Docosane, n.d.)**

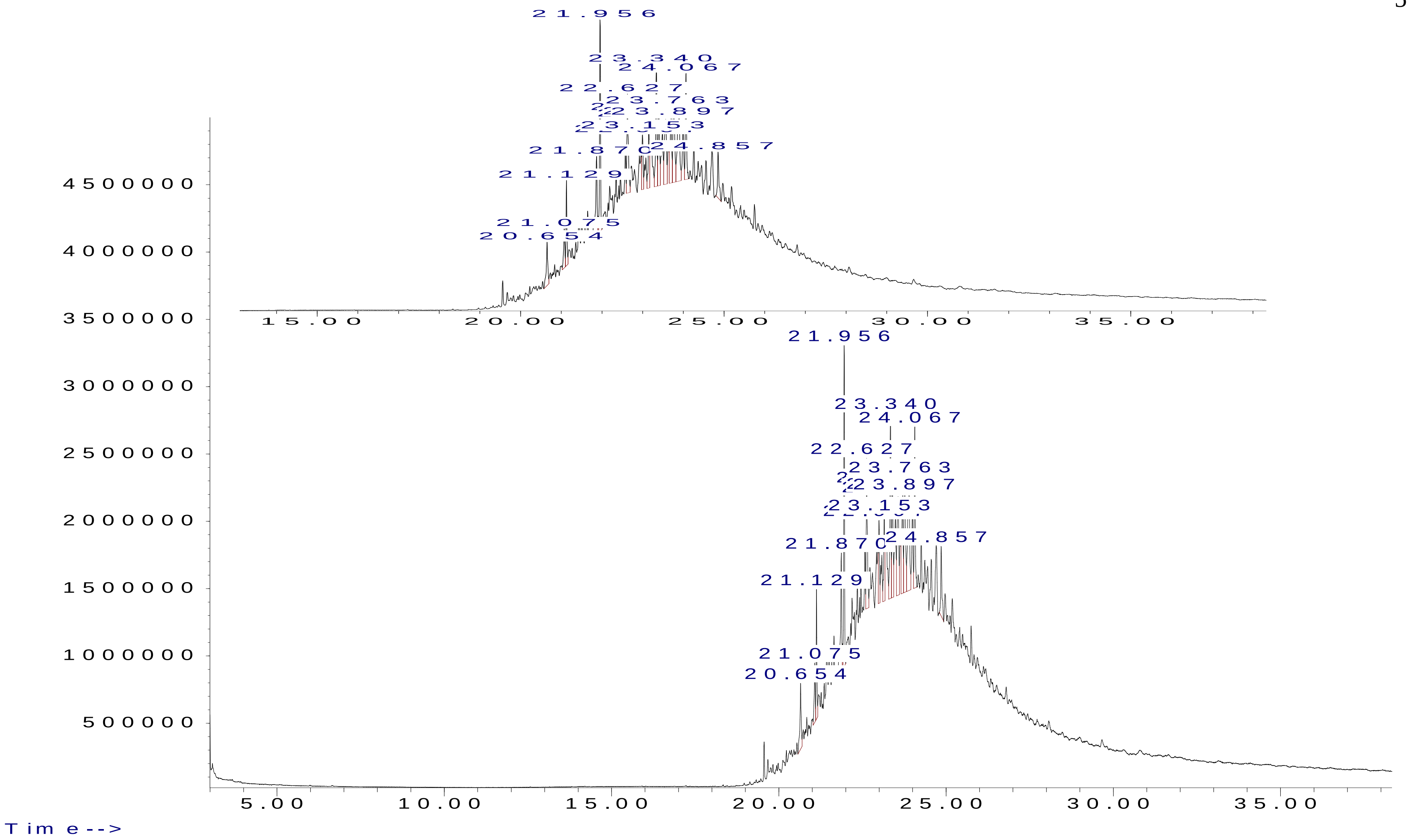


Figure C.6.21. The Total Ion Chromatograms (TIC) of detected soil sample for coordinate (100 m, 75 m) at depth (0.25 m), at contaminated site (Al-Magwa Area).

Table C.6.46. The results of detected soil sample with TPH which tested by GC-MS instrument for T.P.C. (75 m, 100 m) at depth (0.25 m) of contaminated site (Al-Magwa Area).

Peak	Ret. Time	Chemical Composition of the TPH in the Contaminated Soil Sample	Area Under the Curve (m2)	Chemical Composition Formula	Classification of the TPH based on Aliphatic and Aromatic	Concentration of each TPH Chemical Composition Detected in the Contaminated Soil Sample (µg/ml)	Concentration of each TPH Chemical Composition Detected in the Contaminated Soil Sample (mg/kg)	Total Concentration of the Total TPH Compositions Detected in the Contaminated Soil Sample (mg/kg)	References
1	19.563 PV	BHT	10151413	$C_{15}H_{24}$	Aromatic EC12 - EC16	104.832	34.944	532.378	(BHT, n.d.)
2	20.655 VV	n-Dodecane	10529797	$C_{12}H_{26}$	Aliphatic EC12 - EC16	109.733	36.57767		(Dodecane, n.d.)
3	21.130 VV	Tetramethylpentadecane	21392696	$C_{19}H_{40}$	Aliphatic EC16 - EC35	250.407	83.469		(Pristane, n.d.)
4	21.959 VV	Tetramethylhexadecane	13747617	$C_{20}H_{42}$	Aliphatic EC16 - EC35	151.403	50.46767		(Two, 6, 10, 14-tetramethylhexadecane, n.d.)
5	22.459 PV	Di-p-tolylacetylene	51574611	$C_{16}H_{14}$	Aromatic EC16 – EC21	641.263	213.7543		(Di-p-Tolylacetylene, n.d.)
6	22.579 VV	n-cetane	19765174	$C_{16}H_{34}$	Aliphatic EC16 - EC35	229.331	76.44367		(Hexadecane, n.d.)
7	23.339 VV	β-Pregnane	10563236	$C_{21}H_{36}$	Aliphatic EC16 - EC35	110.166	36.722		(Pregnane, n.d.)

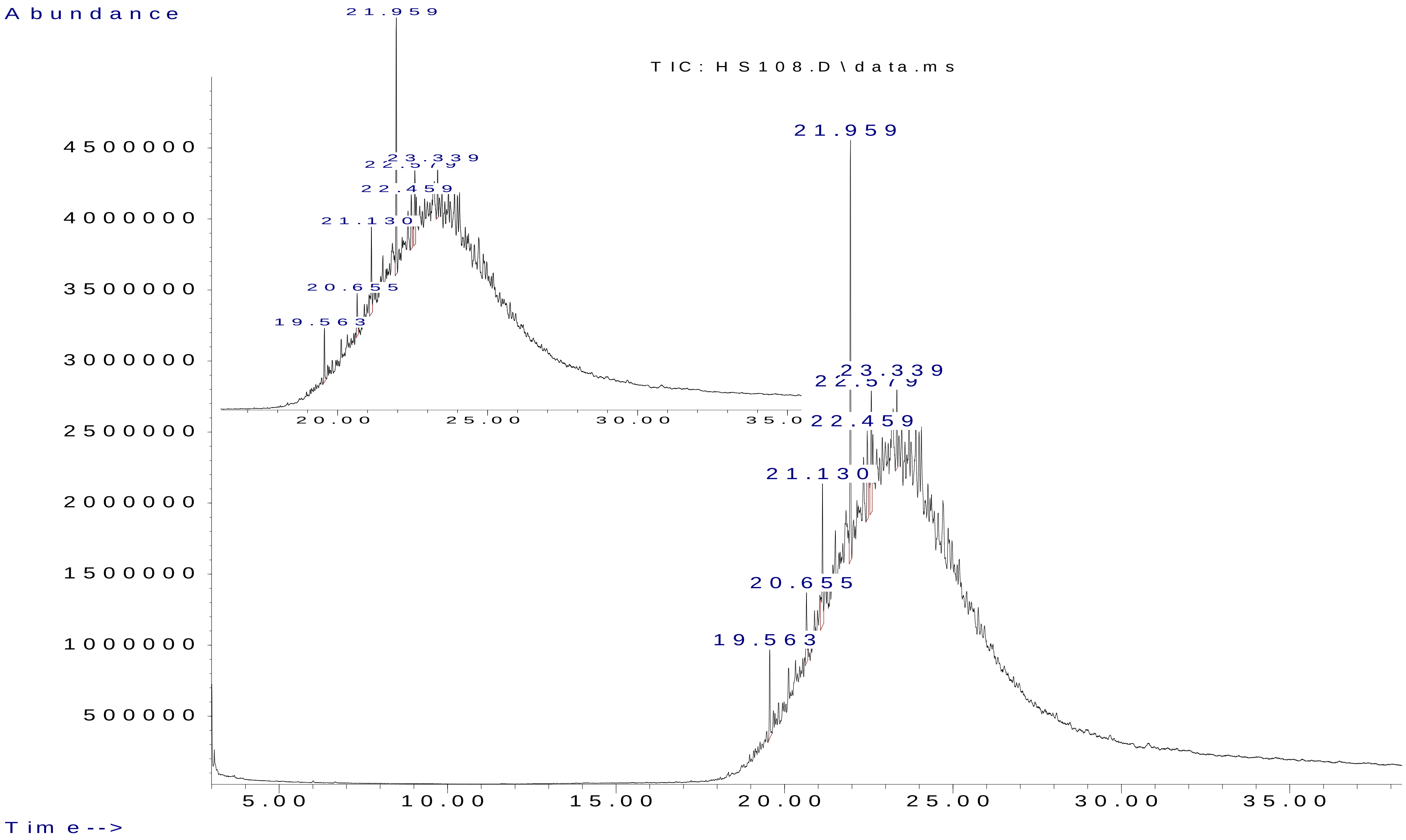


Figure C.6.22. The Total Ion Chromatograms (TIC) of detected soil sample for T.P.C. (75 m, 100 m) at depth (0.25 m), at contaminated site (Al-Magwa Area).

At depth (0.5 m) at contaminated site

Table C.6.47. The results of detected soil sample with TPH which tested by GC-MS instrument for T.P.C. (75 m, 0 m) at depth (0.5 m) of contaminated site (Al-Magwa Area).

Peak	Ret. Time	Chemical Composition of the TPH in the Contaminated Soil Sample	Area Under the Curve (m2)	Chemical Composition Formula	Classification of the TPH based on Aliphatic and Aromatic	Concentration of each TPH Chemical Composition Detected in the Contaminated Soil Sample (µg/ml)	Concentration of each TPH Chemical Composition Detected in the Contaminated Soil Sample (mg/kg)	Total Concentration of the Total TPH Compositions Detected in the Contaminated Soil Sample (mg/kg)	References
1	5.518 BV	Dihydroxydimethylsilane	6545822	$C_2H_8O_2$	-------	58.140	19.38	2.484	(Dimethylsilanediol, n.d.)
2	13.278 BV	BHT	2631697	$C_{15}H_{24}$	Aromatic EC10 - EC12	7.452	2.484		(BHT, n.d.)

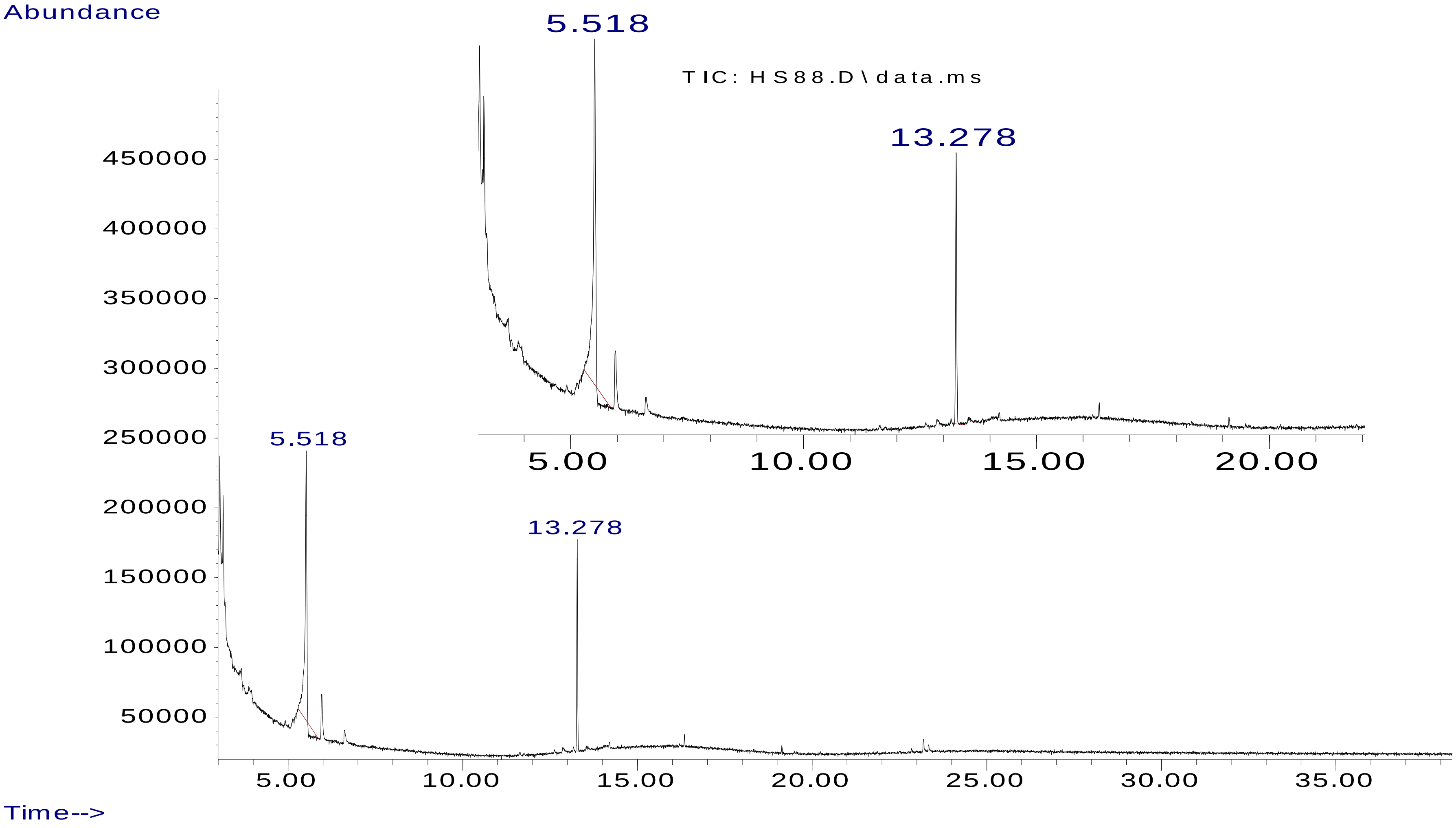


Figure C.6.23. The Total Ion Chromatograms (TIC) of detected soil sample with TPH for coordinate (75 m, 0 m) at depth (0.5 m), at contaminated site (Al-Magwa Area).

Not Detected samples with TPH at contaminated site

At Depth (0.0 m)

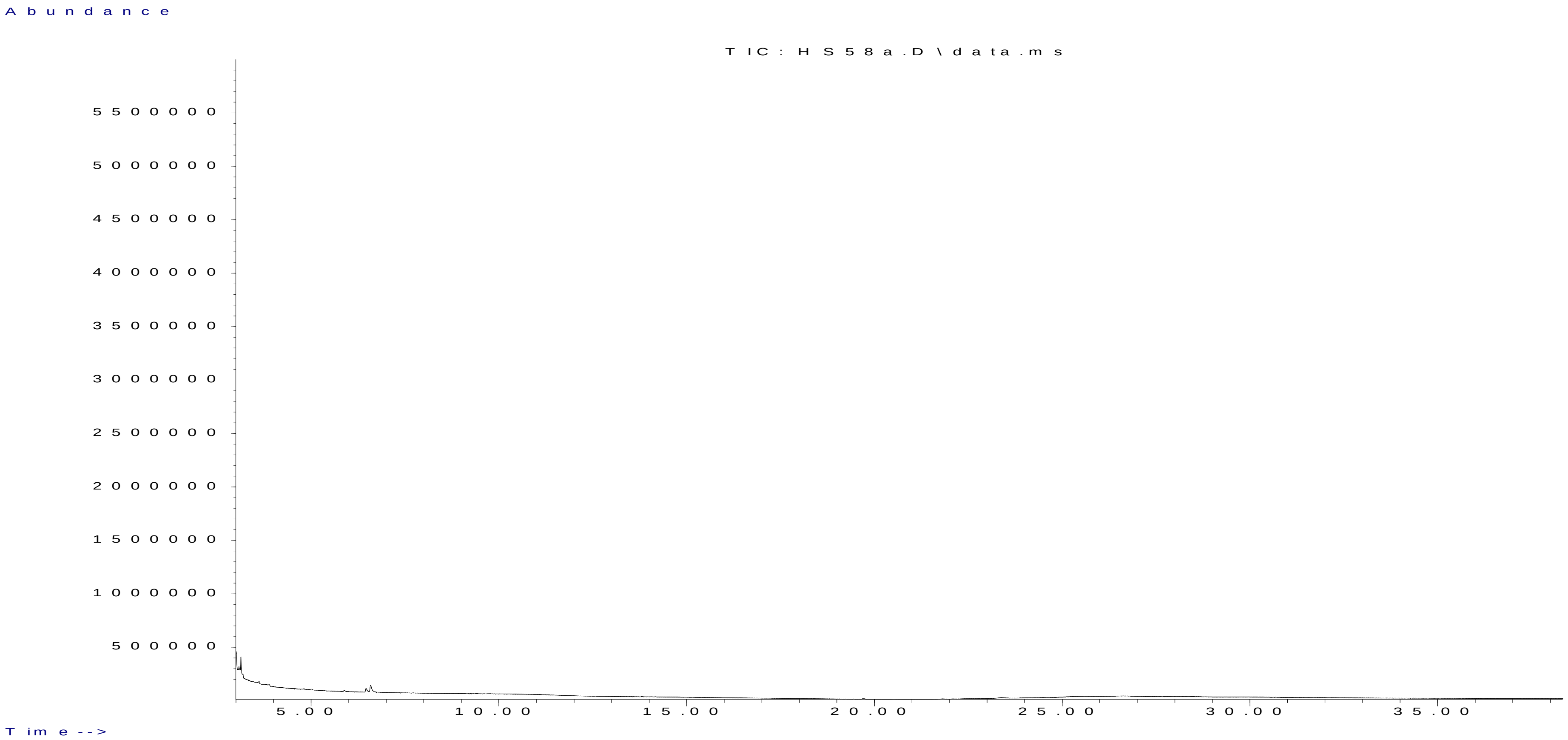


Figure C.6.24. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH for T.P.C. (25 m, 0 m) at depth (0.0 m), at contaminated site (Al-Magwa Area).

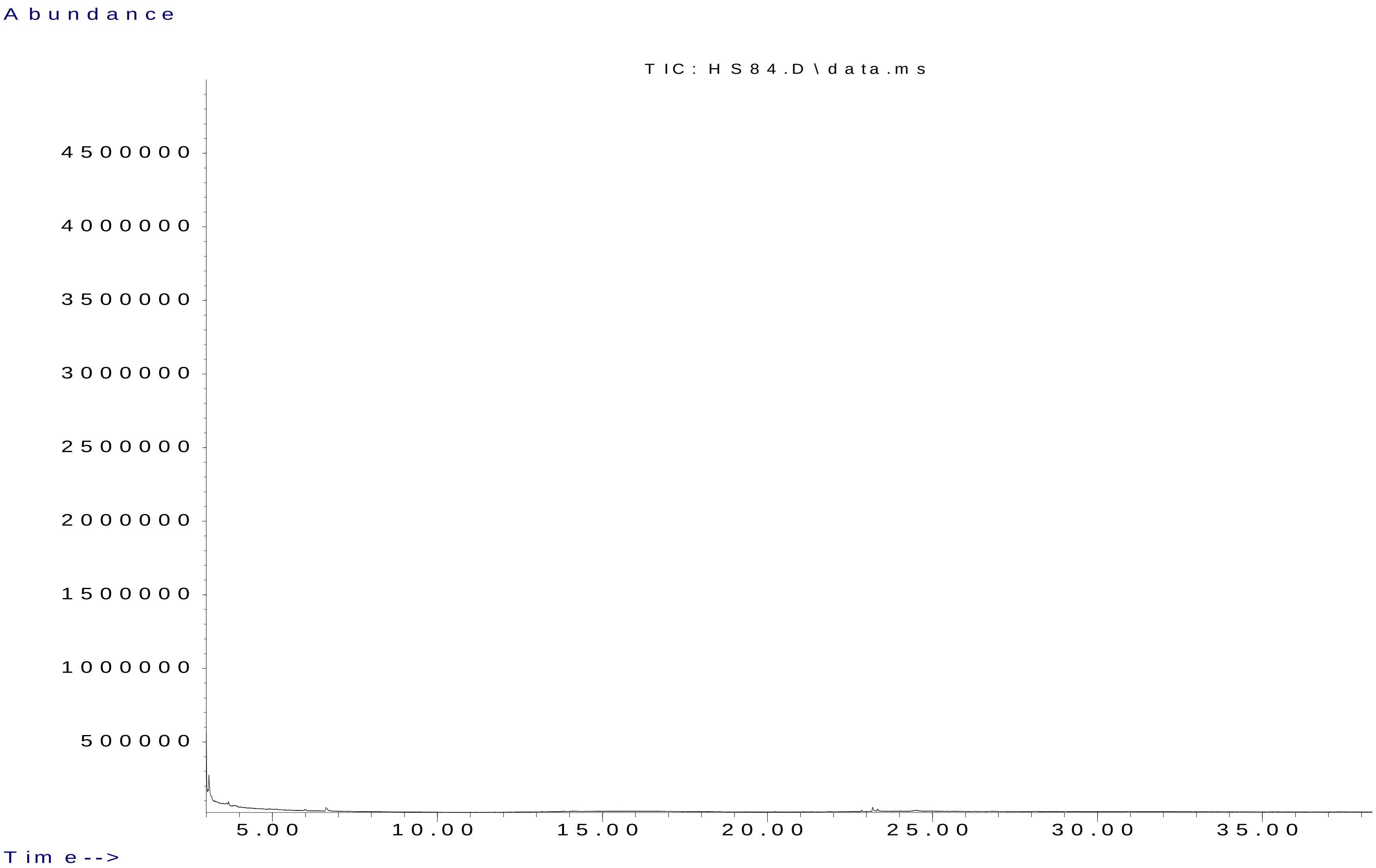


Figure C.6.25. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH for T.P.C. (50 m, 0 m) at depth (0.0 m) at contaminated site (Al-Magwa Area).

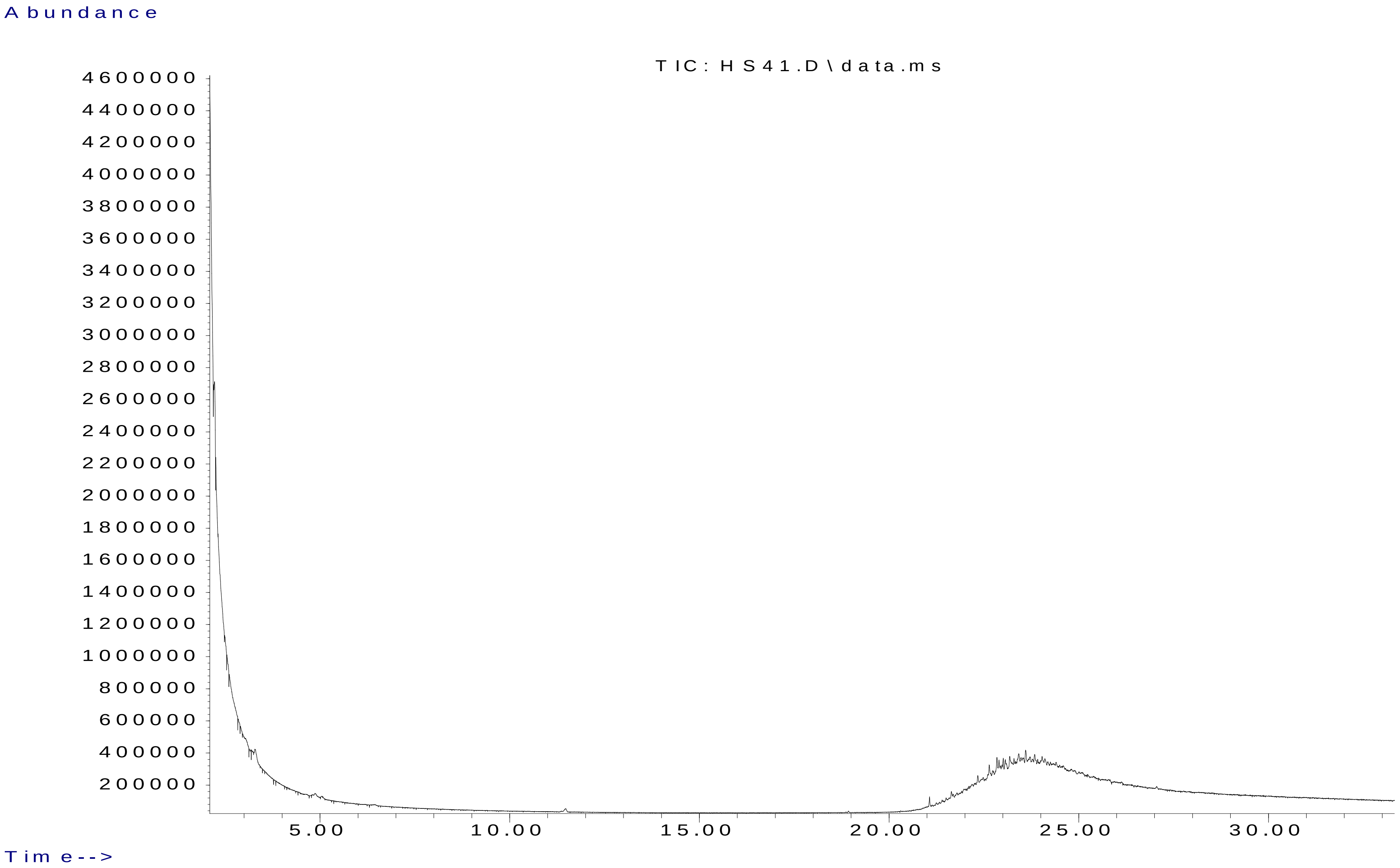


Figure C.6.26. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH for T.P.C. (50 m, 25 m) at depth (0.0 m), at contaminated site (Al-Magwa Area).

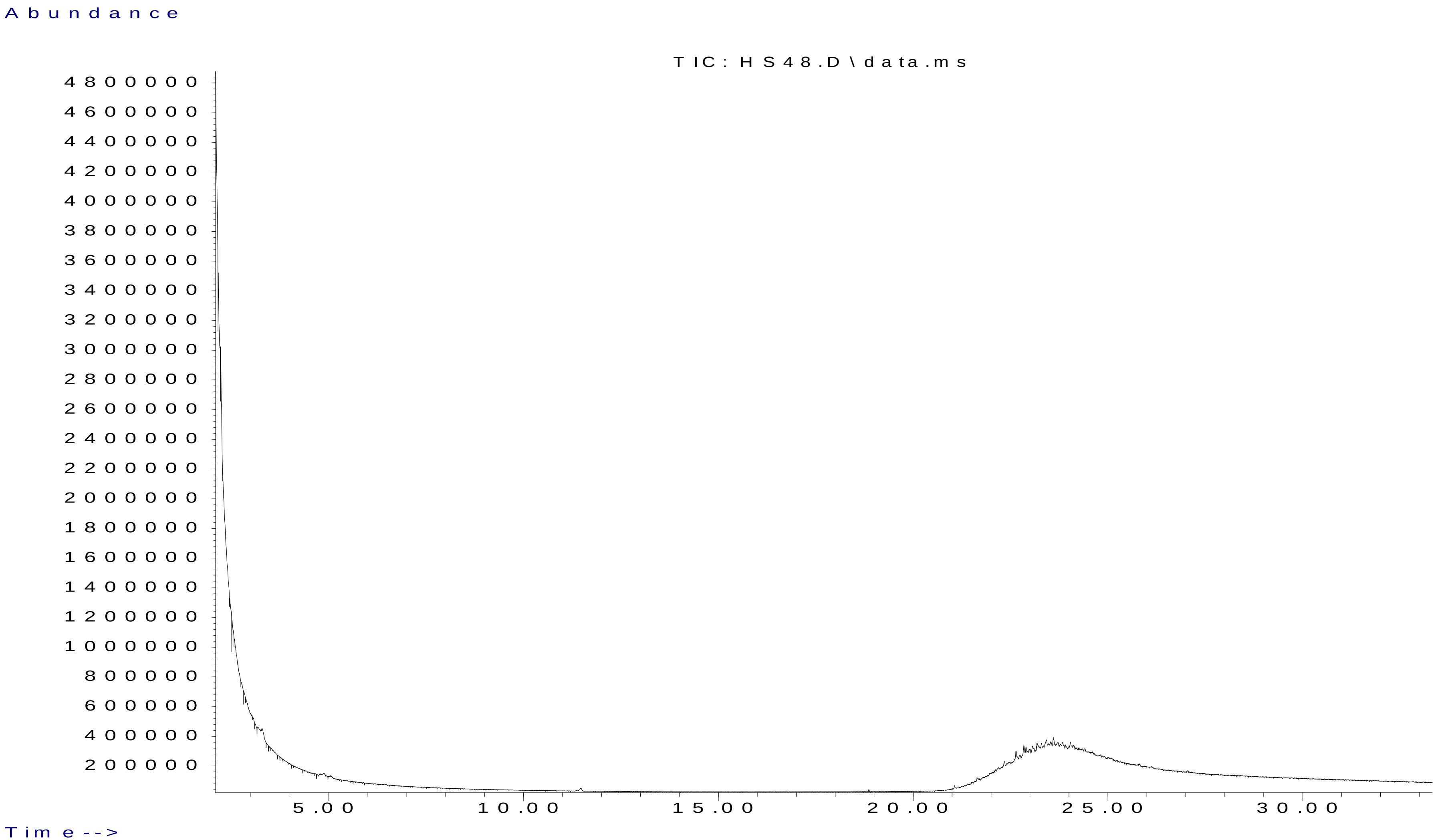


Figure C.6.27. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH for T.P.C. (0 m, 50 m) at depth (0.0 m), at contaminated site (Al-Magwa Area).

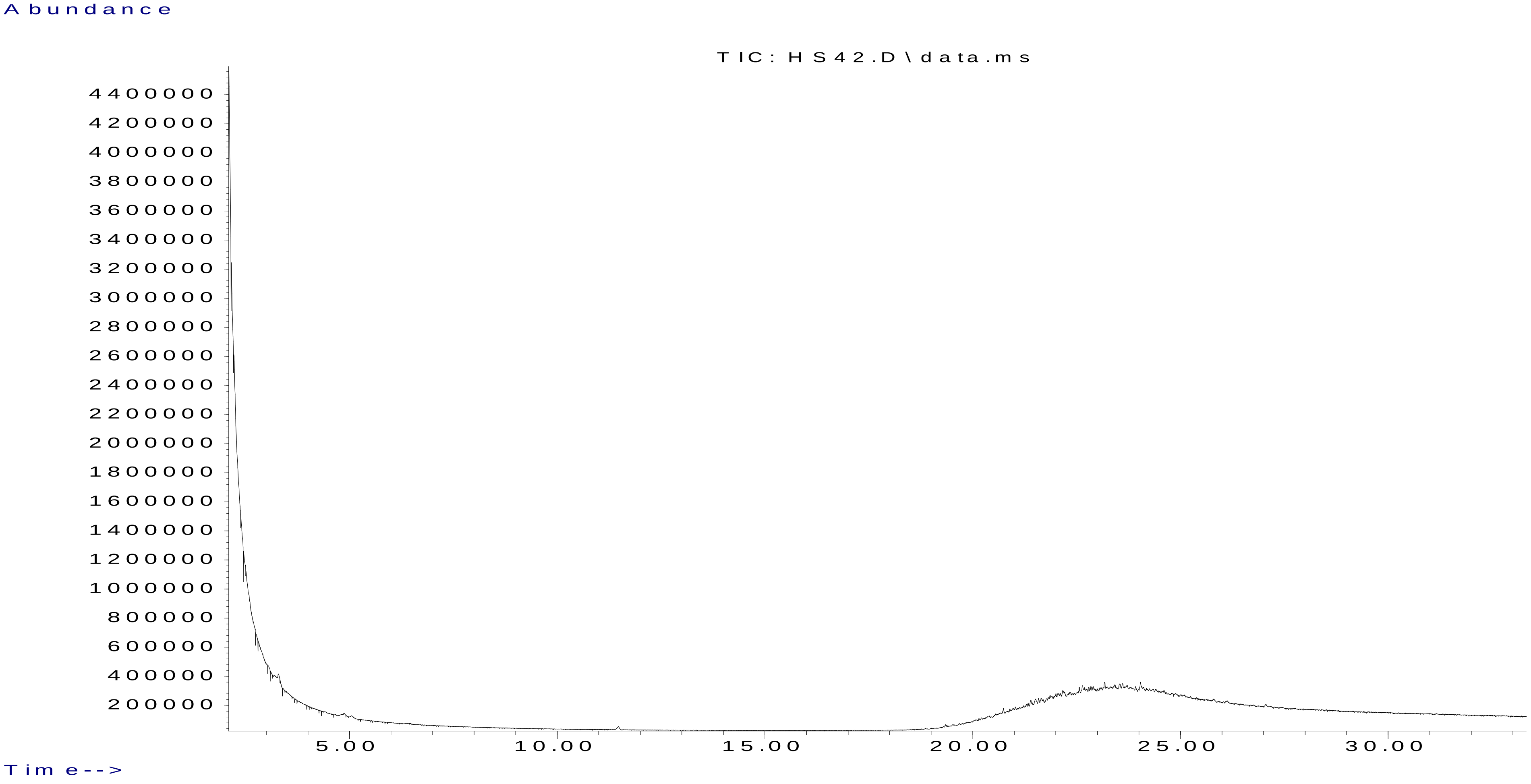


Figure C.6.28. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH for T.P.C. (100 m, 75 m) at depth (0.0 m), at contaminated site (Al-Magwa Area).

At depth (0.25 m)

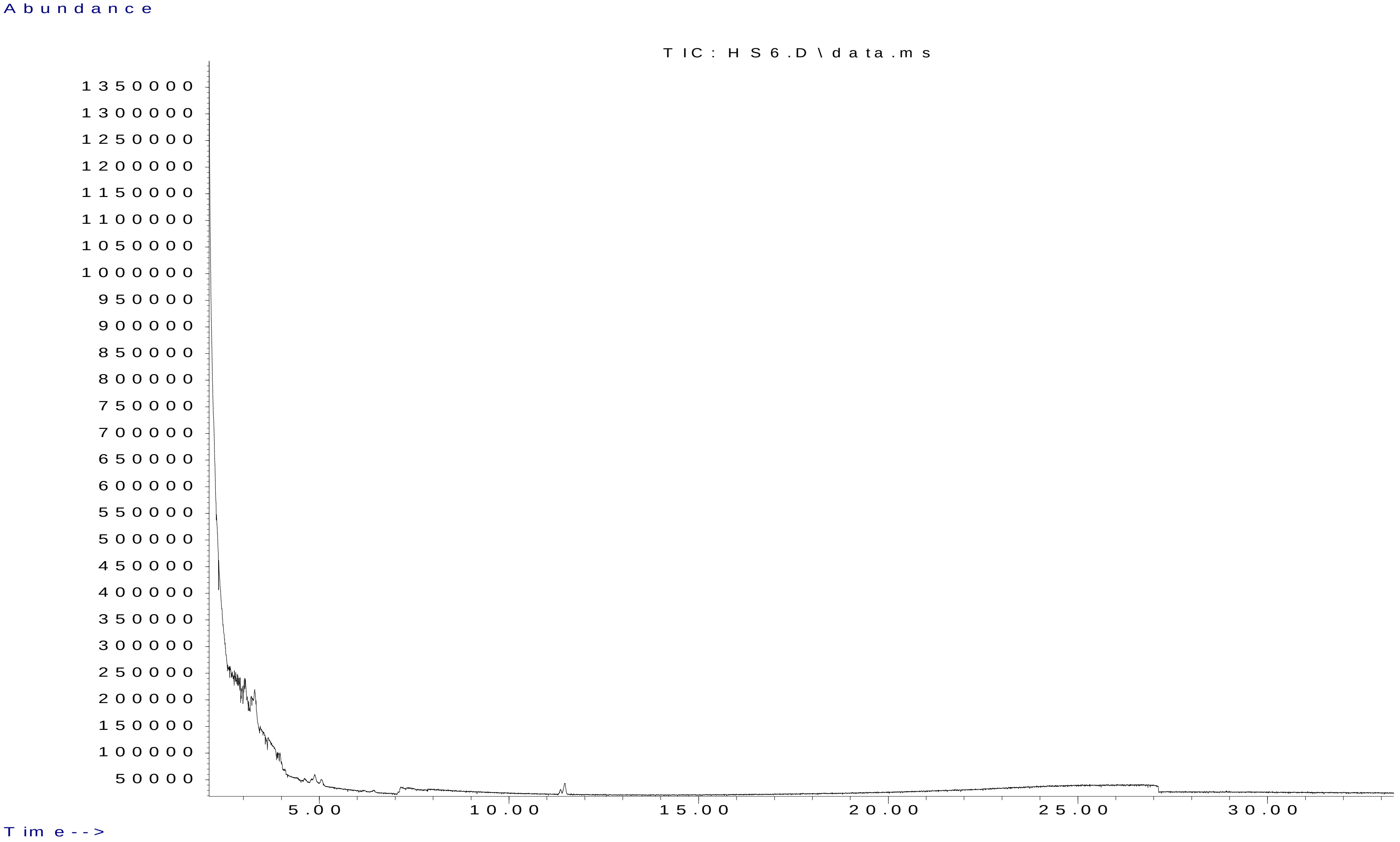


Figure C.6.29. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH for T.P.C. (0 m, 0 m) at depth (0.25 m), at contaminated site (Al-Magwa Area).

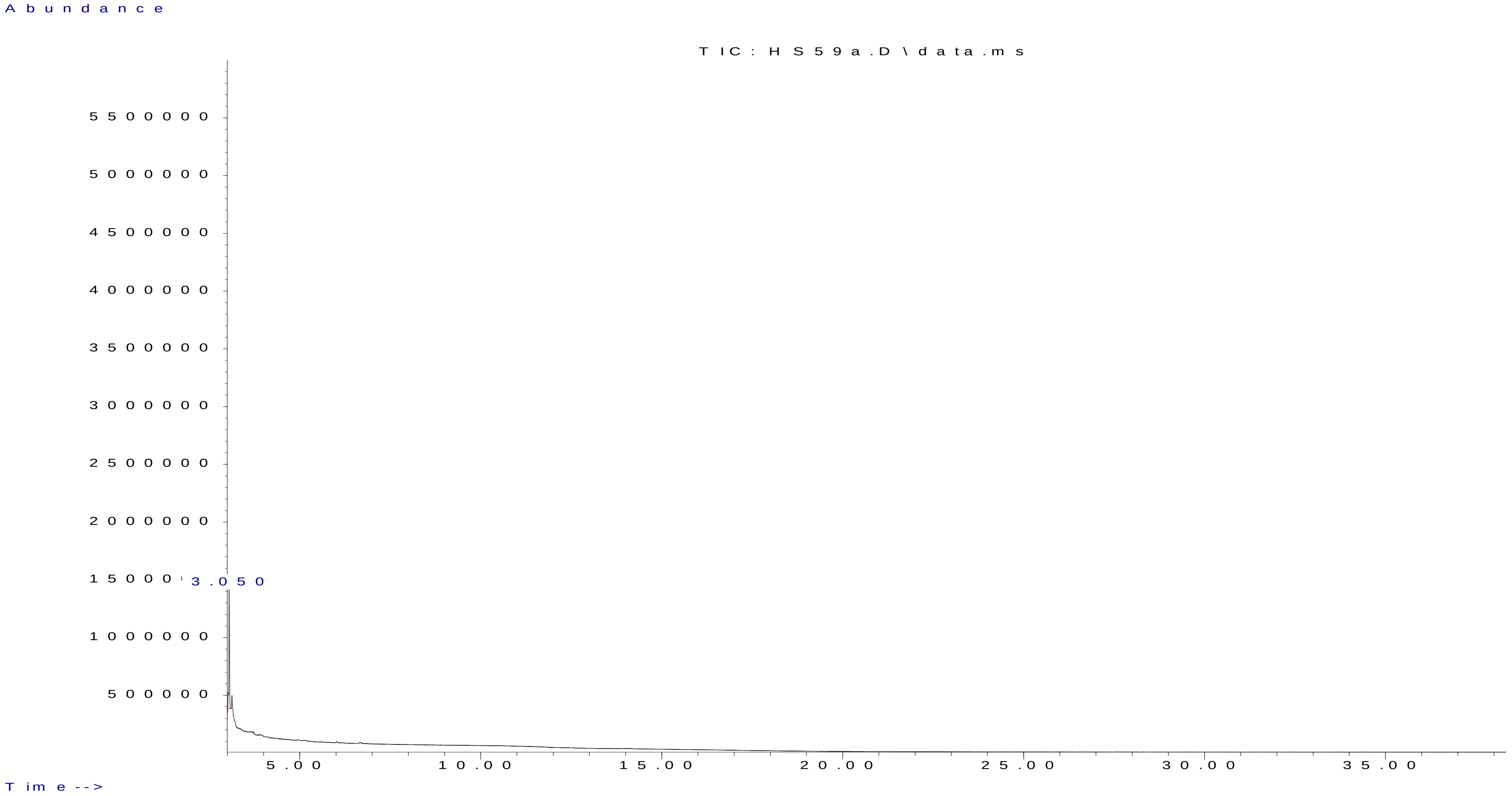


Figure C.6.30. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH for T.P.C. (25 m, 0 m) at depth (0.25 m), at contaminated site (A-Magwa Area).

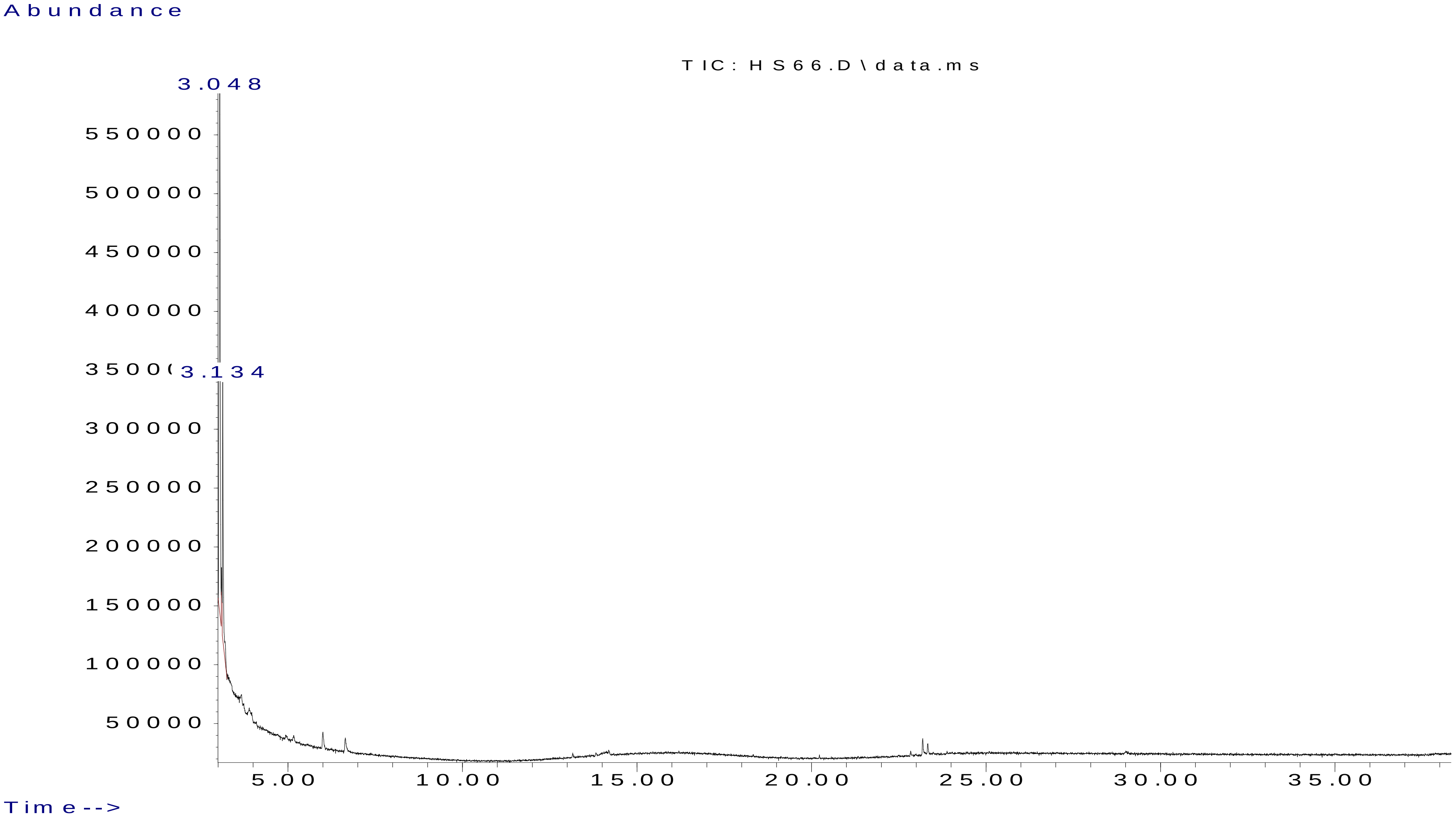


Figure C.6.31. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH for T.P.C. (50 m, 0 m) at depth (0.25 m), at contaminated site (Al-Magwa Area).

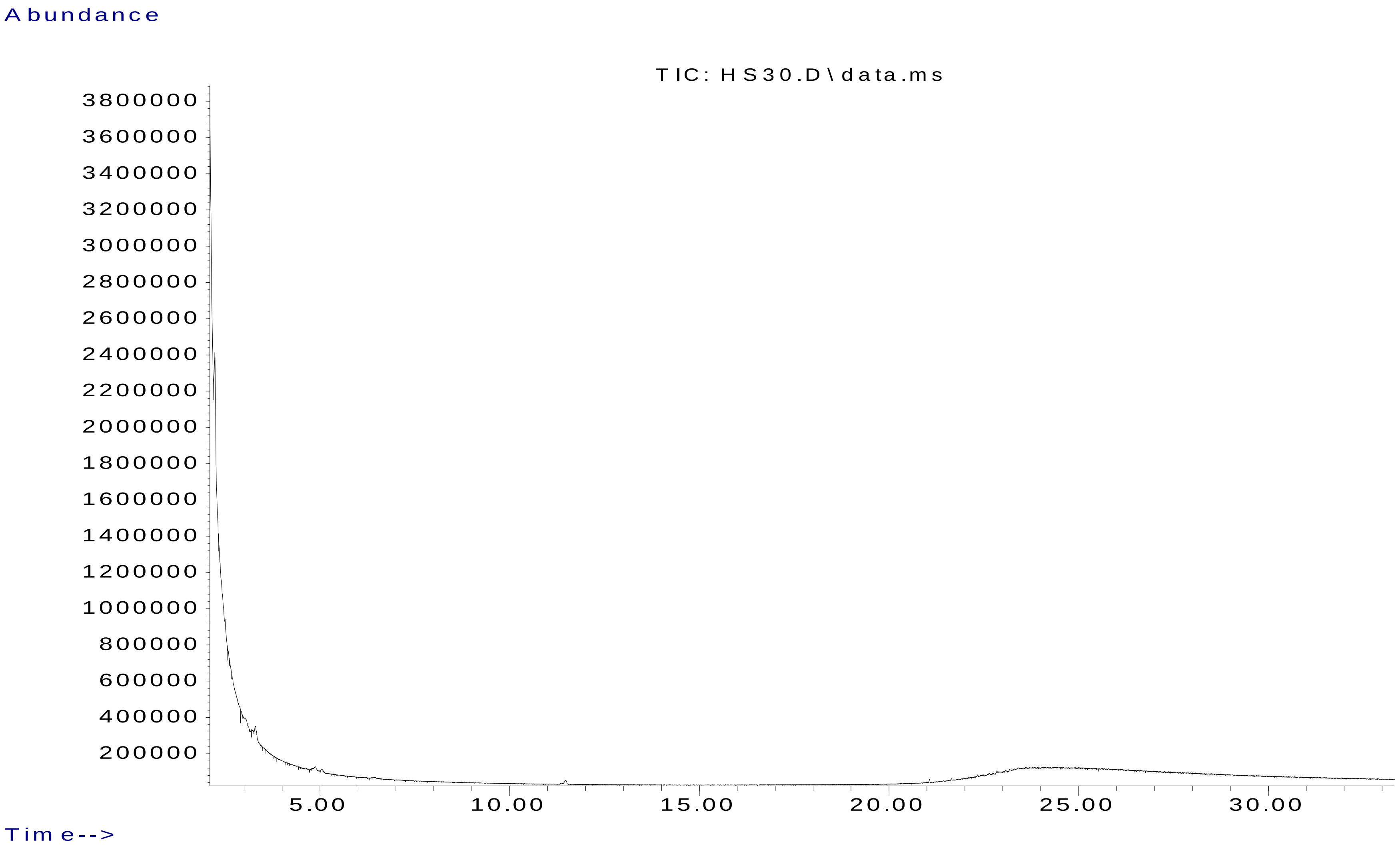


Figure C.6.32. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH for T.P.C. (75 m, 0 m) at depth (0.25 m), at contaminated site (Al-Magwa Area).

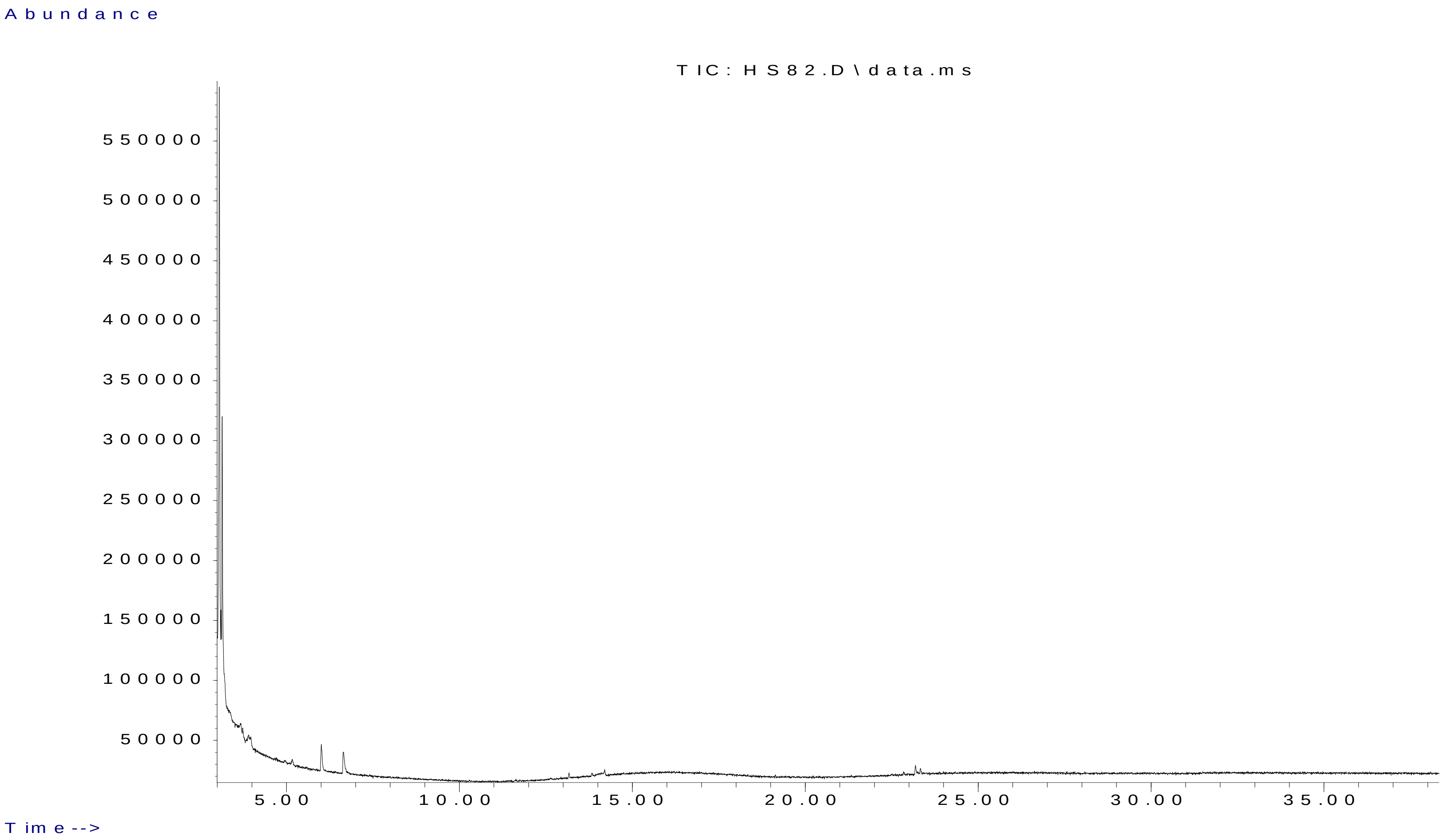


Figure C.6.33. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH for T.P.C. (25 m, 25 m) at depth (0.25 m), at contaminated site (Al-Magwa Area).

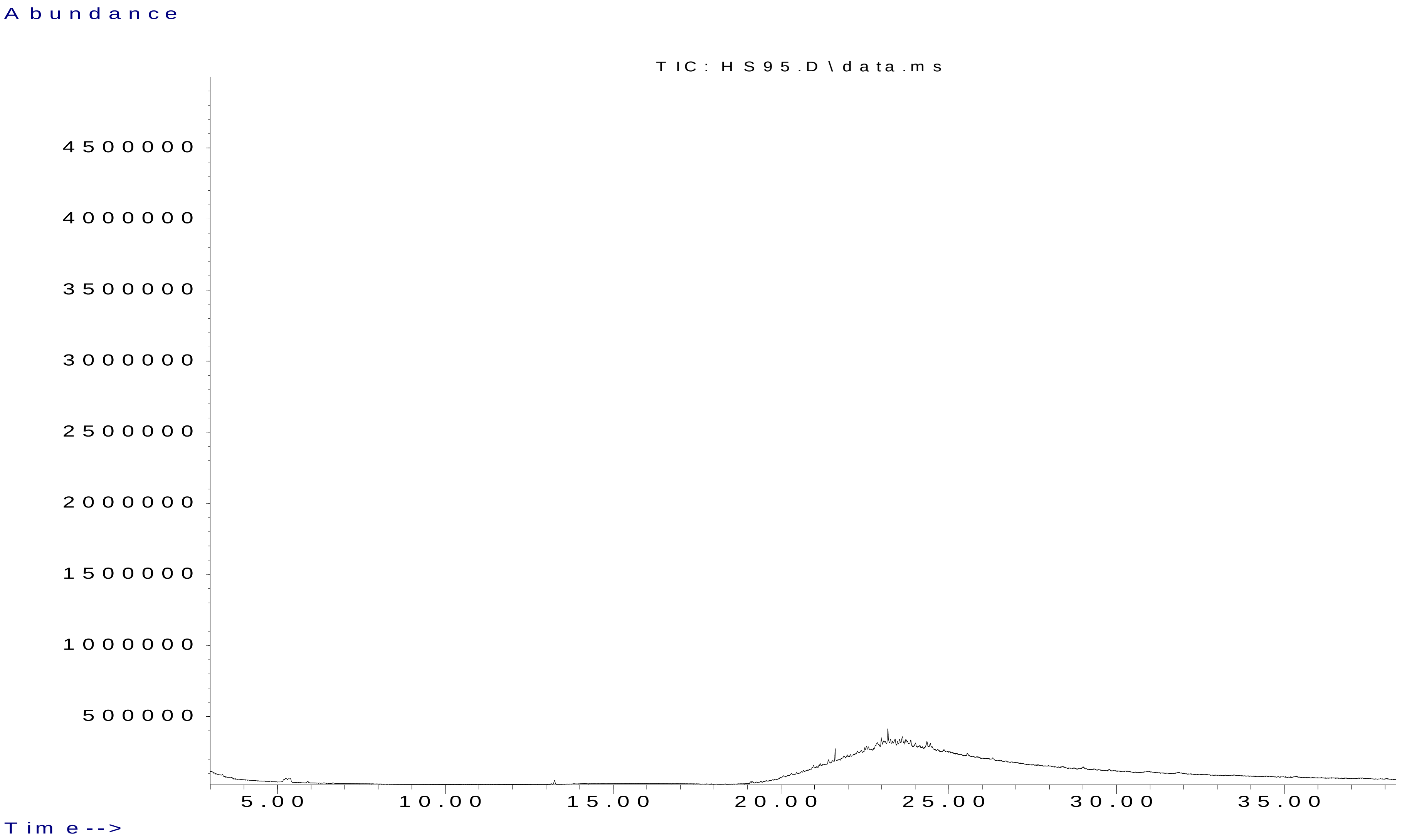


Figure C.6.34. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH for T.P.C. (50 m, 25 m) at depth (0.25 m), at contaminated site (Al-Magwa Area).

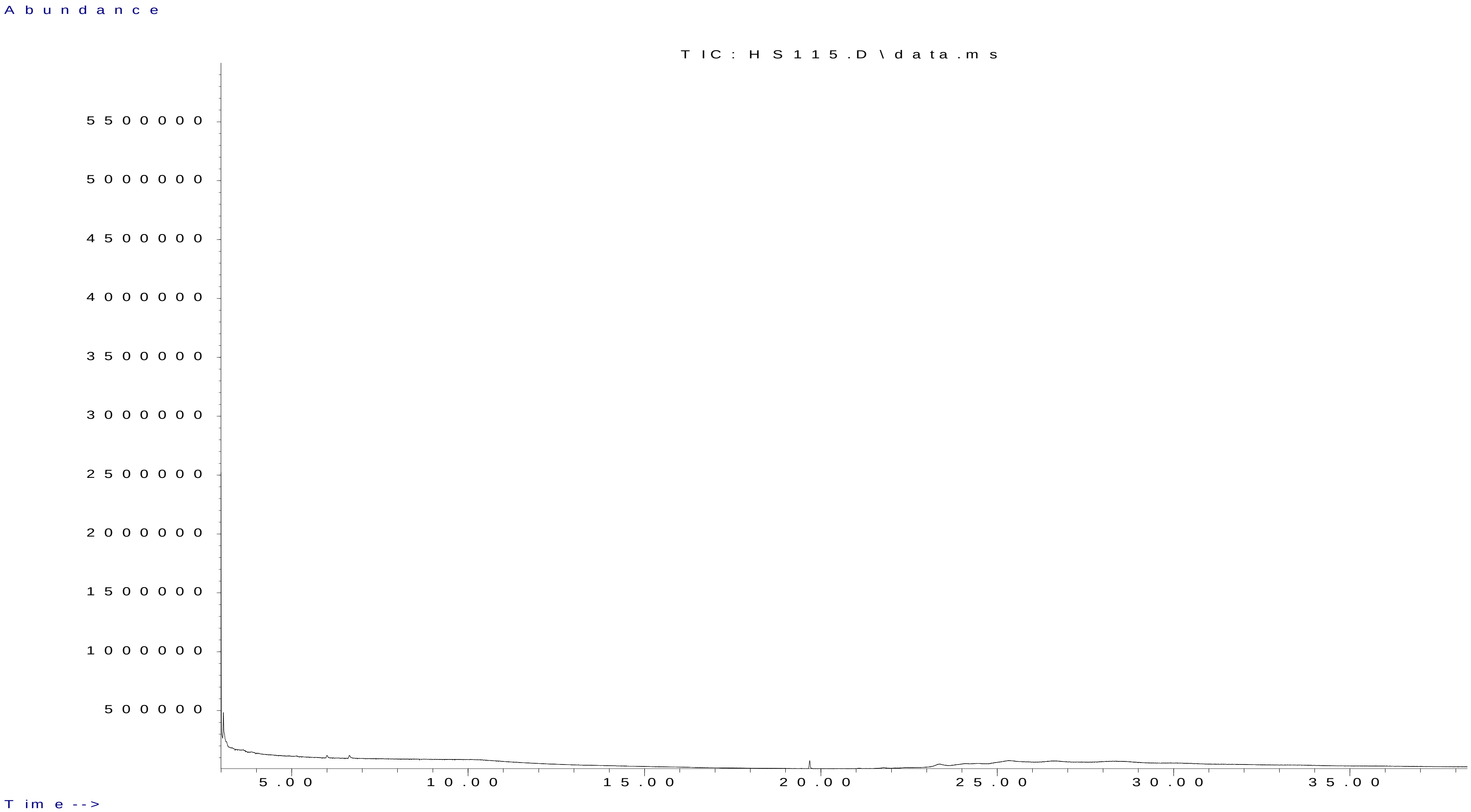


Figure C.6.35. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH for T.P.C. (100 m, 25 m) at depth (0.25 m), at contaminated site (Al-Magwa Area).

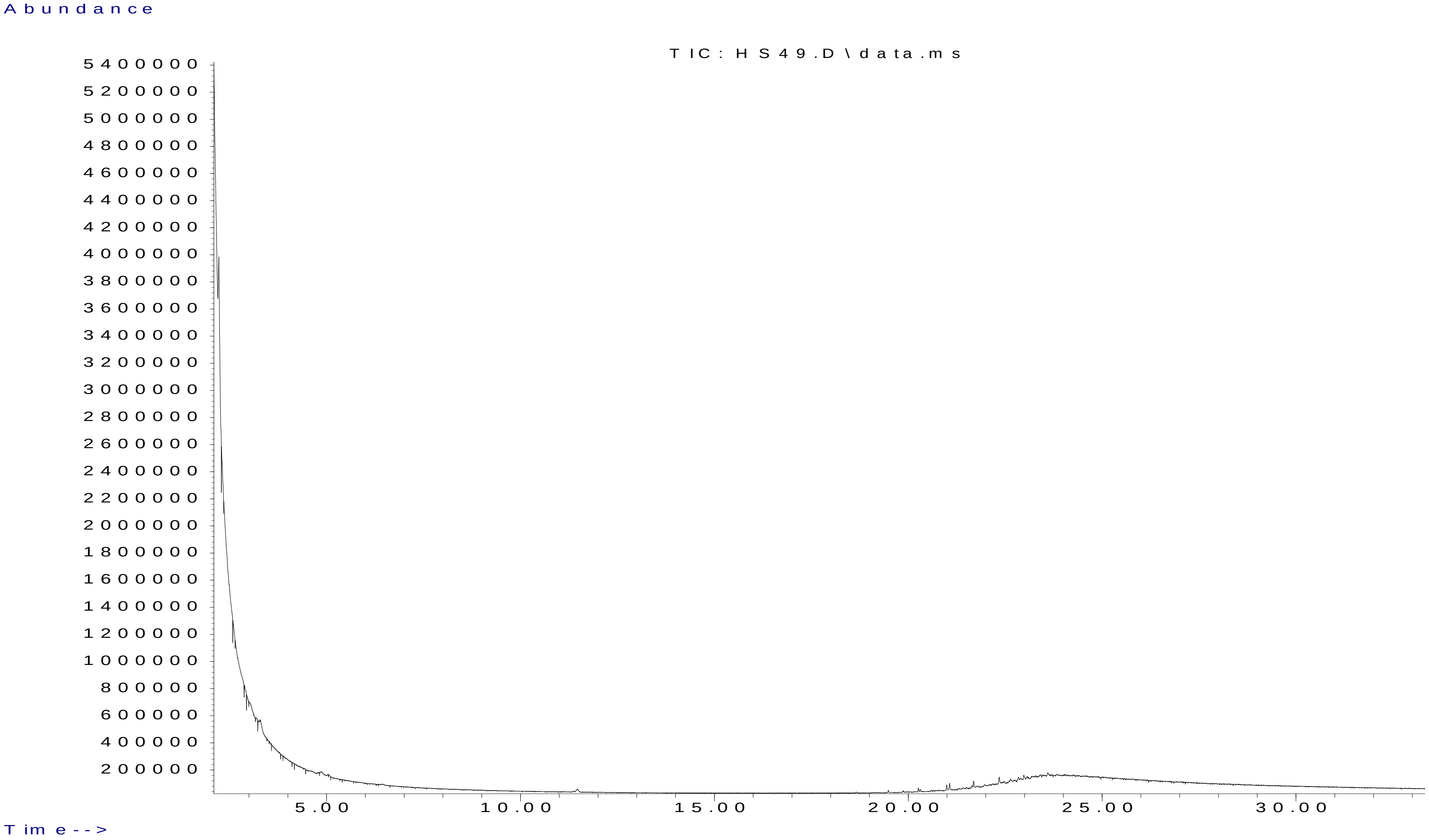


Figure C.6.36. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH for T.P.C. (0 m, 50 m) at depth (0.25 m), at contaminated site (Al-Magwa Area).

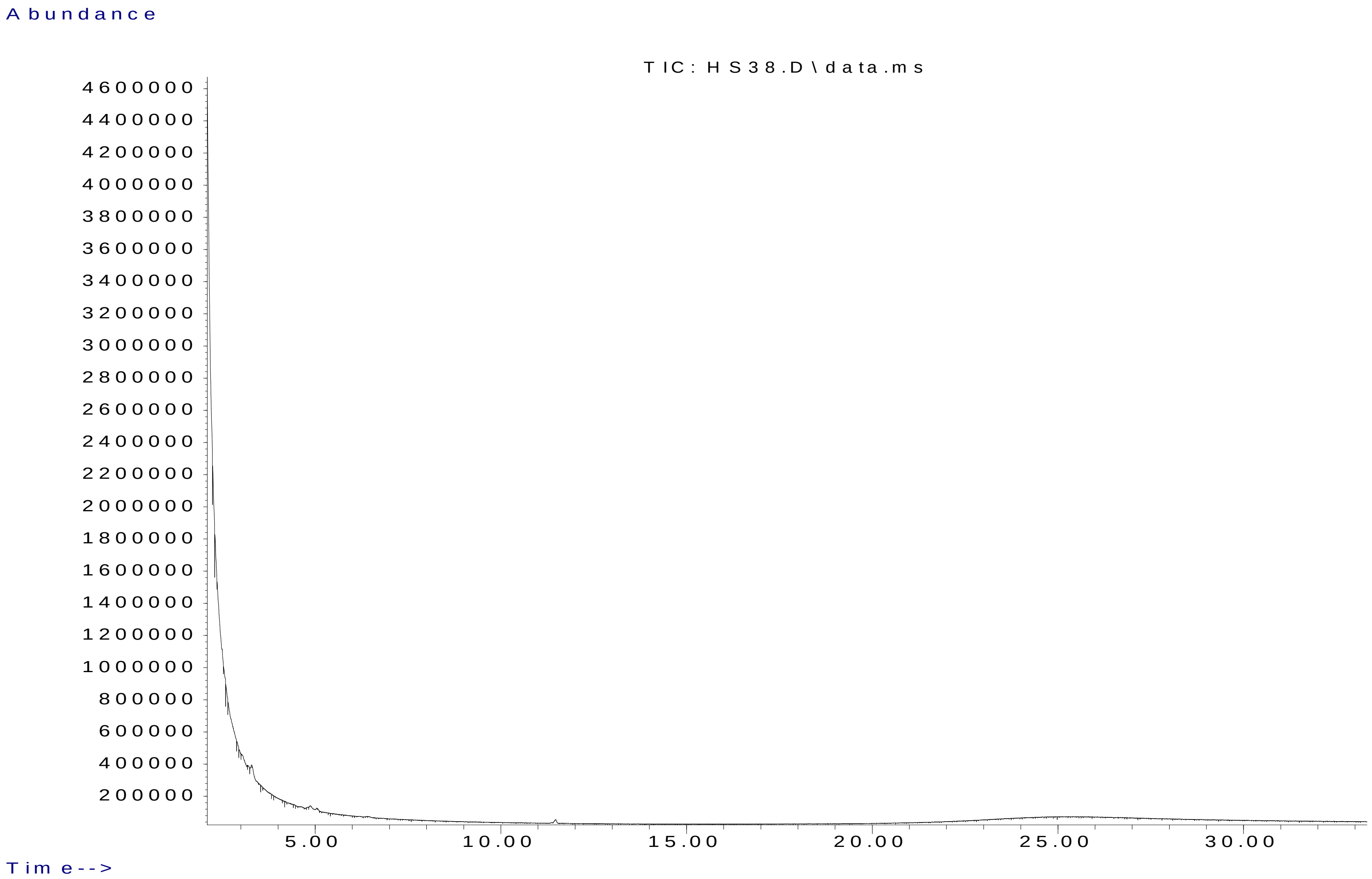


Figure C.6.37. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH for T.P.C. (100 m, 50 m) at depth (0.25 m), at contaminated site (Al-Magwa Area).

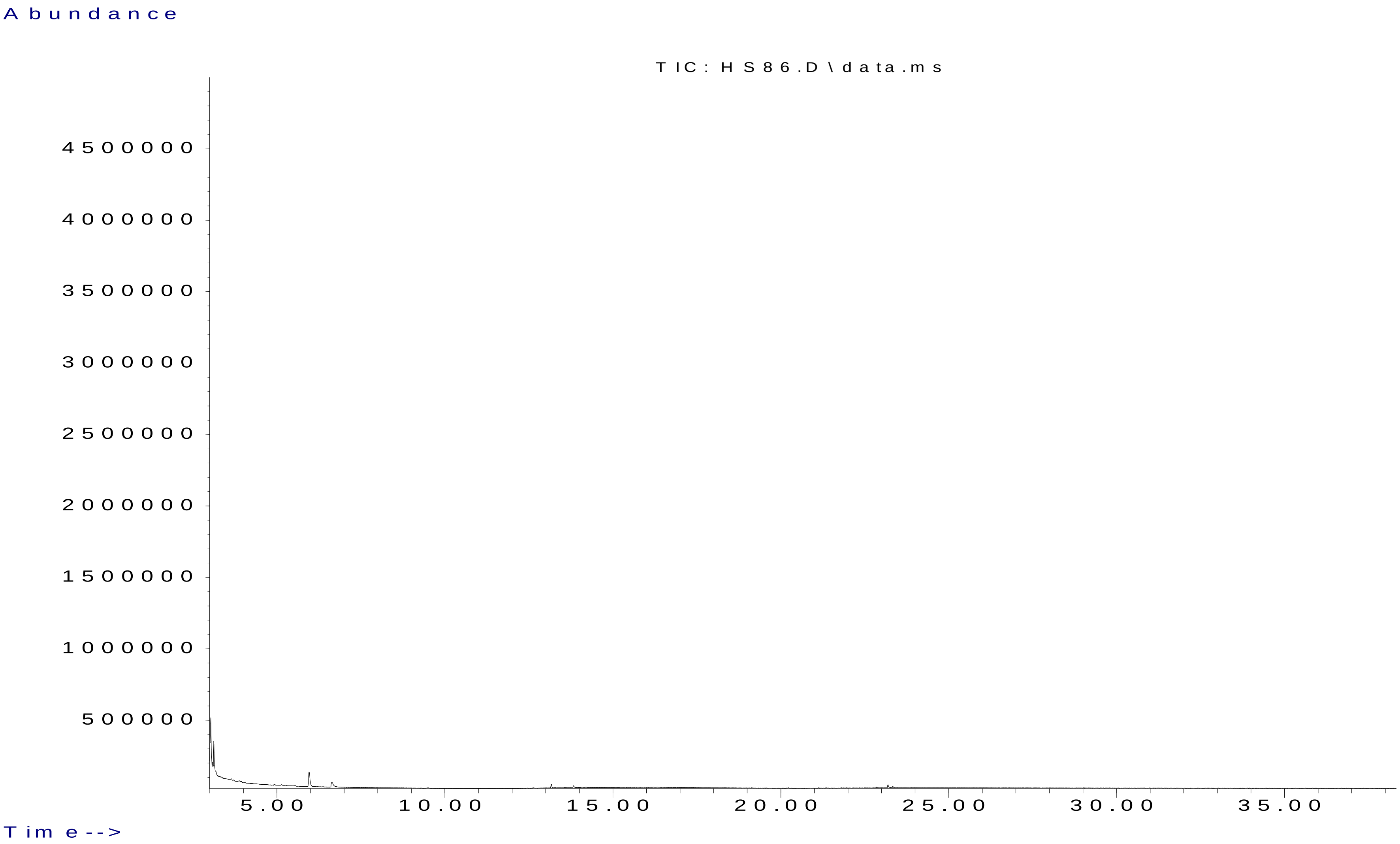


Figure. C.6.38. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH for T.P.C. (25 m, 75 m) at depth (0.25 m), at contaminated site (Al-Magwa Area).

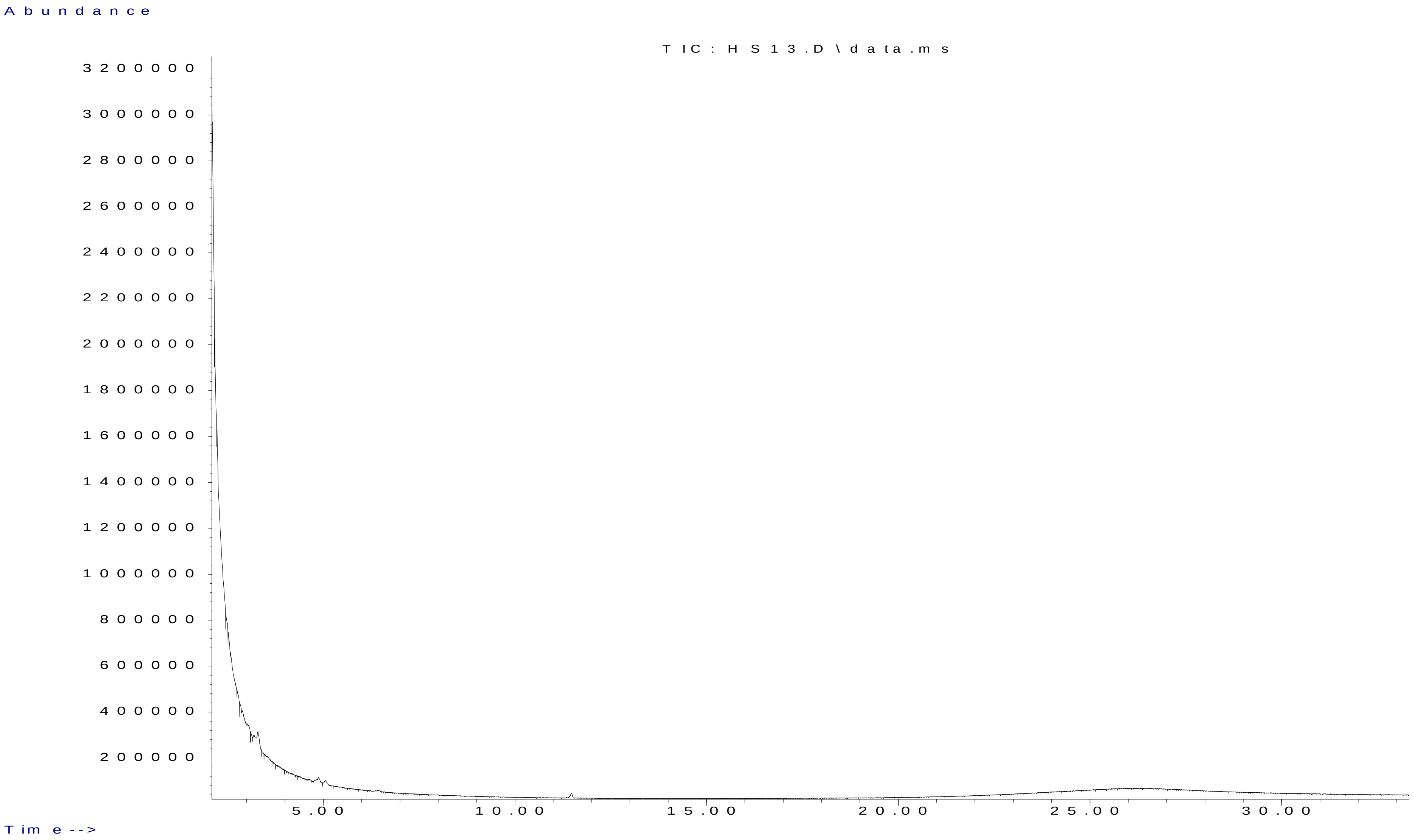


Figure C.6.39. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH for T.P.C. (50 m, 75 m) at depth (0.25 m) at contaminated site (Al-Magwa Area).

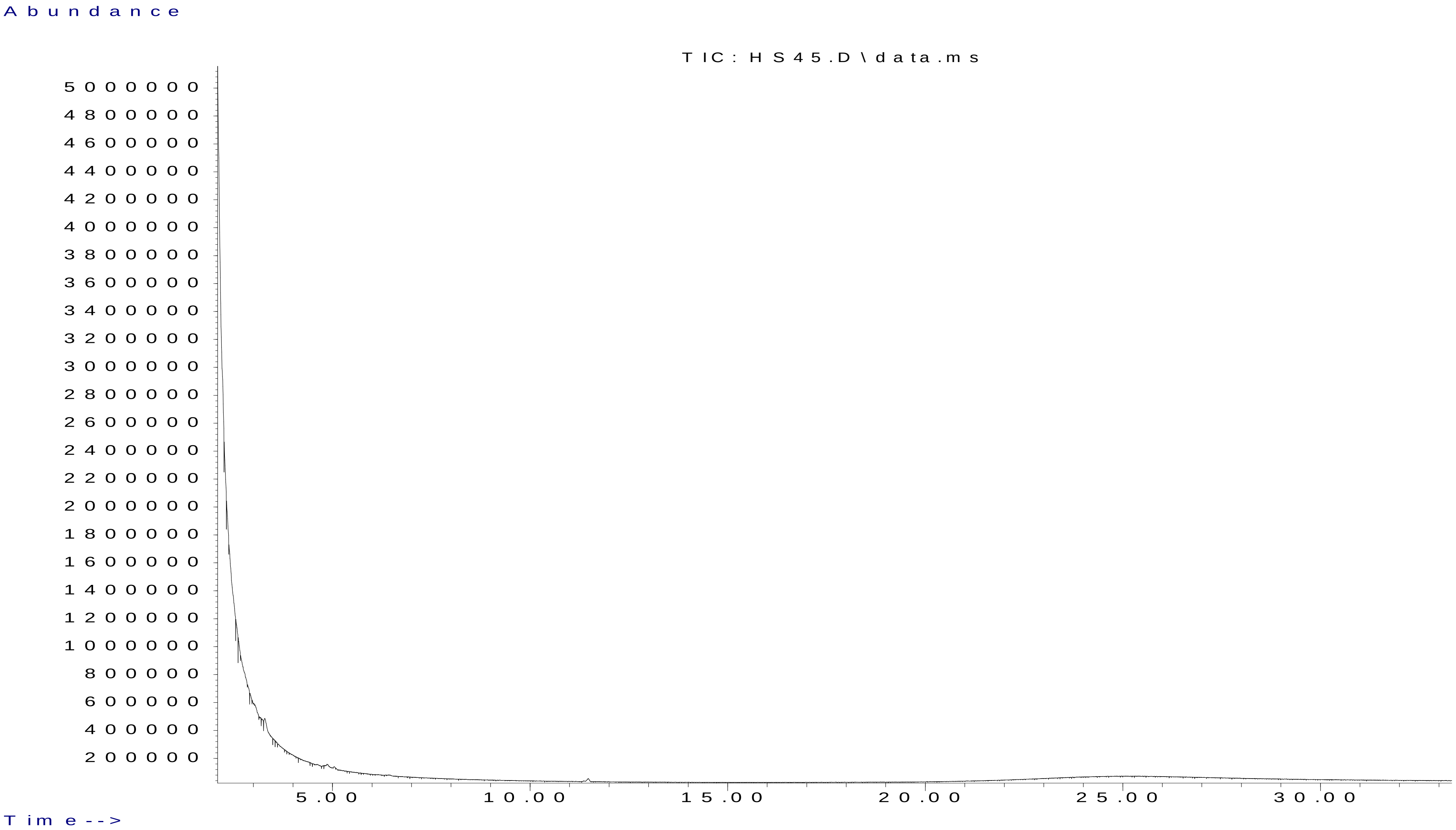


Figure C.6.40. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH for T.P.C. (75 m, 75 m) at depth (0.25 m), at contaminated site (Al-Magwa Area).

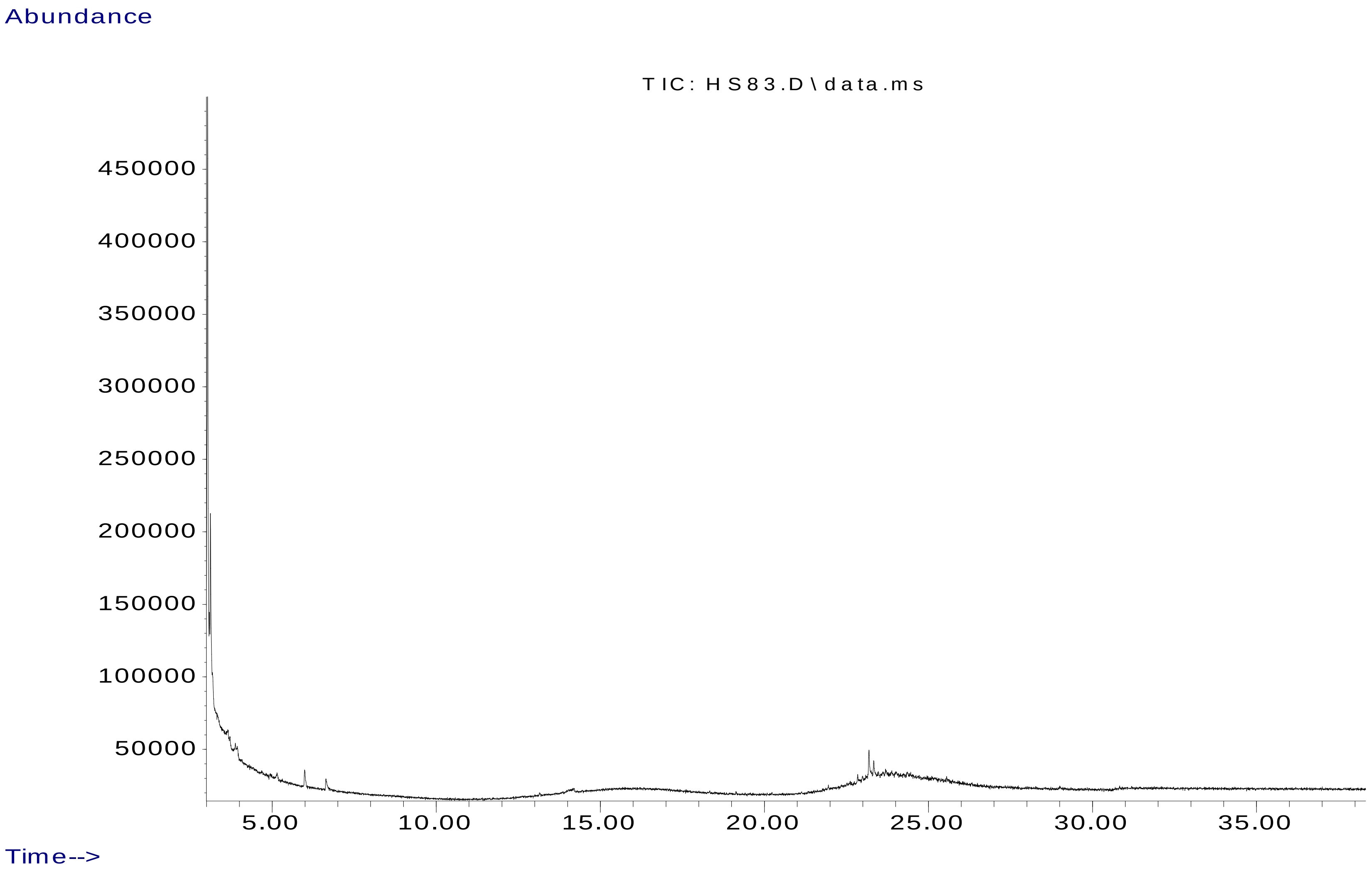


Figure C.6.41. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH for T.P.C. (0 m, 100 m) at depth (0.25 m), at contaminated site (Al-Magwa Area).

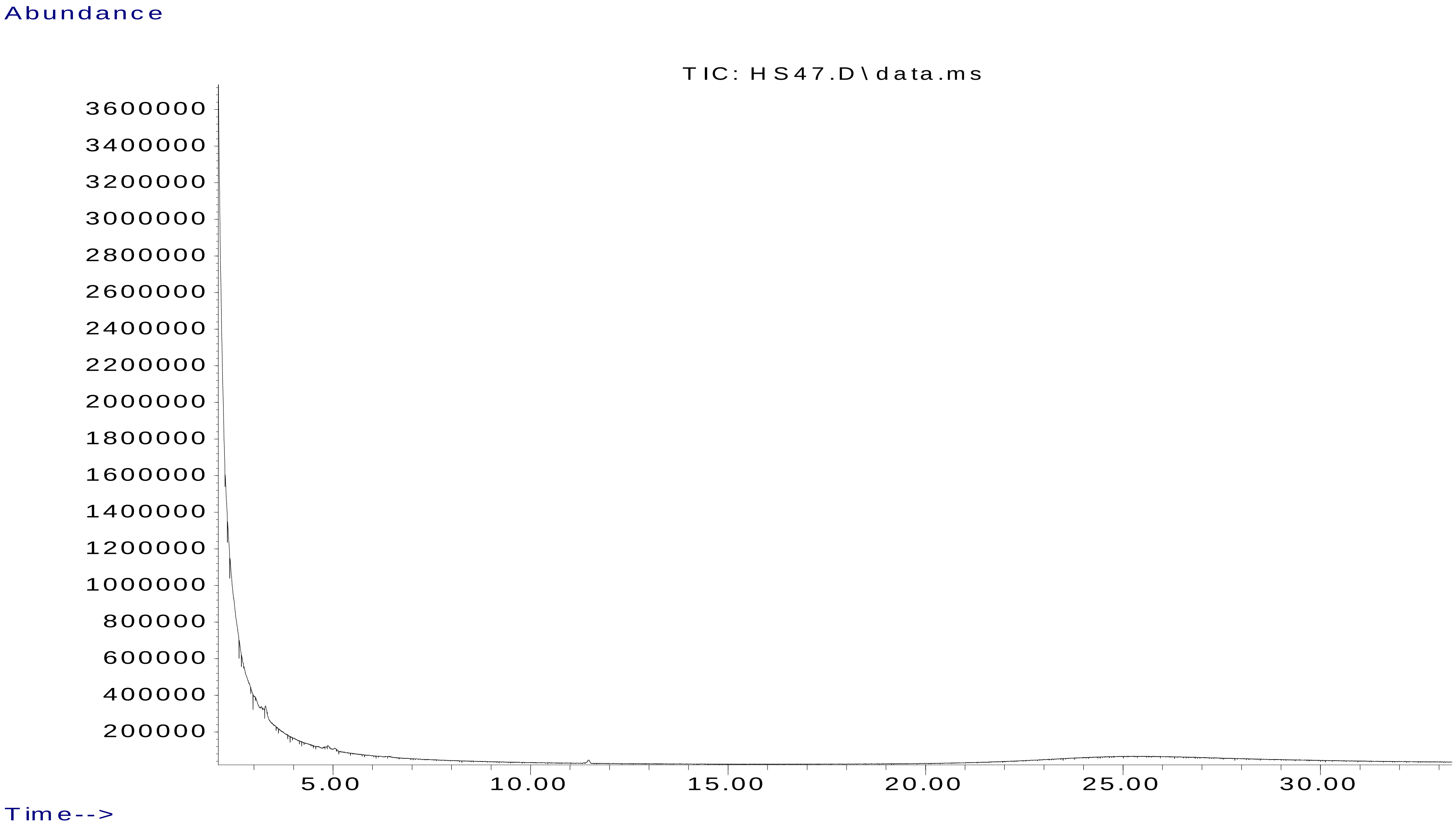


Figure C.6.42. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH for T.P.C. (50 m, 100 m) at depth (0.25 m) at contaminated site (Al-Magwa Area).

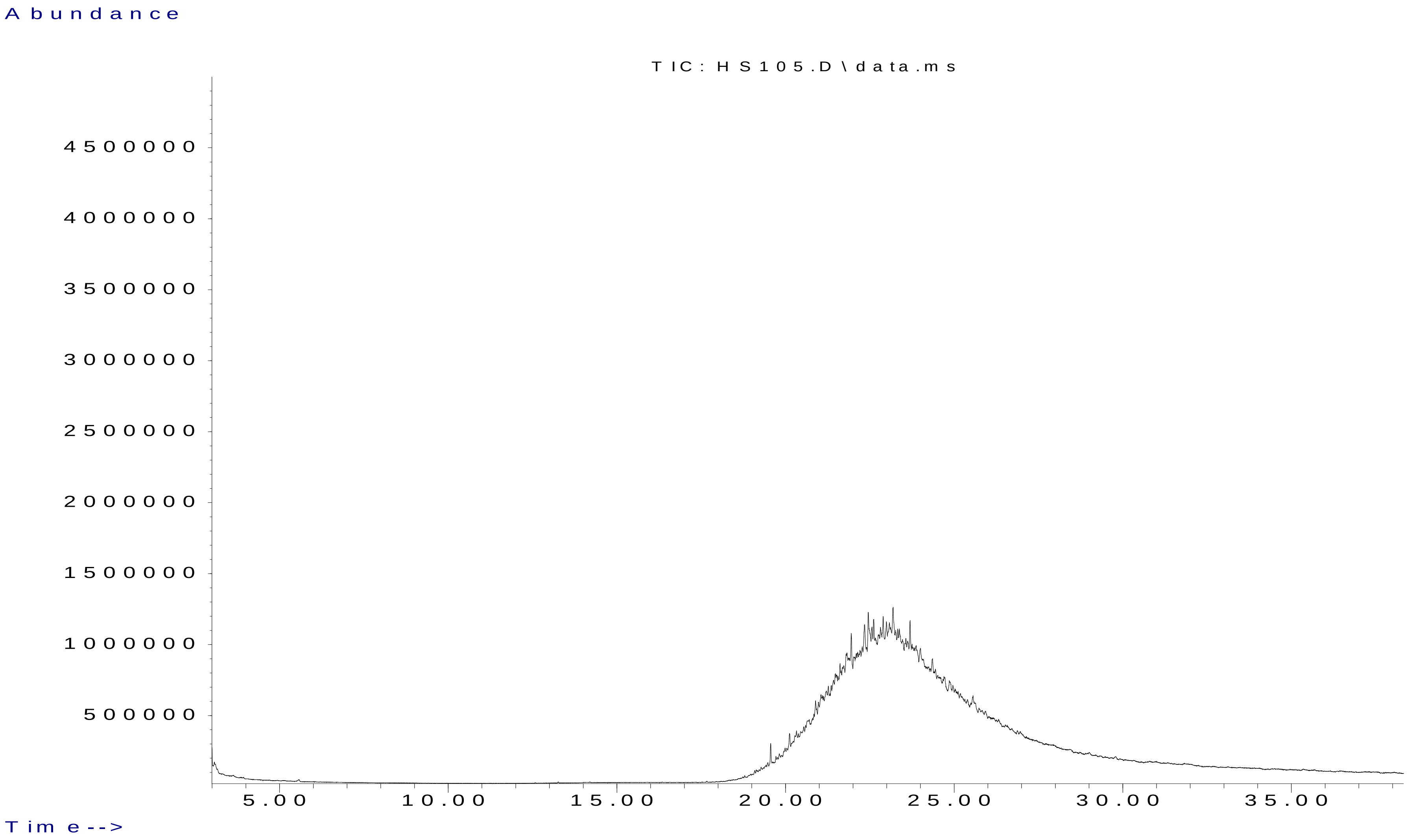


Figure C.6.43. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH for T.P.C. (100 m, 100 m) at depth (0.25 m), at contaminated site (Al-Magwa Area).

At Depth (0.5 m)

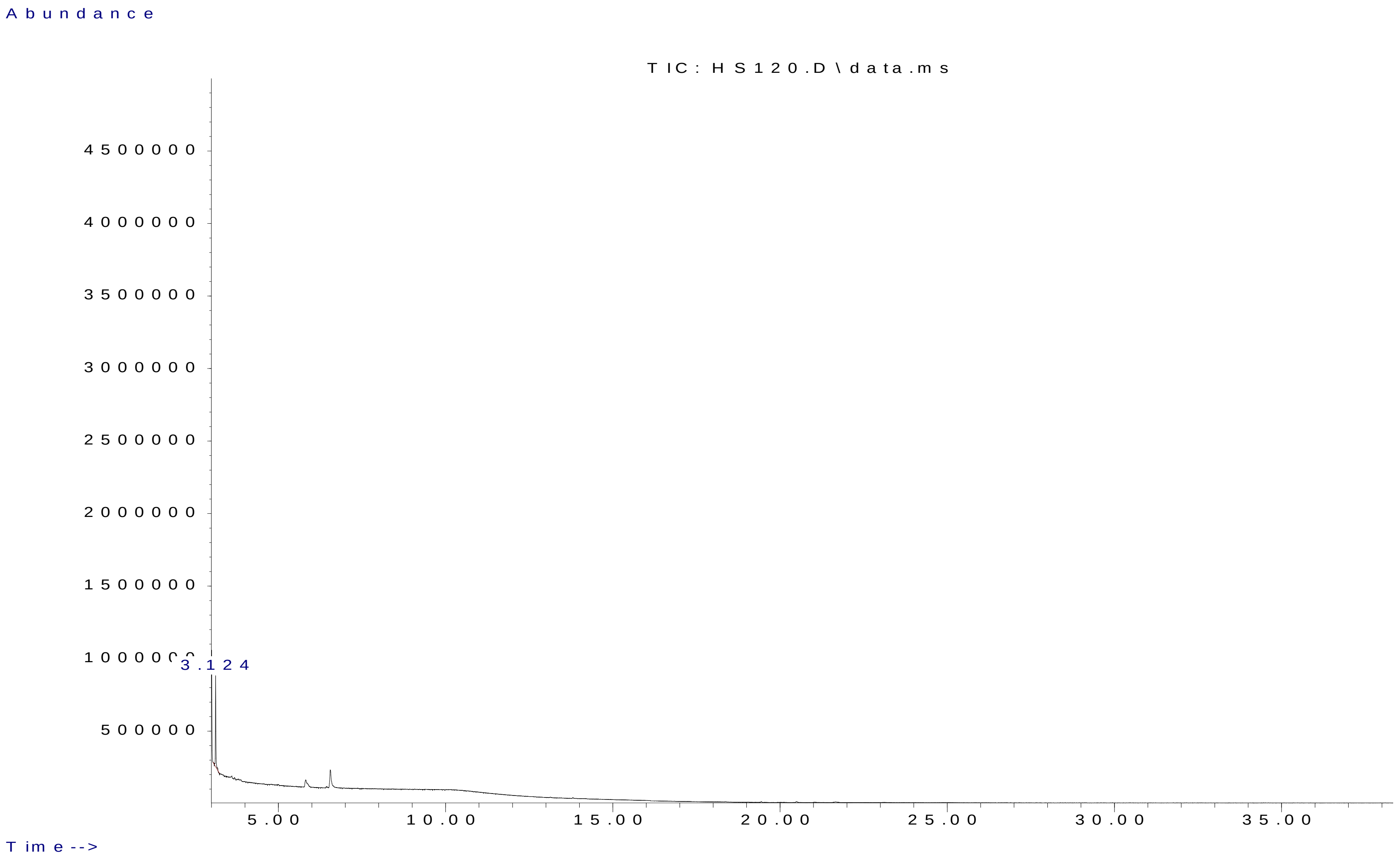


Figure C.6.44. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH for T.P.C. (0 m, 0 m) at depth (0.5 m), at contaminated site (Al-Magwa Area).

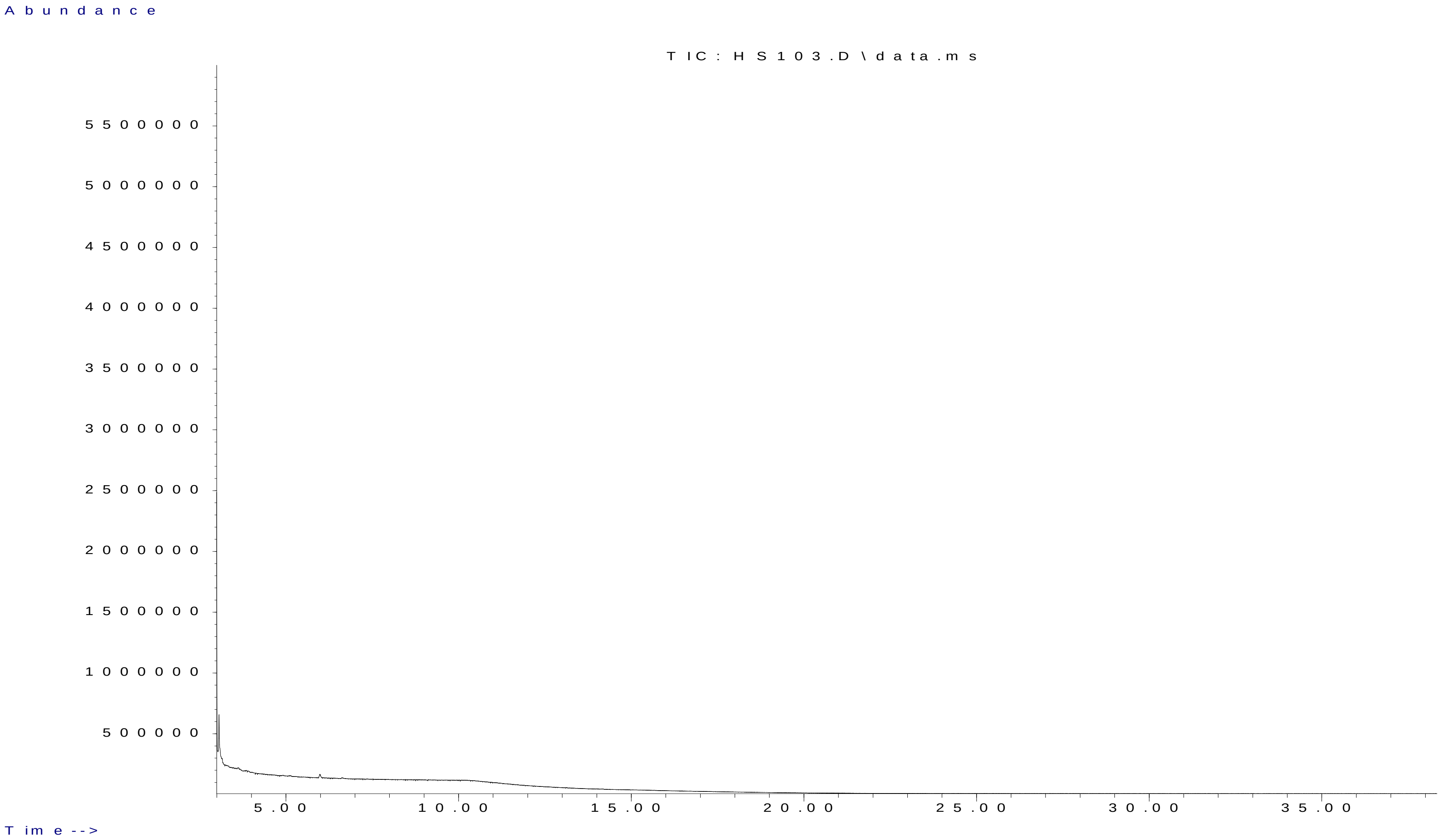


Figure C.6.45. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH for T.P.C. (25 m, 0 m) at depth (0.5 m), at contaminated site (Al-Magwa Area).

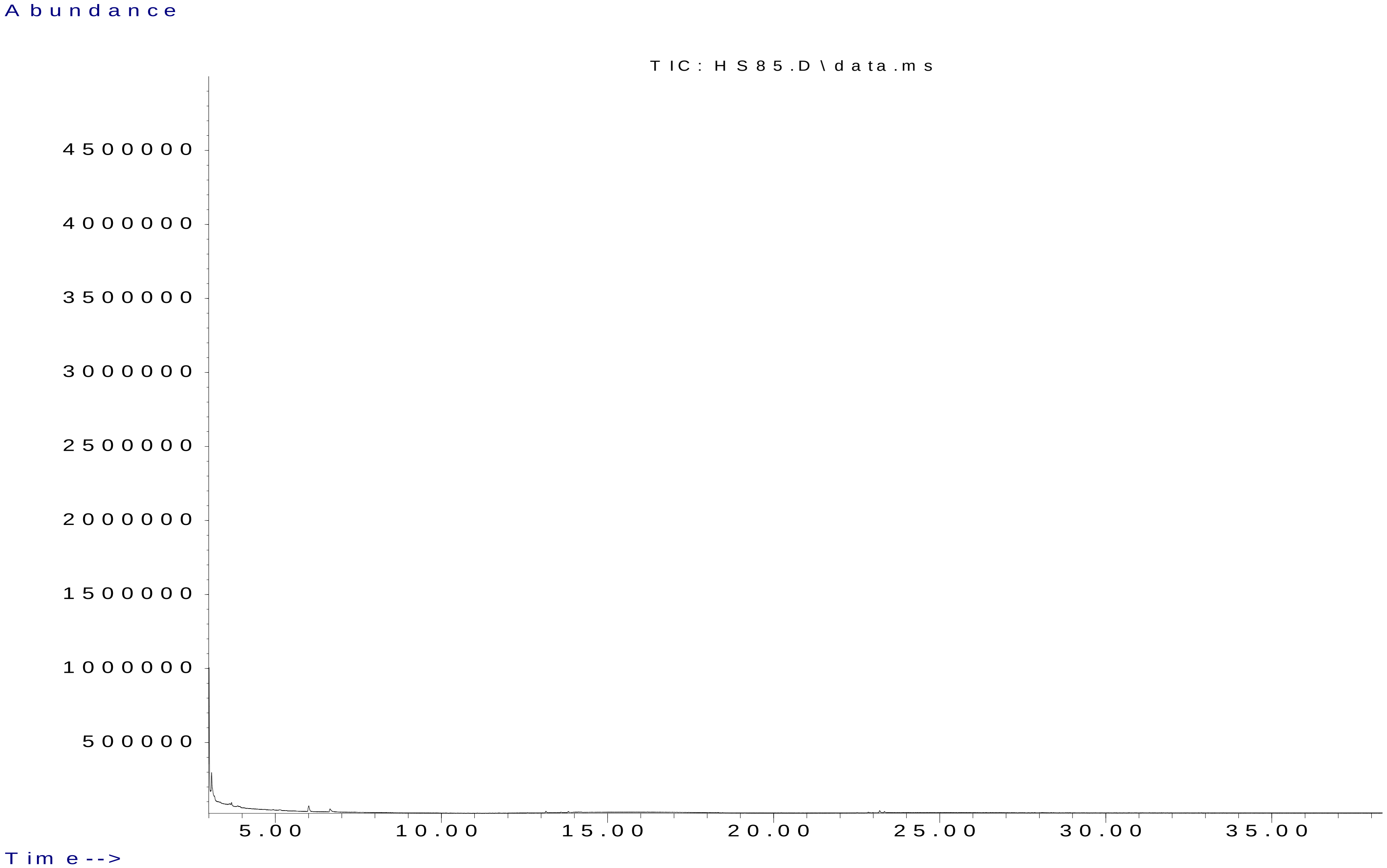


Figure C.6.46. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH for T.P.C. (50 m, 0 m) at depth (0.5 m), at contaminated site (Al-Magwa Area).

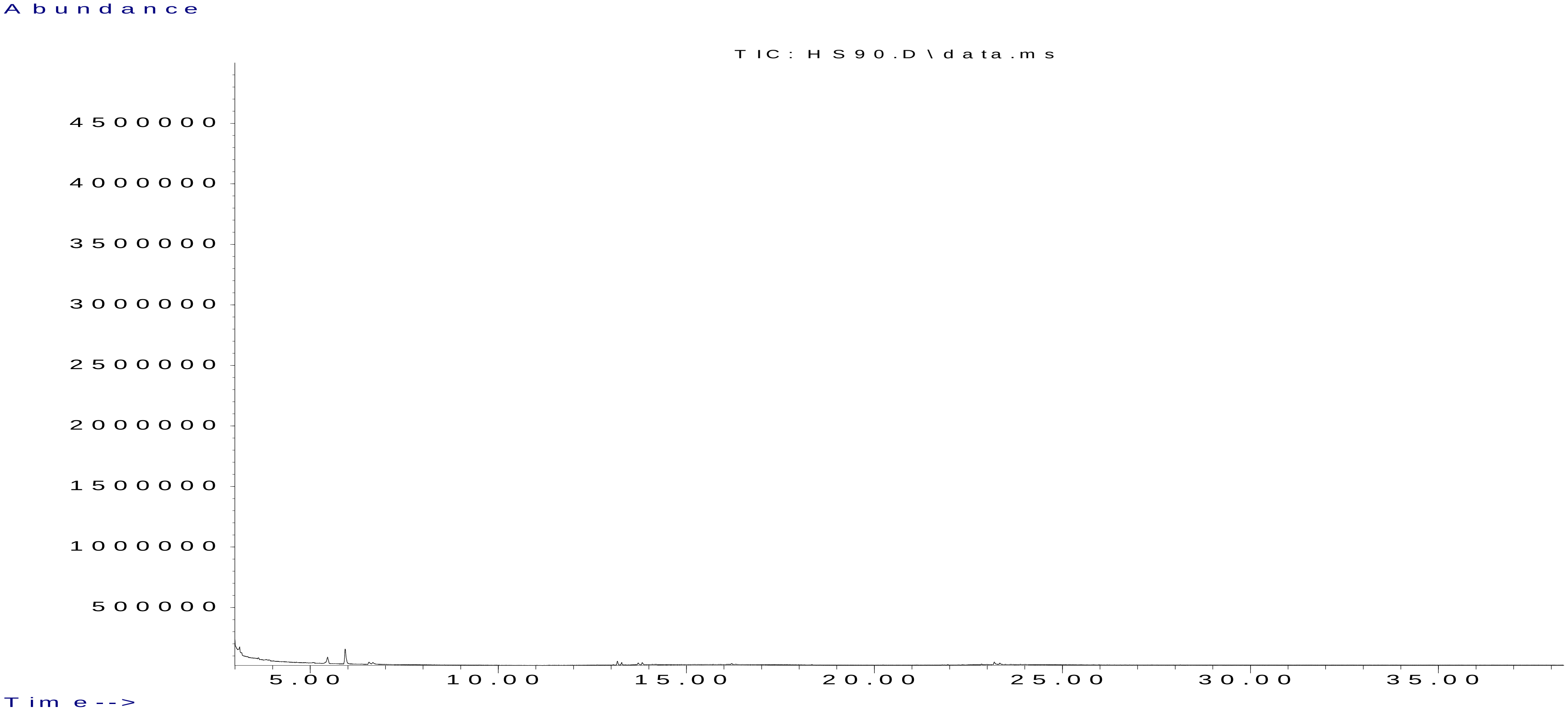


Figure C.6.47. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH for T.P.C. (100 m, 0 m) at depth (0.5 m), at contaminated site (Al-Magwa Area).

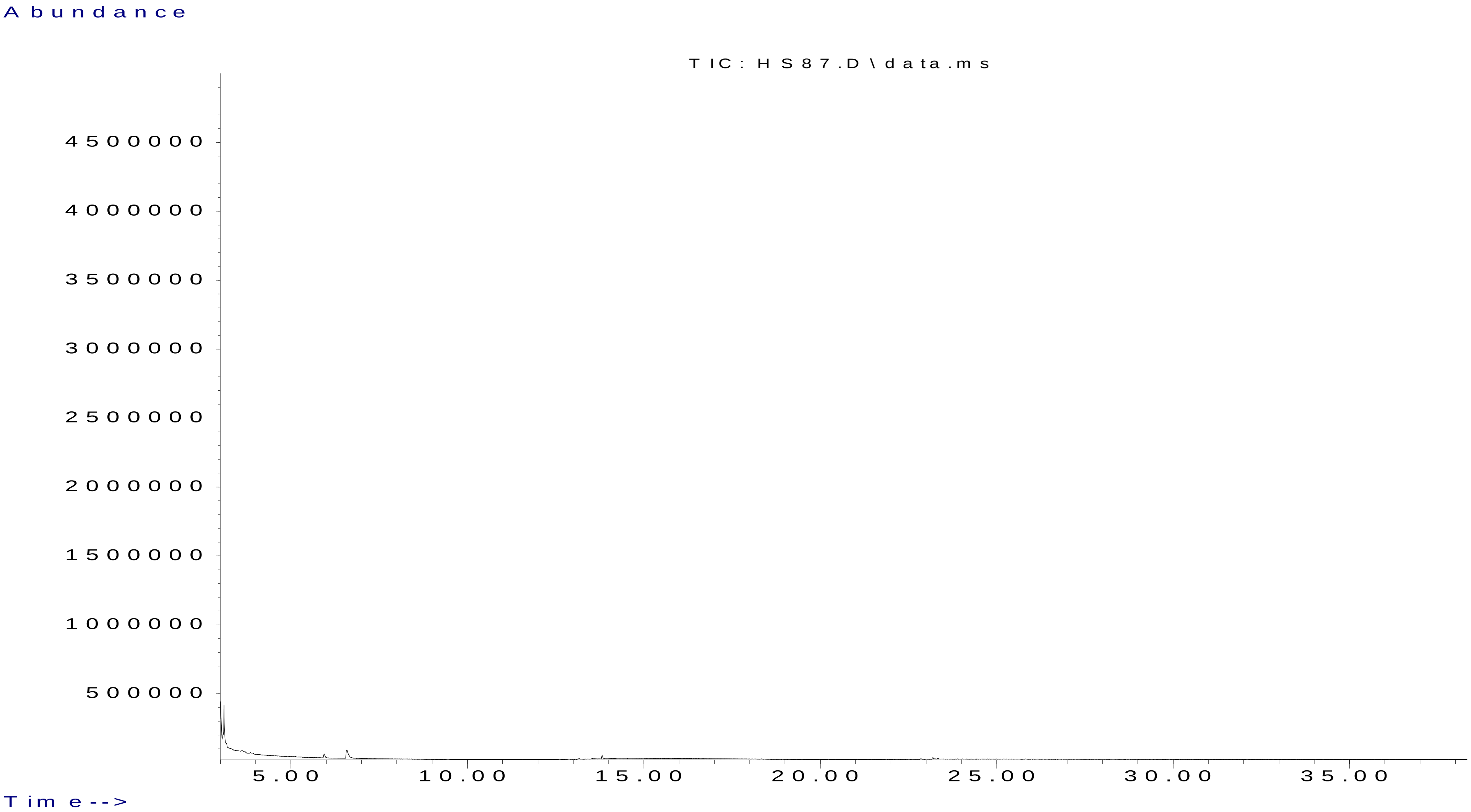


Figure C.6.48. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH for T.P.C. (0 m, 25 m) at depth (0.5 m), at contaminated site (Al-Magwa Area).

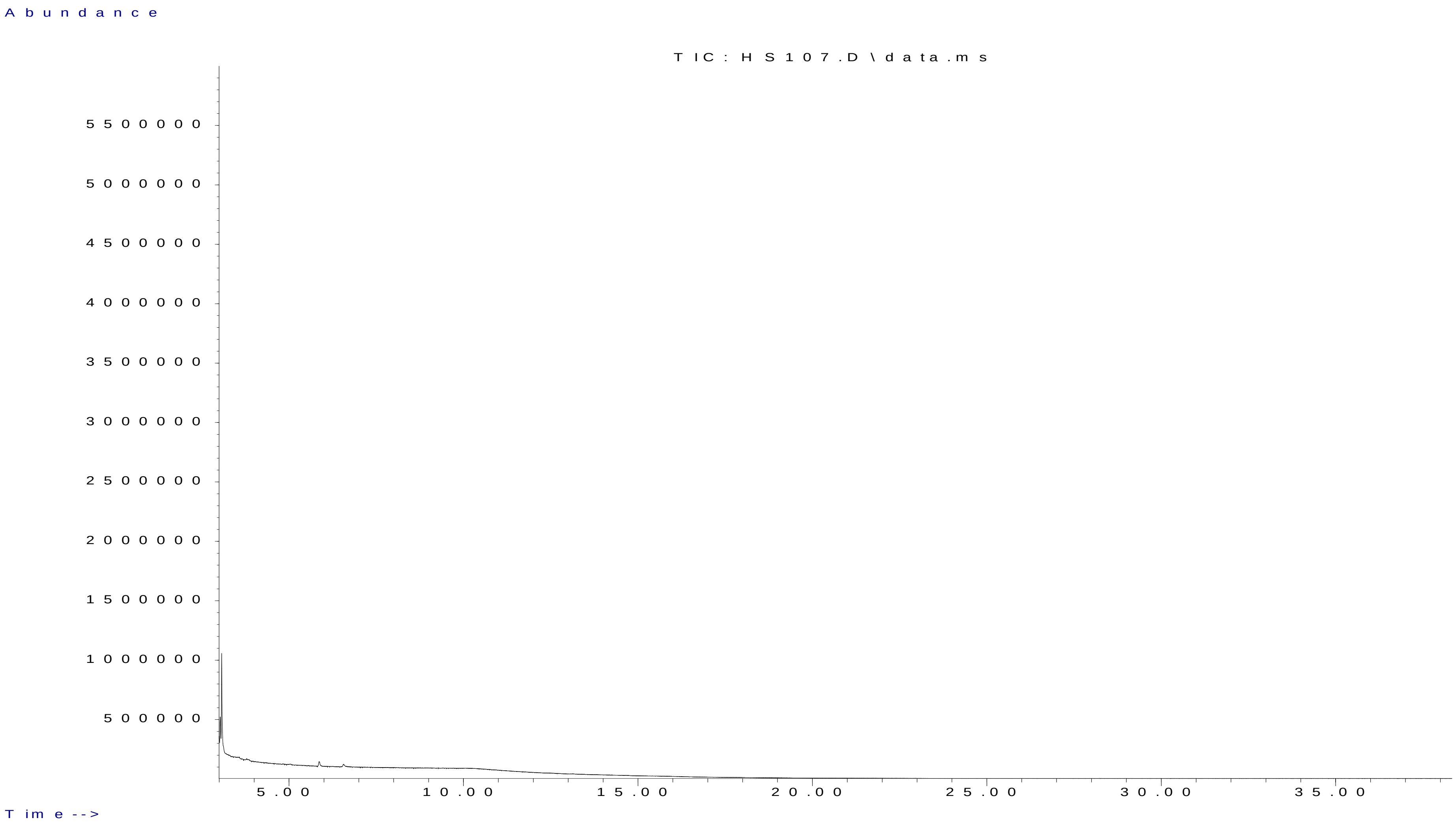


Figure C.6.49. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH for T.P.C. (25 m, 25 m) at depth (0.5 m), at contaminated site (Al-MAgwa Area).

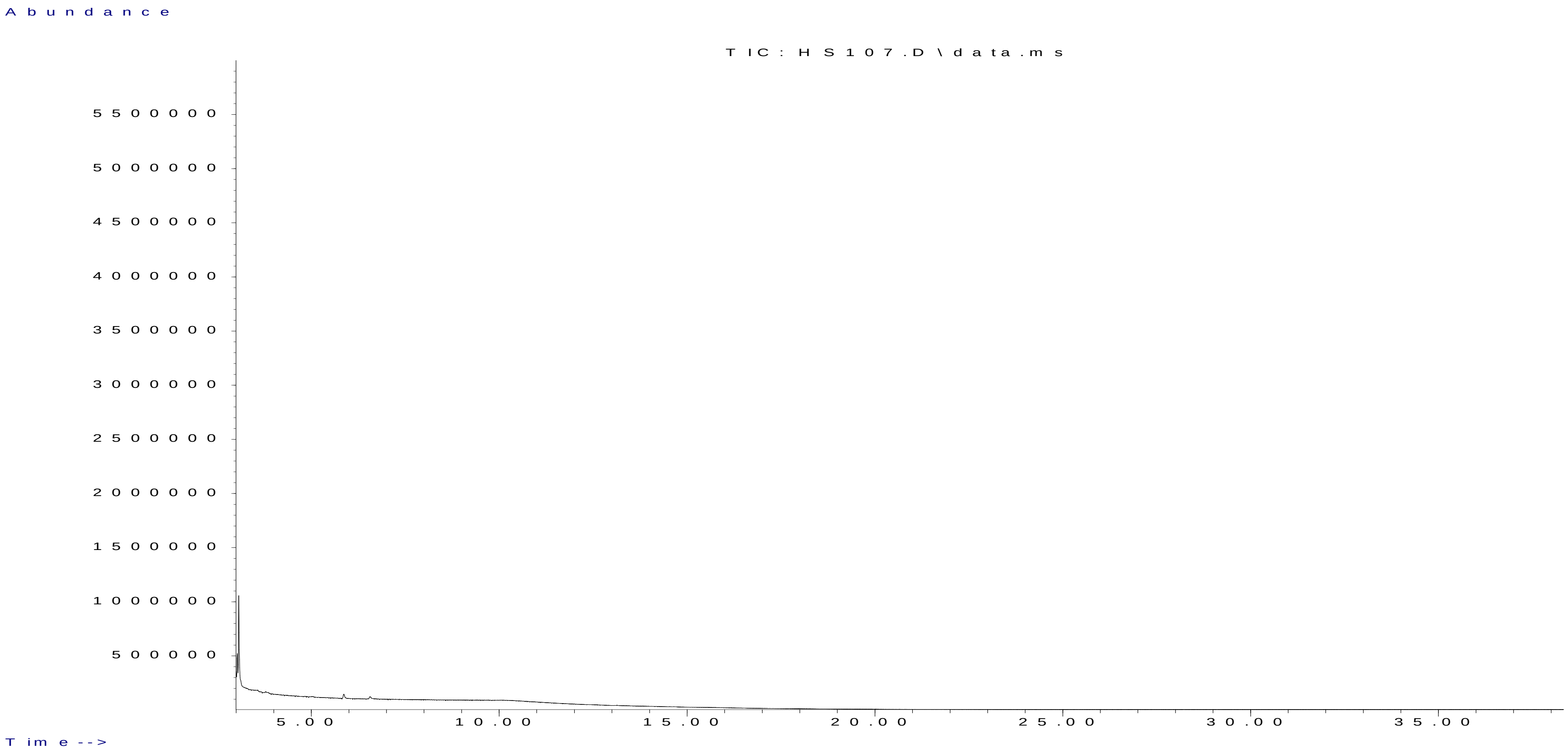


Figure C.6.50. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH for T.P.C. (50 m, 25 m) at depth (0.5 m), at contaminated site (Al-Magwa Area).

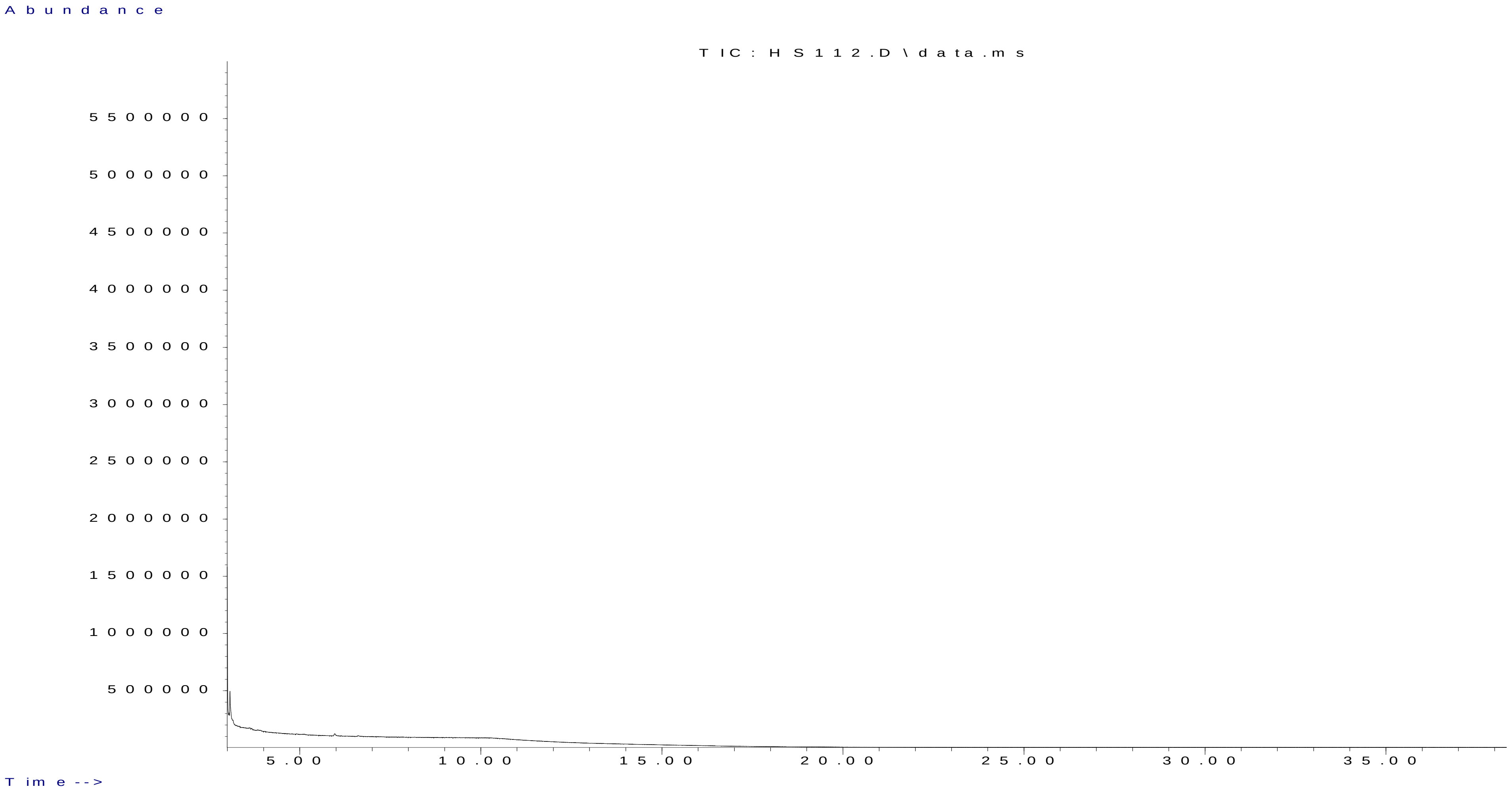


Figure C.6.51. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH for T.P.C. (100 m, 25 m) at depth (0.5 m), at contaminated site (Al-Magwa Area).

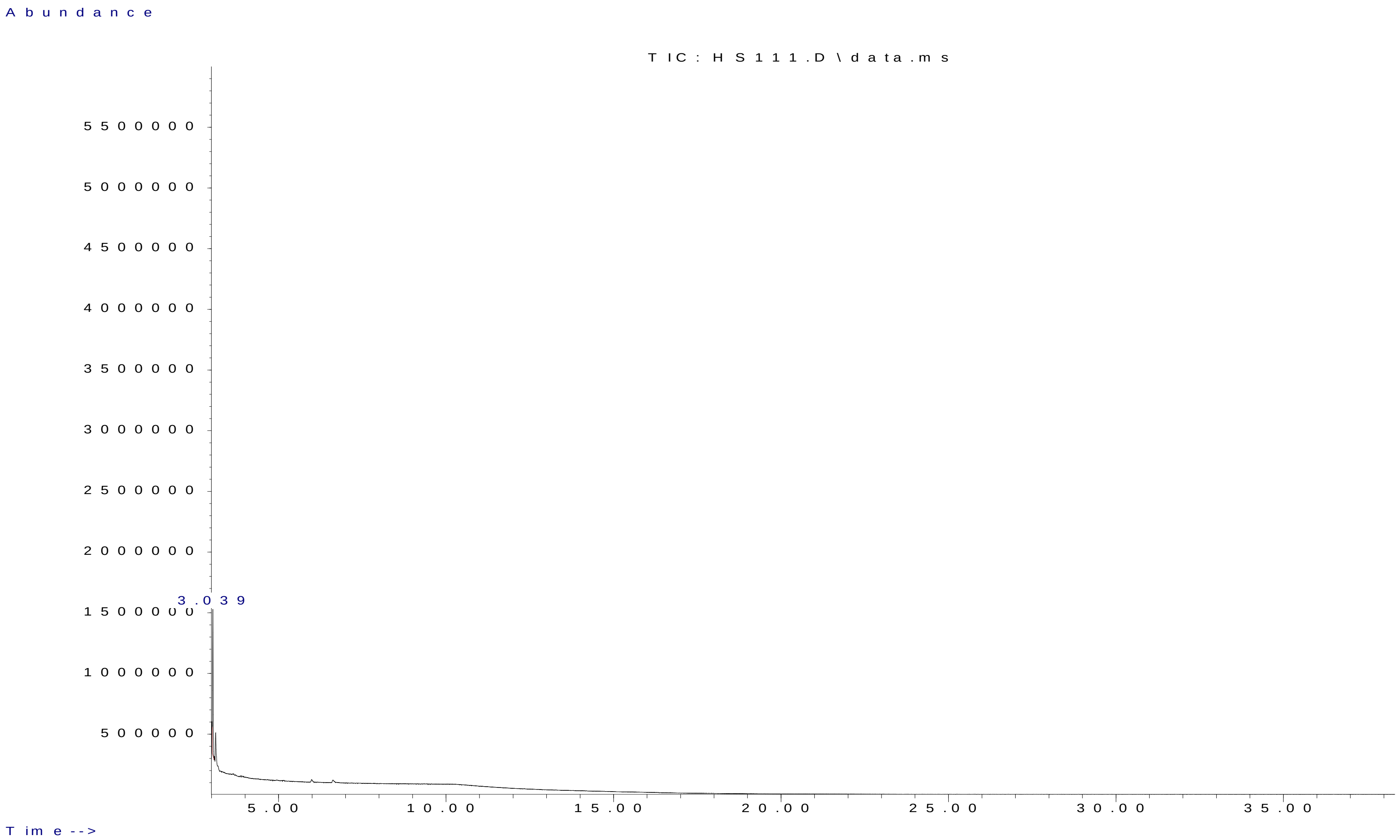


Figure C.6.52. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH for T.P.C. (0 m, 50 m) at depth (0.5 m), at contaminated site (Al-Magwa Area).

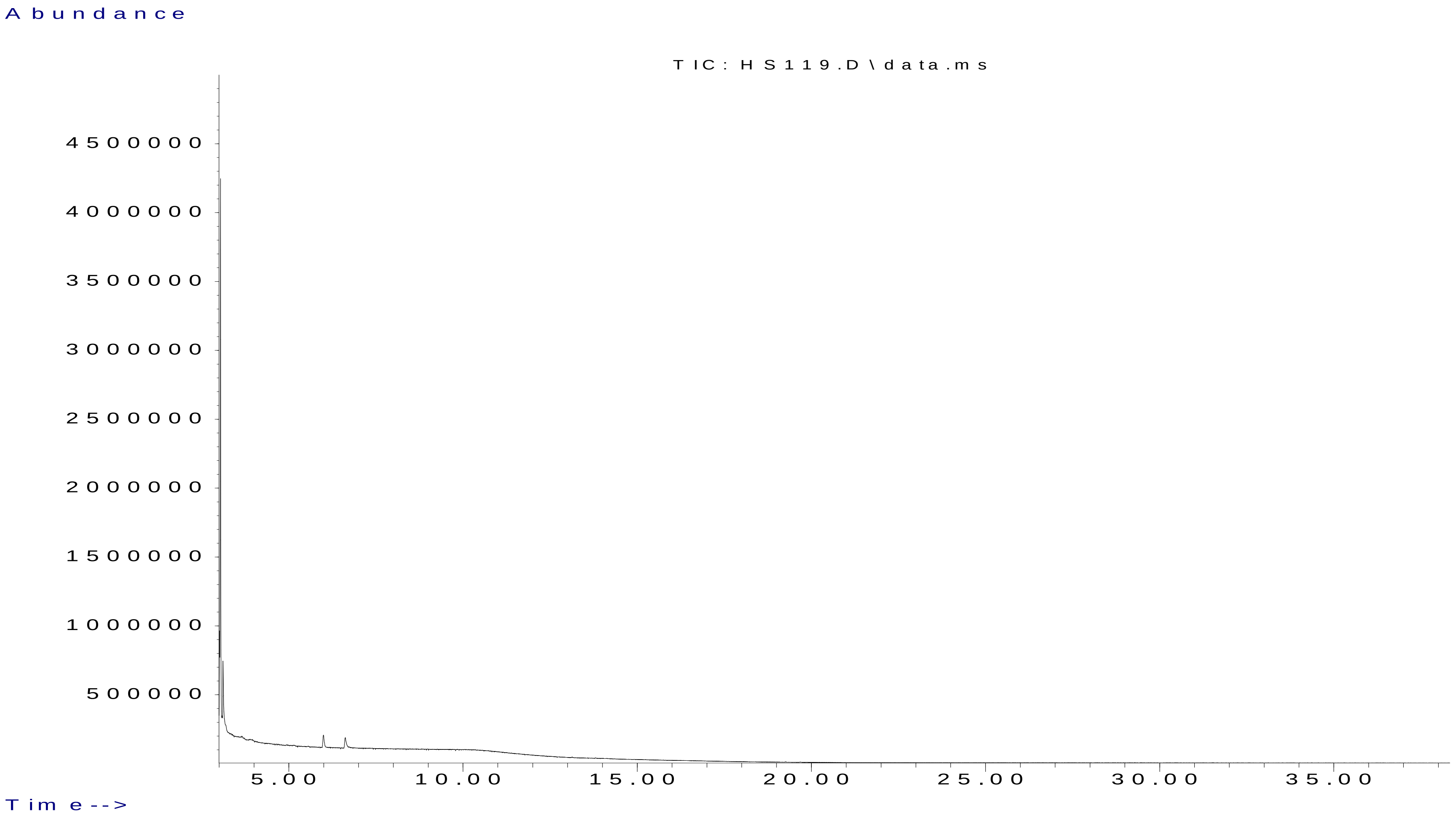


Figure C.6.53. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH for T.P.C. (25 m, 50 m) at depth (0.5 m), at contaminated site (Al-Magwa Area).

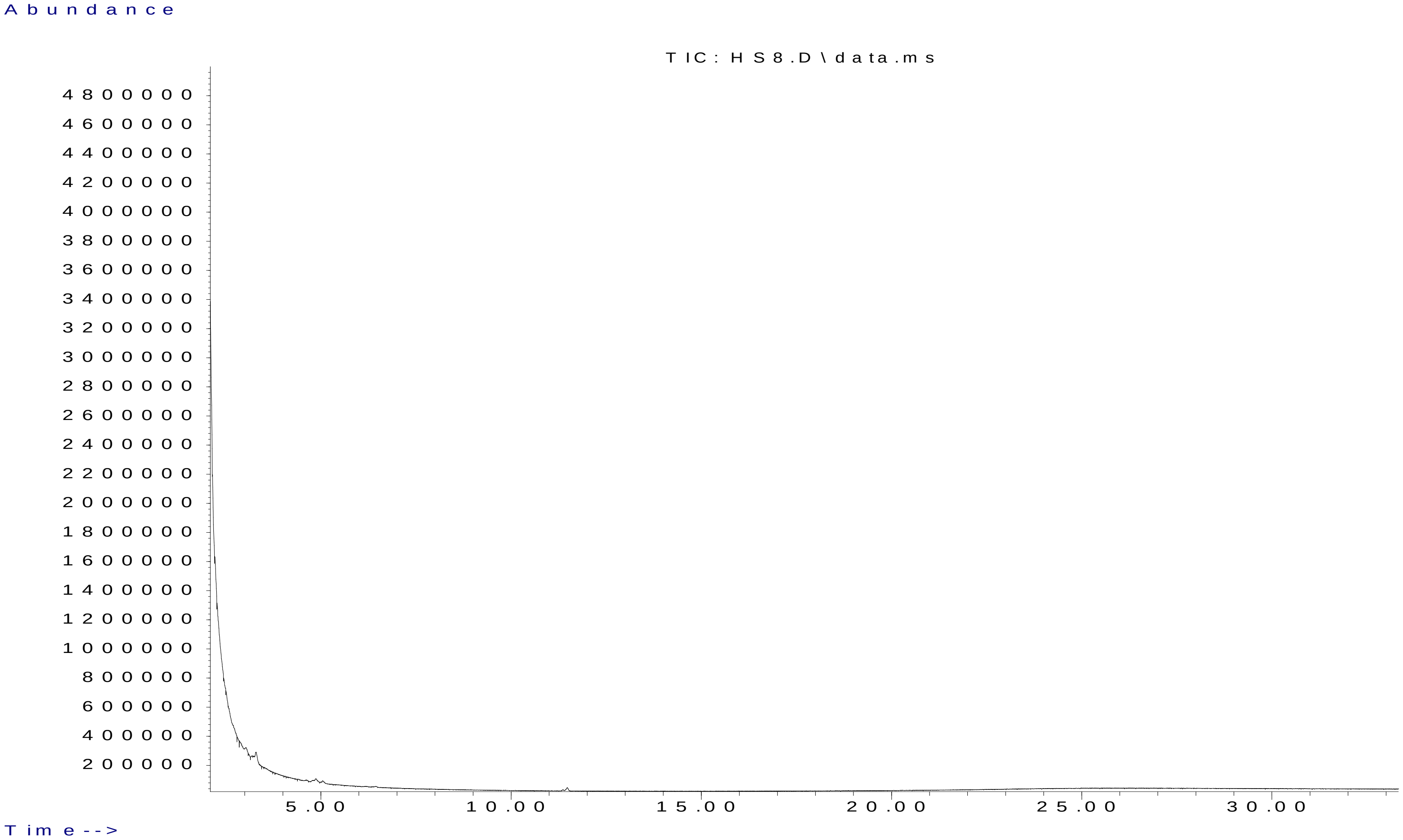


Figure C.6.54. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH for T.P.C. (50 m, 50 m) at depth (0.5 m), at contaminated site (Al-Magwa Area).

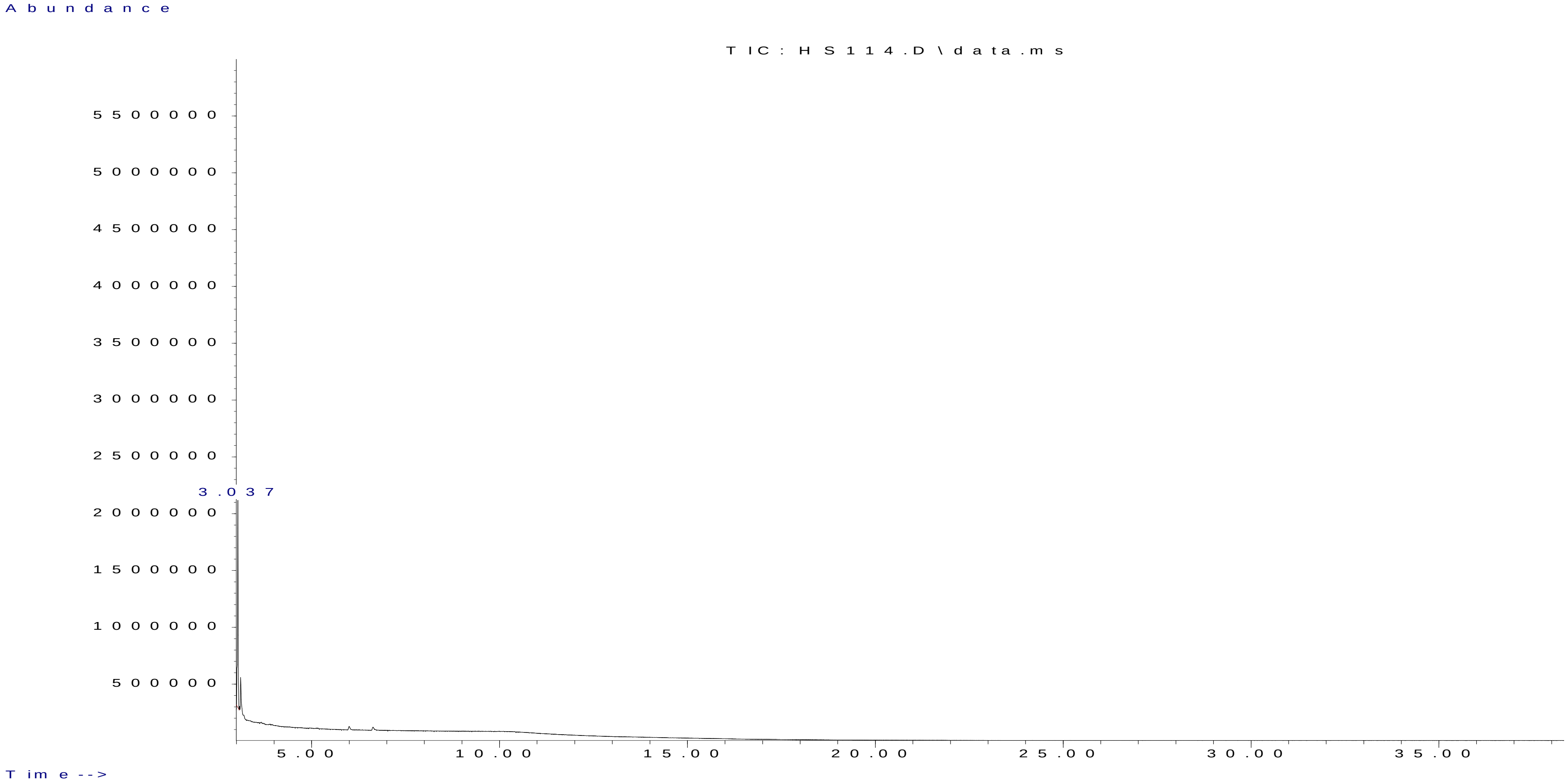


Figure C.6.55. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH for T.P.C. (100 m, 50 m) at depth (0.5 m), at contaminated site (Al-Magwa Area).

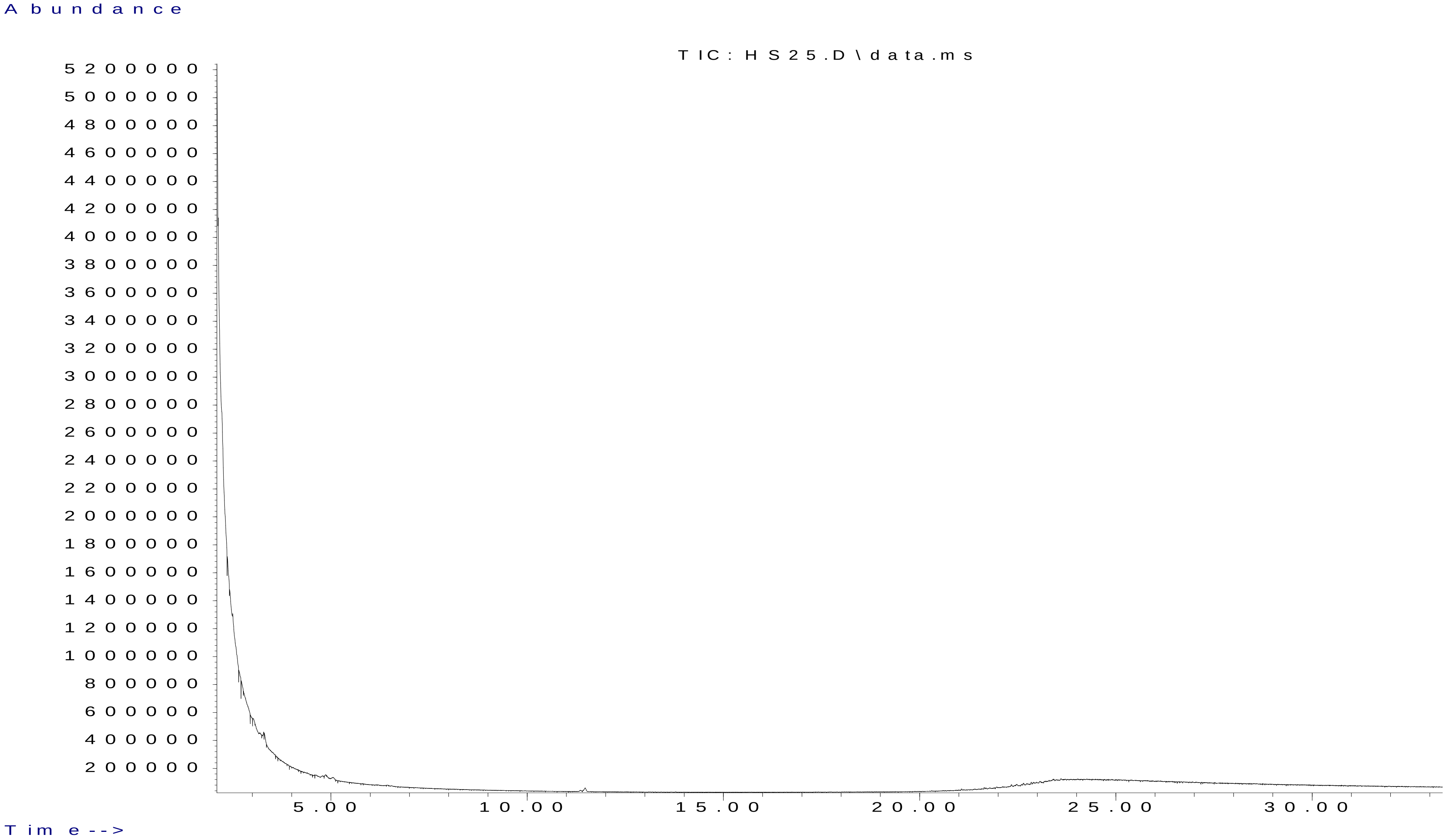


Figure C.6.56. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH for T.P.C. (0 m, 75 m) at depth (0.5 m), at contaminated site (Al-Magwa Area).

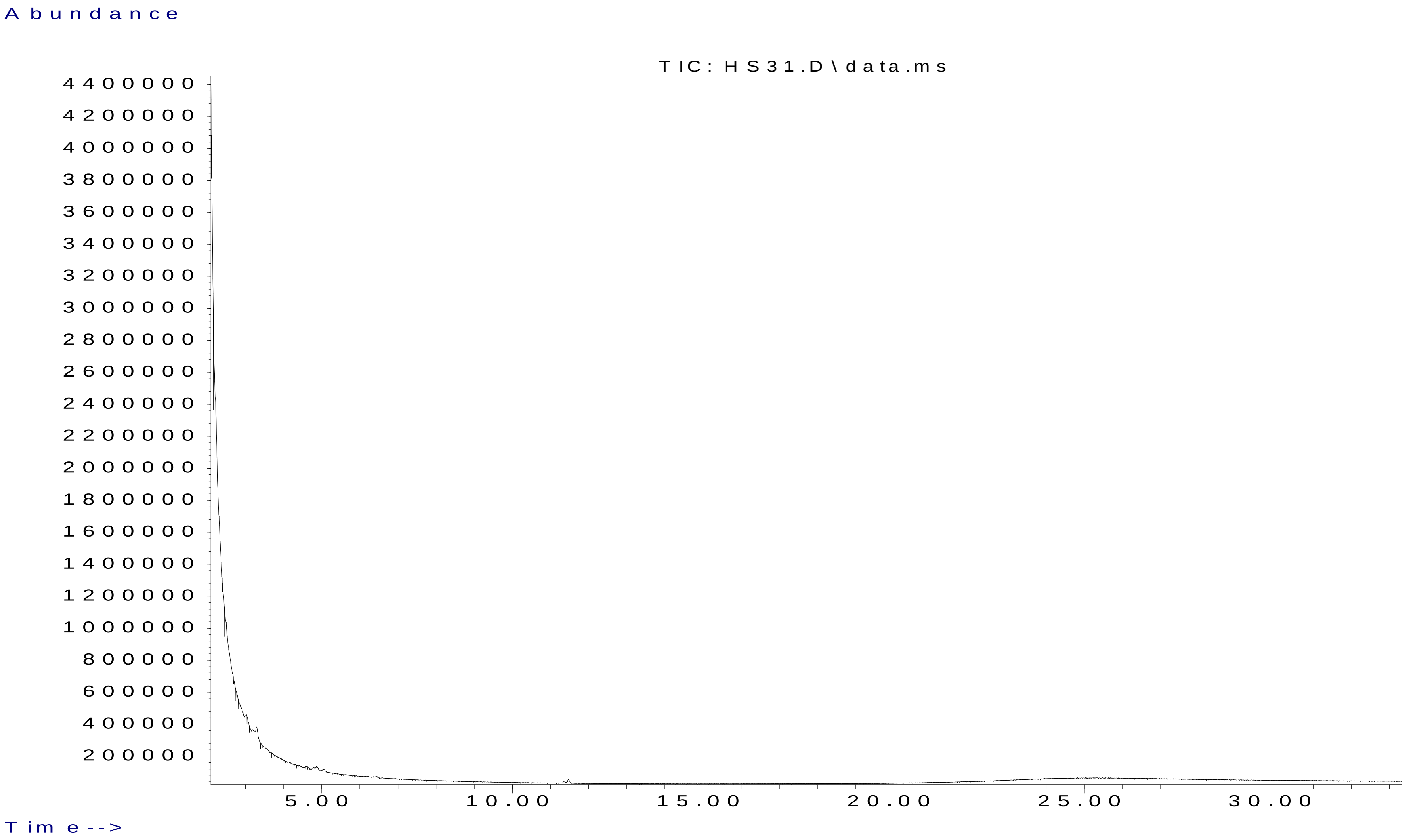


Figure C.6.57. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH for T.P.C. (25 m, 75 m) at depth (0.5 m), at contaminated site (Al-Magwa Area).

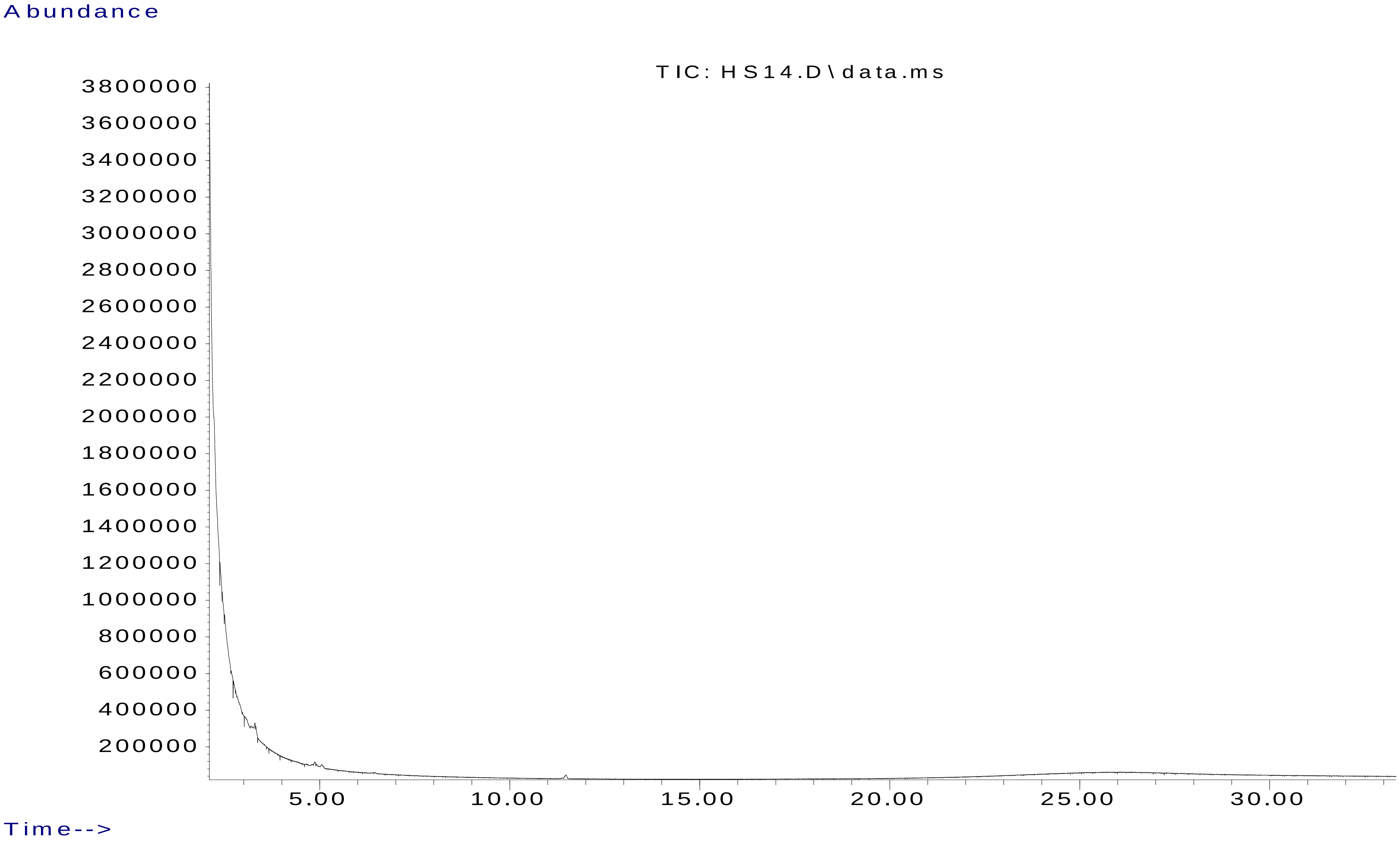


Figure C.6.58. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH for T.P.C. (50 m, 75 m) at depth (0.5 m), at contaminated site (Al-Magwa Area).

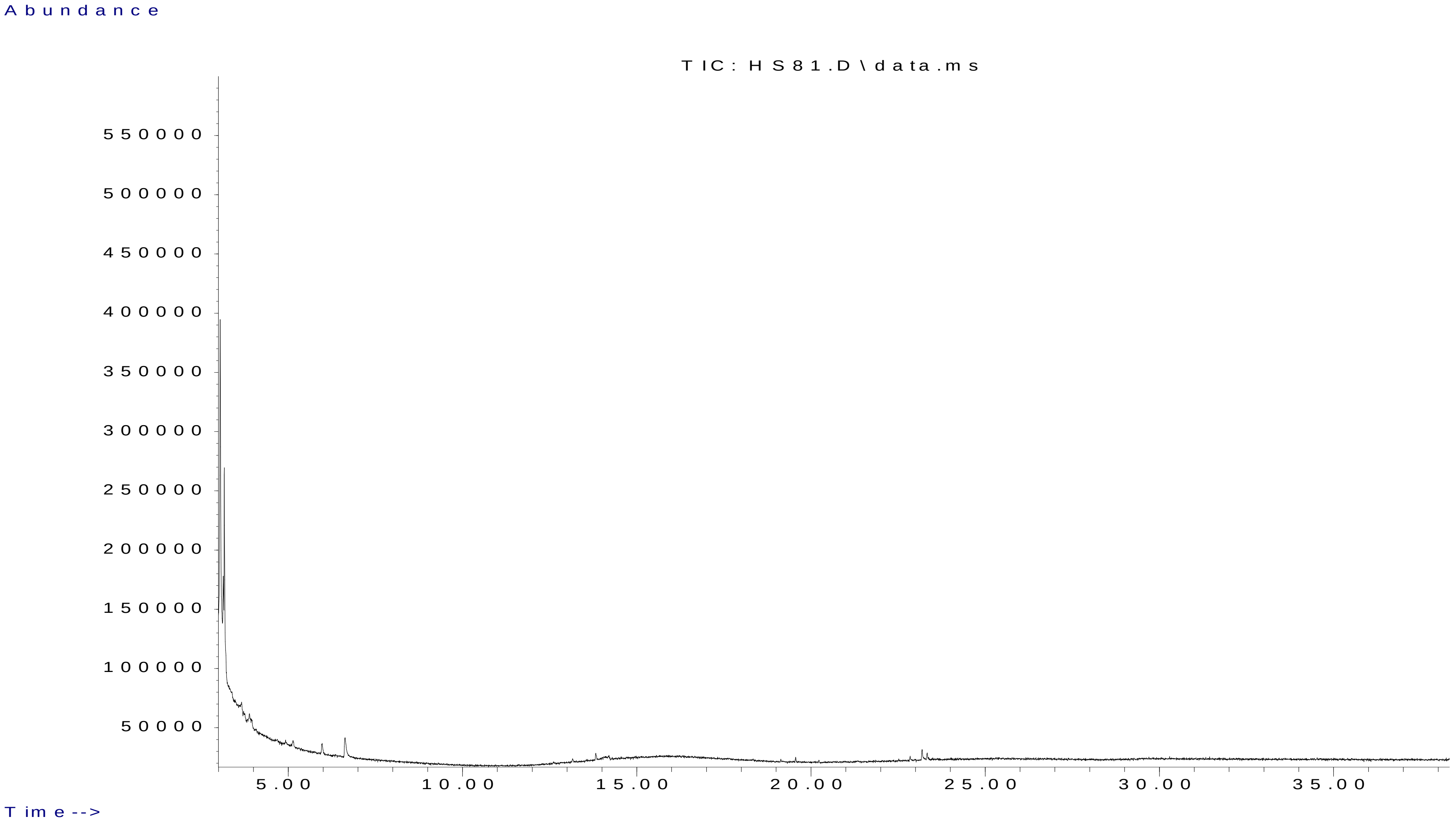


Figure C.6.59. Shows the c Total Ion Chromatograms (TIC) for not detected soil sample with TPH for T.P.C. (75 m, 75 m) at depth (0.5 m), at contaminated site (Al-Magwa Area).

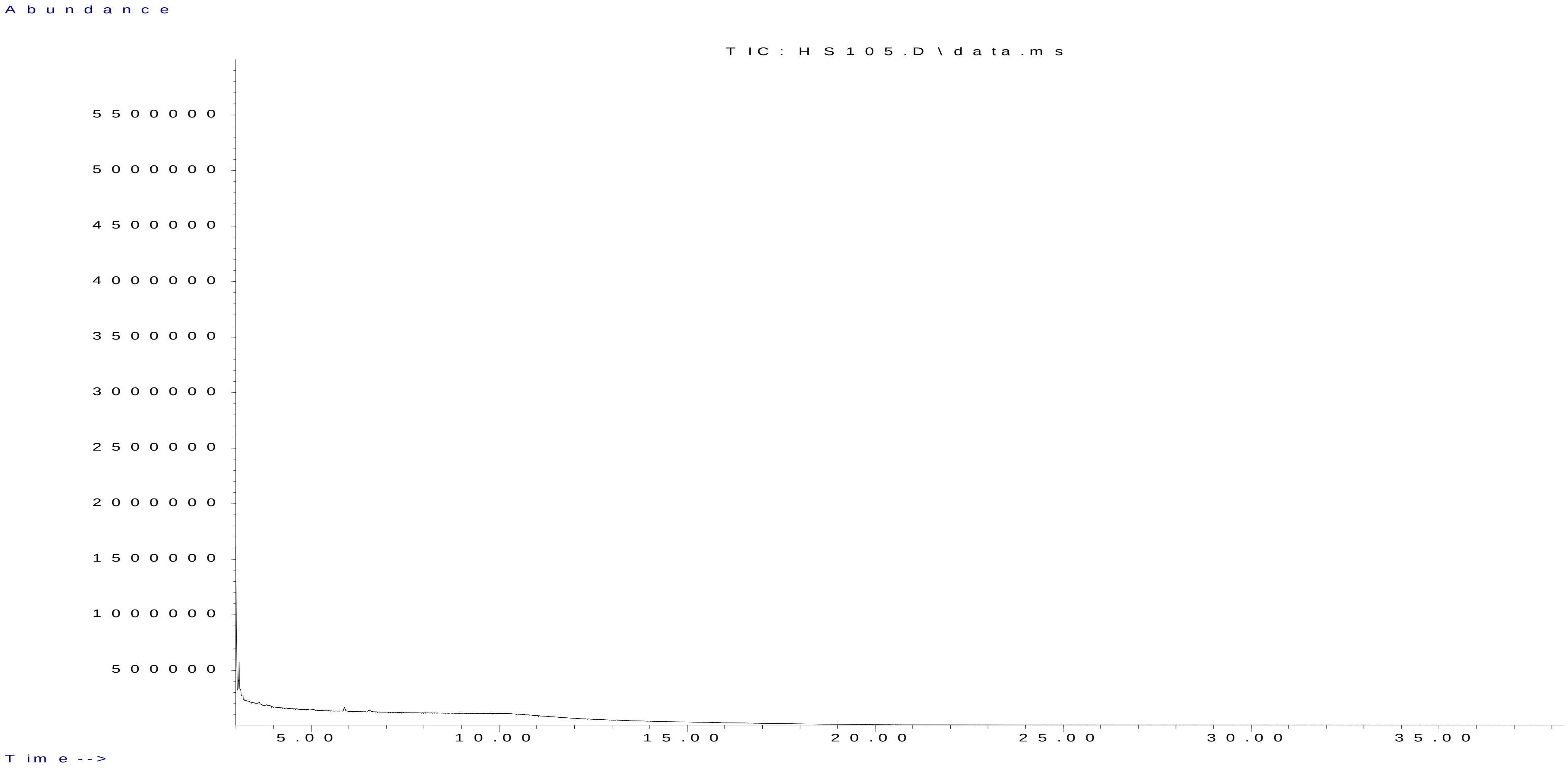


Figure C.6.60. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH for T.P.C. (100 m, 75 m) at depth (0.5 m), at contaminated site (Al-Magwa Area).

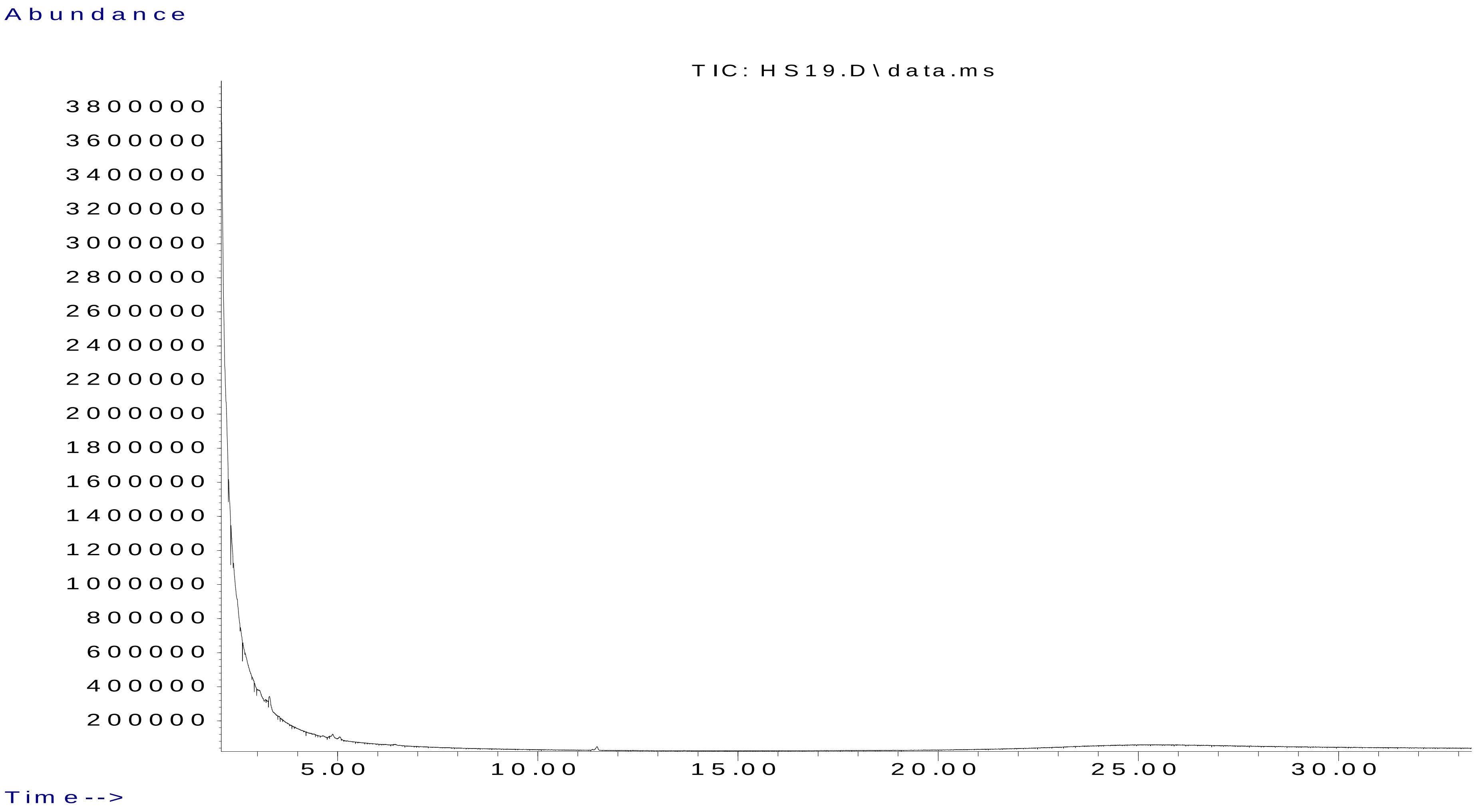


Figure C.6.61. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH for T.P.C. (0 m, 100 m) at depth (0.5 m), at contaminated site (Al-Magwa Area).

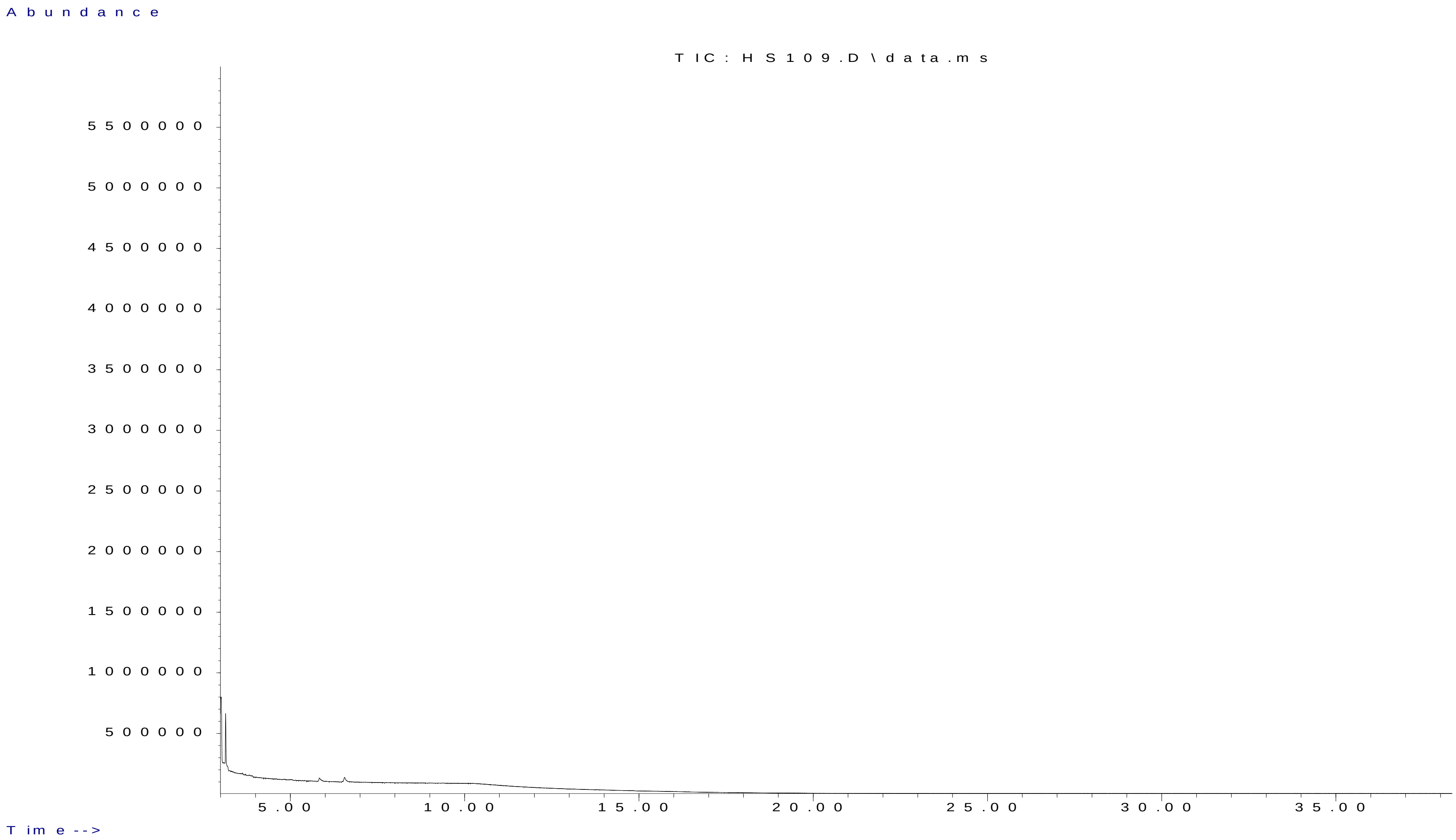


Figure C.6.62. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH for T.P.C. (50 m, 100 m) at depth (0.5 m), at contaminated site (Al-Magwa Area).

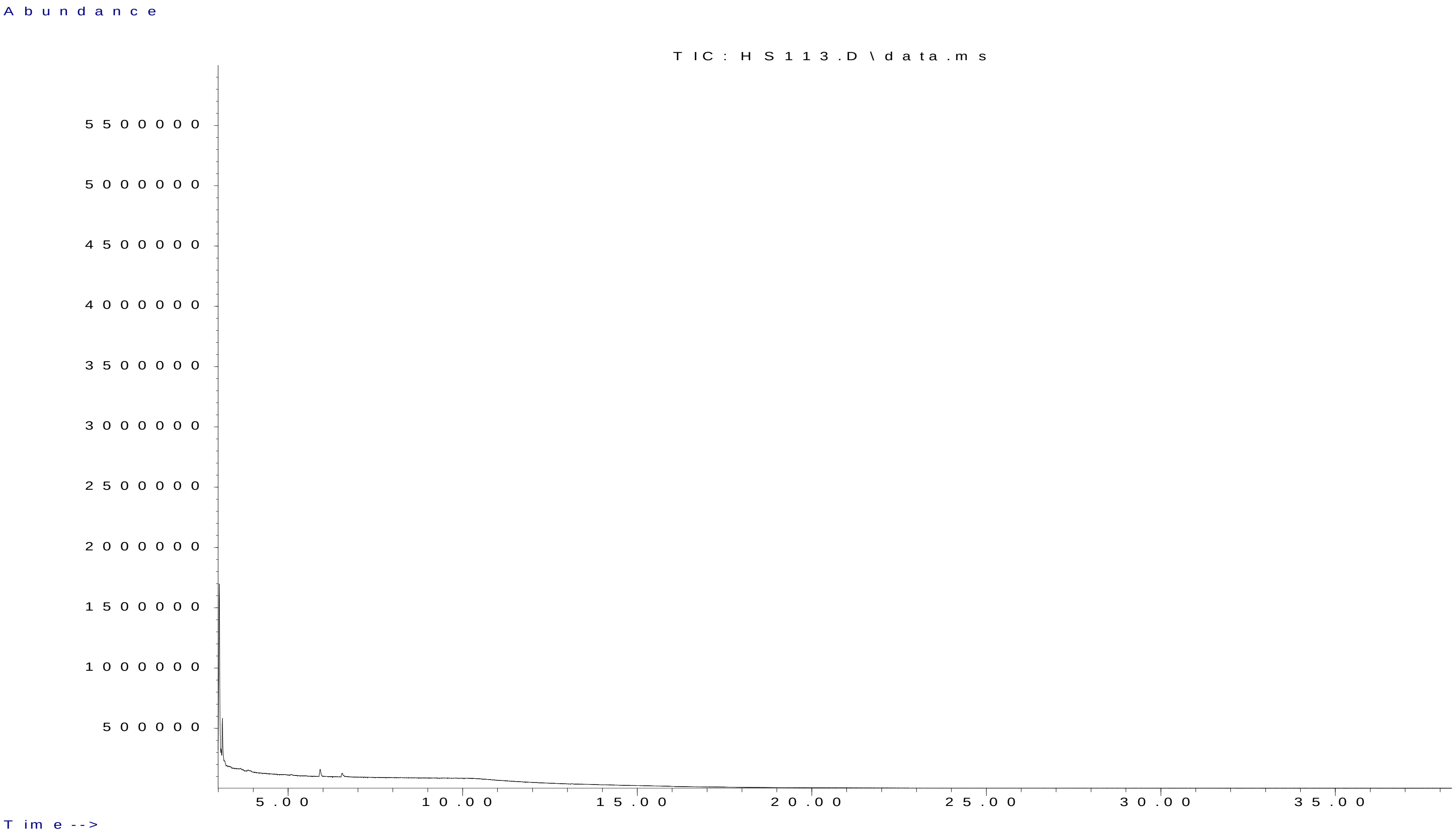


Figure C.6.63. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH for T.P.C. (75 m, 100 m) at depth (0.5 m), at contaminated site (Al-Magwa Area).

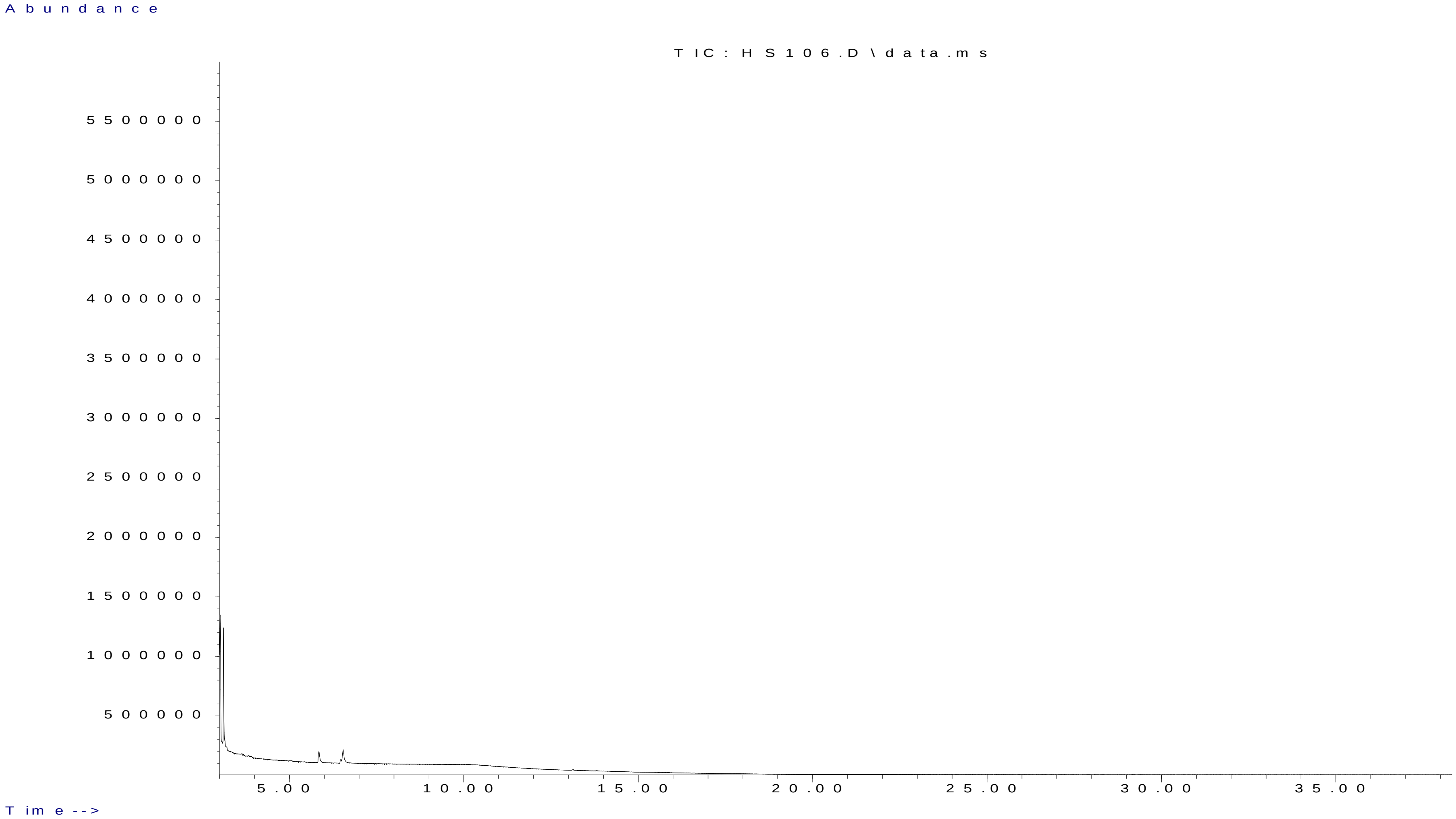


Figure C.6.64. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH for T.P.C. (100 m, 100 m) at depth (0.5 m), at contaminated site (Al-Magwa Area).

At Depth (1.0 m)

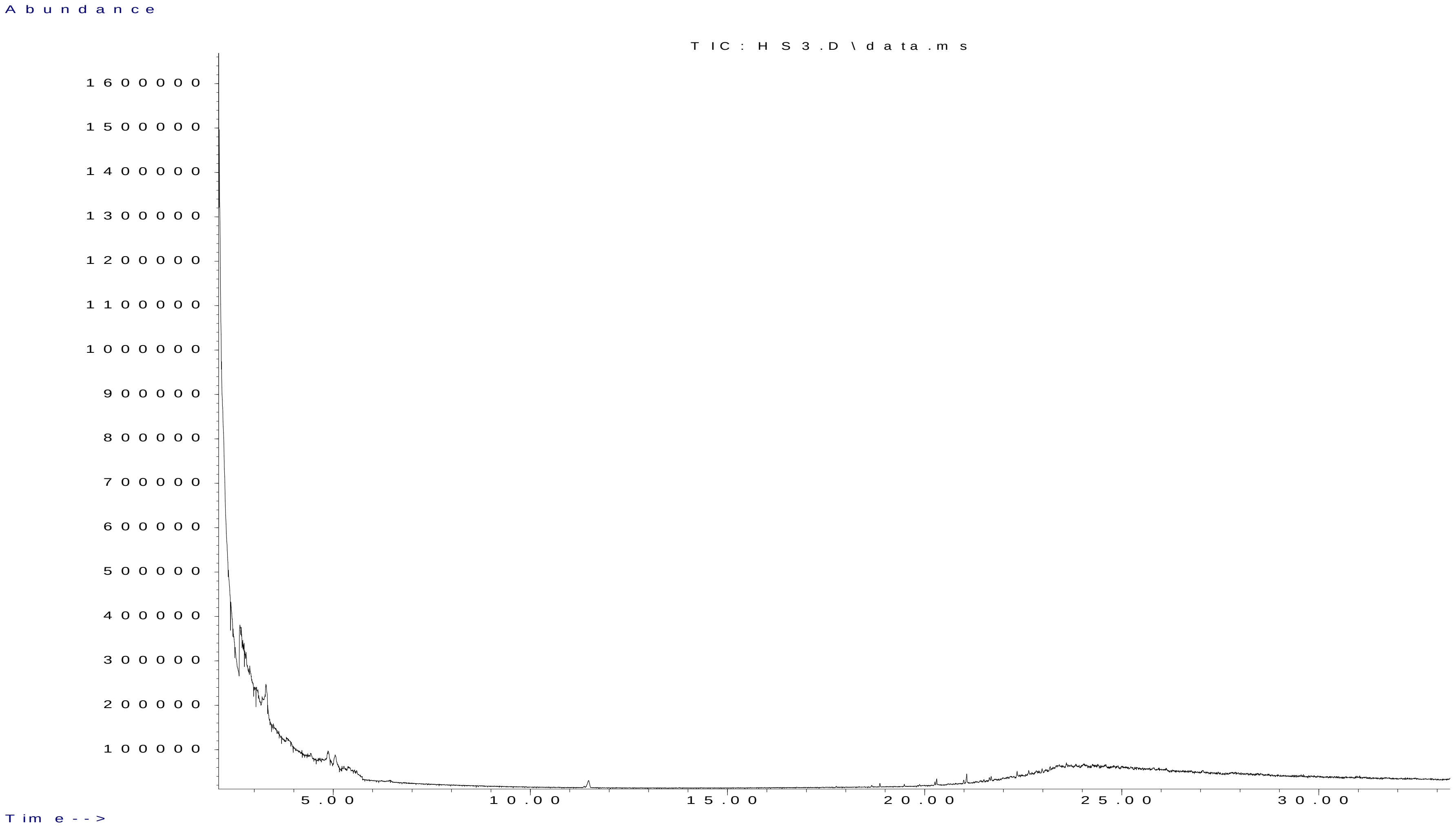


Figure C.6.65. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH for T.P.C. (0 m, 0 m) at depth (1.0 m), at contaminated site (Al-Magwa Area).

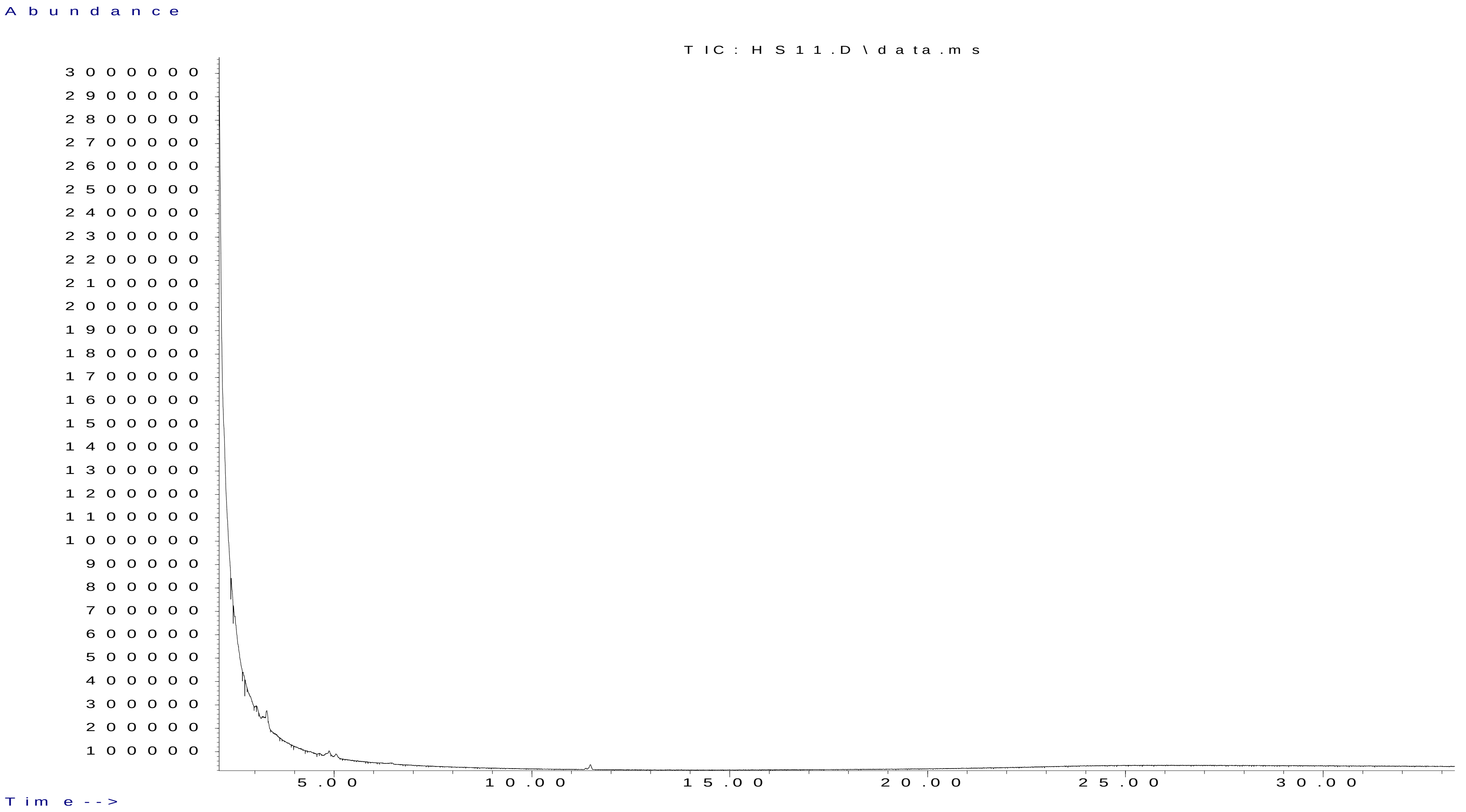


Figure C.6.66. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH sample for T.P.C. (25 m, 0 m) at depth (1.0 m), at contaminated site (Al-Magwa Area).

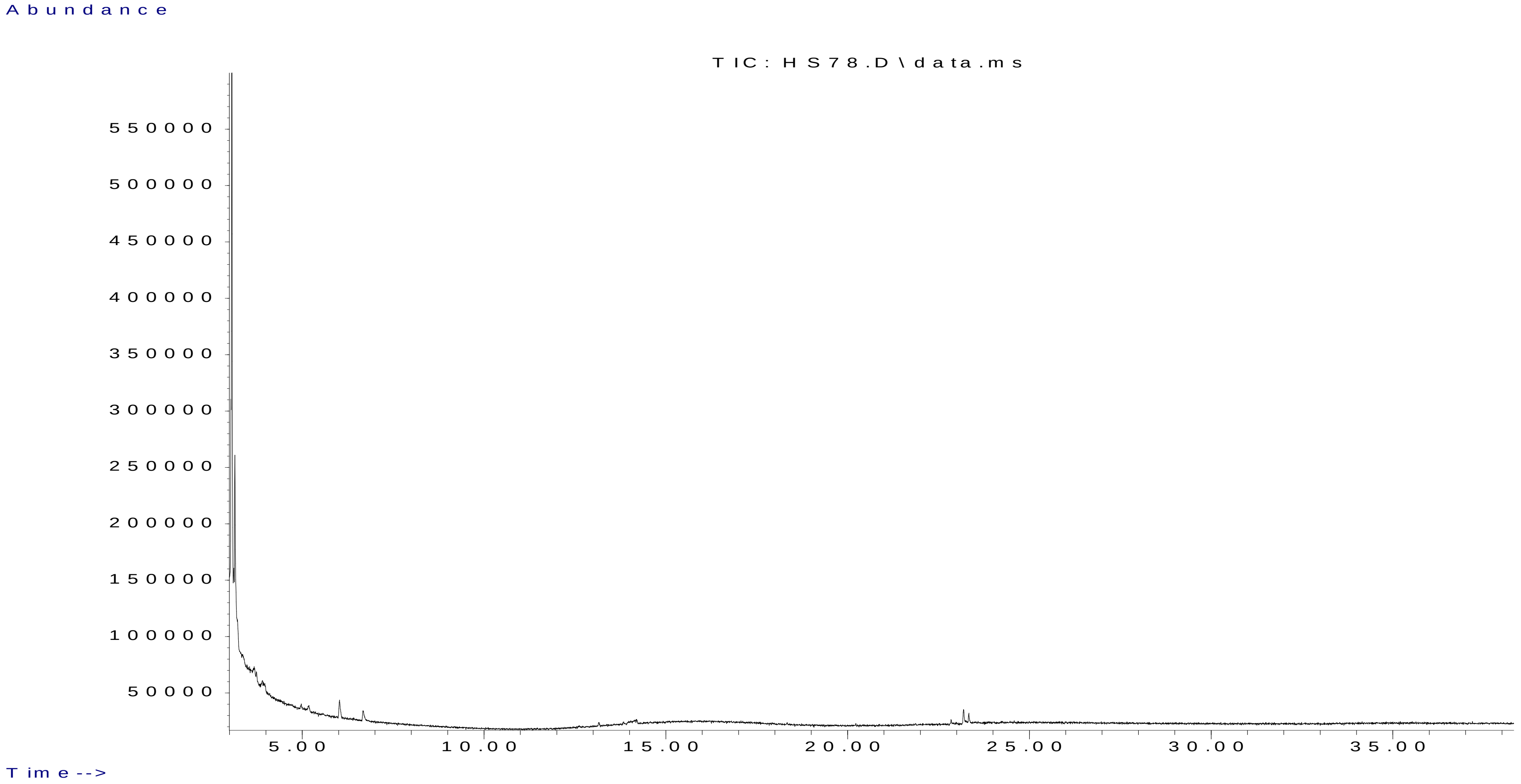


Figure C.6.67. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH sample for T.P.C. (50 m, 0 m) at depth (1.0 m), at contaminated site (Al-Magwa Area).

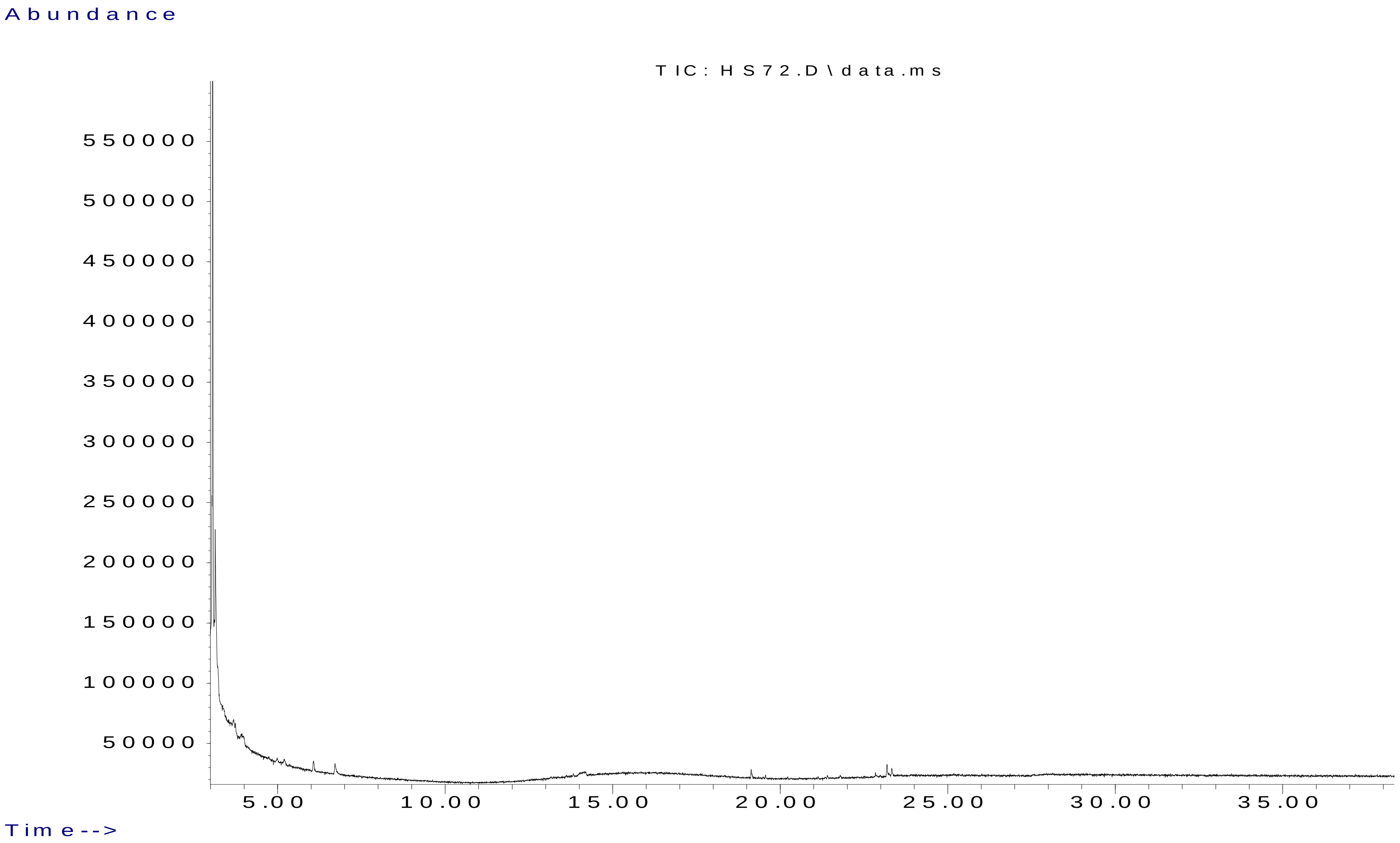


Figure C.6.68. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH sample for T.P.C. (75 m, 0 m) at depth (1.0 m), at contaminated site (Al-Magwa Area).

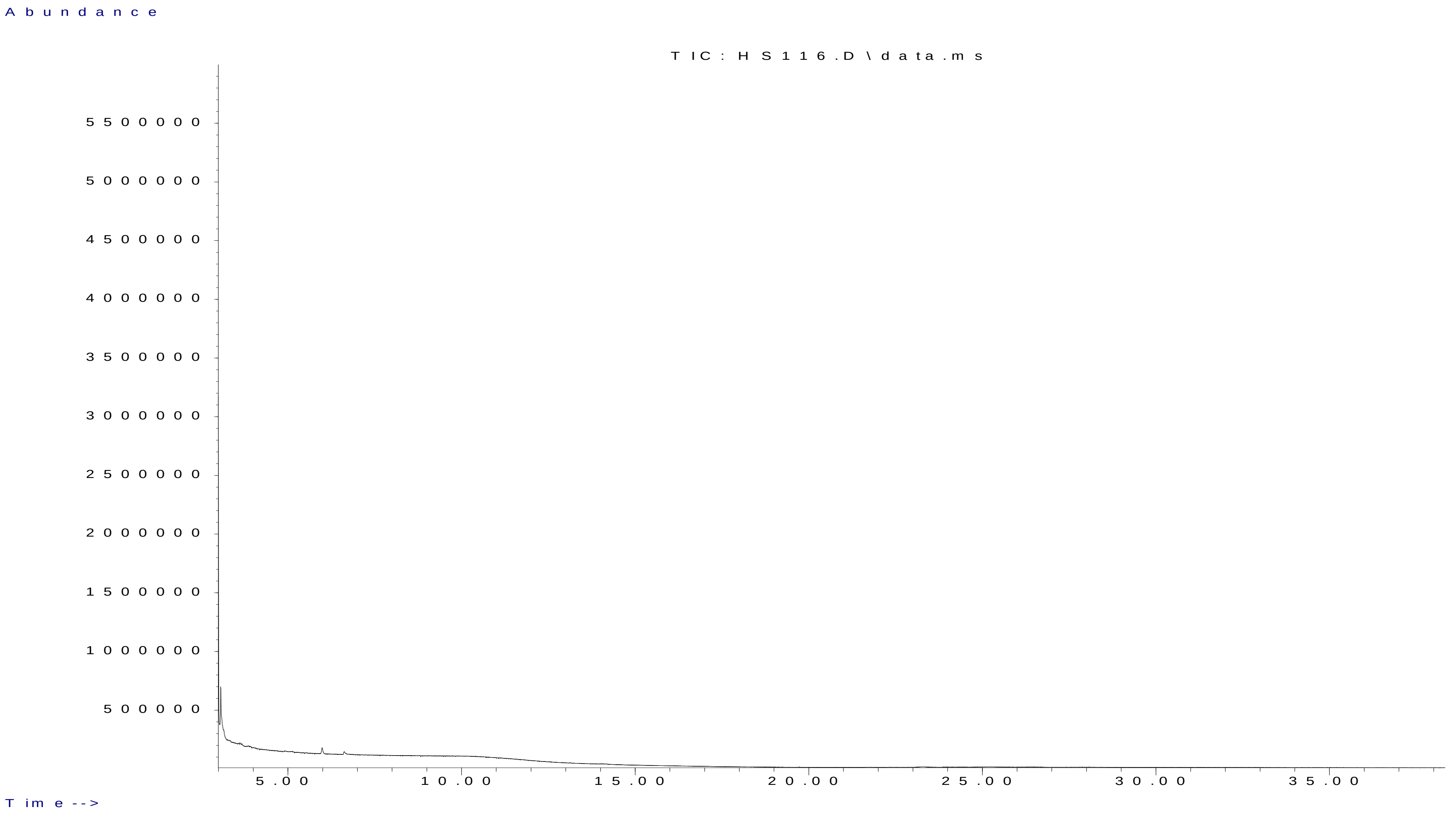


Figure C.6.69. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH sample for T.P.C. (100 m, 0 m) at depth (1.0 m), at contaminated site (Al-Magwa Area).

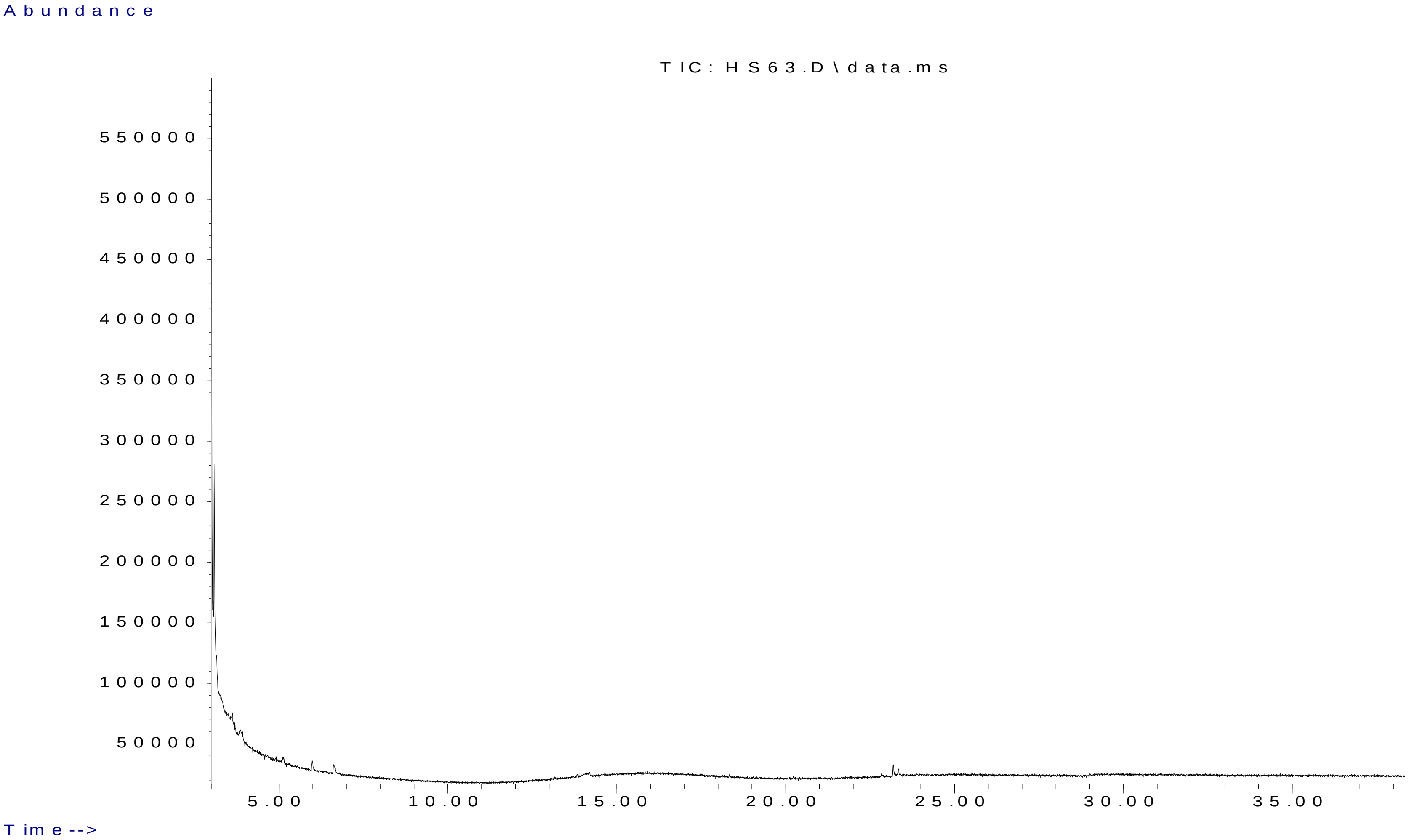


Figure C.6.70. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH sample for T.P.C. (0 m, 25 m) at depth (1.0 m), at contaminated site (Al-Magwa Area).

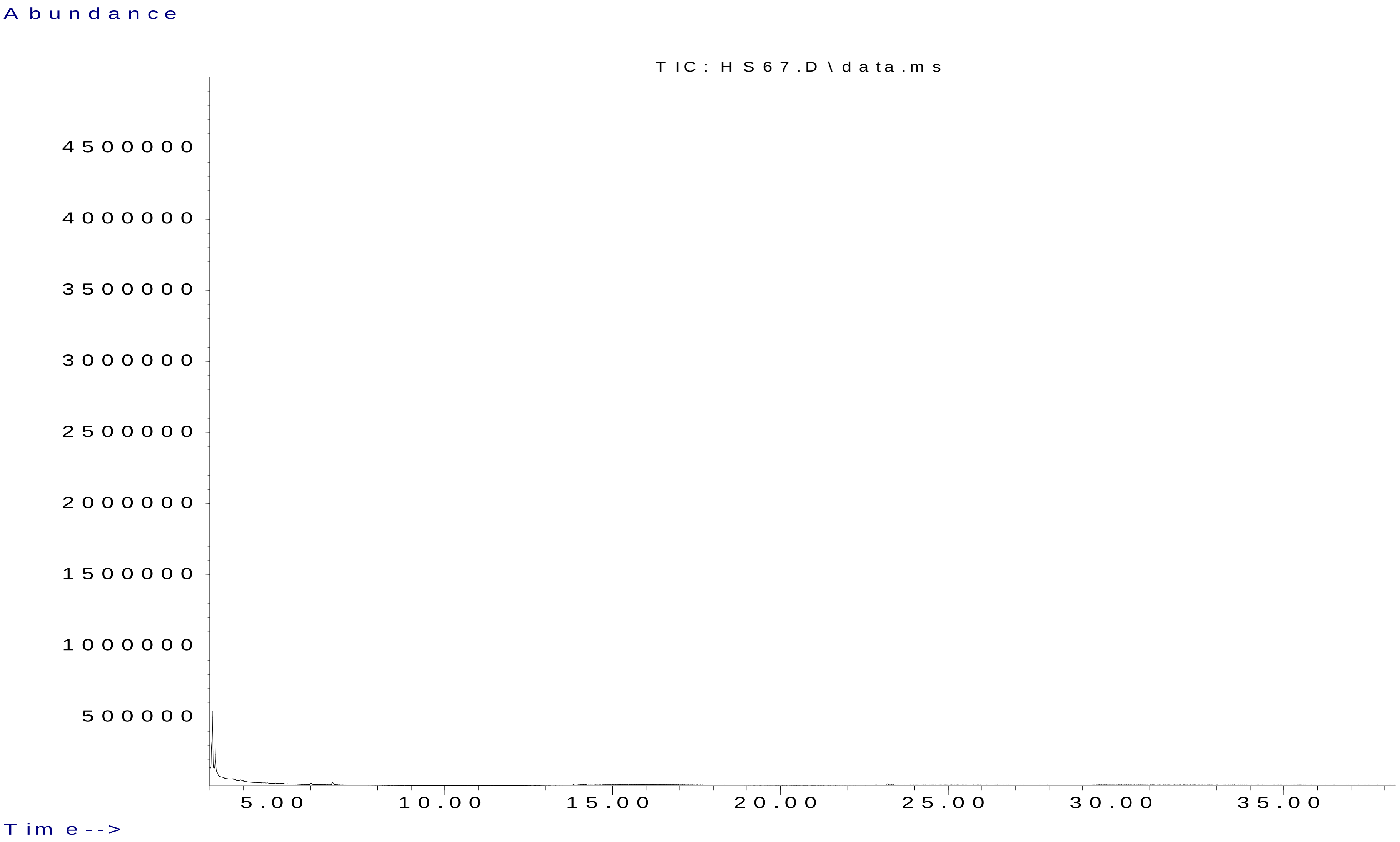


Figure C.6.71. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH sample for T.P.C. (25 m, 25 m) at depth (1.0 m), at contaminated site (Al-Magwa Area).

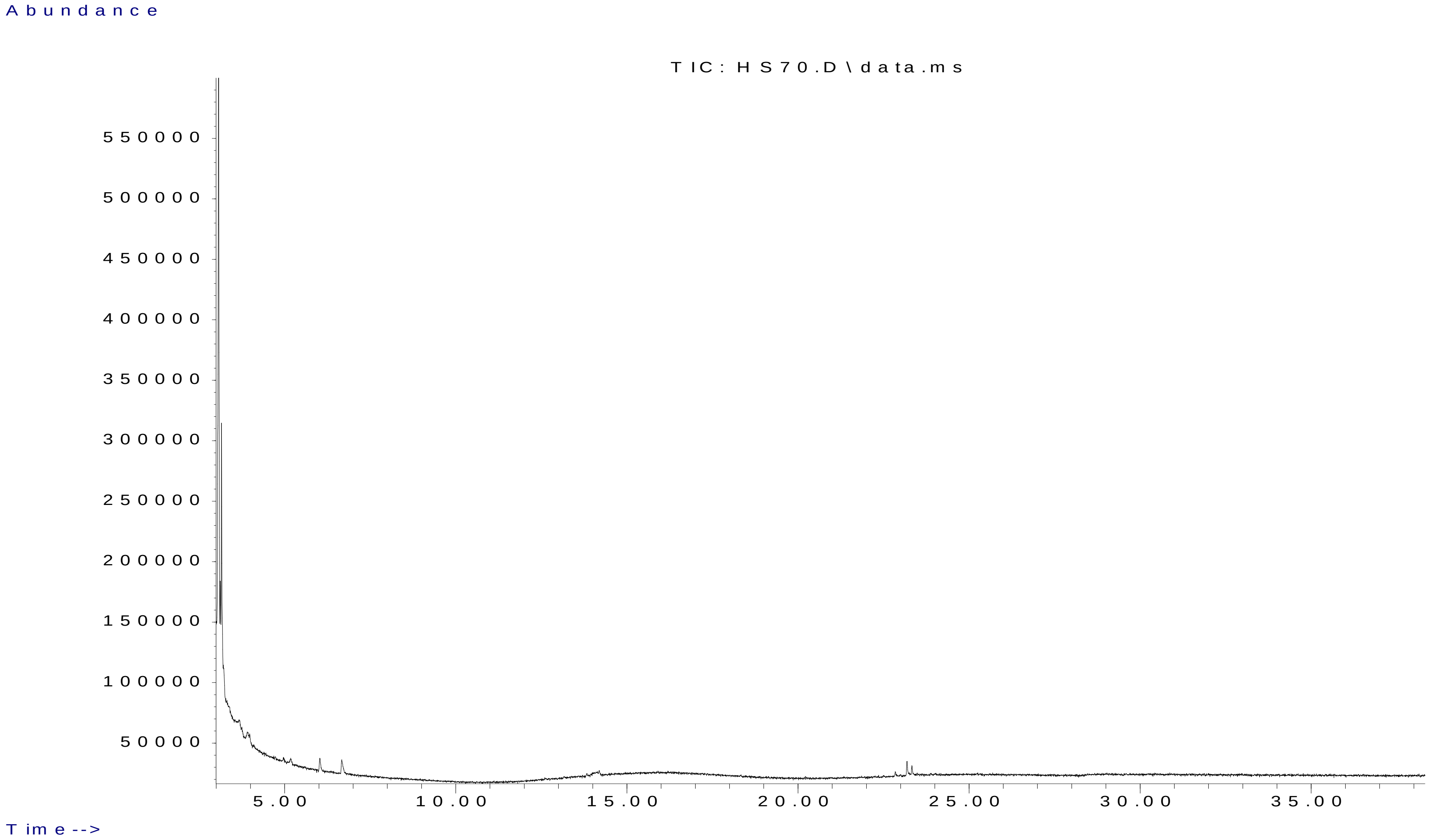


Figure C.6.72. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH sample for T.P.C. (50 m, 25 m) at depth (1.0 m), at contaminated site (Al-Magwa Area).

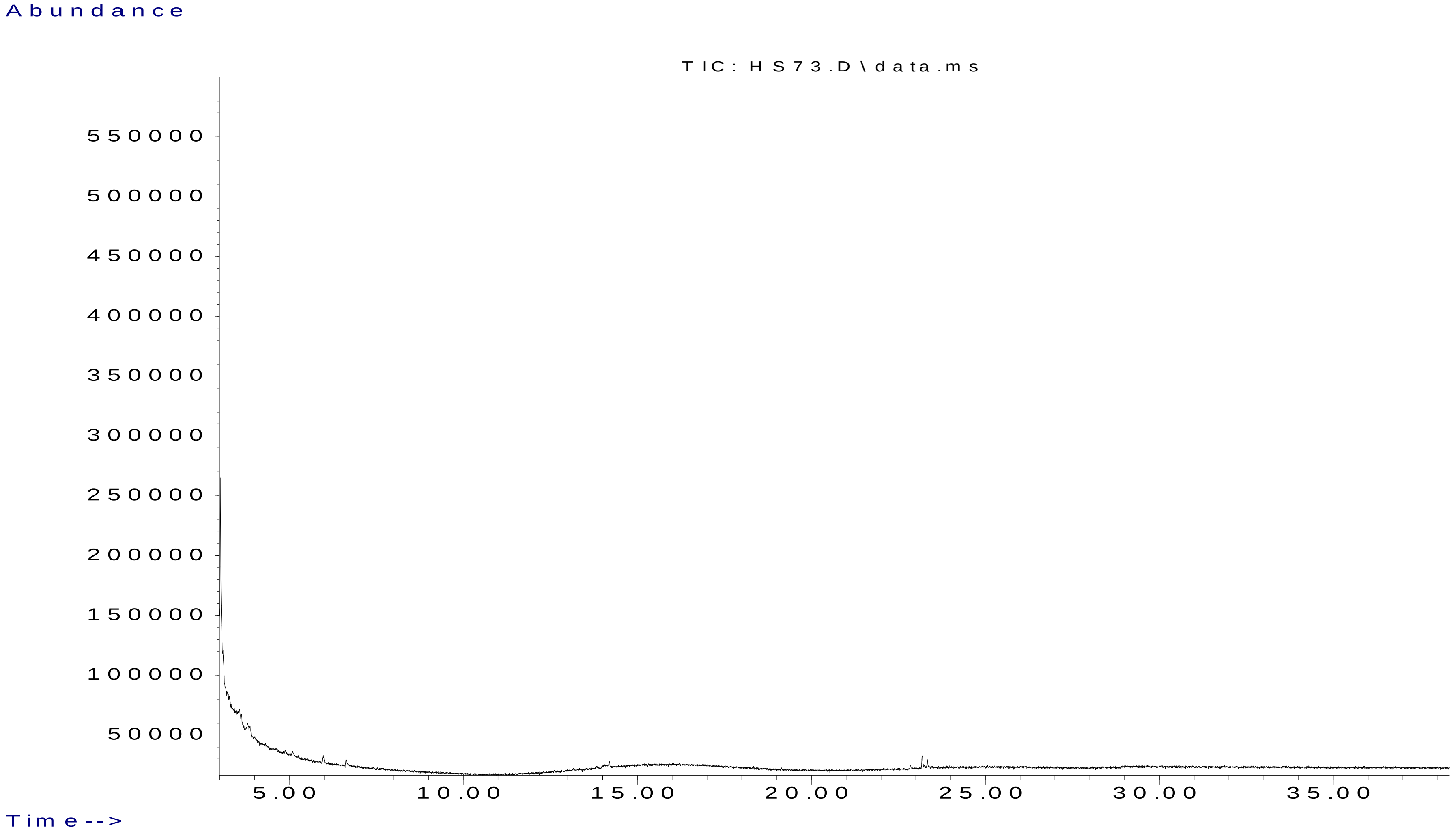


Figure C.6.73. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH sample for T.P.C. (100 m, 25 m) at depth (1.0 m), at contaminated site (Al-Magwa Area).

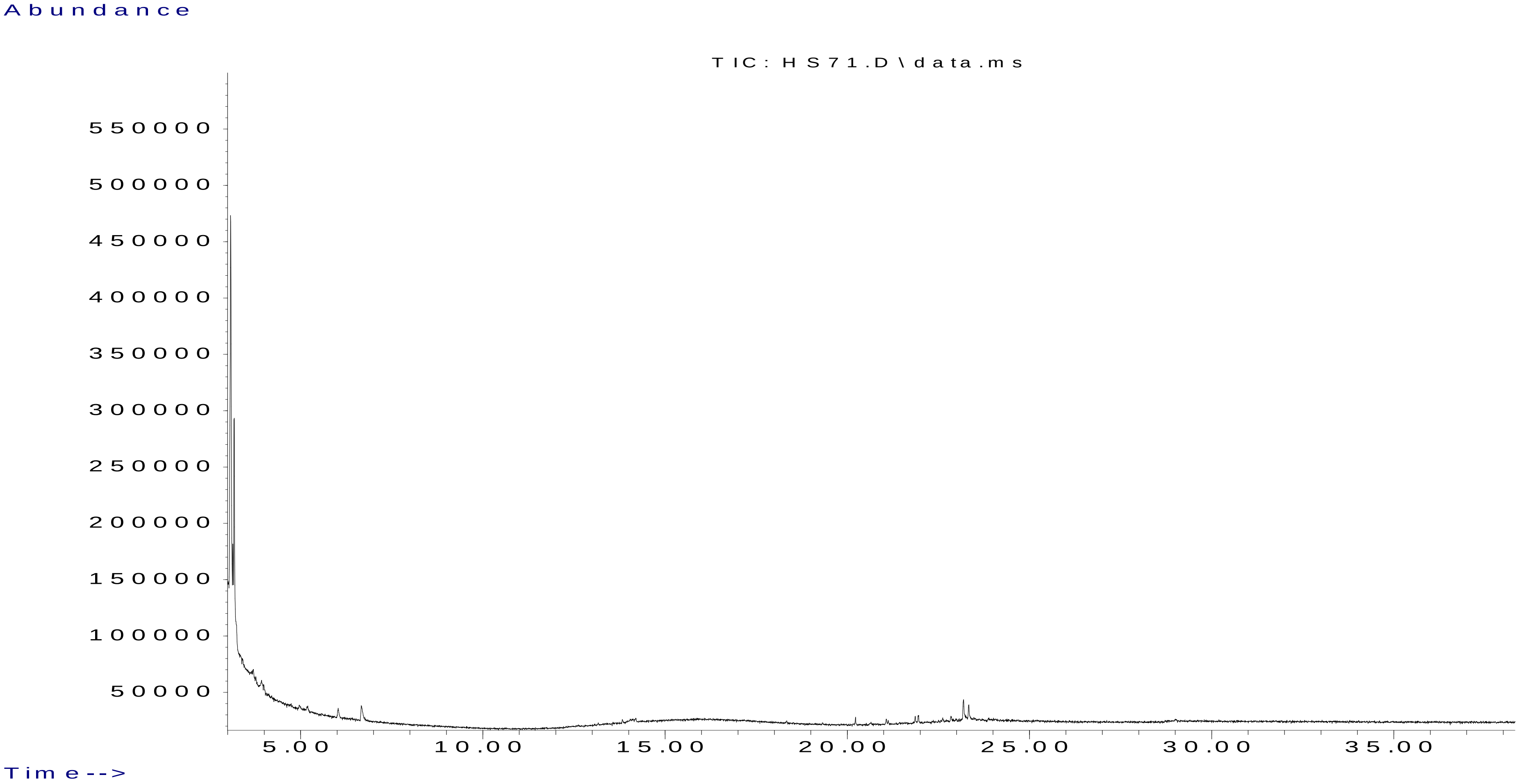


Figure C.6.74. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH sample for T.P.C. (0 m, 50 m) at depth (1.0 m), at contaminated site (Al-Magwa Area).

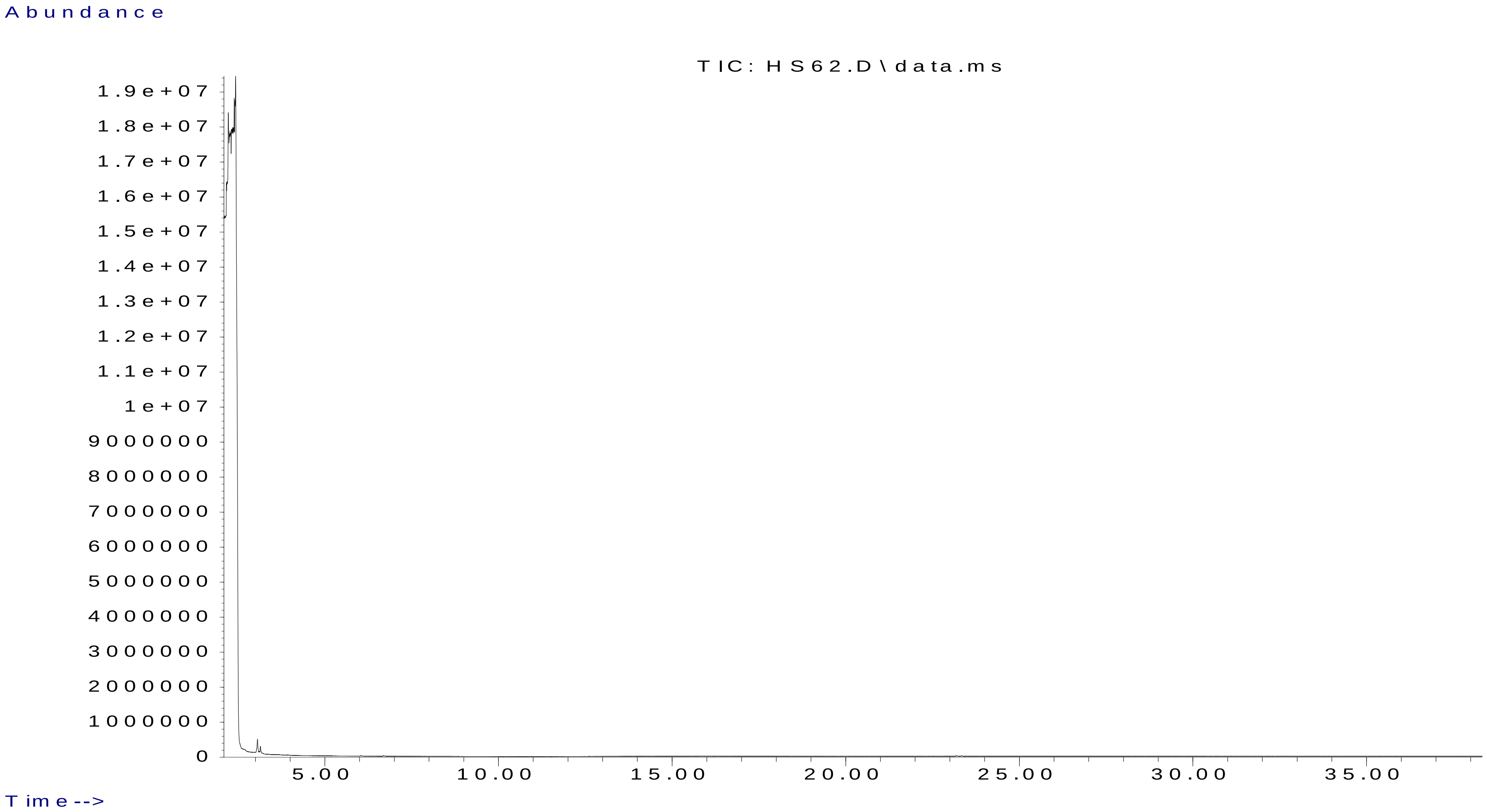


Figure C.6.75. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH sample for T.P.C. (25 m, 50 m) at depth (1.0 m), at contaminated site (Al-Magwa Area).

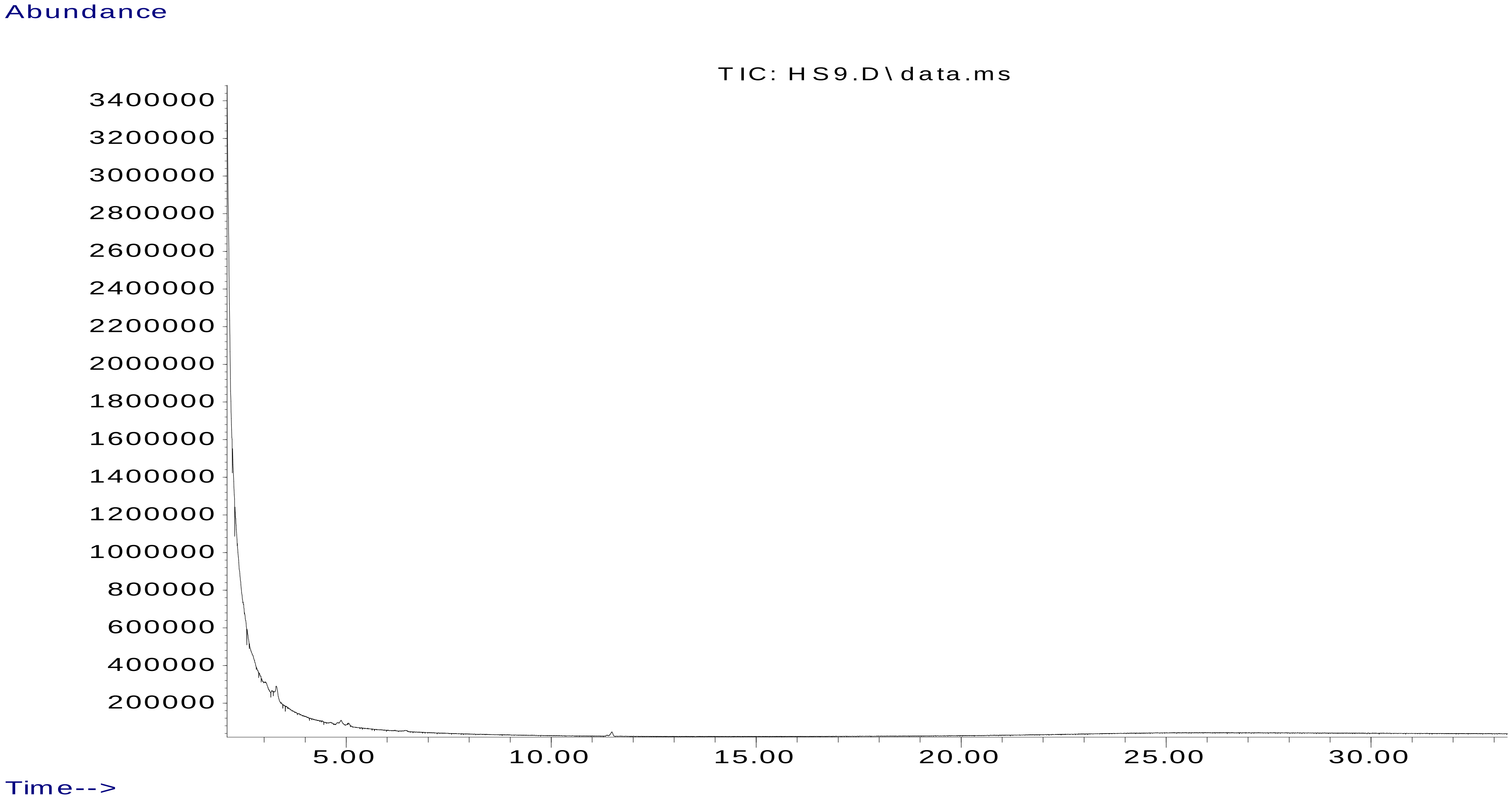


Figure C.6.76. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH sample for T.P.C. (50 m, 50 m) at depth (1.0 m), at contaminated site (Al-Magwa Area).

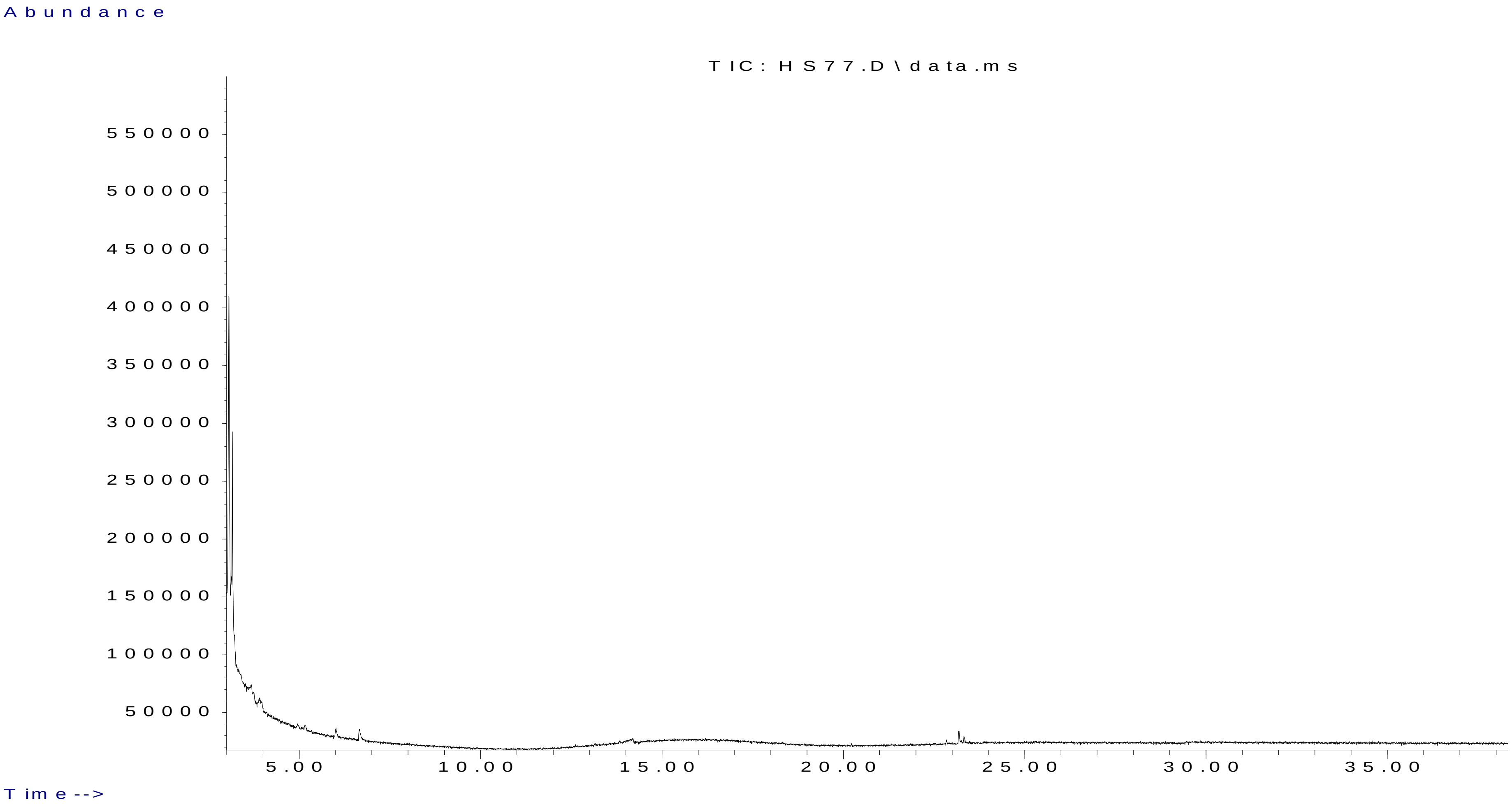


Figure C.6.77. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH sample for T.P.C. (100 m, 50 m) at depth (1.0 m), at contaminated site (Al-Magwa Area).

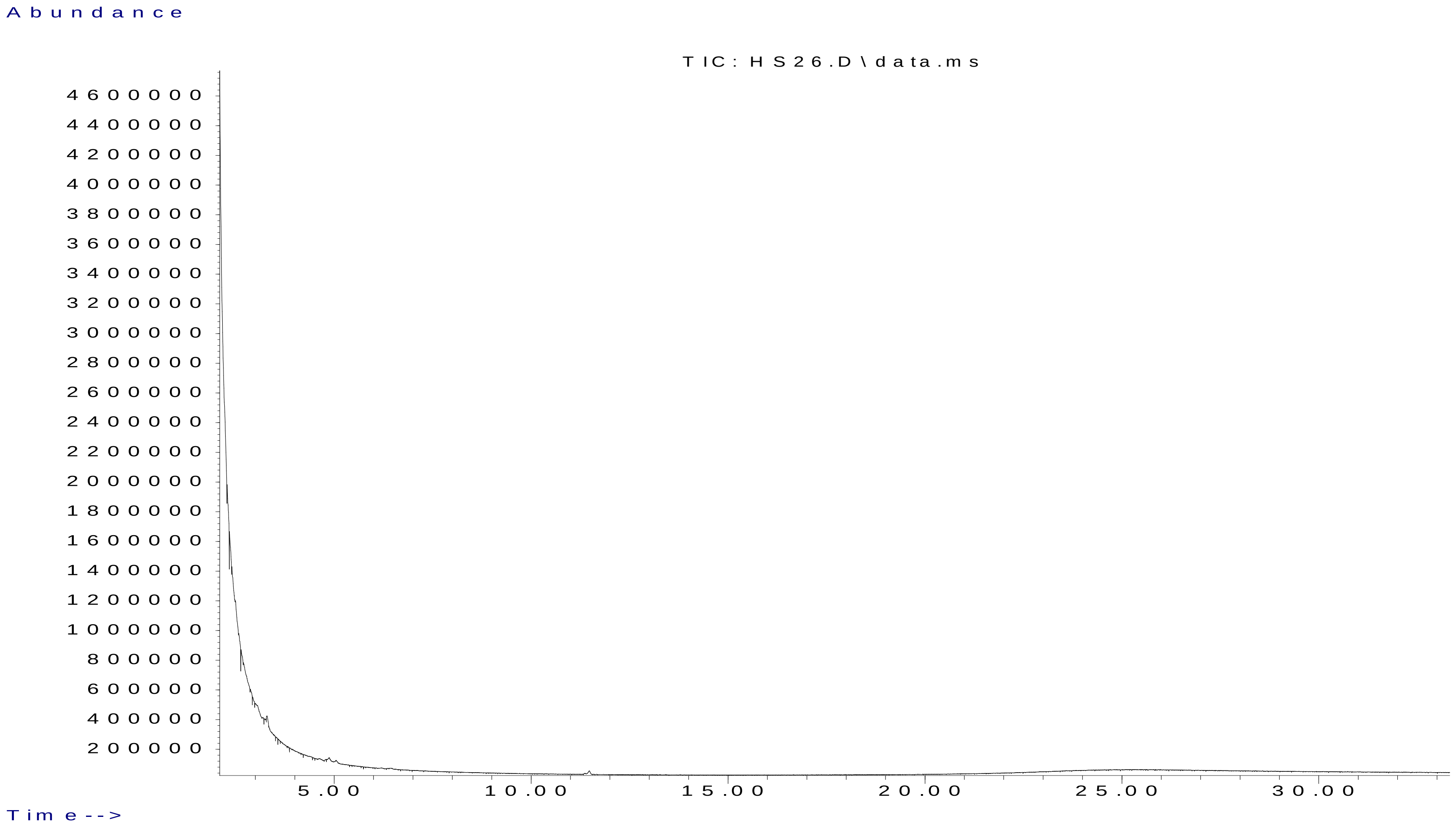


Figure C.6.78. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH sample for T.P.C. (0 m, 75 m) at depth (1.0 m), at contaminated site (Al-Magwa Area).

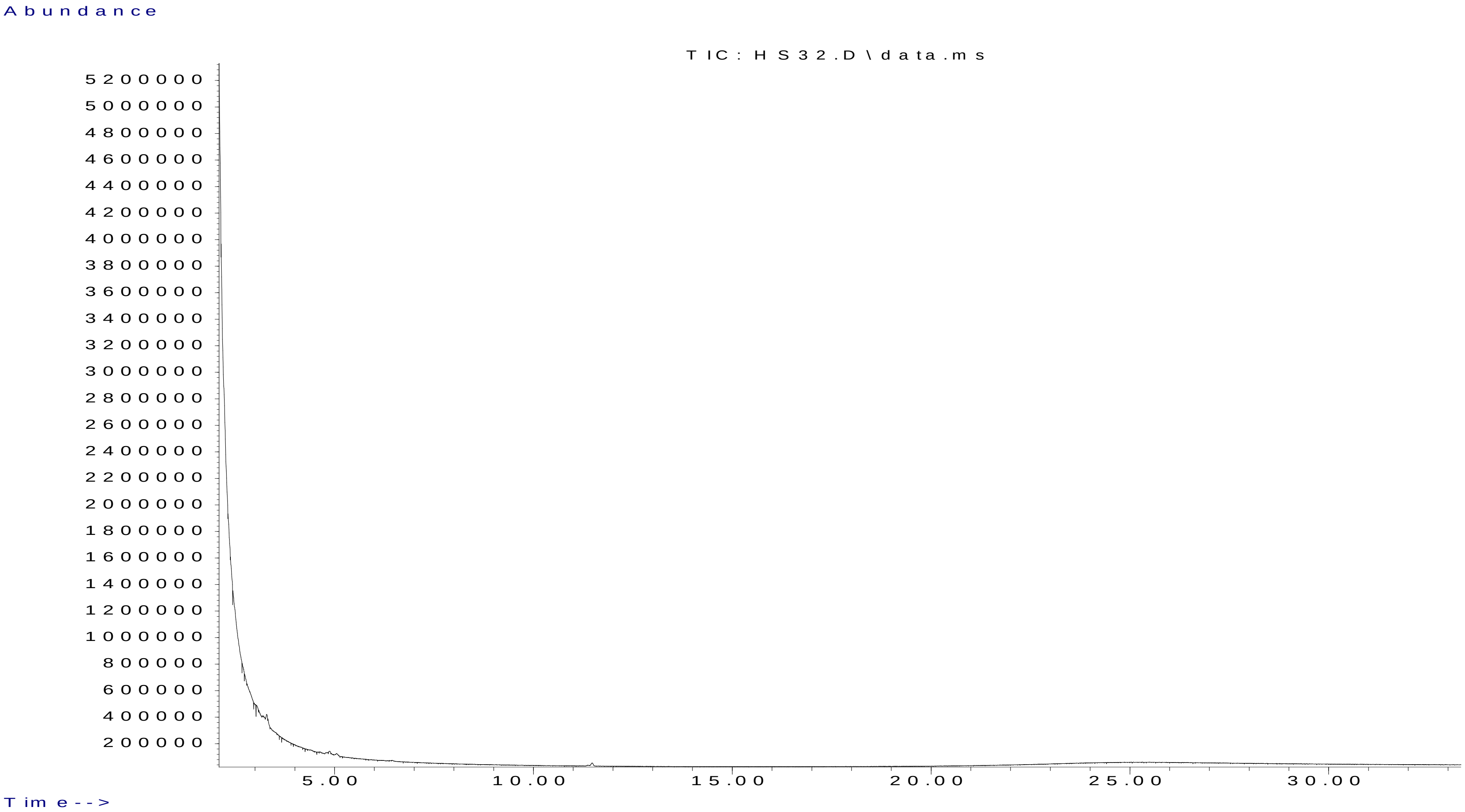


Figure C.6.79. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH sample for T.P.C. (25 m, 75 m) at depth (1.0 m), at contaminated site (Al-Magwa Area).

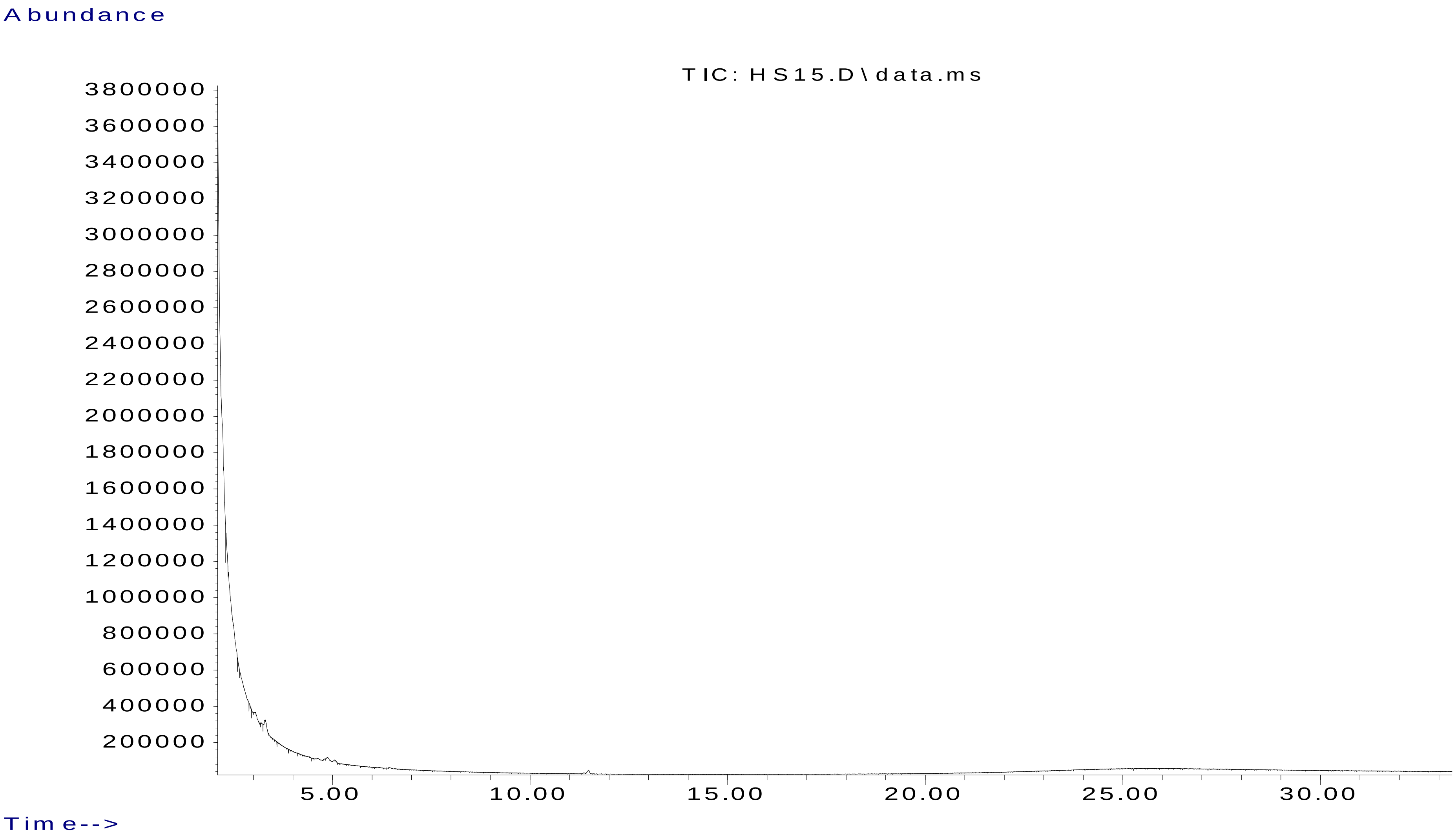


Figure C.6.80. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH sample for T.P.C. (50 m, 75 m) at depth (1.0 m), at contaminated site (Al-Magwa Area).

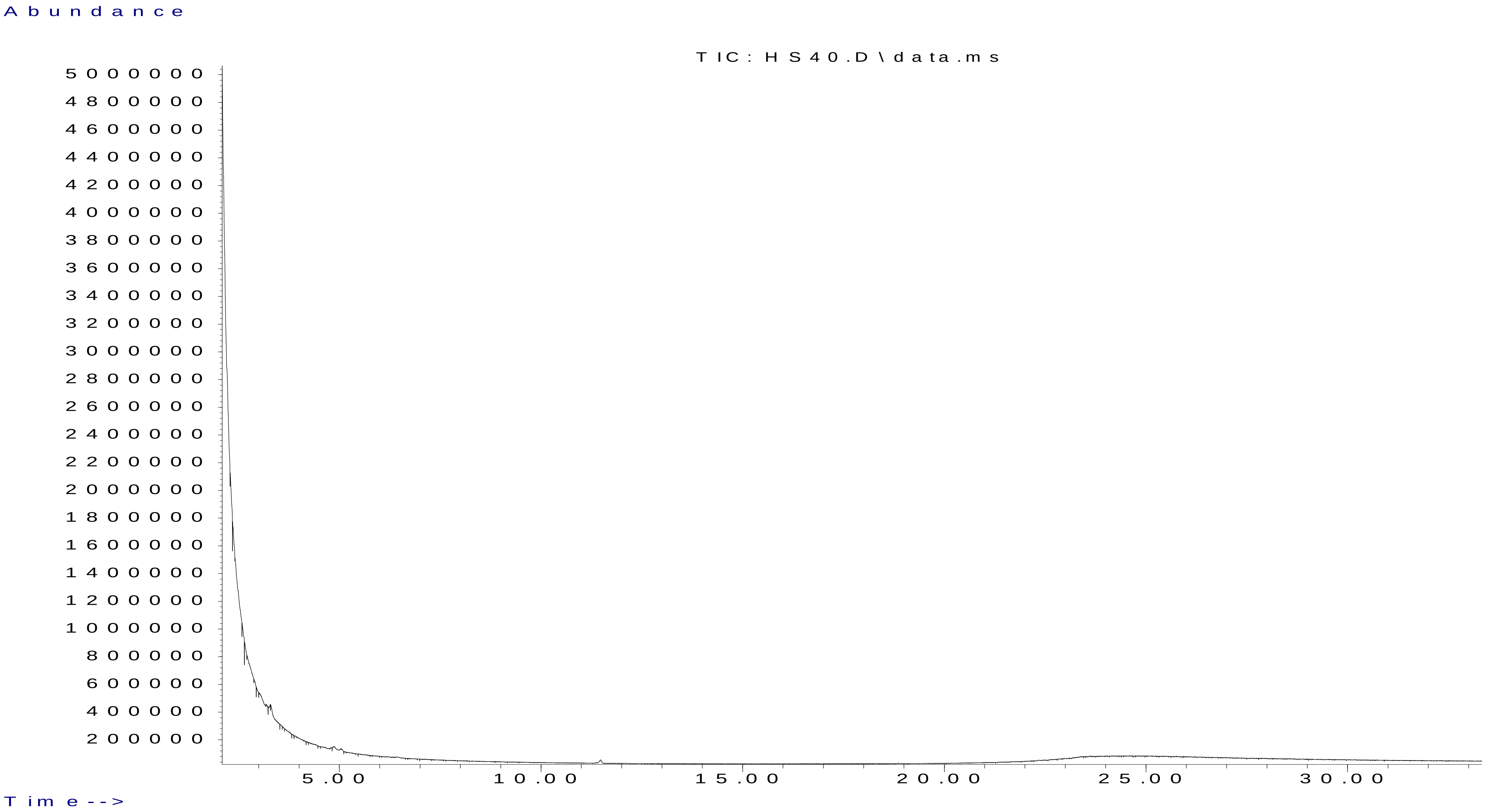


Figure C.6.81. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH sample for T.P.C. (75 m, 75 m) at depth (1.0 m), at contaminated site (Al-Magwa Area).

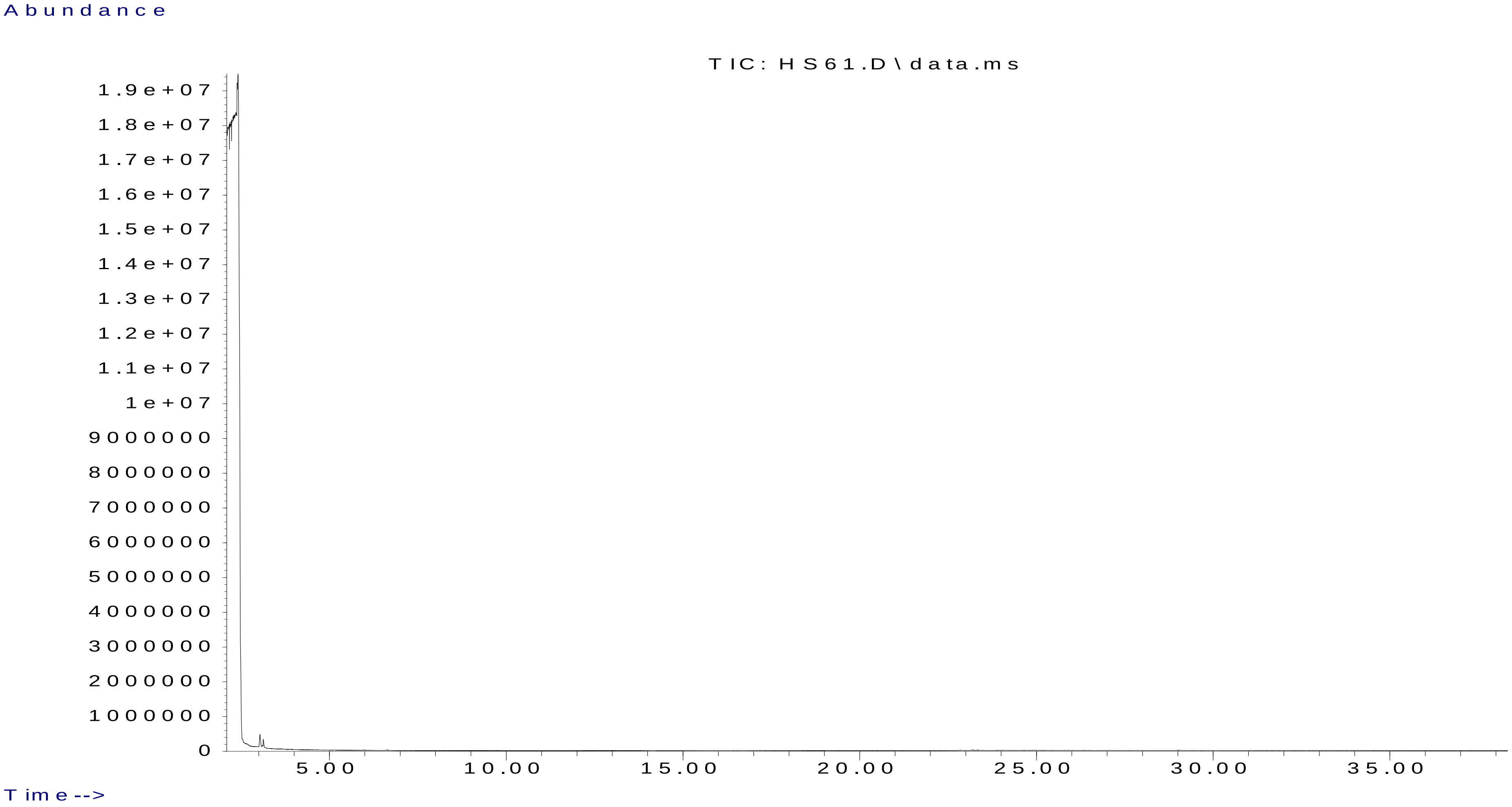


Figure C.6.82. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH sample for T.P.C. (100 m, 75 m) at depth (1.0 m), at contaminated site (Al-Magwa Area).

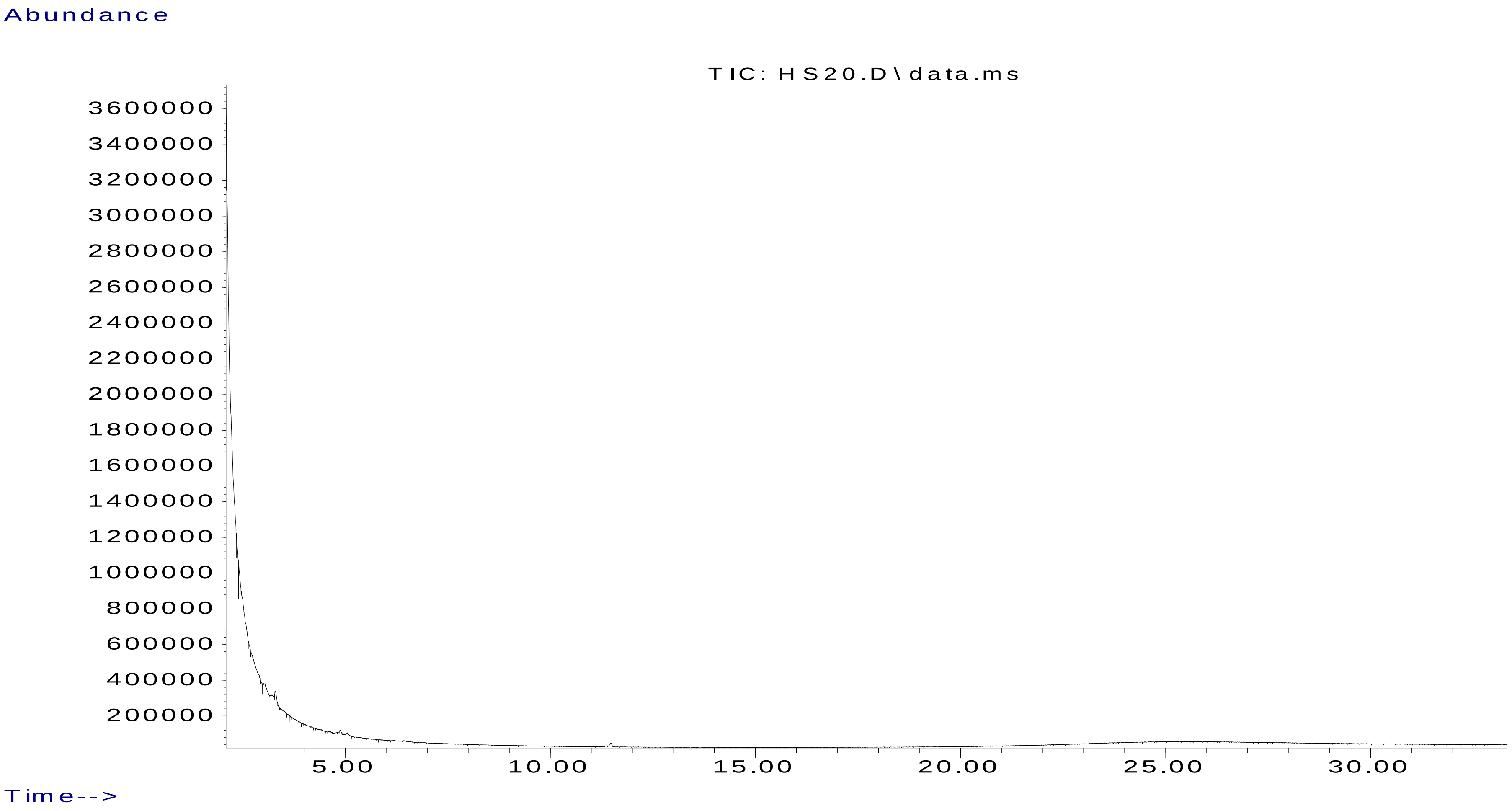


Figure C.6.83. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH sample for T.P.C. (0 m, 100 m) at depth (1.0 m), at contaminated site (Al-Magwa Area).

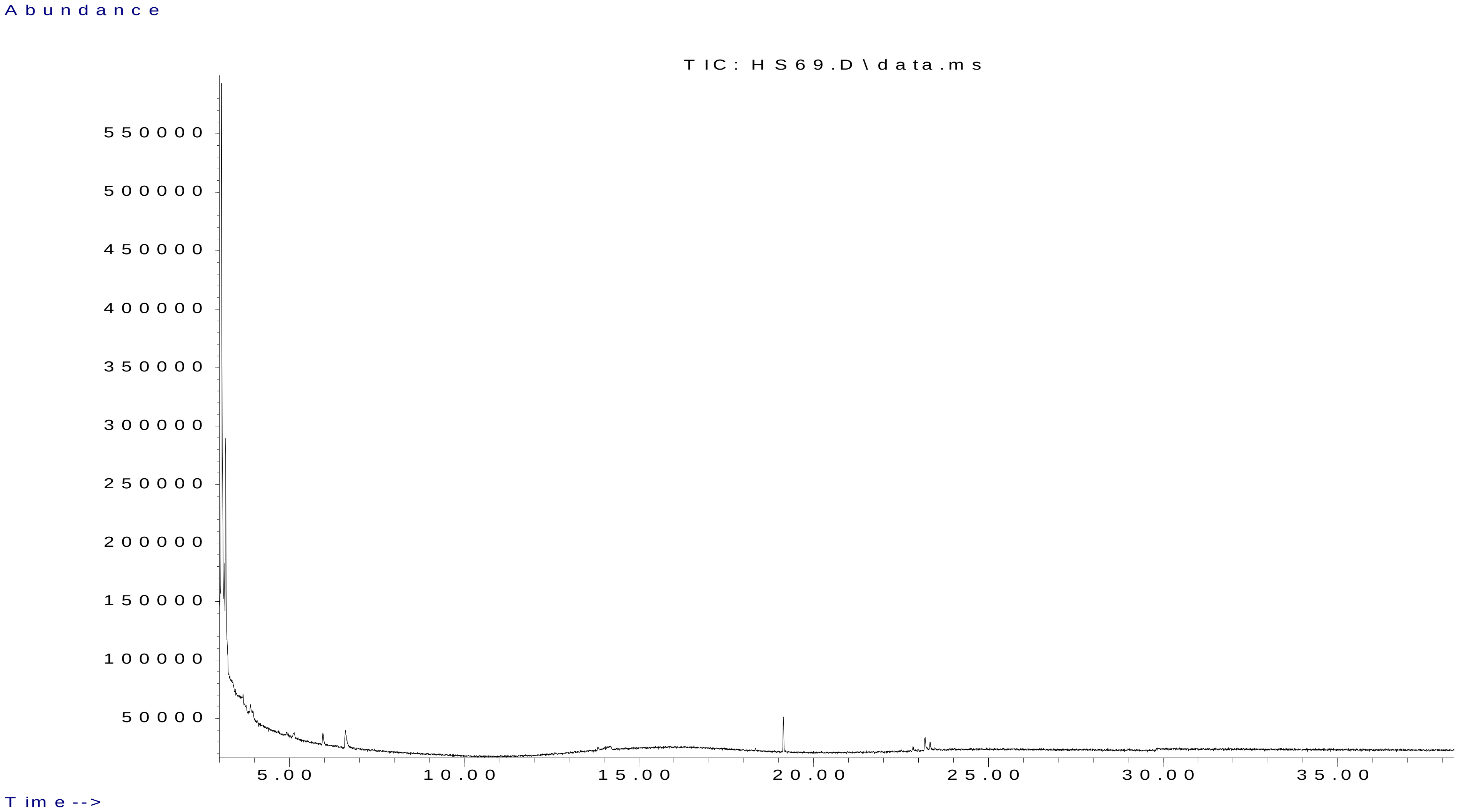


Figure C.6.84. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH sample for T.P.C. (50 m, 100 m) at depth (1.0 m), at contaminated site (Al-Magwa Area).

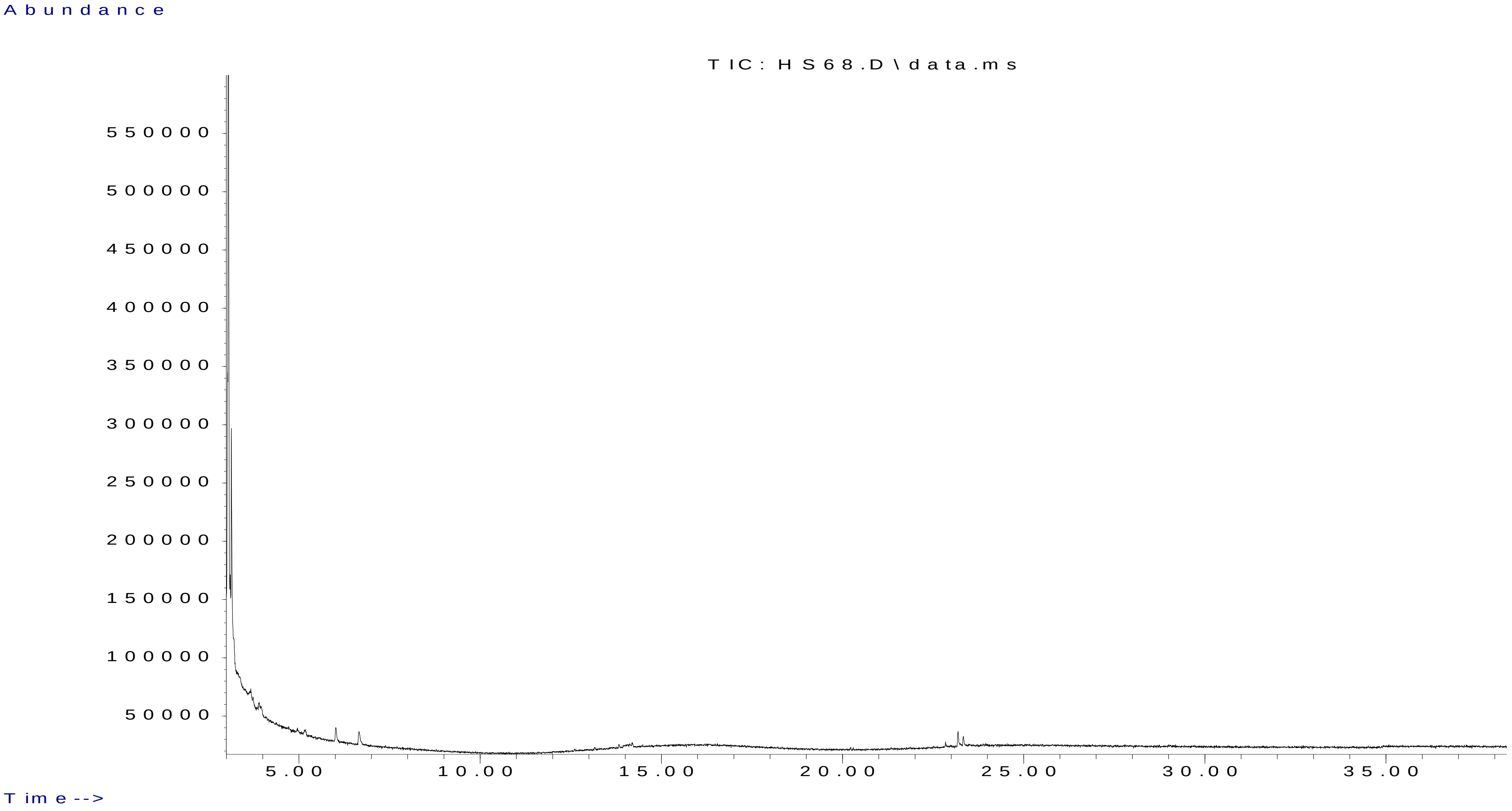


Figure C.6.85. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH sample for T.P.C. (75 m, 100 m) at depth (1.0 m), at contaminated site (Al-Magwa Area).

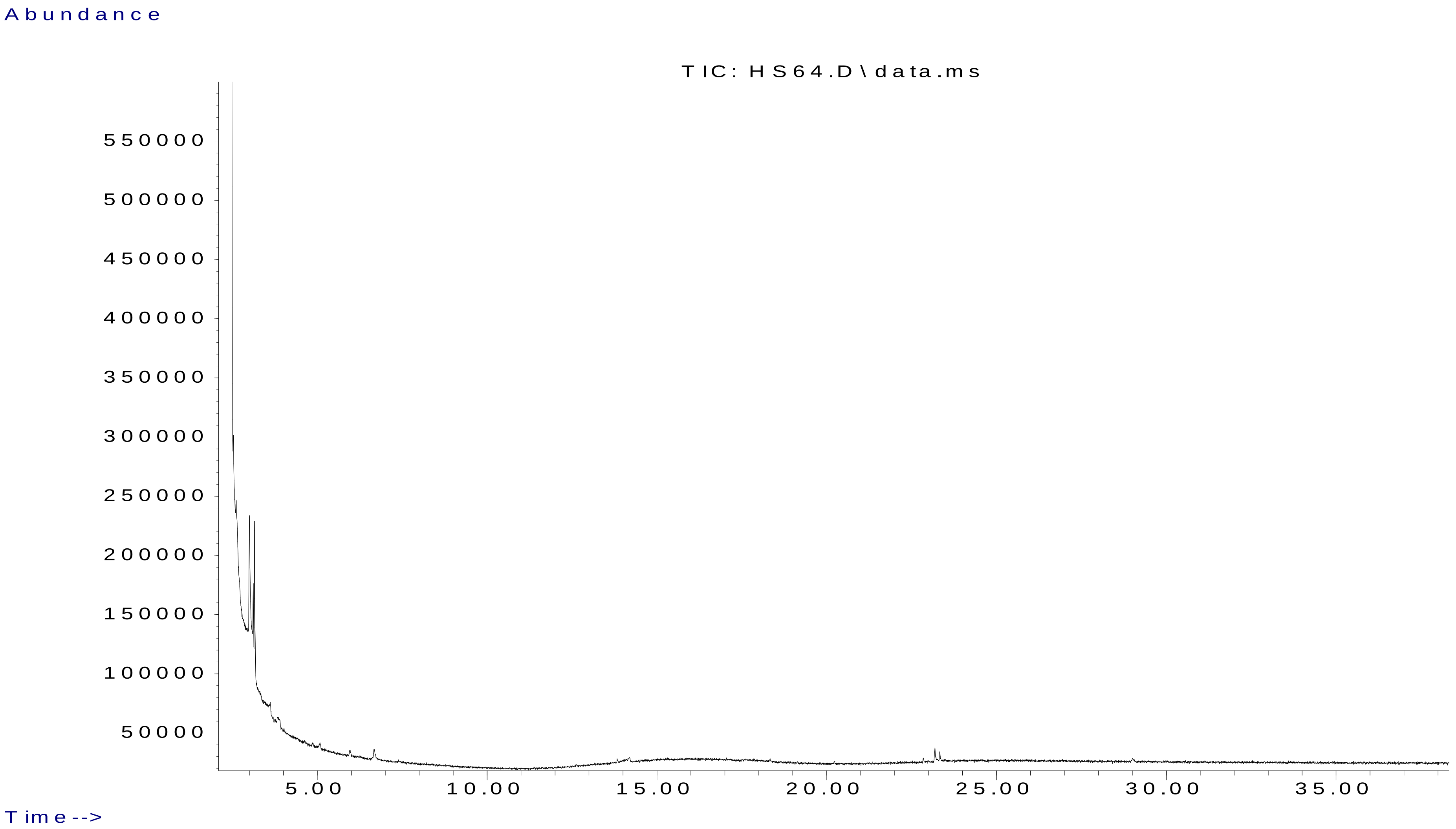


Figure C.6.86. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH sample for T.P.C. (100 m, 100 m) at depth (1.0 m), at contaminated site (Al-Magwa Area).

At Depth (1.5 m)

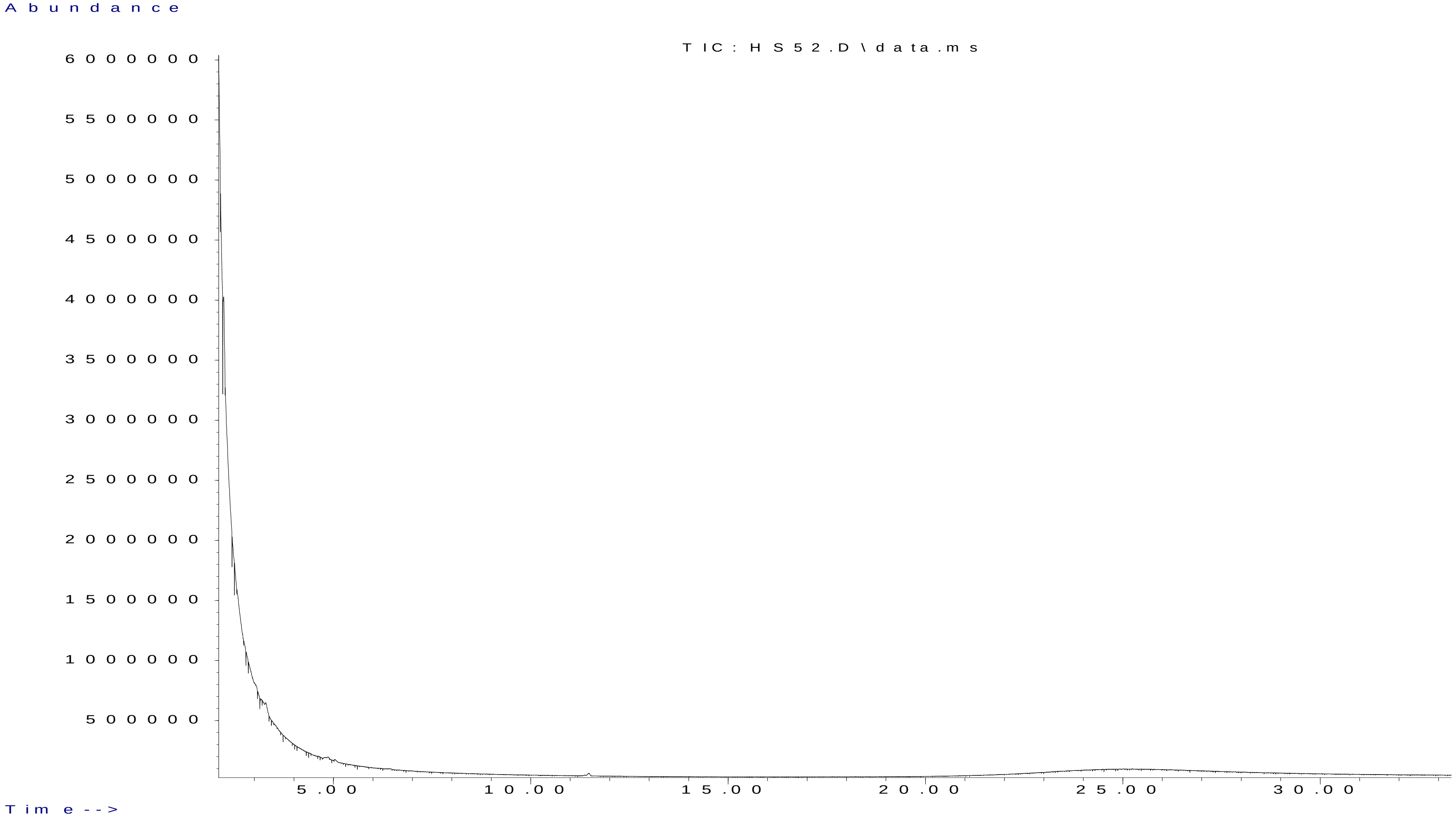


Figure C.6.87. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH sample for T.P.C. (0 m, 0 m) at depth (1.5 m), at contaminated site (Al-Magwa Area).

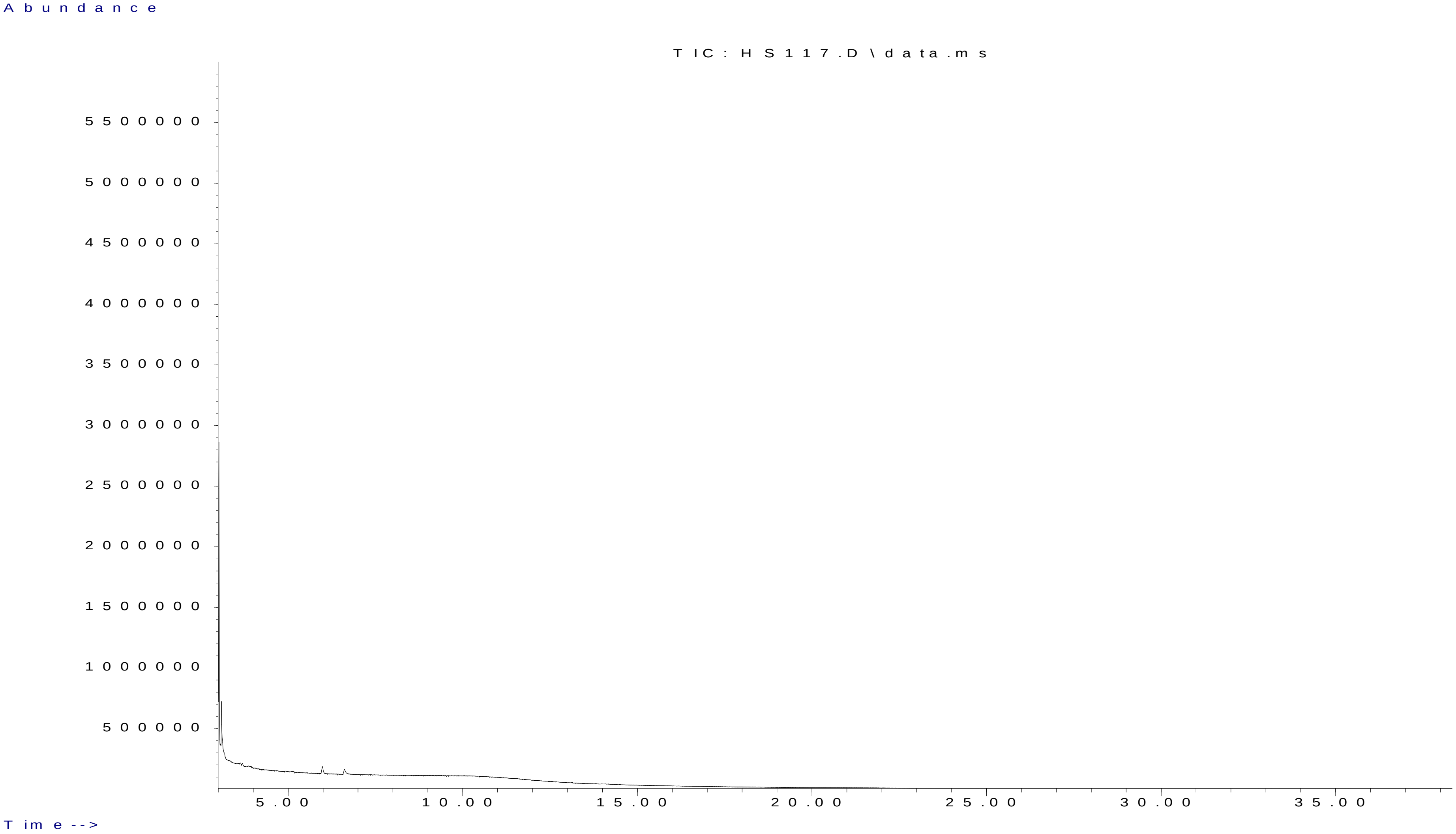


Figure C.6.88. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH sample for T.P.C. (25 m, 0 m) at depth (1.5 m), at contaminated site (Al-Magwa Area).

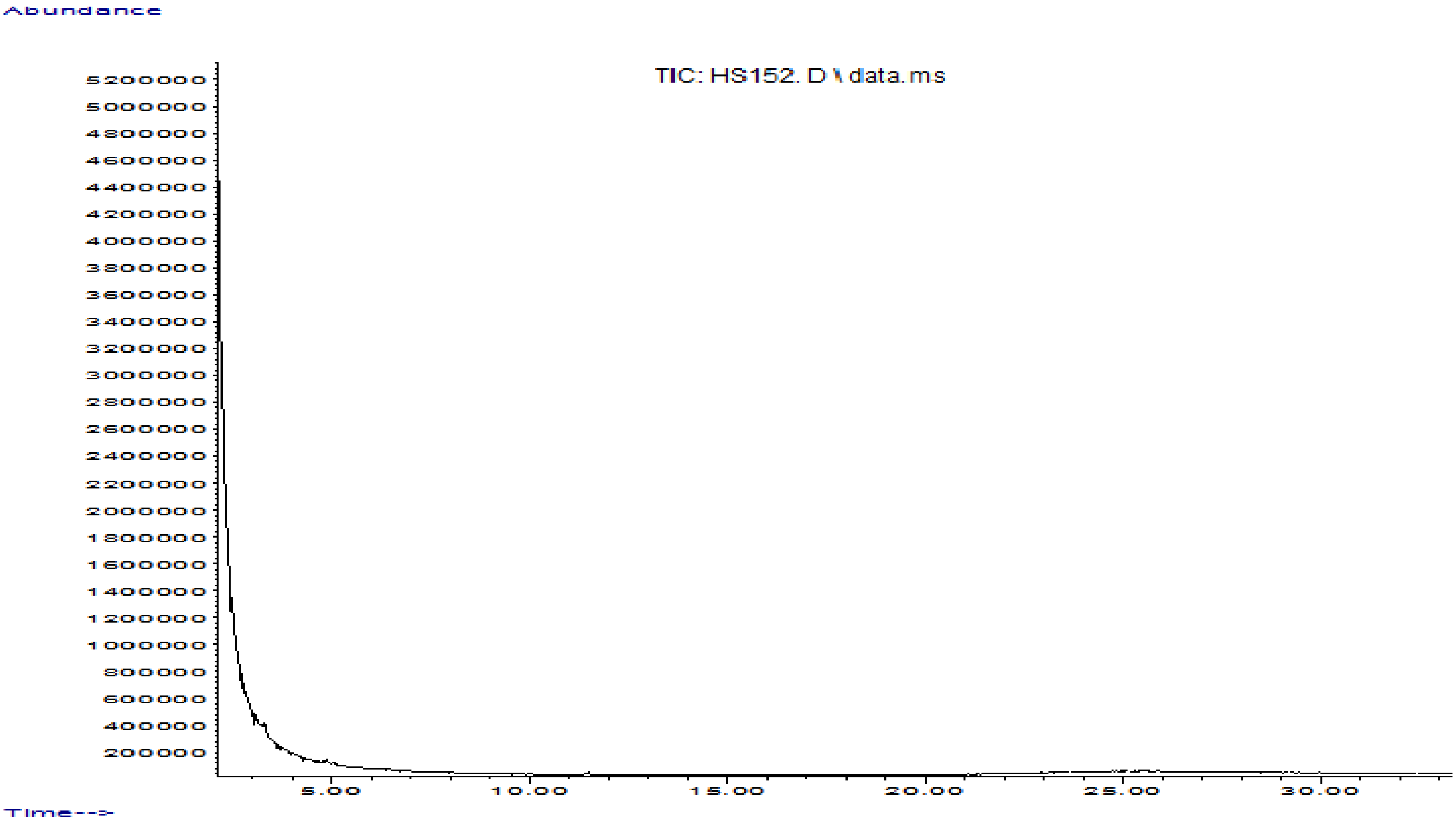


Figure C.6.89. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH sample for T.P.C. (50 m, 0 m) at depth (1.5 m), at contaminated site (Al-Magwa Area).

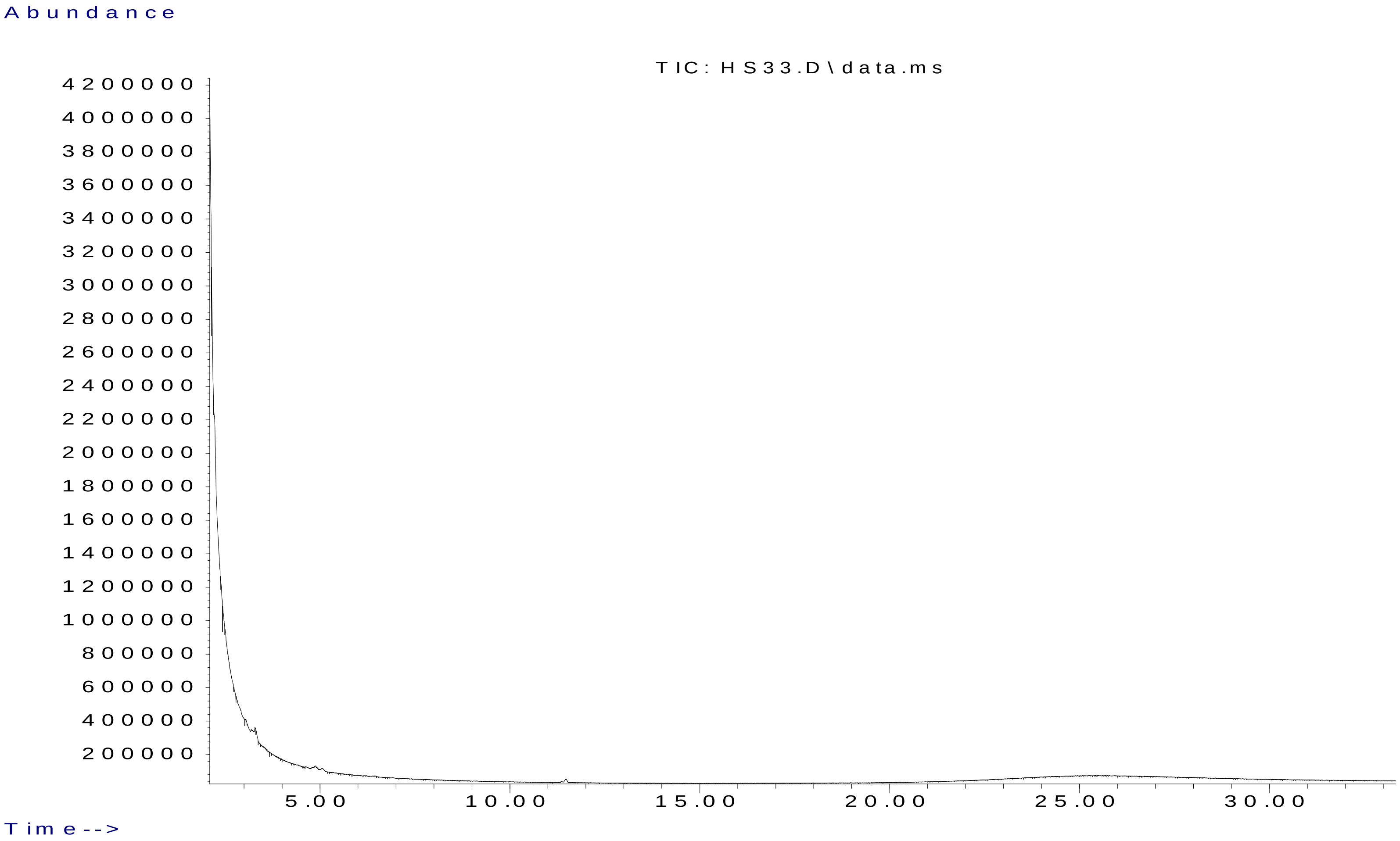


Figure C.6.90. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH sample for T.P.C. (75 m, 0 m) at depth (1.5 m), at contaminated site (Al-Magwa Area).

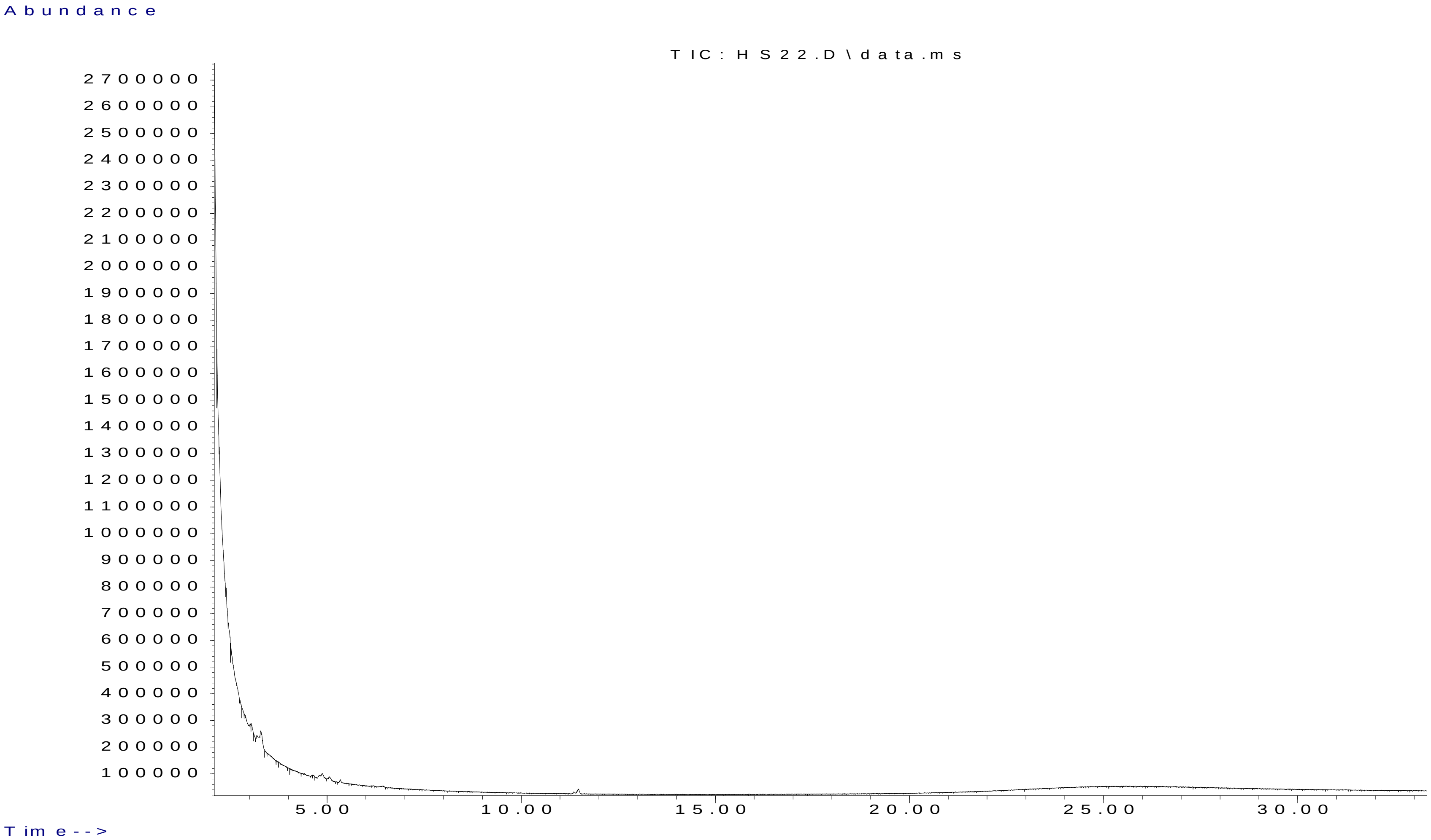


Figure C.6.91. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH sample for T.P.C. (100 m, 0 m) at depth (1.5 m), at contaminated site (Al-Magwa Area).

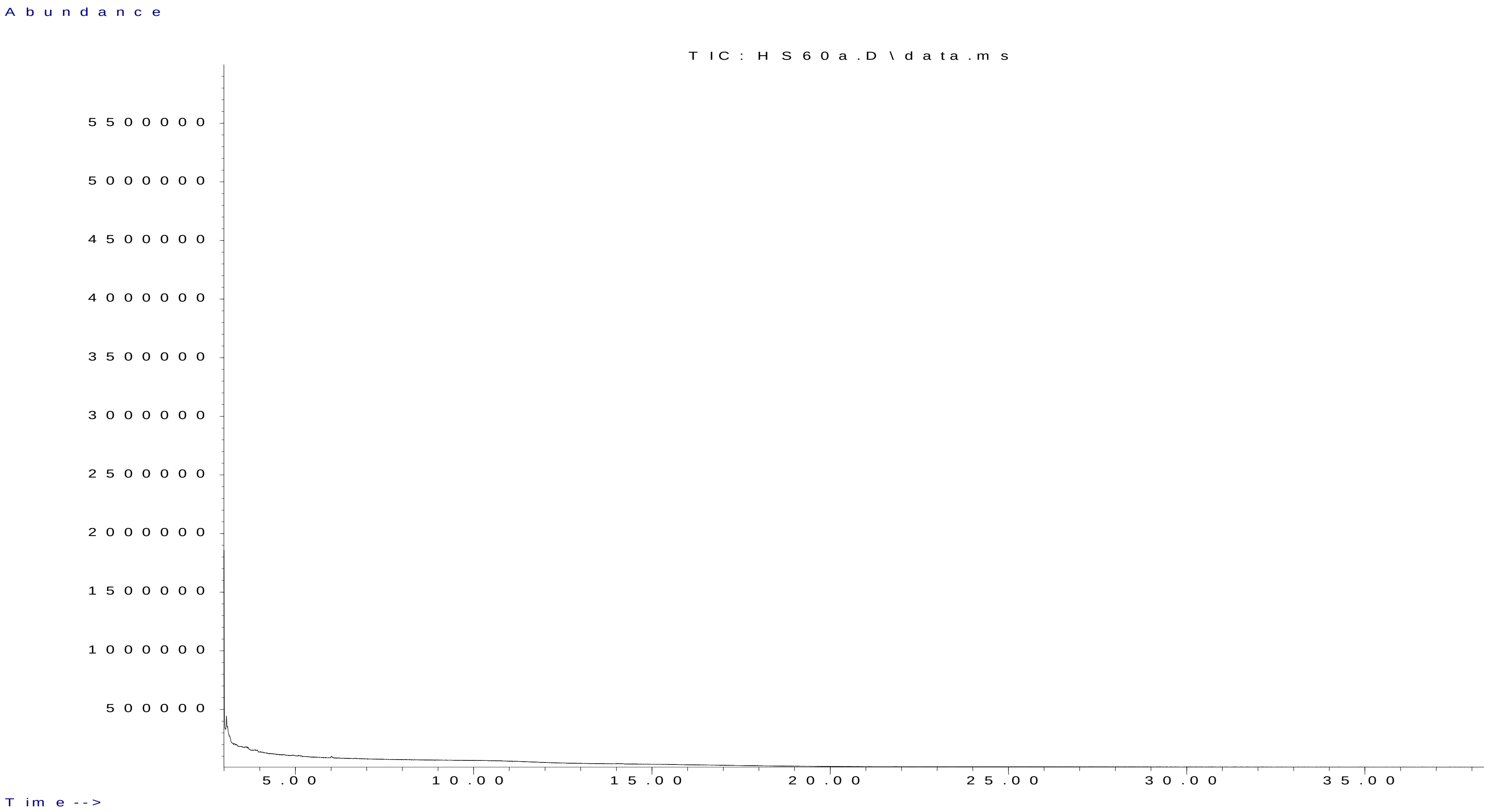


Figure C.6.92. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH sample for T.P.C. (0 m, 25 m) at depth (1.5 m), at contaminated site (Al-Magwa Area).

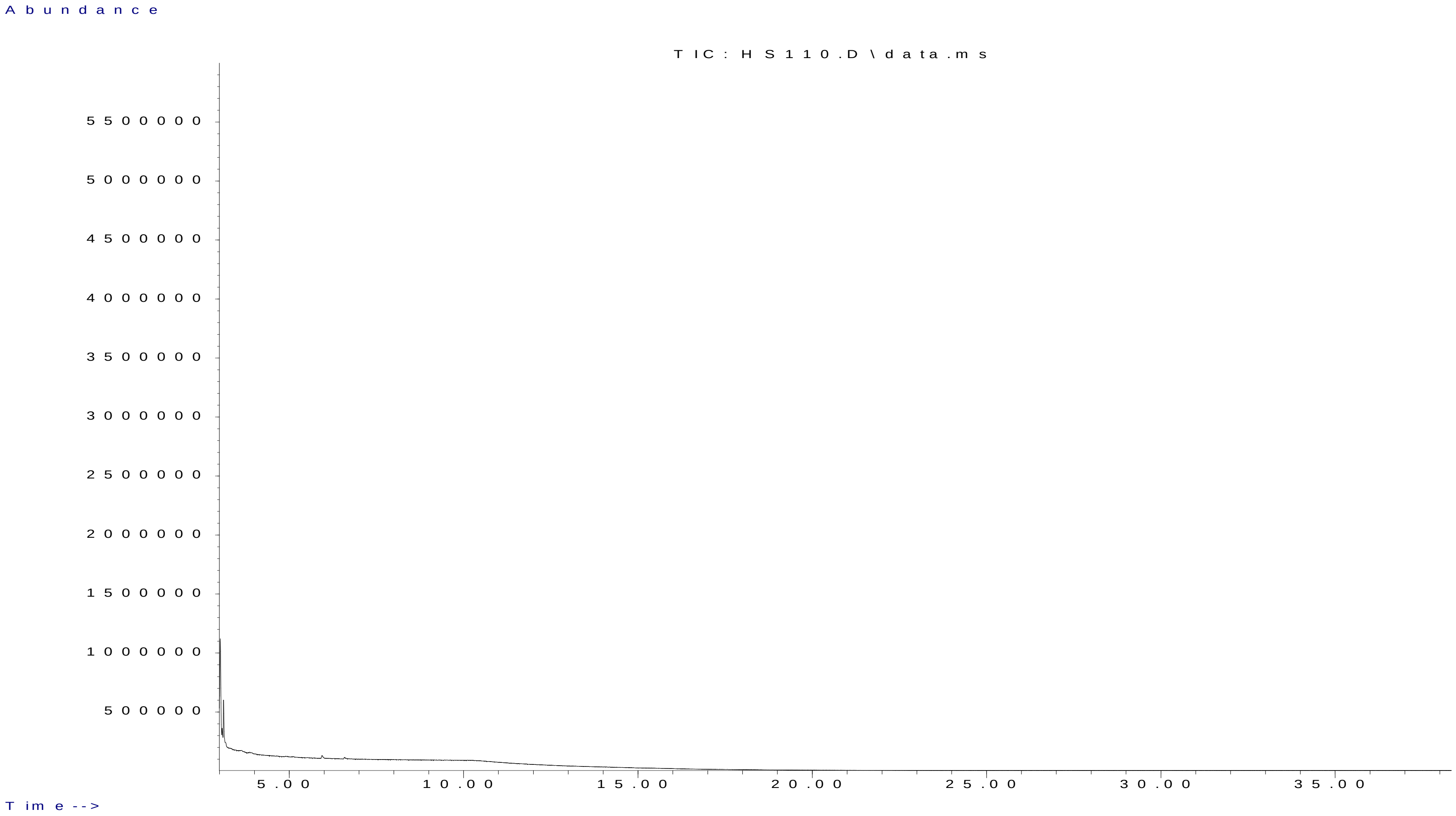


Figure C.6.93. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH sample for T.P.C. (25 m, 25 m) at depth (1.5 m), at contaminated site (Al-Magwa Area).

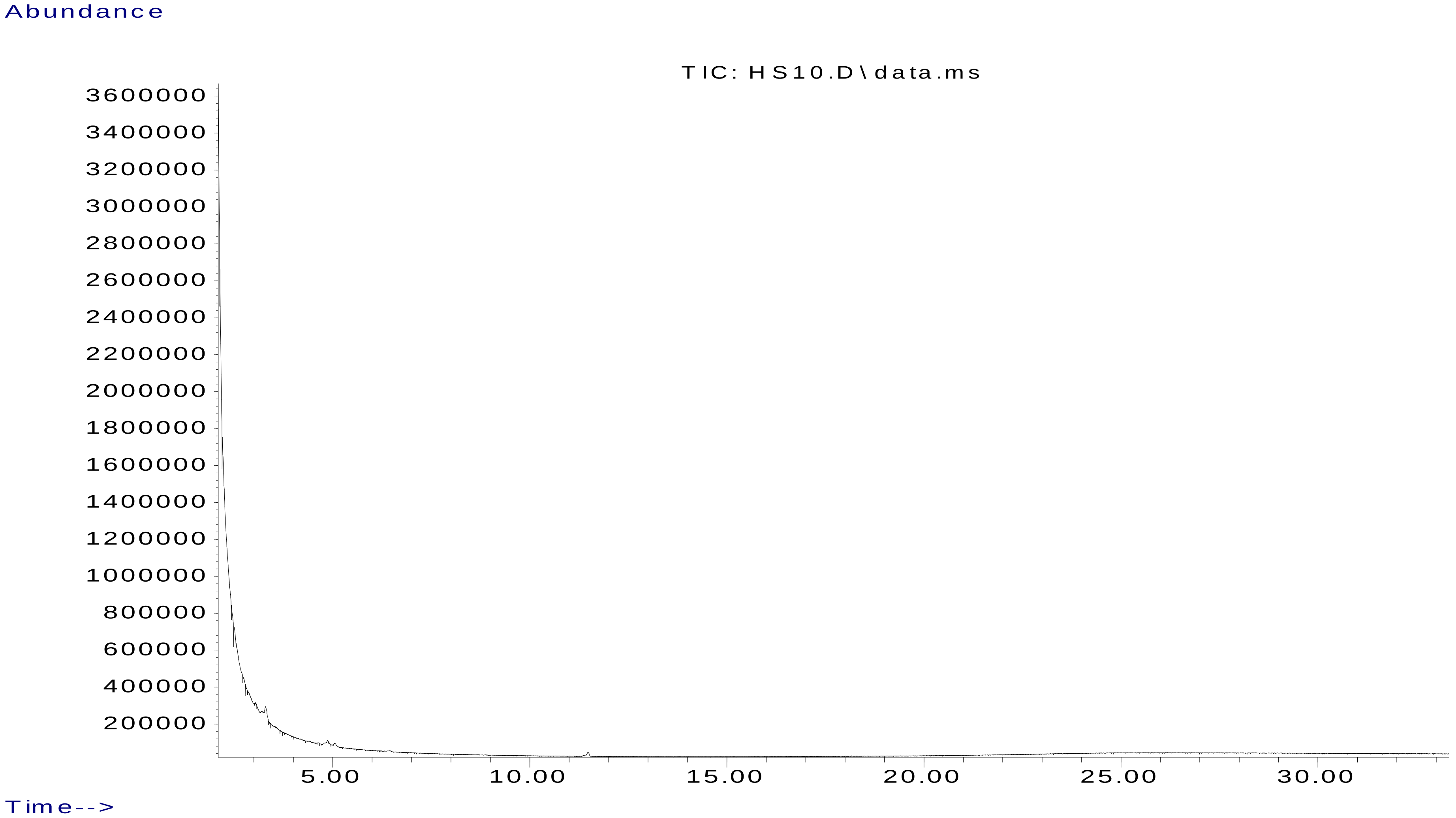


Figure C.6.94. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH sample for T.P.C. (50 m, 25 m) at depth (1.5 m), at contaminated site (Al-Magwa Area).

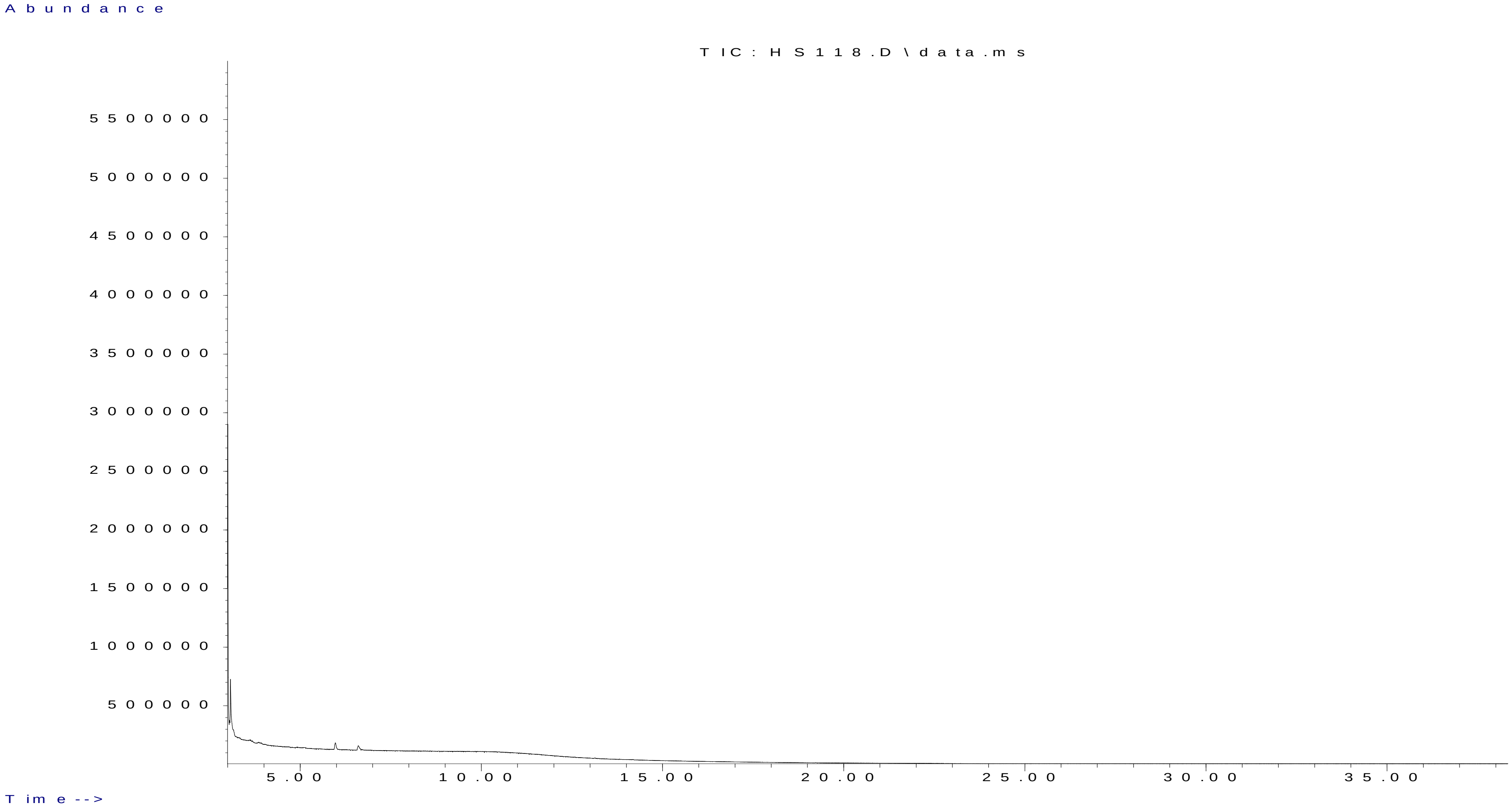


Figure C.6.95. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH sample for T.P.C. (100 m, 25 m) at depth (1.5 m), at contaminated site (Al-Magwa Area).

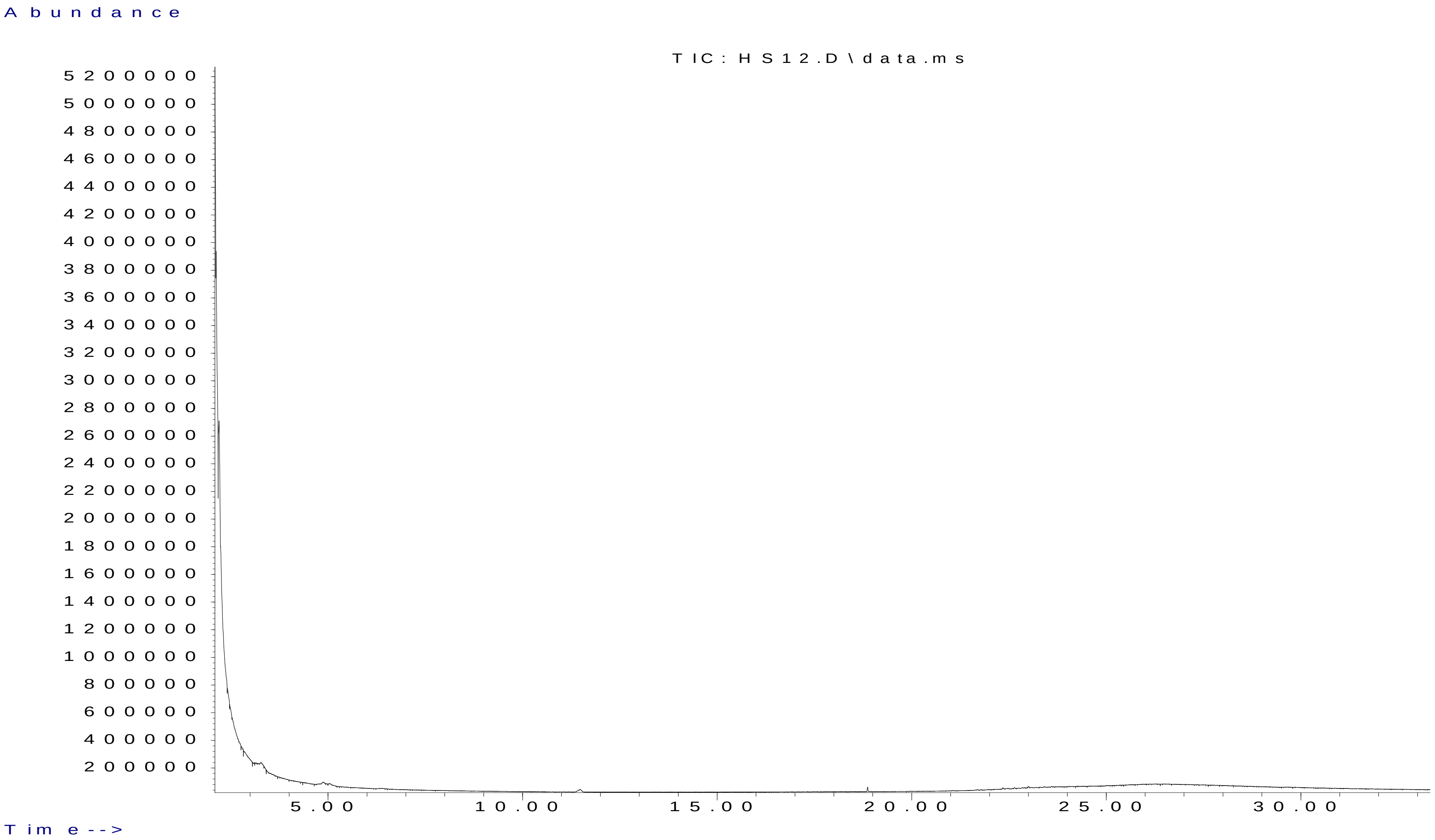


Figure C.6.96. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH sample for T.P.C. (0 m, 50 m) at depth (1.5 m), at contaminated site (Al-Magwa Area).

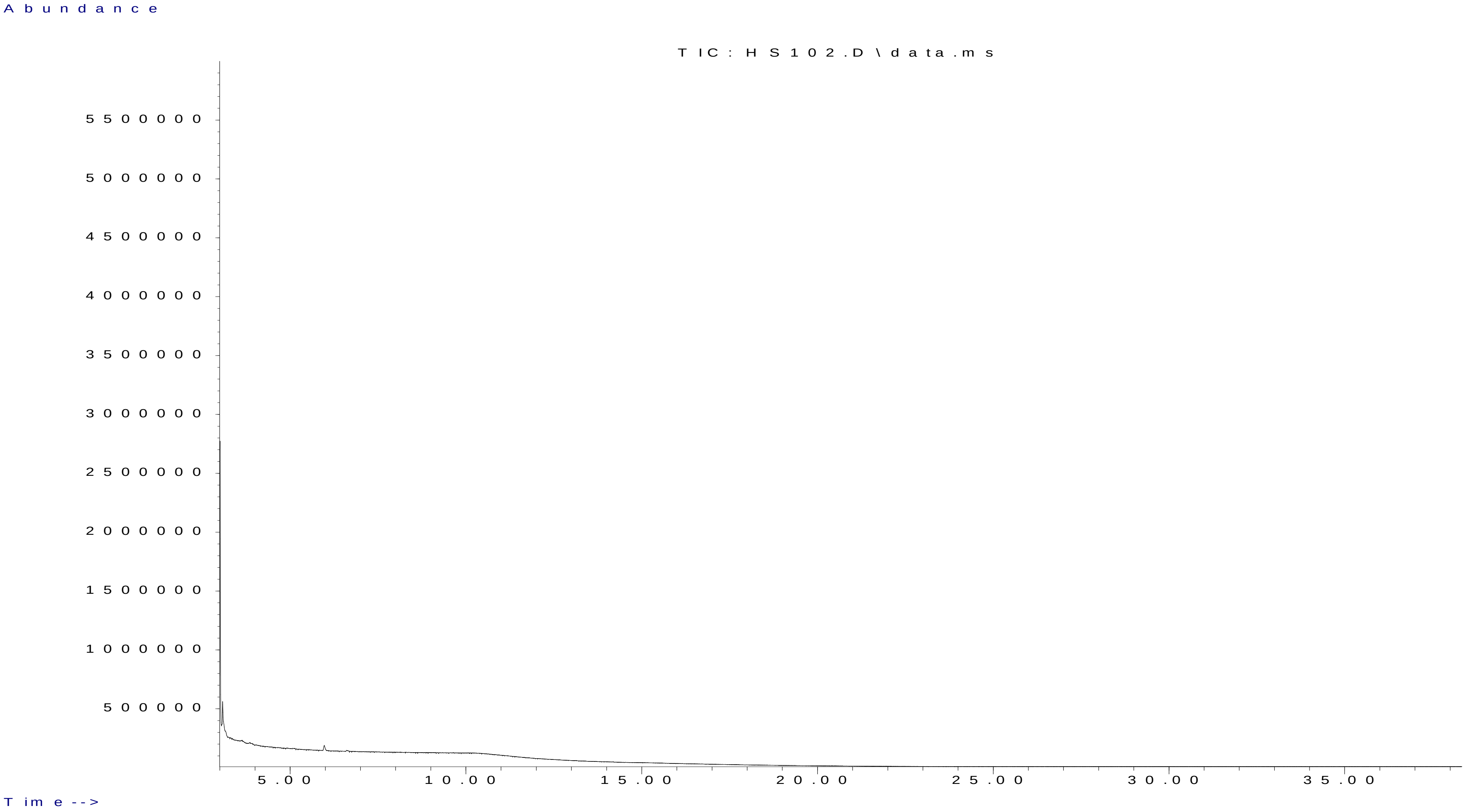


Figure C.6.97. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH sample for T.P.C. (25 m, 50 m) at depth (1.5 m), at contaminated site (Al-Magwa Area).

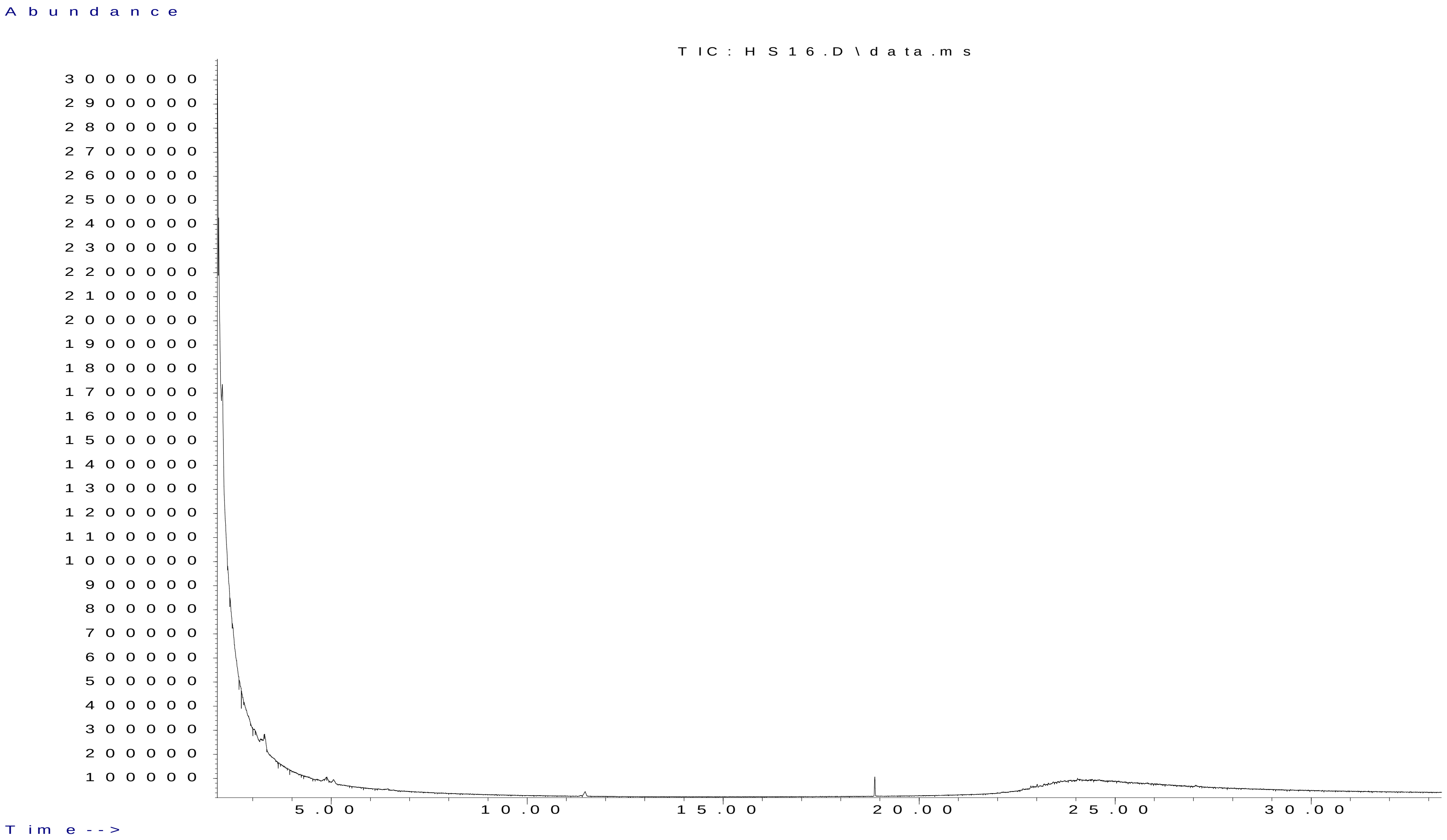


Figure C.6.98. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH sample for T.P.C. (50 m, 50 m) at depth (1.5 m), at contaminated site (Al-Magwa Area).

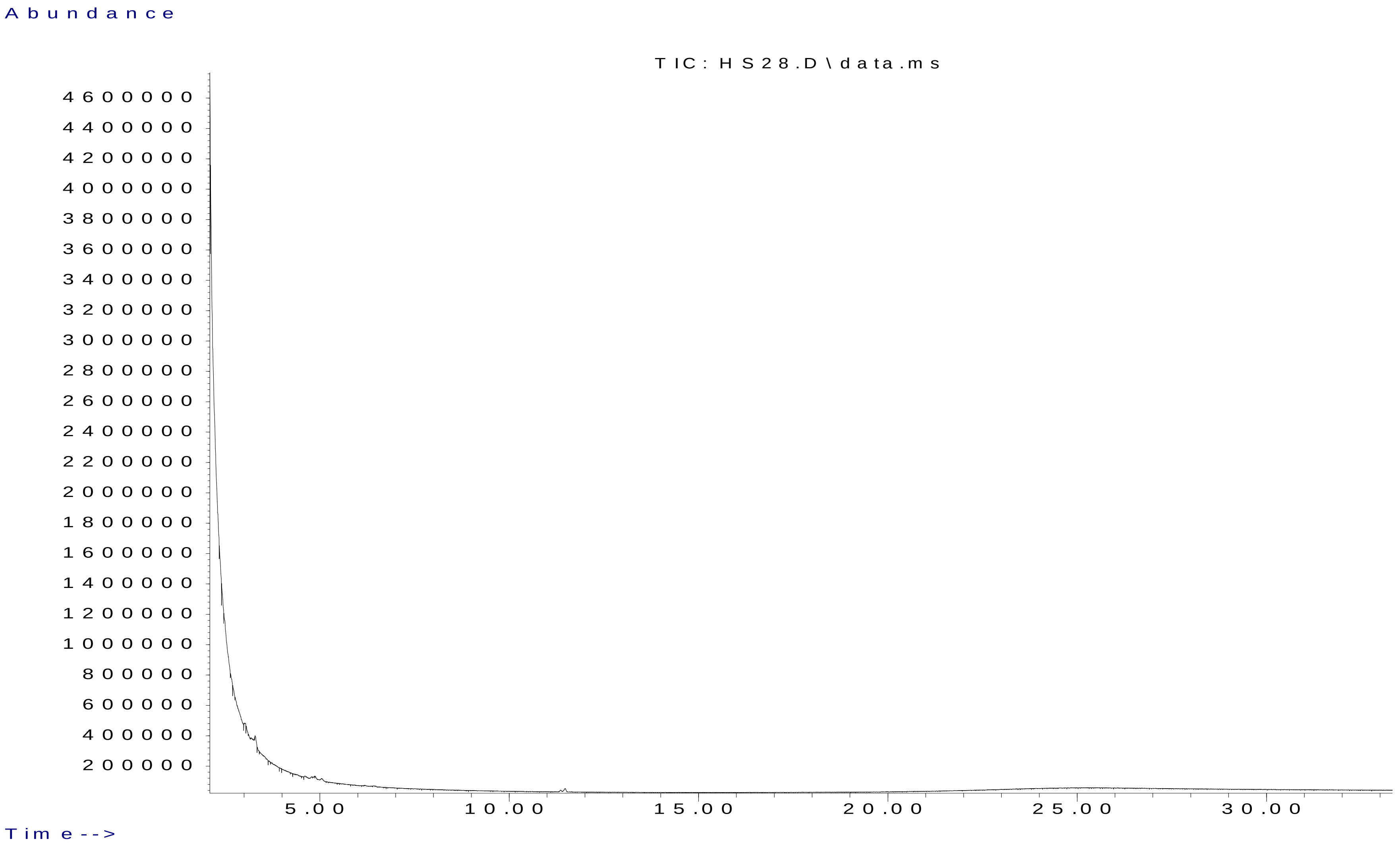


Figure C.6.99. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH sample for T.P.C. (100 m, 50 m) at depth (1.5 m), at contaminated site (Al-Magwa Area).

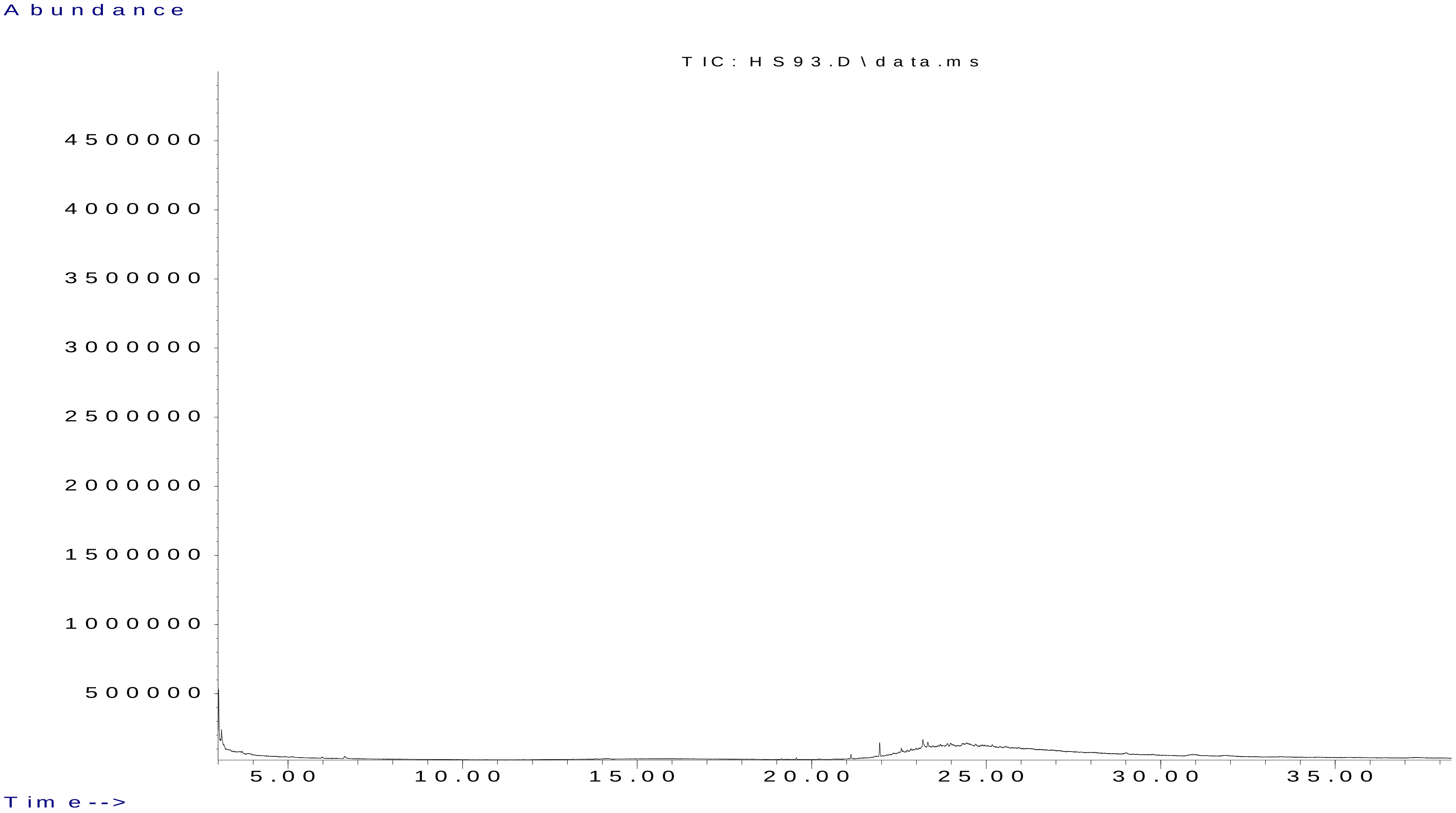


Figure C.6.100. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH sample for T.P.C. (0 m, 75 m) at depth (1.5 m), at contaminated site (Al-Magwa Area).

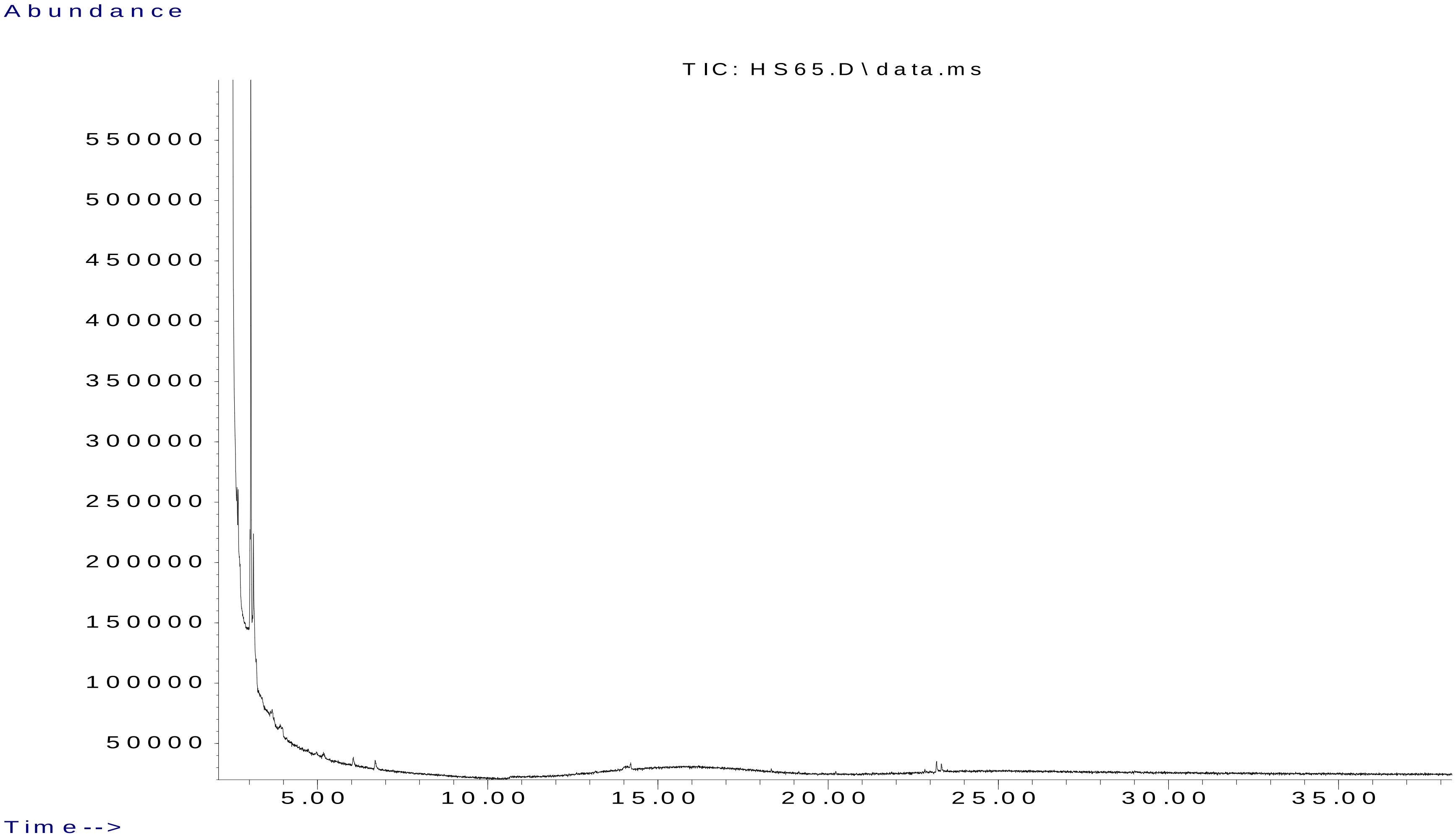


Figure C.6.101. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH sample for T.P.C. (25 m, 75 m) at depth (1.5 m), at contaminated site (Al-Magwa Area).

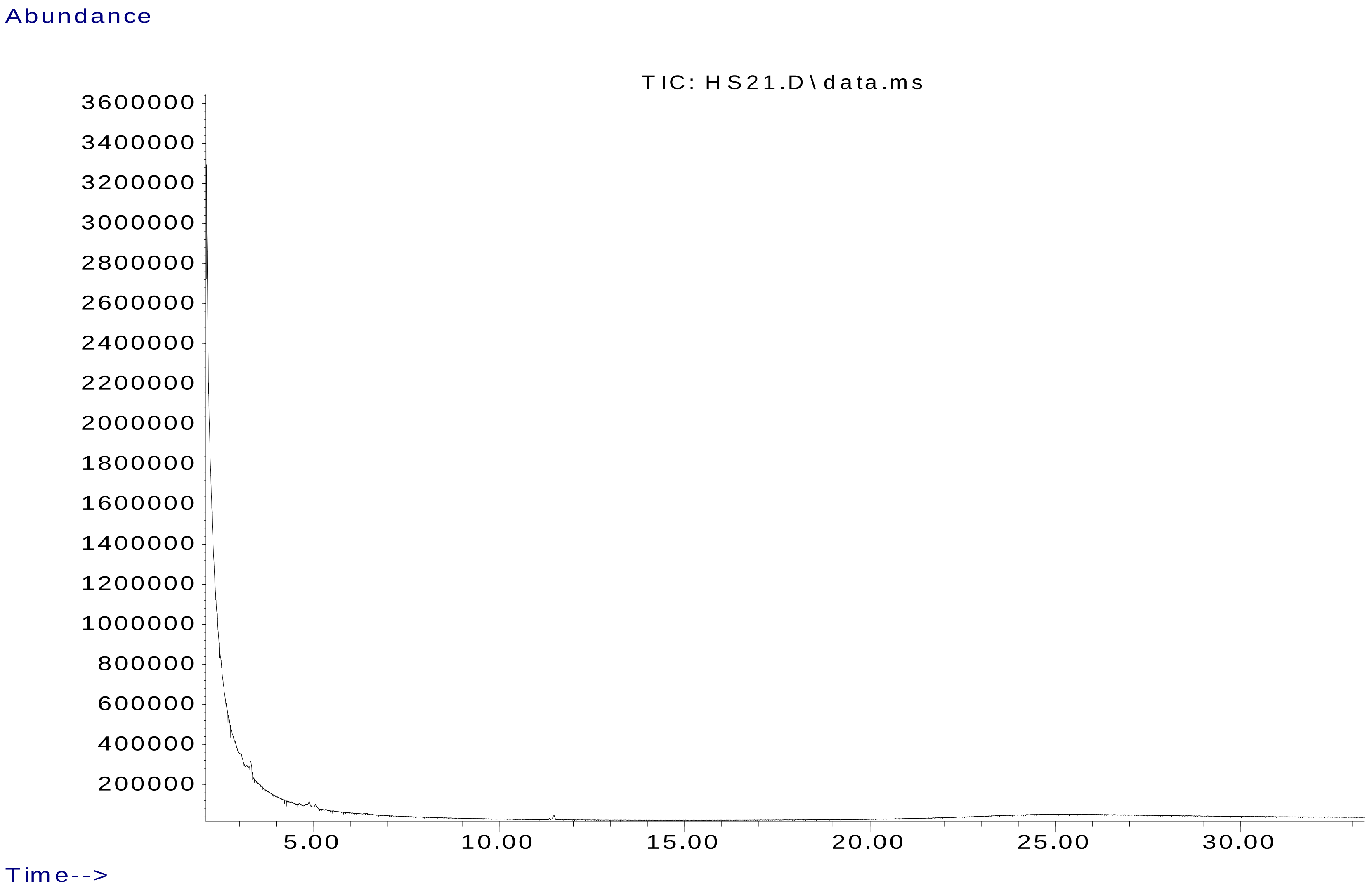


Figure C.6.102. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH sample for T.P.C. (50 m, 75 m) at depth (1.5 m), at contaminated site (Al-Magwa Area).

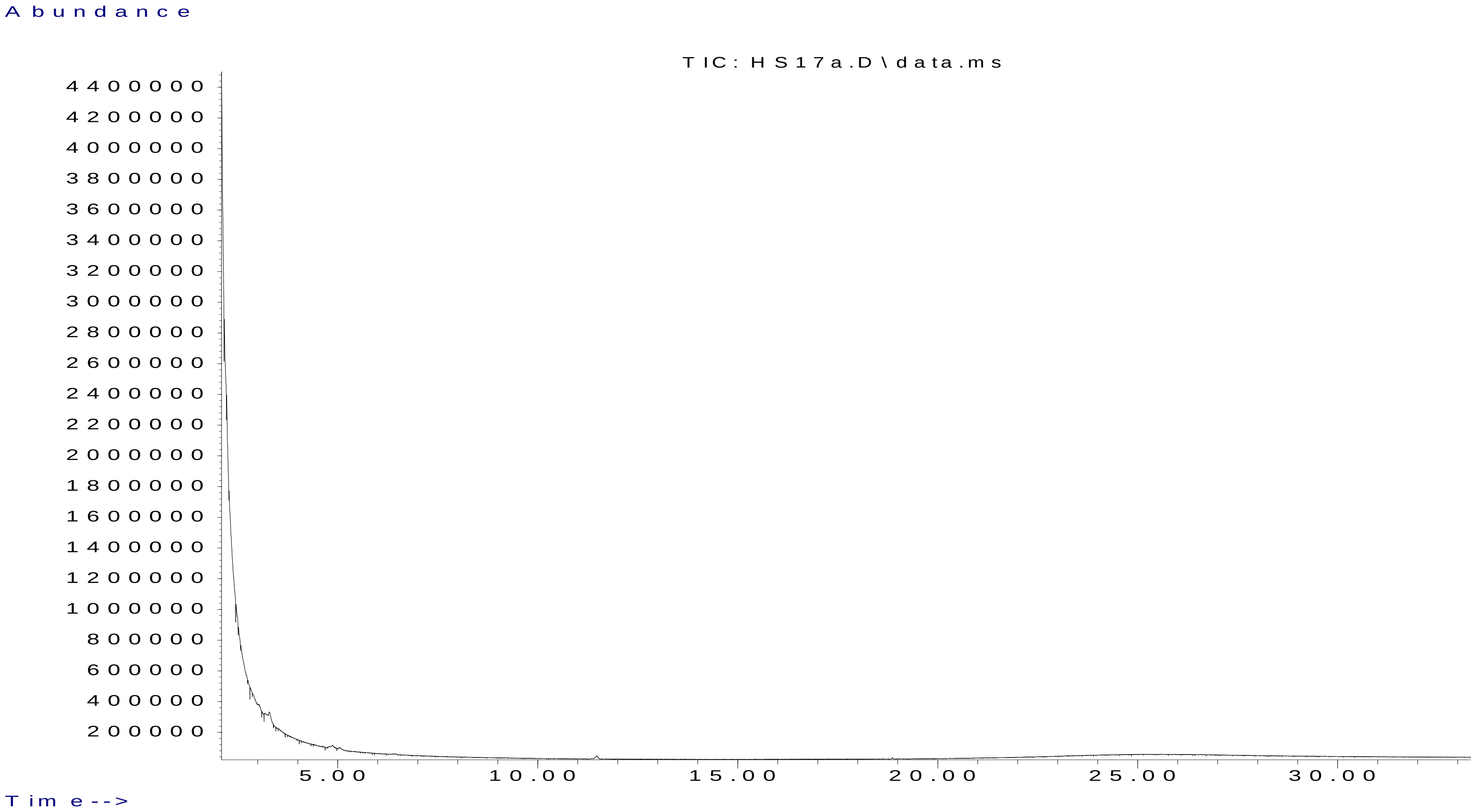


Figure C.6.103. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH sample for T.P.C. (75 m, 75 m) at depth (1.5 m), at contaminated site (Al-Magwa Area).

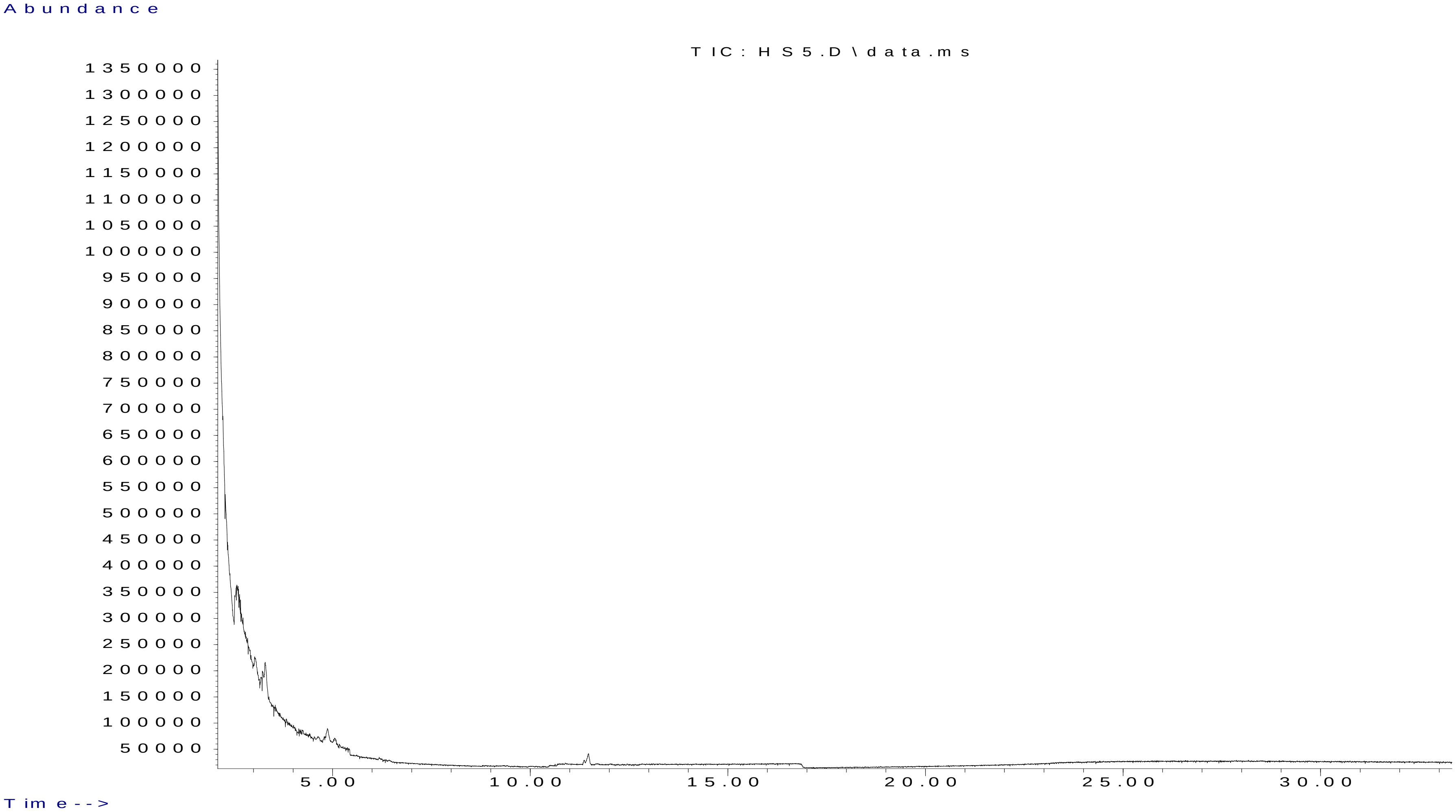


Figure C.6.104. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH sample for T.P.C. (100 m, 75 m) at depth (1.5 m), at contaminated site (Al-Magwa Area).

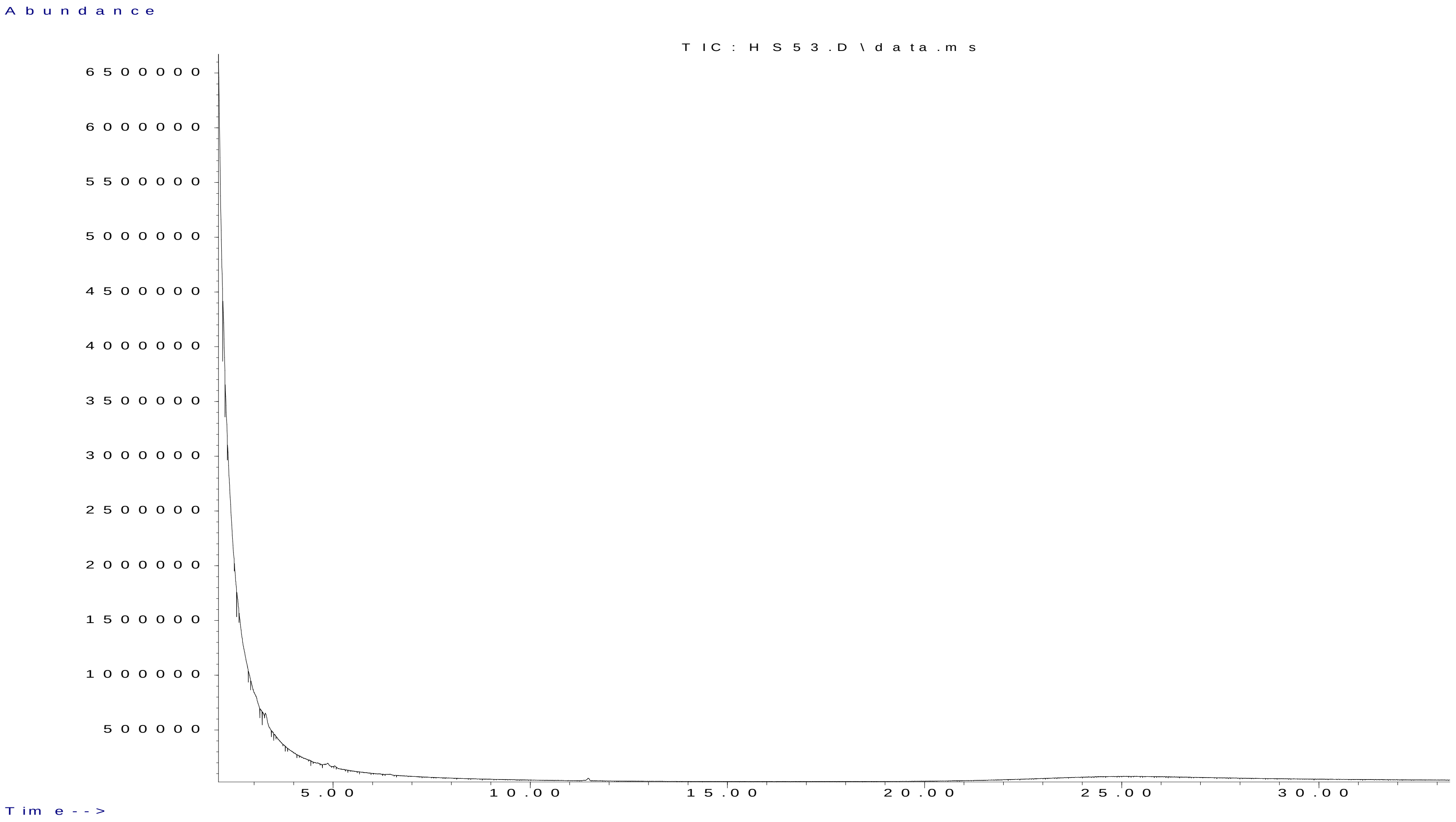


Figure C.6.105. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH sample for T.P.C. (0 m, 100 m) at depth (1.5 m), at contaminated site (Al-Magwa Area).

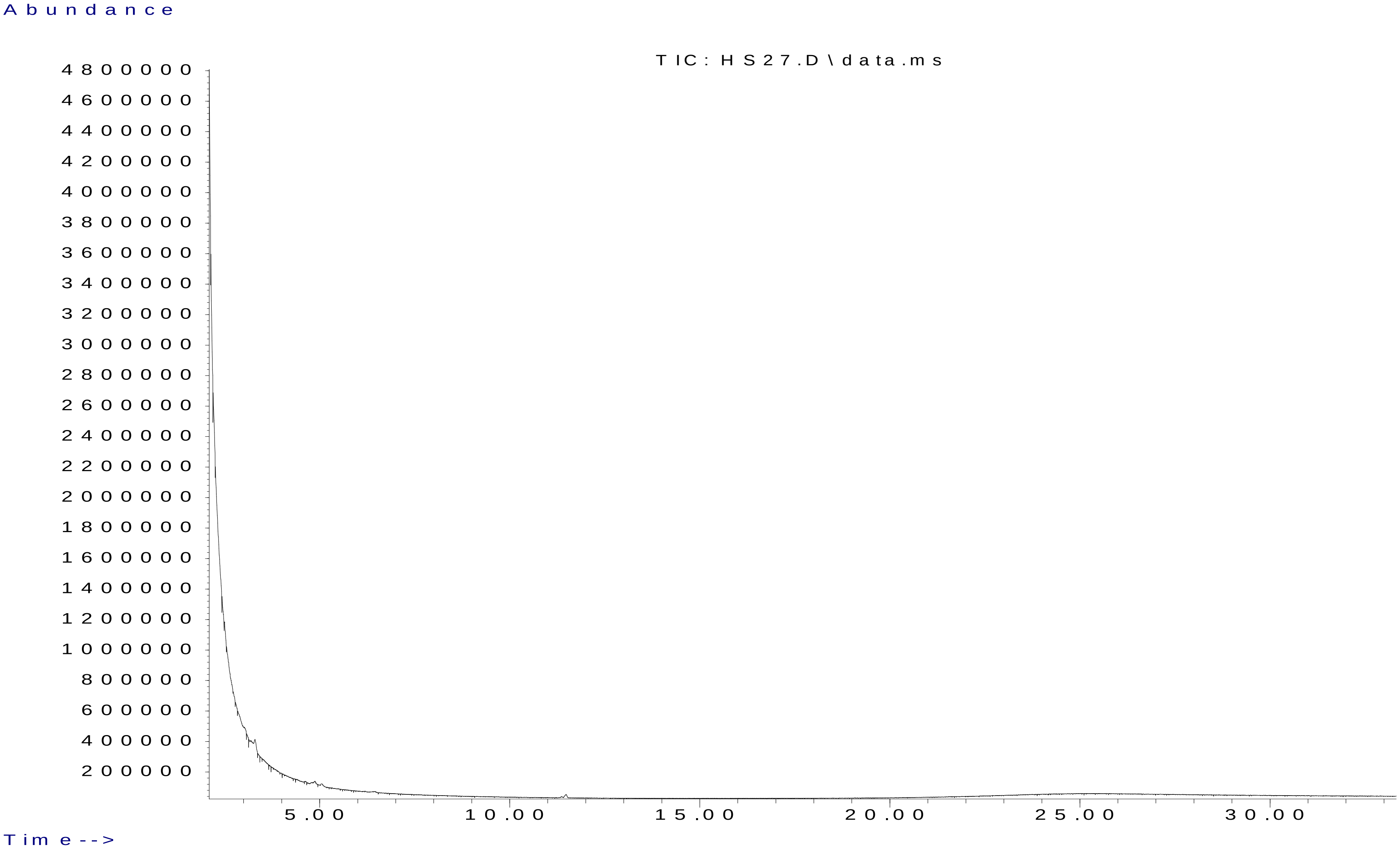


Figure C.6.106. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH sample for T.P.C. (50 m, 100 m) at depth (1.5 m), at contaminated site (Al-Magwa Area).

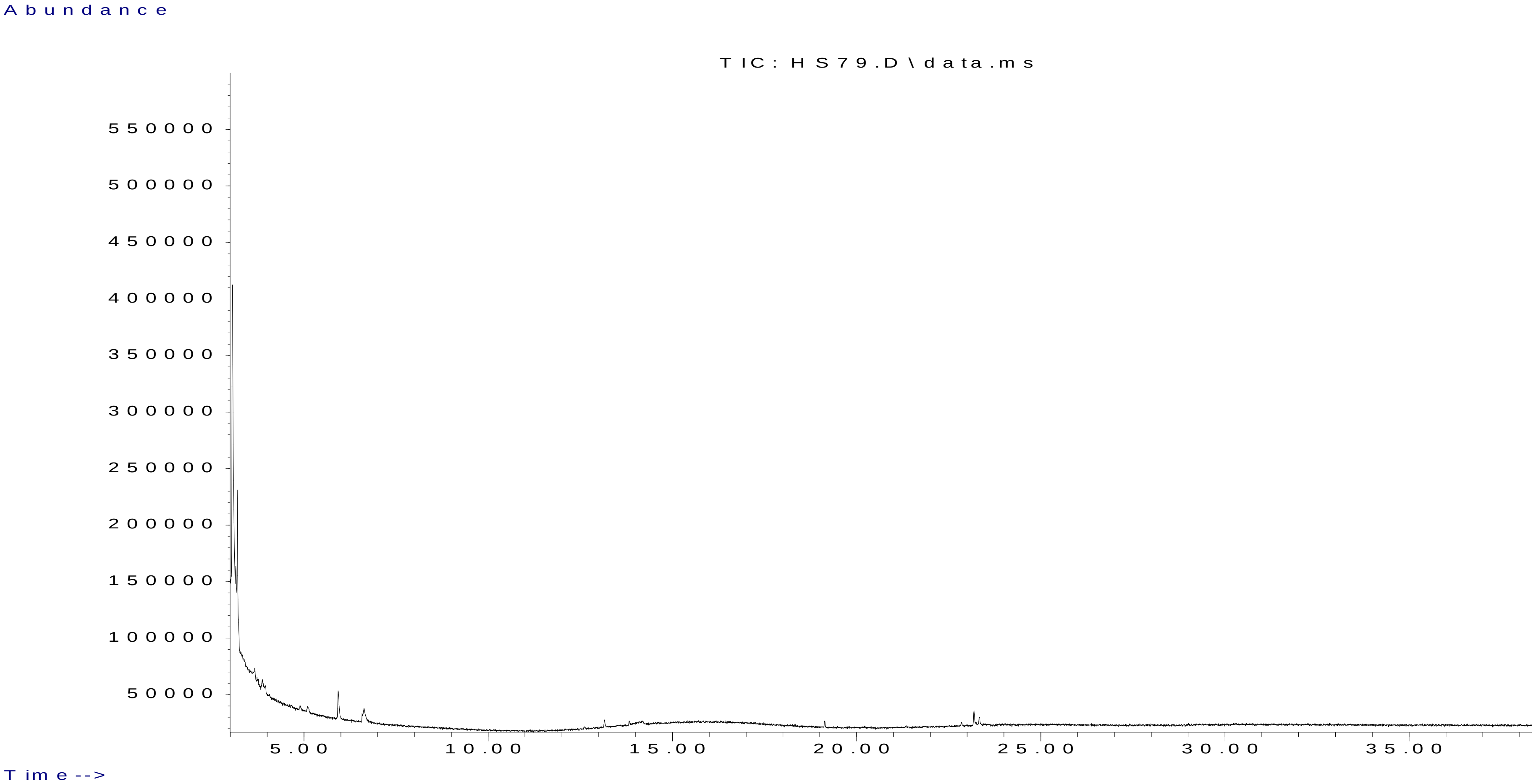


Figure C.6.107. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH sample for T.P.C. (75 m, 100 m) at depth (1.5 m), at contaminated site (Al-Magwa Area).

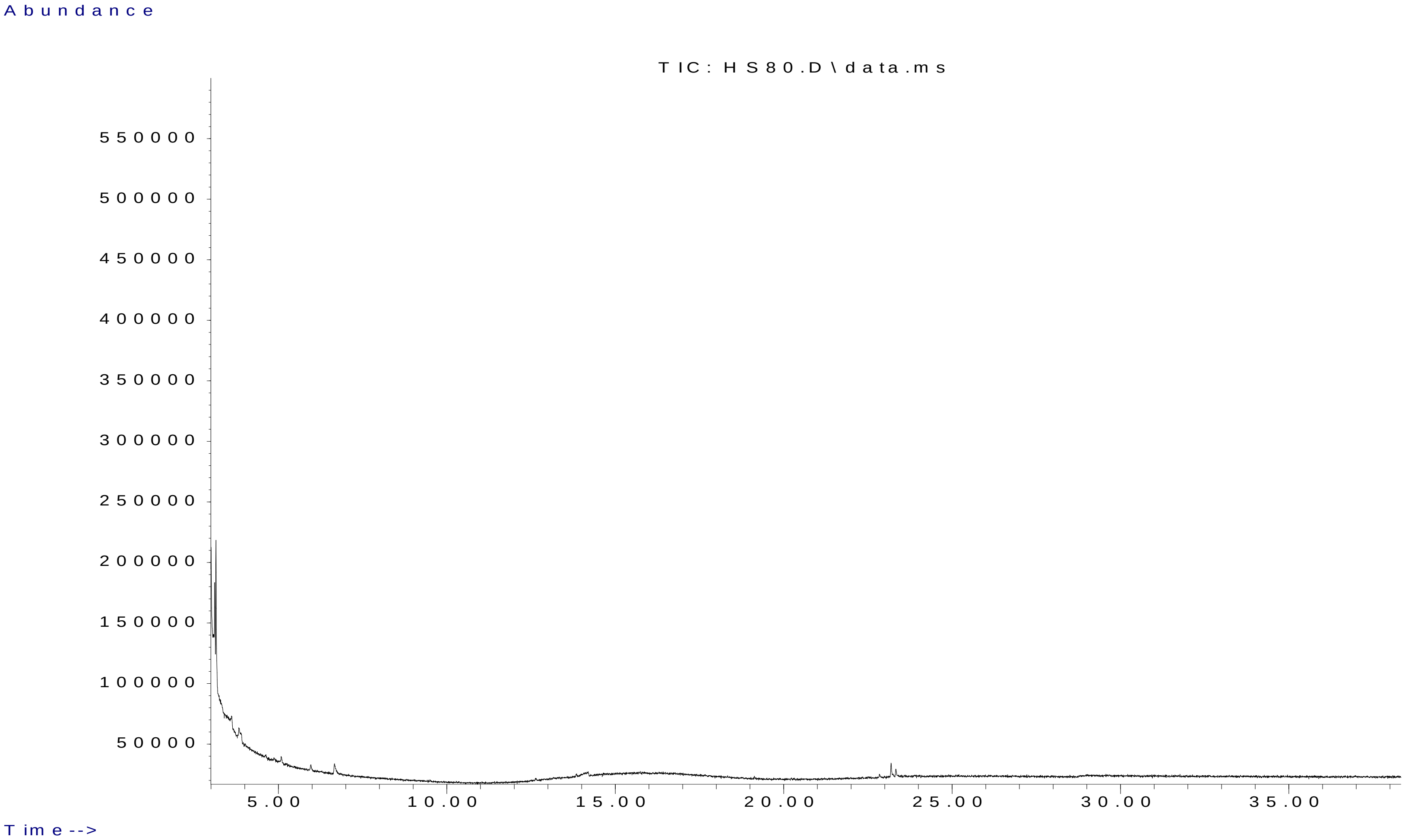


Figure C.6.108. Shows the Total Ion Chromatograms (TIC) for not detected soil sample with TPH sample for T.P.C. (100 m, 100 m) at depth (1.5 m), at contaminated site (Al-Magwa Area).

For Non-Contaminated Samples at depth (0.0 m)

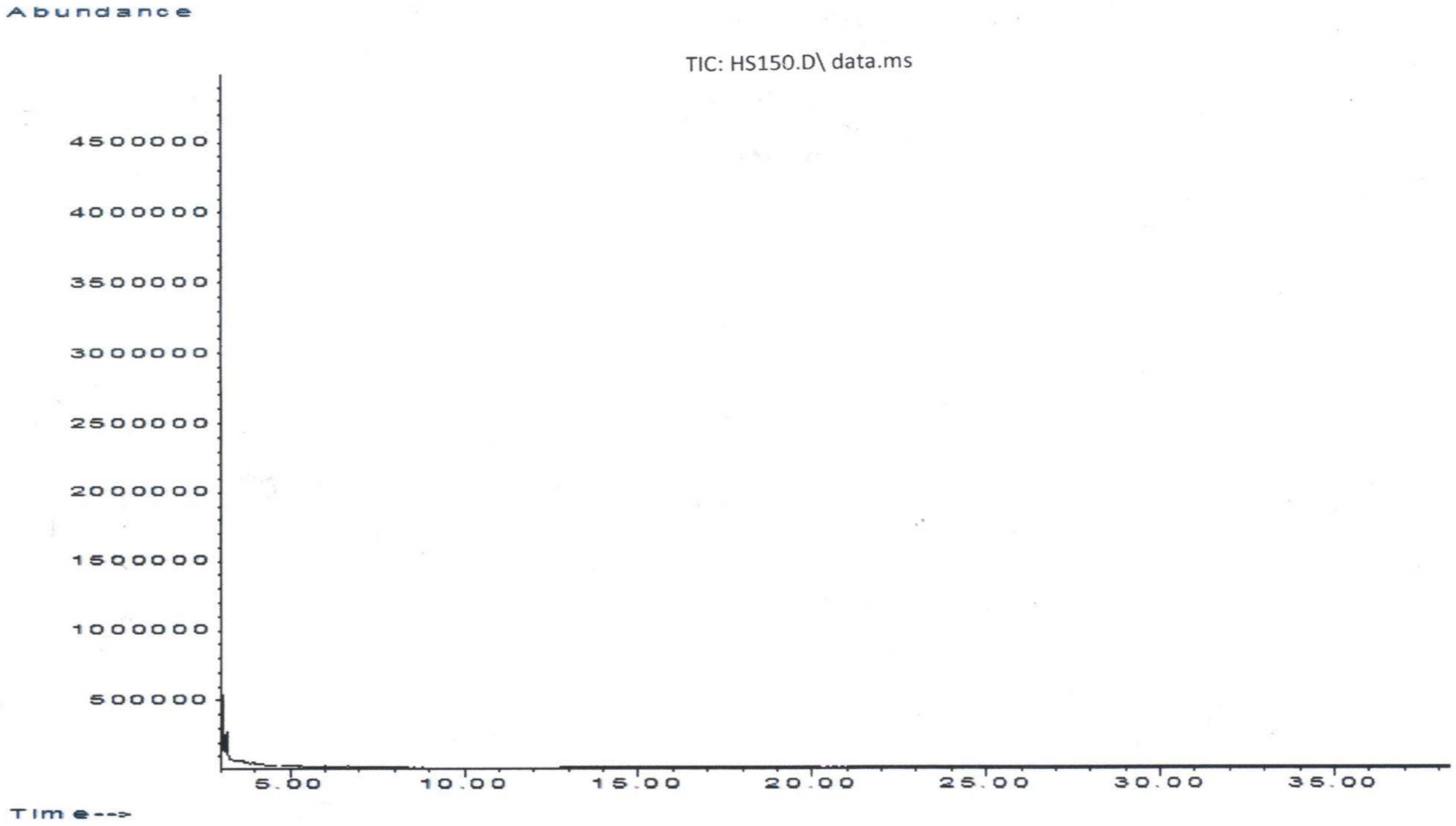


Figure C.6.109. Shows the Total Ion Chromatograms (TIC) of non-contaminated soil sample that found to be not detected with TPH for T.P.C. (0 m, 0 m) at depth (0.0 m), at non-contaminated site (Al-Magwa Area).

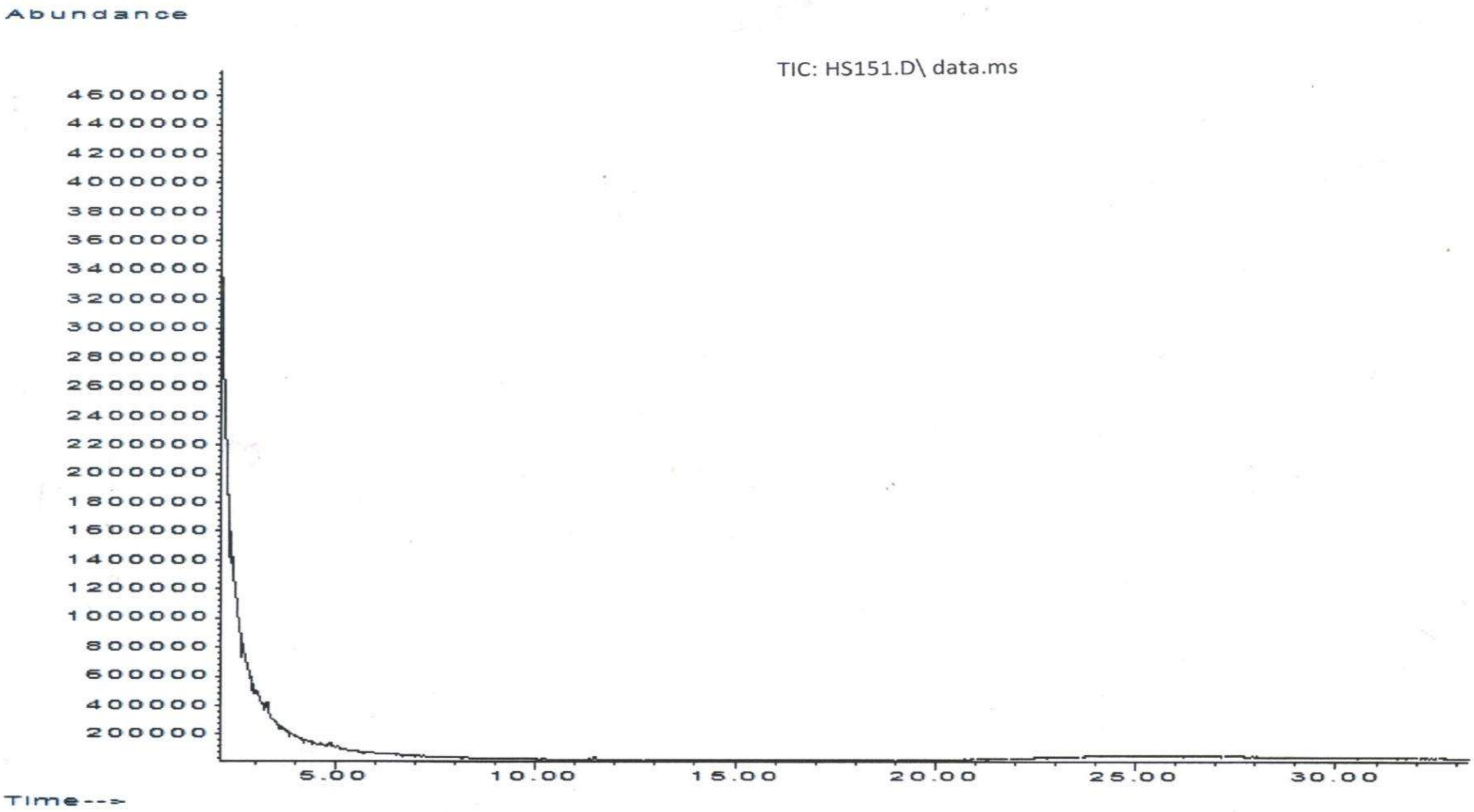


Figure C.6.110. Shows the Total Ion Chromatograms (TIC) of non-contaminated soil sample that found to be not detected with TPH for T.P.C. (100 m, 0 m) at depth (0.0 m), at non-contaminated site (Al-Magwa Area).

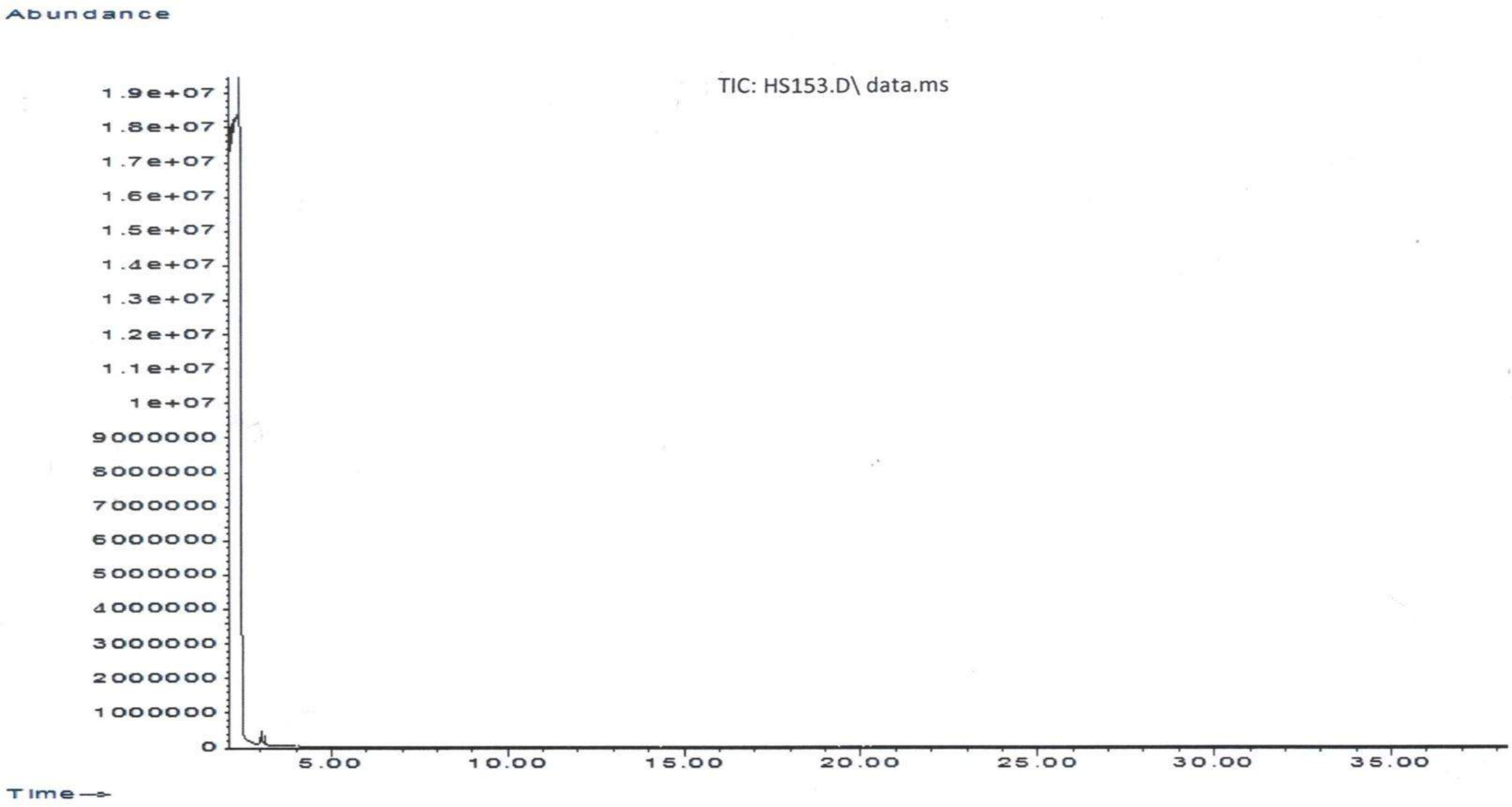


Figure C.6.111. Shows the Total Ion Chromatograms (TIC) of non-contaminated soil sample that found to be not detected with TPH for T.P.C. (0 m, 100 m) at depth (0.0 m), at non-contaminated site (Al-Magwa Area).

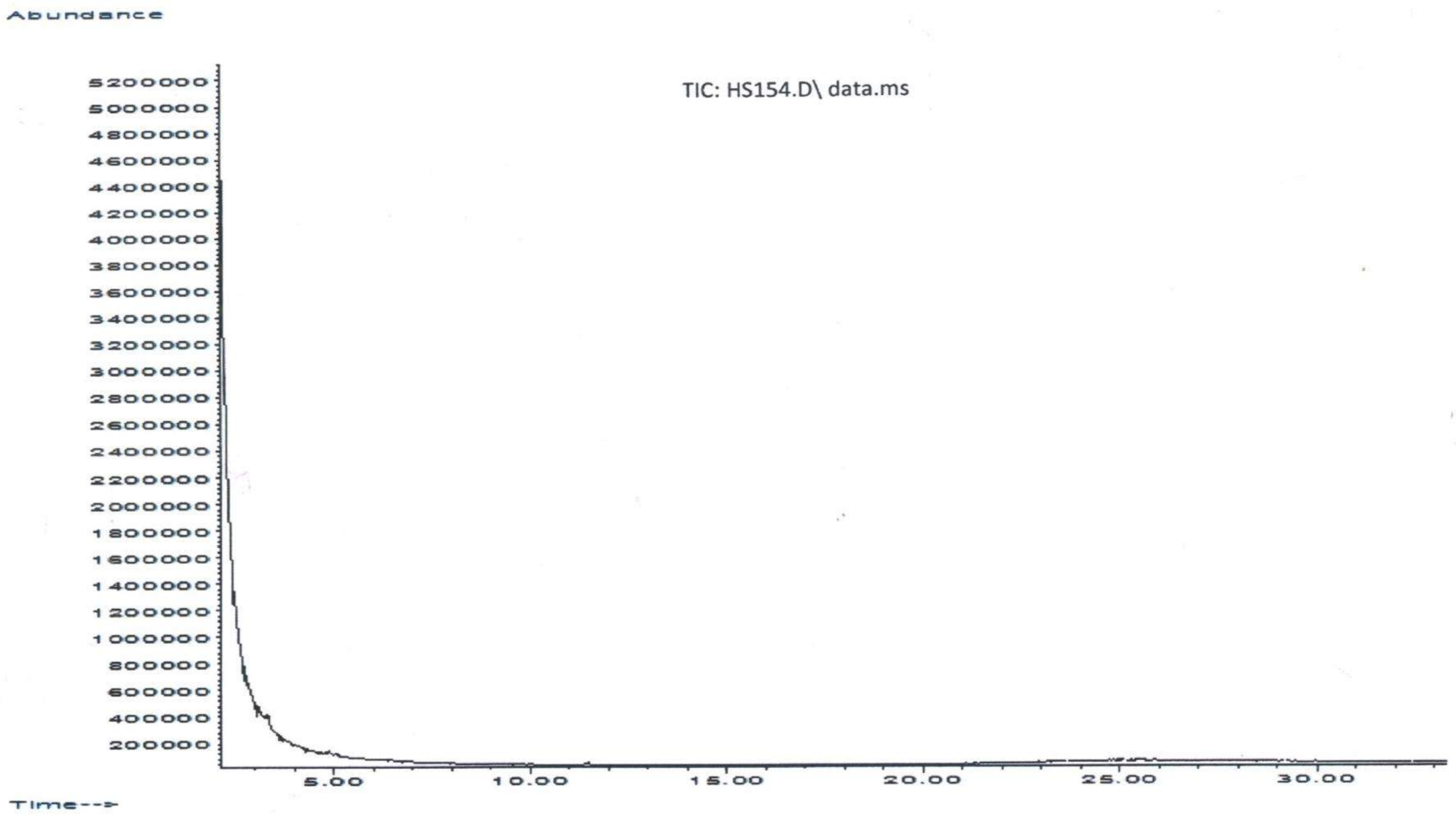


Figure C.6.112. Shows the Total Ion Chromatograms (TIC) of non-contaminated soil sample that found to be not detected with TPH for T.P.C. (100 m, 100 m) at depth (0.0 m), at non-contaminated site (Al-Magwa Area).

For Non-Contaminated Samples at depth (0.25m)

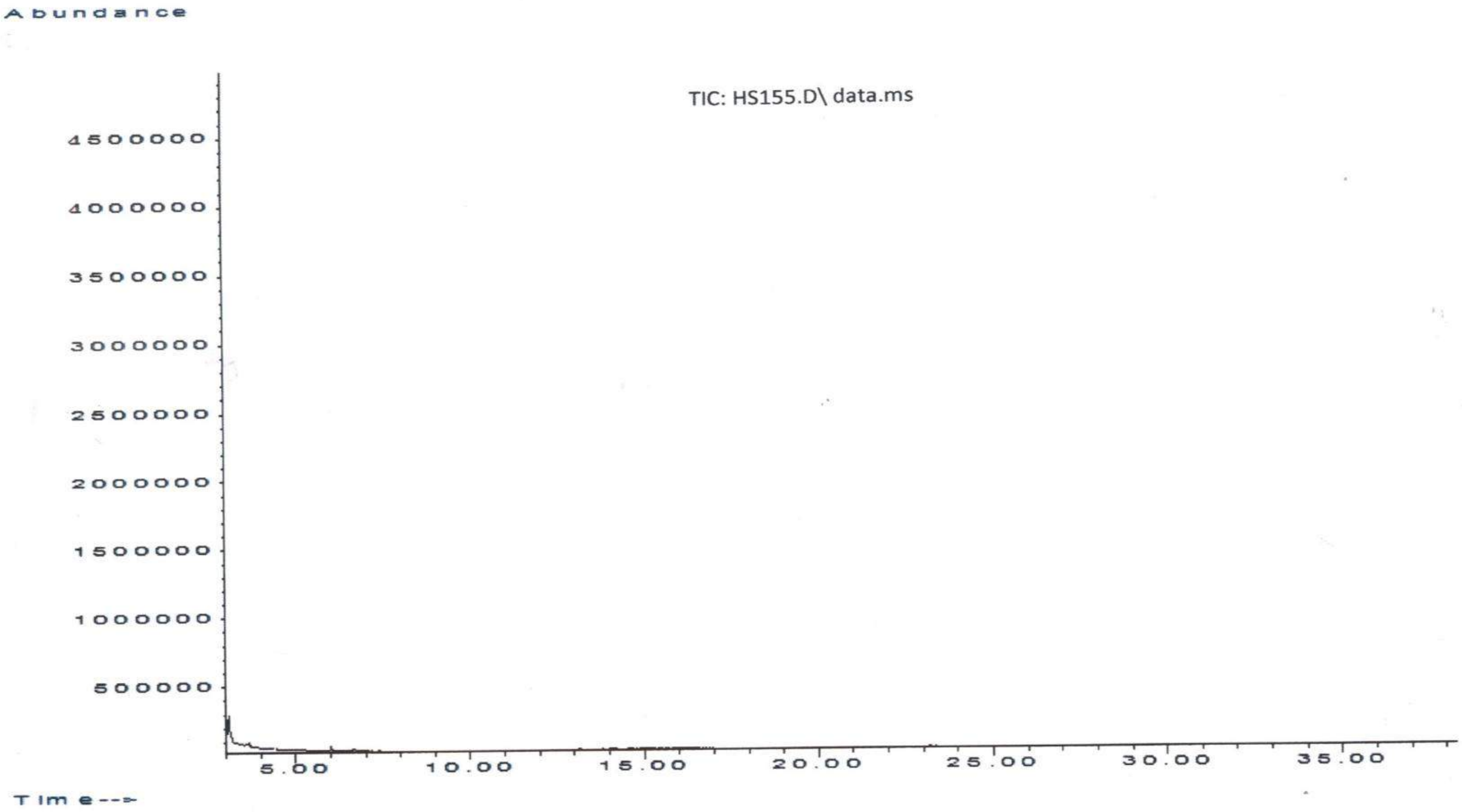


Figure C.6.113. Shows the Total Ion Chromatograms (TIC) of non-contaminated soil sample that found to be not detected with TPH for T.P.C. (0 m, 0 m) at depth (0.25 m), at non-contaminated site in Greater Burgan Oil Field (Al-Magwa Area).

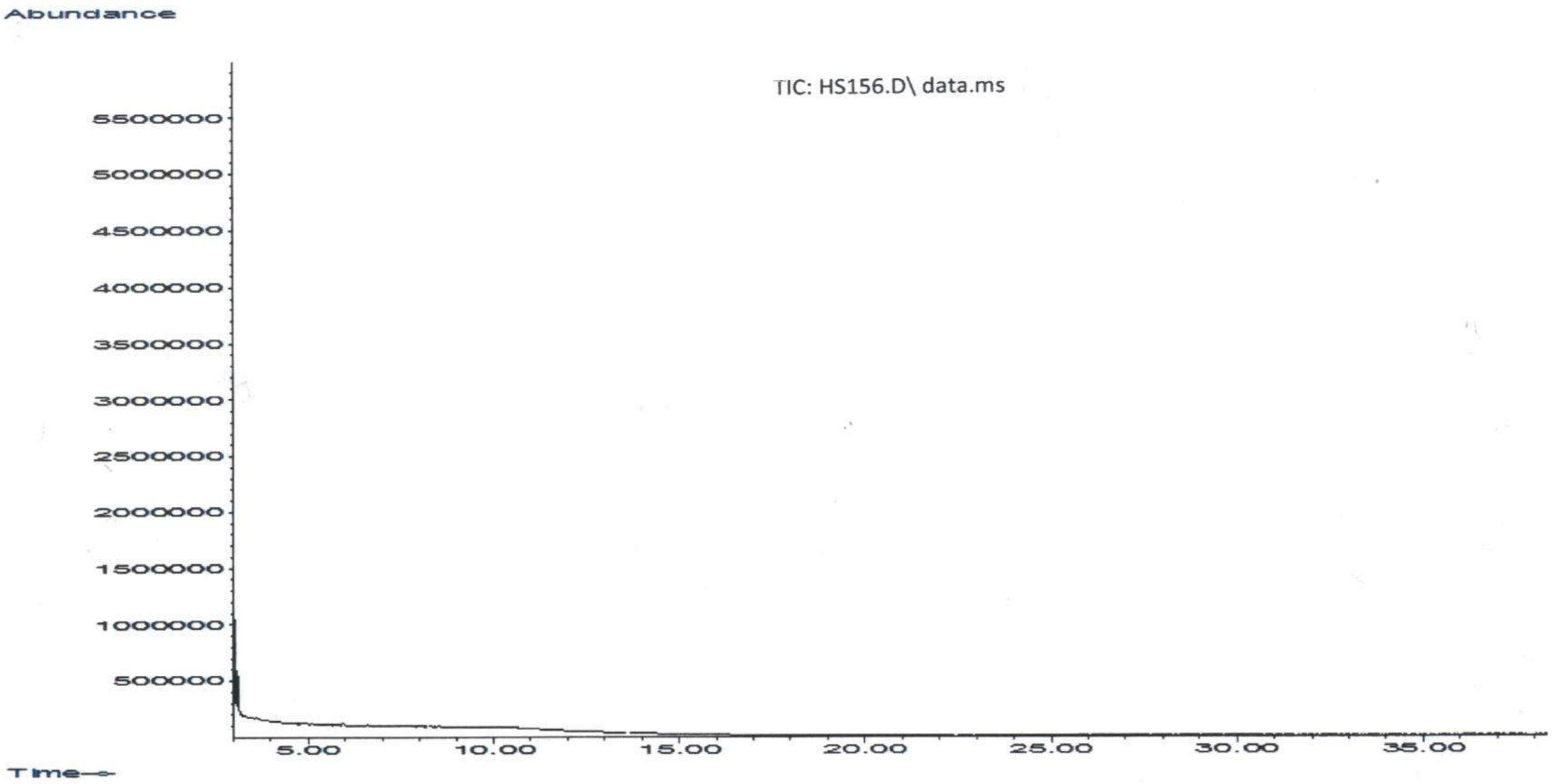


Figure C.6.114. Shows the Total Ion Chromatograms (TIC) of non-contaminated soil sample that found to be not detected with TPH for coordinate (100 m, 0 m) at depth (0.25 m), at non-contaminated site (Al-Magwa Area).

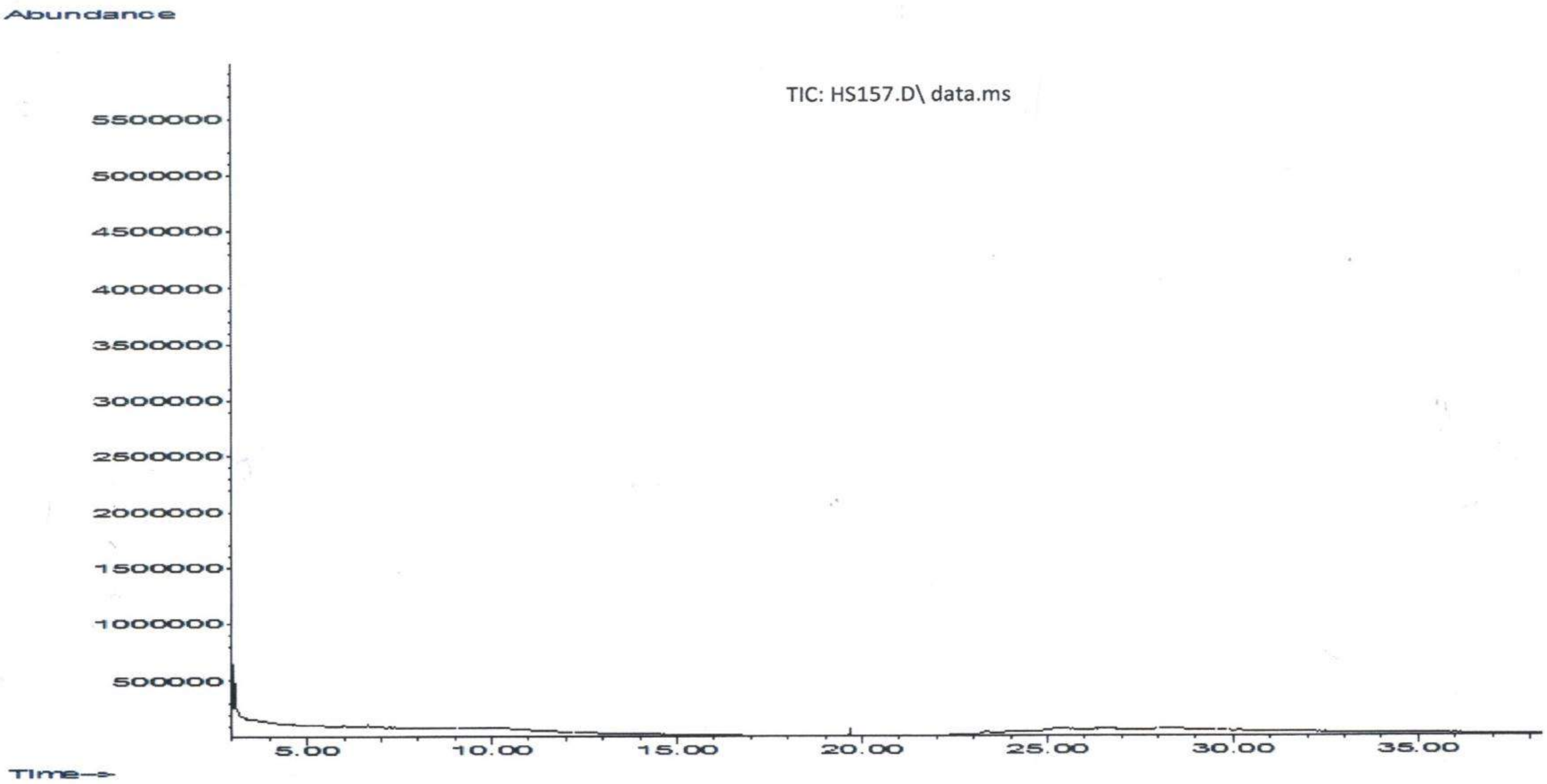


Figure C.6.115. Shows the Total Ion Chromatograms (TIC) of non-contaminated soil sample that found to be not detected with TPH for T.P.C. (50 m, 50 m) at depth (0.25 m), at non-contaminated site (Al-Magwa Area).

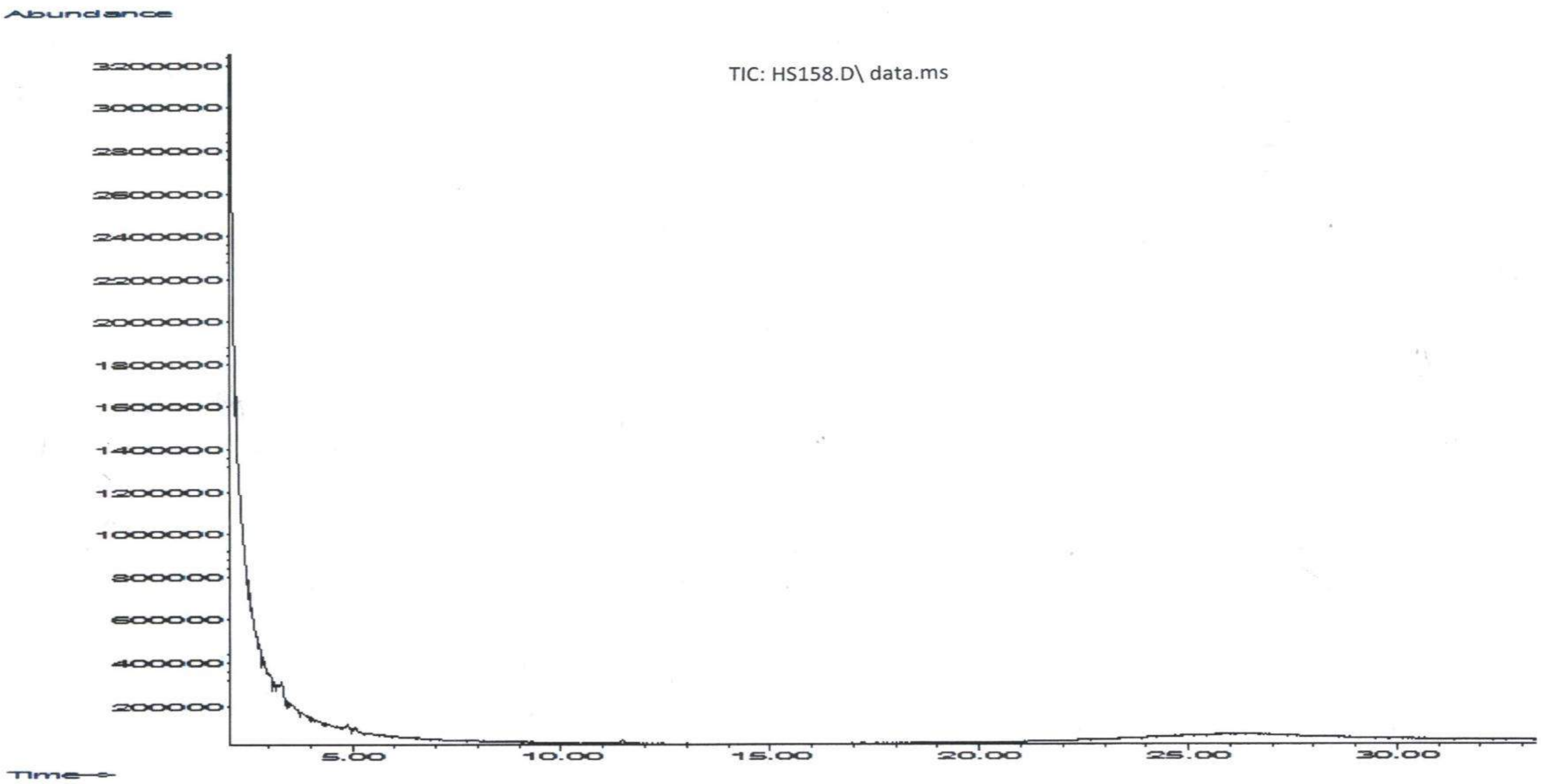


Figure C.6.116. Shows the Total Ion Chromatograms (TIC) of non-contaminated soil sample that found to be not detected with TPH for T.P.C. (0 m, 100 m) at depth (0.25 m), at non-contaminated site (Al-Magwa Area).

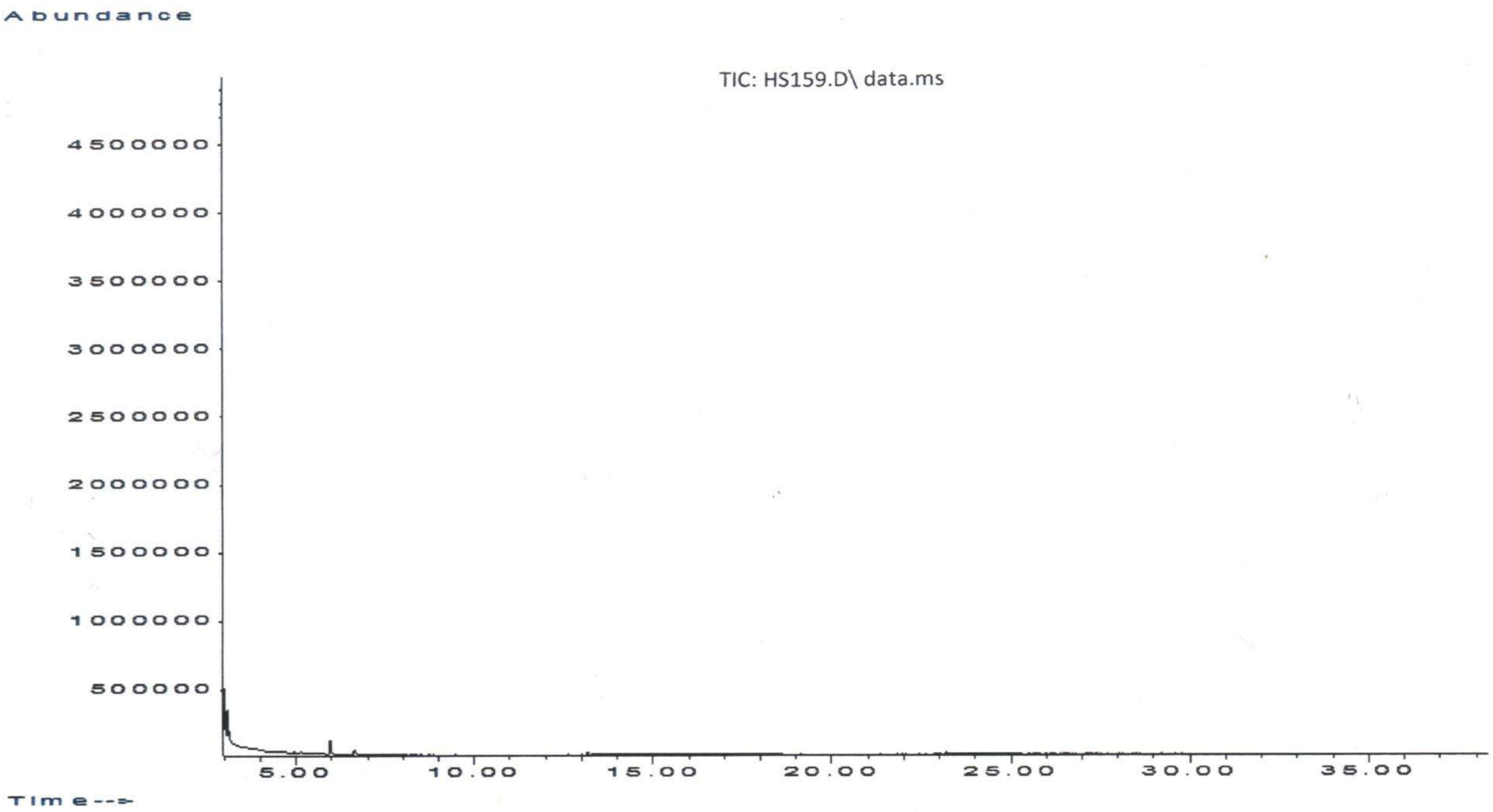


Figure C.6.117. Shows the Total Ion Chromatograms (TIC) of non-contaminated soil sample that found to be not detected with TPH for T.P.C. (100 m, 100 m) at depth (0.25 m), at non-contaminated site (Al-Magwa Area).

Table C.6.48. TPH concentration (mg/kg) for contaminated samples at depth (0.0 m).

Trial Pits Coordinates. (T.P.Cs)	**TPH Concentration in the soil samples (mg/kg)**
(0 m, 0 m)	*ND
(25m, 0 m)	*ND
(50m, 0 m)	*ND
(75m, 0 m)	53.02
(100m, 0 m)	17.801
(0 m, 25m)	352.367
(25m, 25m)	43.166
(50m, 25m)	*ND
(100m, 25m)	324.2
(0 m, 50m)	*ND
(25m, 50m)	113.93
(50m, 50m)	406.83
(100m, 50m)	1330.087
(0 m, 75m)	332.497
(25m, 75m)	35.866
(50m, 75m)	865.223
(75m, 75m)	567.336
(100m, 75m)	*ND
(0 m, 100m)	1.36
(50m, 100m)	331.608
(75m, 100m)	667.227
(100m, 100m)	214.805
Min. Value	1.36
Max. Value	1330.087
Mean Value	257.805
Standard deviation Value	345.77

Note: 1*ND: Means not detected and assumed as concentration equal to 0 mg/kg for the contour map.

Table C.6.49. TPH concentration (mg/kg) for contaminated samples at depth (0.25m).

Trial Pits Coordinates. (T.P.Cs)	**TPH Concentration in the soil samples (mg/kg)**
(0 m, 0 m)	*ND
(25 m, 0 m)	*ND
(50 m, 0 m)	*ND
(75 m, 0 m)	*ND
(100m, 0 m)	2.532
(0 m, 25 m)	42.3
(25 m, 25 m)	*ND
(50 m, 25 m)	*ND
(100 m, 25 m)	*ND
(0 m, 50 m)	*ND
(25 m, 50 m)	203.486
(50 m, 50 m)	3.506
(100 m, 50 m)	*ND
(0 m, 75 m)	225.1
(25 m, 75 m)	*ND
(50 m, 75 m)	*ND
(75 m, 75 m)	*ND
(100 m, 75 m)	1271.038
(0 m, 100 m)	*ND
(50 m, 100 m)	*ND
(75 m, 100 m)	532.378
(100 m, 100 m)	*ND
Min. Value	2.532
Max. Value	1271.038
Mean Value	103.651
Standard deviation Value	289.209

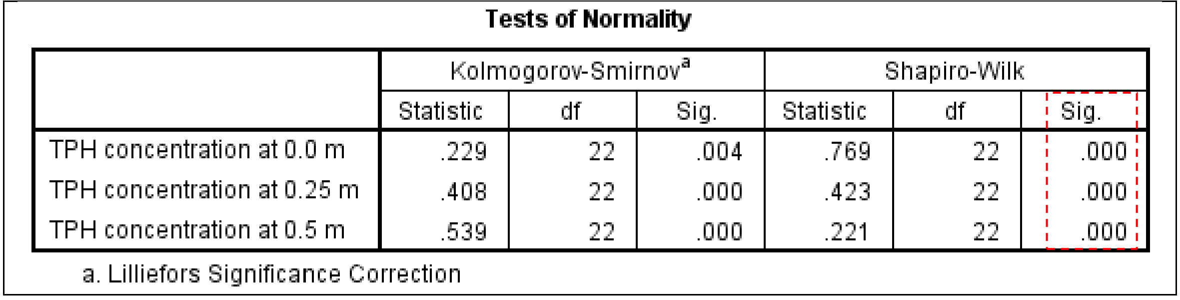
Note: *ND: Means not detected and assumed as concentration equal to 0 mg/kg for the contour map.

Table C.6.50. TPH concentration (mg/kg) for contaminated samples at depth (0.5m).

Trial Pits Coordinates. (T.P.Cs)	**TPH Concentration in the soil samples (mg/kg)**
(0 m, 0 m)	^{1*}ND
(25 m, 0 m)	^{1*}ND
(50 m, 0 m)	^{1*}ND
(75 m, 0 m)	21.86
(100 m, 0 m)	^{1*}ND
(0 m, 25 m)	^{1*}ND
(25 m, 25 m)	^{1*}ND
(50 m, 25 m)	^{1*}ND
(100 m, 25 m)	^{1*}ND
(0 m, 50 m)	^{1*}ND
(25 m, 50 m)	^{1*}ND
(50 m, 50 m)	^{1*}ND
(100 m, 50 m)	^{1*}ND
(0 m, 75 m)	^{1*}ND
(25 m, 75 m)	^{1*}ND
(50 m, 75 m)	^{1*}ND
(75 m, 75 m)	^{1*}ND
(100 m, 75 m)	^{1*}ND
(0 m, 100 m)	^{1*}ND
(50 m, 100 m)	^{1*}ND
(75 m, 100 m)	^{1*}ND
(100 m, 100 m)	^{1*}ND
Min. Value	21.86
Max. Value	21.86
Mean Value	1.0
Standard deviation Value	4.66

Note: ^{1*}***ND: Means not detected and assumed as concentration equal to 0 mg/kg for the contour map.***

Table C.6.51. The significant p-values via normality Shapiro-Wilk test indicate that the TPH values (mg/kg) of the soil at contaminated site at three different depths (0.0 m, 0.25 m & 0.5 m) follow non-normal distribution.

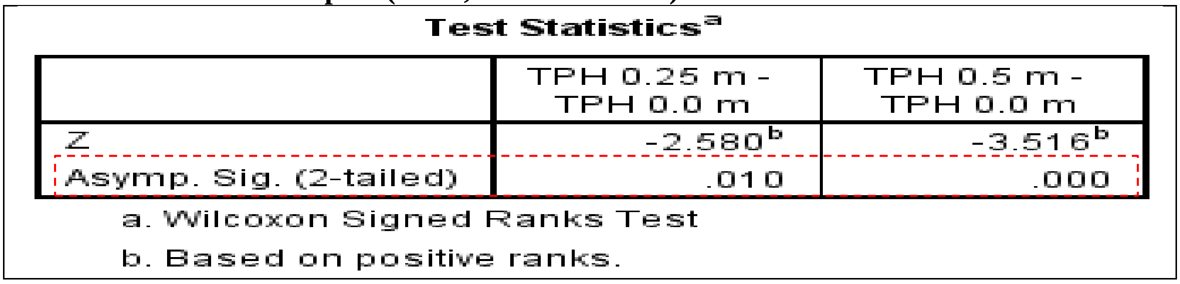


Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
TPH concentration at 0.0 m	.229	22	.004	.769	22	.000
TPH concentration at 0.25 m	.408	22	.000	.423	22	.000
TPH concentration at 0.5 m	.539	22	.000	.221	22	.000

a. Lilliefors Significance Correction

Table C.6.52. Indicates the significant difference between the TPH variable (mg/kg) in the soil between different depths (0.0 m, 0.25 m & 0.5 m) at contaminated site.



Test Statistics[a]

	TPH 0.25 m - TPH 0.0 m	TPH 0.5 m - TPH 0.0 m
Z	-2.580[b]	-3.516[b]
Asymp. Sig. (2-tailed)	.010	.000

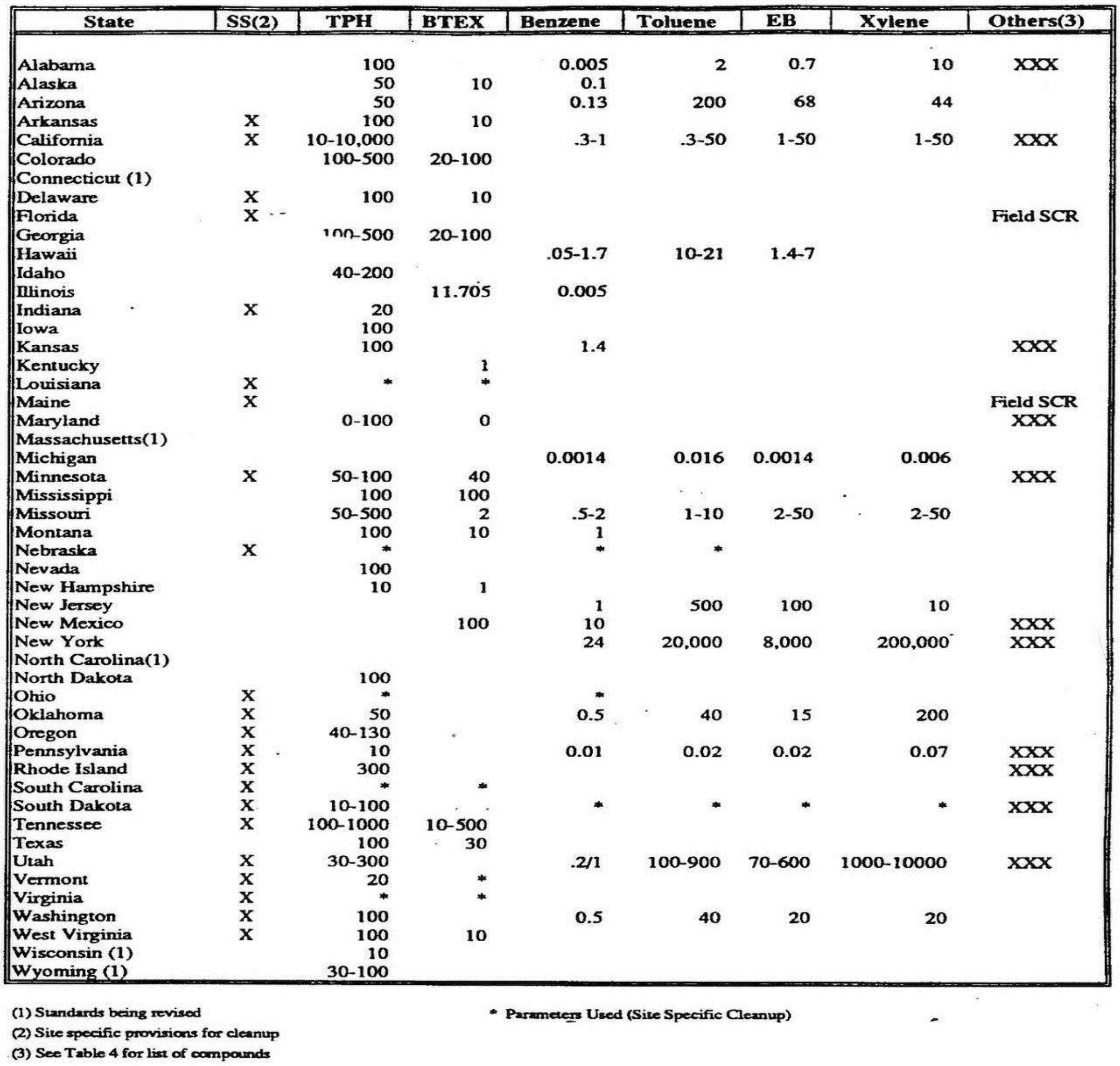
a. Wilcoxon Signed Ranks Test

b. Based on positive ranks.

APPENDIX D

7. HUMAN HEALTH RISK ASSESSMENT (HHRA) of HYDROCARBON CONTAMINATED SOILS.

Table D.7.1. The summary of Gasoline clean up levels (ppm) (AFCEE, 1996).



State	SS(2)	TPH	BTEX	Benzene	Toluene	EB	Xylene	Others(3)
Alabama		100		0.005	2	0.7	10	XXX
Alaska		50	10	0.1				
Arizona		50		0.13	200	68	44	
Arkansas	X	100	10					
California	X	10-10,000		.3-1	.3-50	1-50	1-50	XXX
Colorado		100-500	20-100					
Connecticut (1)								
Delaware	X	100	10					
Florida	X							Field SCR
Georgia		100-500	20-100					
Hawaii				.05-1.7	10-21	1.4-7		
Idaho		40-200						
Illinois			11.705	0.005				
Indiana	X	20						
Iowa		100						
Kansas		100		1.4				XXX
Kentucky			1					
Louisiana	X	*	*					
Maine	X							Field SCR
Maryland		0-100	0					XXX
Massachusetts(1)								
Michigan				0.0014	0.016	0.0014	0.006	
Minnesota	X	50-100	40					XXX
Mississippi		100	100					
Missouri		50-500	2	.5-2	1-10	2-50	2-50	
Montana		100	10	1				
Nebraska	X	*		*	*			
Nevada		100						
New Hampshire		10	1					
New Jersey				1	500	100	10	
New Mexico			100	10				XXX
New York				24	20,000	8,000	200,000	XXX
North Carolina(1)								
North Dakota		100						
Ohio	X	*		*				
Oklahoma	X	50		0.5	40	15	200	
Oregon	X	40-130						
Pennsylvania	X	10		0.01	0.02	0.02	0.07	XXX
Rhode Island	X	300						XXX
South Carolina	X	*	*					
South Dakota	X	10-100		*	*	*	*	XXX
Tennessee	X	100-1000	10-500					
Texas		100	30					
Utah	X	30-300		.2/1	100-900	70-600	1000-10000	XXX
Vermont	X	20	*					
Virginia	X	*	*					
Washington	X	100		0.5	40	20	20	
West Virginia	X	100	10					
Wisconsin (1)		10						
Wyoming (1)		30-100						

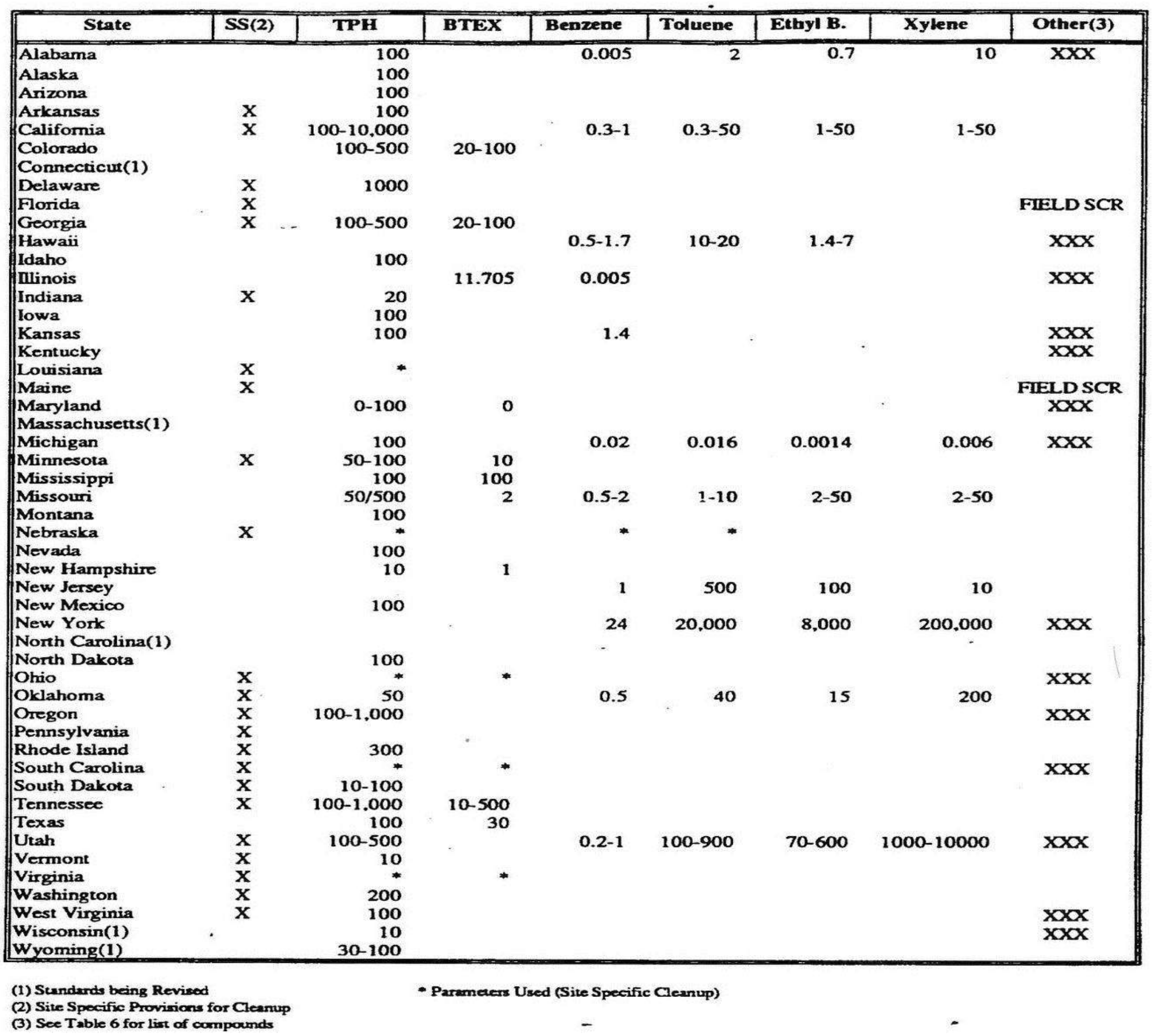
(1) Standards being revised

(2) Site specific provisions for cleanup

(3) See Table 4 for list of compounds

* Parameters Used (Site Specific Cleanup)

Table D.7.2. The summary of Diesel clean up levels (ppm) (AFCEE, 1996).



State	SS(2)	TPH	BTEX	Benzene	Toluene	Ethyl B.	Xylene	Other(3)
Alabama		100		0.005	2	0.7	10	XXX
Alaska		100						
Arizona		100						
Arkansas	X	100						
California	X	100-10,000		0.3-1	0.3-50	1-50	1-50	
Colorado		100-500	20-100					
Connecticut(1)								
Delaware	X	1000						
Florida	X							FIELD SCR
Georgia	X	100-500	20-100					
Hawaii				0.5-1.7	10-20	1.4-7		XXX
Idaho		100						
Illinois			11.705	0.005				XXX
Indiana	X	20						
Iowa		100						
Kansas		100		1.4				XXX
Kentucky								XXX
Louisiana	X	*						
Maine	X							FIELD SCR
Maryland		0-100	0					XXX
Massachusetts(1)								
Michigan		100		0.02	0.016	0.0014	0.006	XXX
Minnesota	X	50-100	10					
Mississippi		100	100					
Missouri		50/500	2	0.5-2	1-10	2-50	2-50	
Montana		100						
Nebraska	X	*		*	*			
Nevada		100						
New Hampshire		10	1					
New Jersey				1	500	100	10	
New Mexico		100						
New York				24	20,000	8,000	200,000	XXX
North Carolina(1)								
North Dakota		100						
Ohio	X	*	*					XXX
Oklahoma	X	50		0.5	40	15	200	
Oregon	X	100-1,000						XXX
Pennsylvania	X							
Rhode Island	X	300						
South Carolina	X	*	*					XXX
South Dakota	X	10-100						
Tennessee	X	100-1,000	10-500					
Texas		100	30					
Utah	X	100-500		0.2-1	100-900	70-600	1000-10000	XXX
Vermont	X	10						
Virginia	X	*	*					
Washington	X	200						
West Virginia	X	100						XXX
Wisconsin(1)		10						XXX
Wyoming(1)		30-100						

(1) Standards being Revised
(2) Site Specific Provisions for Cleanup
(3) See Table 6 for list of compounds

* Parameters Used (Site Specific Cleanup)

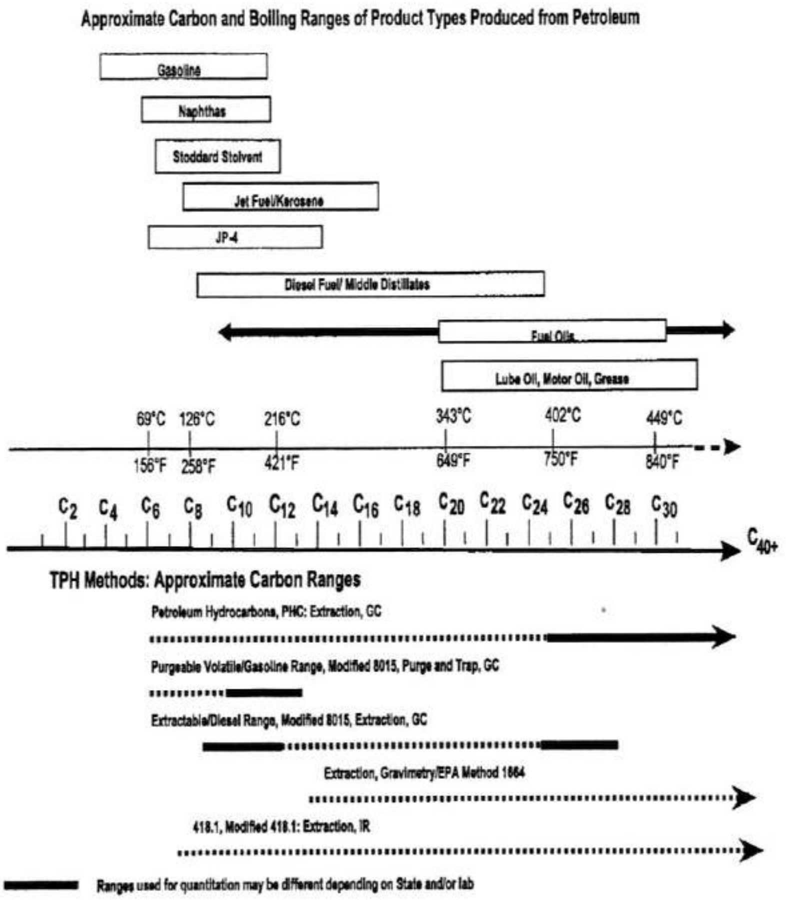
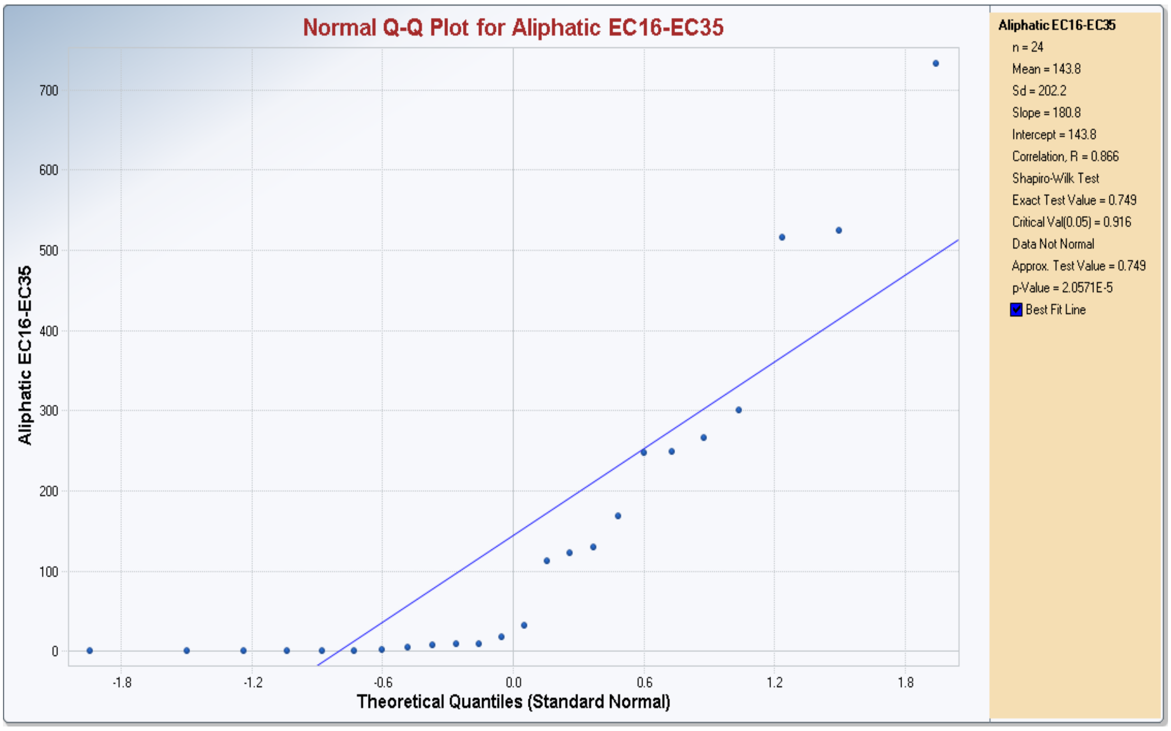
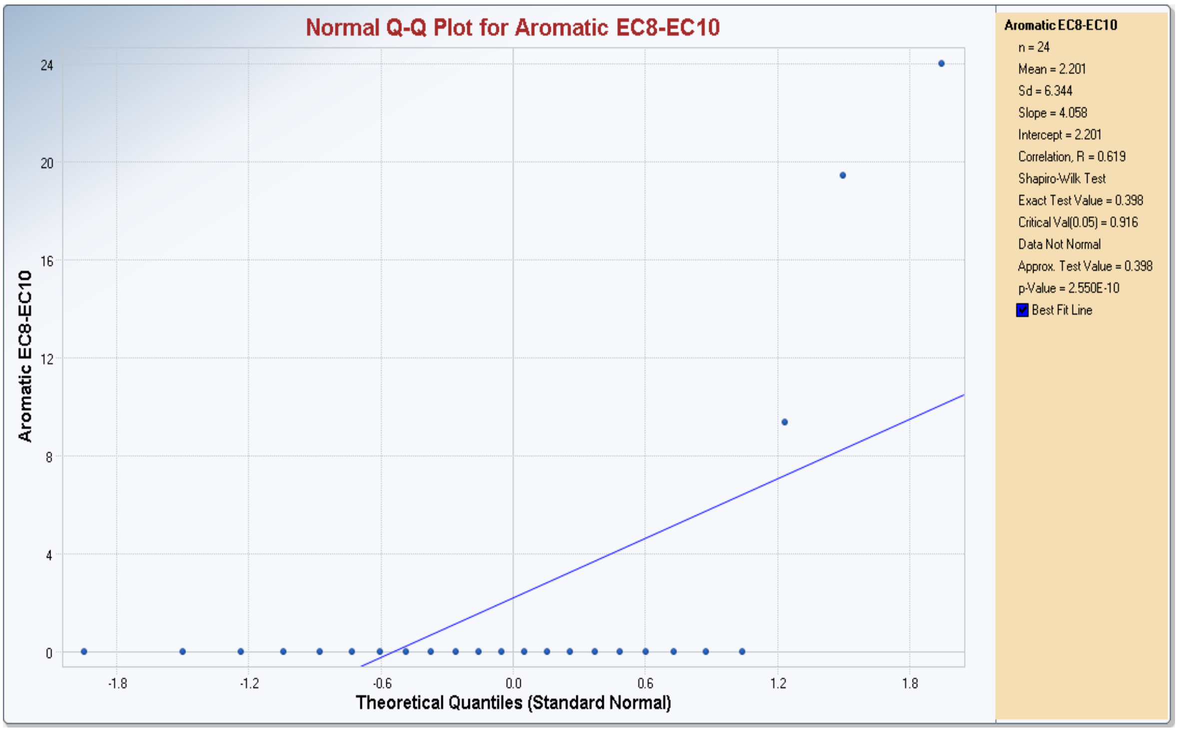


Figure D.7.1. The summary of petroleum product types and TPH and TPH analytical methods with respect to approximate carbon number and boiling point ranges (TPHCWG, 1998).



Aliphatic EC16-EC35
n = 24
Mean = 143.8
Sd = 202.2
Slope = 180.8
Intercept = 143.8
Correlation, R = 0.866
Shapiro-Wilk Test
Exact Test Value = 0.749
Critical Val(0.05) = 0.916
Data Not Normal
Approx. Test Value = 0.749
p-Value = 2.0571E-5
☑ Best Fit Line

Figure D.7.2. The Q-Q plot for TPH aliphatic EC16 - EC35 in dry *crude oil lake* site (Al- Magwa area).



Aromatic EC8-EC10
n = 24
Mean = 2.201
Sd = 6.344
Slope = 4.058
Intercept = 2.201
Correlation, R = 0.619
Shapiro-Wilk Test
Exact Test Value = 0.398
Critical Val(0.05) = 0.916
Data Not Normal
Approx. Test Value = 0.398
p-Value = 2.550E-10
☑ Best Fit Line

Figure D.7.3. The Q-Q plot for TPH aromatic EC8 - EC10 in dry *crude oil lake* site (Al- Magwa area).

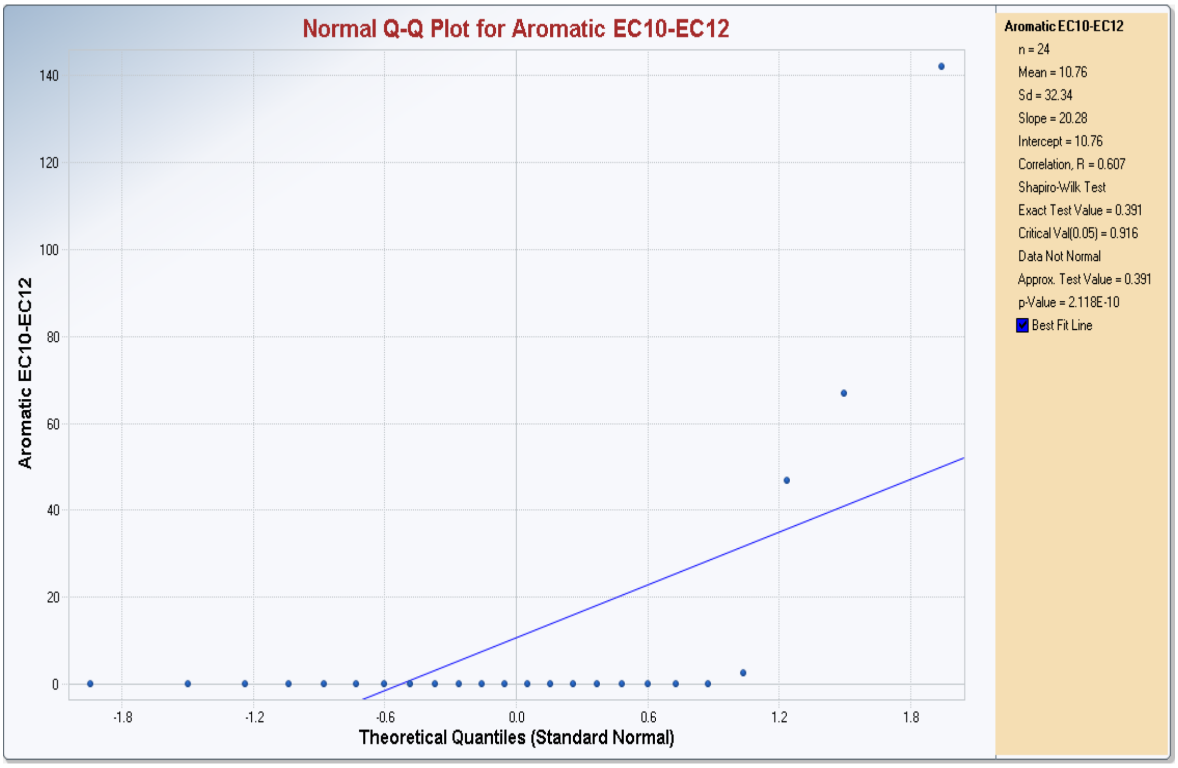


Figure D.7.4. The Q-Q plot for TPH aromatic EC10 - EC12 in dry *crude oil lake* site (Al- Magwa area).

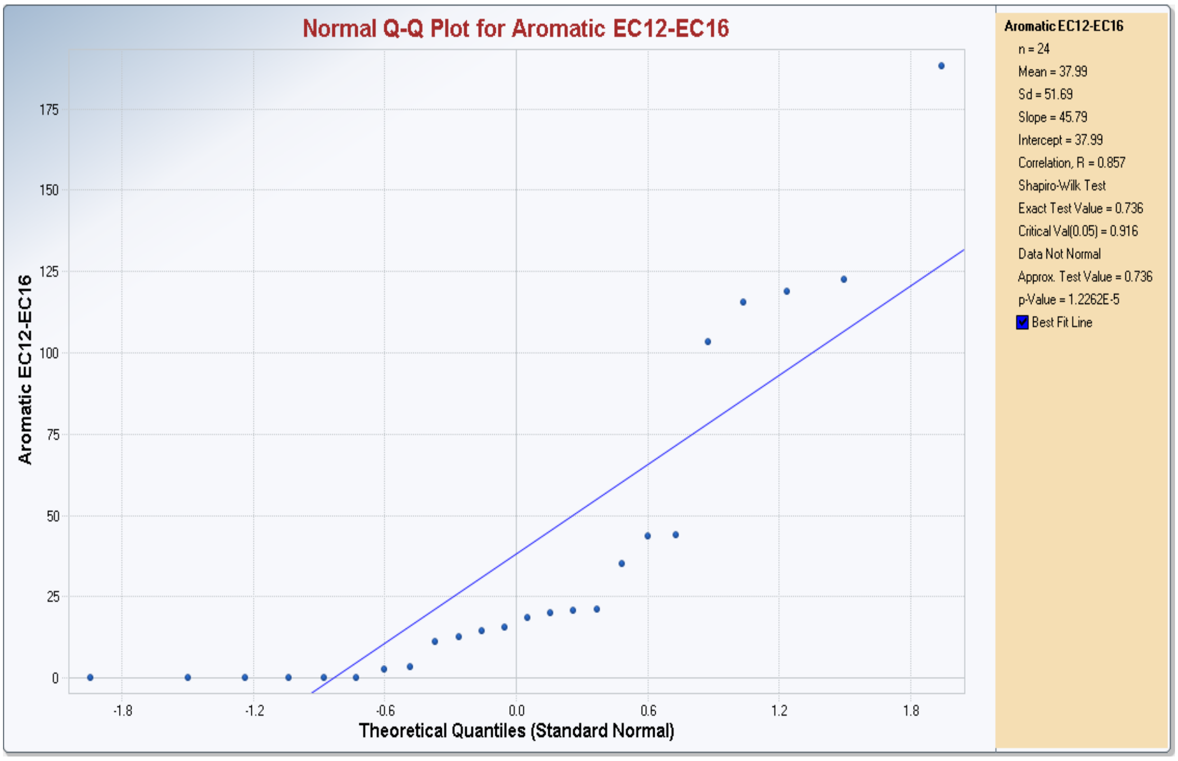


Figure D.7.5. The Q-Q plot for TPH aromatic EC12 – EC16 in dry *crude oil lake* site (Al- Magwa area).

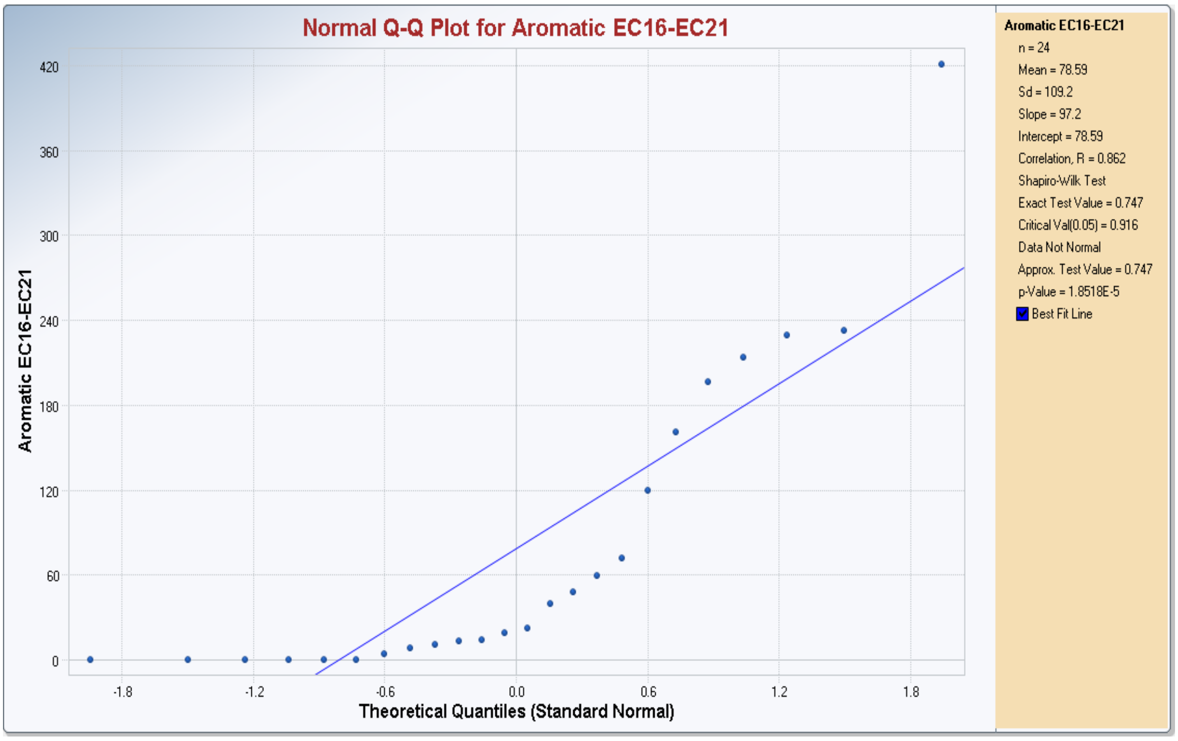


Figure D.7.6. The Q-Q plot for TPH aromatic EC16 – EC21 in dry *crude oil lake* site (Al- Magwa area).

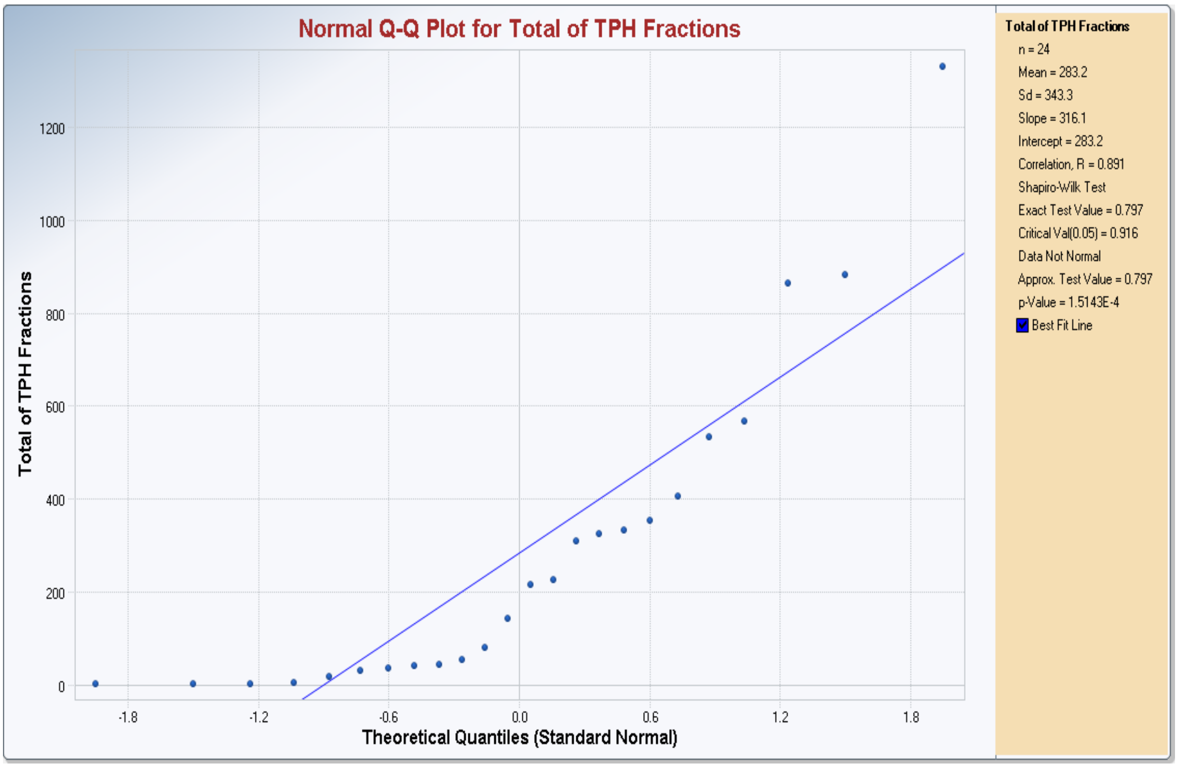
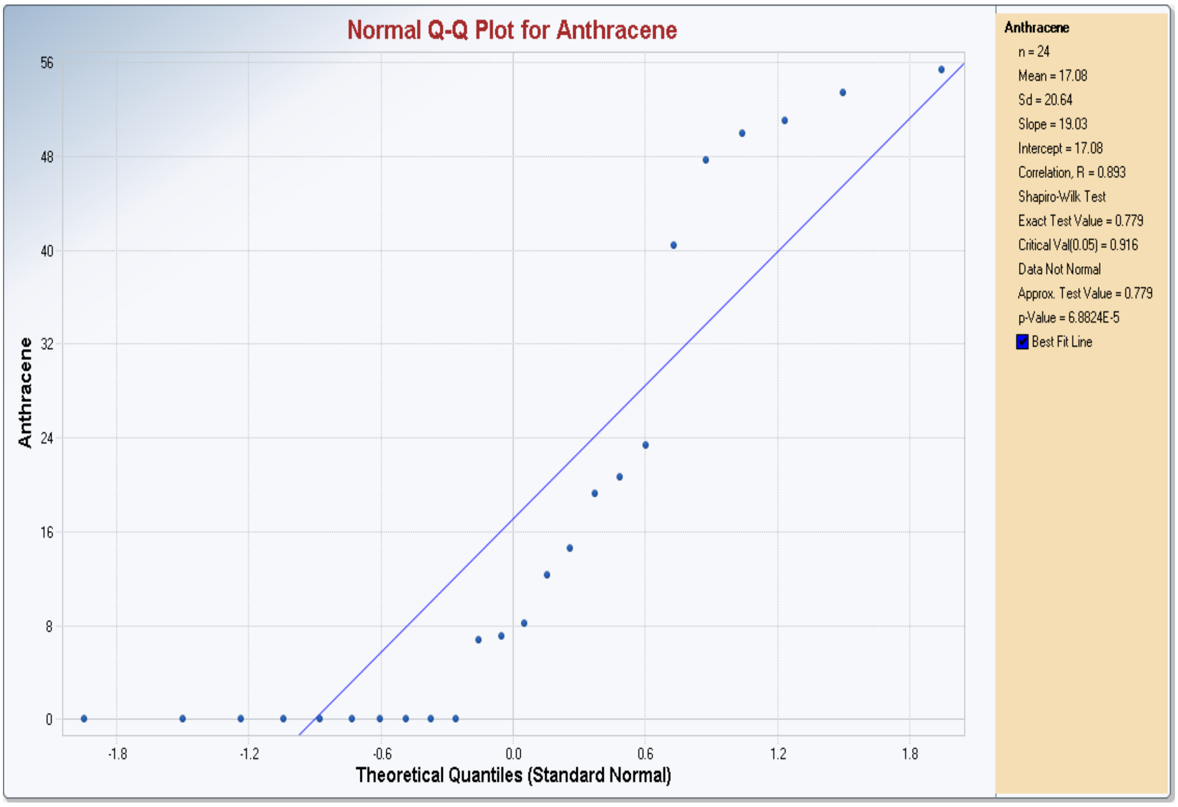
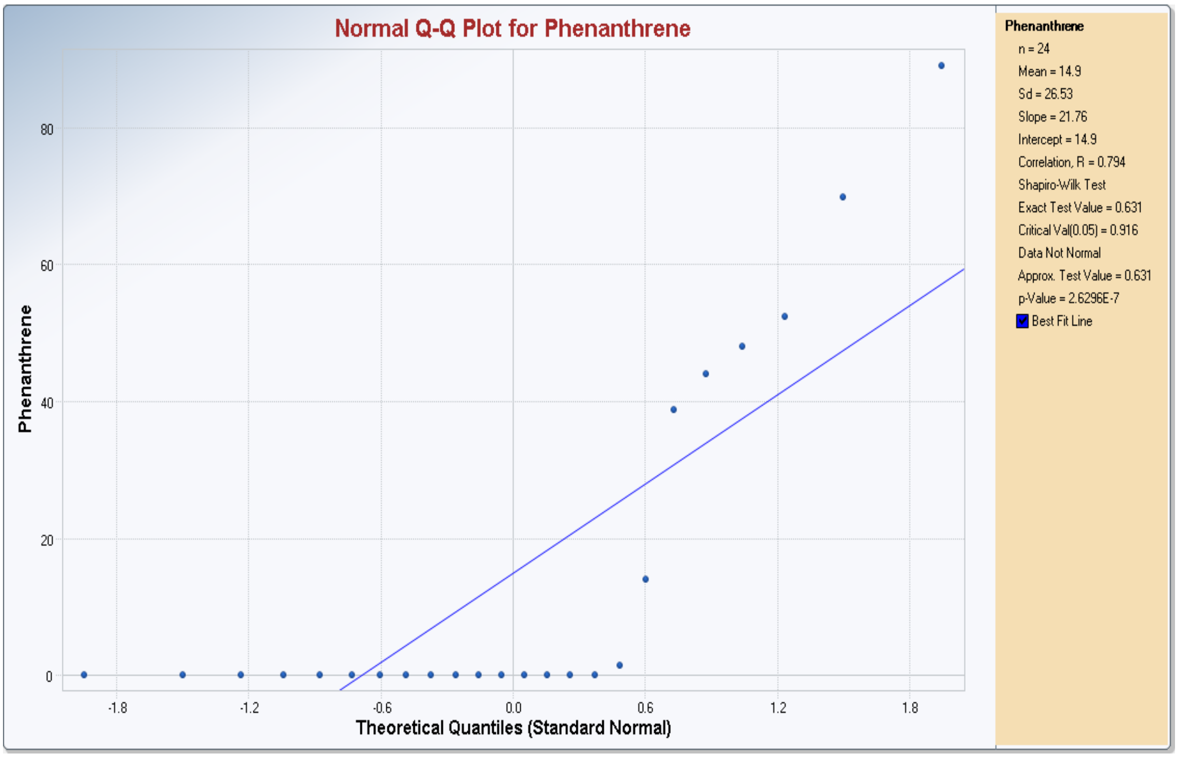


Figure D.7.7. The Q-Q plot for TPH total fractions in dry *crude oil lake* site (Al- Magwa area).



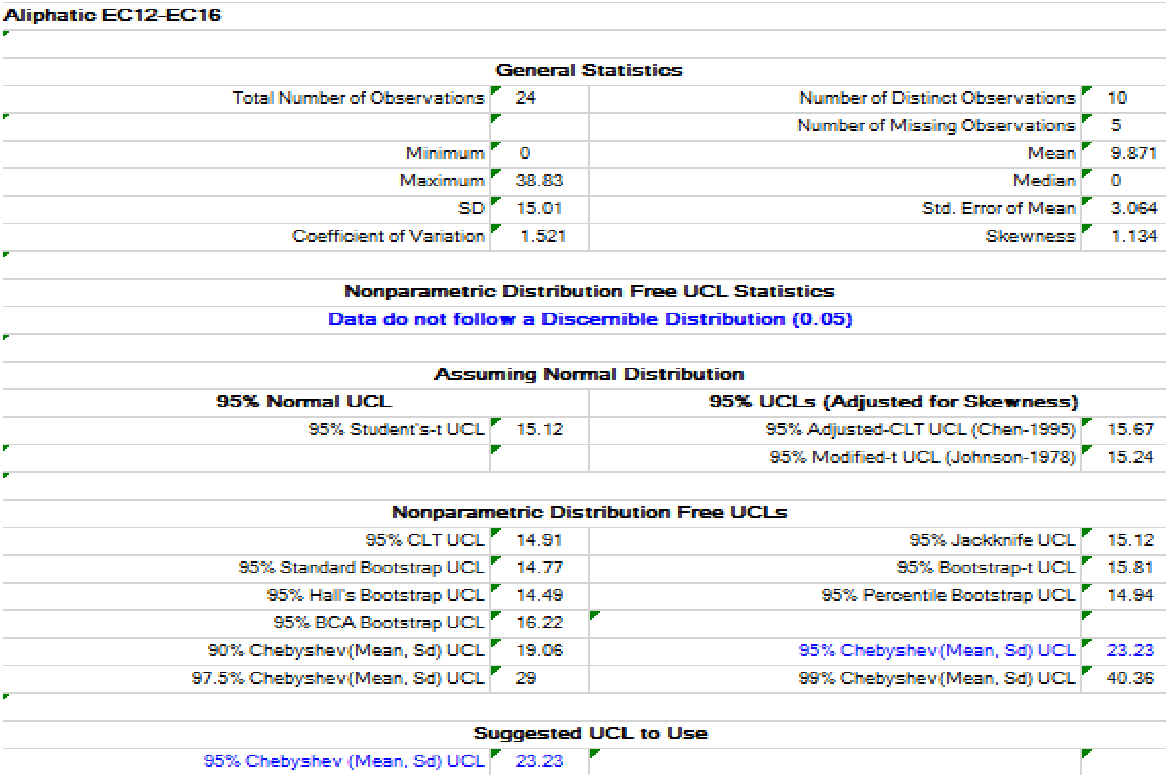
Anthracene
n = 24
Mean = 17.08
Sd = 20.64
Slope = 19.03
Intercept = 17.08
Correlation, R = 0.893
Shapiro-Wilk Test
Exact Test Value = 0.779
Critical Val(0.05) = 0.916
Data Not Normal
Approx. Test Value = 0.779
p-Value = 6.8824E-5

Figure D.7.8. The Q-Q plot for Anthracene substance in dry *crude oil lake* site (Al-Magwa area).



Phenanthrene
n = 24
Mean = 14.9
Sd = 26.53
Slope = 21.76
Intercept = 14.9
Correlation, R = 0.794
Shapiro-Wilk Test
Exact Test Value = 0.631
Critical Val(0.05) = 0.916
Data Not Normal
Approx. Test Value = 0.631
p-Value = 2.6296E-7

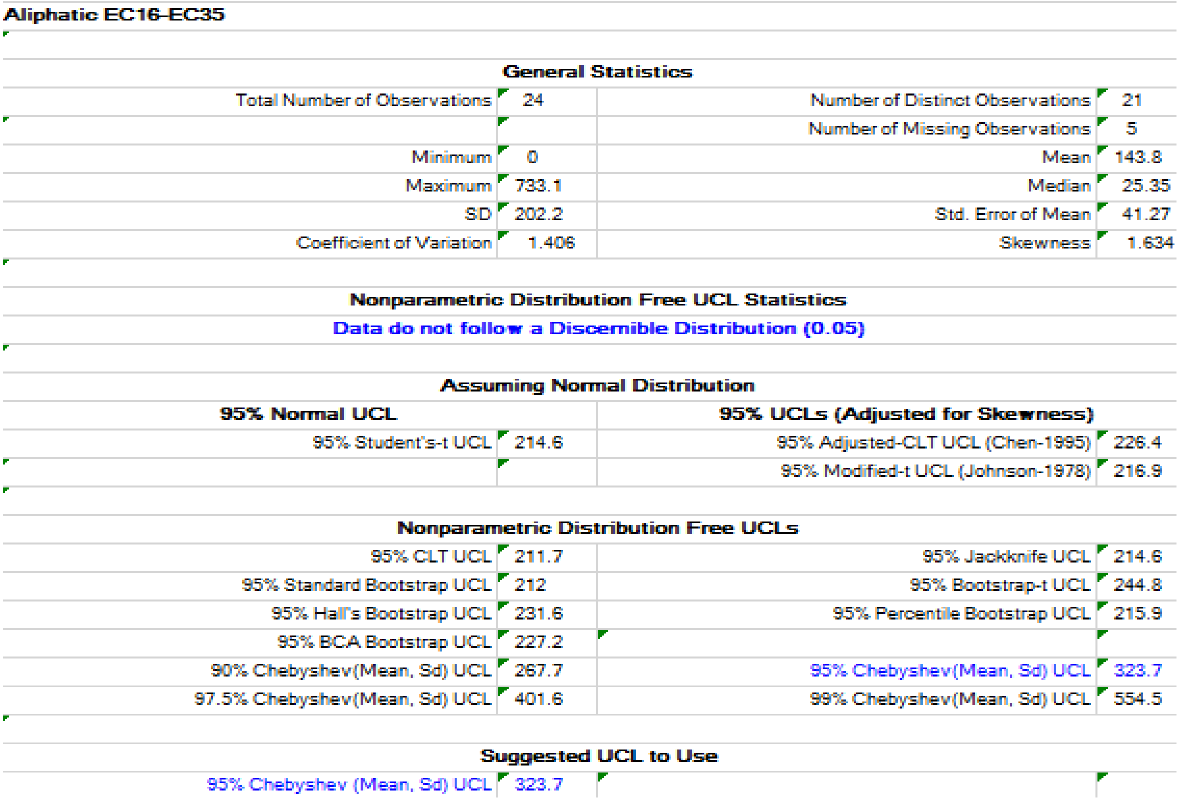
Figure D.7.9. The Q-Q plot for Phenanthrene substance in dry *crude oil lake* site (Al-Magwa area).



Aliphatic EC12-EC16

General Statistics			
Total Number of Observations	24	Number of Distinct Observations	10
		Number of Missing Observations	5
Minimum	0	Mean	9.871
Maximum	38.83	Median	0
SD	15.01	Std. Error of Mean	3.064
Coefficient of Variation	1.521	Skewness	1.134
Nonparametric Distribution Free UCL Statistics			
Data do not follow a Discernible Distribution (0.05)			
Assuming Normal Distribution			
95% Normal UCL		**95% UCLs (Adjusted for Skewness)**	
95% Student's-t UCL	15.12	95% Adjusted-CLT UCL (Chen-1995)	15.67
		95% Modified-t UCL (Johnson-1978)	15.24
Nonparametric Distribution Free UCLs			
95% CLT UCL	14.91	95% Jackknife UCL	15.12
95% Standard Bootstrap UCL	14.77	95% Bootstrap-t UCL	15.81
95% Hall's Bootstrap UCL	14.49	95% Percentile Bootstrap UCL	14.94
95% BCA Bootstrap UCL	16.22		
90% Chebyshev(Mean, Sd) UCL	19.06	95% Chebyshev(Mean, Sd) UCL	23.23
97.5% Chebyshev(Mean, Sd) UCL	29	99% Chebyshev(Mean, Sd) UCL	40.36
Suggested UCL to Use			
95% Chebyshev (Mean, Sd) UCL	23.23		

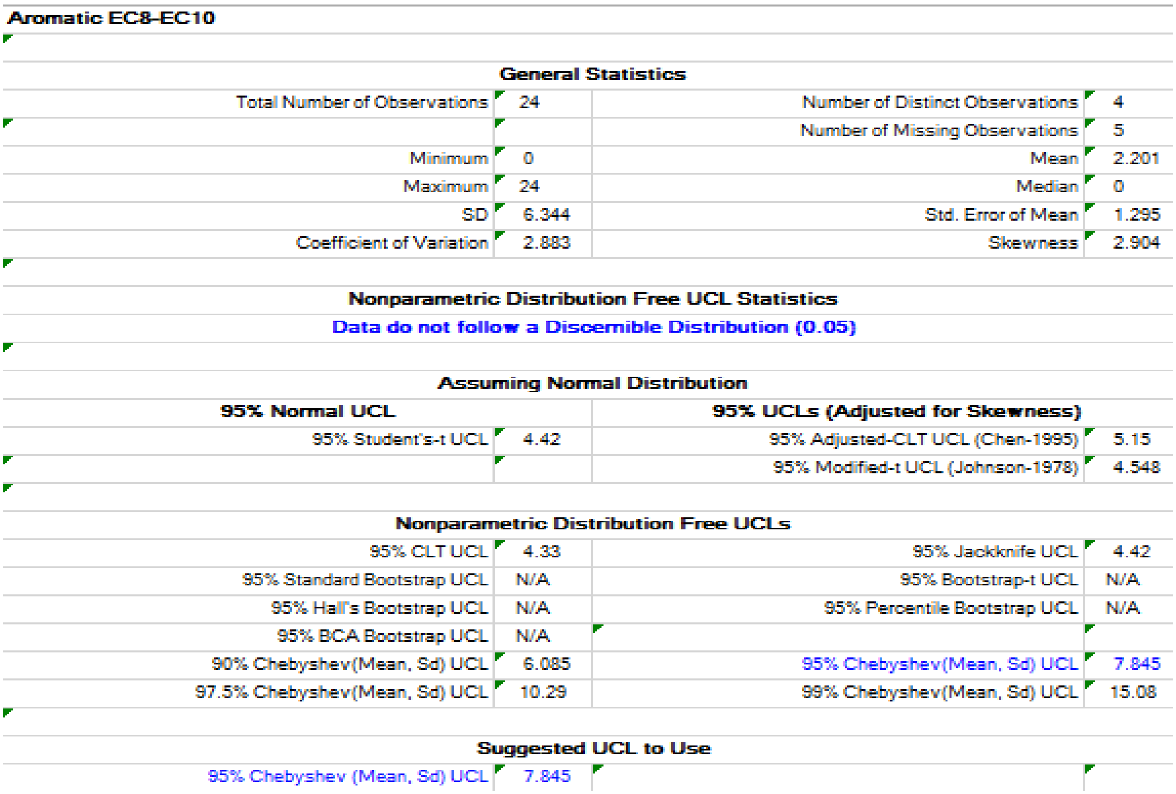
Figure D.7.10. The 95 % UCLs of the mean concentration (mg/kg) for Aliphatic EC12 - EC16 fraction.



Aliphatic EC16-EC35

General Statistics			
Total Number of Observations	24	Number of Distinct Observations	21
		Number of Missing Observations	5
Minimum	0	Mean	143.8
Maximum	733.1	Median	25.35
SD	202.2	Std. Error of Mean	41.27
Coefficient of Variation	1.406	Skewness	1.634
Nonparametric Distribution Free UCL Statistics			
Data do not follow a Discernible Distribution (0.05)			
Assuming Normal Distribution			
95% Normal UCL		**95% UCLs (Adjusted for Skewness)**	
95% Student's-t UCL	214.6	95% Adjusted-CLT UCL (Chen-1995)	226.4
		95% Modified-t UCL (Johnson-1978)	216.9
Nonparametric Distribution Free UCLs			
95% CLT UCL	211.7	95% Jackknife UCL	214.6
95% Standard Bootstrap UCL	212	95% Bootstrap-t UCL	244.8
95% Hall's Bootstrap UCL	231.6	95% Percentile Bootstrap UCL	215.9
95% BCA Bootstrap UCL	227.2		
90% Chebyshev(Mean, Sd) UCL	267.7	95% Chebyshev(Mean, Sd) UCL	323.7
97.5% Chebyshev(Mean, Sd) UCL	401.6	99% Chebyshev(Mean, Sd) UCL	554.5
Suggested UCL to Use			
95% Chebyshev (Mean, Sd) UCL	323.7		

Figure D.7.11. The 95 % UCLs of the mean concentration (mg/kg) for Aliphatic EC16 - EC35 fraction.



Aromatic EC8-EC10

General Statistics

Total Number of Observations	24	Number of Distinct Observations	4
		Number of Missing Observations	5
Minimum	0	Mean	2.201
Maximum	24	Median	0
SD	6.344	Std. Error of Mean	1.295
Coefficient of Variation	2.883	Skewness	2.904

Nonparametric Distribution Free UCL Statistics

Data do not follow a Discernible Distribution (0.05)

Assuming Normal Distribution

95% Normal UCL		**95% UCLs (Adjusted for Skewness)**	
95% Student's-t UCL	4.42	95% Adjusted-CLT UCL (Chen-1995)	5.15
		95% Modified-t UCL (Johnson-1978)	4.548

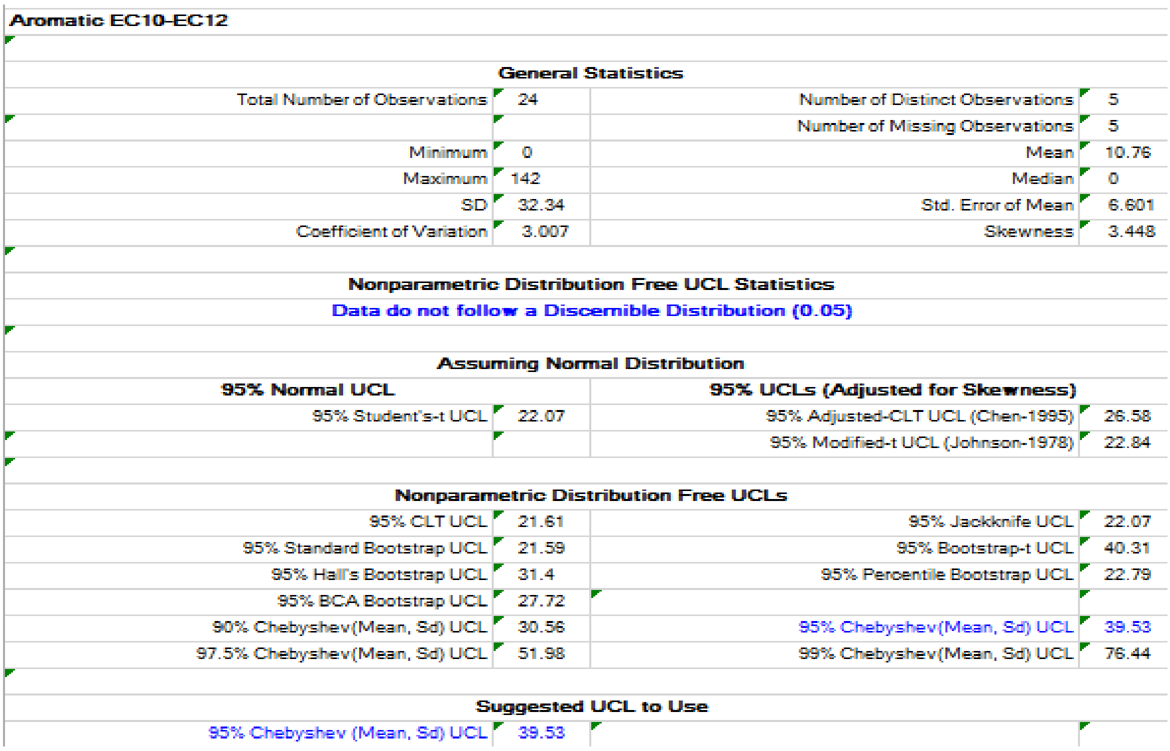
Nonparametric Distribution Free UCLs

95% CLT UCL	4.33	95% Jackknife UCL	4.42
95% Standard Bootstrap UCL	N/A	95% Bootstrap-t UCL	N/A
95% Hall's Bootstrap UCL	N/A	95% Percentile Bootstrap UCL	N/A
95% BCA Bootstrap UCL	N/A		
90% Chebyshev(Mean, Sd) UCL	6.085	95% Chebyshev(Mean, Sd) UCL	7.845
97.5% Chebyshev(Mean, Sd) UCL	10.29	99% Chebyshev(Mean, Sd) UCL	15.08

Suggested UCL to Use

95% Chebyshev (Mean, Sd) UCL	7.845		

Figure D.7.12. The 95 % UCLs of the mean concentration (mg/kg) for Aromatic EC8 - EC10 fraction.



Aromatic EC10-EC12

General Statistics

Total Number of Observations	24	Number of Distinct Observations	5
		Number of Missing Observations	5
Minimum	0	Mean	10.76
Maximum	142	Median	0
SD	32.34	Std. Error of Mean	6.601
Coefficient of Variation	3.007	Skewness	3.448

Nonparametric Distribution Free UCL Statistics

Data do not follow a Discernible Distribution (0.05)

Assuming Normal Distribution

95% Normal UCL		**95% UCLs (Adjusted for Skewness)**	
95% Student's-t UCL	22.07	95% Adjusted-CLT UCL (Chen-1995)	26.58
		95% Modified-t UCL (Johnson-1978)	22.84

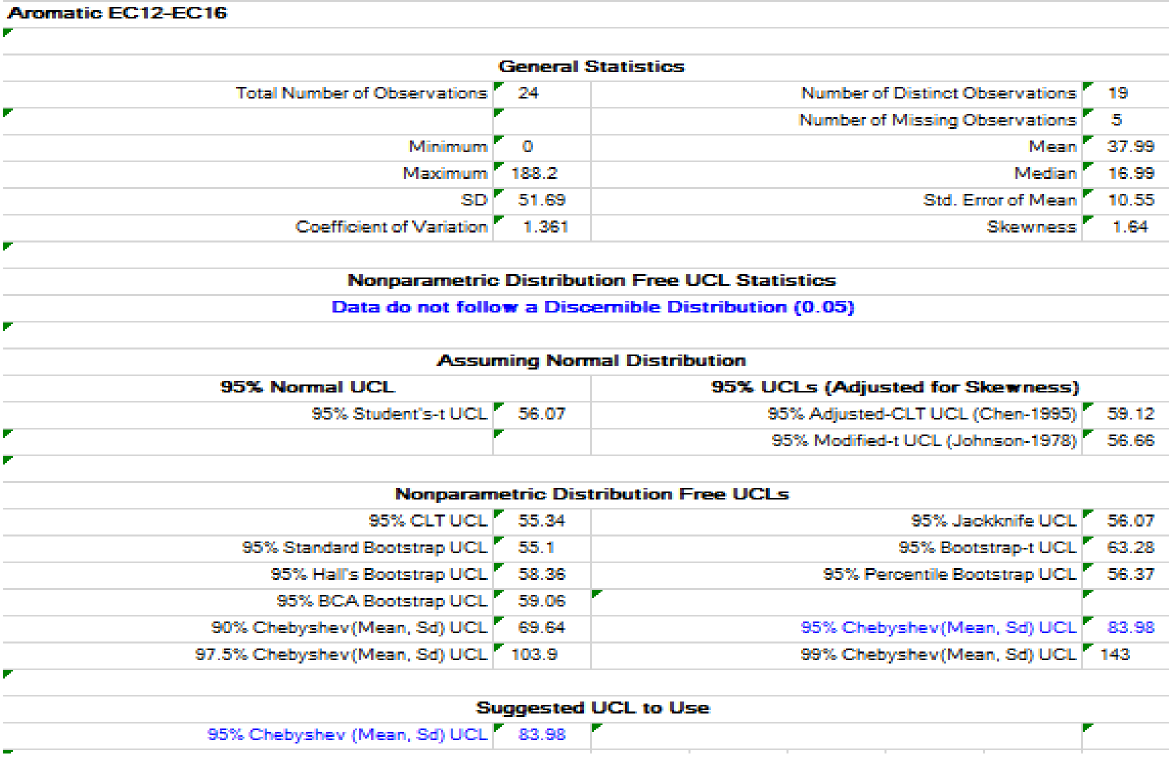
Nonparametric Distribution Free UCLs

95% CLT UCL	21.61	95% Jackknife UCL	22.07
95% Standard Bootstrap UCL	21.59	95% Bootstrap-t UCL	40.31
95% Hall's Bootstrap UCL	31.4	95% Percentile Bootstrap UCL	22.79
95% BCA Bootstrap UCL	27.72		
90% Chebyshev(Mean, Sd) UCL	30.56	95% Chebyshev(Mean, Sd) UCL	39.53
97.5% Chebyshev(Mean, Sd) UCL	51.98	99% Chebyshev(Mean, Sd) UCL	76.44

Suggested UCL to Use

95% Chebyshev (Mean, Sd) UCL	39.53		

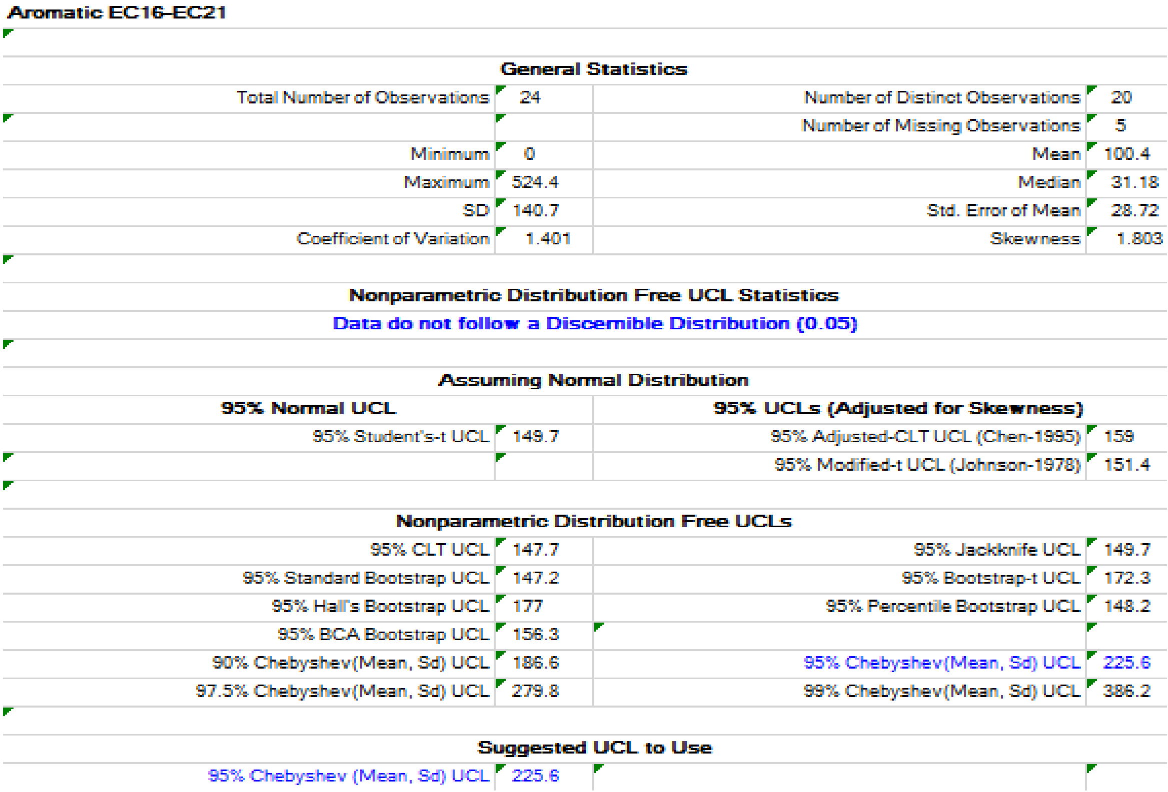
Figure D.7.13. The 95 % UCLs of the mean concentration (mg/kg) for Aromatic EC10 - EC12 fraction.



Aromatic EC12-EC16

	General Statistics		
Total Number of Observations	24	Number of Distinct Observations	19
		Number of Missing Observations	5
Minimum	0	Mean	37.99
Maximum	188.2	Median	16.99
SD	51.69	Std. Error of Mean	10.55
Coefficient of Variation	1.361	Skewness	1.64
	Nonparametric Distribution Free UCL Statistics		
	Data do not follow a Discernible Distribution (0.05)		
	Assuming Normal Distribution		
95% Normal UCL		**95% UCLs (Adjusted for Skewness)**	
95% Student's-t UCL	56.07	95% Adjusted-CLT UCL (Chen-1995)	59.12
		95% Modified-t UCL (Johnson-1978)	56.66
	Nonparametric Distribution Free UCLs		
95% CLT UCL	55.34	95% Jackknife UCL	56.07
95% Standard Bootstrap UCL	55.1	95% Bootstrap-t UCL	63.28
95% Hall's Bootstrap UCL	58.36	95% Percentile Bootstrap UCL	56.37
95% BCA Bootstrap UCL	59.06		
90% Chebyshev(Mean, Sd) UCL	69.64	95% Chebyshev(Mean, Sd) UCL	83.98
97.5% Chebyshev(Mean, Sd) UCL	103.9	99% Chebyshev(Mean, Sd) UCL	143
	Suggested UCL to Use		
95% Chebyshev (Mean, Sd) UCL	83.98		

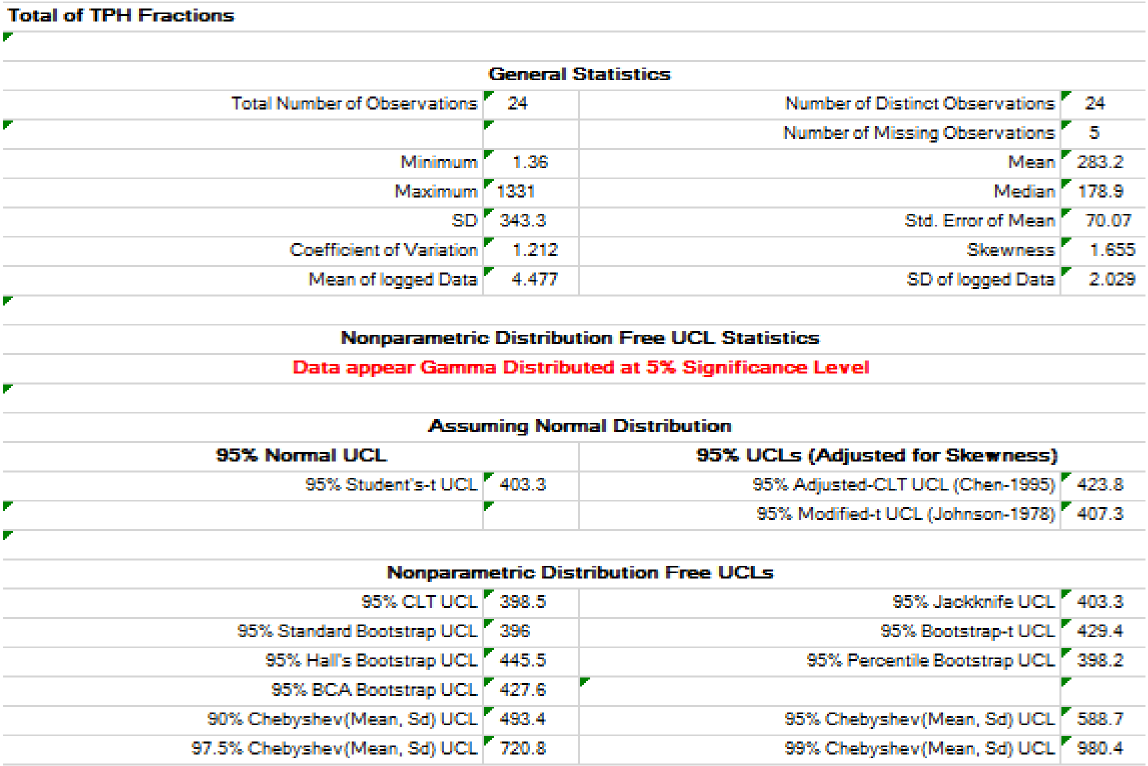
Figure D.7.14. The 95 % UCLs of the mean concentration (mg/kg) for Aromatic EC12 - EC16 fraction.



Aromatic EC16-EC21

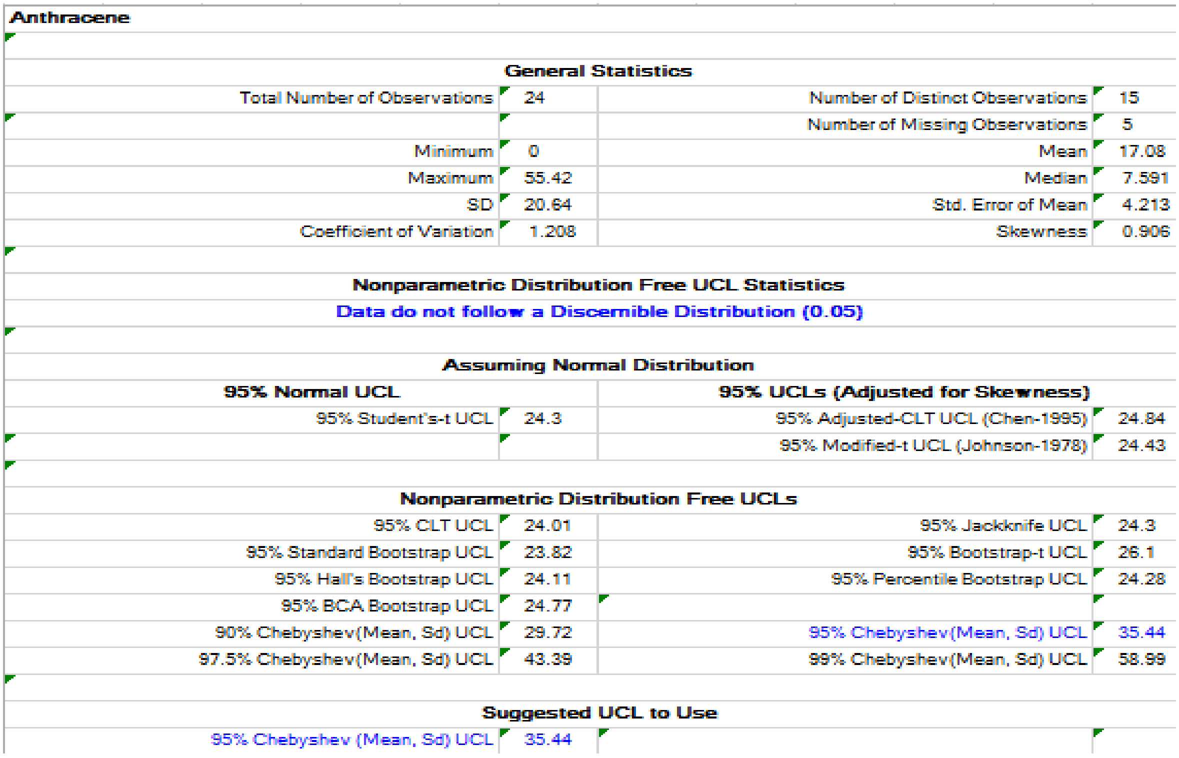
	General Statistics		
Total Number of Observations	24	Number of Distinct Observations	20
		Number of Missing Observations	5
Minimum	0	Mean	100.4
Maximum	524.4	Median	31.18
SD	140.7	Std. Error of Mean	28.72
Coefficient of Variation	1.401	Skewness	1.803
	Nonparametric Distribution Free UCL Statistics		
	Data do not follow a Discernible Distribution (0.05)		
	Assuming Normal Distribution		
95% Normal UCL		**95% UCLs (Adjusted for Skewness)**	
95% Student's-t UCL	149.7	95% Adjusted-CLT UCL (Chen-1995)	159
		95% Modified-t UCL (Johnson-1978)	151.4
	Nonparametric Distribution Free UCLs		
95% CLT UCL	147.7	95% Jackknife UCL	149.7
95% Standard Bootstrap UCL	147.2	95% Bootstrap-t UCL	172.3
95% Hall's Bootstrap UCL	177	95% Percentile Bootstrap UCL	148.2
95% BCA Bootstrap UCL	156.3		
90% Chebyshev(Mean, Sd) UCL	186.6	95% Chebyshev(Mean, Sd) UCL	225.6
97.5% Chebyshev(Mean, Sd) UCL	279.8	99% Chebyshev(Mean, Sd) UCL	386.2
	Suggested UCL to Use		
95% Chebyshev (Mean, Sd) UCL	225.6		

Figure D.7.15. The 95 % UCLs of the mean concentration (mg/kg) for Aromatic EC16 - EC21 fraction.



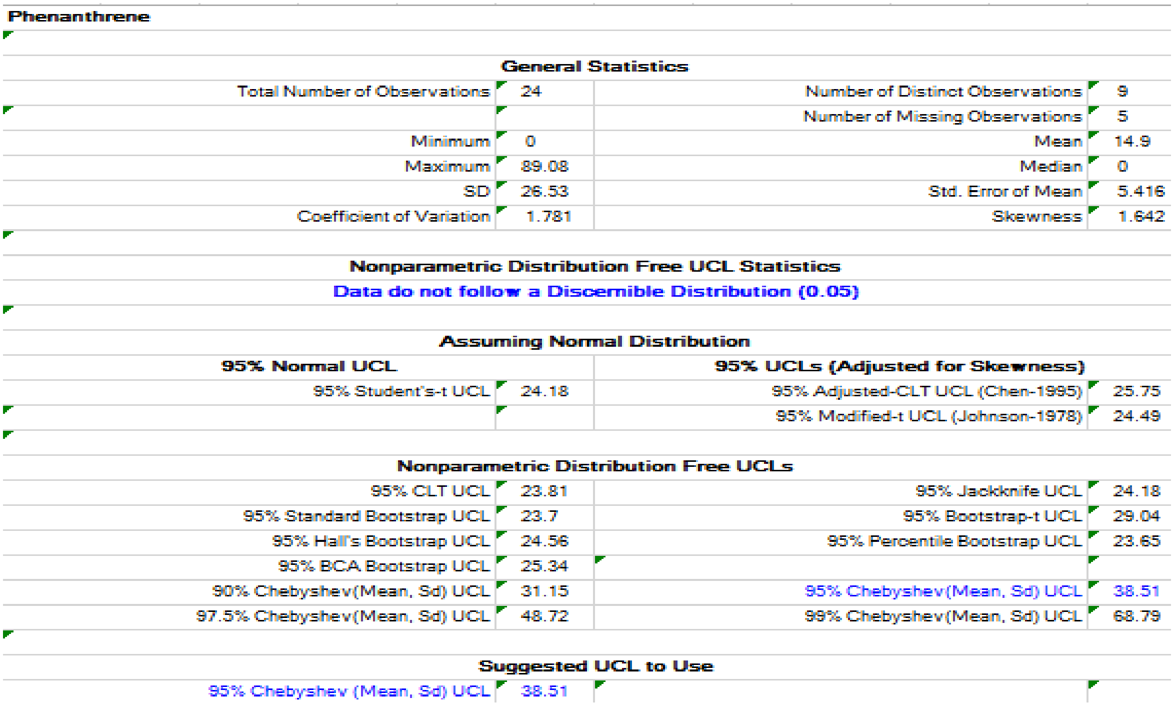
Total of TPH Fractions			
General Statistics			
Total Number of Observations	24	Number of Distinct Observations	24
		Number of Missing Observations	5
Minimum	1.36	Mean	283.2
Maximum	1331	Median	178.9
SD	343.3	Std. Error of Mean	70.07
Coefficient of Variation	1.212	Skewness	1.655
Mean of logged Data	4.477	SD of logged Data	2.029
Nonparametric Distribution Free UCL Statistics			
Data appear Gamma Distributed at 5% Significance Level			
Assuming Normal Distribution			
95% Normal UCL		**95% UCLs (Adjusted for Skewness)**	
95% Student's-t UCL	403.3	95% Adjusted-CLT UCL (Chen-1995)	423.8
		95% Modified-t UCL (Johnson-1978)	407.3
Nonparametric Distribution Free UCLs			
95% CLT UCL	398.5	95% Jackknife UCL	403.3
95% Standard Bootstrap UCL	396	95% Bootstrap-t UCL	429.4
95% Hall's Bootstrap UCL	445.5	95% Percentile Bootstrap UCL	398.2
95% BCA Bootstrap UCL	427.6		
90% Chebyshev(Mean, Sd) UCL	493.4	95% Chebyshev(Mean, Sd) UCL	588.7
97.5% Chebyshev(Mean, Sd) UCL	720.8	99% Chebyshev(Mean, Sd) UCL	980.4

Figure D.7.16. The 95 % UCLs of the mean concentration (mg/kg) for TPH total fractions (i.e. aromatic & aliphatic) detected in the dry *crude oil lake* site (Al-Magwa area).



Anthracene			
General Statistics			
Total Number of Observations	24	Number of Distinct Observations	15
		Number of Missing Observations	5
Minimum	0	Mean	17.08
Maximum	55.42	Median	7.591
SD	20.64	Std. Error of Mean	4.213
Coefficient of Variation	1.208	Skewness	0.906
Nonparametric Distribution Free UCL Statistics			
Data do not follow a Discernible Distribution (0.05)			
Assuming Normal Distribution			
95% Normal UCL		**95% UCLs (Adjusted for Skewness)**	
95% Student's-t UCL	24.3	95% Adjusted-CLT UCL (Chen-1995)	24.84
		95% Modified-t UCL (Johnson-1978)	24.43
Nonparametric Distribution Free UCLs			
95% CLT UCL	24.01	95% Jackknife UCL	24.3
95% Standard Bootstrap UCL	23.82	95% Bootstrap-t UCL	26.1
95% Hall's Bootstrap UCL	24.11	95% Percentile Bootstrap UCL	24.28
95% BCA Bootstrap UCL	24.77		
90% Chebyshev(Mean, Sd) UCL	29.72	95% Chebyshev(Mean, Sd) UCL	35.44
97.5% Chebyshev(Mean, Sd) UCL	43.39	99% Chebyshev(Mean, Sd) UCL	58.99
Suggested UCL to Use			
95% Chebyshev (Mean, Sd) UCL	35.44		

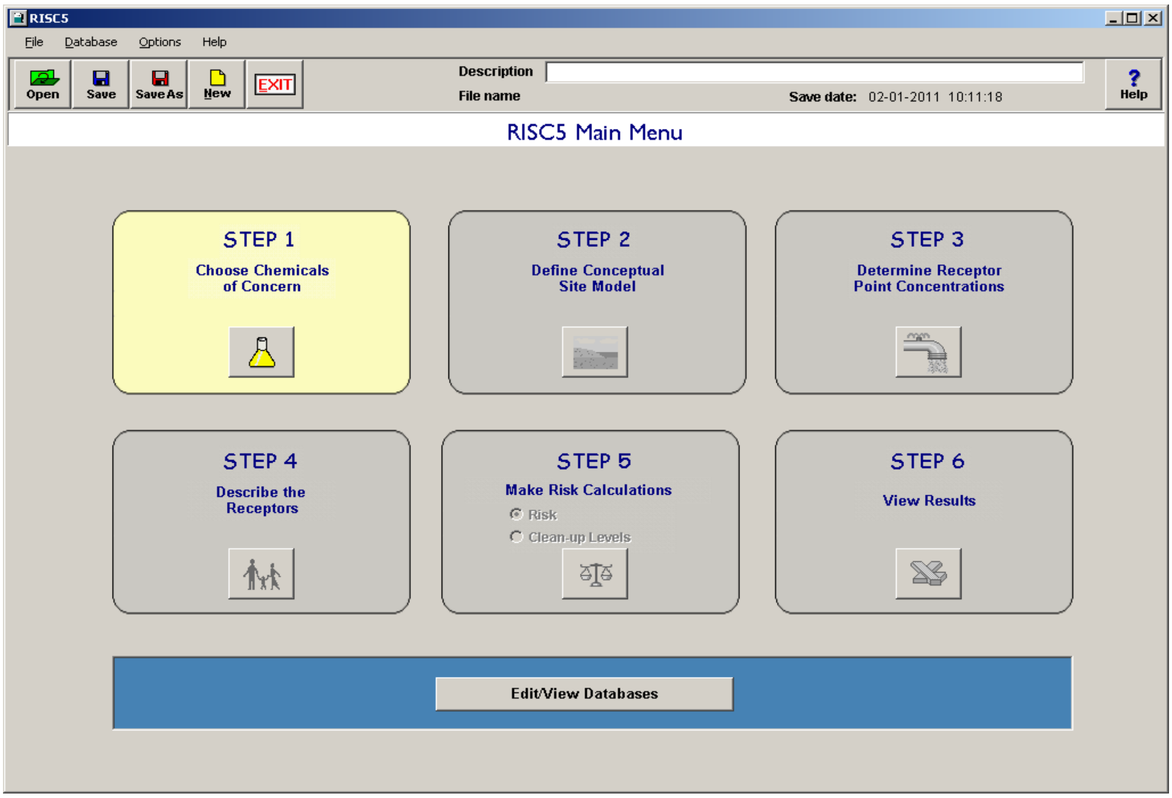
Figure D.7.17. The 95 % UCLs of the mean concentration (mg/kg) for Anthracene substance.



Phenanthrene

General Statistics			
Total Number of Observations	24	Number of Distinct Observations	9
		Number of Missing Observations	5
Minimum	0	Mean	14.9
Maximum	89.08	Median	0
SD	26.53	Std. Error of Mean	5.416
Coefficient of Variation	1.781	Skewness	1.642
Nonparametric Distribution Free UCL Statistics			
Data do not follow a Discernible Distribution (0.05)			
Assuming Normal Distribution			
95% Normal UCL		**95% UCLs (Adjusted for Skewness)**	
95% Student's-t UCL	24.18	95% Adjusted-CLT UCL (Chen-1995)	25.75
		95% Modified-t UCL (Johnson-1978)	24.49
Nonparametric Distribution Free UCLs			
95% CLT UCL	23.81	95% Jackknife UCL	24.18
95% Standard Bootstrap UCL	23.7	95% Bootstrap-t UCL	29.04
95% Hall's Bootstrap UCL	24.56	95% Percentile Bootstrap UCL	23.65
95% BCA Bootstrap UCL	25.34		
90% Chebyshev(Mean, Sd) UCL	31.15	95% Chebyshev(Mean, Sd) UCL	38.51
97.5% Chebyshev(Mean, Sd) UCL	48.72	99% Chebyshev(Mean, Sd) UCL	68.79
Suggested UCL to Use			
95% Chebyshev (Mean, Sd) UCL	38.51		

Figure D.7.18. The 95 % UCLs of the mean concentration (mg/kg) for Phenanthrene substance.

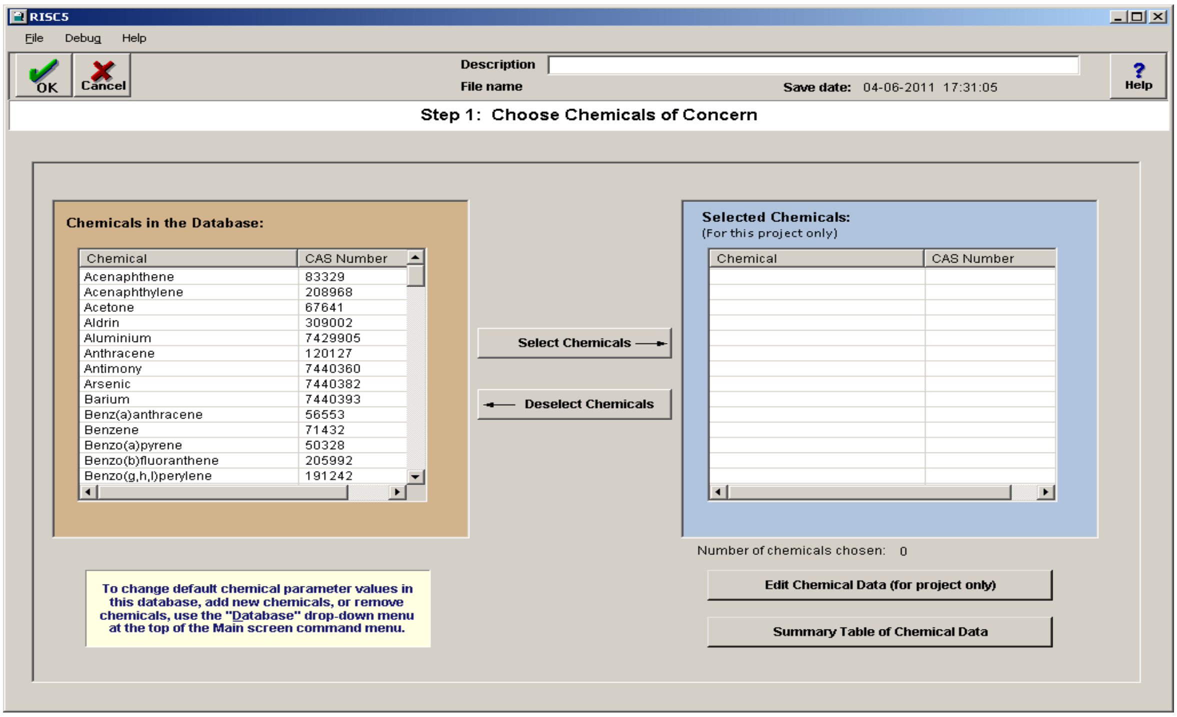


Description

File name

Save date: 02-01-2011 10:11:18

Figure D.7.19. The main screen of RISC (RISC-5, 2011).



Description

File name

Save date: 04-06-2011 17:31:05

Step 1: Choose Chemicals of Concern

Chemicals in the Database:

Chemical	CAS Number
Acenaphthene	83329
Acenaphthylene	208968
Acetone	67641
Aldrin	309002
Aluminium	7429905
Anthracene	120127
Antimony	7440360
Arsenic	7440382
Barium	7440393
Benz(a)anthracene	56553
Benzene	71432
Benzo(a)pyrene	50328
Benzo(b)fluoranthene	205992
Benzo(g,h,l)perylene	191242

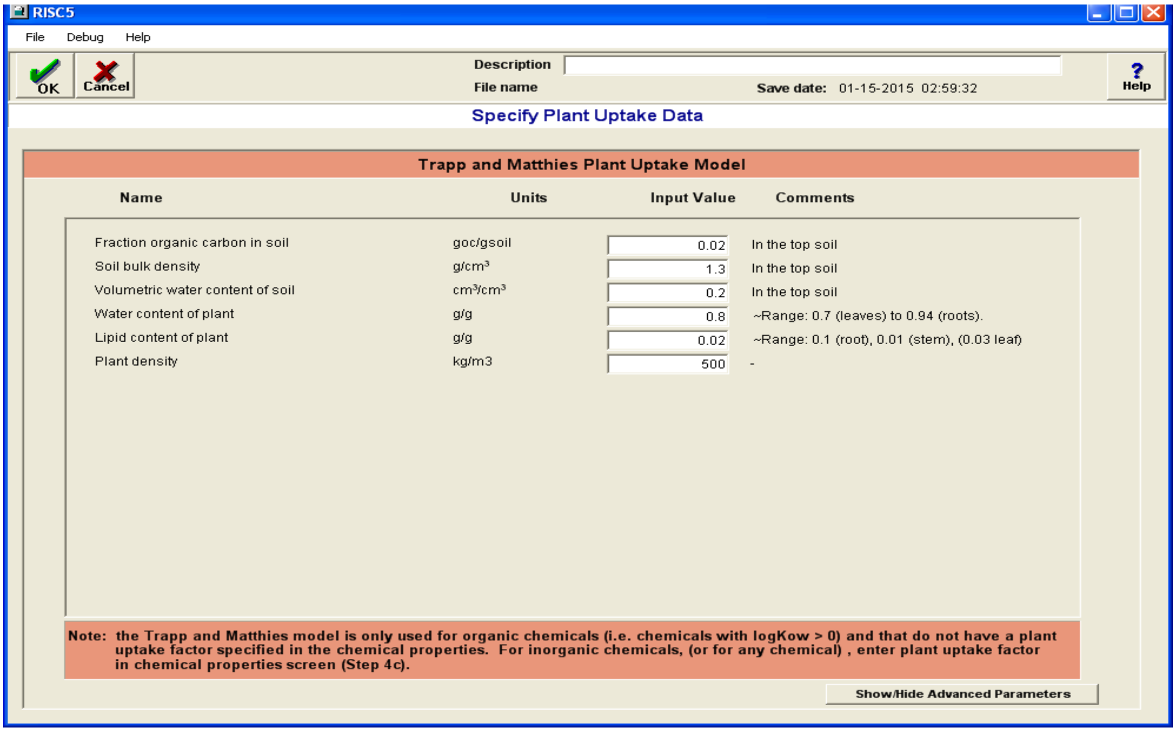
Selected Chemicals:
(For this project only)

Chemical	CAS Number

Number of chemicals chosen: 0

To change default chemical parameter values in this database, add new chemicals, or remove chemicals, use the "Database" drop-down menu at the top of the Main screen command menu.

Figure D.7.20. Main screen of Step 1 before any chemicals have been selected (RISC-5, 2011).



Description

File name

Save date: 01-15-2015 02:59:32

Specify Plant Uptake Data

Trapp and Matthies Plant Uptake Model

Name	Units	Input Value	Comments
Fraction organic carbon in soil	goc/gsoil	0.02	In the top soil
Soil bulk density	g/cm^3	1.3	In the top soil
Volumetric water content of soil	cm^3/cm^3	0.2	In the top soil
Water content of plant	g/g	0.8	~Range: 0.7 (leaves) to 0.94 (roots).
Lipid content of plant	g/g	0.02	~Range: 0.1 (root), 0.01 (stem), (0.03 leaf)
Plant density	kg/m3	500	-

Note: the Trapp and Matthies model is only used for organic chemicals (i.e. chemicals with logKow > 0) and that do not have a plant uptake factor specified in the chemical properties. For inorganic chemicals, (or for any chemical) , enter plant uptake factor in chemical properties screen (Step 4c).

Figure D.7.21. The trapp and matthies plant uptake model at step 4d based on contamination located assumed at unsaturated zone soil pathway selected.

Table D.7.3. The equations used to estimate CADD and LADD in accordance with exposure pathways selected.

Exposure pathways selected	Exposure pathways description	Exposure pathways equation	Equation description	References
Ingestion of Soil or Sediment.	Adults working outdoors may ingest soil through incidental contact of the mouth with hands and clothing. Soil ingestion by children is often the primary exposure route of concern for contaminated soils (Paustenbach, 1989a, b).	$CADD = \frac{\text{Cmax X IR X EF X BIO}}{\text{BW X 365 } \frac{d}{yr}} \text{ x } 10^{-6} \frac{kg}{mg}$ $LADD = \frac{\text{Cavg. X IR X EF X ED X BIO}}{\text{LT X BW X 365 } \frac{d}{yr}} \text{ x } 10^{-6} \frac{kg}{mg}$	CADD = chronic average daily dose [mg/kg-day]. LADD = lifetime average daily dose [mg/kg-day]. Cmax = maximum 7-year average concentration of chemical in soil or sediment [mg/kg]. Cave = time-averaged concentration of chemical in soil or sediment over the exposure duration [mg/kg]. IR = soil ingestion rate [mg/day]. BIO = bioavailability of chemical in soil [mg/mg]. EF = exposure frequency [events/year]. ED = exposure duration [years]. LT = lifetime = 70 years [by definition]. BW = body weight [kg].	(RISC-5, 2011)

Table D.7.3. Continued.

Exposure pathways selected	Exposure pathways description	Exposure pathways equations	Equation description	References
Dermal Contact with Soil or Sediment.	Some soil contaminants may be absorbed across the skin into the bloodstream. Absorption will depend upon the amount of soil in contact with the skin, the concentration of chemicals in soil, the skin surface area exposed, and the potential for the chemical to be absorbed across skin.	$CADD = \frac{\text{Cmax. X SA X AAF X AF X EF}}{\text{BW X 365 } \frac{d}{yr}} \text{ x } 10^{-6} \frac{kg}{mg}$ $LADD = \frac{\text{Cavg. X SA X AAF X AF X EF X ED}}{\text{LT X BW X 365 } \frac{d}{yr}} \text{ x } 10^{-6} \frac{kg}{mg}$	Where Cmax = maximum 7-year average concentration of chemical in soil or sediment [mg/kg]. Cave = time-averaged concentration of chemical in soil or sediment over the exposure duration [mg/kg]. SA = skin surface area exposed to soil [cm2]. AAF = dermal-soil chemical specific absorption adjustment factor [mg/mg]. AF = soil-to-skin adherence factor [mg/cm2/event].	

Table D.7.3. Continued.

Exposure pathways selected	Exposure pathways description	Exposure pathways equations	Equation description	References
Inhalation of Indoor or Outdoor Air.	In this exposure pathway the inhalation of chemicals in breathing space air (either inside or out) is considered.	$CADD = \frac{\text{Cmax. X InhR X ET X EF}}{\text{BW X 365 } \frac{d}{yr}}$ $LADD = \frac{\text{Cavg. X InhR X ET X EF X ED}}{\text{LT X BW X 365 } \frac{d}{yr}}$	Where C_{max} = maximum 7-year concentration of chemical in outdoor air [mg/m3). Cave = time-averaged concentration of chemical in outdoor air over the exposure duration [mg/m3). InhR = inhalation rate outdoors [m3/hr]. ET = exposure time outdoors [hr/day].	(RISC-5, 2011)

Table D.7.3. Continued.

Exposure pathways selected	Exposure pathways description	Exposure pathways equations	Equation description	References
Ingestion of Home-Grown Vegetables Grown in Contaminated Soil	This exposure route is identical to 7.1.8 (vegetables watered with contaminated groundwater) except in the way that the concentration of chemical in the vegetable is calculated. For purposes of estimating concentrations and uptakes, the vegetables are divided into root vegetables and above-ground (or leafy) vegetables. The total dose is the sum of the root vegetables and the above-ground consumed. Concentrations in the root and above-ground vegetables are calculated by multiplying the concentration in soil by an appropriate vegetable uptake factor from soil, Bvr or Bva, respectively. The calculation of the vegetable uptake factors is presented in Appendix O (Section O.8, specifically for a summary).	$CADD = \left[\frac{(B_{vr} \times IR_{vr} + B_{va} \times IR_{va}) \times FI \times EF}{BW \times 365 \frac{d}{yr}} \right] \times C_{max} \times 10^{-3} \frac{kg}{g}$ $LADD = \left[\frac{(B_{vr} \times IR_{vr} + B_{va} \times IR_{va}) \times FI \times EF \times ED}{LT \times BW \times 365 \frac{d}{yr}} \right] \times C_{ave} \times 10^{-3} \frac{kg}{g}$	Where Bvr = soil-to-root uptake factor [mg chemical/kg root per mg chemical/kg soil]. Bva = above ground soil-to-root uptake factor [mg chemical/kg root per mg chemical/kg soil]. Cmax = maximum 7-year average contaminant concentration in soil [mg/kg]. Cave = time-averaged contaminant concentration in soil over the exposure duration [mg/kg]. IRvr = ingestion rate of root vegetables [g/day]. IRva = ingestion rate of above-ground vegetables [g/day]. FI = fraction of the ingested vegetables grown in contaminated soil [-].	(RISC-5, 2011)

Note; workers and trespassers are not expected to be exposed via this pathway.

Table D.7.4. The dialy dose (intake) of risk calculation for Anthracene substance of concern based on exposure routes assumed in the site.

Exposure pathways	Parameters of risk calculation	Child Resident-Upper percent	Adult Resident-Upper percent	Additive Receptor Case
Ingestion of soil	*CADD (mg/kd-d)	4.5E-04	4.8E-05	-
	**LADD (mg/kd-d)	3.8E-05	1.7E-05	5.5E-05
	Cancer Risk (-)	***ND	***ND	0.0E+00
	Hazard index (-)	1.5E-03	1.6E-04	-
Dermal Contact with Soil	*CADD (mg/kd-d)	1.3E-04	2.3E-05	-
	**LADD (mg/kd-d)	1.1E-05	7.9E-06	1.9E-05
	Cancer Risk (-)	***ND	***ND	0.0E+00
	Hazard index (-)	4.2E-04	7.7E-05	-
Ingestion of Vegetables	*CADD (mg/kd-d)	3.9E-03	1.5E-03	-
	**LADD (mg/kd-d)	3.3E-04	5.2E-04	8.5E-04
	Cancer Risk (-)	***ND	***ND	0.0E+00
	Hazard index (-)	1.3E-02	5.0E-03	-
Inhalation of Outdoor Air	*CADD (mg/kd-d)	1.3E-07	7.6E-09	-
	**LADD (mg/kd-d)	1.1E-08	2.6E-09	1.4E-08
	Cancer Risk (-)	***ND	***ND	0.0E+00
	Hazard index (-)	***ND	***ND	-
Inhalation of Particulates	*CADD (mg/kd-d)	2.3E-17	1.4E-18	-
	**LADD (mg/kd-d)	2.0E-18	4.7E-19	2.5E-18
	Cancer Risk (-)	***ND	***ND	0.0E+00
	Hazard index (-)	***ND	***ND	-

Note; *CADD: it means chronic average daily dose (RISC-5, 2011).
*****LADD: it means lifetime average daily dose (RISC-5, 2011).***
******ND: it means not detected.***

Table D.7.5. The daily dose (intake) of risk calculation for Phenanathrene substance of concern based on exposure routes assumed in the site.

Exposure pathways	Parameters of risk calculation	Child Resident-Upper percent	Adult Resident-Upper percent	Additive Receptor Case
Ingestion of soil	*CADD (mg/kd-d)	4.7E-04	5.0E-05	-
	**LADD (mg/kd-d)	4.0E-05	1.6E-05	5.6E-05
	Cancer Risk (-)	***ND	***ND	0.0E+00
	Hazard index (-)	***ND	***ND	-
Dermal Contact with Soil	*CADD (mg/kd-d)	1.0E-04	1.9E-05	-
	**LADD (mg/kd-d)	8.8E-06	5.9E-06	1.5E-05
	Cancer Risk (-)	***ND	***ND	0.0E+00
	Hazard index (-)	***ND	***ND	-
Ingestion of Vegetables	*CADD (mg/kd-d)	4.3E-03	1.7E-03	-
	**LADD (mg/kd-d)	3.7E-04	5.3E-04	9.0E-04
	Cancer Risk (-)	***ND	***ND	0.0E+00
	Hazard index (-)	***ND	***ND	-
Inhalation of Outdoor Air	*CADD (mg/kd-d)	2.1E-06	1.3E-07	-
	**LADD (mg/kd-d)	1.8E-07	4.0E-08	2.2E-07
	Cancer Risk (-)	***ND	***ND	0.0E+00
	Hazard index (-)	***ND	***ND	-
Inhalation of Particulates	*CADD (mg/kd-d)	2.4E-17	1.4E-18	-
	**LADD (mg/kd-d)	2.1E-18	4.6E-19	2.6E-18
	Cancer Risk (-)	***ND	***ND	0.0E+00
	Hazard index (-)	***ND	***ND	-

Note; *CADD: it means chronic average daily dose (RISC-5, 2011).
*****LADD: it means lifetime average daily dose (RISC-5, 2011).***
******ND: it means not detected.***

Table D.7.6. The daily dose (intake) of risk calculation for TPH aliphatic EC12 - EC16 substance of concern based on exposure routes assumed in the site.

Exposure pathways	Parameters of risk calculation	Child Resident-Upper percent	Adult Resident-Upper percent	Additive Receptor Case
Ingestion of soil	*CADD (mg/kd-d)	2.3E-05	2.1E-06	-
	**LADD (mg/kd-d)	2.0E-06	2.1E-07	2.2E-06
	Cancer Risk (-)	***ND	***ND	0.0E+00
	Hazard index (-)	2.3E-04	2.1E-05	-
Dermal Contact with Soil	*CADD (mg/kd-d)	5.0E-05	7.8E-06	-
	**LADD (mg/kd-d)	4.3E-06	7.9E-07	5.1E-06
	Cancer Risk (-)	***ND	***ND	0.0E+00
	Hazard index (-)	5.0E-04	7.8E-05	-
Ingestion of Vegetables	*CADD (mg/kd-d)	1.8E-04	5.8E-05	-
	**LADD (mg/kd-d)	1.5E-05	5.9E-06	2.1E-05
	Cancer Risk (-)	***ND	***ND	0.0E+00
	Hazard index (-)	1.8E-03	5.8E-04	-
Inhalation of Outdoor Air	*CADD (mg/kd-d)	9.7E-05	5.0E-06	-
	**LADD (mg/kd-d)	8.3E-06	5.0E-07	8.8E-06
	Cancer Risk (-)	***ND	***ND	0.0E+00
	Hazard index (-)	5.1E-05	9.1E-06	-
Inhalation of Particulates	*CADD (mg/kd-d)	1.2E-18	6.1E-20	-
	**LADD (mg/kd-d)	1.0E-19	6.1E-21	1.1E-19
	Cancer Risk (-)	***ND	***ND	0.0E+00
	Hazard index (-)	6.2E-19	1.1E-19	-

Note; *CADD: it means chronic average daily dose (RISC-5, 2011).
*****LADD: it means lifetime average daily dose (RISC-5, 2011).***
******ND: it means not detected.***

Table D.7.7. The daily dose (intake) of risk calculation for TPH aliphatic EC16 - EC35 substance of concern based on exposure routes assumed in the site.

Exposure pathways	Parameters of risk calculation	Child Resident-Upper percent	Adult Resident-Upper percent	Additive Receptor Case
Ingestion of soil	*CADD (mg/kd-d)	4.0E-03	4.3E-04	-
	**LADD (mg/kd-d)	3.5E-04	1.5E-04	4.9E-04
	Cancer Risk (-)	***ND	***ND	0.0E+00
	Hazard index (-)	2.0E-03	2.2E-04	-
Dermal Contact with Soil	*CADD (mg/kd-d)	8.8E-03	1.6E-03	-
	**LADD (mg/kd-d)	7.6E-04	5.4E-04	1.3E-03
	Cancer Risk (-)	***ND	***ND	0.0E+00
	Hazard index (-)	4.4E-03	8.0E-04	-
Ingestion of Vegetables	*CADD (mg/kd-d)	1.4E-02	5.6E-03	-
	**LADD (mg/kd-d)	1.2E-03	1.9E-03	3.1E-03
	Cancer Risk (-)	***ND	***ND	0.0E+00
	Hazard index (-)	7.2E-03	2.8E-03	-
Inhalation of Outdoor Air	*CADD (mg/kd-d)	2.8E-05	1.7E-06	-
	**LADD (mg/kd-d)	2.4E-06	5.6E-07	3.0E-06
	Cancer Risk (-)	***ND	***ND	0.0E+00
	Hazard index (-)	***ND	***ND	-
Inhalation of Particulates	*CADD (mg/kd-d)	2.1E-16	1.2E-17	-
	**LADD (mg/kd-d)	1.8E-17	4.2E-18	2.2E-17
	Cancer Risk (-)	***ND	***ND	0.0E+00
	Hazard index (-)	***ND	***ND	-

Note; *CADD: it means chronic average daily dose (RISC-5, 2011).
*****LADD: it means lifetime average daily dose (RISC-5, 2011).***
******ND: it means not detected.***

Table D.7.8. The daily dose (intake) of risk calculation for TPH aromatic EC8 - EC10 substance of concern based on exposure routes assumed in the site.

Exposure pathways	Parameters of risk calculation	Child Resident- Upper percent	Adult Resident- Upper percent	Additive Receptor Case
Ingestion of soil	*CADD (mg/kd-d)	1.9E-06	1.8E-07	-
	**LADD (mg/kd-d)	1.6E-07	1.8E-08	1.8E-07
	Cancer Risk (-)	***ND	***ND	0.0E+00
	Hazard index (-)	4.7E-05	4.4E-06	-
Dermal Contact with Soil	*CADD (mg/kd-d)	4.2E-06	6.5E-07	-
	**LADD (mg/kd-d)	3.6E-07	6.6E-08	4.2E-07
	Cancer Risk (-)	***ND	***ND	0.0E+00
	Hazard index (-)	1.0E-04	1.6E-05	-
Ingestion of Vegetables	*CADD (mg/kd-d)	1.5E-05	4.8E-06	-
	**LADD (mg/kd-d)	1.3E-06	4.9E-07	1.7E-06
	Cancer Risk (-)	***ND	***ND	0.0E+00
	Hazard index (-)	3.6E-04	1.2E-04	-
Inhalation of Outdoor Air	*CADD (mg/kd-d)	3.3E-05	1.7E-06	-
	**LADD (mg/kd-d)	2.8E-06	1.7E-07	3.0E-06
	Cancer Risk (-)	***ND	***ND	0.0E+00
	Hazard index (-)	8.5E-05	1.5E-05	-
Inhalation of Particulates	*CADD (mg/kd-d)	9.8E-20	5.0E-21	-
	**LADD (mg/kd-d)	8.4E-21	5.1E-22	8.9E-21
	Cancer Risk (-)	***ND	***ND	0.0E+00
	Hazard index (-)	2.6E-19	4.6E-20	-

Note; *CADD: it means chronic average daily dose (RISC-5, 2011).
*****LADD: it means lifetime average daily dose (RISC-5, 2011).***
******ND: it means not detected.***

Table D.7.9. The daily dose (intake) of risk calculation for TPH aromatic EC10 - EC12 substance of concern based on exposure routes assumed in the site.

Exposure pathways	**Parameters of risk calculation**	**Child Resident-Upper percent**	**Adult Resident-Upper percent**	**Additive Receptor Case**
Ingestion of soil	*CADD (mg/kd-d)	2.6E-05	2.4E-06	-
	**LADD (mg/kd-d)	2.3E-06	2.5E-07	2.5E-06
	Cancer Risk (-)	***ND	***ND	0.0E+00
	Hazard index (-)	6.6E-04	1.7E-04	-
Dermal Contact with Soil	*CADD (mg/kd-d)	5.8E-05	9.0E-06	-
	**LADD (mg/kd-d)	5.0E-06	9.1E-07	5.9E-06
	Cancer Risk (-)	***ND	***ND	0.0E+00
	Hazard index (-)	1.4E-03	2.3E-04	-
Ingestion of Vegetables	*CADD (mg/kd-d)	2.5E-04	8.2E-05	-
	**LADD (mg/kd-d)	2.1E-05	8.3E-06	2.9E-05
	Cancer Risk (-)	***ND	***ND	0.0E+00
	Hazard index (-)	6.2E-03	2.1E-03	-
Inhalation of Outdoor Air	*CADD (mg/kd-d)	1.6E-04	8.3E-06	-
	**LADD (mg/kd-d)	1.4E-05	8.4E-07	1.5E-05
	Cancer Risk (-)	***ND	***ND	0.0E+00
	Hazard index (-)	4.2E-04	7.6E-05	-
Inhalation of Particulates	*CADD (mg/kd-d)	1.4E-18	7.0E-20	-
	**LADD (mg/kd-d)	1.2E-19	7.1E-21	1.2E-19
	Cancer Risk (-)	***ND	***ND	0.0E+00
	Hazard index (-)	3.6E-18	6.4E-19	-

Note; *CADD: it means chronic average daily dose (RISC-5, 2011).
*****LADD: it means lifetime average daily dose (RISC-5, 2011).***
******ND: it means not detected.***

Table D.7.10. The daily dose (intake) of risk calculation for TPH aromatic EC12 - EC16 substance of concern based on exposure routes assumed in the site.

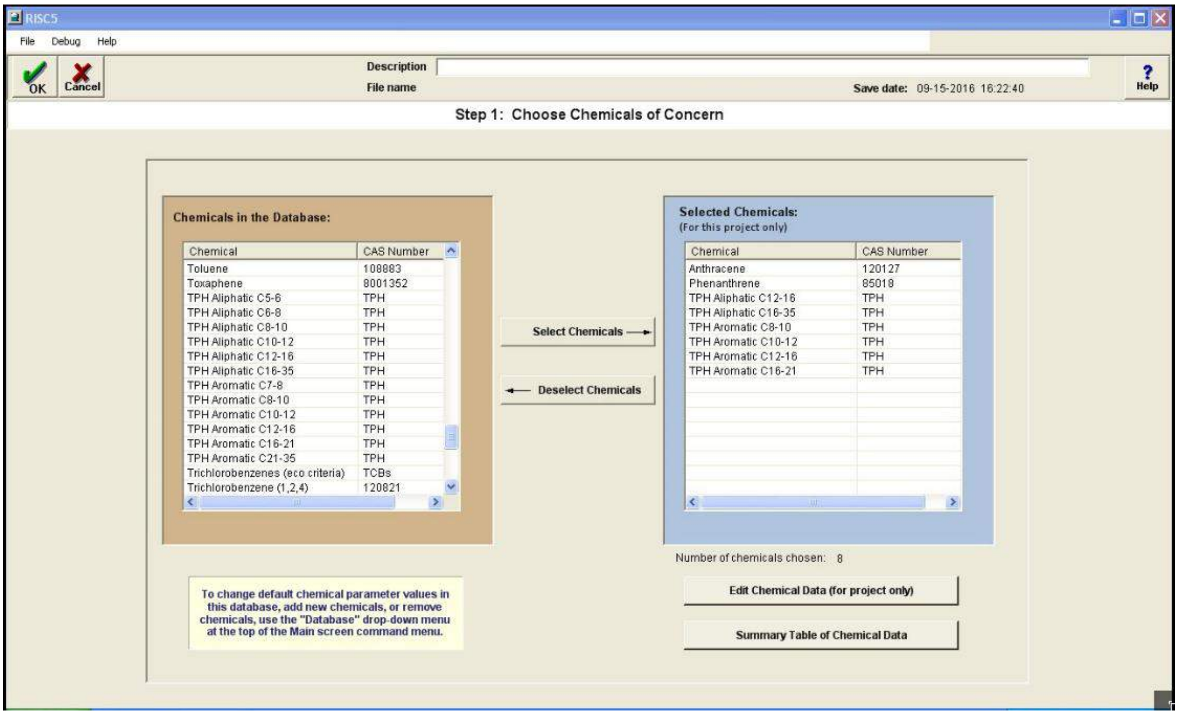
Exposure pathways	Parameters of risk calculation	Child Resident-Upper percent	Adult Resident-Upper percent	Additive Receptor Case
Ingestion of soil	*CADD (mg/kd-d)	3.3E-04	3.1E-05	-
	**LADD (mg/kd-d)	2.8E-05	3.2E-06	3.1E-05
	Cancer Risk (-)	***ND	***ND	0.0E+00
	Hazard index (-)	8.2E-03	7.7E-04	-
Dermal Contact with Soil	*CADD (mg/kd-d)	7.2E-04	1.1E-04	-
	**LADD (mg/kd-d)	6.2E-05	1.2E-05	7.3E-05
	Cancer Risk (-)	***ND	***ND	0.0E+00
	Hazard index (-)	1.8E-02	2.9E-03	-
Ingestion of Vegetables	*CADD (mg/kd-d)	4.3E-03	1.5E-03	-
	**LADD (mg/kd-d)	3.7E-04	1.5E-04	5.2E-04
	Cancer Risk (-)	***ND	***ND	0.0E+00
	Hazard index (-)	1.1E-01	3.6E-02	-
Inhalation of Outdoor Air	*CADD (mg/kd-d)	3.2E-04	1.7E-05	-
	**LADD (mg/kd-d)	2.8E-05	1.7E-06	2.9E-05
	Cancer Risk (-)	***ND	***ND	0.0E+00
	Hazard index (-)	8.4E-04	1.5E-04	-
Inhalation of Particulates	*CADD (mg/kd-d)	1.7E-17	8.8E-19	-
	**LADD (mg/kd-d)	1.5E-18	9.2E-20	1.6E-18
	Cancer Risk (-)	***ND	***ND	0.0E+00
	Hazard index (-)	4.4E-17	8.1E-18	-

Note; * CADD: it means chronic average daily dose (RISC-5, 2011).
*****LADD: it means lifetime average daily dose (RISC-5, 2011).***
******ND: it means not detected.***

Table D.7.11. The daily dose (intake) of risk calculation for TPH aromatic EC16 - EC21 substance of concern based on exposure routes assumed in the site.

Exposure pathways	Parameters of risk calculation	Child Resident-Upper percent	Adult Resident-Upper percent	Additive Receptor Case
Ingestion of soil	*CADD (mg/kd-d)	2.8E-03	3.0E-04	-
	**LADD (mg/kd-d)	2.4E-04	1.0E-04	3.4E-04
	Cancer Risk (-)	***ND	***ND	0.0E+00
	Hazard index (-)	9.3E-02	1.0E-02	-
Dermal Contact with Soil	*CADD (mg/kd-d)	6.1E-03	1.1E-03	-
	**LADD (mg/kd-d)	5.3E-04	3.7E-04	9.0E-04
	Cancer Risk (-)	***ND	***ND	0.0E+00
	Hazard index (-)	2.0E-01	3.7E-02	-
Ingestion of Vegetables	*CADD (mg/kd-d)	6.5E-02	2.5E-02	-
	**LADD (mg/kd-d)	5.6E-03	8.4E-03	1.4E-02
	Cancer Risk (-)	***ND	***ND	0.0E+00
	Hazard index (-)	2.2E+00	8.4E-01	-
Inhalation of Outdoor Air	*CADD (mg/kd-d)	2.2E-05	1.3E-06	-
	**LADD (mg/kd-d)	1.9E-06	4.4E-07	2.3E-06
	Cancer Risk (-)	***ND	***ND	0.0E+00
	Hazard index (-)	***ND	***ND	-
Inhalation of Particulates	*CADD (mg/kd-d)	1.5E-16	8.6E-18	-
	**LADD (mg/kd-d)	1.2E-17	2.9E-18	1.5E-17
	Cancer Risk (-)	***ND	***ND	0.0E+00
	Hazard index (-)	***ND	***ND	-

Note; *CADD: it means chronic average daily dose (RISC-5, 2011).
*****LADD: it means lifetime average daily dose (RISC-5, 2011).***
******ND: it means not detected.***



Description

File name

Save date: 09-15-2016 16:22:40

Step 1: Choose Chemicals of Concern

Chemicals in the Database:

Chemical	CAS Number
Toluene	108883
Toxaphene	8001352
TPH Aliphatic C5-6	TPH
TPH Aliphatic C6-8	TPH
TPH Aliphatic C8-10	TPH
TPH Aliphatic C10-12	TPH
TPH Aliphatic C12-16	TPH
TPH Aliphatic C16-35	TPH
TPH Aromatic C7-8	TPH
TPH Aromatic C8-10	TPH
TPH Aromatic C10-12	TPH
TPH Aromatic C12-16	TPH
TPH Aromatic C16-21	TPH
TPH Aromatic C21-35	TPH
Trichlorobenzenes (eco criteria)	TCBs
Trichlorobenzene (1,2,4)	120821

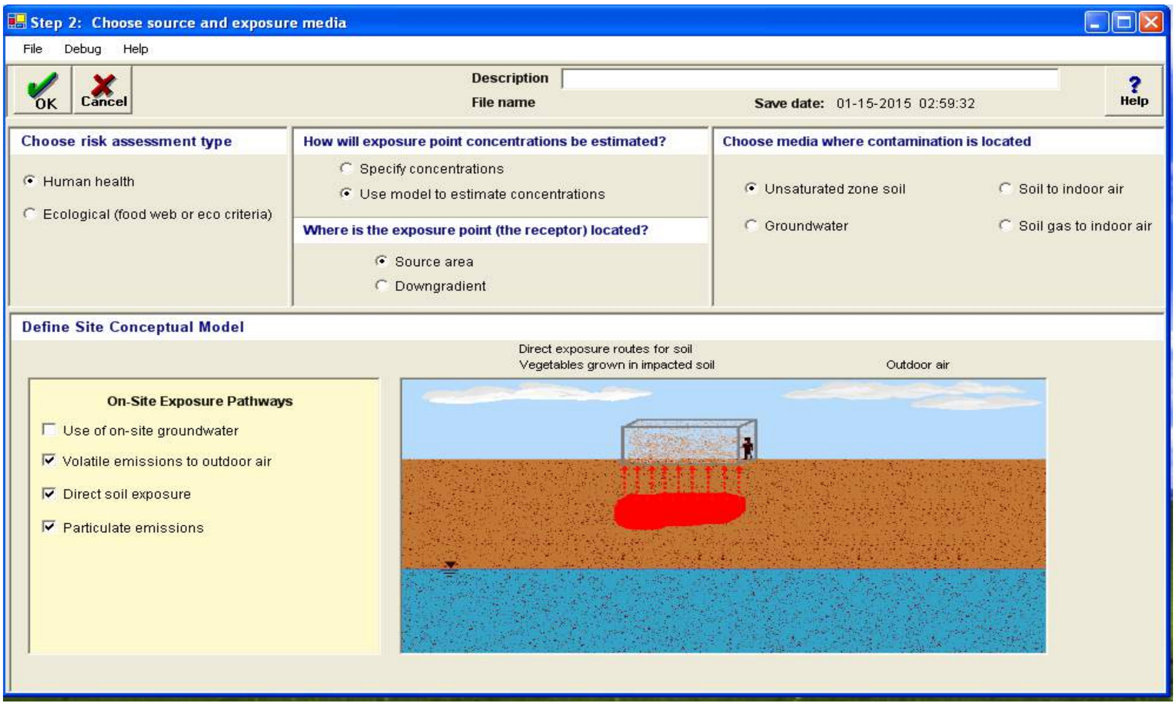
Selected Chemicals:
(For this project only)

Chemical	CAS Number
Anthracene	120127
Phenanthrene	85018
TPH Aliphatic C12-16	TPH
TPH Aliphatic C16-35	TPH
TPH Aromatic C8-10	TPH
TPH Aromatic C10-12	TPH
TPH Aromatic C12-16	TPH
TPH Aromatic C16-21	TPH

Number of chemicals chosen: 8

To change default chemical parameter values in this database, add new chemicals, or remove chemicals, use the "Database" drop-down menu at the top of the Main screen command menu.

Figure D.7.22. The selected chemical of concern (TPH fraction) for Step (1) of the RISC-5 software which is used for risk assessment at dry *crude oil lake* site.



Description

File name

Save date: 01-15-2015 02:59:32

Choose risk assessment type

● Human health

○ Ecological (food web or eco criteria)

How will exposure point concentrations be estimated?

○ Specify concentrations

● Use model to estimate concentrations

Where is the exposure point (the receptor) located?

● Source area

○ Downgradient

Choose media where contamination is located

● Unsaturated zone soil

○ Soil to indoor air

○ Groundwater

○ Soil gas to indoor air

Define Site Conceptual Model

On-Site Exposure Pathways

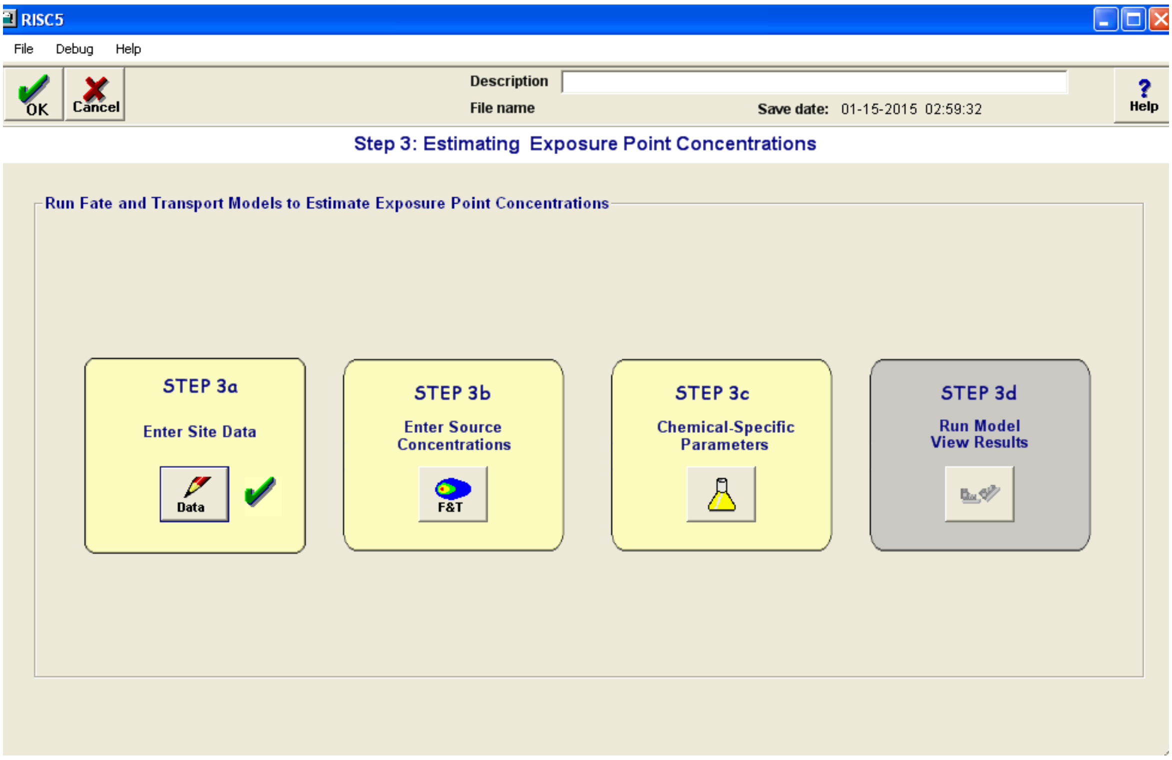
☐ Use of on-site groundwater

☑ Volatile emissions to outdoor air

☑ Direct soil exposure

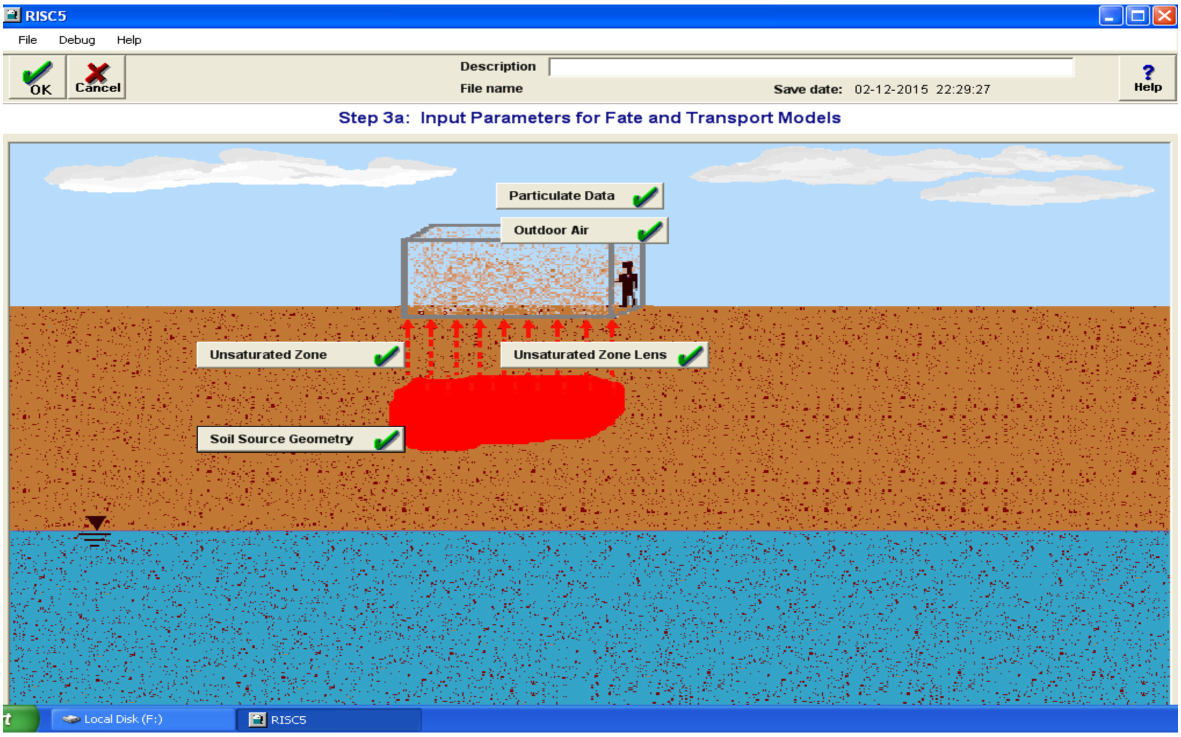
☑ Particulate emissions

Figure D.7.23. The chosen risk assessment type and the exposure media of contamination located assumed at unsaturated zone soil pathway in step-2 of the modelling (RISC-5).



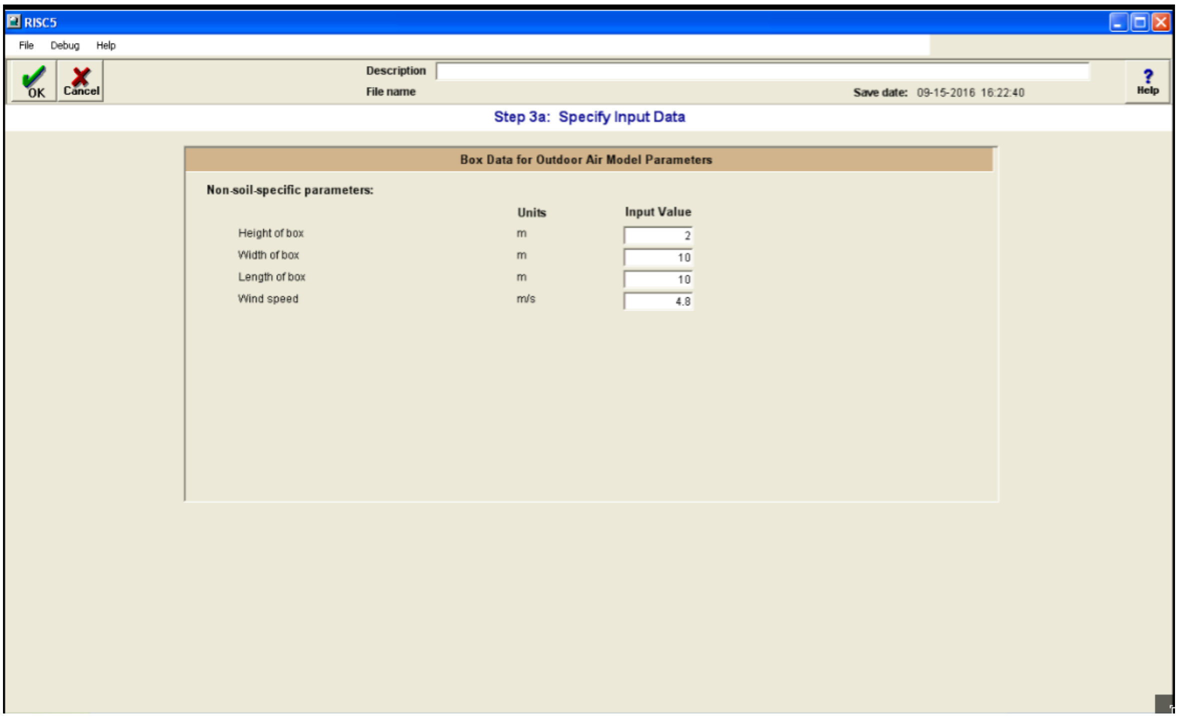
Save date: 01-15-2015 02:59:32

Figure D.7.24. The estimating exposure point concentrations of dry *crude oil lake* site at step 3 for unsaturated zone soil pathway in RISC-5 modelling.



Save date: 02-12-2015 22:29:27

Figure D.7.25. The enter site data at step 3a in accordance with contamination located assumed at unsaturated zone soil pathway.



Description

File name

Save date: 09-15-2016 16:22:40

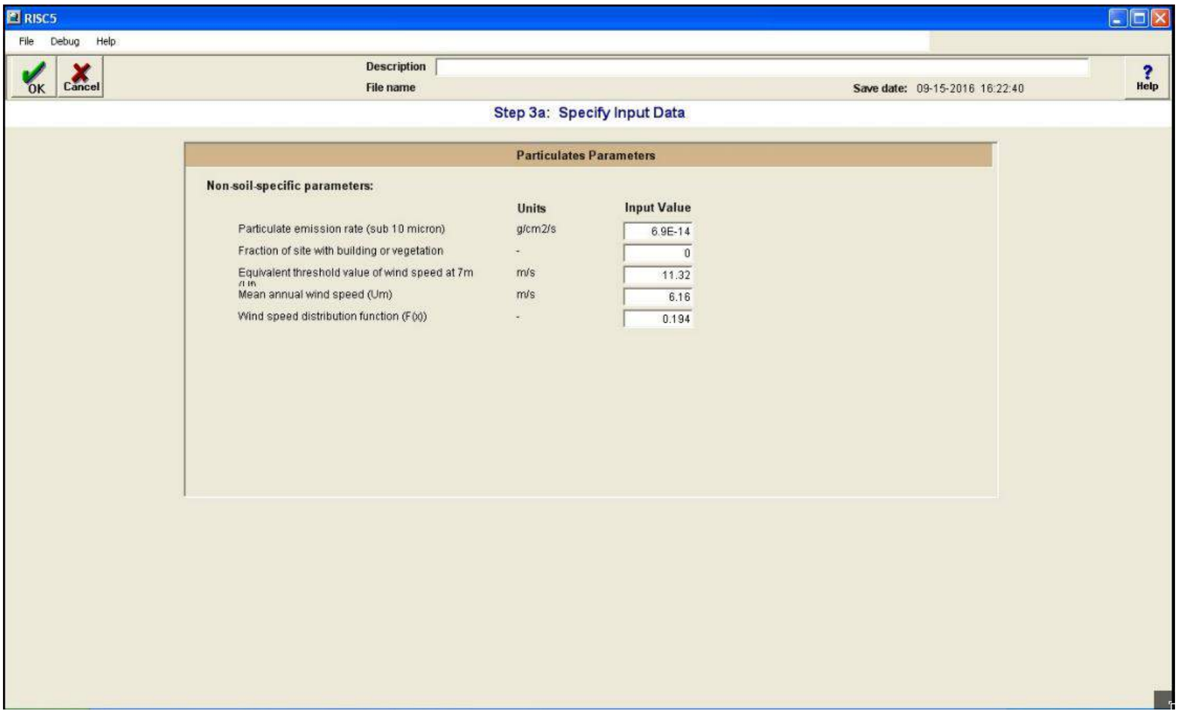
Step 3a: Specify Input Data

Box Data for Outdoor Air Model Parameters

Non-soil-specific parameters:

	Units	Input Value
Height of box	m	2
Width of box	m	10
Length of box	m	10
Wind speed	m/s	4.8

Figure D.7.26. The Box data for the outdoor air model parameters for unsaturated zone soil pathway which assumed in step-3a related to the dry *crude oil lake* site.



Description

File name

Save date: 09-15-2016 16:22:40

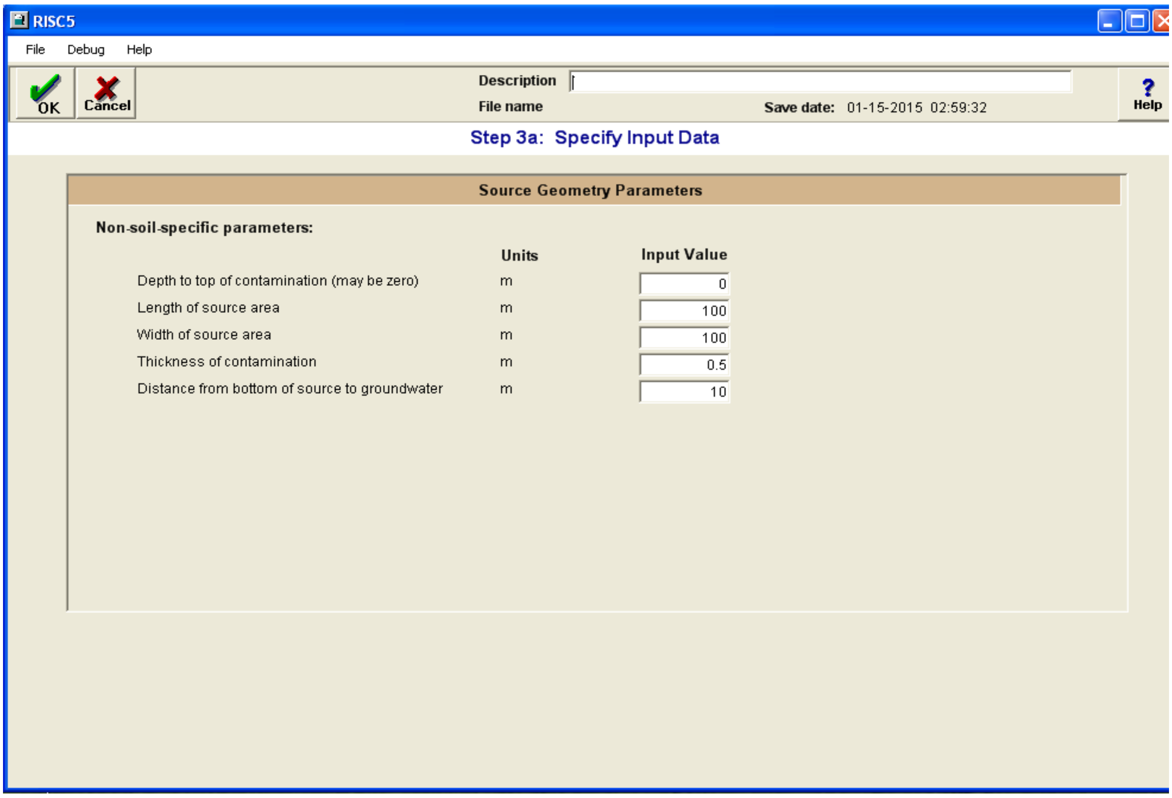
Step 3a: Specify Input Data

Particulates Parameters

Non-soil-specific parameters:

	Units	Input Value
Particulate emission rate (sub 10 micron)	g/cm2/s	6.9E-14
Fraction of site with building or vegetation	-	0
Equivalent threshold value of wind speed at 7m	m/s	11.32
Mean annual wind speed (Um)	m/s	6.16
Wind speed distribution function (F(x))	-	0.194

Figure D.7.27. The particulates parameters for unsaturated zone soil which assumed in step-3a related to the dry *crude oil lake* site.



Description

File name

Save date: 01-15-2015 02:59:32

Step 3a: Specify Input Data

Source Geometry Parameters

Non-soil-specific parameters:

	Units	Input Value
Depth to top of contamination (may be zero)	m	0
Length of source area	m	100
Width of source area	m	100
Thickness of contamination	m	0.5
Distance from bottom of source to groundwater	m	10

Figure D.7.28. The source Geometry parameters for unsaturated zone soil as assumed in step-3a related to the dry *crude oil lake* site.

Description

File name

Save date: 04-02-2015 12:09:19

Step 3a: Specify Input Data

Unsaturated Zone Lens Parameters

Parameters with defaults available from soil property database:

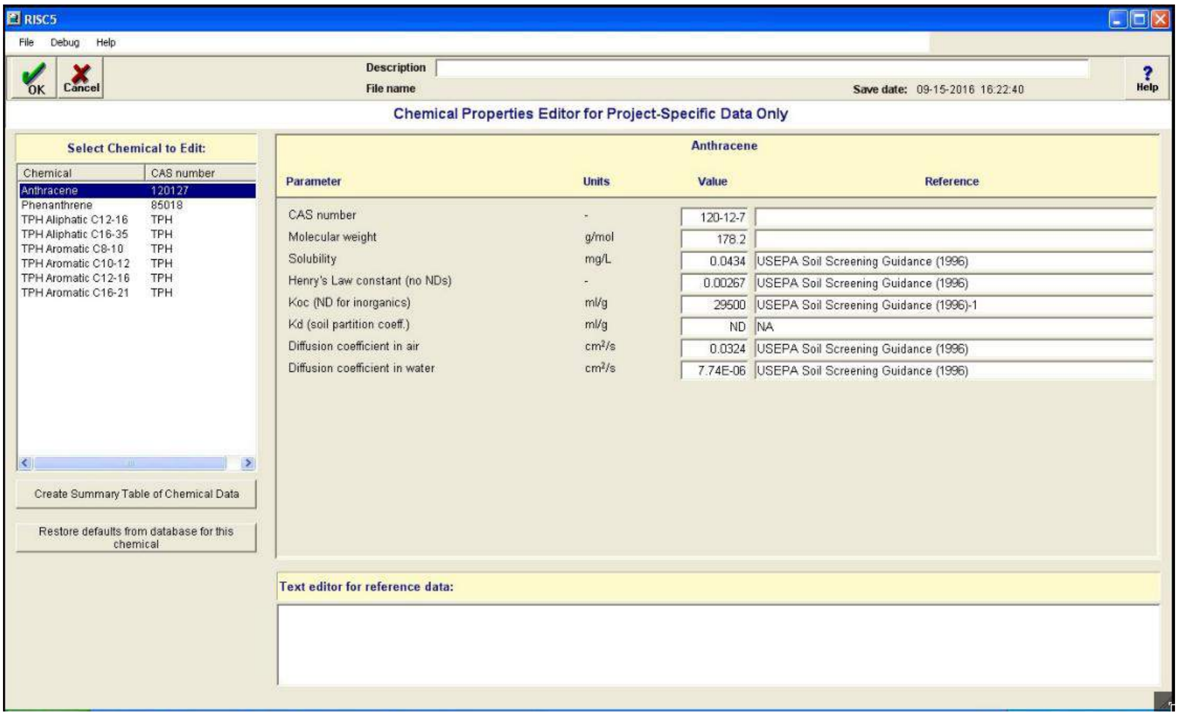
	Units	Input Value	Range
Total porosity of lens	cm³/cm³	0.375	0 to 1
Residual water content of lens	cm³/cm³	0.053	0 to 1
Saturated conductivity of the lens	m/d	6.4	0 to 10000
Value of Van Genuchten's "n" parameter	-	2.68	1 to 3

Soil Property Database: Sand

Non-soil-specific parameters:

	Units	Input Value
Thickness of lens	m	2.0

Figure D.7.29. The unsaturated zone lens parameters for unsaturated zone soil as assumed in step-3a related to the dry *crude oil lake* site.



Description

File name

Save date: 09-15-2016 16:22:40

Chemical Properties Editor for Project-Specific Data Only

Select Chemical to Edit:

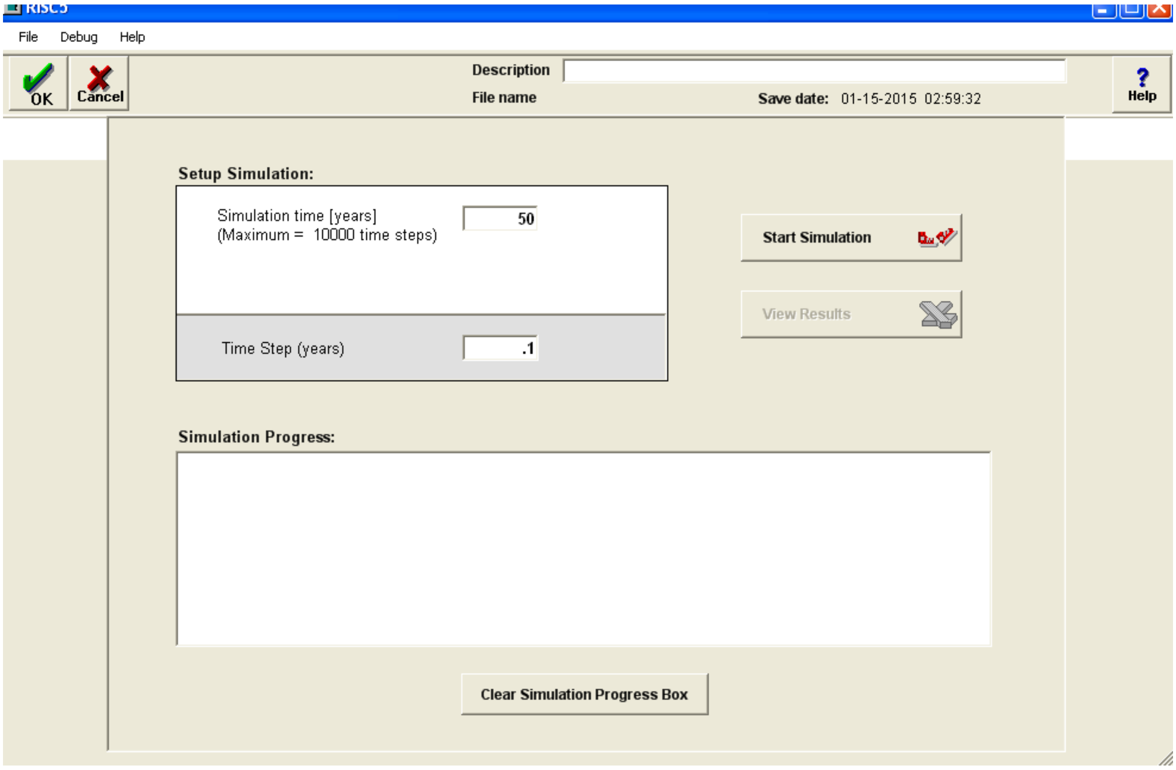
Chemical	CAS number
Anthracene	120127
Phenanthrene	85018
TPH Aliphatic C12-16	TPH
TPH Aliphatic C16-35	TPH
TPH Aromatic C8-10	TPH
TPH Aromatic C10-12	TPH
TPH Aromatic C12-16	TPH
TPH Aromatic C16-21	TPH

Anthracene

Parameter	Units	Value	Reference
CAS number	-	120-12-7	
Molecular weight	g/mol	178.2	
Solubility	mg/L	0.0434	USEPA Soil Screening Guidance (1996)
Henry's Law constant (no NDs)	-	0.00267	USEPA Soil Screening Guidance (1996)
Koc (ND for inorganics)	ml/g	29500	USEPA Soil Screening Guidance (1996)-1
Kd (soil partition coeff.)	ml/g	ND	NA
Diffusion coefficient in air	cm^2/s	0.0324	USEPA Soil Screening Guidance (1996)
Diffusion coefficient in water	cm^2/s	7.74E-06	USEPA Soil Screening Guidance (1996)

Text editor for reference data:

Figure D.7.30. The example of the chemical properties of the Anthracene at step 3c for unsaturated zone soil pathway which found in the dry *crude oil lake* site.



Description

File name

Save date: 01-15-2015 02:59:32

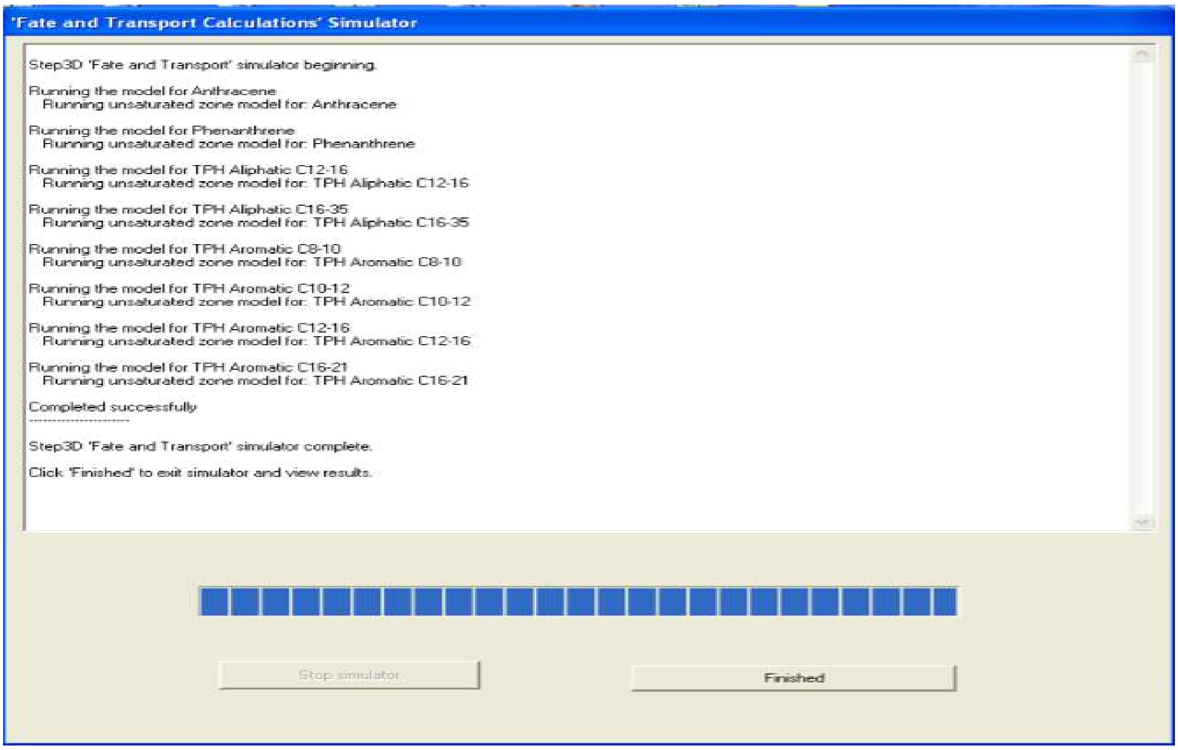
Setup Simulation:

Simulation time [years] (Maximum = 10000 time steps) 50

Time Step (years) .1

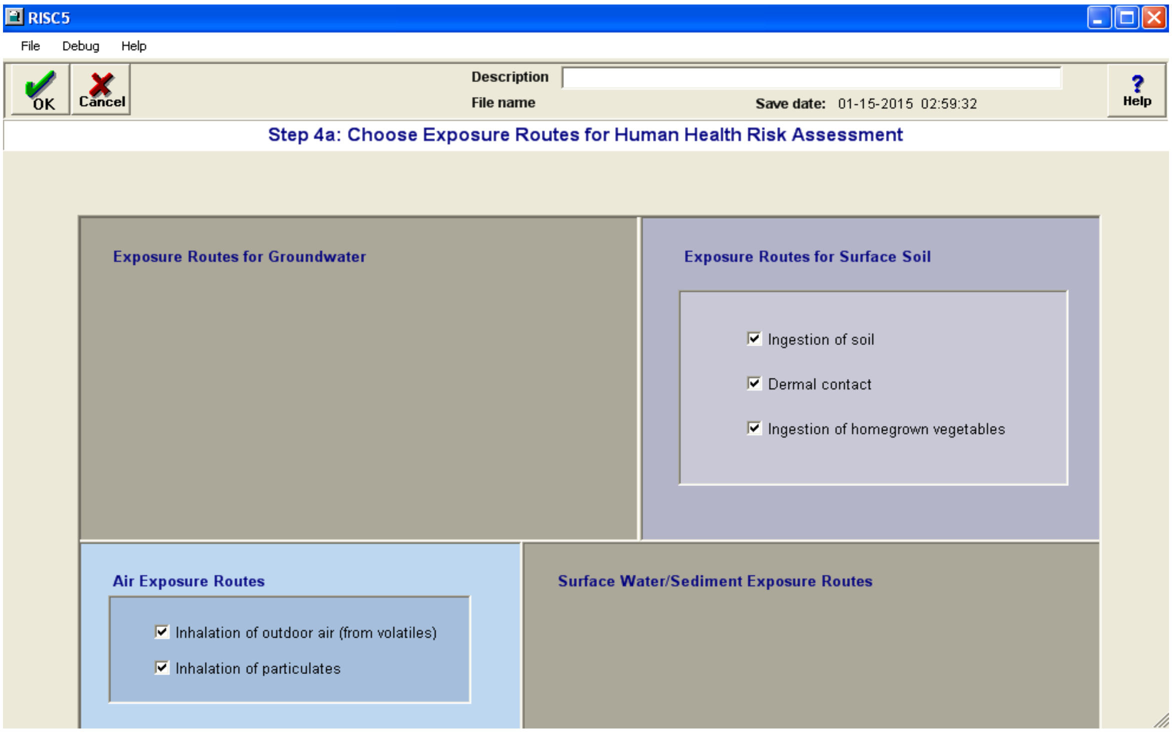
Simulation Progress:

Figure D.7.31. The simulation process for the time by fate and transport model in step 3d which is running for unsaturated zone soil pathway.



```
Step3D 'Fate and Transport' simulator beginning.

Running the model for Anthracene
  Running unsaturated zone model for: Anthracene

Running the model for Phenanthrene
  Running unsaturated zone model for: Phenanthrene

Running the model for TPH Aliphatic C12-16
  Running unsaturated zone model for: TPH Aliphatic C12-16

Running the model for TPH Aliphatic C16-35
  Running unsaturated zone model for: TPH Aliphatic C16-35

Running the model for TPH Aromatic C8-10
  Running unsaturated zone model for: TPH Aromatic C8-10

Running the model for TPH Aromatic C10-12
  Running unsaturated zone model for: TPH Aromatic C10-12

Running the model for TPH Aromatic C12-16
  Running unsaturated zone model for: TPH Aromatic C12-16

Running the model for TPH Aromatic C16-21
  Running unsaturated zone model for: TPH Aromatic C16-21

Completed successfully
------------------------

Step3D 'Fate and Transport' simulator complete.

Click 'Finished' to exit simulator and view results.
```

Figure D.7.31. Step-3d-continous.



Description
File name
Save date: 01-15-2015 02:59:32

Step 4a: Choose Exposure Routes for Human Health Risk Assessment

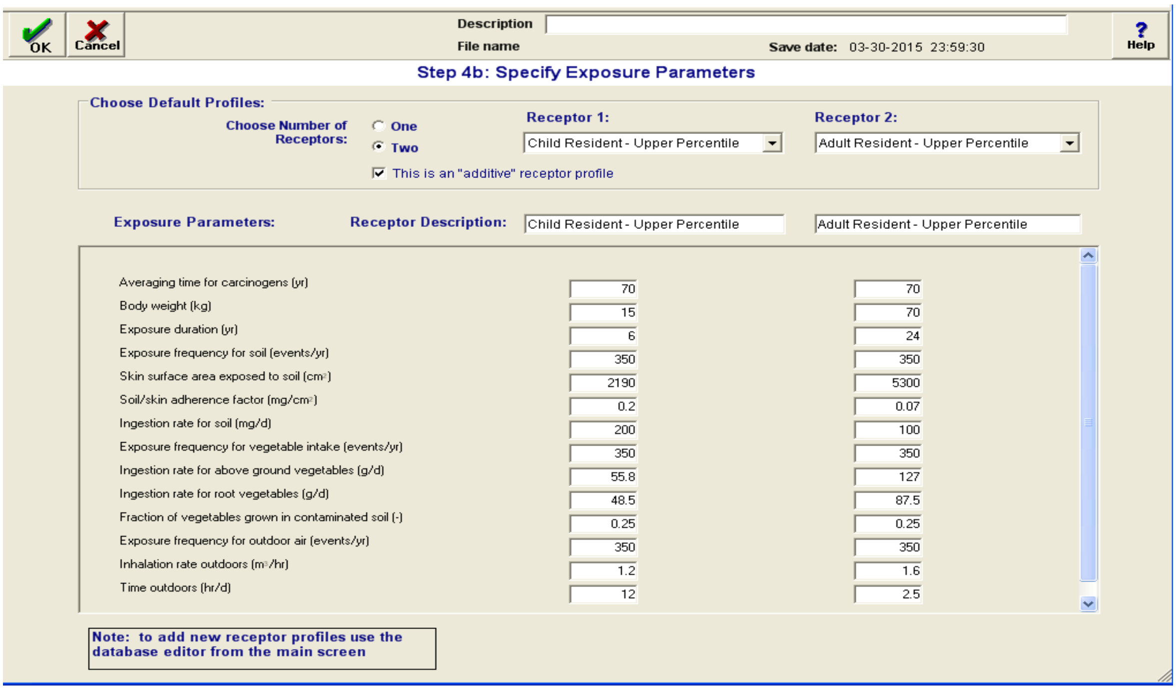
Exposure Routes for Surface Soil

☑ Ingestion of soil
☑ Dermal contact
☑ Ingestion of homegrown vegetables

Air Exposure Routes

☑ Inhalation of outdoor air (from volatiles)
☑ Inhalation of particulates

Figure D.7.32. The exposure routes selected for human health risk assessment at step 4a based on contamination located assumed at unsaturated zone soil pathway selected in accordance with dry *crude oil lake* site.



Description

File name

Save date: 03-30-2015 23:59:30

Step 4b: Specify Exposure Parameters

Choose Default Profiles:

Choose Number of Receptors: ○ One ● Two

Receptor 1: Child Resident - Upper Percentile

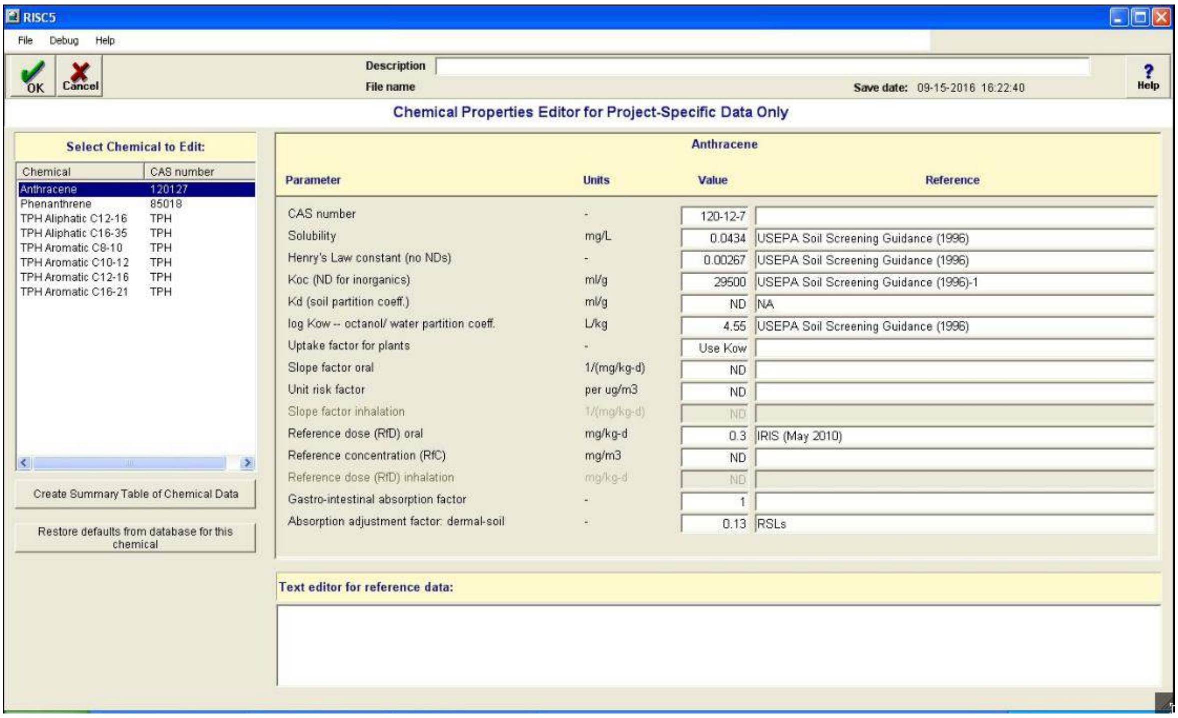
Receptor 2: Adult Resident - Upper Percentile

☑ This is an "additive" receptor profile

Exposure Parameters: Receptor Description:	Child Resident - Upper Percentile	Adult Resident - Upper Percentile
Averaging time for carcinogens (yr)	70	70
Body weight (kg)	15	70
Exposure duration (yr)	6	24
Exposure frequency for soil (events/yr)	350	350
Skin surface area exposed to soil (cm²)	2190	5300
Soil/skin adherence factor (mg/cm²)	0.2	0.07
Ingestion rate for soil (mg/d)	200	100
Exposure frequency for vegetable intake (events/yr)	350	350
Ingestion rate for above ground vegetables (g/d)	55.8	127
Ingestion rate for root vegetables (g/d)	48.5	87.5
Fraction of vegetables grown in contaminated soil (-)	0.25	0.25
Exposure frequency for outdoor air (events/yr)	350	350
Inhalation rate outdoors (m³/hr)	1.2	1.6
Time outdoors (hr/d)	12	2.5

Note: to add new receptor profiles use the database editor from the main screen

Figure D.7.33. The types of the receptors to be considered in risk assessment in step 4b as assumed based on contamination located assumed at unsaturated zone soil pathway selected for dry *crude oil lake* site.



Description

File name

Save date: 09-15-2016 16:22:40

Chemical Properties Editor for Project-Specific Data Only

Select Chemical to Edit:

Chemical	CAS number
Anthracene	120127
Phenanthrene	85018
TPH Aliphatic C12-16	TPH
TPH Aliphatic C16-35	TPH
TPH Aromatic C8-10	TPH
TPH Aromatic C10-12	TPH
TPH Aromatic C12-16	TPH
TPH Aromatic C16-21	TPH

Create Summary Table of Chemical Data

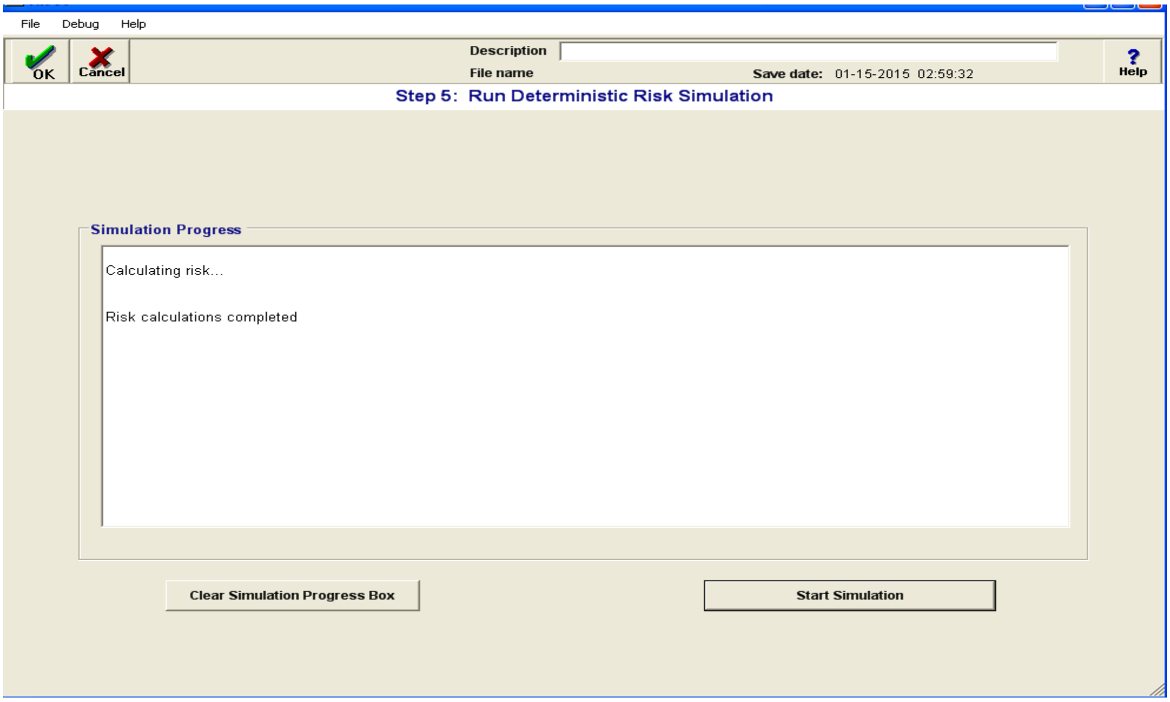
Restore defaults from database for this chemical

Anthracene

Parameter	Units	Value	Reference
CAS number	-	120-12-7	
Solubility	mg/L	0.0434	USEPA Soil Screening Guidance (1996)
Henry's Law constant (no NDs)	-	0.00267	USEPA Soil Screening Guidance (1996)
Koc (ND for inorganics)	ml/g	29500	USEPA Soil Screening Guidance (1996)-1
Kd (soil partition coeff.)	ml/g	ND	NA
log Kow -- octanol/ water partition coeff.	L/kg	4.55	USEPA Soil Screening Guidance (1996)
Uptake factor for plants	-	Use Kow	
Slope factor oral	1/(mg/kg-d)	ND	
Unit risk factor	per ug/m3	ND	
Slope factor inhalation	1/(mg/kg-d)	ND	
Reference dose (RfD) oral	mg/kg-d	0.3	IRIS (May 2010)
Reference concentration (RfC)	mg/m3	ND	
Reference dose (RfD) inhalation	mg/kg-d	ND	
Gastro-intestinal absorption factor	-	1	
Absorption adjustment factor: dermal-soil	-	0.13	RSLs

Text editor for reference data:

Figure D.7.34. Review of the chemical properties as example for the specific anthracene substance concern chosen for risk assessment at step 4c basen on contamination located assumed at unsaturated zone soil pathway selected.



Description

File name

Save date: 01-15-2015 02:59:32

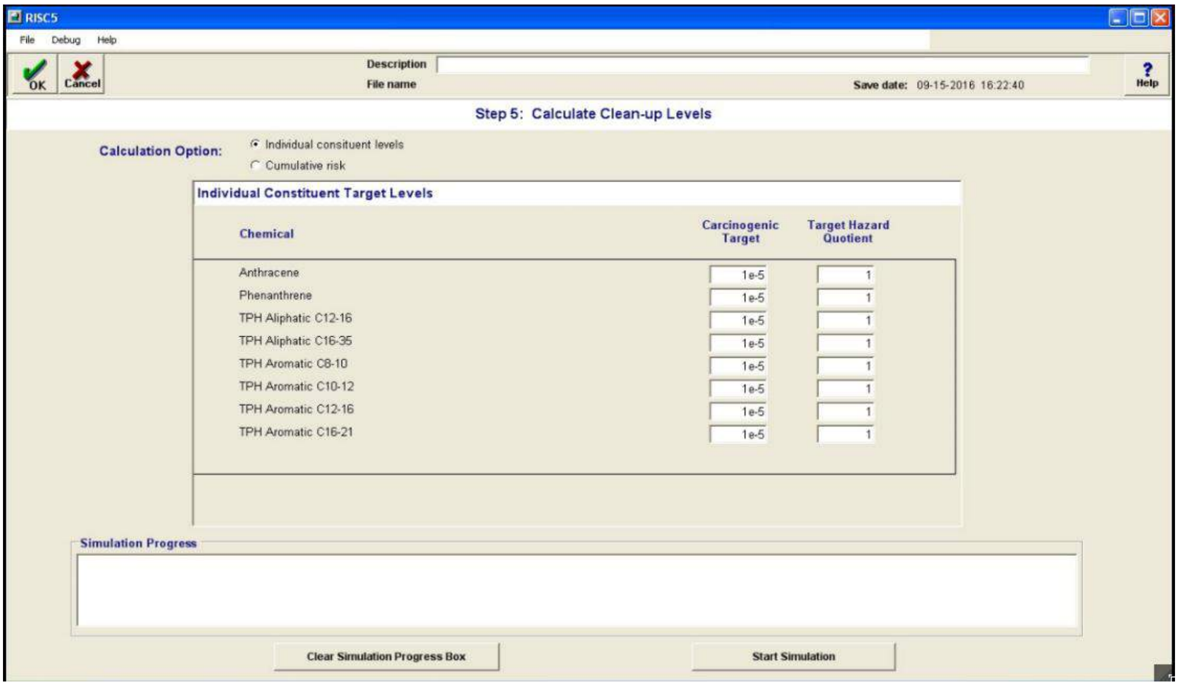
Step 5: Run Deterministic Risk Simulation

Simulation Progress

Calculating risk...

Risk calculations completed

Figure D.7.35. The run deterministic risk simulation for unsaturated zone soil air pathway at step 5 for human health risk assessment in term of carcinogenic and non-carcinogenic.



Description

File name

Save date: 09-15-2016 16:22:40

Step 5: Calculate Clean-up Levels

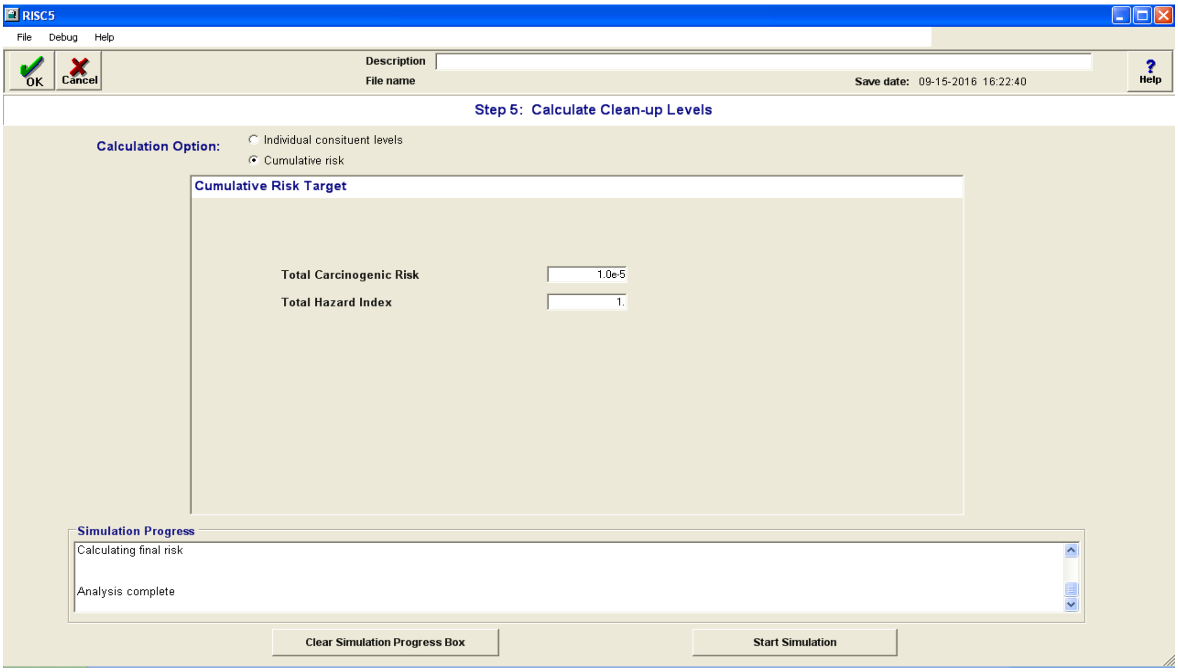
Calculation Option: ● Individual consituent levels ○ Cumulative risk

Individual Constituent Target Levels

Chemical	Carcinogenic Target	Target Hazard Quotient
Anthracene	1e-5	1
Phenanthrene	1e-5	1
TPH Aliphatic C12-16	1e-5	1
TPH Aliphatic C16-35	1e-5	1
TPH Aromatic C8-10	1e-5	1
TPH Aromatic C10-12	1e-5	1
TPH Aromatic C12-16	1e-5	1
TPH Aromatic C16-21	1e-5	1

Simulation Progress

Figure D.7.36. The individual clean-up level calculation process at step 6 in the modelling for each detected hydrocarbon contamination (i.e. aliphatic & aromatic fractions and anthracene and phenanthrene substances) at assumed pathways in unsaturated zone soil.



Save date: 09-15-2016 16:22:40

Calculation Option:
○ Individual consituent levels
● Cumulative risk

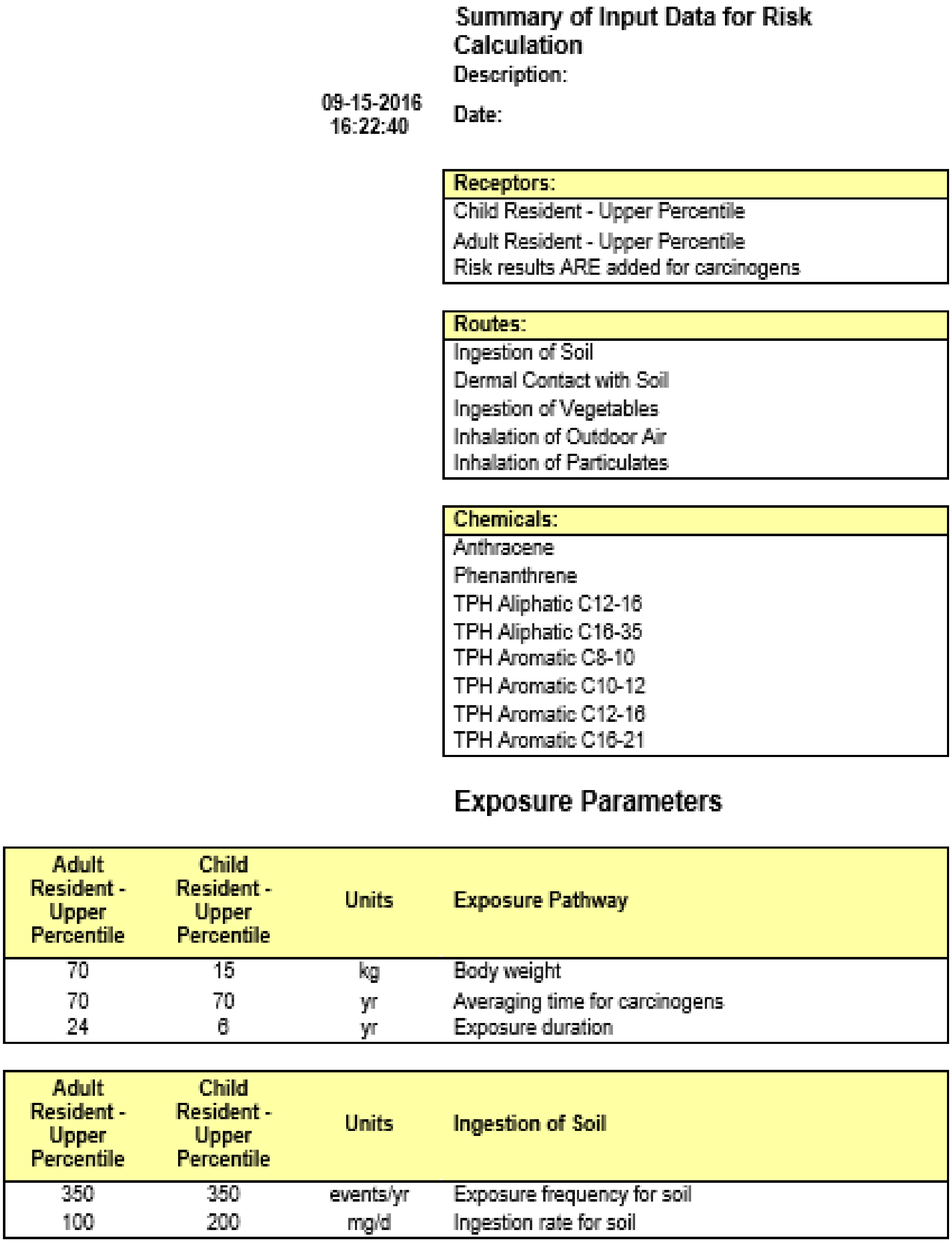
Total Carcinogenic Risk 1.0e-5

Total Hazard Index 1.

```
Calculating final risk

Analysis complete
```

Figure D.7.37. The cumulative clean-up level calculation process at step 6 in the modelling for each detected hydrocarbon contamination (i.e. aliphatic & aromatic fractions and anthracene and phenanthrene substances) at assumed pathways in unsaturated zone soil.

Table D.7.12. The summary of input Data for Risk Calculation at step 6 (view results) in the modelling based on the contamination located assumed at unsaturated zone soil pathway.



Summary of Input Data for Risk Calculation

Description:

Date: 09-15-2016 16:22:40

Receptors:
Child Resident - Upper Percentile
Adult Resident - Upper Percentile
Risk results ARE added for carcinogens

Routes:
Ingestion of Soil
Dermal Contact with Soil
Ingestion of Vegetables
Inhalation of Outdoor Air
Inhalation of Particulates

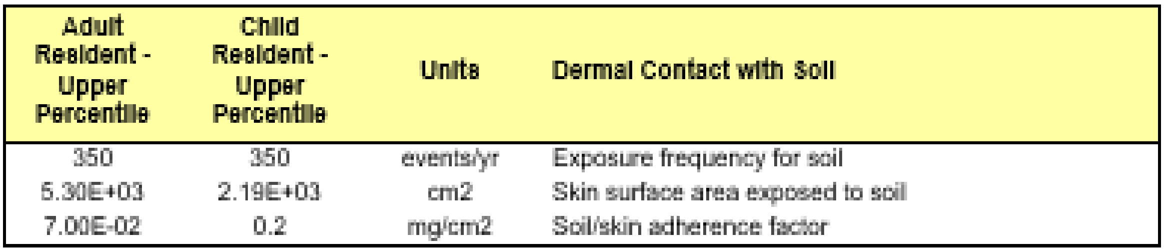
Chemicals:
Anthracene
Phenanthrene
TPH Aliphatic C12-16
TPH Aliphatic C16-35
TPH Aromatic C8-10
TPH Aromatic C10-12
TPH Aromatic C12-16
TPH Aromatic C16-21

Exposure Parameters

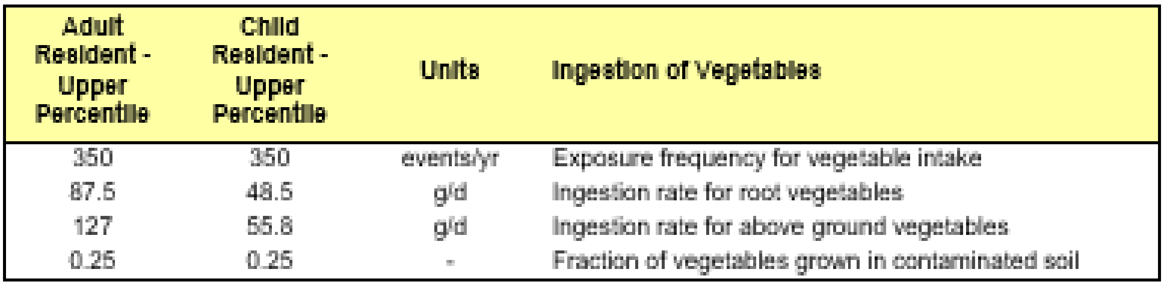
Adult Resident - Upper Percentile	Child Resident - Upper Percentile	Units	Exposure Pathway
70	15	kg	Body weight
70	70	yr	Averaging time for carcinogens
24	6	yr	Exposure duration

Adult Resident - Upper Percentile	Child Resident - Upper Percentile	Units	Ingestion of Soil
350	350	events/yr	Exposure frequency for soil
100	200	mg/d	Ingestion rate for soil

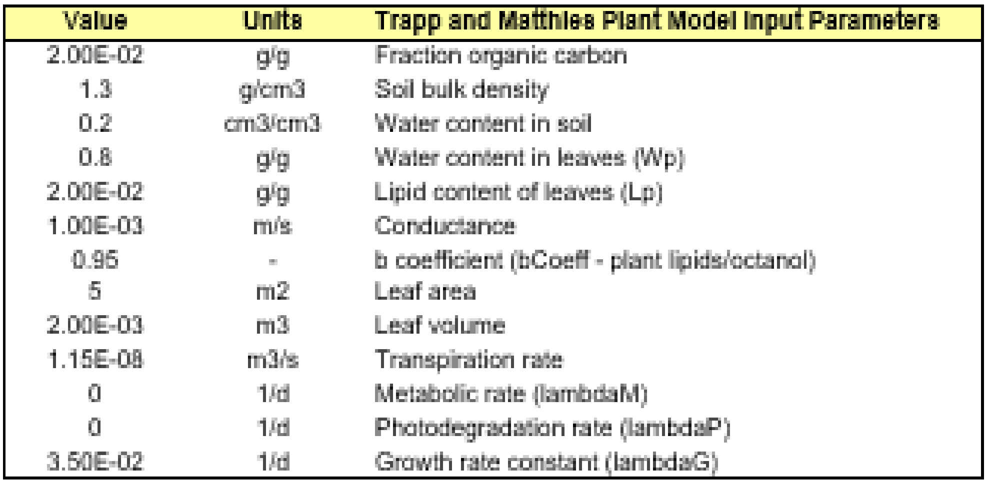
Table D.7.12. Continous.



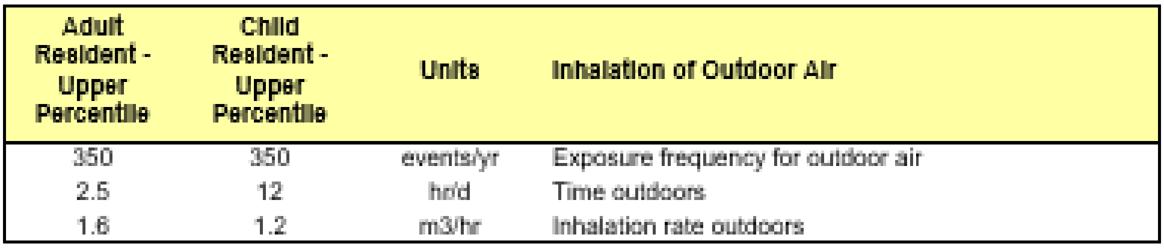
Adult Resident - Upper Percentile	Child Resident - Upper Percentile	Units	Dermal Contact with Soil
350	350	events/yr	Exposure frequency for soil
5.30E+03	2.19E+03	cm2	Skin surface area exposed to soil
7.00E-02	0.2	mg/cm2	Soil/skin adherence factor



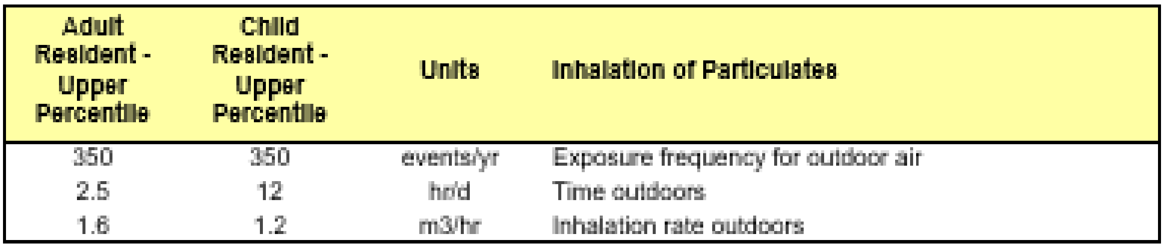
Adult Resident - Upper Percentile	Child Resident - Upper Percentile	Units	Ingestion of Vegetables
350	350	events/yr	Exposure frequency for vegetable intake
87.5	48.5	g/d	Ingestion rate for root vegetables
127	55.8	g/d	Ingestion rate for above ground vegetables
0.25	0.25	-	Fraction of vegetables grown in contaminated soil



Value	Units	Trapp and Matthies Plant Model Input Parameters
2.00E-02	g/g	Fraction organic carbon
1.3	g/cm3	Soil bulk density
0.2	cm3/cm3	Water content in soil
0.8	g/g	Water content in leaves (Wp)
2.00E-02	g/g	Lipid content of leaves (Lp)
1.00E-03	m/s	Conductance
0.95	-	b coefficient (bCoeff - plant lipids/octanol)
5	m2	Leaf area
2.00E-03	m3	Leaf volume
1.15E-08	m3/s	Transpiration rate
0	1/d	Metabolic rate (lambdaM)
0	1/d	Photodegradation rate (lambdaP)
3.50E-02	1/d	Growth rate constant (lambdaG)



Adult Resident - Upper Percentile	Child Resident - Upper Percentile	Units	Inhalation of Outdoor Air
350	350	events/yr	Exposure frequency for outdoor air
2.5	12	hr/d	Time outdoors
1.6	1.2	m3/hr	Inhalation rate outdoors



Adult Resident - Upper Percentile	Child Resident - Upper Percentile	Units	Inhalation of Particulates
350	350	events/yr	Exposure frequency for outdoor air
2.5	12	hr/d	Time outdoors
1.6	1.2	m3/hr	Inhalation rate outdoors

Table D.7.12. Continous.

TPH Aromatic C16-21	TPH Aromatic C12-16	TPH Aromatic C10-12	TPH Aromatic C8-10	TPH Aliphatic C16-35	TPH Aliphatic C12-16	Phenanthrene	Anthracene	Units	Chemical Parameters
1.58E+04	5.01E+03	2.51E+03	1.58E+03	1.00E+09	5.01E+06	2.29E+04	2.95E+04	(mg/l)/mg/l)	Organic Carbon Partition Coefficient (Koc)
4.72	3.93	3.45	3.14	8.91	6.84	4.46	4.55	-	log Kow
ND	ND	ND	ND	ND	ND	ND	ND	-	Vegetable Uptake Factor (if entered)
ND	ND	ND	ND	ND	ND	ND	ND	(mg/L)/(mg/kg)	Partition Coefficient (Kd)

Ingestion of Soil	Absorption Adjustment Factors
-	
1	Anthracene
1	Phenanthrene
1	TPH Aliphatic C12-16
1	TPH Aliphatic C16-35
1	TPH Aromatic C8-10
1	TPH Aromatic C10-12
1	TPH Aromatic C12-16
1	TPH Aromatic C16-21

Slope Factors and Reference Doses

TPH Aromatic C16-21	TPH Aromatic C12-16	TPH Aromatic C10-12	TPH Aromatic C8-10	TPH Aliphatic C16-35	TPH Aliphatic C12-16	Phenanthrene	Anthracene	Units	Chemical
ND	ND	ND	ND	ND	ND	ND	ND	1/(mg/kg-day)	Ingestion Slope Factor
3.00E-02	4.00E-02	4.00E-02	4.00E-02	2	0.1	ND	0.3	mg/kg-day	Ingestion Reference Dose
ND	ND	ND	ND	ND	ND	ND	ND	1/(ug/m3)	Unit risk factor
ND	0.2	0.2	0.2	ND	1	ND	ND	mg/m3	Reference Concentration

Table D.7.12. Continous.

Exposure Point Concentrations for Modeled Media
Obtained from Fate and Transport Output

For carcinogenic risk, concentrations are averaged over the exposu
For non-carcinogenic risk, concentrations are averaged over the m

TPH Aromatic C16-21 mg/kg	TPH Aromatic C12-16 mg/kg	TPH Aromatic C10-12 mg/kg	TPH Aromatic C8-10 mg/kg	TPH Aliphatic C16-35 mg/kg	TPH Aliphatic C12-16 mg/kg	Phenanthrene mg/kg	Anthracene mg/kg	Exposure Duration yr	**Modeled Concentrations for Surface Soil** **Exposure Point Concentration for Carcinogens** **Receptor Description**
									Carcinogens
2.19E+02	2.57E+01	2.06E+00	1.48E-01	3.15E+02	1.80E+00	3.68E+01	3.48E+01	6.00E+00	Child Resident - Upper Percentile
2.12E+02	6.78E+00	5.22E-01	3.76E-02	3.09E+02	4.55E-01	3.41E+01	3.50E+01	2.40E+01	Adult Resident - Upper Percentile

TPH Aromatic C16-21 mg/kg	TPH Aromatic C12-16 mg/kg	TPH Aromatic C10-12 mg/kg	TPH Aromatic C8-10 mg/kg	TPH Aliphatic C16-35 mg/kg	TPH Aliphatic C12-16 mg/kg	Phenanthrene mg/kg	Anthracene mg/kg	Exposure Duration yr	**Modeled Concentrations for Surface Soil** **Exposure Point Concentration for Non-Carcinogens** **Receptor Description**
									Non-Carcinogens
2.19E+02	2.57E+01	2.06E+00	1.48E-01	3.15E+02	1.80E+00	3.68E+01	3.48E+01	6.00E+00	Child Resident - Upper Percentile
2.19E+02	2.24E+01	1.77E+00	1.28E-01	3.15E+02	1.54E+00	3.67E+01	3.49E+01	7.00E+00	Adult Resident - Upper Percentile

Exposure Point Concentrations for Modeled Media
Obtained from Fate and Transport Output

For carcinogenic risk, concentrations are averaged over the exposu
For non-carcinogenic risk, concentrations are averaged over the m

TPH Aromatic C16-21 mg/m3	TPH Aromatic C12-16 mg/m3	TPH Aromatic C10-12 mg/m3	TPH Aromatic C8-10 mg/m3	TPH Aliphatic C16-35 mg/m3	TPH Aliphatic C12-16 mg/m3	Phenanthrene mg/m3	Anthracene mg/m3	Exposure Duration yr	**Modeled Concentrations for Outdoor Air** **Exposure Point Concentration for Carcinogens** **Receptor Description**
									Carcinogens
2.41E-05	3.49E-04	1.76E-04	3.55E-05	3.03E-05	1.06E-04	2.30E-06	1.38E-07	6.00E+00	Child Resident - Upper Percentile
2.34E-05	9.22E-05	4.47E-05	8.98E-06	2.98E-05	2.67E-05	2.13E-06	1.39E-07	2.40E+01	Adult Resident - Upper Percentile

Table D.7.12. Continous.

TPH Aromatic C16-21 mg/m3	TPH Aromatic C12-16 mg/m3	TPH Aromatic C10-12 mg/m3	TPH Aromatic C8-10 mg/m3	TPH Aliphatic C16-35 mg/m3	TPH Aliphatic C12-16 mg/m3	Phenanthrene mg/m3	Anthracene mg/m3	Exposure Duration yr	Modeled Concentrations for Outdoor Air Exposure Point Concentration for Non-Carcinogens Receptor Description
									Non-Carcinogens
2.41E-05	3.49E-04	1.76E-04	3.55E-05	3.03E-05	1.06E-04	2.30E-06	1.38E-07	6.00E+00	Child Resident - Upper Percentile
2.41E-05	3.05E-04	1.52E-04	3.05E-05	3.03E-05	9.08E-05	2.30E-06	1.39E-07	7.00E+00	Adult Resident - Upper Percentile

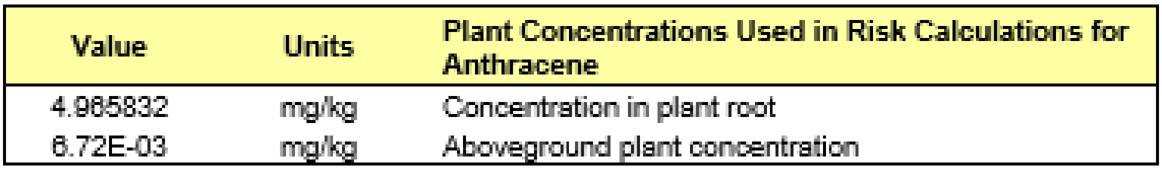
Exposure Point Concentrations for Modeled Media
Obtained from Fate and Transport Output

For carcinogenic risk, concentrations are averaged over the exposure
For non-carcinogenic risk, concentrations are averaged over the mini

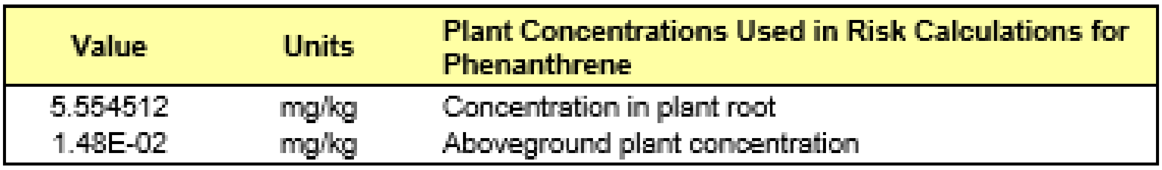
TPH Aromatic C16-21 mg/m3	TPH Aromatic C12-16 mg/m3	TPH Aromatic C10-12 mg/m3	TPH Aromatic C8-10 mg/m3	TPH Aliphatic C16-35 mg/m3	TPH Aliphatic C12-16 mg/m3	Phenanthrene mg/m3	Anthracene mg/m3	Exposure Duration yr	Modeled Concentrations for Particulates in Al Exposure Point Concentration for Carcinogens Receptor Description
									Carcinogens
1.57E-16	1.84E-17	1.48E-18	1.07E-19	2.27E-16	1.29E-18	2.64E-17	2.50E-17	6.00E+00	Child Resident - Upper Percentile
1.53E-16	4.87E-18	3.75E-19	2.70E-20	2.22E-16	3.27E-19	2.45E-17	2.52E-17	2.40E+01	Adult Resident - Upper Percentile

TPH Aromatic C16-21 mg/m3	TPH Aromatic C12-16 mg/m3	TPH Aromatic C10-12 mg/m3	TPH Aromatic C8-10 mg/m3	TPH Aliphatic C16-35 mg/m3	TPH Aliphatic C12-16 mg/m3	Phenanthrene mg/m3	Anthracene mg/m3	Exposure Duration yr	Modeled Concentrations for Particulates in Al Exposure Point Concentration for Non-Carcinogens Receptor Description
									Non-Carcinogens
1.57E-16	1.84E-17	1.48E-18	1.07E-19	2.27E-16	1.29E-18	2.64E-17	2.50E-17	6.00E+00	Child Resident - Upper Percentile
1.57E-16	1.61E-17	1.27E-18	9.17E-20	2.27E-16	1.11E-18	2.64E-17	2.51E-17	7.00E+00	Adult Resident - Upper Percentile

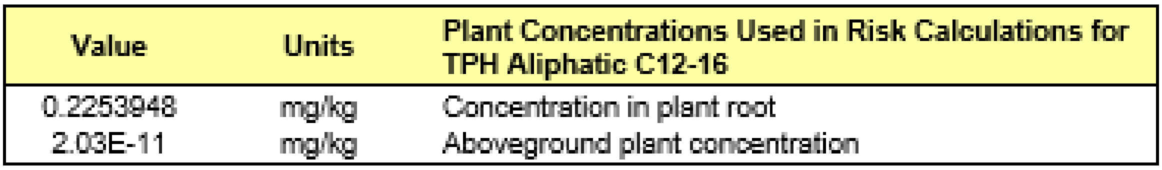
Table D.7.12. Continous.



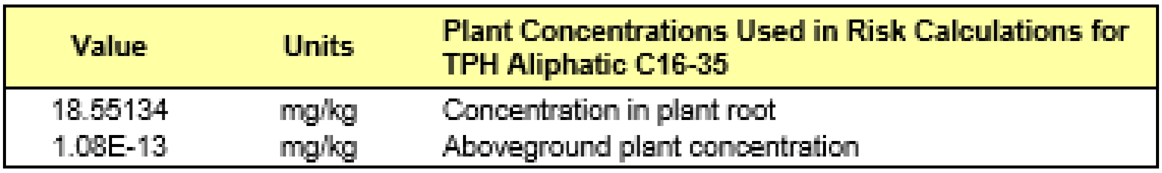
Value	Units	Plant Concentrations Used in Risk Calculations for Anthracene
4.965832	mg/kg	Concentration in plant root
6.72E-03	mg/kg	Aboveground plant concentration



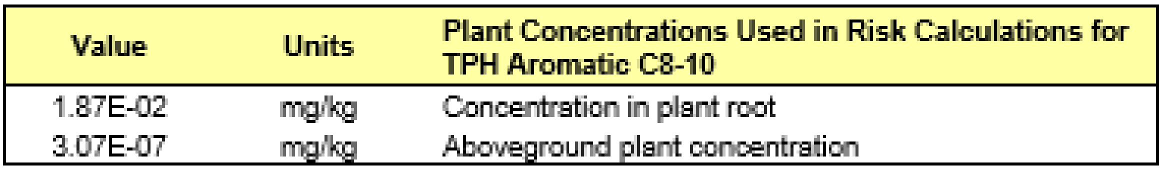
Value	Units	Plant Concentrations Used in Risk Calculations for Phenanthrene
5.554512	mg/kg	Concentration in plant root
1.48E-02	mg/kg	Aboveground plant concentration



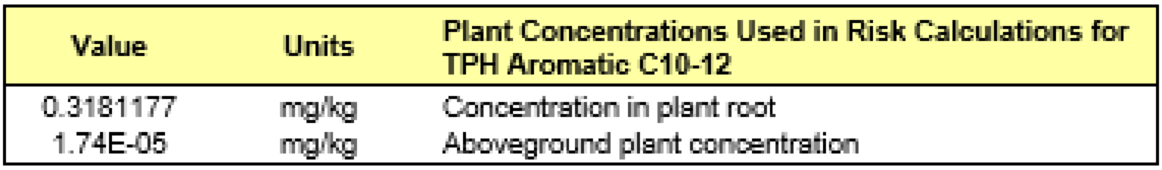
Value	Units	Plant Concentrations Used in Risk Calculations for TPH Aliphatic C12-16
0.2253948	mg/kg	Concentration in plant root
2.03E-11	mg/kg	Aboveground plant concentration



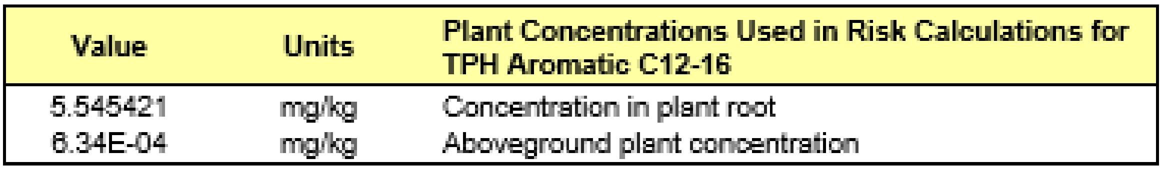
Value	Units	Plant Concentrations Used in Risk Calculations for TPH Aliphatic C16-35
18.55134	mg/kg	Concentration in plant root
1.08E-13	mg/kg	Aboveground plant concentration



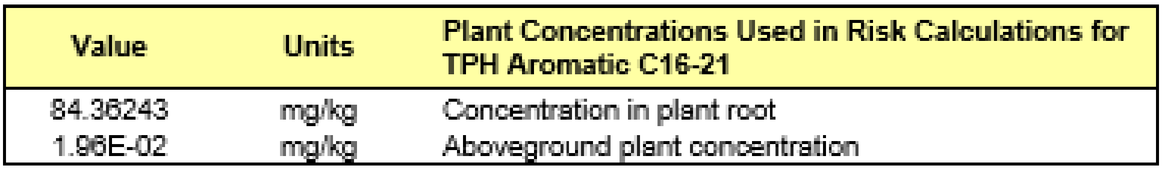
Value	Units	Plant Concentrations Used in Risk Calculations for TPH Aromatic C8-10
1.87E-02	mg/kg	Concentration in plant root
3.07E-07	mg/kg	Aboveground plant concentration



Value	Units	Plant Concentrations Used in Risk Calculations for TPH Aromatic C10-12
0.3181177	mg/kg	Concentration in plant root
1.74E-05	mg/kg	Aboveground plant concentration

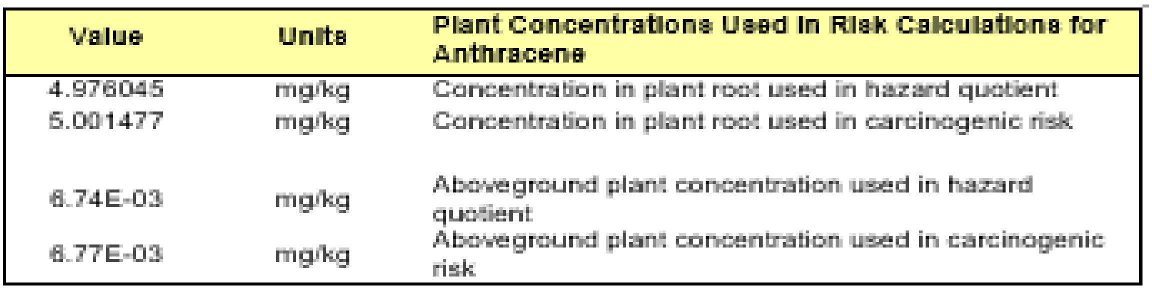


Value	Units	Plant Concentrations Used in Risk Calculations for TPH Aromatic C12-16
5.545421	mg/kg	Concentration in plant root
6.34E-04	mg/kg	Aboveground plant concentration

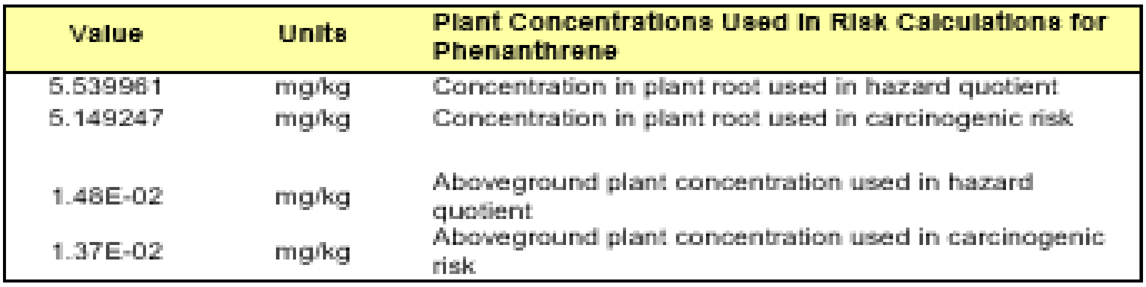


Value	Units	Plant Concentrations Used in Risk Calculations for TPH Aromatic C16-21
84.36243	mg/kg	Concentration in plant root
1.96E-02	mg/kg	Aboveground plant concentration

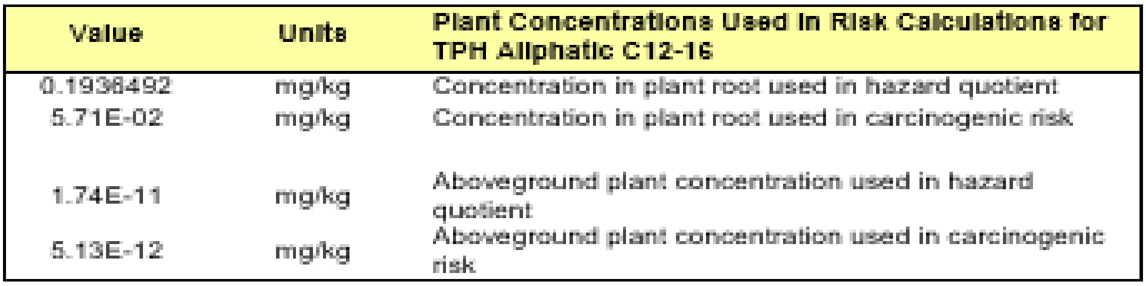
Table D.7.12. Continous.



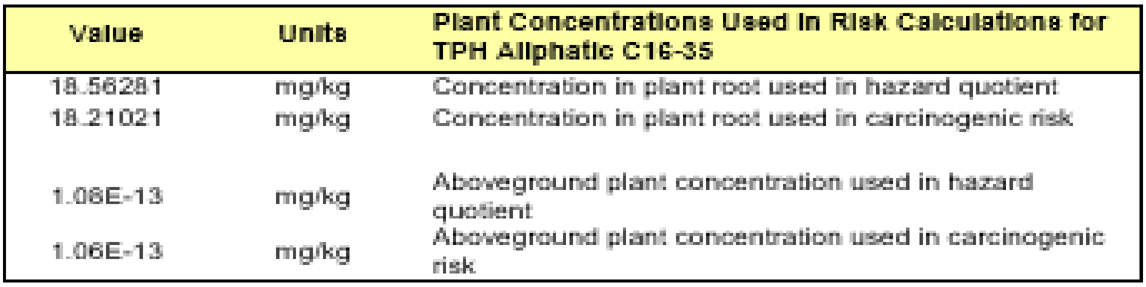
Value	Units	Plant Concentrations Used in Risk Calculations for Anthracene
4.976045	mg/kg	Concentration in plant root used in hazard quotient
5.001477	mg/kg	Concentration in plant root used in carcinogenic risk
6.74E-03	mg/kg	Aboveground plant concentration used in hazard quotient
6.77E-03	mg/kg	Aboveground plant concentration used in carcinogenic risk



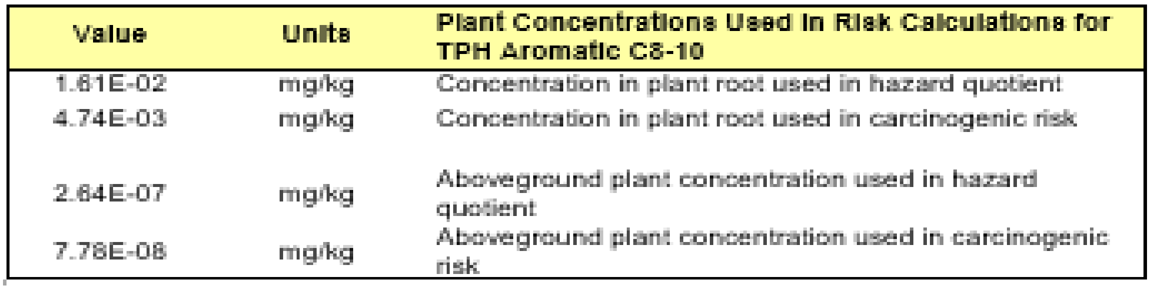
Value	Units	Plant Concentrations Used in Risk Calculations for Phenanthrene
5.539961	mg/kg	Concentration in plant root used in hazard quotient
5.149247	mg/kg	Concentration in plant root used in carcinogenic risk
1.48E-02	mg/kg	Aboveground plant concentration used in hazard quotient
1.37E-02	mg/kg	Aboveground plant concentration used in carcinogenic risk



Value	Units	Plant Concentrations Used in Risk Calculations for TPH Aliphatic C12-16
0.1936492	mg/kg	Concentration in plant root used in hazard quotient
5.71E-02	mg/kg	Concentration in plant root used in carcinogenic risk
1.74E-11	mg/kg	Aboveground plant concentration used in hazard quotient
5.13E-12	mg/kg	Aboveground plant concentration used in carcinogenic risk

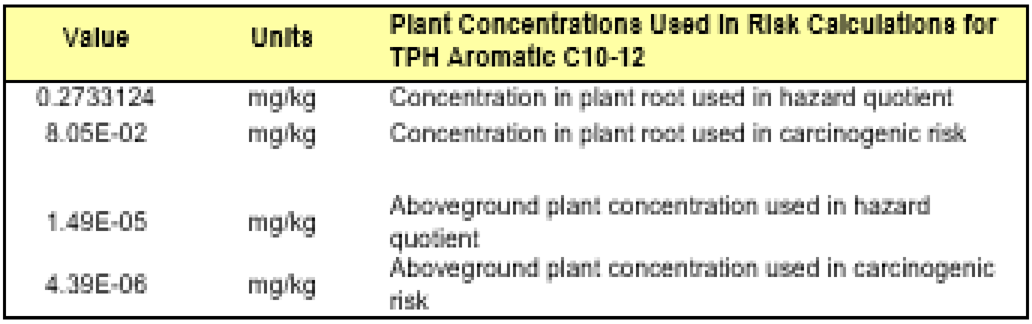


Value	Units	Plant Concentrations Used in Risk Calculations for TPH Aliphatic C16-35
18.56281	mg/kg	Concentration in plant root used in hazard quotient
18.21021	mg/kg	Concentration in plant root used in carcinogenic risk
1.08E-13	mg/kg	Aboveground plant concentration used in hazard quotient
1.06E-13	mg/kg	Aboveground plant concentration used in carcinogenic risk

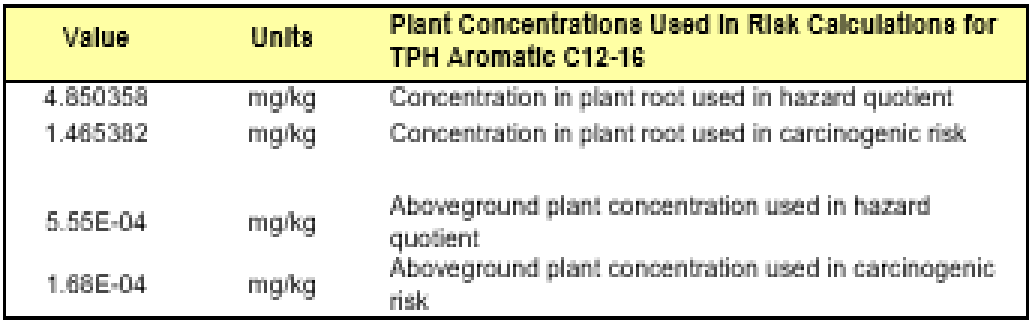


Value	Units	Plant Concentrations Used in Risk Calculations for TPH Aromatic C8-10
1.61E-02	mg/kg	Concentration in plant root used in hazard quotient
4.74E-03	mg/kg	Concentration in plant root used in carcinogenic risk
2.64E-07	mg/kg	Aboveground plant concentration used in hazard quotient
7.78E-08	mg/kg	Aboveground plant concentration used in carcinogenic risk

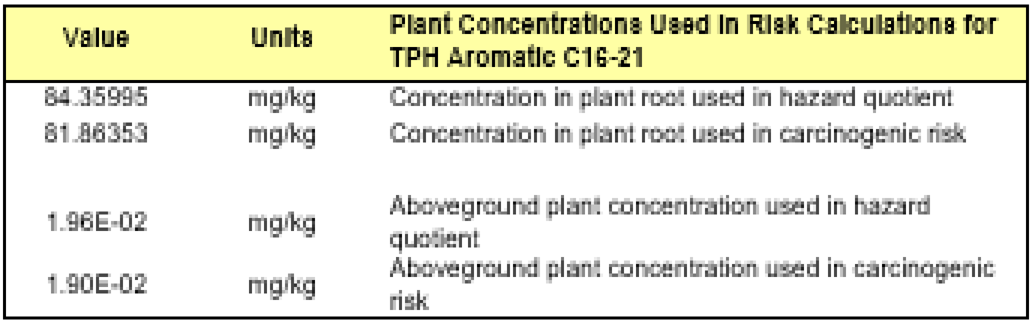
Table D.7.12. Continous.



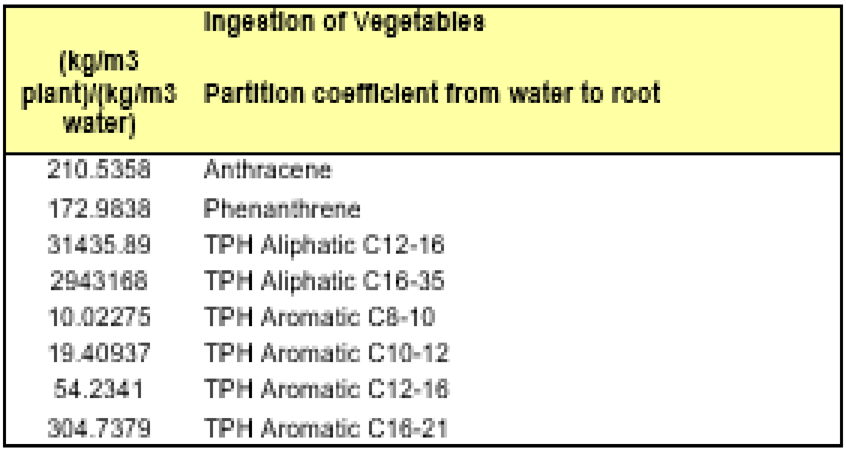
Value	Units	Plant Concentrations Used in Risk Calculations for TPH Aromatic C10-12
0.2733124	mg/kg	Concentration in plant root used in hazard quotient
8.05E-02	mg/kg	Concentration in plant root used in carcinogenic risk
1.49E-05	mg/kg	Aboveground plant concentration used in hazard quotient
4.39E-06	mg/kg	Aboveground plant concentration used in carcinogenic risk



Value	Units	Plant Concentrations Used in Risk Calculations for TPH Aromatic C12-16
4.850358	mg/kg	Concentration in plant root used in hazard quotient
1.465382	mg/kg	Concentration in plant root used in carcinogenic risk
5.55E-04	mg/kg	Aboveground plant concentration used in hazard quotient
1.68E-04	mg/kg	Aboveground plant concentration used in carcinogenic risk

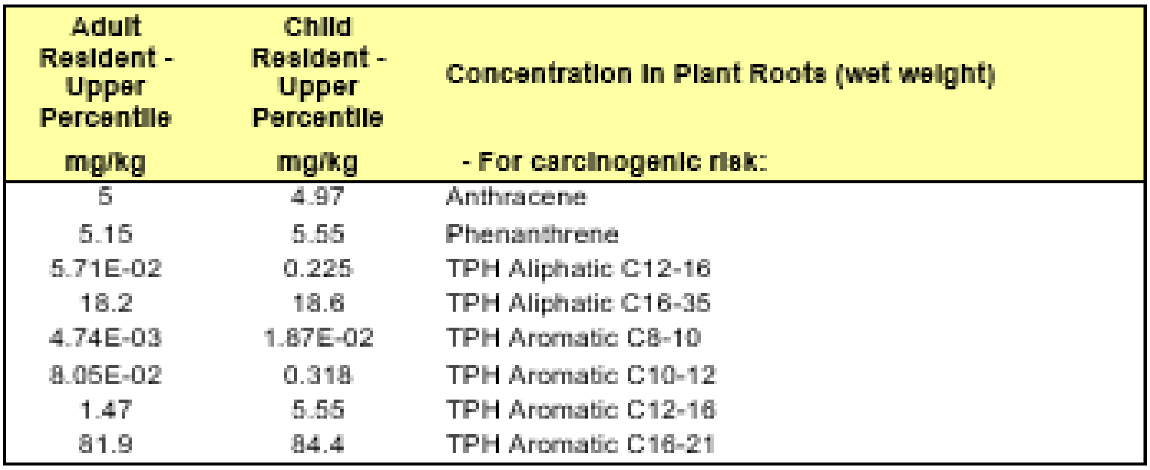


Value	Units	Plant Concentrations Used in Risk Calculations for TPH Aromatic C16-21
84.35995	mg/kg	Concentration in plant root used in hazard quotient
81.86353	mg/kg	Concentration in plant root used in carcinogenic risk
1.96E-02	mg/kg	Aboveground plant concentration used in hazard quotient
1.90E-02	mg/kg	Aboveground plant concentration used in carcinogenic risk

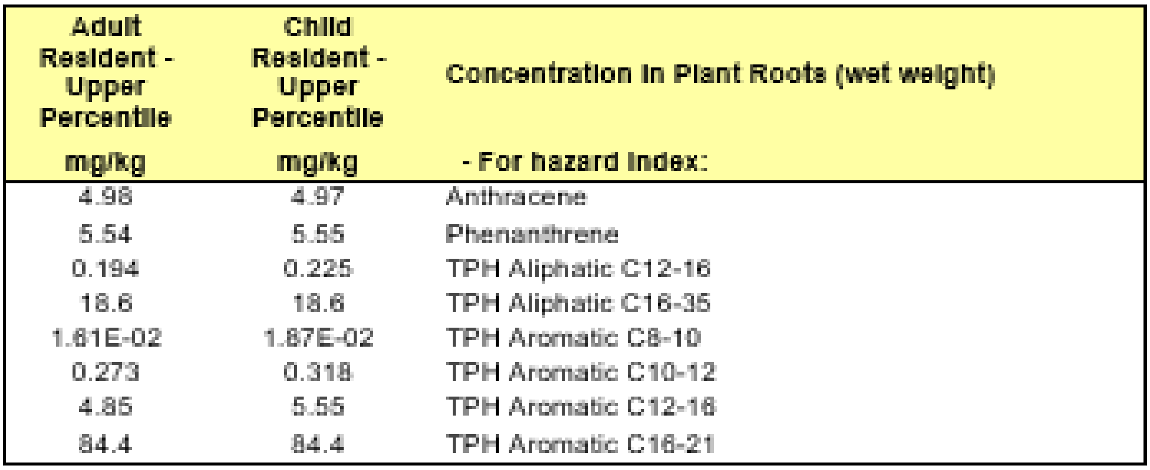


(kg/m3 plant)/(kg/m3 water)	Ingestion of Vegetables Partition coefficient from water to root
210.5358	Anthracene
172.9838	Phenanthrene
31435.89	TPH Aliphatic C12-16
2943168	TPH Aliphatic C16-35
10.02275	TPH Aromatic C8-10
19.40937	TPH Aromatic C10-12
54.2341	TPH Aromatic C12-16
304.7379	TPH Aromatic C16-21

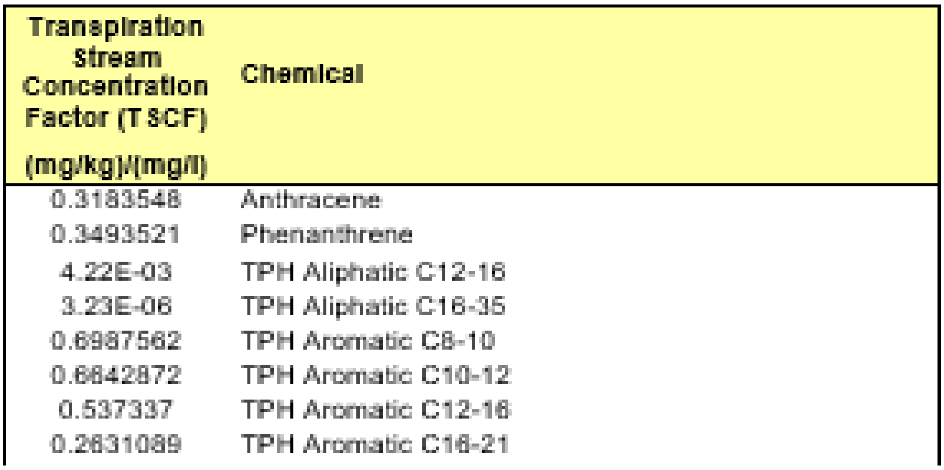
Table D.7.12. Continous.



Adult Resident - Upper Percentile mg/kg	Child Resident - Upper Percentile mg/kg	Concentration in Plant Roots (wet weight) - For carcinogenic risk:
5	4.97	Anthracene
5.15	5.55	Phenanthrene
5.71E-02	0.225	TPH Aliphatic C12-16
18.2	18.6	TPH Aliphatic C16-35
4.74E-03	1.87E-02	TPH Aromatic C8-10
8.05E-02	0.318	TPH Aromatic C10-12
1.47	5.55	TPH Aromatic C12-16
81.9	84.4	TPH Aromatic C16-21

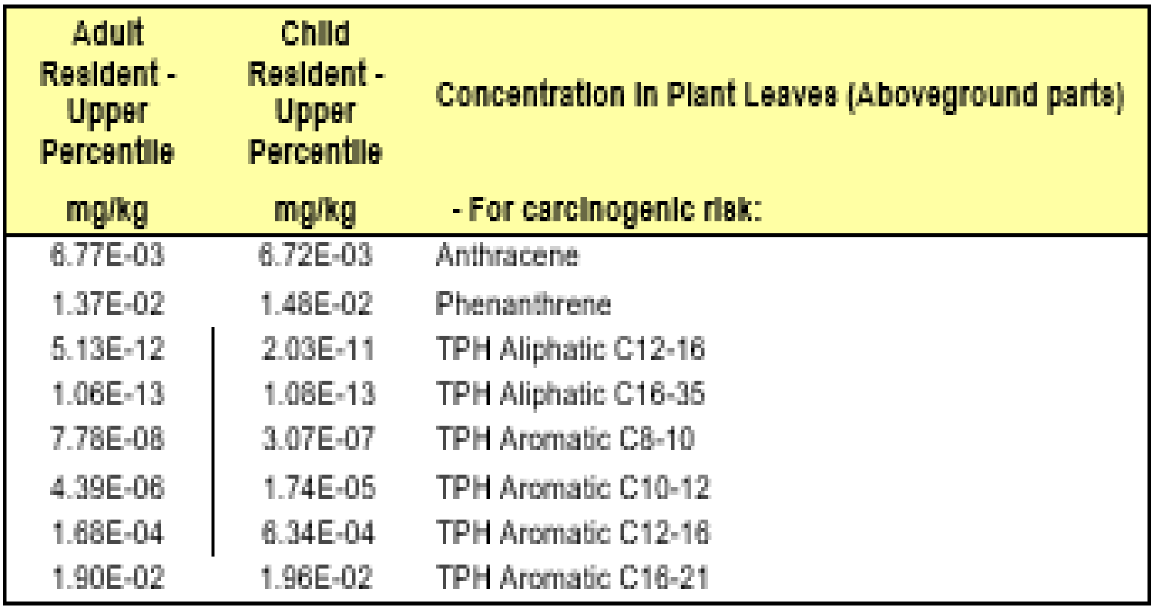


Adult Resident - Upper Percentile mg/kg	Child Resident - Upper Percentile mg/kg	Concentration in Plant Roots (wet weight) - For hazard index:
4.98	4.97	Anthracene
5.54	5.55	Phenanthrene
0.194	0.225	TPH Aliphatic C12-16
18.6	18.6	TPH Aliphatic C16-35
1.61E-02	1.87E-02	TPH Aromatic C8-10
0.273	0.318	TPH Aromatic C10-12
4.85	5.55	TPH Aromatic C12-16
84.4	84.4	TPH Aromatic C16-21

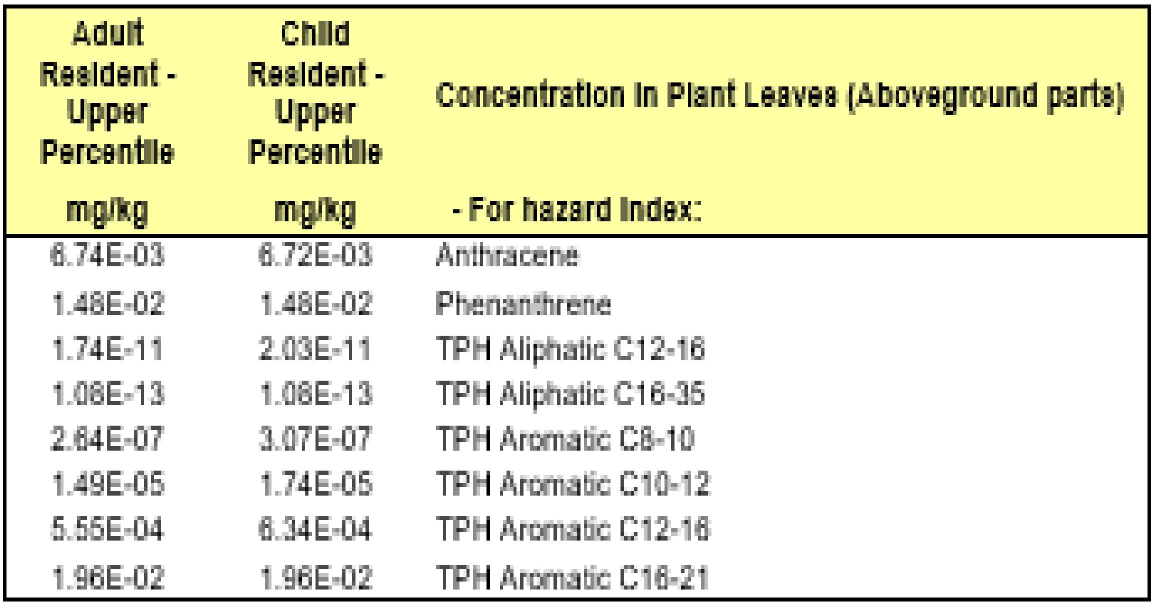


Transpiration Stream Concentration Factor (TSCF) (mg/kg)/(mg/l)	Chemical
0.3183548	Anthracene
0.3493521	Phenanthrene
4.22E-03	TPH Aliphatic C12-16
3.23E-06	TPH Aliphatic C16-35
0.6987562	TPH Aromatic C8-10
0.6842872	TPH Aromatic C10-12
0.537337	TPH Aromatic C12-16
0.2831089	TPH Aromatic C16-21

Table D.7.12. Continous.



Adult Resident - Upper Percentile mg/kg	Child Resident - Upper Percentile mg/kg	Concentration in Plant Leaves (Aboveground parts) - For carcinogenic risk:
6.77E-03	6.72E-03	Anthracene
1.37E-02	1.48E-02	Phenanthrene
5.13E-12	2.03E-11	TPH Aliphatic C12-16
1.06E-13	1.08E-13	TPH Aliphatic C16-35
7.78E-08	3.07E-07	TPH Aromatic C8-10
4.39E-06	1.74E-05	TPH Aromatic C10-12
1.68E-04	6.34E-04	TPH Aromatic C12-16
1.90E-02	1.96E-02	TPH Aromatic C16-21



Adult Resident - Upper Percentile mg/kg	Child Resident - Upper Percentile mg/kg	Concentration in Plant Leaves (Aboveground parts) - For hazard index:
6.74E-03	6.72E-03	Anthracene
1.48E-02	1.48E-02	Phenanthrene
1.74E-11	2.03E-11	TPH Aliphatic C12-16
1.08E-13	1.08E-13	TPH Aliphatic C16-35
2.64E-07	3.07E-07	TPH Aromatic C8-10
1.49E-05	1.74E-05	TPH Aromatic C10-12
5.55E-04	6.34E-04	TPH Aromatic C12-16
1.96E-02	1.96E-02	TPH Aromatic C16-21

Table D.7.13. The short summary plant Model results for petrol substances (Anthracene and Phenanthrene) and TPH fractions at step-6 in RISC software based on contamination located assumed at unsaturated zone soil pathway.

Short Summary Plant Model Results for Anthracene

Value	Units	Inputs and Results
3.5E+01	mg/kg	Concentration in soil (input)
5.9E-02	mg/L	Concentration in water (calculated)
5.0E+00	mg/kg	Trapp and Matthies root concentration
6.7E-03	mg/kg	Trapp and Matthies aboveground concentration

Short Summary Plant Model Results for Phenanthrene

Value	Units	Inputs and Results
3.7E+01	mg/kg	Concentration in soil (input)
8.0E-02	mg/L	Concentration in water (calculated)
5.6E+00	mg/kg	Trapp and Matthies root concentration
1.5E-02	mg/kg	Trapp and Matthies aboveground concentration

Short Summary Plant Model Results for TPH Aliphatic C12-16

Value	Units	Inputs and Results
1.8E+00	mg/kg	Concentration in soil (input)
1.8E-05	mg/L	Concentration in water (calculated)
2.3E-01	mg/kg	Trapp and Matthies root concentration
2.0E-11	mg/kg	Trapp and Matthies aboveground concentration

Short Summary Plant Model Results for TPH Aliphatic C16-35

Value	Units	Inputs and Results
3.2E+02	mg/kg	Concentration in soil (input)
1.6E-05	mg/L	Concentration in water (calculated)
1.9E+01	mg/kg	Trapp and Matthies root concentration
1.1E-13	mg/kg	Trapp and Matthies aboveground concentration

Short Summary Plant Model Results for TPH Aromatic C8-10

Value	Units	Inputs and Results
1.5E-01	mg/kg	Concentration in soil (input)
4.7E-03	mg/L	Concentration in water (calculated)
1.9E-02	mg/kg	Trapp and Matthies root concentration
3.1E-07	mg/kg	Trapp and Matthies aboveground concentration

Table D.7.13. Continous.

Short Summary Plant Model Results for TPH Aromatic C10-12

Value	Units	Inputs and Results
2.1E+00	mg/kg	Concentration in soil (input)
4.1E-02	mg/L	Concentration in water (calculated)
3.2E-01	mg/kg	Trapp and Matthies root concentration
1.7E-05	mg/kg	Trapp and Matthies aboveground concentration

Short Summary Plant Model Results for TPH Aromatic C12-16

Value	Units	Inputs and Results
2.6E+01	mg/kg	Concentration in soil (input)
2.6E-01	mg/L	Concentration in water (calculated)
5.5E+00	mg/kg	Trapp and Matthies root concentration
6.3E-04	mg/kg	Trapp and Matthies aboveground concentration

Short Summary Plant Model Results for TPH Aromatic C16-21

Value	Units	Inputs and Results
2.2E+02	mg/kg	Concentration in soil (input)
6.9E-01	mg/L	Concentration in water (calculated)
8.4E+01	mg/kg	Trapp and Matthies root concentration
2.0E-02	mg/kg	Trapp and Matthies aboveground concentration

Short Summary Plant Model Results for Anthracene

Value	Units	Inputs and Results
3.5E+01	mg/kg	Concentration in soil (input)
5.9E-02	mg/L	Concentration in water (calculated)
5.0E+00	mg/kg	Trapp and Matthies root concentration
6.8E-03	mg/kg	Trapp and Matthies aboveground concentration

Short Summary Plant Model Results for Phenanthrene

Value	Units	Inputs and Results
3.4E+01	mg/kg	Concentration in soil (input)
7.4E-02	mg/L	Concentration in water (calculated)
5.1E+00	mg/kg	Trapp and Matthies root concentration
1.4E-02	mg/kg	Trapp and Matthies aboveground concentration

Short Summary Plant Model Results for TPH Aliphatic C12-16

Value	Units	Inputs and Results
4.5E-01	mg/kg	Concentration in soil (input)
4.5E-06	mg/L	Concentration in water (calculated)
5.7E-02	mg/kg	Trapp and Matthies root concentration
5.1E-12	mg/kg	Trapp and Matthies aboveground concentration

Table D.7.13. Continous.

Short Summary Plant Model Results for TPH Aliphatic C16-35

Value	Units	Inputs and Results
3.1E+02	mg/kg	Concentration in soil (input)
1.5E-05	mg/L	Concentration in water (calculated)
1.8E+01	mg/kg	Trapp and Matthies root concentration
1.1E-13	mg/kg	Trapp and Matthies aboveground concentration

Short Summary Plant Model Results for TPH Aromatic C8-10

Value	Units	Inputs and Results
3.8E-02	mg/kg	Concentration in soil (input)
1.2E-03	mg/L	Concentration in water (calculated)
4.7E-03	mg/kg	Trapp and Matthies root concentration
7.8E-08	mg/kg	Trapp and Matthies aboveground concentration

Short Summary Plant Model Results for TPH Aromatic C10-12

Value	Units	Inputs and Results
5.2E-01	mg/kg	Concentration in soil (input)
1.0E-02	mg/L	Concentration in water (calculated)
8.1E-02	mg/kg	Trapp and Matthies root concentration
4.4E-06	mg/kg	Trapp and Matthies aboveground concentration

Short Summary Plant Model Results for TPH Aromatic C12-16

Value	Units	Inputs and Results
6.8E+00	mg/kg	Concentration in soil (input)
6.8E-02	mg/L	Concentration in water (calculated)
1.5E+00	mg/kg	Trapp and Matthies root concentration
1.7E-04	mg/kg	Trapp and Matthies aboveground concentration

Short Summary Plant Model Results for TPH Aromatic C16-21

Value	Units	Inputs and Results
2.1E+02	mg/kg	Concentration in soil (input)
6.7E-01	mg/L	Concentration in water (calculated)
8.2E+01	mg/kg	Trapp and Matthies root concentration
1.9E-02	mg/kg	Trapp and Matthies aboveground concentration

Table D.7.14. The input Data summary plant Model and their results for petrol substances (Anthracene and Phenanthrene) and TPH fractions at step-6 in RISC software based on contamination located assumed at unsaturated zone soil pathway.

Summary of Plant Model Results for Anthracene

		Kd for Anthracene
3.0E+04	ml/g	Organic carbon partitioning coefficient [Koc]
2.0E-02	g/g	Fraction organic carbon [Foc]
5.9E+02	ml/g	Soil/water partitioning coefficient [Kd]

Value	**Units**	**Media Concentrations**
3.5E+01	mg/kg	Concentration in soil
5.9E-02	mg/L	Concentration in water

		Trapp and Matthies -- Calculating Concentration in Roots
4.6E+00	-	logKow (octanol partitioning coefficient)
8.0E-01	g/g	Water content of plant [Wp]
2.0E-02	g/g	Lipid content of plant [Lp]
9.5E-01	-	b correction factor between lipids and octanol
5.0E+02	kg/m3	Density of plant tissue
1.0E+03	kg/m3	Density of water
2.0E-01	cm3/cm3	Water content of the soil
1.3E+00	g/cm3	Soil bulk density
2.1E+02	g/g	Partitioning coefficient between roots and water
5.0E+00	mg/kg	Concentration in roots (wet weight)

Value	**Units**	**Aboveground Plant Model Results for Anthracene**
		Partitioning between contaminants in leaves and water (Klw)
		Klw = (Wp+Lp*((10^logKow) ^bCoeff))*rhoP_to_rhoW
2.1E+02	[-]	Klw
		Partitioning between contaminants in leaves and air (Kla)
		Kla = Klw / Henrys
7.9E+04	[-]	Kla
3.4E-02	[-]	TSCF using first method (TSCF1)
3.2E-01	[-]	TSCF using second method (TSCF2)
3.2E-01	[-]	Overall TSCF
		Overall rate constant (lambdaE)
		lambdaE = lambdaP * fracSun + lambdaM + lambdaG
0.0E+00	1/d	Photodegradation rate constant
3.0E-01	[-]	Fraction of time in sun
0.0E+00	1/d	Metabolism rate constant
3.5E-02	1/d	Growth rate constant
4.1E-07	1/s	Overall rate constant (metabolism, photo. and growth) [a2]
3.2E-05	1/s	Volatilization losses through leaves [a1]
3.2E-05	1/s	Total losses through all mechanisms [a]
1.1E-04	kg/m3/s	Total sources [b]
3.4E+00	kg/m3	Concentration in leaves, not adjusted for water content [b/a]
5.9E-02	mg/l	Concentration in water
1.1E+00	d	Time to reach steady-state (95%)
6.7E-03	mg/kg	**Concentration in leaves (wet weight)**

Table D.7.14. Continous.

Summary of Plant Model Results for Phenanthrene

		Kd for Phenanthrene
2.3E+04	ml/g	Organic carbon partitioning coefficient [Koc]
2.0E-02	g/g	Fraction organic carbon [Foc]
4.6E+02	ml/g	Soil/water partitioning coefficient [Kd]

Value	Units	Media Concentrations
3.7E+01	mg/kg	Concentration in soil
8.0E-02	mg/L	Concentration in water

		Trapp and Matthies -- Calculating Concentration in Roots
4.5E+00	-	logKow (octanol partitioning coefficient)
8.0E-01	g/g	Water content of plant [Wp]
2.0E-02	g/g	Lipid content of plant [Lp]
9.5E-01	-	b correction factor between lipids and octanol
5.0E+02	kg/m3	Density of plant tissue
1.0E+03	kg/m3	Density of water
2.0E-01	cm3/cm3	Water content of the soil
1.3E+00	g/cm3	Soil bulk density
1.7E+02	g/g	Partitioning coefficient between roots and water
5.6E+00	mg/kg	Concentration in roots (wet weight)

Value	Units	Aboveground Plant Model Results for Phenanthrene
		Partitioning between contaminants in leaves and water (Klw)
		Klw = (Wp+Lp*((10^logKow) ^bCoeff))*rhoP_to_rhoW
1.7E+02	[-]	Klw
		Partitioning between contaminants in leaves and air (Kla)
		Kla = Klw / Henrys
1.2E+05	[-]	Kla
4.1E-02	[-]	TSCF using first method (TSCF1)
3.5E-01	[-]	TSCF using second method (TSCF2)
3.5E-01	[-]	Overall TSCF
		Overall rate constant (lambdaE)
		lambdaE = lambdaP * fracSun + lambdaM + lambdaG
0.0E+00	1/d	Photodegradation rate constant
3.0E-01	[-]	Fraction of time in sun
0.0E+00	1/d	Metabolism rate constant
3.5E-02	1/d	Growth rate constant
4.1E-07	1/s	Overall rate constant (metabolism, photo. and growth) [a2]
2.1E-05	1/s	Volatilization losses through leaves [a1]
2.2E-05	1/s	Total losses through all mechanisms [a]
1.6E-04	kg/m3/s	Total sources [b]
7.4E+00	kg/m3	Concentration in leaves, not adjusted for water content [b/a]
8.0E-02	mg/l	Concentration in water
1.6E+00	d	Time to reach steady-state (95%)
1.5E-02	mg/kg	**Concentration in leaves (wet weight)**

Table D.7.14. Continous.

Summary of Plant Model Results for TPH Aliphatic C12-16

		Kd for TPH Aliphatic C12-16
5.0E+06	ml/g	Organic carbon partitioning coefficient [Koc]
2.0E-02	g/g	Fraction organic carbon [Foc]
1.0E+05	ml/g	Soil/water partitioning coefficient [Kd]

Value	Units	Media Concentrations
1.8E+00	mg/kg	Concentration in soil
1.8E-05	mg/L	Concentration in water

		Trapp and Matthies -- Calculating Concentration in Roots
6.8E+00	-	logKow (octanol partitioning coefficient)
8.0E-01	g/g	Water content of plant [Wp]
2.0E-02	g/g	Lipid content of plant [Lp]
9.5E-01	-	b correction factor between lipids and octanol
5.0E+02	kg/m3	Density of plant tissue
1.0E+03	kg/m3	Density of water
2.0E-01	cm3/cm3	Water content of the soil
1.3E+00	g/cm3	Soil bulk density
3.1E+04	g/g	Partitioning coefficient between roots and water
2.3E-01	mg/kg	Concentration in roots (wet weight)

Value	Units	Aboveground Plant Model Results for TPH Aliphatic C12-16
		Partitioning between contaminants in leaves and water (Klw)
		Klw = (Wp+Lp*((10^logKow) ^bCoeff))*rhoP_to_rhoW
3.1E+04	[-]	Klw
		Partitioning between contaminants in leaves and air (Kla)
		Kla = Klw / Henrys
5.8E+01	[-]	Kla
2.2E-05	[-]	TSCF using first method (TSCF1)
4.2E-03	[-]	TSCF using second method (TSCF2)
4.2E-03	[-]	Overall TSCF
		Overall rate constant (lambdaE)
		lambdaE = lambdaP * fracSun + lambdaM + lambdaG
0.0E+00	1/d	Photodegradation rate constant
3.0E-01	[-]	Fraction of time in sun
0.0E+00	1/d	Metabolism rate constant
3.5E-02	1/d	Growth rate constant
4.1E-07	1/s	Overall rate constant (metabolism, photo. and growth) [a2]
4.3E-02	1/s	Volatilization losses through leaves [a1]
4.3E-02	1/s	Total losses through all mechanisms [a]
4.4E-10	kg/m3/s	Total sources [b]
1.0E-08	kg/m3	Concentration in leaves, not adjusted for water content [b/a]
1.8E-05	mg/l	Concentration in water
8.1E-04	d	Time to reach steady-state (95%)
2.0E-11	mg/kg	**Concentration in leaves (wet weight)**

Table D.7.14. Continous.

Summary of Plant Model Results for TPH Aliphatic C16-35

		Kd for TPH Aliphatic C16-35
1.0E+09	ml/g	Organic carbon partitioning coefficient [Koc]
2.0E-02	g/g	Fraction organic carbon [Foc]
2.0E+07	ml/g	Soil/water partitioning coefficient [Kd]

Value	**Units**	**Media Concentrations**
3.2E+02	mg/kg	Concentration in soil
1.6E-05	mg/L	Concentration in water

		Trapp and Matthies -- Calculating Concentration in Roots
8.9E+00	-	logKow (octanol partitioning coefficient)
8.0E-01	g/g	Water content of plant [Wp]
2.0E-02	g/g	Lipid content of plant [Lp]
9.5E-01	-	b correction factor between lipids and octanol
5.0E+02	kg/m3	Density of plant tissue
1.0E+03	kg/m3	Density of water
2.0E-01	cm3/cm3	Water content of the soil
1.3E+00	g/cm3	Soil bulk density
2.9E+06	g/g	Partitioning coefficient between roots and water
1.9E+01	mg/kg	Concentration in roots (wet weight)

Value	**Units**	**Aboveground Plant Model Results for TPH Aliphatic C16-35**
		Partitioning between contaminants in leaves and water (Klw)
		Klw = (Wp+Lp*((10^logKow) ^bCoeff))*rhoP_to_rhoW
2.9E+06	[-]	Klw
		Partitioning between contaminants in leaves and air (Kla)
		Kla = Klw / Henrys
4.6E+02	[-]	Kla
6.8E-10	[-]	TSCF using first method (TSCF1)
3.2E-06	[-]	TSCF using second method (TSCF2)
3.2E-06	[-]	Overall TSCF
		Overall rate constant (lambdaE)
		lambdaE = lambdaP * fracSun + lambdaM + lambdaG
0.0E+00	1/d	Photodegradation rate constant
3.0E-01	[-]	Fraction of time in sun
0.0E+00	1/d	Metabolism rate constant
3.5E-02	1/d	Growth rate constant
4.1E-07	1/s	Overall rate constant (metabolism, photo. and growth) [a2]
5.4E-03	1/s	Volatilization losses through leaves [a1]
5.4E-03	1/s	Total losses through all mechanisms [a]
2.9E-13	kg/m3/s	Total sources [b]
5.4E-11	kg/m3	Concentration in leaves, not adjusted for water content [b/a]
1.6E-05	mg/l	Concentration in water
6.4E-03	d	Time to reach steady-state (95%)
1.1E-13	mg/kg	**Concentration in leaves (wet weight)**

Table D.7.14. Continous.

Summary of Plant Model Results for TPH Aromatic C8-10

		Kd for TPH Aromatic C8-10
1.6E+03	ml/g	Organic carbon partitioning coefficient [Koc]
2.0E-02	g/g	Fraction organic carbon [Foc]
3.2E+01	ml/g	Soil/water partitioning coefficient [Kd]

Value	Units	Media Concentrations
1.5E-01	mg/kg	Concentration in soil
4.7E-03	mg/L	Concentration in water

		Trapp and Matthies -- Calculating Concentration in Roots
3.1E+00	-	logKow (octanol partitioning coefficient)
8.0E-01	g/g	Water content of plant [Wp]
2.0E-02	g/g	Lipid content of plant [Lp]
9.5E-01	-	b correction factor between lipids and octanol
5.0E+02	kg/m3	Density of plant tissue
1.0E+03	kg/m3	Density of water
2.0E-01	cm3/cm3	Water content of the soil
1.3E+00	g/cm3	Soil bulk density
1.0E+01	g/g	Partitioning coefficient between roots and water
1.9E-02	mg/kg	Concentration in roots (wet weight)

Value	Units	Aboveground Plant Model Results for TPH Aromatic C8-10
		Partitioning between contaminants in leaves and water (Klw)
		Klw = (Wp+Lp*((10^logKow) ^bCoeff))*rhoP_to_rhoW
1.0E+01	[-]	Klw
		Partitioning between contaminants in leaves and air (Kla)
		Kla = Klw / Henrys
2.0E+01	[-]	Kla
3.7E-01	[-]	TSCF using first method (TSCF1)
7.0E-01	[-]	TSCF using second method (TSCF2)
7.0E-01	[-]	Overall TSCF
		Overall rate constant (lambdaE)
		lambdaE = lambdaP * fracSun + lambdaM + lambdaG
0.0E+00	1/d	Photodegradation rate constant
3.0E-01	[-]	Fraction of time in sun
0.0E+00	1/d	Metabolism rate constant
3.5E-02	1/d	Growth rate constant
4.1E-07	1/s	Overall rate constant (metabolism, photo. and growth) [a2]
1.2E-01	1/s	Volatilization losses through leaves [a1]
1.2E-01	1/s	Total losses through all mechanisms [a]
1.9E-05	kg/m3/s	Total sources [b]
1.5E-04	kg/m3	Concentration in leaves, not adjusted for water content [b/a]
4.7E-03	mg/l	Concentration in water
2.8E-04	d	Time to reach steady-state (95%)
3.1E-07	mg/kg	**Concentration in leaves (wet weight)**

Table D.7.14. Continous.

Summary of Plant Model Results for TPH Aromatic C10-12

		Kd for TPH Aromatic C10-12
2.5E+03	ml/g	Organic carbon partitioning coefficient [Koc]
2.0E-02	g/g	Fraction organic carbon [Foc]
5.0E+01	ml/g	Soil/water partitioning coefficient [Kd]

Value	**Units**	**Media Concentrations**
2.1E+00	mg/kg	Concentration in soil
4.1E-02	mg/L	Concentration in water

		Trapp and Matthies -- Calculating Concentration in Roots
3.5E+00	-	logKow (octanol partitioning coefficient)
8.0E-01	g/g	Water content of plant [Wp]
2.0E-02	g/g	Lipid content of plant [Lp]
9.5E-01	-	b correction factor between lipids and octanol
5.0E+02	kg/m3	Density of plant tissue
1.0E+03	kg/m3	Density of water
2.0E-01	cm3/cm3	Water content of the soil
1.3E+00	g/cm3	Soil bulk density
1.9E+01	g/g	Partitioning coefficient between roots and water
3.2E-01	mg/kg	Concentration in roots (wet weight)

Value	**Units**	**Aboveground Plant Model Results for TPH Aromatic C10-12**
		Partitioning between contaminants in leaves and water (Klw)
		Klw = (Wp+Lp*((10^logKow) ^bCoeff))*rhoP_to_rhoW
1.9E+01	[-]	Klw
		Partitioning between contaminants in leaves and air (Kla)
		Kla = Klw / Henrys
1.4E+02	[-]	Kla
2.5E-01	[-]	TSCF using first method (TSCF1)
6.6E-01	[-]	TSCF using second method (TSCF2)
6.6E-01	[-]	Overall TSCF
		Overall rate constant (lambdaE)
		lambdaE = lambdaP * fracSun + lambdaM + lambdaG
0.0E+00	1/d	Photodegradation rate constant
3.0E-01	[-]	Fraction of time in sun
0.0E+00	1/d	Metabolism rate constant
3.5E-02	1/d	Growth rate constant
4.1E-07	1/s	Overall rate constant (metabolism, photo. and growth) [a2]
1.8E-02	1/s	Volatilization losses through leaves [a1]
1.8E-02	1/s	Total losses through all mechanisms [a]
1.6E-04	kg/m3/s	Total sources [b]
8.7E-03	kg/m3	Concentration in leaves, not adjusted for water content [b/a]
4.1E-02	mg/l	Concentration in water
1.9E-03	d	Time to reach steady-state (95%)
1.7E-05	mg/kg	**Concentration in leaves (wet weight)**

Table D.7.14. Continous.

Summary of Plant Model Results for TPH Aromatic C12-16

		Kd for TPH Aromatic C12-16
5.0E+03	ml/g	Organic carbon partitioning coefficient [Koc]
2.0E-02	g/g	Fraction organic carbon [Foc]
1.0E+02	ml/g	Soil/water partitioning coefficient [Kd]

Value	**Units**	**Media Concentrations**
2.6E+01	mg/kg	Concentration in soil
2.6E-01	mg/L	Concentration in water

		Trapp and Matthies -- Calculating Concentration in Roots
3.9E+00	-	logKow (octanol partitioning coefficient)
8.0E-01	g/g	Water content of plant [Wp]
2.0E-02	g/g	Lipid content of plant [Lp]
9.5E-01	-	b correction factor between lipids and octanol
5.0E+02	kg/m3	Density of plant tissue
1.0E+03	kg/m3	Density of water
2.0E-01	cm3/cm3	Water content of the soil
1.3E+00	g/cm3	Soil bulk density
5.4E+01	g/g	Partitioning coefficient between roots and water
5.5E+00	mg/kg	Concentration in roots (wet weight)

Value	**Units**	**Aboveground Plant Model Results for TPH Aromatic C12-16**
		Partitioning between contaminants in leaves and water (Klw)
		Klw = (Wp+Lp*((10^logKow) ^bCoeff))*rhoP_to_rhoW
5.4E+01	[-]	Klw
		Partitioning between contaminants in leaves and air (Kla)
		Kla = Klw / Henrys
1.0E+03	[-]	Kla
1.2E-01	[-]	TSCF using first method (TSCF1)
5.4E-01	[-]	TSCF using second method (TSCF2)
5.4E-01	[-]	Overall TSCF
		Overall rate constant (lambdaE)
		lambdaE = lambdaP * fracSun + lambdaM + lambdaG
0.0E+00	1/d	Photodegradation rate constant
3.0E-01	[-]	Fraction of time in sun
0.0E+00	1/d	Metabolism rate constant
3.5E-02	1/d	Growth rate constant
4.1E-07	1/s	Overall rate constant (metabolism, photo. and growth) [a2]
2.5E-03	1/s	Volatilization losses through leaves [a1]
2.5E-03	1/s	Total losses through all mechanisms [a]
7.9E-04	kg/m3/s	Total sources [b]
3.2E-01	kg/m3	Concentration in leaves, not adjusted for water content [b/a]
2.6E-01	mg/l	Concentration in water
1.4E-02	d	Time to reach steady-state (95%)
6.3E-04	mg/kg	**Concentration in leaves (wet weight)**

Table D.7.14. Continous.

Summary of Plant Model Results for TPH Aromatic C16-21

		Kd for TPH Aromatic C16-21
1.6E+04	ml/g	Organic carbon partitioning coefficient [Koc]
2.0E-02	g/g	Fraction organic carbon [Foc]
3.2E+02	ml/g	Soil/water partitioning coefficient [Kd]

Value	Units	Media Concentrations
2.2E+02	mg/kg	Concentration in soil
6.9E-01	mg/L	Concentration in water

		Trapp and Matthies -- Calculating Concentration in Roots
4.7E+00	-	logKow (octanol partitioning coefficient)
8.0E-01	g/g	Water content of plant [Wp]
2.0E-02	g/g	Lipid content of plant [Lp]
9.5E-01	-	b correction factor between lipids and octanol
5.0E+02	kg/m3	Density of plant tissue
1.0E+03	kg/m3	Density of water
2.0E-01	cm3/cm3	Water content of the soil
1.3E+00	g/cm3	Soil bulk density
3.0E+02	g/g	Partitioning coefficient between roots and water
8.4E+01	mg/kg	Concentration in roots (wet weight)

Value	Units	Aboveground Plant Model Results for TPH Aromatic C16-21
		Partitioning between contaminants in leaves and water (Klw)
		Klw = (Wp+Lp*((10^logKow) ^bCoeff))*rhoP_to_rhoW
3.0E+02	[-]	Klw
		Partitioning between contaminants in leaves and air (Kla)
		Kla = Klw / Henrys
2.3E+04	[-]	Kla
2.3E-02	[-]	TSCF using first method (TSCF1)
2.6E-01	[-]	TSCF using second method (TSCF2)
2.6E-01	[-]	Overall TSCF
		Overall rate constant (lambdaE)
		lambdaE = lambdaP * fracSun + lambdaM + lambdaG
0.0E+00	1/d	Photodegradation rate constant
3.0E-01	[-]	Fraction of time in sun
0.0E+00	1/d	Metabolism rate constant
3.5E-02	1/d	Growth rate constant
4.1E-07	1/s	Overall rate constant (metabolism, photo. and growth) [a2]
1.1E-04	1/s	Volatilization losses through leaves [a1]
1.1E-04	1/s	Total losses through all mechanisms [a]
1.0E-03	kg/m3/s	Total sources [b]
9.8E+00	kg/m3	Concentration in leaves, not adjusted for water content [b/a]
6.9E-01	mg/l	Concentration in water
3.2E-01	d	Time to reach steady-state (95%)
2.0E-02	mg/kg	**Concentration in leaves (wet weight)**

Table D.7.15. The Summary of Dialy Doses (Intake) for Risk Calculation of the chemicals of concern at step-6 in modelling based on the contamination located assumed at unsaturated zone soil pathway.

Summary of Daily Doses (Intake) for Risk Calculation
Description:
09-15-2016 16:22:40 **Date:**

Additive Receptor Case	Adult Resident - Upper Percentile	Child Resident - Upper Percentile	Daily Dose and Risk for: Anthracene Ingestion of Soil
	4.8E-05	4.5E-04	CADD (mg/kd-d)
5.5E-05	1.7E-05	3.8E-05	LADD (mg/kd-d)
0.0E+00	ND	ND	Cancer Risk (-)
	1.6E-04	1.5E-03	Hazard Index (-)

Additive Receptor Case	Adult Resident - Upper Percentile	Child Resident - Upper Percentile	Daily Dose and Risk for: Anthracene Dermal Contact with Soil
	2.3E-05	1.3E-04	CADD (mg/kd-d)
1.9E-05	7.9E-06	1.1E-05	LADD (mg/kd-d)
0.0E+00	ND	ND	Cancer Risk (-)
	7.7E-05	4.2E-04	Hazard Index (-)

Additive Receptor Case	Adult Resident - Upper Percentile	Child Resident - Upper Percentile	Daily Dose and Risk for: Anthracene Ingestion of Vegetables
	1.5E-03	3.9E-03	CADD (mg/kd-d)
8.5E-04	5.2E-04	3.3E-04	LADD (mg/kd-d)
0.0E+00	ND	ND	Cancer Risk (-)
	5.0E-03	1.3E-02	Hazard Index (-)

Additive Receptor Case	Adult Resident - Upper Percentile	Child Resident - Upper Percentile	Daily Dose and Risk for: Anthracene Inhalation of Outdoor Air
	7.6E-09	1.3E-07	CADD (mg/kd-d)
1.4E-08	2.6E-09	1.1E-08	LADD (mg/kd-d)
0.0E+00	ND	ND	Cancer Risk (-)
	ND	ND	Hazard Index (-)

Additive Receptor Case	Adult Resident - Upper Percentile	Child Resident - Upper Percentile	Daily Dose and Risk for: Anthracene Inhalation of Particulates
	1.4E-18	2.3E-17	CADD (mg/kd-d)
2.5E-18	4.7E-19	2.0E-18	LADD (mg/kd-d)
0.0E+00	ND	ND	Cancer Risk (-)
	ND	ND	Hazard Index (-)

Table D.7.15. Continous.

			Daily Dose and Risk for: Phenanthrene
Additive Receptor Case	Adult Resident - Upper Percentile	Child Resident - Upper Percentile	Ingestion of Soil
	5.0E-05	4.7E-04	CADD (mg/kd-d)
5.6E-05	1.6E-05	4.0E-05	LADD (mg/kd-d)
0.0E+00	ND	ND	Cancer Risk (-)
	ND	ND	Hazard Index (-)

			Daily Dose and Risk for: Phenanthrene
Additive Receptor Case	Adult Resident - Upper Percentile	Child Resident - Upper Percentile	Dermal Contact with Soil
	1.9E-05	1.0E-04	CADD (mg/kd-d)
1.5E-05	5.9E-06	8.8E-06	LADD (mg/kd-d)
0.0E+00	ND	ND	Cancer Risk (-)
	ND	ND	Hazard Index (-)

			Daily Dose and Risk for: Phenanthrene
Additive Receptor Case	Adult Resident - Upper Percentile	Child Resident - Upper Percentile	Ingestion of Vegetables
	1.7E-03	4.3E-03	CADD (mg/kd-d)
9.0E-04	5.3E-04	3.7E-04	LADD (mg/kd-d)
0.0E+00	ND	ND	Cancer Risk (-)
	ND	ND	Hazard Index (-)

			Daily Dose and Risk for: Phenanthrene
Additive Receptor Case	Adult Resident - Upper Percentile	Child Resident - Upper Percentile	Inhalation of Outdoor Air
	1.3E-07	2.1E-06	CADD (mg/kd-d)
2.2E-07	4.0E-08	1.8E-07	LADD (mg/kd-d)
0.0E+00	ND	ND	Cancer Risk (-)
	ND	ND	Hazard Index (-)

			Daily Dose and Risk for: Phenanthrene
Additive Receptor Case	Adult Resident - Upper Percentile	Child Resident - Upper Percentile	Inhalation of Particulates
	1.4E-18	2.4E-17	CADD (mg/kd-d)
2.6E-18	4.6E-19	2.1E-18	LADD (mg/kd-d)
0.0E+00	ND	ND	Cancer Risk (-)
	ND	ND	Hazard Index (-)

Table D.7.15. Continous.

Additive Receptor Case	Adult Resident - Upper Percentile	Child Resident - Upper Percentile	Daily Dose and Risk for: TPH Aliphatic C12-16 Ingestion of Soil
	2.1E-06	2.3E-05	CADD (mg/kd-d)
2.2E-06	2.1E-07	2.0E-06	LADD (mg/kd-d)
0.0E+00	ND	ND	Cancer Risk (-)
	2.1E-05	2.3E-04	Hazard Index (-)

Additive Receptor Case	Adult Resident - Upper Percentile	Child Resident - Upper Percentile	Daily Dose and Risk for: TPH Aliphatic C12-16 Dermal Contact with Soil
	7.8E-06	5.0E-05	CADD (mg/kd-d)
5.1E-06	7.9E-07	4.3E-06	LADD (mg/kd-d)
0.0E+00	ND	ND	Cancer Risk (-)
	7.8E-05	5.0E-04	Hazard Index (-)

Additive Receptor Case	Adult Resident - Upper Percentile	Child Resident - Upper Percentile	Daily Dose and Risk for: TPH Aliphatic C12-16 Ingestion of Vegetables
	5.8E-05	1.8E-04	CADD (mg/kd-d)
2.1E-05	5.9E-06	1.5E-05	LADD (mg/kd-d)
0.0E+00	ND	ND	Cancer Risk (-)
	5.8E-04	1.8E-03	Hazard Index (-)

Additive Receptor Case	Adult Resident - Upper Percentile	Child Resident - Upper Percentile	Daily Dose and Risk for: TPH Aliphatic C12-16 Inhalation of Outdoor Air
	5.0E-06	9.7E-05	CADD (mg/kd-d)
8.8E-06	5.0E-07	8.3E-06	LADD (mg/kd-d)
0.0E+00	ND	ND	Cancer Risk (-)
	9.1E-06	5.1E-05	Hazard Index (-)

Additive Receptor Case	Adult Resident - Upper Percentile	Child Resident - Upper Percentile	Daily Dose and Risk for: TPH Aliphatic C12-16 Inhalation of Particulates
	6.1E-20	1.2E-18	CADD (mg/kd-d)
1.1E-19	6.1E-21	1.0E-19	LADD (mg/kd-d)
0.0E+00	ND	ND	Cancer Risk (-)
	1.1E-19	6.2E-19	Hazard Index (-)

Table D.7.15. **Continous.**

			Daily Dose and Risk for: TPH Aliphatic C16-35
Additive Receptor Case	**Adult Resident - Upper Percentile**	**Child Resident - Upper Percentile**	**Ingestion of Soil**
	4.3E-04	4.0E-03	CADD (mg/kd-d)
4.9E-04	1.5E-04	3.5E-04	LADD (mg/kd-d)
0.0E+00	ND	ND	Cancer Risk (-)
	2.2E-04	2.0E-03	Hazard Index (-)

			Daily Dose and Risk for: TPH Aliphatic C16-35
Additive Receptor Case	**Adult Resident - Upper Percentile**	**Child Resident - Upper Percentile**	**Dermal Contact with Soil**
	1.6E-03	8.8E-03	CADD (mg/kd-d)
1.3E-03	5.4E-04	7.6E-04	LADD (mg/kd-d)
0.0E+00	ND	ND	Cancer Risk (-)
	8.0E-04	4.4E-03	Hazard Index (-)

			Daily Dose and Risk for: TPH Aliphatic C16-35
Additive Receptor Case	**Adult Resident - Upper Percentile**	**Child Resident - Upper Percentile**	**Ingestion of Vegetables**
	5.6E-03	1.4E-02	CADD (mg/kd-d)
3.1E-03	1.9E-03	1.2E-03	LADD (mg/kd-d)
0.0E+00	ND	ND	Cancer Risk (-)
	2.8E-03	7.2E-03	Hazard Index (-)

			Daily Dose and Risk for: TPH Aliphatic C16-35
Additive Receptor Case	**Adult Resident - Upper Percentile**	**Child Resident - Upper Percentile**	**Inhalation of Outdoor Air**
	1.7E-06	2.8E-05	CADD (mg/kd-d)
3.0E-06	5.6E-07	2.4E-06	LADD (mg/kd-d)
0.0E+00	ND	ND	Cancer Risk (-)
	ND	ND	Hazard Index (-)

			Daily Dose and Risk for: TPH Aliphatic C16-35
Additive Receptor Case	**Adult Resident - Upper Percentile**	**Child Resident - Upper Percentile**	**Inhalation of Particulates**
	1.2E-17	2.1E-16	CADD (mg/kd-d)
2.2E-17	4.2E-18	1.8E-17	LADD (mg/kd-d)
0.0E+00	ND	ND	Cancer Risk (-)
	ND	ND	Hazard Index (-)

Table D.7.15. **Continous.**

Additive Receptor Case	Adult Resident - Upper Percentile	Child Resident - Upper Percentile	Daily Dose and Risk for: TPH Aromatic C8-10 Ingestion of Soil
	1.8E-07	1.9E-06	CADD (mg/kd-d)
1.8E-07	1.8E-08	1.6E-07	LADD (mg/kd-d)
0.0E+00	ND	ND	Cancer Risk (-)
	4.4E-06	4.7E-05	Hazard Index (-)

Additive Receptor Case	Adult Resident - Upper Percentile	Child Resident - Upper Percentile	Daily Dose and Risk for: TPH Aromatic C8-10 Dermal Contact with Soil
	6.5E-07	4.2E-06	CADD (mg/kd-d)
4.2E-07	6.6E-08	3.6E-07	LADD (mg/kd-d)
0.0E+00	ND	ND	Cancer Risk (-)
	1.6E-05	1.0E-04	Hazard Index (-)

Additive Receptor Case	Adult Resident - Upper Percentile	Child Resident - Upper Percentile	Daily Dose and Risk for: TPH Aromatic C8-10 Ingestion of Vegetables
	4.8E-06	1.5E-05	CADD (mg/kd-d)
1.7E-06	4.9E-07	1.3E-06	LADD (mg/kd-d)
0.0E+00	ND	ND	Cancer Risk (-)
	1.2E-04	3.6E-04	Hazard Index (-)

Additive Receptor Case	Adult Resident - Upper Percentile	Child Resident - Upper Percentile	Daily Dose and Risk for: TPH Aromatic C8-10 Inhalation of Outdoor Air
	1.7E-06	3.3E-05	CADD (mg/kd-d)
3.0E-06	1.7E-07	2.8E-06	LADD (mg/kd-d)
0.0E+00	ND	ND	Cancer Risk (-)
	1.5E-05	8.5E-05	Hazard Index (-)

Additive Receptor Case	Adult Resident - Upper Percentile	Child Resident - Upper Percentile	Daily Dose and Risk for: TPH Aromatic C8-10 Inhalation of Particulates
	5.0E-21	9.8E-20	CADD (mg/kd-d)
8.9E-21	5.1E-22	8.4E-21	LADD (mg/kd-d)
0.0E+00	ND	ND	Cancer Risk (-)
	4.6E-20	2.6E-19	Hazard Index (-)

Table D.7.15. **Continous.**

			Daily Dose and Risk for: TPH Aromatic C10-12
Additive Receptor Case	**Adult Resident - Upper Percentile**	**Child Resident - Upper Percentile**	**Ingestion of Soil**
	2.4E-06	2.6E-05	CADD (mg/kd-d)
2.5E-06	2.5E-07	2.3E-06	LADD (mg/kd-d)
0.0E+00	ND	ND	Cancer Risk (-)
	6.1E-05	6.6E-04	Hazard Index (-)

			Daily Dose and Risk for: TPH Aromatic C10-12
Additive Receptor Case	**Adult Resident - Upper Percentile**	**Child Resident - Upper Percentile**	**Dermal Contact with Soil**
	9.0E-06	5.8E-05	CADD (mg/kd-d)
5.9E-06	9.1E-07	5.0E-06	LADD (mg/kd-d)
0.0E+00	ND	ND	Cancer Risk (-)
	2.3E-04	1.4E-03	Hazard Index (-)

			Daily Dose and Risk for: TPH Aromatic C10-12
Additive Receptor Case	**Adult Resident - Upper Percentile**	**Child Resident - Upper Percentile**	**Ingestion of Vegetables**
	8.2E-05	2.5E-04	CADD (mg/kd-d)
2.9E-05	8.3E-06	2.1E-05	LADD (mg/kd-d)
0.0E+00	ND	ND	Cancer Risk (-)
	2.1E-03	6.2E-03	Hazard Index (-)

			Daily Dose and Risk for: TPH Aromatic C10-12
Additive Receptor Case	**Adult Resident - Upper Percentile**	**Child Resident - Upper Percentile**	**Inhalation of Outdoor Air**
	8.3E-06	1.6E-04	CADD (mg/kd-d)
1.5E-05	8.4E-07	1.4E-05	LADD (mg/kd-d)
0.0E+00	ND	ND	Cancer Risk (-)
	7.6E-05	4.2E-04	Hazard Index (-)

			Daily Dose and Risk for: TPH Aromatic C10-12
Additive Receptor Case	**Adult Resident - Upper Percentile**	**Child Resident - Upper Percentile**	**Inhalation of Particulates**
	7.0E-20	1.4E-18	CADD (mg/kd-d)
1.2E-19	7.1E-21	1.2E-19	LADD (mg/kd-d)
0.0E+00	ND	ND	Cancer Risk (-)
	6.4E-19	3.6E-18	Hazard Index (-)

Table D.7.15. **Continous.**

Additive Receptor Case	Adult Resident - Upper Percentile	Child Resident - Upper Percentile	Daily Dose and Risk for: TPH Aromatic C12-16 Ingestion of Soil
	3.1E-05	3.3E-04	CADD (mg/kd-d)
3.1E-05	3.2E-06	2.8E-05	LADD (mg/kd-d)
0.0E+00	ND	ND	Cancer Risk (-)
	7.7E-04	8.2E-03	Hazard Index (-)

Additive Receptor Case	Adult Resident - Upper Percentile	Child Resident - Upper Percentile	Daily Dose and Risk for: TPH Aromatic C12-16 Dermal Contact with Soil
	1.1E-04	7.2E-04	CADD (mg/kd-d)
7.3E-05	1.2E-05	6.2E-05	LADD (mg/kd-d)
0.0E+00	ND	ND	Cancer Risk (-)
	2.9E-03	1.8E-02	Hazard Index (-)

Additive Receptor Case	Adult Resident - Upper Percentile	Child Resident - Upper Percentile	Daily Dose and Risk for: TPH Aromatic C12-16 Ingestion of Vegetables
	1.5E-03	4.3E-03	CADD (mg/kd-d)
5.2E-04	1.5E-04	3.7E-04	LADD (mg/kd-d)
0.0E+00	ND	ND	Cancer Risk (-)
	3.6E-02	1.1E-01	Hazard Index (-)

Additive Receptor Case	Adult Resident - Upper Percentile	Child Resident - Upper Percentile	Daily Dose and Risk for: TPH Aromatic C12-16 Inhalation of Outdoor Air
	1.7E-05	3.2E-04	CADD (mg/kd-d)
2.9E-05	1.7E-06	2.8E-05	LADD (mg/kd-d)
0.0E+00	ND	ND	Cancer Risk (-)
	1.5E-04	8.4E-04	Hazard Index (-)

Additive Receptor Case	Adult Resident - Upper Percentile	Child Resident - Upper Percentile	Daily Dose and Risk for: TPH Aromatic C12-16 Inhalation of Particulates
	8.8E-19	1.7E-17	CADD (mg/kd-d)
1.6E-18	9.2E-20	1.5E-18	LADD (mg/kd-d)
0.0E+00	ND	ND	Cancer Risk (-)
	8.1E-18	4.4E-17	Hazard Index (-)

Table D.7.15. Continous.

Additive Receptor Case	Adult Resident - Upper Percentile	Child Resident - Upper Percentile	Daily Dose and Risk for: TPH Aromatic C16-21 Ingestion of Soil
	3.0E-04	2.8E-03	CADD (mg/kd-d)
3.4E-04	1.0E-04	2.4E-04	LADD (mg/kd-d)
0.0E+00	ND	ND	Cancer Risk (-)
	1.0E-02	9.3E-02	Hazard Index (-)

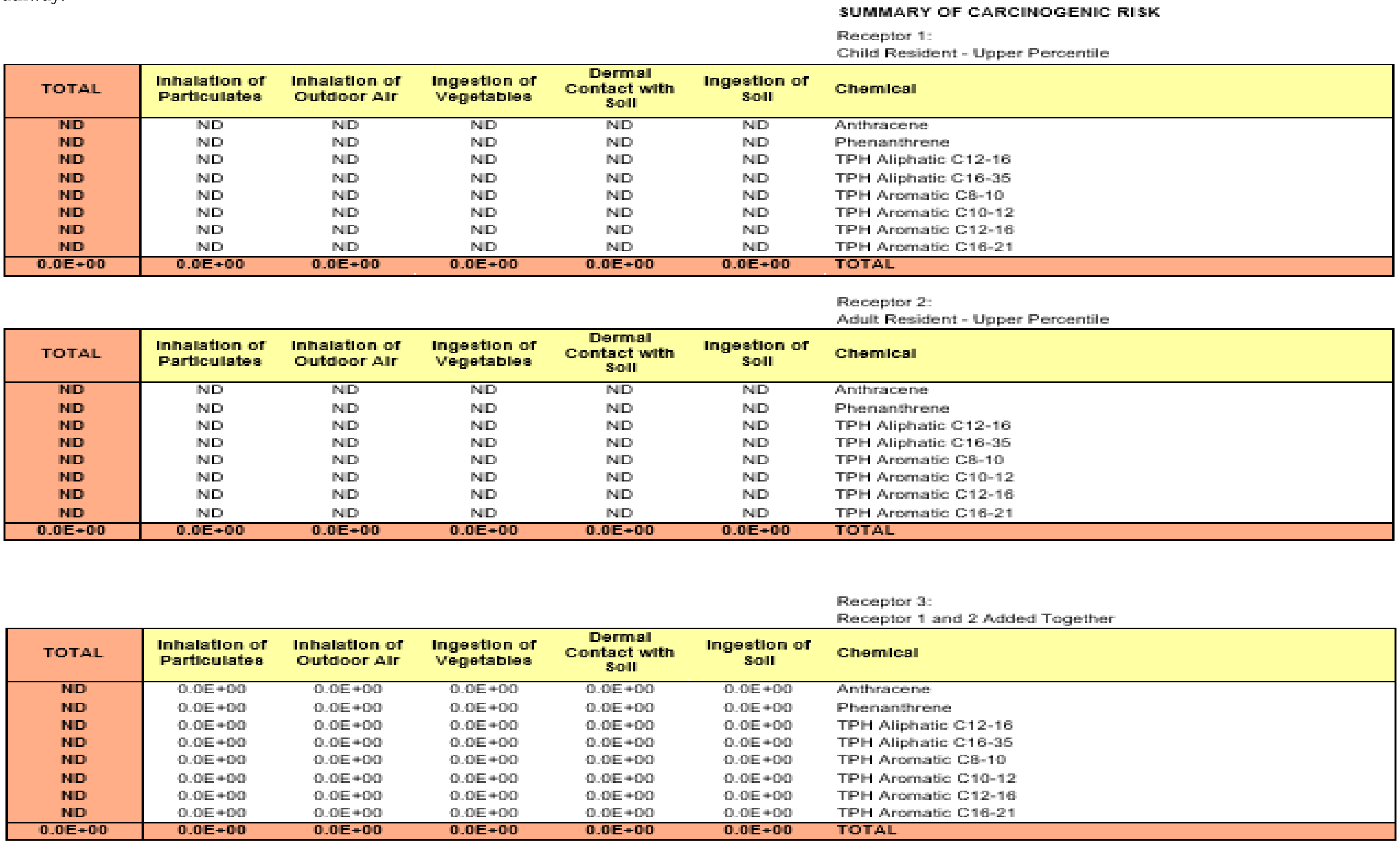
Additive Receptor Case	Adult Resident - Upper Percentile	Child Resident - Upper Percentile	Daily Dose and Risk for: TPH Aromatic C16-21 Dermal Contact with Soil
	1.1E-03	6.1E-03	CADD (mg/kd-d)
9.0E-04	3.7E-04	5.3E-04	LADD (mg/kd-d)
0.0E+00	ND	ND	Cancer Risk (-)
	3.7E-02	2.0E-01	Hazard Index (-)

Additive Receptor Case	Adult Resident - Upper Percentile	Child Resident - Upper Percentile	Daily Dose and Risk for: TPH Aromatic C16-21 Ingestion of Vegetables
	2.5E-02	6.5E-02	CADD (mg/kd-d)
1.4E-02	8.4E-03	5.6E-03	LADD (mg/kd-d)
0.0E+00	ND	ND	Cancer Risk (-)
	8.4E-01	2.2E+00	Hazard Index (-)

Additive Receptor Case	Adult Resident - Upper Percentile	Child Resident - Upper Percentile	Daily Dose and Risk for: TPH Aromatic C16-21 Inhalation of Outdoor Air
	1.3E-06	2.2E-05	CADD (mg/kd-d)
2.3E-06	4.4E-07	1.9E-06	LADD (mg/kd-d)
0.0E+00	ND	ND	Cancer Risk (-)
	ND	ND	Hazard Index (-)

Additive Receptor Case	Adult Resident - Upper Percentile	Child Resident - Upper Percentile	Daily Dose and Risk for: TPH Aromatic C16-21 Inhalation of Particulates
	8.6E-18	1.5E-16	CADD (mg/kd-d)
1.5E-17	2.9E-18	1.2E-17	LADD (mg/kd-d)
0.0E+00	ND	ND	Cancer Risk (-)
	ND	ND	Hazard Index (-)

Table D.7.16. The summary of Carcinogenic Risk results from the contamination site (dry oil lake) at step 6 based on the contamination located assumed at unsaturated zone soil Pathway.



SUMMARY OF CARCINOGENIC RISK

Receptor 1:
Child Resident - Upper Percentile

TOTAL	Inhalation of Particulates	Inhalation of Outdoor Air	Ingestion of Vegetables	Dermal Contact with Soil	Ingestion of Soil	Chemical
ND	ND	ND	ND	ND	ND	Anthracene
ND	ND	ND	ND	ND	ND	Phenanthrene
ND	ND	ND	ND	ND	ND	TPH Aliphatic C12-16
ND	ND	ND	ND	ND	ND	TPH Aliphatic C16-35
ND	ND	ND	ND	ND	ND	TPH Aromatic C8-10
ND	ND	ND	ND	ND	ND	TPH Aromatic C10-12
ND	ND	ND	ND	ND	ND	TPH Aromatic C12-16
ND	ND	ND	ND	ND	ND	TPH Aromatic C16-21
0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	TOTAL

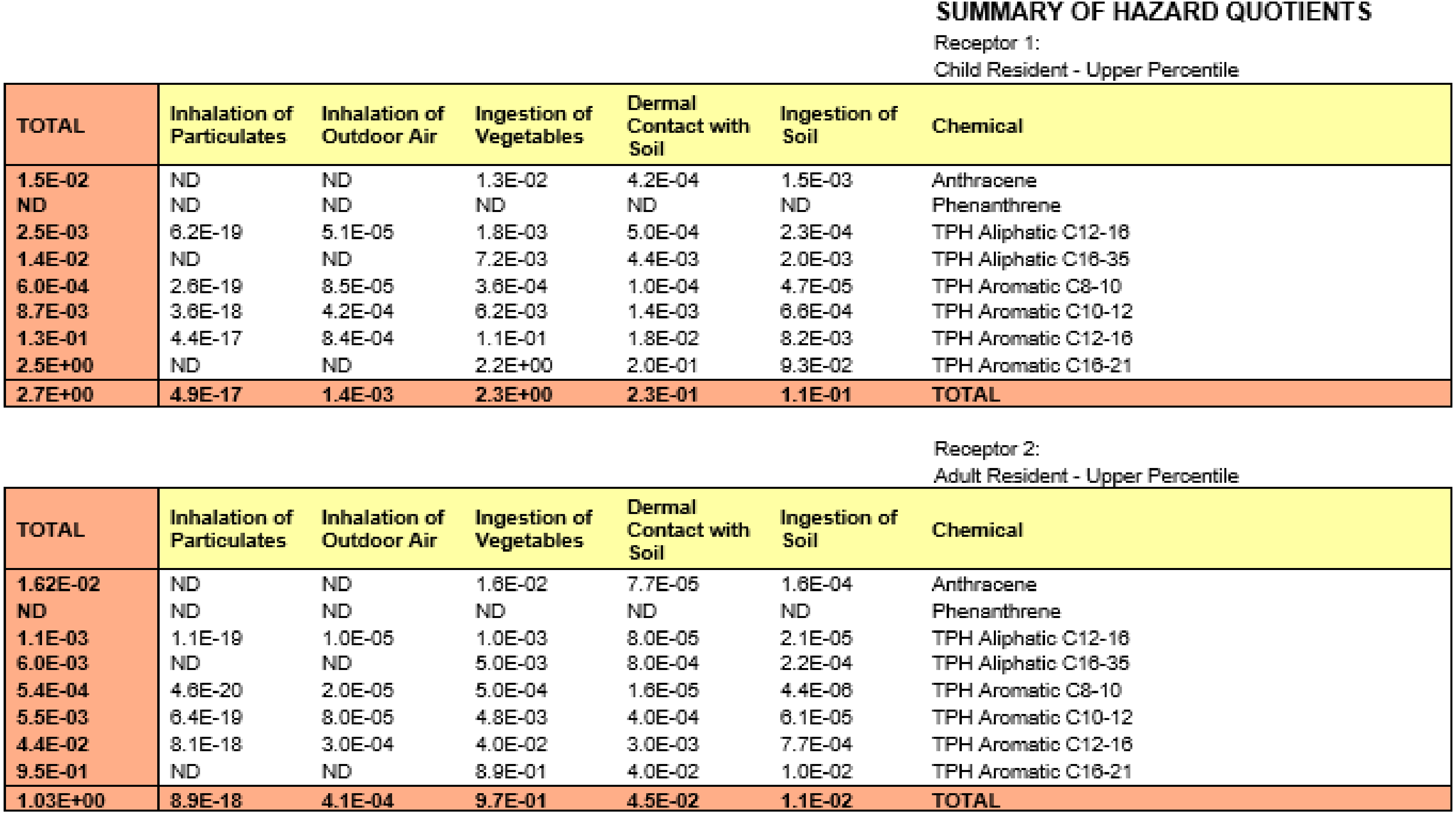
Receptor 2:
Adult Resident - Upper Percentile

TOTAL	Inhalation of Particulates	Inhalation of Outdoor Air	Ingestion of Vegetables	Dermal Contact with Soil	Ingestion of Soil	Chemical
ND	ND	ND	ND	ND	ND	Anthracene
ND	ND	ND	ND	ND	ND	Phenanthrene
ND	ND	ND	ND	ND	ND	TPH Aliphatic C12-16
ND	ND	ND	ND	ND	ND	TPH Aliphatic C16-35
ND	ND	ND	ND	ND	ND	TPH Aromatic C8-10
ND	ND	ND	ND	ND	ND	TPH Aromatic C10-12
ND	ND	ND	ND	ND	ND	TPH Aromatic C12-16
ND	ND	ND	ND	ND	ND	TPH Aromatic C16-21
0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	TOTAL

Receptor 3:
Receptor 1 and 2 Added Together

TOTAL	Inhalation of Particulates	Inhalation of Outdoor Air	Ingestion of Vegetables	Dermal Contact with Soil	Ingestion of Soil	Chemical
ND	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	Anthracene
ND	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	Phenanthrene
ND	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	TPH Aliphatic C12-16
ND	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	TPH Aliphatic C16-35
ND	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	TPH Aromatic C8-10
ND	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	TPH Aromatic C10-12
ND	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	TPH Aromatic C12-16
ND	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	TPH Aromatic C16-21
0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	TOTAL

Table D.7.17. The summary of the Hazard Quotient for the chemicals of concern at step-6 (Risk estimation process in the modelling) found in the site (dry oil lake) based on the contamination located assumed at unsaturated zone soil pathway.



SUMMARY OF HAZARD QUOTIENTS

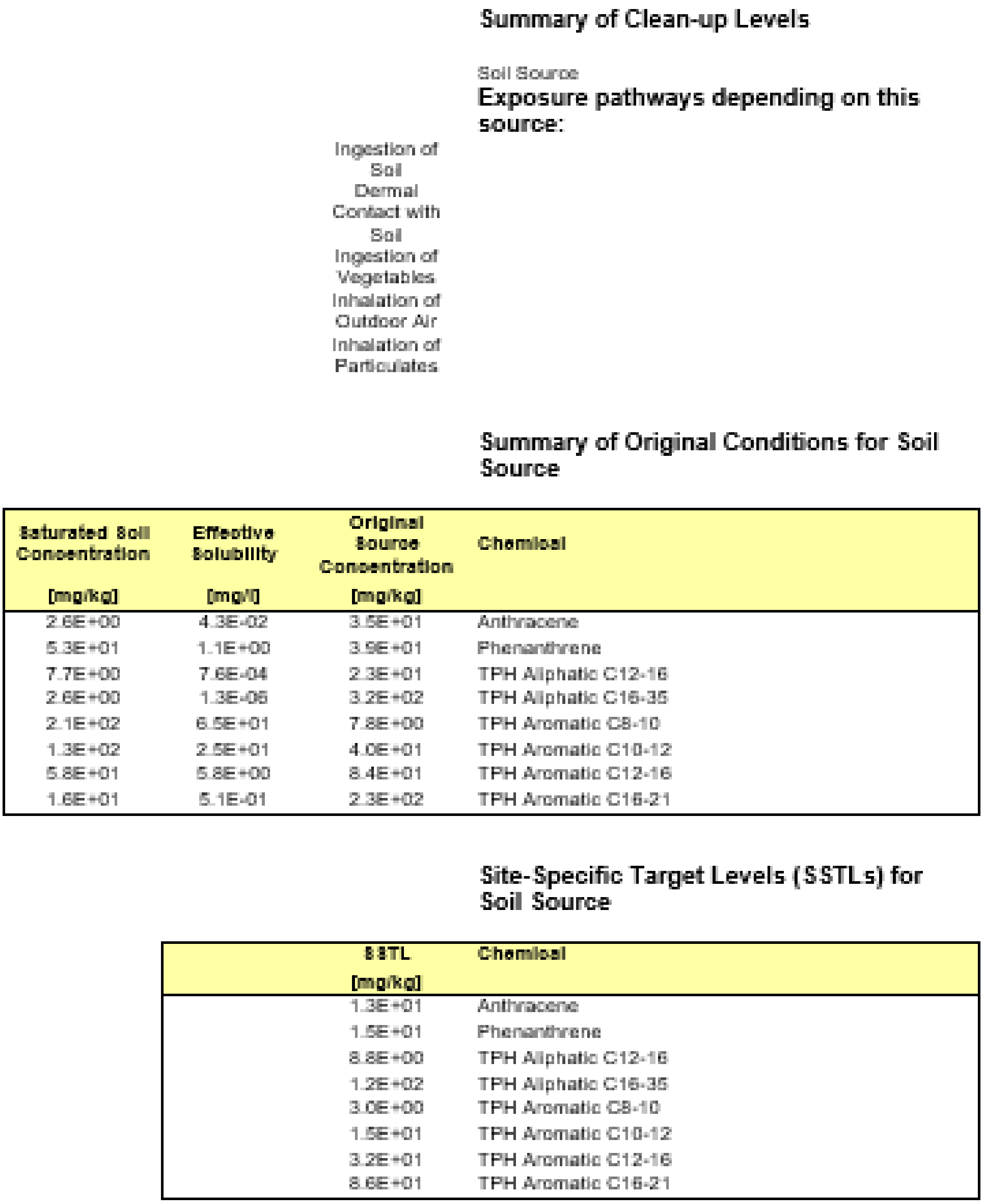
Receptor 1:
Child Resident - Upper Percentile

TOTAL	Inhalation of Particulates	Inhalation of Outdoor Air	Ingestion of Vegetables	Dermal Contact with Soil	Ingestion of Soil	Chemical
1.5E-02	ND	ND	1.3E-02	4.2E-04	1.5E-03	Anthracene
ND	ND	ND	ND	ND	ND	Phenanthrene
2.5E-03	6.2E-19	5.1E-05	1.8E-03	5.0E-04	2.3E-04	TPH Aliphatic C12-16
1.4E-02	ND	ND	7.2E-03	4.4E-03	2.0E-03	TPH Aliphatic C16-35
6.0E-04	2.6E-19	8.5E-05	3.6E-04	1.0E-04	4.7E-05	TPH Aromatic C8-10
8.7E-03	3.6E-18	4.2E-04	6.2E-03	1.4E-03	6.6E-04	TPH Aromatic C10-12
1.3E-01	4.4E-17	8.4E-04	1.1E-01	1.8E-02	8.2E-03	TPH Aromatic C12-16
2.5E+00	ND	ND	2.2E+00	2.0E-01	9.3E-02	TPH Aromatic C16-21
2.7E+00	**4.9E-17**	**1.4E-03**	**2.3E+00**	**2.3E-01**	**1.1E-01**	**TOTAL**

Receptor 2:
Adult Resident - Upper Percentile

TOTAL	Inhalation of Particulates	Inhalation of Outdoor Air	Ingestion of Vegetables	Dermal Contact with Soil	Ingestion of Soil	Chemical
1.62E-02	ND	ND	1.6E-02	7.7E-05	1.6E-04	Anthracene
ND	ND	ND	ND	ND	ND	Phenanthrene
1.1E-03	1.1E-19	1.0E-05	1.0E-03	8.0E-05	2.1E-05	TPH Aliphatic C12-16
6.0E-03	ND	ND	5.0E-03	8.0E-04	2.2E-04	TPH Aliphatic C16-35
5.4E-04	4.6E-20	2.0E-05	5.0E-04	1.6E-05	4.4E-06	TPH Aromatic C8-10
5.5E-03	6.4E-19	8.0E-05	4.8E-03	4.0E-04	6.1E-05	TPH Aromatic C10-12
4.4E-02	8.1E-18	3.0E-04	4.0E-02	3.0E-03	7.7E-04	TPH Aromatic C12-16
9.5E-01	ND	ND	8.9E-01	4.0E-02	1.0E-02	TPH Aromatic C16-21
1.03E+00	**8.9E-18**	**4.1E-04**	**9.7E-01**	**4.5E-02**	**1.1E-02**	**TOTAL**

Table D.7.18. The summary of the cumulative clean-up level at step 6 in the modelling based on the contamination located assumed at unsaturated zone soil pathway.



Summary of Clean-up Levels

Soil Source

Exposure pathways depending on this source:

Ingestion of Soil
Dermal Contact with Soil
Ingestion of Vegetables
Inhalation of Outdoor Air
Inhalation of Particulates

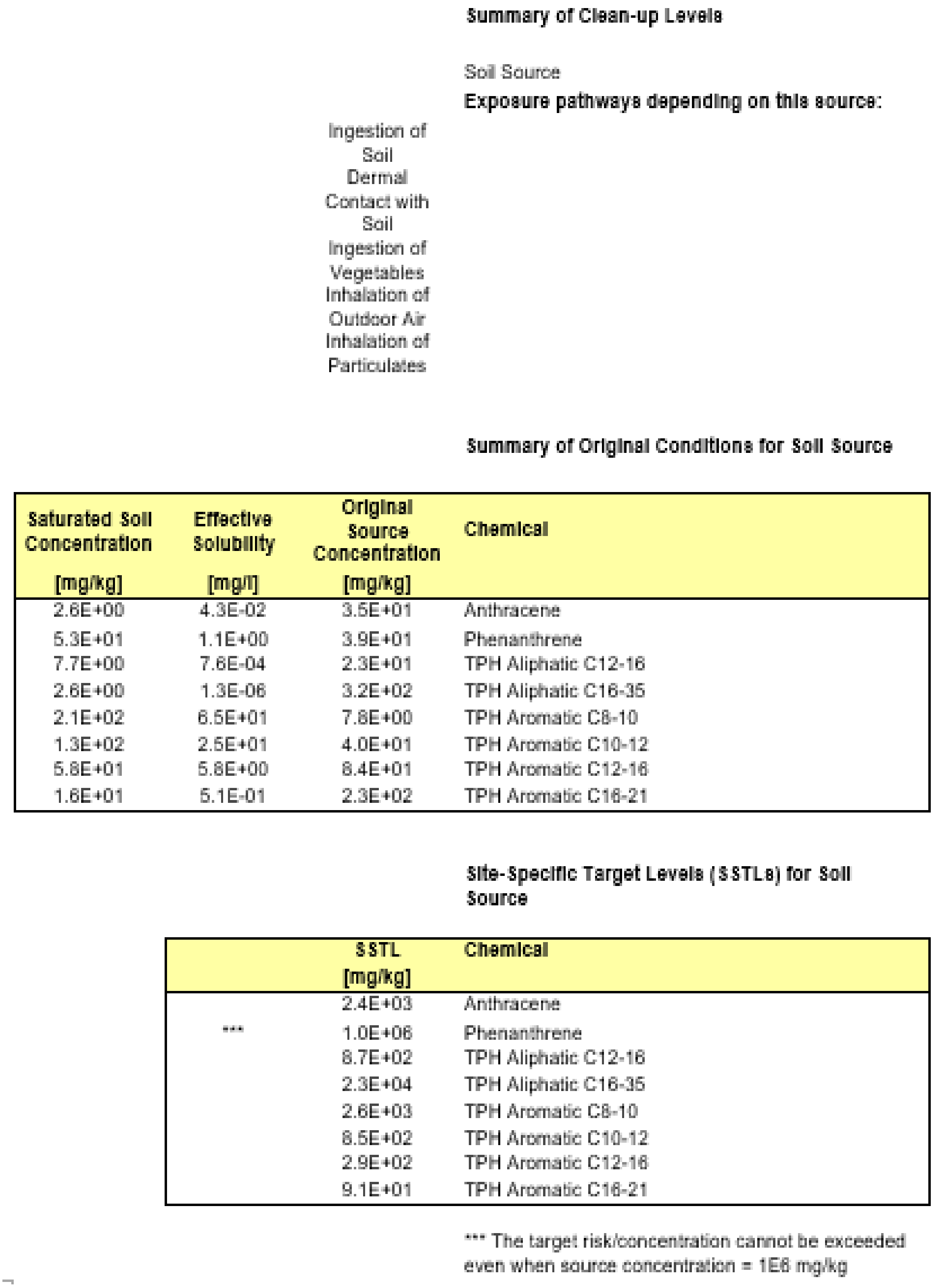
Summary of Original Conditions for Soil Source

Saturated Soil Concentration [mg/kg]	Effective Solubility [mg/l]	Original Source Concentration [mg/kg]	Chemical
2.6E+00	4.3E-02	3.5E+01	Anthracene
5.3E+01	1.1E+00	3.9E+01	Phenanthrene
7.7E+00	7.6E-04	2.3E+01	TPH Aliphatic C12-16
2.6E+00	1.3E-06	3.2E+02	TPH Aliphatic C16-35
2.1E+02	6.5E+01	7.8E+00	TPH Aromatic C8-10
1.3E+02	2.5E+01	4.0E+01	TPH Aromatic C10-12
5.8E+01	5.8E+00	8.4E+01	TPH Aromatic C12-16
1.6E+01	5.1E-01	2.3E+02	TPH Aromatic C16-21

Site-Specific Target Levels (SSTLs) for Soil Source

SSTL [mg/kg]	Chemical
1.3E+01	Anthracene
1.5E+01	Phenanthrene
8.8E+00	TPH Aliphatic C12-16
1.2E+02	TPH Aliphatic C16-35
3.0E+00	TPH Aromatic C8-10
1.5E+01	TPH Aromatic C10-12
3.2E+01	TPH Aromatic C12-16
8.6E+01	TPH Aromatic C16-21

Table D.7.19. The summary of the individual clean-up level at step 6 in the modelling based on the contamination located assumed at unsaturated zone soil pathway.



Summary of Clean-up Levels

Soil Source

Exposure pathways depending on this source:

Ingestion of Soil
Dermal Contact with Soil
Ingestion of Vegetables
Inhalation of Outdoor Air
Inhalation of Particulates

Summary of Original Conditions for Soil Source

Saturated Soil Concentration [mg/kg]	**Effective Solubility [mg/l]**	**Original Source Concentration [mg/kg]**	**Chemical**
2.6E+00	4.3E-02	3.5E+01	Anthracene
5.3E+01	1.1E+00	3.9E+01	Phenanthrene
7.7E+00	7.6E-04	2.3E+01	TPH Aliphatic C12-16
2.6E+00	1.3E-06	3.2E+02	TPH Aliphatic C16-35
2.1E+02	6.5E+01	7.8E+00	TPH Aromatic C8-10
1.3E+02	2.5E+01	4.0E+01	TPH Aromatic C10-12
5.8E+01	5.8E+00	8.4E+01	TPH Aromatic C12-16
1.6E+01	5.1E-01	2.3E+02	TPH Aromatic C16-21

Site-Specific Target Levels (SSTLs) for Soil Source

	SSTL [mg/kg]	**Chemical**
	2.4E+03	Anthracene
***	1.0E+06	Phenanthrene
	8.7E+02	TPH Aliphatic C12-16
	2.3E+04	TPH Aliphatic C16-35
	2.6E+03	TPH Aromatic C8-10
	8.5E+02	TPH Aromatic C10-12
	2.9E+02	TPH Aromatic C12-16
	9.1E+01	TPH Aromatic C16-21

*** The target risk/concentration cannot be exceeded even when source concentration = 1E6 mg/kg

FORM UPR16

Research Ethics Review Checklist

University of Portsmouth

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Postgraduate Research Student (PGRS) Information		**Student ID:**	434923
Candidate Name:	Humoud Melfi Zayed Aldaihani		
Department:	SCES	**First Supervisor:**	Dr. David Giles
Start Date: (or progression date for Prof Doc students)	Jan 2011		

Study Mode and Route:	Part-time ☐ Full-time ✓	MPhil ☐ MD ☐ PhD ✓	Integrated Doctorate (NewRoute) ☐ Prof Doc (PD) ☐

Title of Thesis:	***A Geotechnical, Geochemical and Human Health Risk Assessment of a Dry Oil Lake Site in Kuwait.***
Thesis Word Count: (excluding ancillary data and references)	63,625

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Ethical review number(s) from Faculty Ethics Committee (or from NRES/SCREC):	
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