Levels of selected heavy metals in garden soil in Walmer Township and Wells Estate, Port Elizabeth

By

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AT

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Declaration

I, Ebunoluwa Juliana Ogunfowora (216125111), hereby declare that the dissertation entitled "*Levels of selected heavy metals in garden soil in Walmer Township and Wells Estate, Port Elizabeth*" is my own work and that it has not been submitted previously for any Degree or examination at any other University/Institute.

Signature..............................

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Abstract

Research Overview: Heavy metals are naturally occurring elements that have high densities. Heavy metals have been found to have applications in various sectors such as the industrial, domestic, agricultural and medical sectors, thus resulting in environmental pollution which may pose a hazard to human health. Heavy metals such as arsenic, cadmium, manganese, lead and mercury rank among the priority metals that are of public health significance, and they are commonly found in garden soils. In this study, residential garden soils were sampled in dwelling sites in Wells Estate and Walmer Township, and analysed for mercury, cadmium, arsenic, manganese and lead.

Study Design: A cross sectional design was employed in this study. The research was carried out in two phases; the first phase involved soil sample collection, preparation and laboratory work for the determination of heavy metal concentrations. The second phase focused on the social aspect of the study population which included the use of a pre-approved questionnaire and face-to-face interviews for the collection of human health related information at each dwelling site where soil samples were collected. The research protocol was approved by the Health Sciences Faculty Postgraduate Studies Committees (FPGSC) of Nelson Mandela University.

Methodology: Garden soil from residential yards of Wells Estate (near an industrial site,~2 km) and Walmer Township (further away from the industrial site (~22 km), but relatively close to Port Elizabeth airport,~2 km) were sampled over a total of six sampling sessions resulting in 100 soil samples. Fifty soil samples were collected in Wells Estate and fifty soil samples in Walmer Township during the month of May 2017. Surface soil samples were collected from the top 2 cm of the soil using a sterile stainless-steel spoon. In addition to the collection of soil samples, a visual inspection of the house was undertaken to collect information about the house characteristics, geographic location (GPS coordinates) and characteristics of the surrounding area. Soil samples were prepared for analysis by grinding and drying followed by heavy metal determination using an X-ray fluorescence (XRF) analyser (Bruker s1 TITAN Analyser, USA). A face-to-face questionnaire was administered to a suitable respondent at each dwelling site to obtain information related to health symptoms such as coughing, fever, chest pains, earache, sore throat, headaches, rapid breathing, sneezing, running/blocked nose, teary watery eyes, cancer, hypertension, heart diseases and mental illness.

Results: The mean concentrations of heavy metals were in the order manganese>lead>arsenic for both study sites. In Walmer Township soil samples, the mean concentrations of heavy metals determined were 154.8 mg/kg, 84.4 mg/kg and 5.4 mg/kg for manganese, lead, and arsenic, respectively. Mean concentrations of heavy metals as determined in Wells Estate were 322.2 mg/kg, 11.5 mg/kg, and 3.4 mg/kg for manganese, lead and arsenic, respectively. Manganese concentration across the study sites are below the guideline levels for USA (630 mg/kg) and South African (1500 mg/kg). About 2.0% of the sample exceeded the South African lead guideline level of 230 mg/kg, while 4.1% exceeded European lead level of 400 mg/kg in Walmer Township. Lead levels in Wells Estate were all below the South African, European and United States guideline levels. By contrast, 2.0% of the sample exceeded the South African arsenic guideline level of 48 mg/kg, 2.0% exceeded European arsenic guideline level of 50 mg/kg and 2.0% exceeded USA arsenic guideline level of 11 mg/kg in Walmer Township, while 2.0% exceeded USA arsenic guideline level of 11 mg/kg in Wells Estate. Mann Whitney U test showed statistically significant differences between lead levels ($U=1527$, $p < 0.001$) and manganese levels ($U=2632$, $p < 0.001$) across study sites. Soil manganese level showed significant association with age of house (crude OR: 0.34, 95% CI: 0.14-0.83, p =

0.016). Using data obtained from the questionnaire, a multivariate logistic regression analysis was performed to examine the relationship between soil heavy metals and the various health outcomes. In Walmer Township, manganese showed association with dry cough (OR: 11.35, 95% CI: 1.08-119.20) and sneezing (OR: 11.30, 95% CI: 1.09-116.67). Manganese was also associated with wet cough (OR: 0.19 95% CI: 0.05-0.70), dry cough (OR: 0.22, 95% CI: 0.06-0.83) and watery eye (OR: 4.55, 95% CI: 1.01-20.58) in Wells Estate. Dry cough (OR: 0.31, 95% CI: 0.16-0.64), sneezing (OR: 2.18, 95% CI: 1.06-4.48) and watery eye adjusted (OR: 3.71, 95% CI: 1.63-8.48) were also associated with manganese in the total sample. Confounding factors such as overcrowding (adjusted OR = 2.23; 95% CI: 1.11-4.48) and air pollution (adjusted OR = 2.76; 95% CI:1.39-5.50), predicted wet cough and sneezing, respectively, across the total sample.

Conclusion: Heavy metal concentration in most of the study dwellings of Walmer Township and Wells Estate were below the safe limit recommended by United States, European and South Africa soil reference levels. Nevertheless, we found a strong association between manganese and respiratory symptoms such as dry cough and sneezing in Walmer Township, as well as a strong association between manganese and watery eyes in Wells Estate. There was no evidence of associations between heavy metal exposure and gastrointestinal symptoms, chronic diseases and mental illness.

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Dissertation outline

The dissertation outline gives a short summary of topics covered in each chapter of the dissertation to fulfil the research aim and objectives.

In chapter one, the general background, properties and epidemiology of heavy metals were discussed. The chapter further describes the research problems, hypothesis, aim and objectives.

Chapter two covers literature review on related study, which gives insight and understanding in relation to the sources, environmental transportation, bioaccumulation, exposure pathways and health effects of selected heavy metals. Heavy metal distribution in residential environments of some selected countries, including South Africa was discussed. The chapter further reviewed some public health protection mechanisms for reducing heavy metals in the environment such as industrial/residential planning and international and local soil heavy metals reference levels.

Chapter three provides details about the study design approach, study area, sampling and heavy metal concentration determination methodology. Method for descriptive statistical analyses across study population was reported. Mann-Whitney u test, Spearman correlation, multiple logistic regression analyses to check for significant difference, correlation and associations between heavy metal and health outcomes across study sites were investigated.

Chapter four presents the results of the soil metal distributions of the study sites (Walmer Township and Wells Estate). Results of descriptive statistical analyses, socio demographic and economic profile, housing conditions, cottage industries and surveyed health outcomes, across the study population were presented in this chapter. GIS map showing heavy metal distribution was also presented. Finally, Mann-Whitney u test and multiple logistic regression analyses was employed to check possible significant differences and association between heavy metal and health outcomes.

Chapter five discusses the various statistical results presented in chapter four of the dissertation.

Chapter six gives a summary of the overall results and findings of the study in the form of a conclusion and recommended research needed for future work.

Chapter 1

INTRODUCTION

This chapter covers the general background, properties, harmful effects and epidemiology of heavy metals. Research problems, hypothesis, objectives and the significance of the study were also mentioned in this chapter.

1.1 Background information

Heavy metals are metallic chemical elements with high density and are toxic when absorbed or taken in by humans in relatively low concentrations. Heavy metals are usually known to occur naturally in relatively small amounts (Calderon et al. 2003; Gil, Boluda & Ramos 2004) with densities that are at least five times greater than that of water (Obodai et al. 2011; Rajaganapathy 2011). These metallic elements occur in different forms such as neutral (metallic) and ionic forms, for example cations and anions in soil: this ionic property assists heavy metals to bind strongly with soil.

Some examples of heavy metals include antimony, arsenic, barium, beryllium, bismuth, cadmium, gallium, germanium, gold, indium, lead, lithium, manganese, mercury, nickel, platinum, silver, strontium, tellurium, thallium, tin, titanium, zinc, vanadium, and uranium (WHO/FAO/IAEA 1996).

Heavy metals retain their unique properties over an extended period in the environment as they are non-biodegradable (Adelekan & Abegunde 2011; Friedlova 2010), and this leads to the bioaccumulation of heavy metals (which have long biological half-lives) in humans to dangerous levels, thereby influencing the functionality of human body systems (Aderinola et al. 2009; Obodai et al. 2011; Rajaganapathy 2011).

Over the last few decades, anthropogenic activities such as industry, mining, smelting, vehicle exhausts, sewage sludge, pesticide application of agricultural chemicals and the improper disposal of waste have contributed to the deposition of several heavy metals into soils leading to health concerns. Cottage industries such as car repairs, welding, spray painting, scrap metal recycling, hairdressing, electrical appliance repair, cotton weaving, silk weaving and carpet making have also contributed to the deposition of heavy metals into the soil (Teare et al. 2015). Heavy metal pollution in soils has been of great interest lately due to its rising concentration levels, as well as the resulting adverse effect on human health and the environment (Xu et al. 2014; Alloway 1995; Kachenko & Singh 2006; Montagne et al. 2007; Facchinelli, Sacchi & Mallen 2001; Rodríguez et al. 2013; Zhao et al. 2008; Mathee et al. 2006; Kootbodien et al. 2012; Mathee 2005).

Recently, Anyakora et al. (2013) reported that soil samples from dump yards, mattress manufacturing companies and soft drink bottling industries within the city of Lagos, Nigeria contained high levels of some toxic heavy metals such as cadmium, arsenic, and lead, and these heavy metal levels were reported to have exceeded the European Regulatory Standards.

In Europe, studies reported by Alloway (1995); and McGrath, Zhao & Lombi (2001), focused on some heavy metals of concern emitted from waste incinerators: these heavy metals are arsenic, cadmium, cobalt, chromium, copper, mercury, manganese, nickel, lead, tin, and thallium. It was discovered that over 300,000 sites in Western Europe were now contaminated with the studied elements (McGrath, Zhao & Lombi 2001). Similarly, studies conducted in New Zealand showed high concentrations of cadmium, nickel, and zinc in drainage leachates of soils treated with bio-solids (Keller 2002; Mclaren et al. 2004).

Heavy metal concentrations in soil influence the levels found in groundwater as there is no boundary between the two in the subsoil level. Rainwater leaches heavy metals into the underground water reservoir thus polluting the water. These metals are leached into the waters by forming ionic species soluble in virtually any medium and can quickly be absorbed into plants such as vegetables that are consumed by humans (Hogan 2010).

The potential health and social risks associated with heavy metal contamination and possible ingestion currently constitute a priority environmental health concern in several countries. Long and short-term exposure to high levels of heavy metals could give rise to abdominal pain, constipation, headaches, irritation, body weakness, neurological disorders, reproductive problems, diminished intelligence, high blood pressure, heart disease, kidney disease, and could also lead to cancer (Facchinelli, Sacchi & Mallen 2001; Zhao et al. 2008; Zhao et al. 2014; Mathee et al. 2006; Montgomery & Mathee 2005). In Nigeria, several hundred child deaths were reported in Zamfara state due to lead contamination (Anyakora, Ehianeta & Umukoro 2013).

It is therefore vital to identify soil polluted with heavy metals and sources of pollution to formulate pollution control policies, as well as enforce industrial and residential planning. To summarise, heavy metals such as arsenic, cadmium, manganese, lead, and mercury rank among the priority metals that are of public health significance due to their high degree of toxicity, especially in neurodevelopmental health outcomes mostly in vulnerable groups such as children who spend most of their time playing with soil. Interpretation of epidemiologic evidence regarding potential causal associations between heavy metal and health outcomes is a complex process and relies on a wide range of supporting information.

1.2 Epidemiology

Epidemiology studies the trends and patterns of human-related diseases in a given population, and this enables the researcher to understand and identify the various sources of human-related diseases as well as identify different methods of preventing the disease (National Research Council 1997). Epidemiological studies are important in linking exposure to human health directly through the identification of variable factors such as disease occurrence, progression, and intervention through health-related programs (Kjellström 1999; Brunekreef, Dockery & Krzyanowski 1995; Grandjean 1993).

Environmental epidemiology is an evolving field of epidemiology which focuses on external environmental factors such as physical, biological and chemical factors and their relationship to human health in a population. Environmental epidemiology also involves the distribution of health-related events in the specified population in relation to hazards in their living environment (Rothman 1993; Lipfert 1997; Thomas, Stram & Dwyer 1993). In recent years, there have been concerns about significant environmental and health related problems caused by heavy metals in environmental epidemiological studies. It is well known that some of these elements, like copper and zinc, are essential for sustaining life, but the vast majority have no safe exposure level.

Lead for example, is found in the environment owing to its various applications as well as its non-degradable properties. In the 80s to early 90s, leaded paints were used for painting dwellings and this has resulted in children living in approximately 4 million dwellings in the United States being exposed to lead. Studies also show that blood lead levels of less than 5 μg/dL have adverse neurodevelopmental outcomes in children younger than five years (Canfield et al. 2003; Jusko et al. 2008), and this has resulted in the elimination of leaded paint. The Centre for Disease Control and Prevention (CDC, 2007) has reported that no safe blood lead levels in children have been identified as very low levels (<5 μg/dL) have been shown to affect IQ and academic achievement (Blood Lead Levels 2017). The adult population is exposed to lead mainly in occupational settings, for example, in mining, manufacturing, and construction. In 2009, China experienced one or more epidemics of lead poisoning involving more than 2000 children living near smelting plants, some of which sparked riots (Parry 2009; Watts 2009).

Exposure to arsenic can occur through many routes such as (i) the use of arsenic trioxide (chemotherapeutic agent) for treatment of cancerous disease, (ii) human exposure to waste products of smelting plants, and (iii) application of arsenic-containing pesticides in cotton fields (Hughes et al. 2011). In 2014, 682 adults were reported to be exposed to arsenic in America (Mowry et al. 2014). The data was obtained from the American Association of Poison Control Centres' (AAPCC) National Poisoning Data System (NPDS).

Mercury in its elemental form, inorganic salt, or organic mercury form mainly enters the human system via inhalation of mercury vapour during mercury melting and through ingestion of contaminated soil and animals, such as fish (Clarkson & Magos 2006). Dwelling site residential soils are also contaminated through emissions, thus leading to long-term exposure of children to heavy metals such as mercury through the ingestion of soil. Generally, heavy metals could result in human mortality, and this appears to be largely dependent on age.

Mortality: Bioaccumulation of heavy metals in humans is usually toxic to the human system altering human metabolic processes. High concentration levels of heavy metals could lead to chronic disease such as encephalopathy (brain disease, damage, or malfunction) which may lead to the death of the patient (Adal & Wiener 2015).

Age: The toxicity levels of heavy metal vary with age; children are more susceptible to heavy metals' toxicity than adults. The amount of heavy metals absorbed by adults in an ingested substance is only about 10%, whereas, children absorb more than 50% of heavy metals present in the ingested sample (Adal & Wiener 2015). Lead toxicity in children and infants has been shown to influence developmental behaviours within these age groups (Hornung, Lamphear & Dietrich 2009).

1.3 Motivation

Despite the large amount of literature on heavy metal soil contamination and increasing concern regarding heavy metal toxicity, few studies regarding soil protection and sustainability have been reported (Alloway 1994). Industrial activities have led to growing concerns over soil pollution resulting in environmental and human contamination (Obodai et al. 2011; Rajaganapathy 2011). These effects have highlighted the importance of monitoring soil for heavy metals due to their influence on the ecosystem.

Studies indicated that children spend most of their time in residential gardens as well as public playgrounds (Li, Poon & Liu 2001). High levels of heavy metal exposure in children may produce undesirable effects on brain development. Studies on heavy metals in ecosystems undertaken elsewhere (Zhuang et al. 2009; Keller 2002; McLaren et al. 2004) indicated that many areas near urban districts, industries and major road systems contain anomalously high concentrations of some toxic heavy metals. Residential activities such as cottage industries have also been reported to contribute to heavy metal levels of soil (Teare et al. 2015). Therefore, it is important to study the residential soils of the study sites (21.6 km apart) and the health symptoms of the study population in the city of Port Elizabeth.

Port Elizabeth is an appropriate city for an investigation into heavy metals in the Eastern Cape Province of South Africa, as there is limited empirical research reported in the literature due to its status as a coastal, industrial city. The proposed study, therefore, seeks to begin to fill this gap by researching the distribution and associated health risks of heavy metals in soils in Wells Estate and Walmer Township (study sites). Interestingly, the chosen study sites provide diverse socio demographic information such as age, education level, sex, and socioeconomic status (confounding factors) that may influence health symptoms caused by heavy metals (Caussy 2003). This knowledge may be used for monitoring environmental quality, hence improving local environmental health.

1.4 Research Problem

Heavy metal contamination of soil has become a worldwide problem in the 21st century. Modern society has now become increasingly concerned by environmental and health issues related to heavy metal pollution leading to the introduction of recommended heavy metal levels in soil by protection agencies (United States, South Africa and European Protection Agency). Studies have also proven that heavy metal causes a series of health problems such as gastrointestinal disorders, diarrhoea, haemorrhage, arthritis, diabetes, anaemia, cardiovascular disease, cirrhosis, bronchiolitis, emphysema, alveolitis, reduced fertility, kidney dysfunction, hypertension, headaches and even cancer (Khan et al. 2013; Kamunda, Mathuthu & Madhuku 2016).

Therefore, it was important to investigate the heavy metal distribution and related health risk status as they may show the relationship between anthropogenic activities and soil heavy metal levels in the study population. In order to achieve this a cross-sectional study has been employed to study the association of heavy metals with surveyed health symptoms.

1.5 Research Aim and Objectives

1.5.1 Aim

This research aims to determine the level and distribution of selected heavy metals (lead, arsenic, manganese, mercury, and cadmium) in the residential soil of Wells Estate and Walmer Township. It further aims to investigate the association of heavy metals with surveyed health symptoms.

1.5.2 Objectives

In order to meet the above-mentioned aims, the following objectives were met:

1. To determine the levels of heavy metal concentrations of lead, arsenic, manganese, mercury, and cadmium in samples of soil collected from residential gardens of Wells Estate and Walmer Township.
2. To compare soil metal concentrations in the two study sites (Wells Estate and Walmer Township).
3. To assess if the sites are deemed contaminated on the basis of existing standard levels, such as the United States Environmental Protection Agency (United States Environmental Protection Agency 2002; Gorospe 2012; He, Yang & Stofella 2015), the South African heavy metal limits and the European soil guideline values for soils.
4. To determine if there is an association between residential soil heavy metal concentrations and the surveyed health outcomes in Walmer Township and Wells Estate. Surveyed health symptoms at various dwelling sites include coughing, fever, chest pains, earache, sore throat, headaches, rapid breathing, sneezing, running /blocked nose, teary watery eyes, cancer, hypertension, heart diseases and mental illness.

1.6 Hypotheses

I. Heavy metal concentration will vary between study site due to variable industrial and cottage industries. This may be as a result of heterogeneous cottage industries at each site.

II. Dwellings with or around high-risk cottage/industrial industries will have high heavy metal levels and low risk industrial/cottage industries will have low heavy metal levels.

III. There is no significant relationship between the surveyed health effects and residential heavy metal concentrations (null hypothesis).

1.7 Significance of the study

Heavy metals such as lead, arsenic, manganese, mercury, and cadmium rank among the priority metals that are of public health significance due to their high degree of toxicity, especially in neurodevelopmental health outcomes mostly in vulnerable groups such as children as they spend most of their time playing in and around residential soil.

The analytical results from this study will provide important baseline data on the levels of selected heavy metal concentrations in the residential soils of Wells Estate and Walmer Township. Results obtained from this study will provide scientific data to the health authorities, municipal departments and environmental protection agencies.

Chapter 2

LITERATURE REVIEW

This chapter gives an overview of selected heavy metals. This section further discusses various sources of selected heavy metals, their environmental transportation, bioaccumulation and concentration, exposure pathways, health effects of human exposure to heavy metals, vulnerable groups, and public health protection mechanisms.

2.1 Sources of heavy metals

Heavy metals are usually found in the earth's crust at relatively low concentration levels (Obodai et al. 2011; United State Department of Agriculture and Natural Resources Conservation Services 2000). Studies have shown that metal concentration levels differ with locations, and this is probably due to natural factors such as rock weathering and volcanic effect. Despite the natural occurrence of heavy metals, some natural elements such as lead, arsenic, mercury, and cadmium are listed among the ten chemicals of major public concern by the World Health Organization (WHO) for their potential to be carcinogenic and inflict acute organ damage (Tchounwou et al. 2012).

D'amore et al. (2005, p.1707) reported that heavy metals essentially become pollutants in the soil environments because: "(i) their rates of generation through man-made cycles are more rapid relative to natural ones, (ii) they become transferred from industrial zones to random environmental locations where higher potentials of direct exposure occur, (iii) the concentrations of the metals in discarded products are relatively high compared to those in the receiving environment, and (iv) the chemical form (species) in which a metal is found in the receiving environmental system may render it more bioavailable."

Over the years, concentration levels of heavy metals in soil samples have increased above the natural levels in most cities due to increased anthropogenic activities. Some of the activities as well as sources that have led to an increase in heavy metal concentration levels in the environment include industrial production and use, agricultural use of metals and metal-containing compounds, pharmaceutical use of metals and metal-containing compounds, metal corrosion, atmospheric deposition, soil erosion of metal ions and leaching of heavy metals, sediment re-suspension and metal evaporation from water resources to soil and ground water, (Tchounwou et al. 2012; Thornton 1981; He et al. 2005; Ene, Bosneaga & Georgescu 2009; Obodai et al. 2011; Fergusson 1990; Bradl 2005; USDA & NRCS 2000; Wei & Yang 2010; Varalakshmi & Ganeshamurthy 2010).

Industrial sources of heavy metal include metal processing in refineries, coal burning in coal power plants (such as ESKOM power plant), burning of plastics, textiles printing, metal purification, precious metal mining, microelectronics, use of wood preservation chemicals, cement and paper processing plants (Arruti, Fernández-Olmo & Irabien 2010; Pacyna 1996; Ene, Bosneaga & Georgescu 2010; Yildiz et al. 2010; Nassef et al. 2006; Dávila, Gómez-Bernal & Ruíz-Huerta 2012; Obodai et al. 2011; Suciu et al. 2008).

Solid waste also contributes to soil pollution through the solid wastes to soils pathway, and industrial solid waste constitutes the main source of heavy metal. When these wastes are being piled, heavy metals are leached out of the solid waste over time through several processes: the most dominant process known is through rainfall and it results in washing off heavy metals from waste piles (Ding 2000). Solid wastes such as municipal wastewater, sewage sludge, mining waste and mineral ore, heavy metal processing and smelting wastes all contribute to a major source of lead, arsenic and manganese pollution (Piscator 1979b; Hronec et al. 2010).

The use of fertilizers and pesticide application on farmlands mainly constitutes agricultural use (El-Bouraie et al. 2010; Ene, Bosneaga & Georgescu 2009). Irrigation systems in farmlands that employed metal containing pesticides and fungicides contribute to the transportation of heavy metals from the polluted soil to the non-polluted soil through metal ion transportation as the metals are known to be soluble in water. This therefore leads to the deposition of heavy metals such as mercury, cadmium, lead, and chromium into unpolluted soil. Dead and decomposing vegetation and organic matter also give rise to heavy metals. Heavy metals obtained from these groups are also transported to other soil via several means (Obodai et al. 2011; Wufem 2009).

2.1.1 Lead

Lead is a naturally occurring bluish-grey metal present in small amounts in the earth's crust. Natural levels of lead in soil range from 7 to 20 mg/kg (Environmental Protection Agency 2017; Holmgren et al. 1993).

The deposition of fine lead particles to city centres from industrial waste sites occur through the transportation of generated lead aerosols by the wind. Smelting industries are known to operate at relatively high temperatures hence vaporising heavy metals such as arsenic, cadmium, and lead. These metals are converted to oxides at high temperatures in the presence of air followed by their release into the atmosphere and finally condensing the oxides to fine particulates which are deposited onto the earth's crust (Smith, Means & Chen 1995; US EPA 1997). To further support the above fact, industrial factories such as copper production plants, sulphuric acid plants, paint factory and chemical plants were reported to be the primary sources of lead pollution in the central city of Sweden in 1998 (Lin 1998). Automobile transportation and automotive industries are two major sources of heavy metal contamination. Heavy metals such as lead is released into the atmosphere and residential soils through automotive transport (Thornton 1981; Falahi-Ardakani 1984). Though the use of leaded gasoline has been phased out in most of the world more recently, however, the deposited lead in the environment remains and is not bio-degradable. Before the ban of leaded gasoline, studies showed that exhaust from a vehicle contained lead up to 20 ~ 50 µg/L depending on the car traffic volume (Smith, Means & Chen 1995; US EPA 1997). Vehicle tyres produce tyre dust (dark soot around the car rim) during use due to wearing, this dust contains heavy metals which are found in the original tyre as reinforcement during manufacture and are deposited on the earth surface.

Basically, there are two major industrial sources of lead contamination: 1) lead-based paint where contamination may occur when paint chips from old buildings mix with the soil; and, 2) lead from auto emissions. Studies conducted in urban areas, have shown that soil lead levels are highest around building foundations and within a few feet of busy streets (Rolfe, Haney & Reinbold 1977; Singer & Hanson 1969). Although lead is not presently used to any great extent in paint and gasoline, once lead has been deposited it moves very slowly through the soil and can persist for a long time. There is inadequate information on the impact of non-point sources such as emissions from leaded aviation fuel and exposure from small scale, unregulated cottage industries, such as battery-recycling, craft making, and electronic waste recovery (World Health Organization 2010a).

Heavy metals such as zinc, manganese, copper, lead, mercury, cadmium and arsenic are of industrial and economic importance and are utilized as raw materials in the manufacturing of several chemical based products. Some specific uses and forms of lead includes

Lead from coal-burning electric power plants, paints, plumbing and incinerators (Okunola, Uzairu & Ndukwe 2007) are transported in ionic form. Lead (II) oxides and hydroxides are the general forms of lead found in soil and surface waters. Lead forms several basic salts, such as $Pb(OH)_2$- $2PbCO_3$ in an alkaline medium; this was once the most widely employed white paint pigment which has now been banned for use around the world. To summarise, lead exists in an aqueous polar state thus offering a greater affinity for sandy soil, which is known to be mostly polar in nature, with a limited amount of organic components. It could be concluded that lead binds more to soils with polar organic matter than soil which contains non-polar organic matter (Kirmani et al. 2011). Lead is largely produced industrially in large quantities to produce lead-acid batteries, ammunition, leaded metal products such as lead pipes, lead oxides for paint, lead coated glass, pigments and devices (sheet lead) to shield X-rays (Gabby 2003, 2006).

2.1.2 Arsenic

Arsenic is a heavy metal that exists in nature and mostly in two states, inorganic and organic forms: methylarsinic acid $(CH_3)AsO_2H_2$ and dimethylarsinic acid $(CH_3)_2AsO_2H$ are known to be the most predominant organic forms of arsenic. Arsenic is an element that has raised a lot of concerns due to its toxic effect when it is accumulated by humans. In aerobic environments, arsenic exists in the form of arsenate (AsO_4^{3-}). Arsenic oxides, when reduced to As (III) could also exist as arsenite (AsO_3^{3-}) (Sarubbo et al. 2015). Arsenite(AsO_3^{3-}) is absorbed easily into sulphur-containing compounds as well as naturally occurring metal sulphides found in soils which are easily leached out of the soil and transported to groundwater and surface water (Sarubbo et al. 2015). Most soil samples contain a relatively low concentration of arsenic compared with other heavy metals (Agency for Toxic Substances and Disease Registry 2000; Tchounwou et al. 2012). Natural levels of arsenic in soil usually range from 1 to 40 mg/kg (Tchounwou et al. 2012). The level of arsenic in the earth's crust is very little being in the range 0.001 to 0.02 mg/kg (Kabata-Pendias & Mukherjee 2007).

Arsenic is mostly utilized to produce agricultural based products such as insecticides, herbicides and fungicides. Arsenic is also used in the production of wood preservatives and dyes. In the field of medicine, arsenic-based drugs are used for the treatment of tropical diseases such as African sleeping sickness and in amoebic dysentery drugs, and in veterinary medicine (some medicinal uses are currently being reviewed), it is also used to treat parasitic diseases.

2.1.3 Manganese

Manganese is considered to be the 12th most abundant element in the biosphere (Howe, Malcolm & Dobson 2004). It occurs naturally in more than 100 minerals including various sulphides, oxides, carbonates, silicates, phosphates, and borates with background levels in soil ranging from 40 to 900 mg/kg, with an estimated mean background concentration of 330 mg/kg (Barceloux 1999).

Manganese forms several salts, such as manganese sulphate and manganese oxides when combusted (Pearson & Greenway 2005). The salts are reported to dissolve easily in soils hence facilitating their transportation within the ecosystem. However, manganese in its inorganic salt form is manufactured and used as an anti-knock agent for vehicle fuel. An example is methylcyclopentadienyl manganese tricarbonyl (MMT) used in vehicle engines and exhaust gas recirculation (EGR) systems for lowering oxides of nitrogen (NOx) emissions from a diesel engine (Majestic et al. 2007). Automobile exhaust contains manganese in an inorganic form such as manganese phosphate and manganese sulphate, and this leads to the release of gaseous manganese (manganese oxides such as manganese tetroxide) to the environment through the vehicle's exhaust during use (Waldron 1980). Thus, vehicles are mostly responsible for atmospheric manganese (Waldron 1980). Several researchers have confirmed this occurrence, in 1998, Sierra et al. (1998) attributed the high concentration levels of manganese in areas/cities with high traffic density to the combustion of methylcyclopentadienyl manganese tricarbonyl in vehicles (Sierra et al. 1998; Manta et al. 2002; Markus & McBratney 1996; Zhang 2006).

Manganese-containing waste has also been a major source of manganese releases into the environment as the waste can be transported to other areas by wind (Howe, Malcolm & Dobson 2004). It is also used for rust and corrosion prevention on steel. Minor contributors of manganese to the environment include manganese welding during vehicle exhaust production and the application of fungicides containing manganese.

2.1.4 Mercury

The mercury level in the Earth's crust is very low being in the range 0.02 to 0.06 mg/kg (Kabata-Pendias & Mukherjee 2007). It is also a heavy metal that exists in nature and in three states, such as elemental (metallic form), inorganic, and organic (solid or liquid form). Each state of arsenic presents a variable level of toxicity (Clarkson, Magos & Myers 2003). Zalups & James (2000) reported that elemental mercury exists as a liquid at room temperature, hence can be released into the environment as mercury vapour.

Coal-fired plants and metal ore processing stations are known to release large quantities of mercury into the environment (Smith, Means & Chen 1995). Mercury is also released into the environment from manometers at laboratories and pressure measuring stations in oil refinery pipelines. In most laboratories, the release of mercury occurs through breakage of thermometers, while in the industrial pressure systems release may occur at higher temperatures. Mercury usually exists as mercurous sulphate (inorganic salt) or alkylated mercury (organomercury compounds) when found in soil. Mercury's existence in various species (form) is determined by the redox potential and pH (acidity and alkalinity conditions). An alkylated form of mercury is the most toxic form of mercury. This form of mercury is known to possess high solubility and volatility in aqueous systems and air respectively (Smith, Means & Chen 1995). Mercury (II) is the most soluble species of mercury, and it forms strong complexes with several inorganic and organic ligands, thus, making it very soluble in oxidised aquatic and soil systems. It is by far one of the most lethal heavy metals in elemental form on the earth's crust.

In the middle and late 1800s, mercury was used as a medicine to treat various diseases, such as syphilis and typhoid fever or parasites: the use of mercury for medicinal purposes has been abandoned. Due to its toxicity, many uses of mercury such as thermostats, dental amalgams (Dental amalgam 2017), and battery production are being phased out or are under review. Mercury is now mainly used in the chemical industry as catalysts. It is also used in some electrical switches and rectifiers. Some other industrial applications of mercury include antifungal agents for wood processing, and as a preservative for some pharmaceutical products (Tchounwou et al. 2003).

2.1.5 Cadmium

Cadmium is mostly found in sedimentary rocks, and marine phosphates (IPCS 1992; Sodhi 2009). A study conducted by a group of experts in 1987 discovered that the highest amount of cadmium in a typical natural environment is approximately 15 mg/kg (Gesamp 1987).

Generally, cadmium is mostly utilized in battery and alloy production industries (Wilson 1988). It is also used as an anti-corrosion resistance agent for vessels, aerospace and vehicle coatings. Gradual leaching of cadmium from this equipment through acid rain has led to the mobility of metal to the soil and underground water (Campbell 2007). The application of cadmium to produce agricultural based products such as insecticides, herbicides and fungicides and its use on the farm has led to an increase in the increase in the total concentration of cadmium in soils (Weggler, McLaughylin & Graham 2004; Li et al. 2010).

Some of the sources of heavy metals in the world, and the main sources are subdivided into agricultural and industrial sources as shown in Table 2.1.

Table 2.1: Sources of selected heavy metals polluting soils in the world (1000t.a^{-1}) (Adapted from Nriagu & Pacyna 1988)

Sources	Arsenic	Cadmium	Mercury	Lead
Agricultural and food waste	0~0.6	0~0.3	0~1.5	1.5~2.7
Farmyard manure	1.2~4.4	0.2~1.2	0~0.2	3.2~20
Logging and timber	0~3.3	0~2.2	0~2.2	6.6~8.2
Industrial Wastes				
Municipal Wastes	0.09~0.7	0.88~7.5	0~0.26	18~62
Municipal sludge	0.01~0.24	0.02~0.34	0.01~0.8	5.0~22
Organic Wastes	0~0.25	0~0.01	-	0.02~1.6
Metal processing	0.01~0.21	0~0.08	0~0.08	4.1~11
Solid Wastes				
Coal Ash	6.7~37	1.5~13	0.37~4.8	45~242
Fertilizer	0~0.02	0.03~0.25	-	0.42~2.3
Marl	0.04~0.5	0~0.11	0~0.02	0.45~2.6
Commodity	36~41	0.78~1.6	0.55~0.82	195~390
Impurities				
Atmospheric deposition	8.4~18	2.2~8.4	0.63~4.3	202~263
Total	52~112	5.6~38	106~544	479~1113

Source: Nriagu & Pacyna 1988.

Heavy metals can be found in the air, dust, soil, and water, as well as inside homes and metals in various consumer goods. These chemicals can be found in the air with concentrations peaking near industrial/metal processing sites and waste incinerators. It is widely known that the transportation of heavy metals in soil depends greatly on the chemical state and speciation of the metals. Metals can travel long distances before settling to the ground and sticking to soil particles. These can then be re-suspended into the air, seep into the groundwater, or be absorbed by vegetation.

2.2 Environmental transportation

There is now considerable interest in the area of heavy metal transport because of the implications for soil contamination. However, the transport processes for heavy metals across soil at the molecular level is still rudimentary in most cases (Adelekan & Abegunde 2011; Aderinola et al. 2009; Bhagure & Mirgane 2011; Ene, Bosneaga & Georgescu 2009; Obodai et al. 2011; Meshalkina 1996). Similarly, a Ground-Water Remediation Technologies company which focuses on heavy metal remediation and treatment indicated that “heavy metal form influence transport mechanisms, concentration, and distribution of metal contaminants found in soil" (Evanko & Dzombak 1997). Therefore, it is necessary to understand the various chemical forms of heavy metals in soil at molecular levels. Once a metal is in the soil, it adsorbs steadily, and usually occurs in several chemical forms which influence bioavailability, mobility, and toxicity within the soil (Shiowatana et al. 2001; Majestic, Schauer & Shafer 2007).

A comprehensive understanding of heavy metal transport in soil indicated that metal chemical forms are influenced by four factors: (i) mineral ore dissolution through pH effects; acid brines are mostly employed by industries for ore processing and leaching; (ii) ion exchange, adsorption, and desorption, through shifting the reduction-oxidation potential conditions after the deposition of solutions containing several species of heavy metal in their ionic form;

(iii) increasing existence of complexing agents for heavy metals contribute to the number of soluble metal complexes as well as trace metals found in the earth’s crust, these metals are absorbed by porous solid matter, (iv) oxidation of metal sulphide (heavy metals) and biomethylation organometallic complexes are catalysed by microbes and biomolecules, (v) salting effect increases the concentration of heavy metals onto solid surfaces, hence increasing its sorption properties on solid surfaces. The possible formation of soluble chloro-complexes of trace metals gives rise to this effect, and (vi) plant uptake (Levy et al. 1992).

Generally, once heavy metals get into the soil and water system, they are easily taken up and accumulate in living tissues of humans after exposure. Such forms of accumulation occur when humans eat produce containing high heavy metal concentrations, and these metals can build up to large concentrations therefore putting human health at risk because of the inability to metabolise the heavy metals (Buekers 2007).

2.3 Bioaccumulation and bioconcentrations

Bioaccumulation is a general term applied when there is a net accumulation of a chemical (organic and/or inorganic) by humans when in contact with these chemicals through different routes of exposure (Oregon Department of Environmental Quality 2007).

Heavy metals are easily leached from sediment fractions due to weak interactions holding the metals to the sediments; when in solution metals became mobile and are transported to different areas within the soil at different rates. The rate of remobilisation of heavy metals within the soil is determined by several environmental factors (Fergusson 1990; Connell et al. 1999). These factors are classified as (i) geographical factors and (ii) chemical factors, and some examples include organic carbon, water hardness, temperature, pH, dissolved oxygen and sediment grain size (Sharaky, Salem & Aal 2016).

The degree of bioaccumulation of heavy metals in the ecosystem is dependent on several factors, and these are (i) the total amount of heavy metals bioavailable in the biota (biological environment), (ii) route of heavy metal uptake (such as oral, dermal and inhalation), (iii) heavy metal storage, and (v) heavy metal excretion mechanisms. Generally, for heavy metals to bioaccumulate, in living organisms, the metal must be bioavailable. Bioavailability is generally used to describe the extent and rate of absorption of a toxic substance that enters the systemic circulation in the unaltered form from the exposure site. This concept is more complex as some metals may not be available in its parent form (oxidation state zero), but after metabolism may be converted into a form that can enter the systemic circulation. Bioavailability of trace heavy metals is also controlled by geographical, biological and chemical factors (Morse et al. 1993; Morse & Rowe 1999; Chaturvedi et al. 2015). Biological factors control the degree of bioaccumulation in the biological system as several metals prefer certain biological environments. Chemical and geological factors have been mentioned earlier.

The term bioaccumulation also includes bio-concentration, which is the net accumulation of a chemical directly from the living environment by an organism (and human). Bishop & Maki (1980) presented bio-concentration as a measure of the potential of a chemical to accumulate in the tissues of aquatic organisms. An example is the bioaccumulation of mercury as an organomercury compound (methylmercury); the transformation of this metal, mercury, to a methylated compound is achieved by some bacteria found in fish (Bishop & Maki 1980; Hrudey, Chen & Rousseaux 1996; Berlin 1979a).

Plants are the foundation of our food chain, and given heavy metal acute toxicity and resistance to decay, even the smallest concentration of heavy metal uptake is cause for concern. Food continues to be the major source of heavy metal exposure despite metal's slow downward mobility in soil and low absorption rate by plant roots. Heavy metal content of plants is largely attributed to atmospheric deposition. Several studies by Ebbs, Talbott & Sankaran (2006); Grant et al. (1998); Pillay & Jonnalagadda (2007); and Nagajyoti, Lee & Sreekanth (2010) have shown that various crops accumulate heavy metals in plant tissues. Heavy metals accumulate in roots, shoots, leaves, and fruits of crops. Golia, Dimirkou & Mitsois (2008) reported that potatoes and lettuce accumulated cadmium at slightly higher rates than tomatoes. The rate of adsorption of several heavy metals into vegetable matter varies with the metal: cadmium and zinc from the soil is absorbed at higher rates than lead into carrots than into squash and beans (Sipter et al. 2008).

Finster, Gray & Binns (2004) reported a similar study, and they observed that cadmium accumulates in roots more than in shoots, leaves, and fruit of many crops. The variable rate of absorption is dependent on the chemical and biological environment of the various branches of the plant. An increase in pH condition was found to decrease the rate of adsorption of cadmium in plants. This further demonstrates the relationship between the geological factor and chemical factor as soil characteristics (geological factor) such as soil types and chemical factors such as soil pH, influence the rate of heavy metal absorption (Grant et al. 1998). Golia, Dimirkou & Mitsois (2008) also observed a negative rate of absorption as soil pH decreases for cadmium, chromium, lead, and nickel. A similar study was also compiled by Madejon et al. (2009), where a negative correlation of heavy metal, namely cadmium, copper and zinc were observed with soil pH: this also affects the level of bioavailability of the studied metal in soil samples. Gorospe (2012) also reported that the amount of heavy metal present in soil could be absorbed equally by plants or animals in the environment based on several physicochemical properties such as soil type, heavy metal concentration, and pH. Therefore, it was concluded that the soil heavy metals are potentially bioavailable for plants and animals. The level of heavy metal concentration in the environment has also influenced its concentration levels in human and biological systems, Ray, McLeese & Peterson (1981) followed up this study and observed that the concentration of heavy metals, namely copper, zinc, cadmium, and lead, accumulated by marine invertebrates in polluted estuarine sediments, was three times higher than the normal levels found in similar vertebrates in less polluted environments.

In humans, nutritional diet also influences the rate at which heavy metals are absorbed into the body. Studies have shown that diets deficient in iron (Mahaffey 1990) and calcium (Farias et al. 1996; Hernandez-Avila et al. 1996) have resulted in elevated blood lead levels. This is somewhat due to the chemistry of metals in the human blood. High lead concentration (with an oxidation state of +2) could easily displace other metals with a similar oxidation state and in a lower concentration due to its stronger binding effect. Intawongse & Dean (2006) demonstrated that the human gastrointestinal tract absorbs between 45 and 62% of cadmium, copper and zinc from vegetables. Therefore, the subsequent remobilisation of these metals from soil and their transfer to the food web can impact communities, as well as their sources of livelihood.

Due to environmental and health concerns across the world, it is important to monitor and assess the level of heavy metal bioaccumulation both on aquatic life and biological systems. From the discussion, it has been shown that metallic chemical elements are non-degradable and persist for a long time in the environment. They are also bioaccumulative in living cells of biological systems, and can be transported from one place to another over a long period. Hence, understanding bioaccumulation and its relationship to the pathway of heavy metal exposure in the human population is very important.

2.4 Pathways of human exposure

Human exposure to heavy metal takes place through several pathways and they are: (i) contact with soil, by means of ingestion (hand to mouth), (ii) eating crops that have heavy metals in them or on their surfaces and (iii) inhalation, heavy metals such as lead mainly enter the human body through the digestive tract and respiratory tract, and then enter the circulatory system in the form of soluble salts, protein complexes or ions. Heavy metal exposure could also take place in children’s playgrounds, from industrial and municipal waters, and food services (Calderon et al. 2003). Traditional crafts like lead-tainted ceramics, homemade cosmetics, and herbal medicine can be routes of exposure.

2.4.1 Geophagia

Soil eating (geophagia) is most common in children under three years of age. They are very likely to eat soil while playing outdoors; and they are therefore thought to be at the highest risk from contaminated soil. Sand attached to the surface of food (e.g. unwashed fruits and vegetables) may be ingested unintentionally by adults and children. Eating soil has become a widespread practice throughout the world: it is mostly common in Haiti and some parts of Africa, especially in South Africa and neighbouring countries: adults, especially pregnant and lactating women deliberately eat soil for several personal and cultural reasons. Children are known to ingest more soil through intentional and unintentional means by putting soil-stained hands and objects into their mouths (Tchounwou et al. 1999).

2.4.2 Inhalation and dermal contact

Heavy metals released into the atmosphere in gaseous oxide form are inhaled by humans (most especially by those around the site). Farm employees and construction labourers are regularly susceptible to this form of heavy metal exposure. Lower concentrations of heavy metals are absorbed through inhalation than via other heavy metal exposure routes.

Trace amounts of heavy metals such as arsenic, cadmium and lead are usually found in vegetable crops such as potatoes, grains, seeds, and aquatic animals such as crustaceans and molluscs and mammal organs such as liver and kidneys, and are known to bio accumulate in humans after consumption thus increasing heavy metal concentration in human bodies (Satarug et al. 2003). Flora, Flora & Saxena (2006) reported that the various human body parts take up a different amount of heavy metals. Adsorption pathways of some heavy metals of interest are described below.

Exposure to lead is predominantly through direct ingestion (eating) of contaminated soil or dust. Studies have shown that lead does not readily accumulate in the fruiting parts of vegetable and fruit crops (e.g., corn, beans, squash, tomatoes, strawberries, apples). Higher concentrations are more likely to be found in leafy vegetables (e.g. lettuce) and on the surface of root crops (e.g. carrots). Since plants do not take up large quantities of soil lead, the lead levels in soil considered safe for plants will be much higher than soil lead levels where eating of soil is a concern. It has been reported that adults absorb 35 to 50% of lead through drinking water from leaded pipes, while children absorb a much greater percent due to their high adsorption rate (ATSDR 1992; ATSDR 1999).

Human exposure to arsenic takes place through the various exposure pathways such as an oral route (ingestion), inhalation and dermal contact (ATSDR 2000; Tchounwou et al. 1999; NRCC 1978). As mentioned earlier, arsenic in its organic form is usually released to the environment in varying quantities. In non-industrialized or less populated areas, arsenic concentrations in the air range from 1 to 3 ng/m^3, while a much higher concentration that ranges from 20 to 100 ng/m^3 in industrialised environments is observed due to human activities. This concentration level of arsenic is nontoxic to humans. An interesting twist to this is that soil arsenic levels, especially farm soil samples, are usually in the range of 1 to 40 mg/kg, which is quite high, and it is believed to be so due to the use of arsenic-containing pesticides and fungicides (Tchounwou et al. 2004). The high arsenic concentrations in soil, in turn, contribute to the concentration of the crops, typically, food crop concentration levels range from 20 to 140 ng/kg (Morton & Dunnette 1994).

Mercury exposure usually takes place through food contamination, dental care, preventive medical practices, industrial and agricultural operations, and occupational operations (Sarkar 2005). The use of dental amalgams for tooth fillings as well as the consumption of mercury-contaminated fish have been reported as the major sources of chronic mercury exposure.

Mercury is usually alkylated by algae and bacteria found in water, this makes it easy for organo-mercury (methylmercury) to enter the food chain such as in fish, shellfish, and eventually into humans (Sanfeliu et al. 2003).

These heavy metals may interfere metabolically with nutritionally essential metals such as iron, calcium, copper, and zinc (Lopez Alonso et al. 2004; Abdulla & Chmielnicka 1989). Hence, there is a need to assess the impacts of heavy metals' pollution on the health and well-being of the population, especially vulnerable groups (children and adults) living in Walmer Township and Wells Estate, Port Elizabeth.

2.5 Heavy metal health effects

Heavy metals are essential to the human body (in minute quantities), playing a role in protein structure, enzyme catalysis, osmotic balance, and transport processes. However, the heavy metals in higher concentrations are non-biodegradable and bio magnify in living cells. Their toxicity and tendency to accumulate in biological systems make them a significant health hazard. At high concentrations, metals are said to be toxic to marine and terrestrial organisms. They affect body organs and systems negatively, some parts affected include kidneys, liver, reproductive system, nervous system, urinary system. Heavy metals lower the body's immune system and affect the basic physiological processes that takes place in cells and genes (Aderinola et al. 2009; Bhagure & Mirgane 2010; Obodai et al. 2011; Adelekan & Abegunde 2011; USDA & NRCS 2000; Yildiz et al. 2010). An overview of target-organ toxicity of some selected metals of interest is presented in Table 2.2.

Table 2.2: An overview of target-organ toxicity of some selected heavy metals

	TARGET ORGAN SYSTEM													
	Reproductive system	Renal system	Nervous system	Liver	Gastrointestinal tract	Respiratory system	Haematopoietic	Bones	Endocrine system	Muscle system	Eye	Skin	Immune system	Cardiovascular System
As	×	×	×	×	×	×	×		×	×	×	×	×	
Cd		×	×	×	×	×	×	×					×	×
Pb	×	×	×	×	×		×	×					×	×
Mn	×		×			×								
Hg	×	×	×		×	×						×	×	×

As=arsenic; Cd=cadmium; Pb=lead; Mn=Manganese and Hg=Mercury.
Adapted from Bhattacharya, Nordqvist & Jacks 1996 and Chang, Magos & Suzuki 1996

According to Table 2.2, when selected heavy metals bioaccumulate in the body organs and systems of humans, at high concentrations above the permissible levels, they tend to affect the human system.

2.5.1 Lead

Lead exposure mostly occurs in developing regions, and it also accounts for about 1% of the world's disease (Fewtrell et al. 2004). Lead exposure is classified in two ways: acute and chronic lead poisoning. Acute toxicity is indicative of severe short-term exposure, whereas chronic toxicity describes repeated exposure, often at lower levels. Acute lead exposure is relevant to disease burden in children because their brain and nervous systems can absorb four to five times as much lead as adults (World Health Organization 2017b; Flora, Flora & Saxena 2006).

Lead exposure is associated with increased specific childhood internalising behaviours such as anxiety and social problems. Several authors have reported that children exposed to lead, especially those under the age of six, are susceptible to having lower IQs, impaired mental development, shortened attention duration, hyperactivity, and mental deterioration (Needleman et al. 1990; Bellinger et al. 1992; Qin, Zhao & Liu 2008). Lead exposure in adults results in loss of memory, nausea, insomnia, and weakness of body joints (NSC 2009; Lustberg & Silbergeld 2002; Weisskopf et al. 2004; ATSDR 2007). Lead is also associated with hypertension (Navas-Acien et al. 2007) and peripheral vascular disease in adults (Navas-Acien et al. 2004). Exposure to lead is of special concern among women, particularly during pregnancy.

Lead absorbed by a pregnant mother is readily transported to the developing foetus, and it results in a birth weight loss as well as neuro-developmental abnormalities in offspring (Ong et al. 1981; Andrews, Savitz & Hertz-Picciotto 1994; Huel et al. 1992). Lead can potentially impair normal foetal bone growth by competing with calcium for deposition into bone because lead and calcium have similar chemical properties (Potula 2005). It is reported that lead alters tissue levels of many essential elements, including iron, zinc, copper, and calcium (Bhattacharya, Nordqvist & Jacks 1996; Chang, Magos & Suzuki 1996). Biologically, a high level of heavy metal exposure influences brain development (Weiss 2000, Bondy & Campbell 2005). Other effects include the deficiency in cognitive function due to the destruction of the central nervous system (Giddings 1998). A headache, poor attention, irritability, loss of memory and dullness are the early symptoms of the effects of lead exposure on the central nervous system (CDCP 2001). The nervous system is also the most vulnerable target of lead poisoning.

2.5.2 Arsenic

Arsenic is a Group 1 human carcinogen, causing tumours of the lung, liver, bladder, prostate and skin (Garcia-Vargas & Cebrian 1996). Arsenic damages the skin by increasing the risk of skin cancer, and it is also responsible for health-related problems associated with the circulatory system and gastrointestinal tract (Gerber, Leonard & Hantson 2002; Friberg, Nordberg & Vouk 1979). Several studies have associated arsenic to cancer. However, limited evidence still exists in relating arsenic exposure to tumours in humans (Chappell et al. 1997).

Arsenic spreads through the human body through the blood vessels, by binding to the globin of haemoglobin. Less than 5% of absorbed arsenic in humans is retained in the lungs and gastrointestinal tract, however, over 95% of arsenic is transported around the human body. The severity of arsenic pollution is dependent on the dosage in the human system (Tchounwou et al. 2002; Yedjou, Moore & Tchounwou 2006).

2.5.3 Manganese

The toxicity of manganese in humans is rarely observed, however, most toxic exposure is associated with industries responsible for vehicle exhaust manufacturing and manganese welding (Romero, Abbott & Bradbury 1996; Piscator 1979b). Manganese bio accumulates in the brain, especially in the basal ganglia, resulting in an irreversible neurological syndrome similar to Parkinson's disease (Agency for Toxic Substances and Disease Registry 2008; Takeda 2003). This syndrome has been observed with miners, battery manufacture workers and automotive repair workers exposed to manganese (ATSDR 2008; Takeda 2003). High levels of manganese exposure in a male may result in loss of sex drive and sperm damage (Takeda 2003). A recent study conducted in Nigeria indicated that women with the history of miscarriage are reported to have a blood manganese level of >25 mg/dL during pregnancy

(Amadi, Igweze & Orisakwe 2017). Metabolic interference may take the form of displacing iron, calcium, copper and zinc for manganese. Heavy metals have adverse effects on reproduction and development (Wright et al. 2006; Ettinger et al. 2009; Tian et al. 2009; Zota et al. 2009; Manahan 2003).

Several studies that addressed the interaction of heavy metal with human tissues reported that co-exposure to heavy metal mixtures such as arsenic, lead and cadmium have produced more severe health effects in humans, such as pronounced renal damage within a shorter space of time as compared to the health effect observed with individual heavy metal exposure (Wang & Fowler 2008; Nordberg et al. 2005).

2.5.4 Cadmium

Cadmium causes acute ingestion symptoms such as abdominal pain, burning sensation, nausea, vomiting, salivation, muscle cramps, vertigo, shock, loss of consciousness and convulsions upon inhalation or ingestion (Baselt & Cravey 1995; Baselt 2000). It also affects several enzymes in the human body (IPSC 1992). Cadmium has also been reported to reduce the activity of enzymes such as delta-aminolevulinic acid synthetase, arylsulfatase, alcohol dehydrogenase, and lipoamide dehydrogenase (Manahan 2003; Satarug et al. 2003; Satarug et al. 2010; Qin, Wu & Wang 1994). Cadmium usually damages enzymes responsible for reabsorption of proteins in kidney tubules and this results in renal system damage in exposed humans (IPSC 1992; Azimi, Daneshmand & Pardakhti 2006; Adelekan & Abegunde 2011; Asio 2009).

Long-term exposure to low dose cadmium has also been linked with a loss of re-absorptive capacity for nutrients, vitamins and minerals in exposed human (IPCS 1992). Cadmium also displaces zinc in many enzymatic reactions, thus, resulting in disruption of activity, therefore, leading to acute gastroenteritis (Sodhi 2009). The Agency for Toxic Substances Management

Committee listed cadmium as the sixth most toxic chemical (heavy metal) that damages human health when ingested or inhaled (IPSC 1992).

2.5.5 Mercury

Mercury, when consumed or inhaled in large quantities, has been listed by the United States occupational safety and health administration as the most toxic heavy metal that damages human health and immune systems. Organo-mercury vapour is easily inhaled from refinery pressure plants: it penetrates the human body system easily and is detrimental to the nervous, digestive and immune systems. Once absorbed at high concentration levels, mercury can affect virtually every organ and may lead to death. Salts of mercury are also corrosive to the skin, eyes and gastrointestinal tract when ingested (Friberg, Nordberg and Vouk 1979). Severe inhalation of mercury compounds (organic or inorganic) could lead to neurological and behavioural disorders. These neurological and behavioural disorders include tremors, insomnia, memory loss, neuromuscular effects, headaches and cognitive and motor dysfunction.

A brief overview indicates that selected heavy metals at toxic levels in soils can penetrate human organs. High levels of heavy metal in human systems can cause nervous breakdown, miscarriage, premature birth, foetal malformations, and even result in death. Hence, research focusing on the environmental level of exposure of certain groups of the population, such as those living near a major industry is needed. This information is necessary for assessing the need to conduct health studies on these populations. Toxic levels of heavy metals in the blood as reported by Adal & Wiener in 2015 are presented in Table 2.3, the table is not intended to guide clinical decision making.

Table 2.3: Selected heavy metals acute and chronic diseases as well as toxic concentration levels (adapted from Adal &Wiener 2015)

Metal	Acute	Chronic	Toxic Concentration
Arsenic	Nausea, vomiting, "rice-water" diarrhoea, encephalopathy,	Diabetes, hypopigmentation/ hyperkeratosis, cancer: lung, bladder, skin, encephalopathy	24-h urine: ≥50 µg/L urine, or 100 µg/g creatinine
Cadmium	Pneumonitis (oxide fumes)	Proteinuria, lung cancer, osteomalacia	≥15 µg/ g creatinine
Lead	Nausea, vomiting, encephalopathy (headache, seizures, ataxia, obtundation)	Encephalopathy, anaemia, abdominal pain, nephropathy, foot-drop/ wrist-drop	[Pb] >5 µg/dL (blood) (CDC guidelines, 2017)
Manganese	(inhaled)	Parkinson-like syndrome, respiratory, neuropsychiatric	No clear reference standard
Mercury	Elemental (inhaled): fever, vomiting, diarrhoea, ALI; Inorganic salts (ingestion): caustic gastroenteritis	Nausea, metallic taste, gingivostomatitis, tremor, neurasthenia, nephrotic syndrome; hypersensitivity (Pink disease)	Background exposure "normal" limits: 10 µg/L (whole blood); 20 µg/L (24-h urine)

Vulnerable populations such as children and low-income populations absorb higher amounts of heavy metal: once absorbed, metals can affect virtually every organ and remain in bones for decades. Thus, long-term exposure in these groups may cause persistent health problems.

2.6 Vulnerable groups

Vulnerable populations are a set or a group of a population who are unable to cope, resist or recover easily from the impact of heavy metal contamination. Children are more vulnerable as they are unable to recover easily from adverse health effects of soil heavy metal exposure due to their high absorption rate, small body size and their developing nervous system (Maddaloni et al. 1998). Less than 5% of absorbed lead in an adult's body is retained when it is ingested, in the lungs and gastrointestinal tract, however, over 50% of absorbed lead is retained in children due to their less developed gastrointestinal tract and high adsorption rate (Maddaloni et al. 1998). Prior to the ban of lead paint, children living in lead painted homes could achieve blood lead concentrations of above 20 µg/dL and children with blood levels as high as 20 µg/dL have been reported to experience low IQ (Charney, Sayre & Coulter 1980).

In recent times, the use of lead paints, ceramic products, caulking, and pipe solder has reduced significantly (Center for Disease Control 1991). Despite this progress, in New Orleans, United States, 29% of children aged 0.5–5 years had elevated blood lead levels, and in Johannesburg, South Africa, 78% of children aged 6–9 had blood lead levels above the international action level. These elevated levels could be attributed to the re-contamination of children with lead through dust and soil. Children who play on contaminated soil are more susceptible to lead poisoning than children who play on uncontaminated soil (Rabito, Shorter & White 2003; Mathee et al. 2002; Farfel & Chisolm 1991; CDCP 2001; ATSDR 1999).

Due to the toxic effect created by lead, the Center for Disease Control and Prevention (CDCP) established a blood lead level of concern for children with more than 3 µg dL^{-1} (CDCP 2016). Current information from the CDCP website indicated that no safe blood lead level had been found.

Several heavy metal exposure pathways exist for children and they include soil ingestion via hand-to-mouth pathway, where soil is ingested intentionally when playing or through putting dirty hands and objects into their mouths (Thornton et al. 1994; Sheppard & Evenden 1994; Lanphear & Roughmann 1997; Schütz et al. 1997).

A study conducted on 2-year-old children in the United Kingdom by Thornton et al. (1994) revealed that the ingestion of sand and dust by means of hand-to-mouth activity accounted for over 50% of children's lead intake. Li et al. (2001), also reported that the level of soil ingestion (soil heavy metal exposure) is directly proportional to the time spent playing in outdoor soil and playing facilities. In order words, soil heavy metal exposure is dependent on the time spent outside while playing with contaminated soil or dust (Li et al. 2001).

Manganese exposure in children results in undesirable effects such as incomplete brain development, leading to learning difficulties. Extreme exposure levels cause severe symptoms of manganism disease, which results in speech and walking difficulties (Amadi, Igweze & Orisakwe 2017). Socioeconomic factors can be a telling predictor of metal-related threats. Low-income communities often face greater risk due to substandard housing, and residential proximity to polluting industries (World Health Organization 2010a). A study conducted by WHO discovered that lead smelting factories employ the poorest populations in most poverty-stricken countries. These groups are often unaware of the hazards and lack the financial means to receive adequate medical treatment (World Health Organization 2010b). Marginalized communities are therefore most vulnerable and often disproportionately affected by lead poisoning.

Higher concentration levels of heavy metals are released to the urban environment with traffic and industries than their rural counterparts (Thornton 1991). Since heavy metals are non-degradable and can bio accumulate in plants and the human body system, there is a need to protect both the vulnerable of the urban and rural population to maintain a healthy community.

2.7 Soil metal distributions in residential environments

2.7.1 International distributions of soil metals

In the past few years, the study of urban soil heavy metal concentrations has been an important area in environmental health research due to several factors such as the level of soil pollution, industrialisation and town planning. A study by Su (2014) reported heavy metal distribution in agricultural (Table 2.4) and urban (Table 2.5) soil for some industrialised countries such as Iran, China, India, USA and Spain. These metals are deposited into the soil through human and agricultural activities.

According to Table 2.4 the agricultural soil of India presented the lowest concentration of lead (0.95 mg/kg), while the agricultural soil of Spain was reported to have the highest concentration of lead (213.93 mg/kg), thus indicating that fertilisers with a high lead content are employed in most farmlands of Spain. Generally, low concentrations of cadmium were observed in all countries, except for USA (Su 2014).

According to Table 2.5, the urban soil of Spain presented the highest concentration of lead (1505.45 mg/kg): other sampled countries presented lead concentrations which are relatively low. The high lead concentrations observed in the urban soil of Spain are because of a series of anthropogenic activities (Su 2014). Generally, low concentrations of cadmium were observed in all countries, except for the USA (Su 2014). Arsenic and manganese distribution was only reported for Korea (heavy metals in agricultural soil). The observed heavy metal concentrations are above the safety limits.

Table 2.4: The content of heavy metals in agricultural soil (mg/kg)

Country	Lead	Cadmium	Mercury	Arsenic
Beijing	18.48	0.18	-	-
Spain	213.93	1.42	-	-
America	23.00	0.78	-	-
Korea	5.25	0.12	0.05	0.78
Slovakia	139.00	-	-	-
USA	55.00	13.5	-	-
India	0.95	0.82	-	-
Iran	5.17	0.34	-	-

Source: Su 2014

Table 2.5: The content of heavy metals in urban soil (mg/kg)

Country	Lead	Zinc	Nickel	Cadmium
Beijing/China	28.60	65.60	27.80	0.15
Hong Kong	94.60	125.00	12.40	0.62
Syria	17.00	103.00	39.00	-
France	43.14	43.14	14.47	0.53
Spain	1505.45	596.09	-	3.76
Iran	46.59	94.09	37.53	1.53
Turku, Finland	17.00	90.00	24.10	0.17

Source: Su 2014

A study conducted by Clark, Hausladen & Brabander (2008) observed that between 40 and 80% of soil with lead originated from lead-based paint in Germany and some other European nations despite the discontinued use of lead-based paints and leaded gasoline in Europe, as these were phased out in the early 1920s. A confirmatory report showed that the lead levels around homes built before 1920 have the highest overall lead concentrations: average lead levels in Karlsruhe were 160 mg/kg for homes built before 1920 (Clark, Hausladen & Brabander 2008).

However, lead remains in the soil for a long time due to its non-degradable nature and as it is easily transported to surrounding areas and suburbs. The effect of heavy metal transportation has led to an increase in its concentration levels in surrounding residential areas. A study conducted in 2001 indicated that lead levels of 120 mg/kg were present in residential areas much closer to older buildings (lead-painted buildings), 117 mg/kg in high traffic areas (deposited lead from leaded gasoline), and 112 mg/kg in industrial zones (Norra et al. 2001). The levels observed in Karlsruhe, Germany were way above the European background lead level in soils at the time (11.4 mg/kg), thereby confirming the contamination of urban soils.

Williams et al. (2009) reported high concentrations of some heavy metals (such as cadmium, arsenic, and lead) in soils and rice planted near old or currently active ore processing facilities in Hunan, China. The effect of heavy metal bioaccumulation and biomagnification was observed in the urine of the villagers as they were reported to have a high heavy metal concentration in their blood. They reported that thousands of villagers living in the surrounding areas were reported to have high heavy metal concentrations in their blood or urine. The accumulation took place via transportation from the original source to residential homes and farmlands. Heavy metals in polluted soil are also absorbed by crops planted in farmlands (rice husk). These crops are consumed by residents thus leading to the accumulation of these metals in large quantities. Low levels of exposure are usually observed through inhalation.

Similar exposure pathways were also reported in garden soil of Pueblo, Colorado (Diawara et al. 2006). The presence of ore smelting facilities resulted in elevated lead levels of the residential soil of low-income Hispanic and African Americans living in the neighbourhood (Diawara et al. 2006). In another study, cadmium was found in food crops, and it was linked to cadmium polluted soil were the food crop was planted as well as other secondary sources such as exposure of food crops to smoking areas, where the air is contaminated (Clemens 2006; Li et al. 2001).

Tóth et al. (2016) investigated over 23,000 topsoil samples from the land of the European Union (EU) in 2009 and 2012 within the frame of the Land Use/Land Cover Area Frame Survey (LUCAS). Based on the observed results, heavy metals (arsenic, cadmium, chromium, copper, mercury, lead, zinc, cobalt and nickel) in the topsoil of the European Union were found to be present in variable amounts, with minimum concentrations below the mandated European levels. An overview of some of the heavy metal concentrations, ranges and mean value is presented in Table 2.6. A large proportion of the soils, with industrial and mining activities, show elevated concentrations (most especially for arsenic, cadmium, lead, and mercury).

Table 2.6: Heavy metal concentrations in the topsoil of the European Union

	Concentration (mg/kg)			
Heavy metals	**Minimum**	**Maximum**	**Mean**	**Std. deviation**
Cadmium	0.02	3.17	0.09	0.11
Arsenic	0.46	252.53	3.72	2.92
Lead	1.63	151.12	15.3	8.33
Manganese	9.62	2285.23	373.05	237.68
Mercury	0	1.59	0.04	0.04

Source: Tóth et al. 2016

2.7.2 Africa/South Africa

In Africa, there is a growing call for proper protection of the environment despite rapid economic development through industrialisation (Akiwumi & Butler 2008; Norman et al. 2007; Rashad & Barsoum 2006; Osibote & Rabiu, 2016). Polluting industrial activities like non-regulated lead-acid battery recycling, metal mining, and fossil fuel production tend to concentrate in developing countries where existing regulatory oversight may be insufficient. A recent study conducted in eastern Nigeria indicated that the concentration of lead was slightly elevated due to past emissions from vehicles (leaded gasoline), waste disposal from automobile repair shops and the indiscriminate dumping of solid industrial wastes (Osibote & Rabiu 2016). South Africa, a hotspot for mining and agricultural in Africa, has observed increased soil pollution due to the increased industrial activities over the years (Crafford & Avenant-Oldewage 2010; Gordon & Muller 2010; Gemmell & Schmidt 2013; Olaniran, Naicker & Pillay 2014; Okoro & Fatoki 2012). As such, South Africa produces large amounts of agricultural and solid mine waste containing high concentrations of heavy metals and covering vast areas of land. Wahl (2014) reported on heavy metal soil concentrations in four different land use types (such as agricultural, industrial, natural and mining lands) taken from the KwaZulu-Natal and North-West provinces in South Africa. Soil samples of different levels (soil profiling) were collected from mine areas, agricultural areas, residential areas and natural areas at depths of 0-5 cm, 5-15 cm and 15-25 cm. Soil analysis indicated that heavy metal pollution is greater in agricultural sites. The study reported a high concentration of heavy metals (of interest is lead) in the agricultural soil of KwaZulu-Natal and North-West provinces. Osibote & Rabiu (2016) also reported increased concentrations of heavy metals at residential dwelling sites' soil closer to roads in the city of Cape Town.

Ikenaka et al. (2010) investigated heavy metal contamination in residential and urban soil in various cities and towns in Zambia. The result indicated that heavy metal pollution in Zambia was increasing due to human and industrial activities. The observed heavy metal distributions in residential environments are presented in Table 2.7. Proper environmental management has become much more vital considering the increase in industrial activities across Africa (Idowu, Inyang & Ezenwaji 2004; Ogoyi et al. 2011).

Table 2.7: Concentration range [mg/kg] of heavy metals in Zambia soil

	Arsenic (mg/kg)	**Cadmium (mg/kg)**	**Mercury (mg/kg)**	**Lead (mg/kg)**
Lusaka	1-5	0.03-0.33	0.00-0.04	8-134
Kabwe	3-54	1.36.18.65	0.03-0.22	880-16951
Eastern area	1-3	0.02-0.07	0.00-0.01	2-42
Western area	2-4	0.03-0.09	0.01-0.01	0-9
Southern area	1-4	0.03-0.1	0.00-0.01	4-132
Northern area	1-9	0.03-0.34	0.00-0.06	2-184

Source: Ikenaka et al. 2010

2.8 Public health protection mechanisms

2.8.1 Industrial/residential planning

Global consumption of heavy metal is increasing driven mainly by the growing demand for metal related products. Much of this new demand is in countries experiencing industrialization and urbanization, thus resulting in the contaminating of soil (Obodai et al. 2011). Due to heavy metals' toxic effect, soil pollutant concentrations levels have been established in developed countries across the world. For example, the Netherlands (Crommentuijn, Polder & Van der Plassche 1997), the US (Efroymson, Will & Suter 1997), Europe (Rodrigues 2009) and South Africa (Herselman, Steyn & Fey 2005) have all gazetted soil pollutants levels and remediation protocols.

The soil is a material basis for economic, healthy and socially sustainable development. The specific type of metal contamination found in contaminated soil is directly related to the industrial/environmental activity that is occurring in the area. Protecting the soil environment is a major component to promote ecological progress and safeguard national ecological security. To reduce heavy metal exposure, scientists are currently identifying sources of heavy metal contamination in soils.

Regulation of soil quality in several countries has been achieved through various government structures. In the Netherlands a policy known as the "Soil Protection Act" was enacted to address soil use and soil quality. A soil protection act was developed, and constant assessment of soil quality was enforced. The policy provides guidance for soil classification: soil heavy metal levels are sub-divided into target values and intervention values, a target value is a value that indicates good quality soil, while an intervention value is a value above the target value: it signals the point at which soil remediation is required. If the intervention levels are left unattended, it may result in potential health risks to the population and the ecosystems (Swartjes & Walthaus 2006). Generally, the soil is sub-divided into four classes based on the allowed concentration levels (Boekhold 2008). These categories are as follows:

1. Soil employed for all use,
2. Soil appropriate for residential purposes and industrial use,
3. Soil suitable for industries,
4. Soil not suitable for use, i.e. soil which is above the intervention levels.

Across the world, an action plan (environmental assessment) is being formulated to effectively strengthen soil pollution prevention and control by planning industrial/residential areas.

2.8.2 International and local exposure reference levels.

Polluted soil presents health and environmental issues through the disruption of soil's physico-chemical and biological processes, hence, influencing soil quality. To protect humans from harmful effects of heavy metals, the World Health Organization (WHO) set values for toxicity, termed provisional maximum tolerable weekly intakes (PMTWI) and provisional maximum tolerable daily intakes (PMTDI). The WHO has recommended a PMTWI of cadmium and lead as 0.025 mg/kg body mass (equal to 17.50 mg/week for a 70-kg adult) and 0.007 mg/kg body mass (equal to 0.49 mg /week for a 70-kg adult) respectively (FAO/WHO 1999). Soil quality standards created by the World Health Organization (WHO) also provided a guideline for heavy metal concentration limits in soils. This guideline is important as it ensures that plant crops and food produced from residential gardens and farms meets food quality standards (FQS) set by the WHO (Romkens et al. 2011).

Several countries have recommended maximum permissible metal levels in the soil to protect the environment. The standard for soil, as established by the Indian standards for heavy metals, is 3–6 and 250–500 mg/kg for cadmium and lead, respectively (Bhagure & Mirgane 2010).

In Nigeria, the Department of Petroleum Resources (DPR) recommended guidelines for target values and intervention values (Table 2.8). The values were proposed as interim and further studies regarding standard values are ongoing. According to the table, the target values proposed are very high, most especially for arsenic, cadmium and mercury. This is because the levels are mandated for refinery industries, where high levels of heavy metals are generated (DPR-EGASPIN 2002). Recommended guidelines for polluted soil remediation based on the intervention values and target values were also proposed (DPR-EGASPIN 2002).

Table 2.8: Recommended guideline values for industrial soil

Metal	Target value (mg/kg)	Intervention value (mg/kg)
Arsenic	200	625
Lead	35	210
Cadmium	100	380
Mercury	85	530

(Department of petroleum resources (DPR-EGASPIN 2002)).

Riley, Zachara & Wobber (1992); and the New Jersey Department of Environmental Protection (1996) also reported soil heavy metal guidelines (Table 2.9). The target value is defined as the value required to maintain soil quality: this level is required for soil sustainability. It is important to maintain these target levels to preserve soil's functionality in the ecosystem.

Table 2.9: Soil regulatory guidelines for some heavy metals.

Metal	**Regulatory limits ($mgkg^{-1}$)**
Lead	600
Cadmium	100
Chromium	100
Mercury	270

[Riley, Zachara & Wobber 1992]; Non-residential direct contact soil clean-up criteria [New Jersey Department of Environmental Protection 1996]

To minimize the risk of heavy metal exposure worldwide countries have made a concerted global effort to establish and enforce policies to eliminate irreversible and costly health impacts. Higher income countries have already enacted effective, scientifically-backed regulations, such as the European Union’s Registration and the United States Environmental Protection Agency (USEPA) (Yoshinaga 2012). Similar laws are being adapted by countries lacking adequate surveillance of pollution risks. Balancing economic development with pollution control and prevention will be key to ensuring the long-term safety of public health and the environment. The USEPA (He et al. 2015), the European soil levels (He et al. 2015) and South Africa (Department of Environmental Affairs 2010). Guideline concentrations in soil are provided in Table 2.10.

Table 2.10: Guideline levels of heavy metals in soil (mg/kg).

Metals	US EPA levels [a] (mg/kg)	European soil levels [b] (mg/kg)	South Africa Heavy metal limits (mg/kg)[c]
Arsenic	11	50	48
Cadmium	48	10	32
Lead	400	200	230
Mercury	1	2	1
Manganese	630	n/a	1500

n/a = not available

[a,b]He et al. 2015

[c]DEA 2010.

Chapter 3

STUDY DESIGN AND METHODOLOGY

This chapter deals with the study design, study area and methodology that was employed in the research such as sample size determination, soil sample collection for selected heavy metal analysis, data entry and statistical analysis. It also discusses the importance of carcinogenic and non-carcinogenic health risk assessment.

3.1 Study design

A cross-sectional study design was employed in this study. The research was carried out in two phases; the first phase involved soil sample collection, preparation and laboratory work to determine the concentration of heavy metals. The second phase focused on the social aspect of the study which involved the use of a pre-approved questionnaire and a face-to-face interview for the collection of human health-related information at each dwelling site where soil samples were collected.

This masters' research protocol was approved by the Health Sciences Faculty Postgraduate Studies Committees (FPGSC) of Nelson Mandela University. A pre-approved questionnaire employed for the collection of socio-demographic information and surveyed health data was supplied by Ibhayi Environment and Health Study.

The Ibhayi Environment and Health Study is a collaborative project between the Department of Environmental Health at the Nelson Mandela University (NMU), the Nelson Mandela Bay Municipality (NMBM), and the South African Medical Research Council (SAMRC) with a mandate to conduct population-based research on environmental risks to health, with special emphasis on those living in poverty.

3.2 Study area

Port Elizabeth is situated in the Eastern Cape province of South Africa. It has an estimated population of around 1 152 115 with an average of 708 inhabitants per square kilometre (Nelson Mandela Bay, 2016). It is a tourist centre and a major seaport that ships diamonds, wool, fruit, and other items. Automobile assembly is the chief industry, while small and medium scale industries such as shoe manufacturing, metal and timber processing, food processing, tanning and chemical production are also available in the city.

The selected study areas are Wells Estate and Walmer Township. The soil types are mainly compost, sandy and clay soils. Walmer Township lies between latitude 33° 58' south and longitude 25° 35' east with a population distribution of 46 persons/hectare (with approximately seventy thousand people). The area is a formal settlement located within 2 km from Port Elizabeth international airport, it is one of the densely populated inner city townships in Port Elizabeth, and the suburb is heavily trafficked as well as intermixed with a variety of formal commercial activities. A study reported by Goliger (2016) showed that strong winds at a speed >10.7 m/s in the direction of West and South West axis (W and SW) and South West (SW) was predominant in the city of Port Elizabeth.

Wells Estate lies between latitude 33° 50' south and longitude 25° 38' east with a population distribution of 26-50 persons/hectare and a population of 18,844 people (Nelson Mandela Bay 2015). Wells Estate is a formal area located around 2 km from Coega and Markman Industrial areas. The industries situated near Wells Estate (Coega and Markman industrial zone) specialize in the following: (i) manufacture of steel, and cast iron, (ii) laser welding, (iii) manufacturing of catalytic converters, car exhausts, silencer shells, and gearbox tubing, (iv) recycling of metals scraps, (v) manufacture of cement, bricks and blocks, (vi) manufacture of hide, skin, wool and leather, (vii) manufacture of automotive seating and electrical parts, (viii) sales of coal and coke, and (ix) truck sales and servicing services. Industries operating near Walmer Township specialize in (i) manufacture of high-quality synthetic metal oxide (e.g. iron oxide) pigments for road construction, and (ii) collection and recycling of waste.

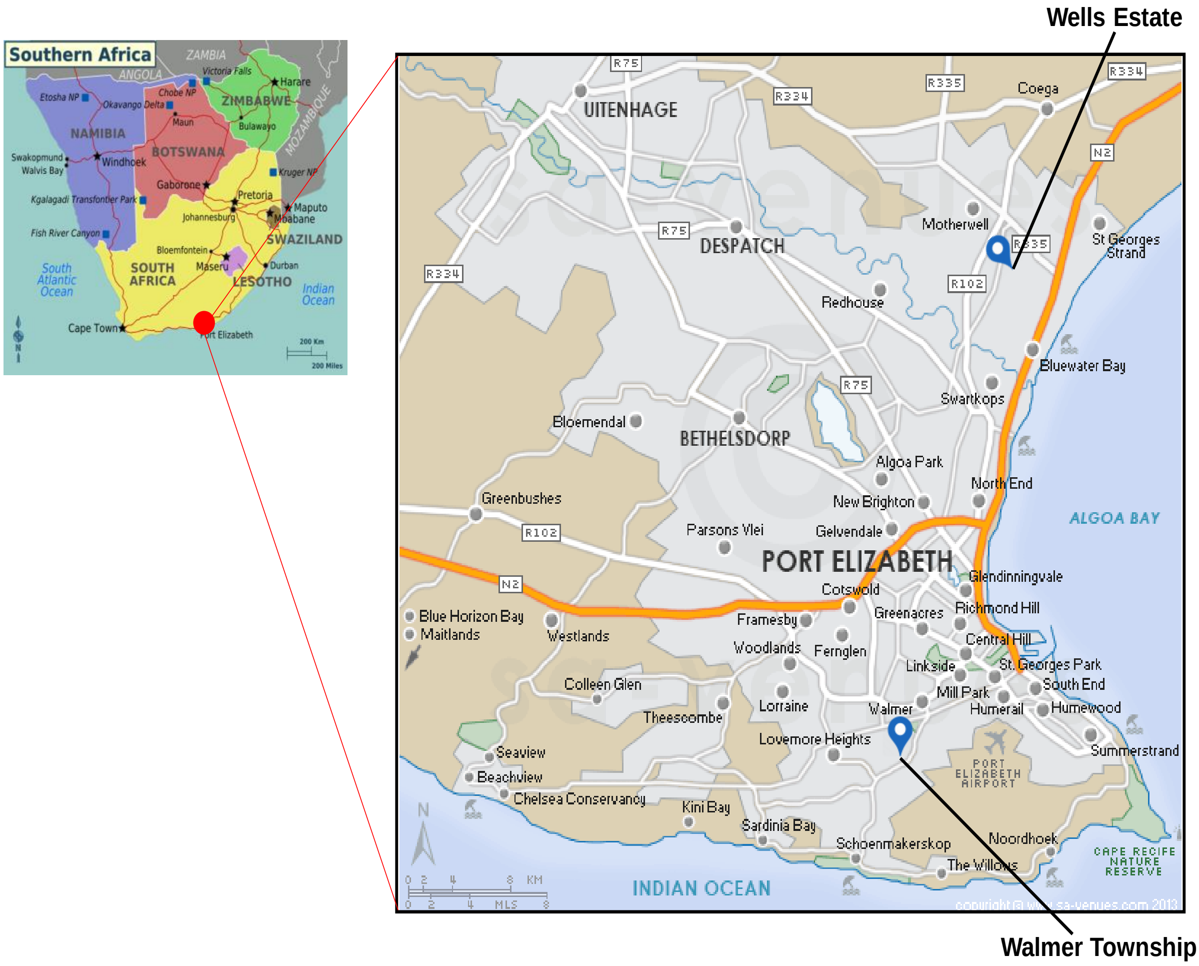

Figure 3.1: Map of the city of Port Elizabeth, South Africa showing the study location (Walmer Township and Wells Estate)

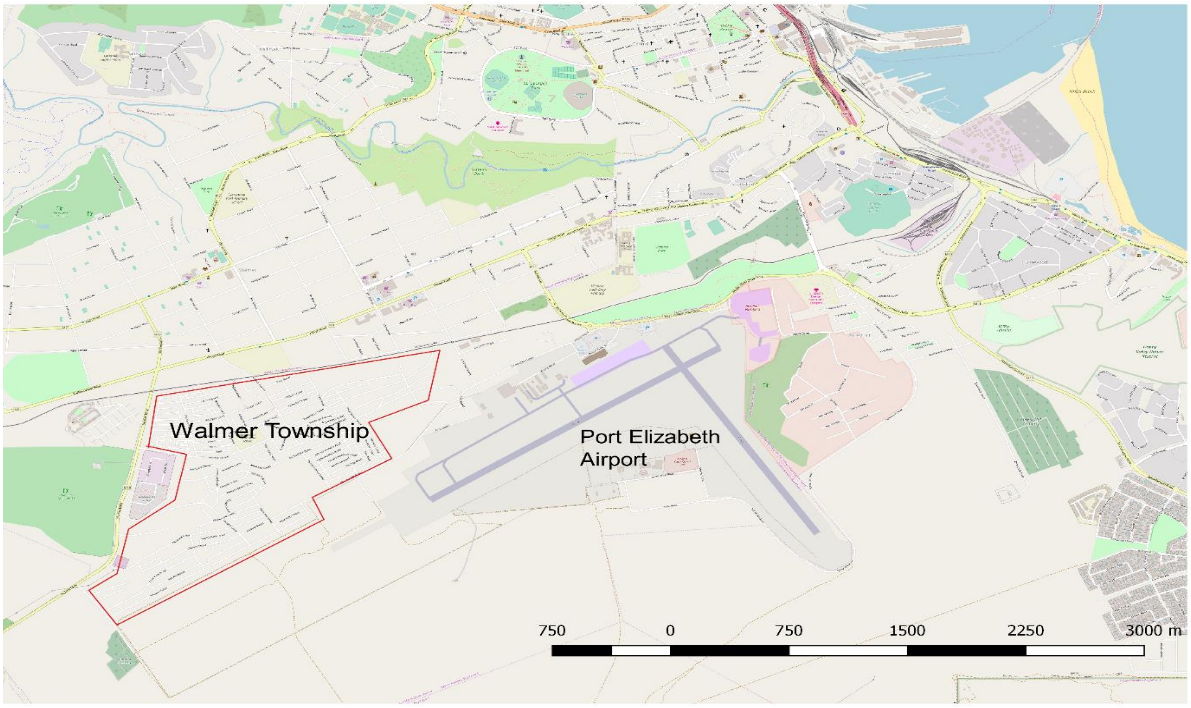

Figure 3.2: Map of Walmer Township, Port Elizabeth.

This Map shows the proximity of Walmer Township to Port Elizabeth airport.

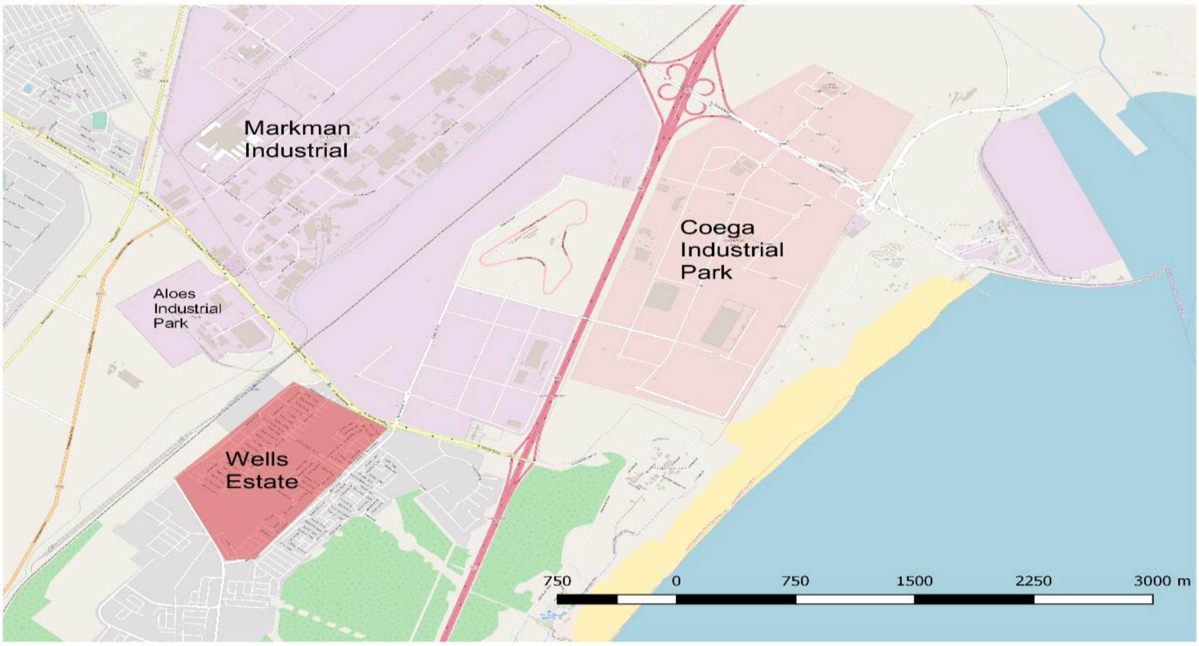

Figure 3.3: Map of Wells Estate, Port Elizabeth

Geographical map of Wells Estate which shows the proximity of the Coega and Markman industrial area.

3.3 Sample size determination

This study intended to investigate the relationship between select heavy metals and health effects, the number of residential dwelling soils to be sampled for this study was determined by applying cross sectional studies sample size formula reported by Charan & Biswas 2013.

$N=Z^2p(1-p)/d^2$

where N= is the desired sample size

Z- Is the standard normal deviation = 1.96, which corresponds to 95% confidence interval

p= proportion exceeding guideline levels from previous study (0.92)

d= the level of statistical significant set at 0.05

To establish an appropriate sample size for this study, a calculation was performed based on an understanding of guideline values as well as data collected from previous studies (Aelion et al. 2009; Kootodien et al. 2012). According to the work published by Aelion et al. 2009, it was estimated that 92% of the total sample exceeded the US EPA arsenic reference level in urban area (population ~40,000), with land mostly used for residential, commercial, and industrial purposes. Hence, in determining the sample size it was assumed that the total sample with high arsenic level exceeding US EPA reference level may not exceed 92%. Therefore, for the study 113 soil samples was required, however, resources and funds available for sample analysis only allowed for, 100 soil samples.

3.4 Soil sample and data collection

Residential garden soil at each of the study sites (Wells Estate and Walmer Township) was sampled. Prior to soil sample collection, an observation of the physical appearance, texture, and colour of the soil was carried out. The surface soil sampling technique was employed at the study sites: this method is used primarily to collect surface and shallow subsurface soil samples (USEPA 2014).

Sampling of soils was carried out in one hundred residential gardens of Walmer Township (50) and Wells Estate (50). In addition to the collection of soil samples, visual dwelling site inspections, which included information about house characteristics, geographic location (GPS coordinates) and characteristics of the surrounding area were undertaken (Appendix 1).

Soil samples were collected from residential gardens of the dwellings, dirt and debris were removed from the surface of the soil before sampling. Garden soil was chosen mainly because the vulnerable population (such as children) may be exposed to heavy metals in gardens where they play. The main exposure pathway for children is ingestion via the hand-to-mouth pathway. Adults may also be exposed to heavy metals in the gardens through inhalation of the soil particles and ingestion (Sheppard & Evenden 1994; Lanphear & Roughmann 1997).

Surface soil samples were collected by the researcher (a MTech Research student) from the top 2 cm using a sterile stainless-steel spoon and were transferred into labelled zip-lock plastic bags and immediately transferred to a cooler box (US EPA 1995; Riederer et al. 2005). Prior to heavy metal analysis soil samples were stored in the laboratory refrigerator at 4°C. All soil samples were analysed at the Department of Chemistry, Nelson Mandela University.

A pre-structured question (designed for the purposes of the Ibhayi study) was administered to a suitable respondent at each dwelling to obtain information related to age, gender, socio economic status and health related symptoms.

3.5 Determination of heavy metal concentration in soil samples using X-ray Fluorescence Spectroscopy (XRF)

3.5.1 Laboratory analysis

The laboratory analysis of soil samples was done at the Department of Chemistry laboratory, Nelson Mandela University. Soil samples were dried at 40°C and sieved through 2 mm mesh according to MSZ 21470-2 (US EPA 1990c). Images of the soil sample before and after drying is presented in Fig 3.4

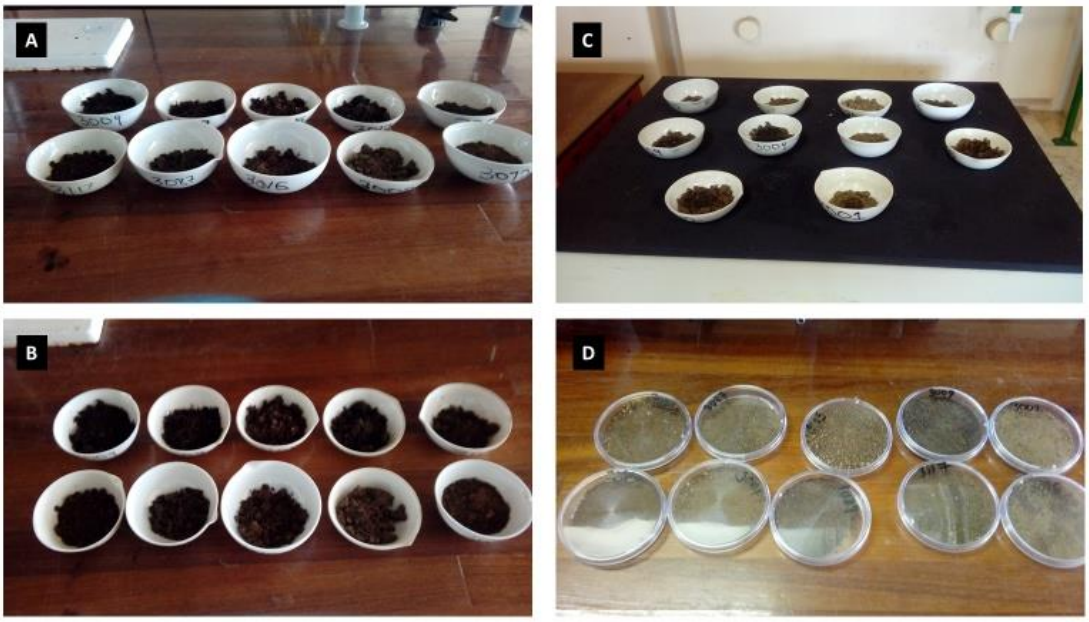

Figure 3.4: Soil images (A & B) before drying, (C) drying at (40°C) and (D) sieved dried soil samples.

3.5.2 XRF analysis

Two grams of soil were prepared in XRF sample cups with 6 mm thick Mylar film windows. Soil samples were analysed using a handheld energy dispersive X-ray fluorescence (Bruker s1-TITAN 600-800 Analyzer) instrument (Figure 3.5).

Figure 3.5: A photo of the handheld energy dispersive X-ray fluorescence (Bruker s1-TITAN Analyzer) instrument.

3.6 Principle and operation of XRF

3.6.1 X-Ray Fluorescence Spectroscopy (XRF)

The energy dispersive X-ray fluorescence spectroscopy (XRF) is a method employed for determining the elemental composition of a material sample, this analysis can either be qualitative and quantitative. The principle of the X-Ray Fluorescence Spectroscopy (XRF) is based on the excitation of an electron within a sample using primary X-radiation (Figure 3). During the electron excitation, the inner electron shells are knocked (K shells) by X-ray. Electrons from outer electron shells (K and L shell) fill the resultant voids emitting a fluorescence radiation (K_α and K_β radiation) that is characteristic in its energy distribution for a particular metal electron. This fluorescence radiation is evaluated by the detector. The generation of the X-ray fluorescence radiation is shown simplified in Figure 3.3 below (Buhrke, Jenkins & Smith 1998; Jenkins 1988).

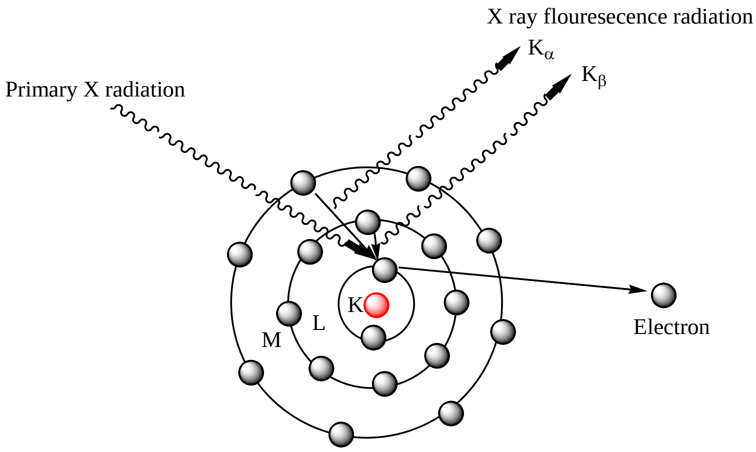

Figure 3.6: Diagrammatic illustration of the Principle of the X-Ray Fluorescence Spectroscopy (XRF).

3.6.2 Quality assurance and control

A strict quality assurance and quality control measures were adopted to ensure reliability of the results. All XRF cups used were of high purity. A blank analysis was done after every 20 soil samples using a silicon dioxide (SiO_2) to check if the instrument calibration had not deviated. The limit of detection (LOD) for each element was achieved as follows:

- Cadmium: 9 mg/kg,
- Arsenic: 3 mg/kg
- Manganese: 18 mg/kg,
- Lead: 11 mg/kg
- Mercury: 3 mg/kg.

The accuracy and reproducibility of the analytical procedure was determined by measuring the concentrations of known standards (certified standard reference). The metals (standard concentrations; measured concentrations) of interest are as follows (Table 3.1). The laboratory is accredited in accordance with an international laboratory (ISO/IEC 17025). ISO/IEC 17025:

The general requirement for the competence of testing and calibration laboratories is the main ISO standard used by testing and calibration laboratories.

Table 3.1: Accuracy and reproducibility of metal concentrations

Metals	Certified Reference Material (CRM) concentrations (mg/kg)	Measured concentrations (mg/kg)	Percentage recovery (%)
Chromium	87	81	94
Arsenic	33	33	100
Bromine	786	771	98
Cadmium	137	132	96
Mercury	13	13	100
Lead	75	75	100

The concentration measured by the XRF using standard calibration curve is provided in Figure 3.7 below.

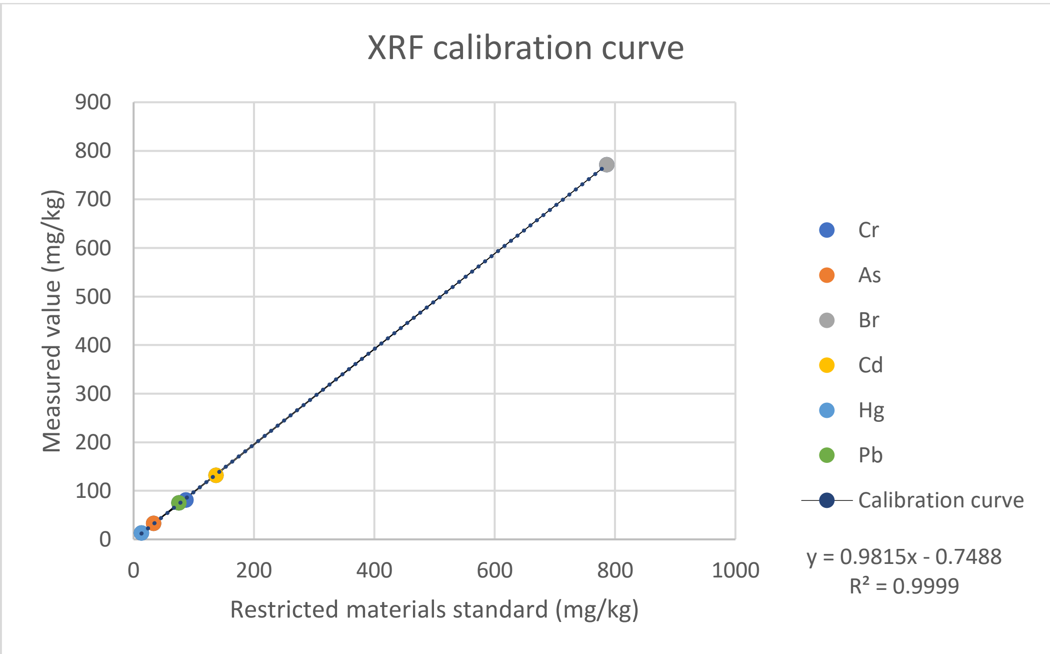

Figure 3.7: XRF standard calibration curves.

3.6.3 XRF control chart

Control charts identify when assignable causes of variation or changes have entered the process. Control charts are useful for detecting the change in process conditions. It is important to know when changes have entered the process, so that the cause may be identified and corrected before a large number of unacceptable items are produced. Analysis was carried out in July 2017. Control chart (Figure 3.8) for the period when analysis was carried out indicated that measured concentrations were within control limits.

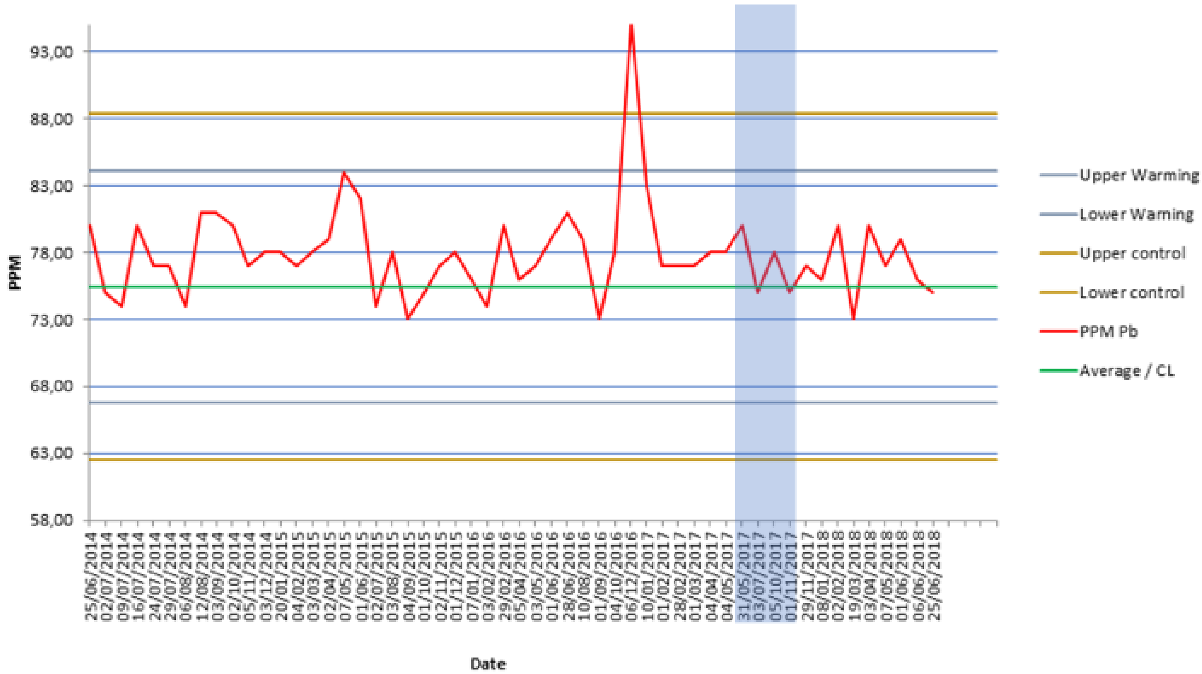

Figure 3.8: XRF control chart from 2014 to 2018 (analysis was carried out in July 2017).

3.7 Data entry and statistical analysis

Interview responses were processed after the face-to-face interview took place. The results were subdivided into categories for easy display of the information in an excel worksheet. The excel worksheet allows the data to be organized into a logical and coherent format. When all the data from the dwellings had been transcribed into an excel worksheet, the information was further processed using STATISTICA 64 statistical software. In STATISTICA 64, the information was sub-divided into data and variables for statistical analysis.

A normality distribution test was carried out to determine if the heavy metal concentrations were normally distributed in order to choose an appropriate statistical method (Appendix 2). Measures of central tendency and spread such as mean, range, and standard deviation was computed for the distribution of heavy metals (objective one). The range measures the largest and smallest observation in the data. Standard deviation is a measure of the spread of data about the mean, and it is a very useful measure of dispersion (Wallnau 2000; Manikanda 2011). In addition, socio demographic and other characteristics were measured. These variables were reported using frequencies (n) and proportions (%).

The Mann-Whitney U test was used to compare metal concentrations between the study sites (objective two). Heavy metal percentage greater than South Africa, European and United States guideline levels was also computed across study sites (objective three). Binary logistic regression was used to determine the association between the soil metal concentrations with, age of house, indoor and outdoor paint peeling.

To determine the associations between metal concentrations and health outcomes, multiple logistic regression analysis was used (objective four). Health outcomes were defined as a binary variable: “no and yes”. Predictors of health outcomes were determined using a logistic regression model adjusted for probable confounders. Metal concentrations (the main variable) and potentially confounding factors such as age, gender, socio-economic status, educational status, cigarette smoking, mould, dampness and overcrowding were included in the model. A larger p-value (>0.05) suggests that changes in the predictor are not associated or of significant difference with changes in the response. A low p-value (<0.05) suggests that changes in the predictor are associated with changes in the response (Cheung & Klotz 1997). Geographic information system (GIS) mapping was also done using QGIS software to show the metal concentration distribution in the study sites.

3.8 Ethical Considerations

Permission was sought from the Nelson Mandela University Ethics Research Committee (reference number HI4-NEA-ENV-004). Participants participated in the study voluntarily and informed consent was sought from the individual participants after explaining to them the objective of the study (Appendix 3). The respondents were assured of the confidentiality of their responses. The data will be stored in the form of a thesis and may also be published in a research journal.

Chapter 4

RESULTS

This chapter presents the sociodemographic, socioeconomic and housing characteristics, as well as the health profile and garden soil metal concentrations in the study sample and areas. Geographical information system (GIS) mapping of heavy metal concentrations is also presented in this chapter. Furthermore, heavy metal levels were analysed and statistically examined for significant differences and possible associations with health outcomes, taking account of potential confounding factors.

4.1 Sociodemographic profile of the study population

4.1.1 Sociodemographic and socioeconomic information

Sociodemographic and socioeconomic information, which gives an indication of the characteristics of a population, were obtained through the administration of a pre-structured questionnaire. The characteristics include gender, age, country of birth of respondent, language spoken, educational level, employment status, government grants received, access to medical aid and number of years that the household had lived in the dwelling.

One participant (respondent) from each of 100 households was interviewed. The total study population comprised 385 people; of these, 205 were from Wells Estate and 180 were from Walmer Township. Table 4.1 summarises the sociodemographic information of the study population. Most sociodemographic and economic variables had similar distributions in the two suburbs.

Table 4.1: Sociodemographic data for the study population

Demographic profile	**Frequency (%)**	
	Walmer Township	**Wells Estate**
Gender (Respondents)		
Male	16 (32%)	18 (36%)
Female	34 (68%)	32 (64%)
Total	50 (100%)	50 (100%)
Gender (Study population)		
Male	83 (46%)	96 (47%)
Female	97 (54%)	109 (53%)
Total	180 (100%)	205 (100%)
Country of birth (Respondents)		
South African	47 (94%)	50 (100%)
Other	3 (6%)	0 (0%)
Total	50 (100%)	50 (100%)
Language spoken		
Xhosa	47 (94%)	49 (98%)
English	1 (2%)	0 (0%)
Afrikaans	0 (0%)	1 (2%)
Other	2 (4%)	0 (0%)
Total	50 (100%)	50 (100%)
Age (Study population)		
0-5 years	9 (5%)	16 (8%)
6 -18 years	28 (16%)	47 (23%)
19-69 years	129 (72%)	133 (65%)
>69 years	14 (8%)	9 (4%)
Total	180 (100%)	205 (100%)
Educational Level		
None (Adult)	13 (7%)	17 (8%)
Primary	44 (24%)	71 (35%)
Secondary (High school)	104 (58%)	94 (46%)
College/University	14 (8%)	12 (6%)
(Children < 5 years)	5 (3%)	11 (5%)
Total	180 (100%)	205 (100%)

Years household has lived in current dwelling		
< 1 year	1 (2%)	1 (2%)
1 – 10 years	4(8%)	4(8%)
> 10 years	45 (90%)	45 (90%)
Total	50 (100%)	50 (100%)

High unemployment in Walmer Township (37%, n=67) and Wells Estate (39%, n=79) translates into low socioeconomic status in both study sites. The data in Table 4.2 indicate that dwellings with no income and with an income between R 1001 - R 5000 are the two most significant household income categories in both study sites. The proportion of homes with no income to an income of less than R 1000 per month was found to be similar in the two study sites, with 40% in Walmer Township (n =20) compared to 58% in Wells Estate (n=29). It can also be seen that the proportion of households with medical aid was similar in the two suburbs (10% in Walmer Township compared to 6% in Wells Estate). Table 4.2 summarises the economic information of the study population.

Table 4.2: Socioeconomic data for the study population

Socioeconomic profile	**Frequency (%)**	
	Walmer Township	**Wells Estate**
Weekly activities and employment status		
Full time job	25 (14%)	16 (8%)
Part time job	18 (10%)	13 (6%)
Unemployed	67 (37%)	79 (39%)
Housewife/husband	1 (1%)	8 (4%)
Informal job	7 (4%)	9 (4%)
Tertiary education	6 (3%)	5 (2%)
School	32 (18%)	52 (25%)
Creche	1 (1%)	0 (0%)
Retired	16 (9%)	13 (6%)

Other	7 (4%)	10 (5%)
Total	180 (100%)	205 (100%)
Household monthly income		
No income	14 (28%)	22 (44%)
Less than R 1000	6 (12%)	7 (14%)
R 1001 - R 5000	23 (46%)	17 (34%)
R 5001 - R 10 000	2 (4%)	2 (4%)
More than R 10 000	5 (10%)	2 (4%)
Total	50 (100%)	50 (100%)
Government Grants		
No grant	9 (14%)	9 (16%)
Old age grant	26 (40%)	16 (29%)
Disability grant	8 (12%)	3 (5%)
Child grant	21 (33%)	28 (50%)
Total	64 (100%)	56 (100%)
Medical aid		
Households with medical aid	5 (10%)	3 (6%)
Households without medical aid	45 (90%)	47 (94%)
Total	50 (100%)	50 (100%)

4.2 Housing, sanitation, smoking status and fuel use in the study sites.

4.2.1 Housing conditions

The type and age of dwellings as well as the prevalence of indoor and outdoor paint peeling, cracks in walls, ventilation, lighting, various types of mould in the house, leaking pipes and rooves, broken windows, odour around dwelling, overcrowding, and information on the number of rooms and toilets, all of which may influence the health quality of residents are presented for the total sample and by study site. (see Figures 4.1- 4.5). The mean and median age of the participants in Walmer Township was 37 years (SD 21.7) and 42 years, while in Wells Estate it was 32 years (SD 21.2) and 14 years, respectively. Across the study sites the proportion of houses 1-20 years old was 61%. Figure 4.1 gives the graphical representation of the age of the houses in the total sample and by study site.

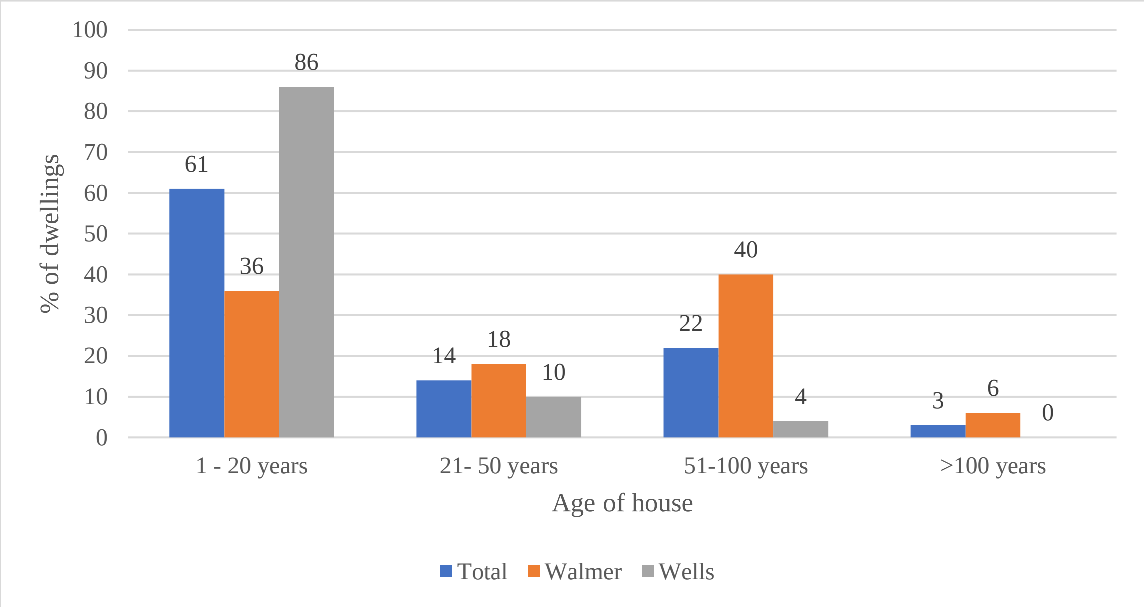

Figure 4.1: Age of house in the total sample, and by study site.

Most dwellings across both study sites had households consisting of an average of five people with 83% of the total living in formal dwellings. The majority of respondents in both suburbs reported that their houses had 1-2 bedrooms (80% in Walmer Township compared to 96% in Wells Estate), and the proportion of houses that had bathrooms and toilets as opposed to those without was 68% in Walmer Township compared to 88% in Wells Estate. Across both study sites 51% and 52% respectively, reported having wall paint peeling inside and outside the house and 62% had dust settling inside the house. All houses visited had piped water in the dwellings. Figures 4.2 and 4.3 give the distribution of the type of house and the visible defects across both study sites.

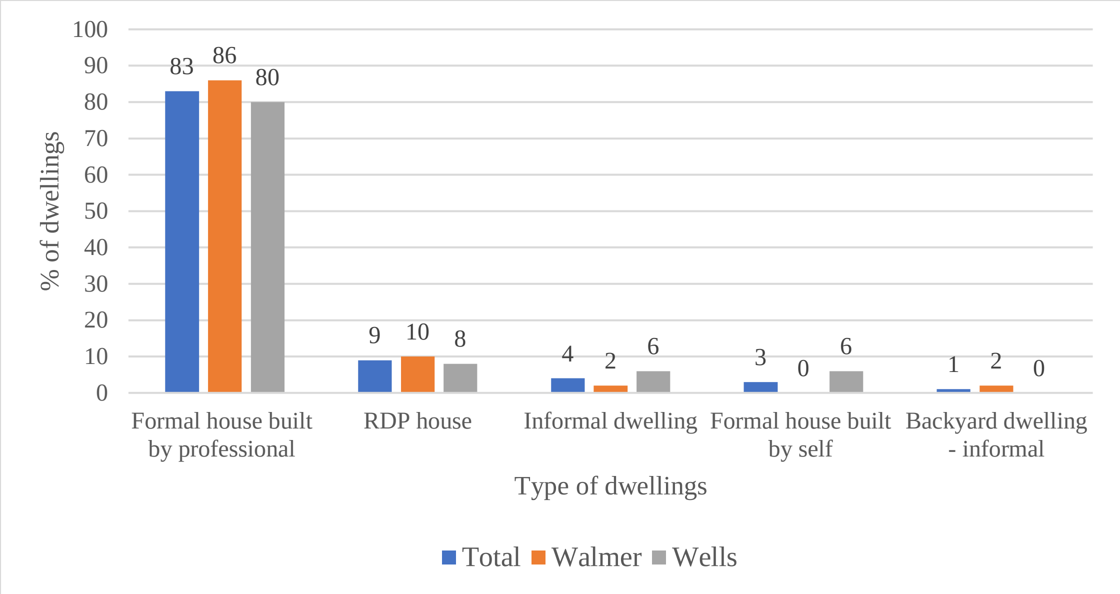

Figure 4.2: Type of dwellings in the total sample and by study site.

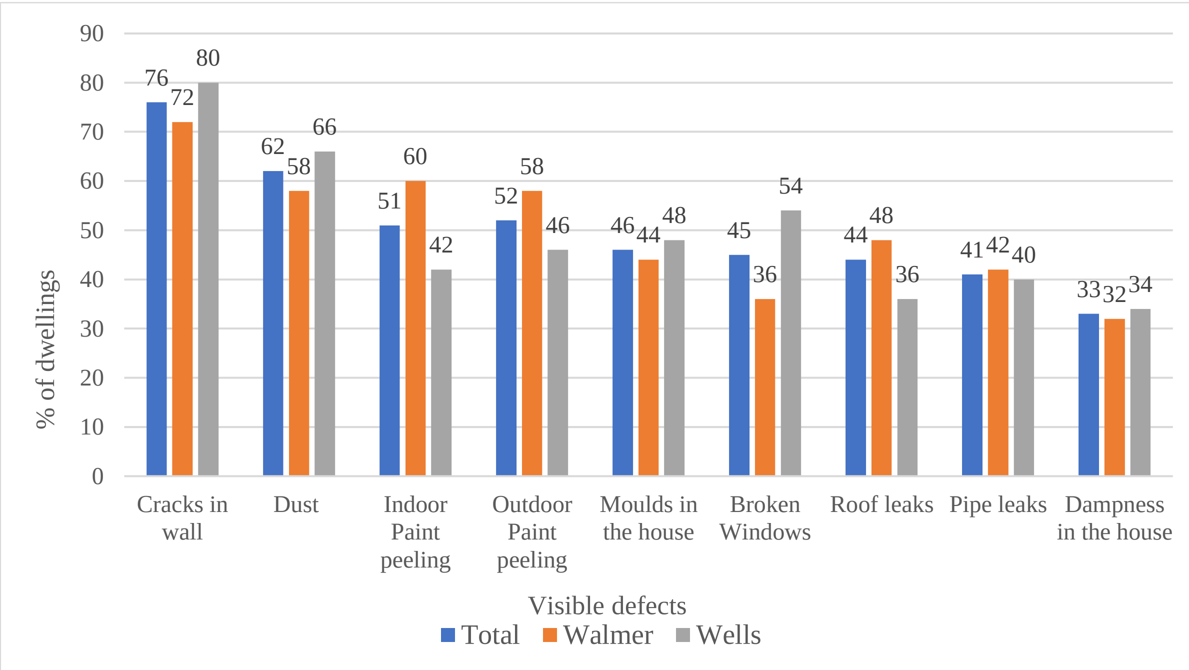

Figure 4.3: Dwelling defects in the study sites.

The respondents were asked how they perceived the issues of overcrowding, air pollution, bad odour and ventilation in the dwelling. The responses are given in Table 4.3. Overcrowding in other dwellings in the neighbourhood in the total sample (41%) was perceived to be twice as high as overcrowding in the main dwelling (20%).

Table 4.3: Perceived problems in dwellings of the study sites.

How would you describe the following issues in this dwelling?	Frequency (%)		
	Walmer Township (N=50)	Well Estate (N=50)	Total sample (N=100)
Ventilation (a good supply of fresh air)	9 (18%)	4 (8%)	13 (13%)
Odours (bad smell) in the area	24 (48%)	17 (34%)	41 (41%)
Air pollution in the neighbourhood	24 (48%)	33 (66%)	57 (57%)
Overcrowding in the main dwelling	11 (22%)	9 (18%)	20 (20%)
Overcrowding in other dwelling	24 (48%)	17 (34%)	41 (41%)

4.2.2 Sanitation and domestic hygiene practices

The respondents were asked how often mould was removed from indoor surfaces, and the frequency with which the floors of the house were cleaned. Most sanitation and domestic hygiene practices had similar distributions in the two study sites, the proportion of house floor cleaning whenever dirt was noticed was 50% and 48% in Walmer Township and Wells Estate respectively, and the proportion of house mould cleaning whenever mould was noticed was 67% in Walmer Township compared to 65% in Wells Estate.

Table 4.4: Sanitation and hygiene practices in study site

Sanitation and hygiene practices	Frequency (%)		
	Walmer Township (N=50)	**Wells Estate (N=50)**	**Total sample (N=100)**
House floor cleaning			
Whenever it is noticed	25 (50%)	24 (48%)	49 (49%)
Every week	21 (42%)	22 (44%)	43 (43%)
Every month	2 (4%)	4 (8%)	6 (6%)
Seldom	2 (4%)	0 (0%)	2 (2%)
Total	50 (100%)	50 (100%)	100 (100%)
House mould cleaning			
Whenever it is noticed	10 (67%)	13 (65%)	23 (66%)
Every week	0 (0%)	0 (0%)	0 (0%)
Every month	0 (0%)	3 (15%)	3 (9%)
Seldom	5 (33%)	4 (20%)	9 (26%)
Total	15 (100%)	20 (100%)	35(100%)

4.2.3 Fuel use in study sites

The primary fuels used by households were grouped into solid fuels (*imbhawula*, wood and charcoal) and non-solid fuels (kerosene, gas and electricity). Electricity was the main source of energy for cooking in 95% of homes. Across both study sites paraffin, electricity and gas were the three most widely used sources of energy for indoor heating (36%, 26% and 2% respectively). Figure 4.5 presents the fuel sources used for indoor heating across the study sites.

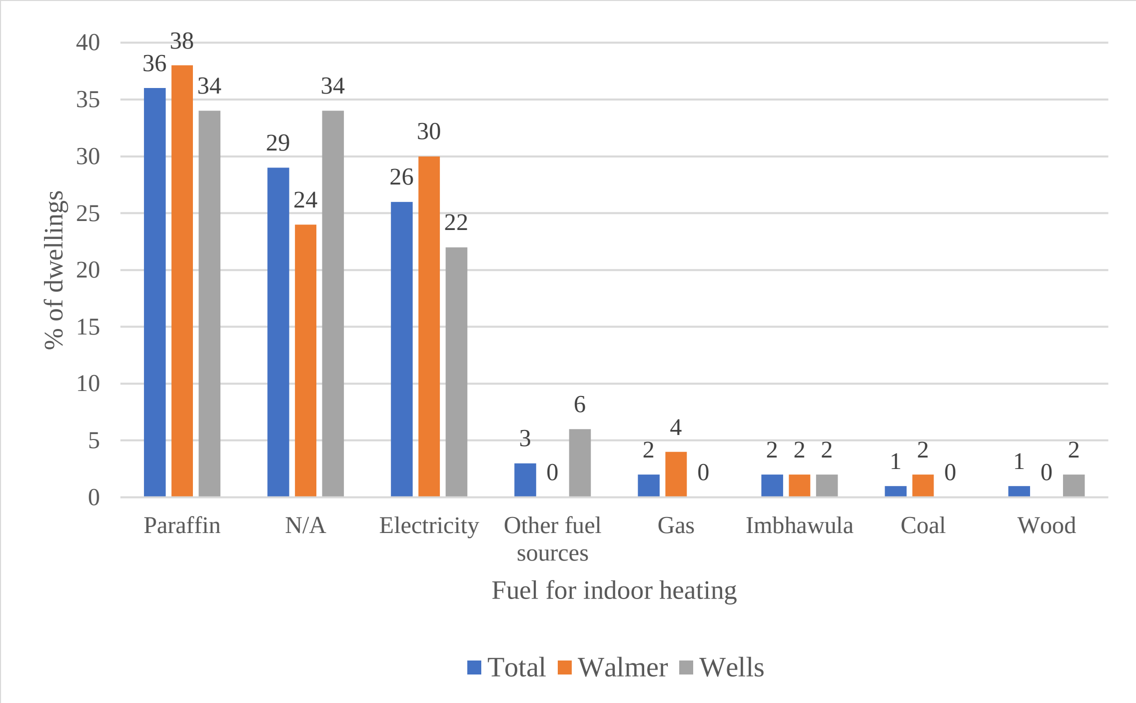

Figure 4.4: Fuel use for indoor heating in the total sample and by study site.

1.1.4 Smoking status in study sites

The prevalence of smoking across households is grouped into non-smokers and smokers. Non-smoking households outnumbered smoking households across both study sites. The number of households with smokers in Walmer Township was lower than in Wells Estate (17% and 21% respectively). Smoking behaviour of respondents was grouped into cigarettes, pipe tobacco, hubbly bubbly/hookahs and electric cigarettes. Cigarette and pipe tobacco were the two most consumed across both study sites. In Walmer Township, 30% of the households smoked cigarettes and 4% pipe tobacco, while 42% smoked cigarettes in Wells Estate.

4.3 Cottage industry

A total of 28 dwellings operated cottage industries in the study sites. Of these, 13 were in Walmer Township and 15 in Wells Estate. Cottage industries reported included car repairs, spray painting, scrap metal recycling, electrical appliance repairs, welding and hairdressing, and the data in this regard are presented in Figure 4.6. Responses were categorized based on the perceived risk level i.e. low risk (associated with low risk of heavy metals); and high risk (associated with high risk of heavy metals). Low risk cottage industries included activities such as hairdressing, carpentry, grass cutting, gardening, street vending and the collection of plastics. High risk activities included welding, scrap metal recycling, fixing electrical appliances and the making of metal jewellery. In Walmer Township, 38% of the households engaged in activities such as carpentry, grass cutting, gardening, street vending and collection of plastics, while 44% of households in Wells Estate engaged in similar activities.

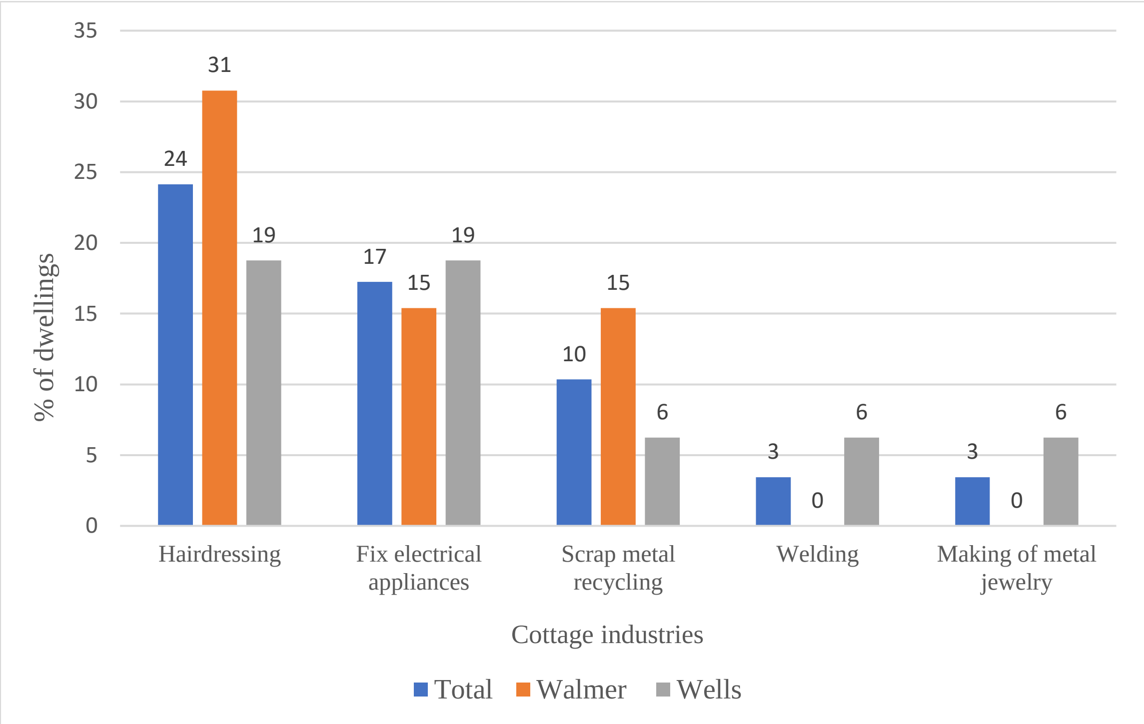

Figure 4.5: Proportion of cottage industries in the total sample, and by study site.

4.4 Soil characteristic of the study sites.

Soil characteristics such as soil type, colour and texture are reported to influence soil heavy metal retention abilities. The various characteristics are presented in Table 4.5 below. In

Walmer Township, 92% of the dwellings had fine soil texture and 90% sandy soil type, while 52% of the dwellings in Wells Estate had fine soil texture and 70% sandy soil type.

Table 4.5: Surface soil characteristics in the total sample, and by study site

	Frequency (%)		
Soil type	**Walmer Township (N=50)**	**Wells Estate (N=50)**	**Total sample (N=100)**
Sandy	45 (90%)	35 (70%)	80 (80%)
Loamy	5 (10%)	13 (26%)	18 (18%)
Clay	0 (0%)	2 (4%)	2 (2%)
Total	50 (100%)	50 (100%)	100 (100%)
Soil texture			
Fine	46 (92%)	26 (52%)	72 (72%)
Coarse	3 (6%)	12 (24%)	15 (15%)
Slit	1 (2%)	11 (22%)	12 (12%)
Gravel	0 (0%)	1 (2%)	1 (1%)
Total	50 (100%)	50 (100%)	100 (100%)
Soil colour			
Dark brown	13 (26%)	17 (34%)	30 (30%)
Brown	32 (64%)	25 (50%)	57 (57%)
Black	0 (0%)	3 (6%)	3 (3%)
Grey	5 (10%)	5 (10%)	10 (10%)
Total	50 (100%)	50 (100%)	100 (100%)

4.5 Health profile of the study population

Figures 4.6- 4.9 give the reported prevalence of selected ill health symptoms and diseases at the time of the study in Walmer Township and Wells Estate. Health information reported by the respondents was divided into acute ill health symptoms and chronic diseases; general acute ill health symptoms, respiratory symptoms, gastrointestinal symptoms, chronic diseases and mental illness.

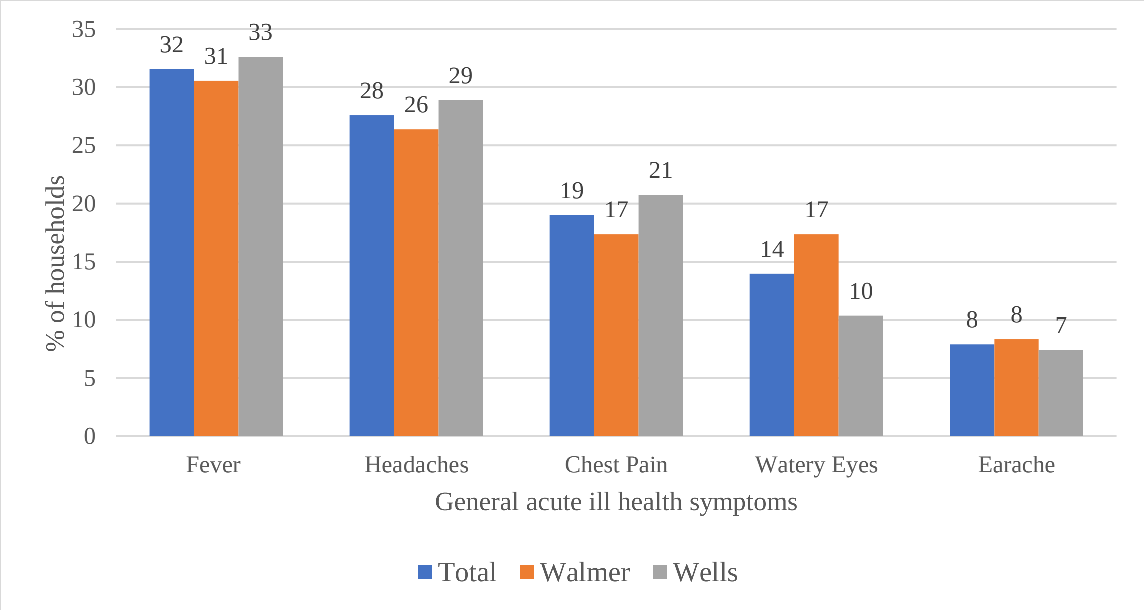

Figure 4.6: General acute ill health symptoms in the total sample, and by study site.

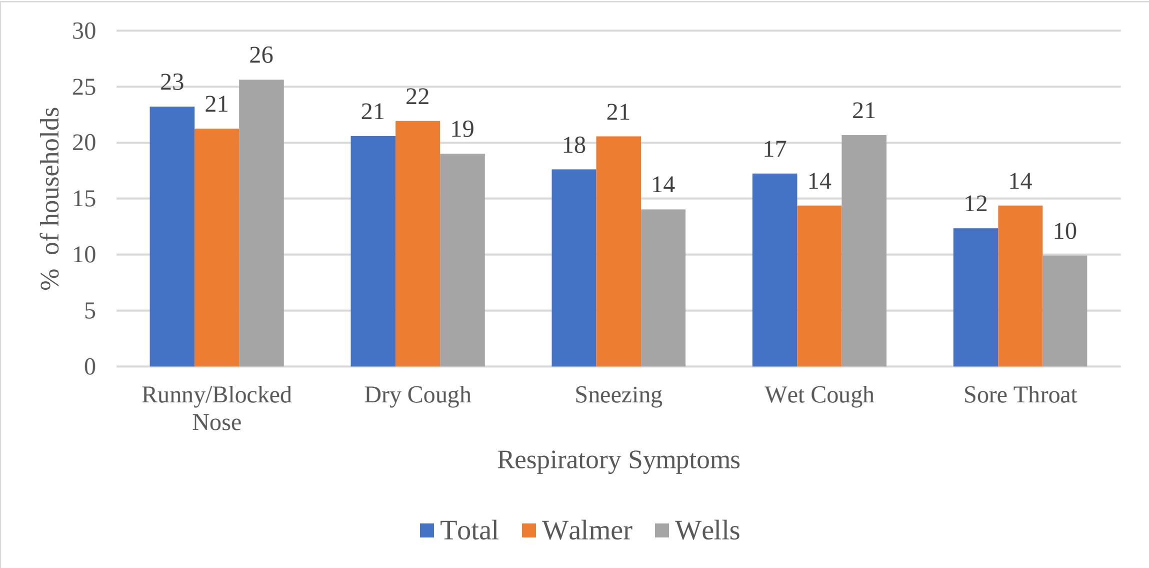

Figure 4.7: Respiratory symptoms in the total sample, and by study site.

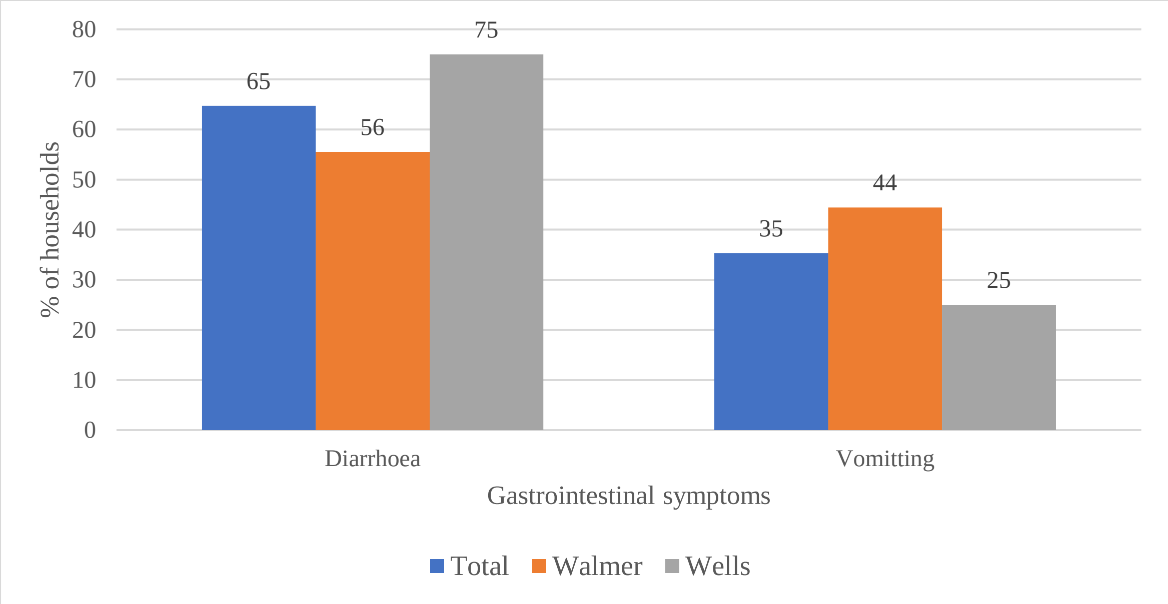

Figure 4.8: Gastrointestinal symptoms in the total sample, and by study site.

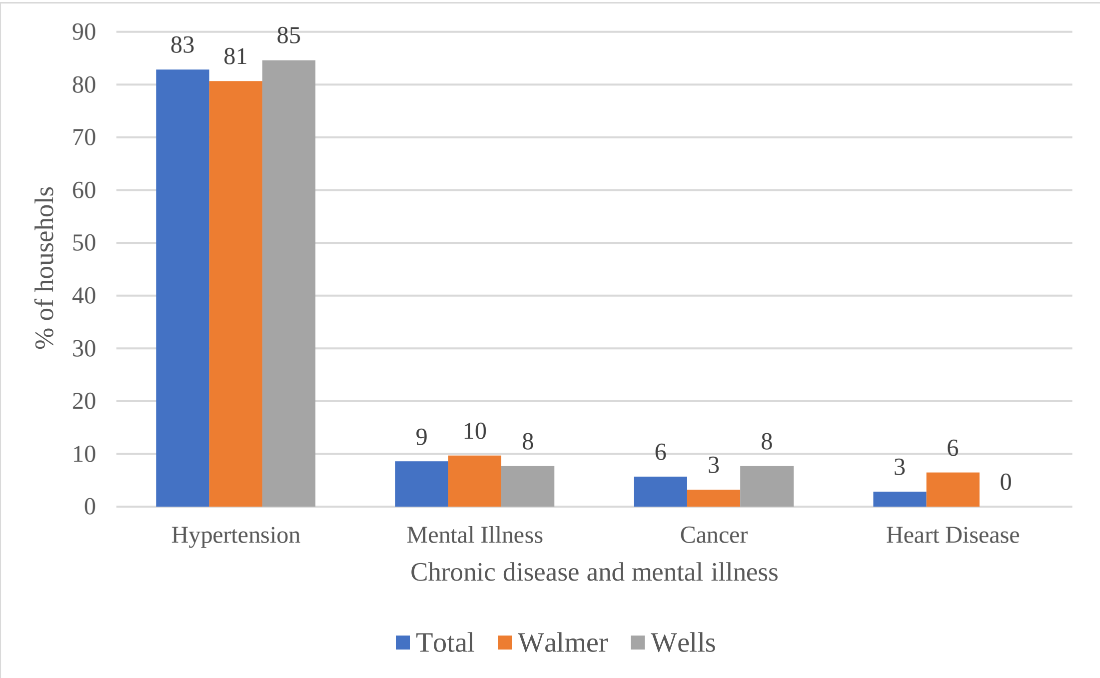

Figure 4.9: Chronic disease and mental illness in the total sample, and by study site.

4.6 Heavy metal concentrations

The concentrations of lead, arsenic, manganese, mercury and cadmium were determined from the soil samples collected at dwellings of Walmer Township and Wells Estate. Soil concentrations of lead, arsenic and manganese in the total sample, and by study site are presented in Figures 4.16, 4.19, and 4.22. All the results for mercury and cadmium were below the limit of detection (<LOD) and were therefore, excluded from statistical analyses. In the subsequent subsection, lead, arsenic and manganese concentrations are presented.

4.6.1 Outlier detection

Outlier detection discovers data points that are significantly different than the rest of the data. In this study, an outlier analysis was employed to detect outlier(s) in the soil metal distributions. One outlier in the data (lead concentration in Walmer Township) was identified (Figure 4.10). The outlier was removed from further statistical analysis and is instead presented as a case study (Section 4.9). Further investigation was undertaken to understand the reason(s) for the observed elevated concentration (outlier).

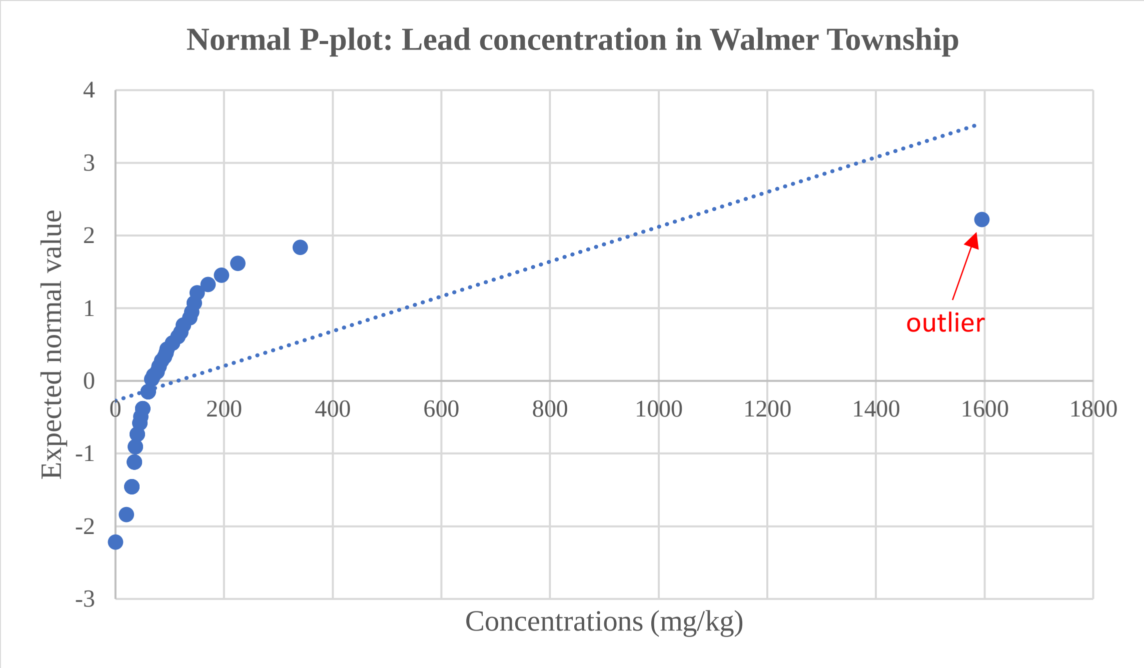

Figure 4.10: Outlier analysis of lead concentration in Walmer Township.

4.7 Descriptive statistics of the soil metal concentrations in the study sites.

Descriptive statistics including range, mean, median, standard deviation (SD) and proportion equalling or exceeding the guideline levels for South Africa (DEA 2010), Europe (He, Yang & Stofella 2015), and the United States of America (He, Yang & Stofella 2015) for soil in the study sites are presented in Tables 4.6- 4.8. Higher concentrations of manganese were found relative to lead and arsenic concentrations. The mean concentration of manganese in Wells Estate (322.2 mg/kg) was twice as high as that determined in Walmer Township soil samples (154.8 mg/kg). Conversely, lead and arsenic concentrations were lower in Wells Estate soil compared to Walmer Township garden soil. The mean ratios of Walmer Township soil concentrations to Wells Estate soil concentrations were 0.48 for manganese, 7.3 for lead and 1.7 for arsenic.

4.7.1 Manganese

Manganese was the most abundant heavy metal found across both study sites (n=100), with a concentration range of 70 to 560 mg/kg, the mean and median levels respectively equalled 238.5 mg/kg (SD 111.1 mg/kg) and 221.7 mg/kg. Table 4.6 gives the distribution of manganese concentrations in the residential garden soil samples in relation to the guideline levels of South Africa, Europe and the United States, as well as the mean for the total study sample. The soil concentrations across both study sites were below the guideline levels.

Table 4.6: Levels of Manganese in residential garden soil.

Manganese (mg/kg)			
	Walmer Township N=50	Wells Estate N=50	Total sample N=100
Range	70-355	170-560	70-560
Mean (Standard deviation)	154.8 (61.1)	322.2 (83.7)	238.5 (111.1)
Median	146.7	314.2	221.7
%> South African guideline levels	0%	0%	0%
%> European guideline levels	0%	0%	0%
%> United States guideline levels	0%	0%	0%

Figure 4.11 gives a graphical presentation of the soil manganese percentage distribution in the total sample, and by study site.

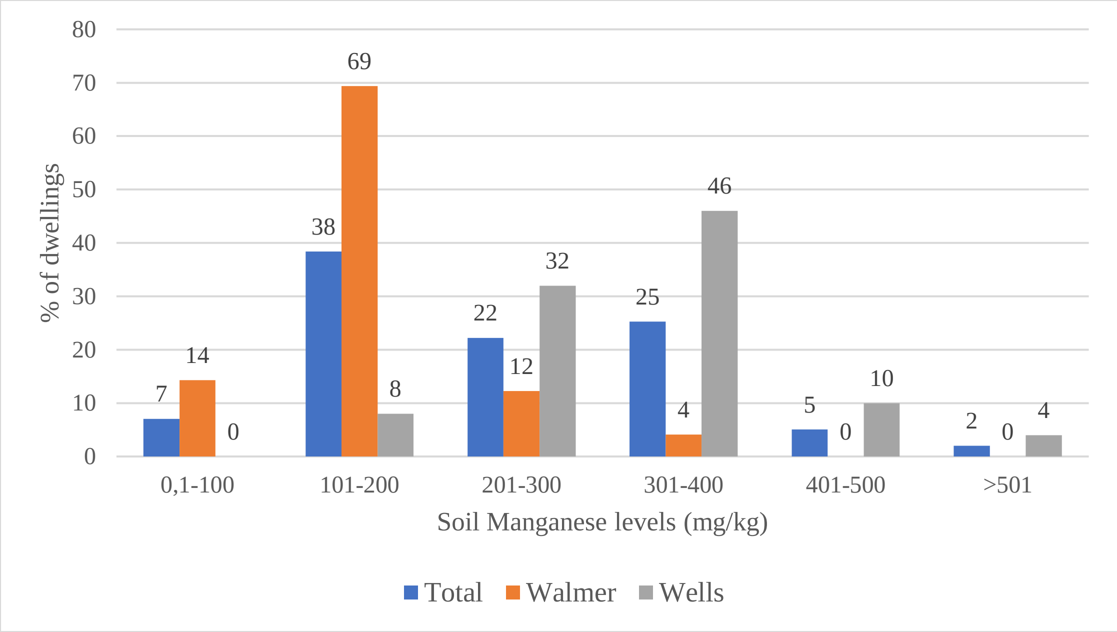

Figure 4.11: Distribution of soil manganese levels in the total sample, and by study site.

The distribution of the soil manganese concentration levels in Walmer Township and Wells Estate are presented in Figures 4.12 and 4.13 respectively. The geographical information retrieved from the study sites was analysed using the Geographical Information System (GIS) to show the metal levels across both the study sites.

Figure 4.12: Manganese soil concentration distribution in Walmer Township.

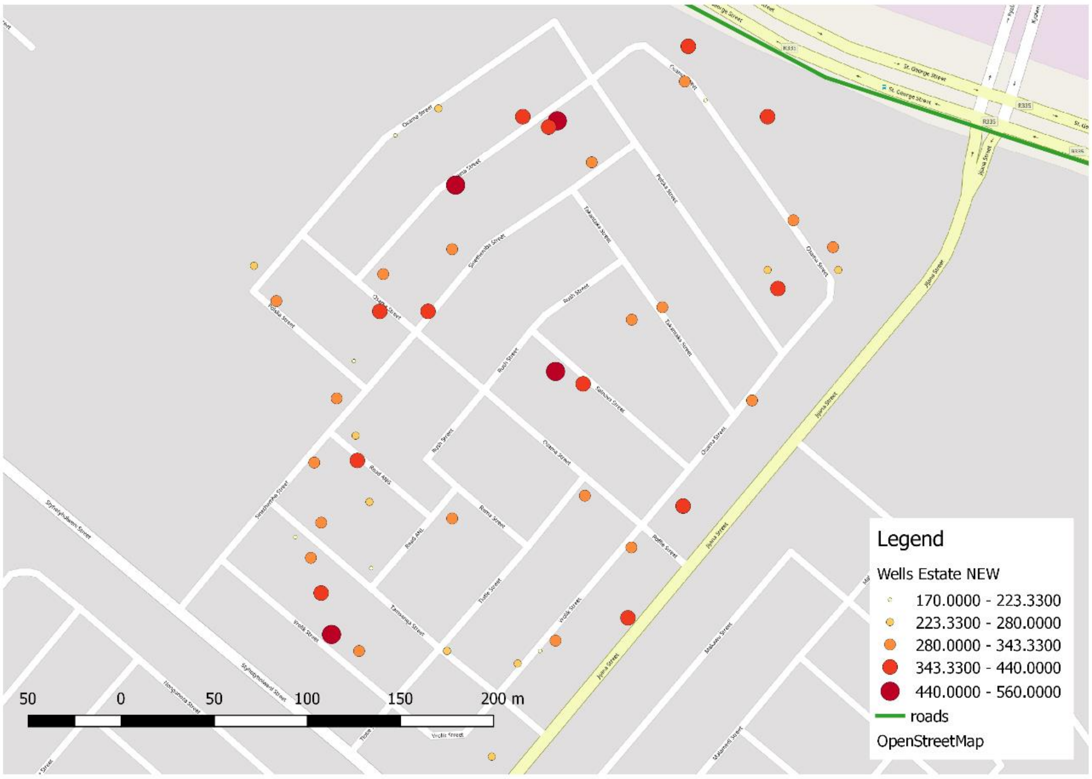

Figure 4.13: Manganese soil concentration distribution in Wells Estate.

4.7.2 Lead concentrations in soil.

The distribution of soil lead concentrations in the residential garden soil samples in relation to the guideline levels for South Africa, Europe and the United States are presented in Table 4.7. The mean soil lead concentration in the total sample (n=99) was 47.6 mg/kg (SD 57.9 mg/kg), while the median was 30 mg/kg, the range was from below limit of detection to 340 mg/kg. Across both study sites, 1.0% of samples exceeded the South African guideline level of 230 mg/kg, while 2.0% exceeded the European guideline level of 200 mg/kg. In Walmer Township, 2.0% of samples exceeded the South African guideline level of 230 mg/kg, while 4.1% exceeded the European level of 200 mg/kg. Samples in Wells Estate were below the South African, European and United States guideline levels.

Table 4.7: Levels of lead in residential garden soil.

Lead (mg/kg)			
	Walmer Township N=49	Wells Estate N=50	Total sample N=99
Range	0-340	0-100	0-340
Mean (Standard deviation)	84.4 (60.8)	11.5 (19.6)	47.6 (57.9)
Median	60	0	30
%> South African guideline levels	2.0%	0%	1.0%
%> European guideline levels	4.1%	0%	2.0%
%> United States guideline levels	0%	0%	0%

Figure 4.14 gives a graphical presentation of the soil lead percentage distribution in the total sample, and by study site.

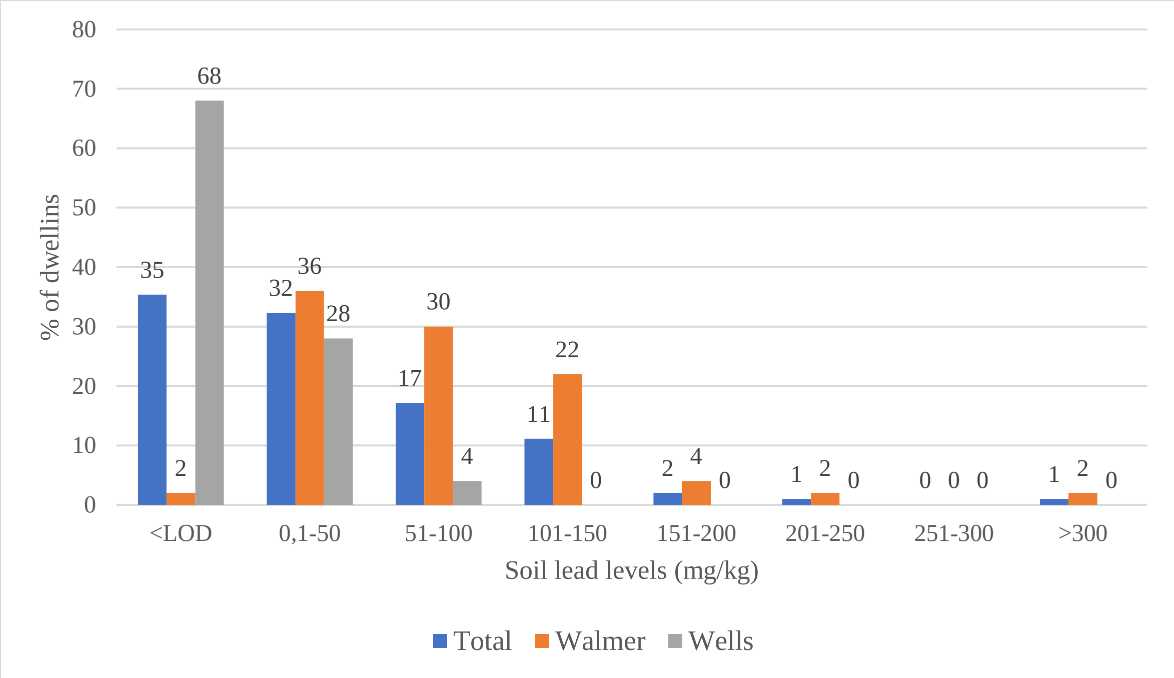

Figure 4.14: Soil lead distribution in the total sample, and by study site.

The distribution of the soil lead concentration levels in Walmer Township and Wells Estate are presented in Figures 4.15 and 4.16 respectively. The geographical information retrieved from the study sites was analysed using the Geographical Information System (GIS) to show the metal levels across both the study sites.

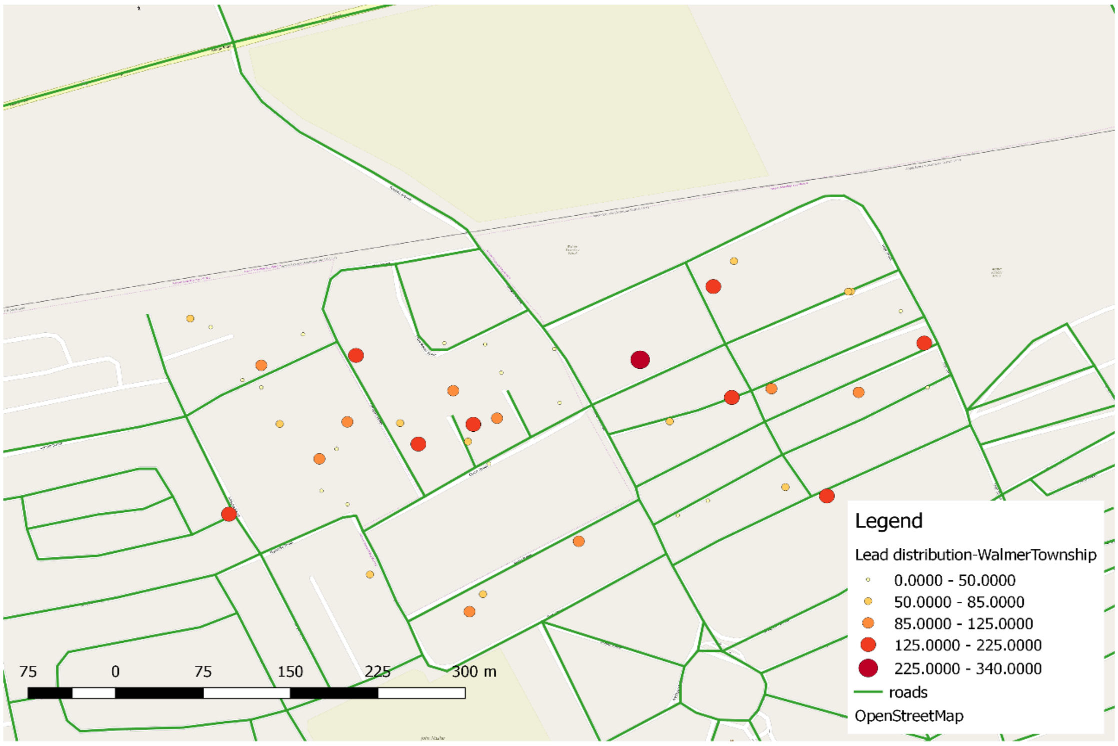

Figure 4.15: Distribution of soil lead levels in the total sample, and by study site.

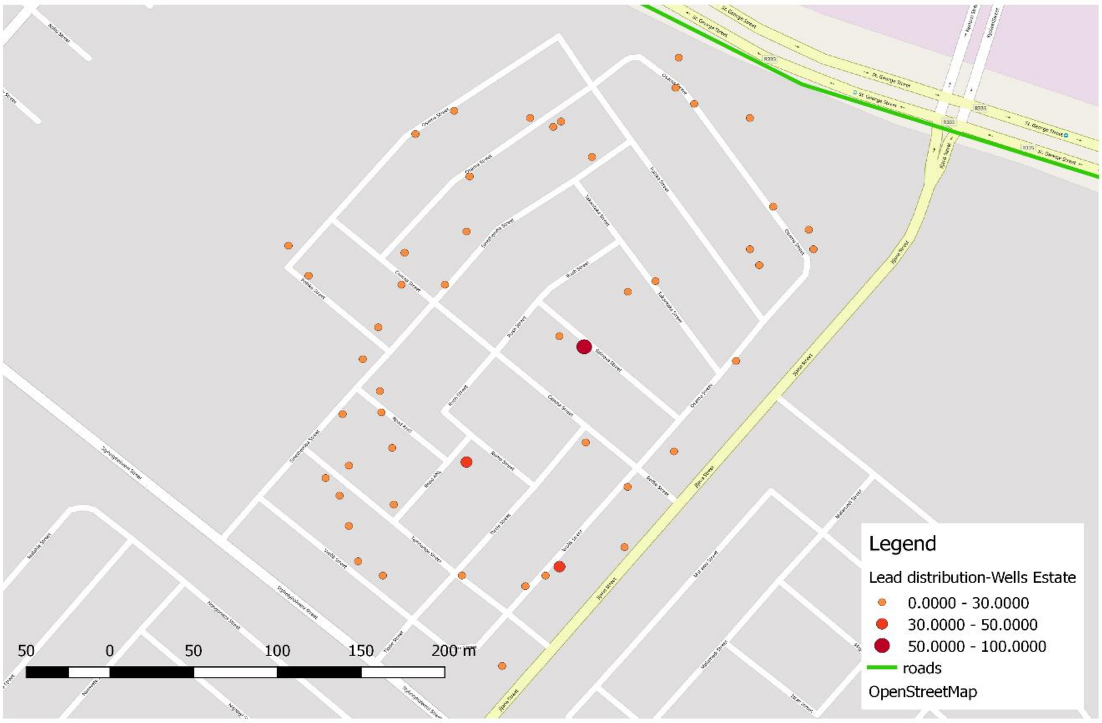

Figure 4.16: Lead soil concentration distribution in Wells Estate.

4.7.3 Arsenic concentrations in soil

The soil arsenic concentration presented in Table 4.8 gives the distribution of arsenic concentration in the residential garden soil samples in relation to the guideline levels of South Africa, Europe and the United State. The total sample (n=100) ranged from 0 to 50 mg/kg with the mean equalling 4.3 mg/kg (SD 6.6 mg/kg). Across both study sites, 1.0% of samples exceeded the South African guideline level of 47 mg/kg and European guideline level of 50 mg/kg, while 2.0% exceeded the USA guideline level of 11 mg/kg.

Table 4.8: Levels of Arsenic in residential garden soil.

Arsenic (mg/kg)			
	Walmer Township N=50	Wells Estate N=50	Total sample N=100
Range	0-50	0-20	0-50
Mean (Standard deviation)	5.4 (7.9)	3.4 (4.7)	4.3 (6.6)
Median	5	0	0
%> South African guideline levels	2.0%	0%	1.0%
%> European guideline levels	2.0%	0%	1.0%
%> United States guideline levels	2.0%	2.0%	2.0%

Figure 4.17 gives a graphical presentation of the soil arsenic percentage distribution in the total sample, and by study site.

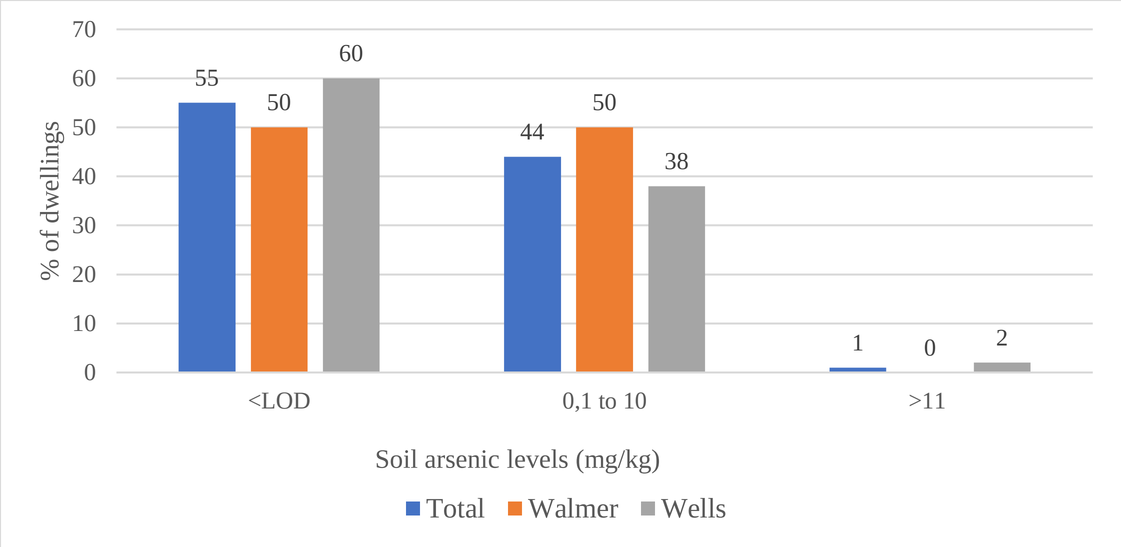

Figure 4.17: Distribution of soil arsenic levels in the total sample, and by study site.

The distribution of the soil arsenic concentration levels in Walmer Township and Wells Estate are presented in Figures 4.18 and 4.19 respectively. The geographical information retrieved from the study sites was analysed using the Geographical Information System (GIS) to show the metal levels across both the study sites.

Figure 4.18: Arsenic soil concentration distribution in Walmer Township.

Figure 4.19: Arsenic soil concentration distribution in Wells Estate.

4.8 Comparison and association of all soil metals concentration with health outcomes in the study sites.

4.8.1 Comparison of the soil metal concentrations in study sites

The Mann Whitney U test was used to compare the soil metal concentrations in the study sites. Levels of arsenic, lead and manganese in residential soil in Walmer Township were compared with that in Wells Estate. Statistically significant differences in lead (U=1527, p<0.0001) and manganese levels (U=2632, p<0.0001) were obtained between Walmer Township and Wells Estate. There was no statistically significant difference in arsenic levels (p=0.08583, U=16578) between the study sites.

4.8.2 Association between soil metal concentration and age of house, indoor and outdoor paint peeling

In the bivariate analysis, soil manganese level showed association with age of house (crude OR: 0.34, 95% CI: 0.14-0.83) in the total sample. Indoor and outdoor paint peeling also showed no association with heavy metals (Appendix 5).

4.8.3 Association between the soil metal concentrations and health outcomes

Tables 4.9 to 4.11 show the associations between the heavy metal concentration and dichotomous outcomes of respiratory symptoms and acute ill health symptoms. From the bivariate analysis in Walmer Township the odds of a member of the household having a dry cough was 4.57 times more likely in the presence of manganese exposure (OR: 4.57, 95% CI: 0.58-35.93) however, this result was not significant (p = 0.146). After adjusting for potential confounding factors in the multivariate analysis, soil manganese levels were significantly associated with dry cough (OR: 11.35, 95% CI: 1.08-119.20) and sneezing (OR: 11.30, 95%

CI: 1.09-116.67) (Table 4.9). In the bivariate analysis in Wells Estate, wet cough showed association with the manganese levels (OR: 0.34, 95% CI: 0.13-0.88). After adjusting for potential confounding factors in the multivariate logistic regression, manganese level was associated with wet cough (OR: 0.19, 95% CI: 0.05-0.70), the association was found to be consistent even after adjusting with potential confounding factors with other metals (OR: 0.19, 95% CI: 0.05-0.74). In the multivariate analysis dry cough was associated with the manganese level (OR: 0.22, 95% CI: 0.06-0.83), this result was found to be consistent even after adjusting with confounding factors with other metals (Table 4.9).

In general, acute ill health symptoms such as watery eye was significantly associated with the manganese level (OR: 4.02, 95% CI: 1.13-12.29). An increase in the odds (OR: 4.55, 95% CI: 1.01-20.58) was observed after adjusting for potential confounding factors in the multivariate analysis (Table 4.10).

Table 4.9: Odds ratio and 95% confidence interval for respiratory symptoms associated with lead, arsenic, and manganese after multivariate logistic regression model.

Respiratory symptoms	**Walmer Township**			**Wells Estate**		
	Arsenic (mg/kg)	**Lead (mg/kg)**	**Manganese (mg/kg)**	**Arsenic (mg/kg)**	**Lead (mg/kg)**	**Manganese (mg/kg)**
Wet cough						
Crude OR (C.I)	1.14 (0.45-2.85)	1.78 (0.71-4.49)	0.37 (0.05-2.95)	0.57 (0.23-1.41)	0.00	**0.34 (0.13-0.88)** *
Adjusted OR[a] (C.I)	0.93 (0.32-2.67)	1.64 (0.56-4.81)	0.30 (0.03-2.76)	0.64 (0.23-1.75)	0.00	**0.19 (0.05-0.70)** *
Adjusted OR[b] (C.I)	1.18 (0.37-3.81)	1.81 (0.59-5.55)	0.44 (0.03-5.49)	0.69 (0.24-1.97)	0.00	**0.19 (0.05-0.74)** *
Dry cough						
Crude OR (C.I)	1.32 (0.60-2.86)	1.33 (0.59-2.99)	4.57 (0.58-35.93)	0.67 (0.27-1.66)	0.00	0.38 (0.14-1.02)
Adjusted OR[a] (C.I)	1.67 (0.65-4.67)	1.53 (0.60-3.88)	**11.35 (1.08-119.20)** *	0.70 (0.25-1.96)	0.00	**0.22 (0.06-0.83)** *
Adjusted OR[b] (C.I)	1.07 (0.39-2.93)	1.04 (0.38-2.84)	9.12 (0.67-124.10)	0.79 (0.27-2.32)	0.00	**0.22 (0.06-0.86)** *
Sneezing						
Crude OR (C.I)	1.32 (0.60-2.86)	1.33 (0.59-2.99)	4.56 (0.58-35.92)	0.66 (0.24-1.79)	0.00	0.30 (0.04-2.41)
Adjusted OR[a] (C.I)	1.14 (0.56-3.52)	1.28 (0.51-3.25)	**11.30 (1.09-116.67)** *	0.13 (0.01-3.23)	0.00	0.32 (0.03-3.34)
Adjusted OR[b] (C.I)	0.88 (0.32-2.38)	0.91 (0.34-2.45)	10.16 (0.69-147.60)	0.36 (0.01-14.17)	0.00	0.38 (0.04-3.91)

*Significant at $p < 0.05$.

[a]Model for association of metal exposure with health symptoms adjusting with age, gender, educational status, dust, income, air pollution, smoking, mould, dampness, overcrowding.

[b]Model for association of metal exposure with health symptoms adjusting with age, gender, educational status, dust, income, air pollution, smoking, mould, dampness, overcrowding and heavy metals.

Table 4.10: Odds ratio and 95% confidence interval for acute ill health symptoms associated with lead, arsenic, and manganese after multivariate logistic regression model.

Acute ill health symptoms	Walmer Township			Wells Estate		
	Arsenic (mg/kg)	Lead (mg/kg)	Manganese (mg/kg)	Arsenic (mg/kg)	Lead (mg/kg)	Manganese (mg/kg)
Watery eye						
Crude OR (C.I)	1.29 (0.55-3.04)	0.99 (0.42-2.30)	3.35 (0.42-26.60)	3.31 (0.89-12.19)	0.00	**4.02 (1.31-12.29)** *
Adjusted OR[a] (C.I)	1.43 (0.53-3.83)	0.95 (0.36-2.56)	5.36 (0.60-47.72)	3.54 (0.84-14.96)	0.00	**4.55 (1.01-20.58)** *
Adjusted OR[b] (C.I)	1.01 (0.33-3.05)	0.78 (0.27-2.21)	3.43 (0.28-41.75)	3.29 (0.72-14.99)	0.00	4.31 (0.92-20.18)

*Significant at $p < 0.05$.

[a]Model for association of metal exposure with health symptoms adjusting with age, gender, educational status, dust, income, air pollution, smoking, mould, dampness, overcrowding.

[b]Model for association of metal exposure with health symptoms adjusting with age, gender, educational status, dust, income, air pollution, smoking, mould, dampness, overcrowding and heavy metals.

Table 4.11 shows the association between soil metal levels and the reported health outcomes in the total sample. From the bivariate analysis, dry cough (OR: 0.39, 95% CI: 0.21-0.73), sneezing (OR: 2.05, 95% CI: 1.09-3.83) and watery eye (OR: 3.35, 95% CI: 1.58-7.08) were significantly associated with soil manganese level. After adjusting with the potential confounding factors in the multivariate logistic regression, dry cough was significantly associated with manganese level (OR: 0.31, 95% CI: 0.16-0.64), the association remained consistent even after adjusting with the potential confounder and other metals. In the multivariate analysis sneezing was significantly associated with manganese level (OR: 2.18, 95% CI: 1.06-4.48), after adjusting with the potential confounding factors and other metals the odds increased to 2.23 times more likely of a member having dry cough in the presence of manganese (OR: 2.23, 95% CI: 1.07-4.61). Watery eye was also significantly associated with manganese level after adjusting (OR: 3.71, 95% CI: 1.63-8.48) with the confounders. After adjusting with the potential confounding factors and other metals, the odds decrease slightly (OR: 3.57, 95% CI: 1.52-8.37). There is no significant association between arsenic, lead and the health outcomes (Appendix 7).

Table 4.11: Odds ratio and 95% confidence interval for health outcomes associated with lead, arsenic, and manganese in total sample after multivariate logistic regression model.

Health outcomes	**Total sample**		
	Arsenic (mg/kg)	**Lead (mg/kg)**	**Manganese (mg/kg)**
Dry cough			
Crude OR (95% C.I)	0.74 (0.42-1.33)	1.05 (0.51-2.15)	**0.39 (0.21-0.73)** *
Adjusted OR[a] (95% C.I)	0.86 (0.46-1.61)	0.93 (0.41-2.09)	**0.31 (0.16-0.64)** *
Adjusted OR[b] (95% C.I)	0.96 (0.49-1.87)	0.68 (0.29-1.59)	**0.31 (0.15-0.63)** *
Sneezing			
Crude OR (95% C.I)	0.96 (0.53-1.76)	0.80 (0.38-1.66)	**2.05 (1.09-3.83)** *
Adjusted OR[a] (95% C.I)	0.84 (0.44-1.62)	1.16 (0.48-2.74)	**2.18 (1.06-4.48)** *
Adjusted OR[b] (95% C.I)	0.73 (0.36-1.43)	1.49 (0.61-3.63)	**2.23 (1.07-4.61)** *
Watery eye			
Crude OR (95% C.I)	1.68 (0.85-3.33)	0.68 (0.32-1.48)	**3.35 (1.58-7.08)** *
Adjusted OR[a] (95% C.I)	1.56 (0.75-3.25)	0.75 (0.31-1.82)	**3.71 (1.63-8.48)** *
Adjusted OR[b] (95% C.I)	1.48 (0.69-3.20)	1.01 (0.38-2.68)	**3.57 (1.52-8.37)** *

*Significant at $p < 0.05$.

[a]Model for association of metal exposure with health symptoms adjusting with age, gender, educational status, dust, income, air pollution, smoking, mould, dampness, overcrowding.

[b]Model for association of metal exposure with health symptoms adjusting with age, gender, educational status, dust, income, air pollution, smoking, mould, dampness, overcrowding and heavy metals.

4.8.3.1 Risk factors influencing health outcomes

Statistical analysis examining the influence of variables such as age, gender, educational status, dust, air pollution, smoking, mould, dampness, income, overcrowding was carried out to assess the possible risk factors influencing health outcomes.

Confounding factors such as mould (adjusted OR = 0.23; 95% CI: 0.07-0.73) and overcrowding (adjusted OR = 0.19; 95% CI: 0.05-0.63) were found to be strong predictors for dry cough in Walmer Township, while income (adjusted OR = 6.19; 95% CI: 1.15-41.29) was the strong predictor for wet cough in Wells Estate (Table 4.12).

For sneezing, variables such as mould in the house (adjusted OR = 0.21; 95% CI: 0.06-0.70) and air pollution (adjusted OR = 3.43; 95% CI: 1.15-10.20) were found to be strong predictors in Walmer Township, while age (adjusted OR = 0.24; 95% CI: 0.07-0.79) and overcrowding (adjusted OR = 13.75; 95% CI: 1.25-150.67) were the strong predictors in Wells Estate. Mould in the house (adjusted OR = 0.24; 95% CI: 0.06-0.87) was the strong predictor for watery eye in Walmer Township (Table 4.12).

Table 4.12: Odds ratio and 95% confidence interval of confounding factors after multivariate logistic regression model

Variables	Walmer Township		Wells Estate		Total sample	
	Crude OR (95% C.I)	Adjusted OR (95% C.I)	Crude OR (95% C.I)	Adjusted OR (95% C.I)	Crude OR (95% C.I)	Adjusted OR (95% C.I)
Dry cough						
Mould	**0.31 (0.14-0.71)** *	**0.23 (0.07-0.73)** *	0.80 (0.33-1.96)	0.69 (0.23-2.01)	1.44 (0.80-2.58)	1.61 (0.79-3.26)
Overcrowding	**0.41 (0.19-0.92)** *	**0.19 (0.05-0.63)** *	1.16 (0.40-3.37)	1.77 (0.45-6.95)	**1.92 (1.04-3.57)** *	**2.23 (1.11-4.48)** *
Wet cough						
Income	1.34 (0.45-3.99)	0.87 (0.24-3.14)	2.93 (0.85-10.09)	**6.19 (1.15-41.29)** *	1.77 (0.79-3.93)	0.86 (0.43-1.73)
Overcrowding	0.58 (0.18-1.82)	0.84 (0.18-3.91)	0.15 (0.02-1.16)	0.17 (0.02-1.52)	**0.36 (0.14-0.96)** *	0.38 (0.14-1.04)
Sneezing						
Age	0.94 (0.43-2.03)	0.92 (0.37-2.26)	**0.31 (0.10-0.91)** *	**0.24 (0.07-0.79)** *	0.63 (0.35-1.16)	0.62 (0.33-1.17)
Mould	**0.37 (0.16-0.84)** *	**0.21 (0.06-0.70)** *	1.13(0.41-3.11)	0.75 (0.19-3.00)	0.73 (0.39-1.36)	0.61 (0.28-1.27)
Dampness	**0.45 (0.21-0.99)** *	0.96 (0.32-2.83)	0.95(0.34-2.62)	0.82 (0.22-3.06)	0.59 (0.32-1.07)	0.64 (0.34-1.40)
Overcrowding	0.81 (0.35-1.88)	0.31 (0.08-1.17)	4.18(0.53-32.96)	**13.75 (1.25-150.67)** *	1.06 (0.52-2.18)	0.97 (0.44-2.12)
Air pollution	1.96 (0.89-4.32)	**3.43 (1.15-10.20)** *	2.23(0.82-6.10)	3.07 (0.93-10.17)	**2.27 (1.23-4.19)** *	**2.76 (1.39-5.50)** *
Watery eye						
Mould	0.49 (0.20-1.23)	**0.24 (0.06-0.87)** *	0.88 (0.31-2.56)	1.23 (0.35-4.29)	0.77 (0.39-1.51)	0.58 (0.26-1.29)

* Significant at $p < 0.05$.

4.9 Case study of house with elevated soil lead concentration

Table 4.13 gives the distribution of lead concentration in the garden soil samples (taken in May 2018) in relation to reference levels of South Africa, Europe and the United States as well as the mean for the study sample. The mean lead level of samples taken in May 2018 (1277.9 mg/kg) was 19.8% less than the mean value obtained in May 2017 (1595 mg/kg).

Lead soil concentrations ranged from 571 to 1669 mg/kg across the total sample in the residential garden, and the mean and median soil lead levels respectively equalling 1277.9 mg/kg (SD 426.5) and 1494.7 mg/kg. Across the sample site, 100% of the sample exceeded the South African (230 mg/kg), European (200 mg/kg) and the United State guideline level of 400 mg/kg. Figure 4.22 gives the percentage distribution of soil lead concentrations for the study sample. During home interviews conducted with the dwelling respondent, it emerged that a cottage industry activity involving the use of heavy metals took place in the dwelling. The cottage industry operating in the dwelling was the collection of scrap metals and coal burning was observed in the soil in different part of the dwelling at the time of sampling. The dwelling is 56 years old with cracks in the wall of the house with faded and peeling paint both indoors and outdoors.

An investigation into the educational status of the occupants of the dwelling indicated that 29% of a household had primary education and 71% of a household had secondary education. Household income from informal jobs ranged between R1001-R5000. Soil samples taken from the house indicated that the garden at the side of the building (with a concentration of 1669 mg/kg) was worst affected (Figure 4.22). A total of seven people lived in the house, of these four persons had health related issues. The distribution of health issues of those affected revealed that 50% had fever, 25% had chest pain and 25% had headache.

Table 4.13: Descriptive statistics of soil lead levels in the house with elevated concentration.

Lead concentration (mg/kg) (N=7)	
Range	571-1669
Mean	1277.94 (426.58)
Median	1494.7
%> South African guideline levels	100%
%> European guideline levels	100%
%> United States guideline levels	100%

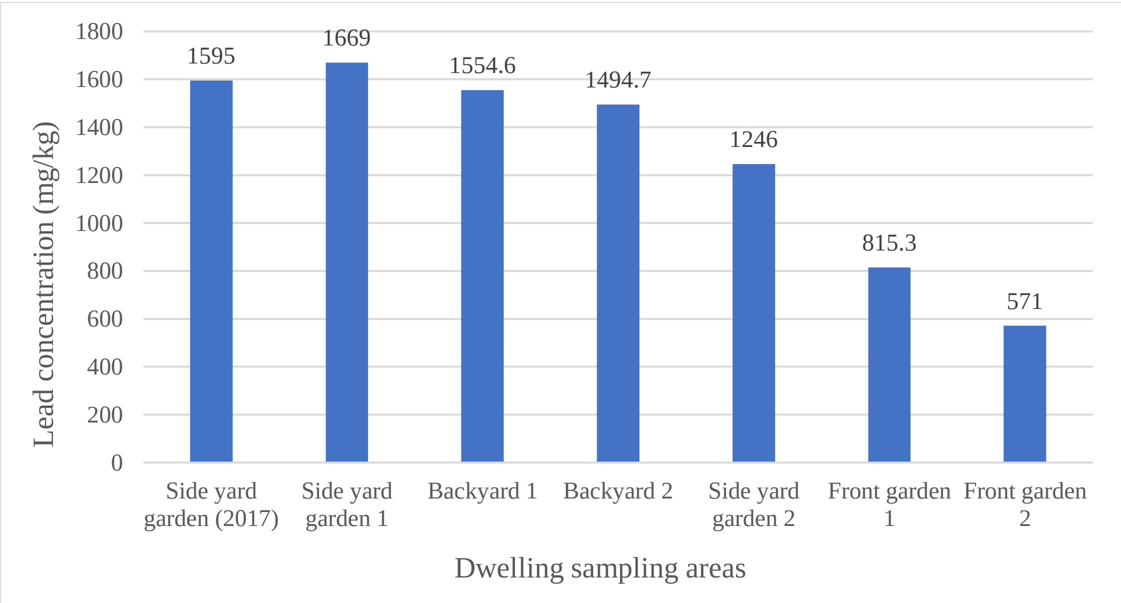

Figure 4.20: Distribution of lead soil concentration in the garden soil

Chapter 5

DISCUSSION

This chapter discusses the results of the demographics, housing conditions, levels of heavy metals (manganese, lead and arsenic) and health outcomes that are associated with exposure to the levels of heavy metals in the study population.

This present study is aimed at assessing and comparing the levels of lead, arsenic and manganese in the residential garden soil of Wells Estate and Walmer Township, sources of selected heavy metals, determining if the sites are deemed contaminated on the basis of existing soil guideline levels from such as the United States Environmental Protection Agency, South Africa, and Europe, and to check for possible associations between selected soil heavy metal levels and surveyed health outcomes.

5.1 Distribution of soil metal level and activities

In this study, it was found that the levels of soil metal concentrations (manganese, lead and arsenic) varied significantly across and within the selected study sites and samples. Similar soil texture was observed across all study samples. Most of the residential gardens in Walmer Township (90%) and Wells Estate (92%) had no observable activities. However, children's day care playground facilities (2%) and spilled spent oil (2%) were found in Wells Estate and Walmer Township, respectively.

5.2 Manganese

The mean soil manganese concentrations (238.5 mg/kg) in this study across all study samples were found to be lower than the South Africa guideline level of 1500 mg/kg and the USA guideline level of 630 mg/kg. The soil manganese levels of 238.5 mg/kg across all study samples are lower in comparison with soil manganese levels elsewhere. For example, a study undertaken in Nigeria showed that manganese levels were generally high but within the safe levels with a mean of 132 mg/kg (Okunola, Uzairu & Ndukwe 2007). In a similar study conducted in Southern Brazil, a mean soil manganese level of 1,235.9 mg/kg was reported (Hermes et al. 2013). The authors concluded that mining operations played a significant role in soil manganese levels. Hence, there is a strong relationship between soil manganese levels and anthropogenic activity.

A further study conducted around a closed ferromanganese plant outside of Montreal in Canada showed mean soil concentrations of 6232±5100 mg/kg (Pavilonis et al. 2015). Despite the plant being closed, manganese concentrations were still elevated compared to guideline values, which shows the persistent effect of metal contamination in the environment. A study conducted in the Valcamonica region of Northern Italy (Barceloux 1999) showed that the mean soil manganese level within 0.5 km of all ferroalloy plants was 4600 ± 7400 mg/kg which is one to two orders above the average range of manganese found in typical uncontaminated soil (40–900 mg/kg) (Barceloux 1999).

Studies have shown elevated manganese concentrations in residential soil close to metal related industry. For example, a study undertaken in Canada showed that atmospheric concentrations of manganese 800 m from a ferromanganese plant were approximately three times higher than the USEPA reference concentration. It was concluded that manganese dust from the ferromanganese plant was re-suspended in the surrounding community (Boudissa et al. 2006). According to the study reported by Pavilonis et al. (2015), distance to the nearest plant and geographic localization contributed largely to the variability in manganese concentrations, and in other studies, variables such as cigarette smoke (Crump 2000), motor vehicle traffic (Lynam et al. 1999), and low socioeconomic status (Chattopadhyay, Lin & Feitz 2003) also affected soil manganese concentration. The prevalence of soil manganese levels in residential areas with heavy traffic could be closely linked to a manganese containing fuel additive, methylcyclopentadienyl manganese tricarbonyl (MMT), that was introduced to automobile fuel formulas as an octane boosting and ''anti-knock'' agent, thus either replacing or reducing the lead content in petrol. MMT has been officially approved for use by the governments of Argentina, Australia, Bulgaria, the United States, France, and Russia, and conditionally in New Zealand (Health Canada 2003). Multivariate analysis in this study also showed that sneezing, dry cough and watery eye were all associated with increased soil manganese levels. Exposure to manganese has been shown to have detrimental effects on the lungs and the brain (Lucchini et al. 1995; Mergler et al. 1994).

It is evident from this study that manganese concentrations in Walmer Township were significantly different to the levels obtained in Wells Estate ($p<0.0001$). Thus, this investigation found considerable variation in the distribution of soil manganese concentrations in the study samples with higher levels observed in Wells Estate, which is relatively close to Coega and Markman industrial areas compared to Walmer Township. Industrial activities such as recycling of metals scraps; laser welding; production of steel, cast iron, catalytic converters, car exhausts, silencer shells, gearbox tubing; cement, bricks, automotive seating and electrical parts, high-quality synthetic metal oxide and truck sales took place in the industrial areas at the time of the study. Hence, it is highly probable that a substantial proportion of the observed soil manganese concentration in Wells Estate may be due to the combined activities of motor vehicle traffic and industrial activities. It is expected that further increases in soil manganese distribution amongst study samples will be seen due to increased industrial activities in the industrial zone of Port Elizabeth, additional effort will be needed to monitor and control the amount of respiratory manganese released into the environment.

5.3 Lead

Overall, this study found soil lead concentrations in Walmer Township to be significantly different to levels obtained in Wells Estate ($p<0.0001$). The assessment of lead levels across both study sites indicated that 1.0% of all samples exceeded the South Africa guideline level of 230 mg/kg, and 2.0% exceeded the European guideline level of 200 mg/kg. The mean soil lead concentration in Wells Estate (11.5 mg/kg) is more comparable with that determined in the United States (10 mg/kg) (Shacklette & Boerngen 1984). In another study, rural topsoil in South Carolina in the United States of America gave a mean soil lead concentration of 12 mg/kg (Aelion et al. 2008). The soil lead concentrations in the study sites (especially in Wells Estate) are much lower than those determined in rural and urban settings of some developing countries. For example, a study undertaken in some major suburbs of Southern Nigeria in 2007 and 2008 showed mean lead soil levels of 120.00 and 80.36 mg/kg in Onitsha for 2007 and 2008 respectively, mean lead soil levels of 33.40 and 4,238.29 mg/kg in Nnewi for 2007 and 2008 respectively and mean lead soil levels of 22.56 and 21.28 mg/kg for 2007 and 2008 respectively in Aba (Nduka & Orisakwe 2010).

Scientists have reported that soil lead levels decrease with nearness to high traffic roads (Manta et al. 2002). A similar finding was reported by other researchers (Olowoyo, Van Heerden & Fischer 2013; Gülser & Eraydın 2004). In another study, three different soil locations of Van province in Turkey in which there was heavy traffic, indicated that the concentration of lead in soil decreases from the initial point (busy road) to samples collected at 15 m and 30 m away from the roadside (Gülser & Eraydın 2004).

Particulates derived from lead-based paint are reported as a major source of lead in residential garden soils and this was evident from the study reported by Clark, Hausladen & Brabander (2008). They reported that elevated lead levels in garden soil were associated with homes built more than 40 years ago prior to the ban of paint containing > 0.06% lead (Clark, Hausladen & Brabander 2008). Interestingly, there was no association between lead and the age of the house across both the study sites (p=0.143). A possible explanation for this finding may be due to the observed moderate outdoor paint peeling (51%) as well as atmospheric transport of lead dust by wind (a constant climatic condition) in Port Elizabeth.

The inconsistent distribution of lead concentrations in residential soil of the study samples showed that even residential gardens located close to each other could have divergent concentrations. A study conducted in West Oakland, USA showed that lead levels could vary significantly from plot to plot within a neighbourhood (McClintock 2011). Together, Walmer Township, Wells Estate and West Oakland findings indicated that a common, single point source was likely not the most influential contributor of lead. Thus, residential cottage industrial activities could be a major factor contributing to the observed levels.

5.4 Arsenic

The current study found higher mean arsenic levels in Walmer Township (5.4 mg/kg) compared to Wells Estate (3.4 mg/kg), with the concentrations not statistically different (p>0.100). A similar investigation that was conducted in other suburbs of South Africa such as in Riverlea (18.3 mg/kg), Bertrams (5.3 mg/kg), Braamfischerville (4.6 mg/kg) and Hospital Hill (3.7 mg/kg) have shown high levels of arsenic, and in some instances are comparable, (Mathee et al. 2018). Preliminary investigations from the study by Mathee et al. (2018) indicated that arsenic levels in the suburb of Riverlea were due to the nearby mine tailings facilities. The absence of such mining activities in the current study might have contributed to the observed low levels.

5.5 The Influence of cottage industries on garden soil

Cottage industry activities such as repairing of motor vehicles, repairs to electrical appliances using lead solder and welding, are informal sectors which play a key role in the socioeconomic development of a household and may also put household members at high risk of exposure to toxic metal (Ligthelm, 2004). In this study, there were more metal-related cottage industry activities (31%) compared to non-metal-related cottage industry activities (24%) such as hair dressing across the total sample. The study further found that metal-related cottage industry activities in Wells Estate (37%) were lower compared to Walmer Township (30%). Metal-related cottage industry activities in the studied communities included: welding, scrap metal recycling, fixing electrical appliances and the making of metal jewellery. Lead-related activities were being undertaken on the plot with the highest soil lead concentrations of 1595 mg/kg, and this was above the guideline levels. This study also found that soil heavy metal levels increased on the plot with metal- related cottage industry activities, such as in the case of the household involved in scrap metal collection and recycling activities, although this was not confirmed with the multivariate model. In this study other cottage industrial activities such as poultry keeping (4%), vegetable gardening (4%) and activities of mechanics (4%) were observed across all study sites. In vegetable gardening, fertilizers are usually used to improve plant growth. A study reported by Atarfar et al. (2010) found that the concentrations of lead and arsenic in garden soil increased from 5.89 mg/kg to 26.40 mg/kg after the application of fertilizers. Also, activities of mechanics may result in the spillage of motor oil into the soil (Zali et al. 2015).

5.6 Risk factors for health-related outcomes

It is evident from this study that contributing factors such as age, income, air pollution, smoking, mould and overcrowding may influence health outcomes.

5.6.1 Age

The current study shows that age group within the bracket of 0 to 5 years was higher in Wells Estate (8%) compared to Walmer Township (5%), thus indicating that there are more children in the study sites of Wells Estate. In the multivariate analysis, age of the population was a strong predictor for sneezing with negative associations in Walmer Township (adjusted OR= 0.31; 95% CI: 0.10-0.91) and Wells Estate (adjusted OR = 0.24; 95% CI: 0.07-0.79). This suggested that as the age of the study population increase, sneezing health symptoms decrease. The study performed by Maddaloni et al. (1998) reported that children were more vulnerable to heavy metal exposure due to their high absorption rate, small body size, and developing nervous system (Maddaloni et al. 1998). These findings, however, cannot be compared to this study as heavy metal exposure was not measured.

5.6.2 Socio-economic Status

Variations of socioeconomic status were evident in study sites. The study showed that income was positively associated with wet cough (adjusted OR = 6.19; 95% CI: 1.15-41.29) in Wells Estate, suggesting an increase in income could prevent increased wet cough symptoms. The findings of the current study are in agreement with the study by Adler & Newman (2002), who reported that low socioeconomic status is associated with lack of adequate health care, thereby leading to health-related diseases. In a related study, Winkleby et al. (1992) and Elo & Preston (1996) revealed that low education and employment attainment are strongly correlated with health-related diseases through a number of pathways such as lifestyle, health behaviour, social relations and self-esteem. The low income status (no income to less than R 1000 per month), of 40% in Walmer Township (n =20) and 58% in Wells Estate (n=29) may give an indication for the low number of households with medical aid across the entire study sample (10% in Walmer Township (n =5) compared to 5% in Wells Estate (n=3)). However, the association between income status and homes with medical aid was not measured in this study.

5.6.3 Housing Conditions

This study found that visible defects and perceived problems such as wall cracks, peeling paint, air quality and moisture were similar across the total sample. In the multivariate analysis, mould in the house was a predictor for sneezing (adjusted OR = 0.21; 95% CI: 0.06-0.70) and watery eye (adjusted OR = 0.24; 95% CI: 0.06-0.87) in Walmer Township. The relationships were negative, suggesting that increases of mould in the house, may not contribute to sneezing and watery eye. However, these associations were in contrast with other investigations. Atcheson (1991) reported that moulds are responsible for respiratory problems such as asthma, rhinitus, aveolitus and other allergies. The flow of outdoor air related properties such as odour, ventilation and air pollution into a building influences indoor environmental quality (Awbi 2002). In this study, air pollution (adjusted OR = 3.43; 95% CI: 1.15-10.20) was a strong predictor for sneezing in Walmer Township and across the entire sample (adjusted OR = 2.76; 95% CI: 1.39-5.50). This positive association suggests that increases in air pollution leads to increases in sneezing. These findings are in agreement with the outcomes of other investigations (Awbi 2002). WHO noted in their report: “Inadequate ventilation which leads to poor air quality gives rise to higher risk of airborne infectious disease transmission, including tuberculosis, as well as the accumulation of indoor pollutants and dampness” (World Health Organization, 2010, p.17.).

5.6.4 Overcrowding

In the multivariate analysis, overcrowding in the main dwelling was a strong predictor and was positively associated with sneezing (adjusted OR = 13.75; 95% CI: 1.25-150.67) in Wells Estate. Similarly, overcrowding in the main dwelling was positively associated with dry cough across the entire study sample (adjusted OR = 2.23; 95% CI: 1.11-4.48). These positive associations suggest that an increase in overcrowding within the main dwelling may have contributed to sneezing and dry cough at the time of the study. These associations were similar to those reported in other investigations. For example, Rosenberg et al. (1997) reported that crowded living conditions are often associated with increased infectious disease transmission spread mainly by the respiratory route, such as tuberculosis, fever, runny nose, coughing and sneezing. Clearly, living in a crowded house is hazardous to public health.

Chapter 6

CONCLUSION

6.1 Conclusion

The results of this study indicate that the mean concentrations of lead and arsenic in soil samples of Walmer Township are higher compared to Wells Estate. By contrast, mean manganese level was much higher in Wells Estate, compared to Walmer Township. Lead and manganese were significantly different ($p<0.0001$) levels across all study samples. This variation is most likely a collective impact of age of house, cottage industrial activities as well as the proximity to Coega and Markman industrial areas.

Soil metal concentrations in most of the study sample in Walmer Township and Wells Estate were below the guideline limit recommended by the United States, Europe and South Africa. Cottage industry activities may be the significant contributor to elevated soil heavy metal guideline levels. For example, a dwelling involved in scrap metal collection and recycling activities gave the highest soil lead concentration in this study.

Results from multiple logistic analyses showed a strong association between manganese and dry cough and sneezing in Walmer Township, while significant association was found between manganese and watery eye in Wells Estate. There were no evidences of association between soil heavy metal and gastrointestinal symptoms, chronic diseases and mental illness. Contributing variables such as age, income, air pollution, smoking, mould and overcrowding were observed to be the major predictors to wet cough, dry cough, watery eye and sneezing.

6.2 Study weakness

This study was conducted to assess the level of heavy metals and associated health risks in the suburbs of Walmer Township and Wells Estate in the city of Port Elizabeth. The cross-sectional design has limited the ability to account for seasonal variations that might have influenced certain health outcomes. For example, seasonal changes in the climatic condition (summer and winter) are likely to affect acute respiratory symptoms. The soil metal safe level information to estimate exposure levels was relied upon, however, the safe level of manganese could not be ascertained: the soil manganese median levels were used. Lastly, the size of the soil sample collected relative to the study population is small.

6.3 Strengths

Known contributors such as age, gender, educational status, dust, air pollution, smoking, mould, dampness, income, and overcrowding were considered by adjusting exposure effects using multiple logistic analysis. Also, the use of (i) valid, specific, and reliable analytical instruments as well as (ii) data collection in the primary study, strengthened this analysis.

6.4 Recommendations

1. Effective legislation and detection of areas within communities where there are higher levels of heavy metals are necessary.
2. Manufacturing and cottage industry activities contribute to soil heavy metal levels thus leading to health risks. Public health education programmes on the diverse sources of heavy metals and health risks should be carried out in communities.

6.5 Suggestions for further research work

1. The cross-sectional design which limited the ability to account for seasonal differences that might have influenced certain health outcomes, especially respiratory outcomes, should be considered in further studies.

2. Metal samples in the air should also be analysed to ascertain the level of heavy metal in the air. Plant samples around study communities should also be analysed.

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APPENDICES

Appendix 1

Soil sampling observation sheet

Wells Estate

Date	
Sampling Area	Front yard (**FY**), back yard (**BY**), garden (**GA**), playground (**PG**), lawn (**LA**), planting bed (**PB**).
Soil Colour	Grey(**G**), Yellow (**Y**), Brown(**BR**), Dark brown(**DBR**), Black(**BL**), Red(**R**)
Soil Types	Sandy (**S**), Loamy (**L**) and Clay (**C**)
Soil Texture	Fine (**F**), Very fine (**VF**), Coarse (**C**), Silt (**S**), Gravel (**G**)

	Sampling Area	**Soil Color**	**Soil Type**	**Soil Texture**	**Environmental Activities**
1	GA	DBR	L	F	Vegetable garden
2	BY	BR	L	F	No observable physical activities
3	BY	BR	L	F	Close to the high way
4	FY	DBR	L	G	No observable physical activities
5	BY	DBR	L	F	No observable physical activities
6	GA	BL	L	F	Vegetable garden
7	BY	Y	S	C	Construction going on beside the house
8	FY	BR	S	C	No observable physical activities
9	FY	BR	L	F	Close to the high way and construction going on in the house
10	BY	BL	L	F	No observable physical activities
11	PG	BR	S	S	Children's day care playground
12	FY	BR	S	S	No observable physical activities
13	FY	BR	S	S	No observable physical activities

14	BY	BR	S	C	No observable physical activities
15	BY	G	S	F	No observable physical activities
16	GA	DBR	S	S	Vegetable garden
17	GA	BR	S	S	No observable physical activities
18	BY	BR	S	S	Mechanic activities
19	FY	DBR	S	F	No observable physical activities
20	FY	BR	S	F	No observable physical activities
21	FY	G	S	VF	No observable physical activities
22	FY	BR	L	F	No observable physical activities
23	FY	G	S	C	No observable physical activities
24	BY	Y	S	C	No observable physical activities
25	FY	BR	S	C	No observable physical activities
26	FY	BR	S	F	No observable physical activities
27	FY	Y	S	C	No observable physical activities
28	FY	G	S	F	No observable physical activities
29	FY	BR	S	S	No observable physical activities
30	FY	DBR	S	F	No observable physical activities
31	FY	BR	S	F	No observable physical activities
32	FY	G	S	F	No observable physical activities
33	FY	BR	S	F	No observable physical activities
34	FY	BR	S	VF	No observable physical activities
35	FY	DBR	S	S	Vegetable farming activities
36	FY	BR	S	F	No observable physical activities
37	FY	DBR	L	F	No observable physical activities
38	FY	Y	C	S	No observable physical activities

39	FY	BR	L	S	No observable physical activities
40	BY	DBR	C	S	No observable physical activities
41	FY	DBR	S	C	Vegetable garden in the compound
42	FY	DBR	S	C	No observable physical activities
43	GA	DBR	L	F	No observable physical activities
44	GA	BR	S	F	No observable physical activities
45	GA	BL	L	F	No observable physical activities
46	FY	DBR	S	C	No observable physical activities
47	FY	DBR	S	F	No observable physical activities
48	BY	DBR	S	C	No observable physical activities
49	FY	DBR	S	F	No observable physical activities
50	BY	DBR	S	C	No observable physical activities

Soil sampling observation worksheet

Walmer Township

Date	
Sampling Area	Front yard (**FY**), back yard (**BY**), garden (**GA**), playground (**PG**), lawn (**LA**), planting bed (**PB**).
Soil Colour	Grey(**G**), Yellow (**Y**), Brown(**BR**), Dark brown(**DBR**), Black(**BL**), Red(**R**)
Soil Types	Sandy (**S**), Loamy (**L**) and Clay (**C**)
Soil Texture	Fine (**F**), Very fine (**VF**), Coarse (**C**), Silt (**S**), Gravel (**G**)

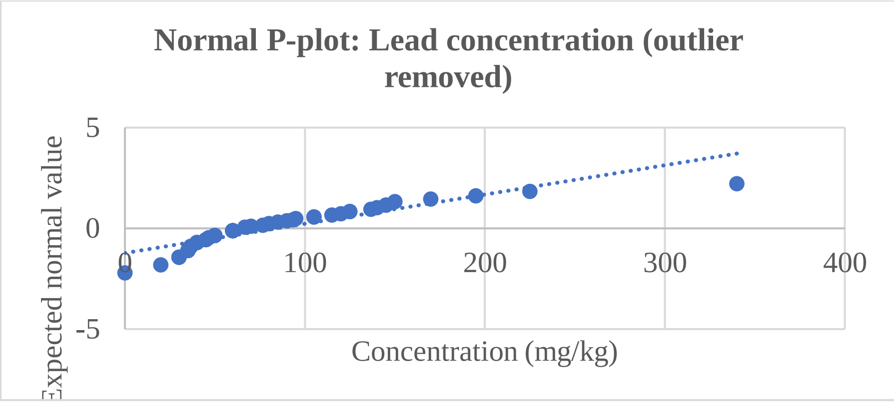
	Sampling Area	**Soil Color**	**Soil Type**	**Soil Texture**	**Environmental Activities**
1	FY	G	S	C	No observable physical activities
2	FY	DBR	S	F	No observable physical activities

3	Side	BR	S	F	No observable physical activities
4	PG	BR	S	F	No observable physical activities
5	FY	DBR	S	VF	No observable physical activities
6	FY	BR	S	F	No observable physical activities
7	FY	DBR	S	F	No observable physical activities
8	BY	BR	S	F	No observable physical activities
9	FY	G	S	F	No observable physical activities
10	Side	G	S	F	Vegetable garden
11	FY	BR	S	F	No observable physical activities
12	Side	BR	S	C	No observable physical activities
13	FY	BR	S	F	No observable physical activities
14	FY	BR	S	F	Poultry farming
15	Side	BR	S	F	No observable physical activities
16	BY	DBR	S	S	No observable physical activities
17	FY	BR	S	F	No observable physical activities
18	FY	BR	S	F	No observable physical activities
19	FY	BR	S	F	No observable physical activities
20	GA	BR	S	F	No observable physical activities
21	BY	DBR	L	F	Spent oil spill on the soil
22	FY	G	S	F	No observable physical activities
23	FY	BR	S	VF	No observable physical activities
24	Side	BR	S	F	No observable physical activities

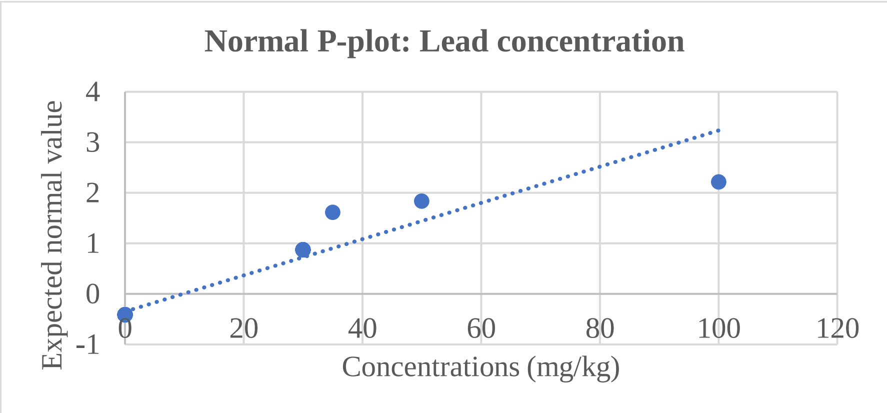
25	BY	BR	S	F	No observable physical activities
26	FY	BR	S	F	No observable physical activities
27	FY	G	S	VF	No observable physical activities
28	BY	DBR	S	F	Poultry farming and vegetable garden
29	FY	BR	S	F	Farming (vegetable garden)
30	BY	Y	S	C	No observable physical activities
31	FY	BR	S	F	No observable physical activities
32	FY	BR	S	F	No observable physical activities
33	BY	BR	S	F	No observable physical activities
34	FY	BR	S	F	No observable physical activities
35	G	BR	S	F	No observable physical activities
36	FY	BR	S	F	No observable physical activities
37	Side	BR	S	F	No observable physical activities
38	BY	BR	S	F	No observable physical activities
39	G	DBR	S	F	No observable physical activities
40	FY	BR	S	F	No observable physical activities
41	BY	DBR	S	F	No observable physical activities
42	FY	DBR	S	F	No observable physical activities
43	G	DBR	L	F	No observable physical activities
44	BY	BR	L	F	No observable physical activities
45	G	DBR	L	F	No observable physical activities
46	FY	BR	S	F	No observable physical activities

47	BY	DBR	S	F	No observable physical activities
48	FY	BR	S	F	No observable physical activities
49	G	DBR	L	F	No observable physical activities
50	FY	BR	S	F	No observable physical activities

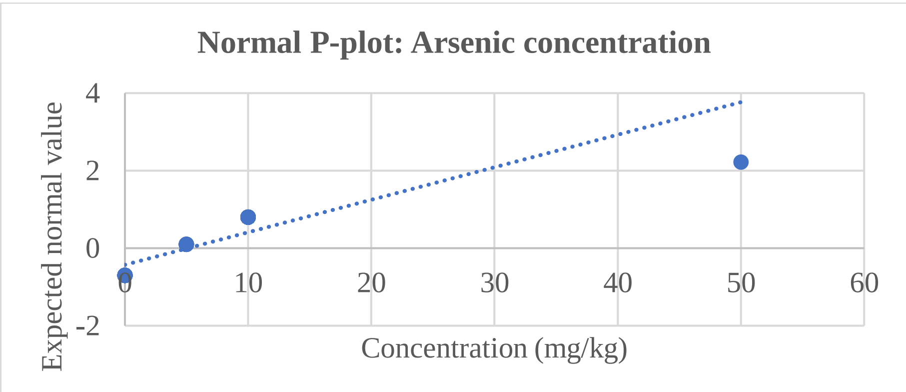
<u>Appendix 2</u>: Normality plots.



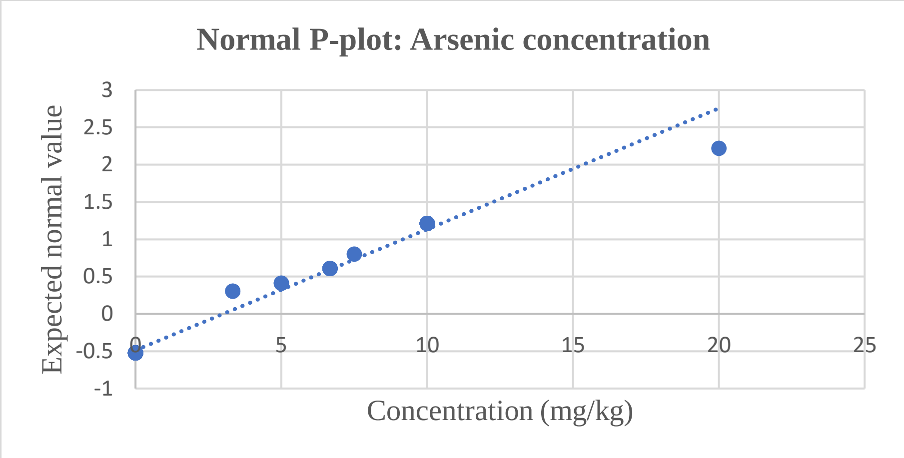
Normality test for lead concentration (mg/kg) in Walmer Township (p=0.00001)



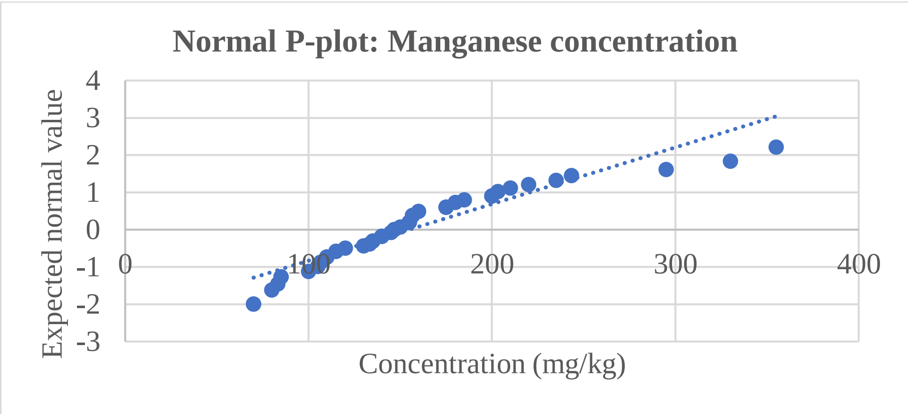
Normality test for lead concentration (mg/kg) in Wells Estate ($p<0.00001$).



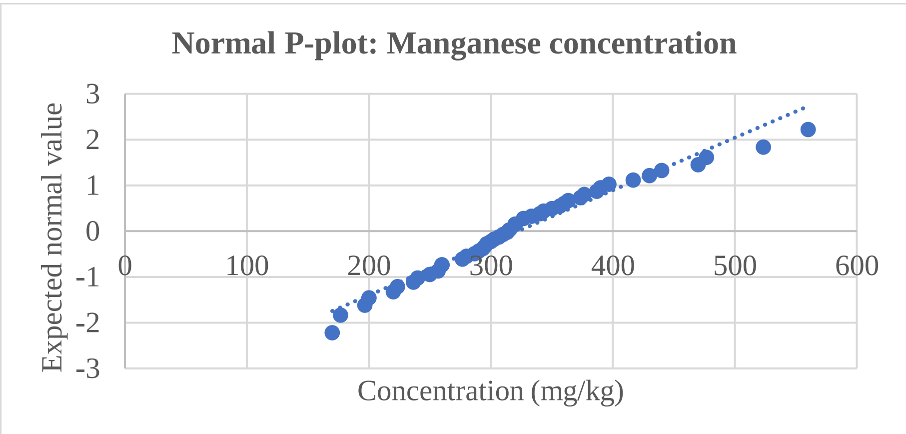
Normality test for arsenic concentration (mg/kg) in Walmer Township ($p<0.0001$).



Normality test for arsenic concentration (mg/kg) in Wells Estate (p<0.00001).



Normality test for manganese concentration (mg/kg) in Walmer Township(p=0.0045).



Normality test for manganese concentration (mg/kg) in Wells Estate (p=0.185).

Appendix 3: Consent form.

CONSENT FORM

Participant's Name:	
Contact telephone number:	
Study identification number:	

I………………………………………………………………………………………………

(Participant's Name)

hereby agree to participate in the **THE IBHAYI ENVIRONMENTAL HEALTH STUDY** undertaken by the Medical Research Council and the Nelson Mandela Metropolitan University.

The research objectives have been explained to me and I understand that I will be interviewed on issues regarding air quality in my home and neighbourhood and my and my family's health.

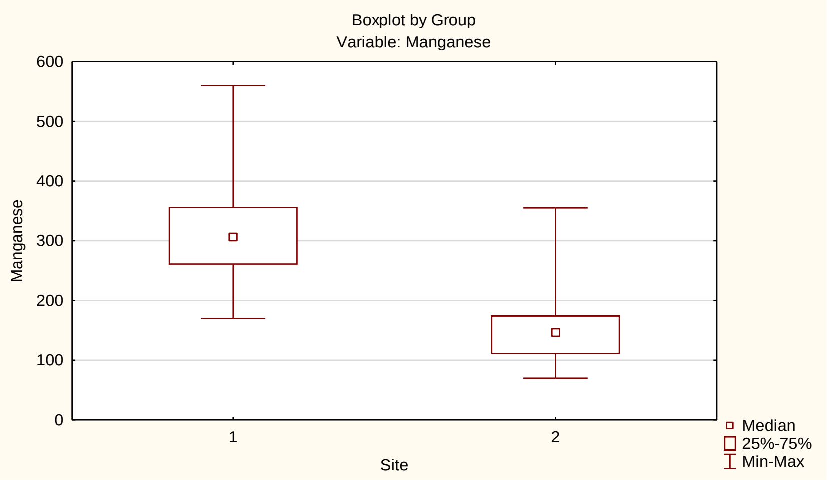
I have been informed that everything I say in this interview will be confidential; my name will not be attached to what I say. So nobody will know what I said. The information will be used for research purposes only.

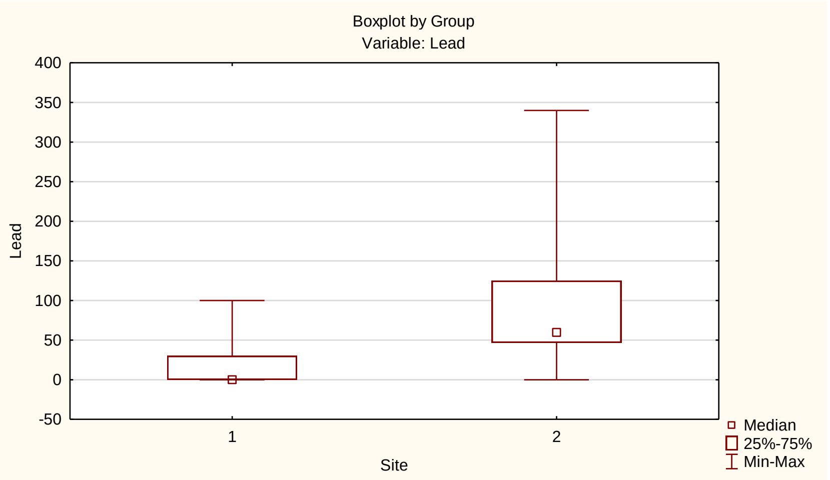
I acknowledge that the results of this research project may be published in medical and scientific journals; however, my name will not be mentioned. The results will be reported only as a group.

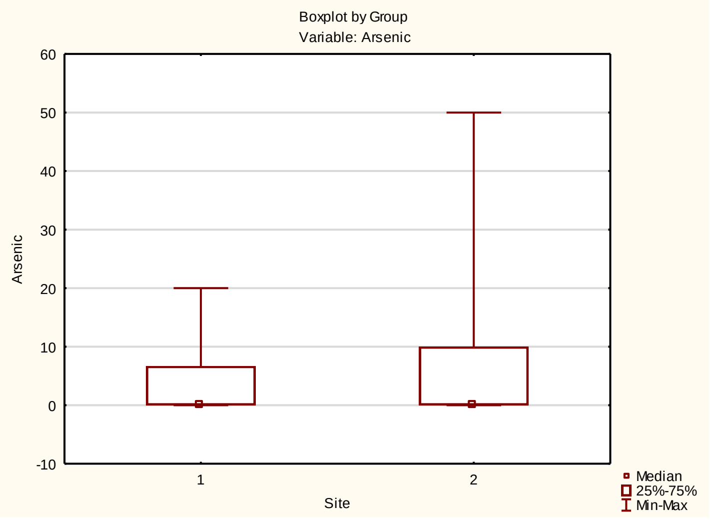
I understand that my participation is voluntary, and that I am free to withdraw from the project at any time without giving any reasons.

Signature: …………………… Date:________/______/17

<u>Appendix 4</u>: Mann Whitney box plots for soil metal concentrations







Appendix 5: Odds ratio and 95% confidence interval for age of house, indoor and outdoor paint peeling associated with lead, arsenic, and manganese in the bivariate logistic regression model.

	Age of house OR (95% CI)	**Indoor paint peeling OR (95% CI)**	**Outdoor paint peeling OR (95% CI)**
Walmer Township			
Arsenic	1.63 (0.52-5.15)	0.88 (0.27-2.79)	0.74 (0.23-2.35)
Lead	1.03 (0.32-3.36)	1.09 (0.33-3.62)	1.35 (0.41-4.44)
Manganese	0.69 (0.10-4.81)	1 (0.14-6.92)	0.91 (0.13-6.31)
Wells Estate			
Arsenic	0.88 (0.18-4.36)	0.61 (0.19-2.03)	0.55 (0.17-1.76)
Lead	0.00	0.00	0.00
Manganese	0.00	1.52 (0.24-9.63)	0.55 (0.08-3.46)
Total sample			
Arsenic	1.52 (0.65-3.58)	0.93 (0.42-2.06)	0.61 (0.27-1.35)
Lead	2.11 (0.76-5.88)	1.25 (0.46-3.39)	1.07 (0.39-2.92)
Manganese	**0.34 (0.14-0.83)** *	0.62 (0.28-1.38)	1.27 (0.57-2.81)

*Significant at $p < 0.05$.

Appendix 6: Odds ratio and 95% confidence interval for health outcomes associated with lead, arsenic, and manganese after multivariate logistic regression model.

1. Odds ratio and 95% confidence interval for respiratory symptoms associated with lead, arsenic, and manganese after multivariate logistic regression model.

Respiratory symptoms	**Walmer Township**			**Wells Estate**		
	Arsenic (mg/kg)	**Lead (mg/kg)**	**Manganese (mg/kg)**	**Arsenic (mg/kg)**	**Lead (mg/kg)**	**Manganese (mg/kg)**
Wet cough						
Crude OR	1.14 (0.45-2.85)	1.78 (0.71-4.49)	0.37 (0.05-2.95)	0.57 (0.23-1.41)	0.00	**0.34 (0.13-0.88)** *
Adjusted OR[a]	0.93 (0.32-2.67)	1.64 (0.56-4.81)	0.30 (0.03-2.76)	0.64 (0.23-1.75)	0.00	**0.19 (0.05-0.70)** *
Adjusted OR[b]	1.18 (0.37-3.81)	1.81 (0.59-5.55)	0.44 (0.03-5.49)	0.69 (0.24-1.97)	0.00	**0.19 (0.05-0.74)** *
Dry cough						
Crude OR	1.32 (0.60-2.86)	1.33 (0.59-2.99)	4.57 (0.58-35.93)	0.67 (0.27-1.66)	0.00	0.38 (0.14-1.02)
Adjusted OR[a]	1.67 (0.65-4.67)	1.53 (0.60-3.88)	**11.35 (1.08-119.20)** *	0.70 (0.25-1.96)	0.00	**0.22 (0.06-0.83)** *
Adjusted OR[b]	1.07 (0.39-2.93)	1.04 (0.38-2.84)	9.12 (0.67-124.10)	0.79 (0.27-2.32)	0.00	**0.22 (0.06-0.86)** *
Runny nose						
Crude OR	1.23 (0.56-2.69)	1.06 (0.47-2.37)	4.38 (0.56-34.53)	0.68 (0.30-1.50)	0.00	0.48 (0.19-1.20)
Adjusted OR[a]	1.02 (0.41-2.53)	0.87 (0.35-2.15)	7.86 (0.84-73.8)	0.68 (0.28-1.69)	0.00	0.34 (0.10-1.11)
Adjusted OR[b]	0.64 (0.23-1.76)	0.60 (0.23-1.61)	11.4 (0.84-154.50)	0.75 (0.29-1.89)	0.00	0.35 (0.10-1.17)
Rapid breathing						
Crude OR	0.98 (0.29-3.19)	0.92 (0.27-3.06)	1.40 (0.17-11.64)	0.64 (0.18-2.19)	0.00	0.95 (0.19-4.64)
Adjusted OR[a]	1.06 (0.28-4.06)	0.93 (0.25-3.48)	2.79 (0.26-29.30)	0.75 (0.19-2.87)	0.00	0.79 (0.12-5.30)

Adjusted OR[b]	0.76 (0.16-3.46)	0.79 (0.18-3.44)	2.39 (0.13-45.64)	0.76 (0.19-2.93)	0.00	0.82 (0.12-5.60)
Sore throat						
Crude OR	1.06 (0.45-2.50)	1.48 (0.60-3.69)	0.90 (0.24-3.36)	0.41 (0.11-1.59)	0.00	0.00
Adjusted OR[a]	1.28 (0.49-3.35)	1.63 (0.57-4.60)	0.89 (0.19-4.05)	0.41 (0.09-1.89)	0.00	0.00
Adjusted OR[b]	1.30 (0.47-3.62)	2.05 (0.65-6.45)	0.28 (0.04-1.85)	0.44 (0.10-1.93)	0.00	0.00
Sneezing						
Crude OR	1.32 (0.60-2.86)	1.33 (0.59-2.99)	4.57 (0.58-35.93)	0.66 (0.24-1.79)	0.00	0.30 (0.04-2.41)
Adjusted OR[a]	1.14 (0.56-3.52)	1.28 (0.51-3.25)	**11.30 (1.09-116.67)** *	0.13 (0.01-3.23)	0.00	0.32 (0.03-3.34)
Adjusted OR[b]	0.88 (0.32-2.38)	0.91 (0.34-2.45)	10.16 (0.69-147.60)	0.36 (0.01-14.17)	0.00	0.38 (0.04-3.91)

* Significant at $p < 0.05$.

[a]Model for association of metal exposure with health symptoms adjusting with age, gender, educational status, dust, air pollution, smoking, mould, dampness, income, overcrowding.

[b]Model for association of metal exposure with health symptoms adjusting with age, gender, educational status, dust, air pollution, smoking, mould, dampness, income, overcrowding and heavy metals.

2. Odds ratio and 95% confidence interval for acute ill health symptoms associated with lead, arsenic, and manganese after multivariate logistic regression model.

Acute ill health symptoms	Walmer Township			Wells Estate		
	Arsenic (mg/kg)	Lead (mg/kg)	Manganese (mg/kg)	Arsenic (mg/kg)	Lead (mg/kg)	Manganese (mg/kg)
Fever						
Crude OR	1.46 (0.74-2.85)	1.13 (0.56-2.28)	2.15 (0.59-7.76)	1.25 (0.64-2.45)	0.00	1.01 (0.39-2.63)
Adjusted OR[a]	1.92 (0.87-4.21)	1.09 (0.48-2.44)	3.60 (0.85-15.13)	1.14 (0.53-2.42)	0.00	0.66 (0.22-2.06)
Adjusted OR[b]	1.53 (0.65-3.57)	0.76 (0.33-1.79)	8.21 (0.70-95.11)	1.16 (0.54-2.52)	0.00	0.65 (0.21-2.02)
Chest pain						
Crude OR	1.69 (0.72-3.96)	1.49 (0.60-3.69)	1.59 (0.34-7.36)	0.61(0.26-1.44)	0.00	0.63 (0.23-1.70)
Adjusted OR[a]	1.97 (0.76-5.13)	1.26 (0.46-3.47)	3.01 (0.54-16.62)	0.94 (0.36-2.44)	0.00	0.86 (0.26-2.92)
Adjusted OR[b]	1.61 (0.57-4.61)	0.89 (0.30-2.59)	4.25 (0.32-56.60)	0.96 (0.36-2.51)		0.87 (0.26-3.00)
Earache						
Crude OR	0.84 (0.25-2.89)	1.28 (0.37-4.39)	0.00	0.86 (0.23-3.18)	0.00	0.42 (0.10-1.74)
Adjusted OR[a]	0.83 (0.24-2.94)	1.85 (0.42-8.06)	0.00	0.82 (0.17-3.81)	0.00	0.29 (0.04-2.31)
Adjusted OR[b]	0.87 (0.25-3.08)	1.78 (0.40-7.93)	0.00	0.92 (0.18-4.64)	0.00	0.28 (0.03-2.23)
Headache						
Crude OR	1.35 (0.65-2.77)	0.77 (0.36-1.65)	0.92 (0.28-2.97)	1.30 (0.64-2.63)	0.00	1.07 (0.41-2.81)
Adjusted OR[a]	1.28 (0.54-2.99)	0.94 (0.39-2.25)	0.56 (0.15-2.16)	1.16 (0.51-2.63)	0.00	0.99 (0.29-3.36)
Adjusted OR[b]	1.60 (0.63-4.06)	0.96 (0.37-2.49)	0.59 (0.10-3.45)	1.48 (0.60-3.65)	0.00	0.96 (0.29-3.25)
Watery eye						
Crude OR	1.29 (0.55-3.04)	0.99 (0.42-2.30)	3.35 (0.42-26.60)	3.31 (0.89-12.19)	0.00	**4.02 (1.31-12.29)** *

Adjusted OR[a]	1.43 (0.53-3.83)	0.95 (0.36-2.56)	5.36 (0.60-47.72)	3.54 (0.84-14.96)	0.00	**4.55 (1.01-20.58)** *
Adjusted OR[b]	1.01 (0.33-3.05)	0.78 (0.27-2.21)	3.43 (0.28-41.75)	3.29 (0.72-14.99)	0.00	4.31 (0.92-20.18)

* Significant at $p < 0.05$.

[a]Model for association of metal exposure with health symptoms adjusting with age, gender, educational status, dust, air pollution, smoking, mould, dampness, income, overcrowding.

[b]Model for association of metal exposure with health symptoms adjusting with age, gender, educational status, dust, air pollution, smoking, mould, dampness, income, overcrowding and heavy metals.

3. Odds ratio and 95% confidence interval for chronic diseases and mental illness associated with lead, arsenic, and manganese after multivariate logistic regression model.

Chronic diseases and mental illness	Walmer Township			Wells Estate		
	Arsenic (mg/kg)	**Lead (mg/kg)**	**Manganese (mg/kg)**	**Arsenic (mg/kg)**	**Lead (mg/kg)**	**Manganese (mg/kg)**
Cancer						
Crude OR	0.00	0.00	0.00	0.64 (0.05-7.36)	0.00	0.00
Adjusted OR[a]	0.00	0.00	0.00	0.73 (0.05-9.46)	0.00	0.00
Adjusted OR[b]	0.00	0.00	0.00	0.73 (0.05-9.46)	0.00	0.00
Hypertension						
Crude OR	0.58 (0.25-1.33)	1.23 (0.53-2.88)	1.74 (0.37-8.06)	1.15 (0.53-2.48)	0.00	0.70 (0.23-2.19)
Adjusted OR[a]	1.03 (0.35-3.00)	1.11 (0.36-3.44)	2.69 (0.45-16.25)	1.14 (0.47-2.72)	0.00	0.48 (0.13-1.79)
Adjusted OR[b]	0.78 (0.25-2.44)	1.21 (0.35-4.08)	0.74 (0.08-6.82)	1.21 (0.50-2.90)	0.00	0.46 (0.13-1.75)
Heart disease						
Crude OR	0.00	0.00	0.00	0.00	0.00	0.00
Adjusted OR[a]	0.00	0.00	0.00	0.00	0.00	0.00

Adjusted OR[b]	0.00	0.00	0.00	0.00	0.00	0.00
Mental illness						
Crude OR	2.06 (0.18-23.6)	0.75 (0.06-8.58)	4.15 (0.35-48.85)	0.65 (0.06-7.36)	0.00	0.00
Adjusted OR[a]	0.00	1.42 (0.07-26.63)	4.01 (0.21-75.48)	0.45 (0.03-6.83)	0.00	0.00
Adjusted OR[b]	1.45 (0.08-24.3)	1.07 (0.02-49.08)	3.00 (0.05-163.11)	0.53 (0.04-6.66)	0.00	0.00

* Significant at $p < 0.05$.

[a]Model for association of metal exposure with health symptoms adjusting with age, gender, educational status, dust, air pollution, smoking, mould, dampness, income, overcrowding.

[b]Model for association of metal exposure with health symptoms adjusting with age, gender, educational status, dust, air pollution, smoking, mould, dampness, income, overcrowding and heavy metals.

4. Odds ratio and 95% confidence interval for gastrointestinal health symptoms associated with lead, arsenic, and manganese after multivariate logistic regression model.

Gastrointestinal health symptoms	**Walmer Township**			**Wells Estate**		
	Arsenic (mg/kg)	**Lead (mg/kg)**	**Manganese (mg/kg)**	**Arsenic (mg/kg)**	**Lead (mg/kg)**	**Manganese (mg/kg)**
Diarrhoea						
Crude OR	0.67 (0.10-4.18)	0.36 (0.04-3.41)	0.00	0.64 (0.11-3.63)	0.00	0.00
Adjusted OR[a]	0.57 (0.08-3.71)	0.44 (0.02-8.11)	0.00	0.48 (0.07-3.37)	0.00	0.00
Adjusted OR[b]	0.71 (0.09-5.33)	0.41 (0.02-9.27)	0.00	0.48 (0.07-3.37)	0.00	0.00
Vomiting						
Crude OR	0.33 (0.03-3.31)	0.49 (0.05-4.94)	0.00	0.00	0.00	0.00
Adjusted OR[a]	0.26 (0.02-2.64)	0.00	0.00	0.00	0.00	0.00

Adjusted OR[b]	0.37 (0.02-4.81)	0.00	0.00	0.00	0.00	0.00

* Significant at $p < 0.05$.

[a]Model for association of metal exposure with health symptoms adjusting with age, gender, educational status, dust, air pollution, smoking, mould, dampness, income, overcrowding.

[b]Model for association of metal exposure with health symptoms adjusting with age, gender, educational status, dust, air pollution, smoking, mould, dampness, income, overcrowding and heavy metals.

5. Odds ratio and 95% confidence interval for respiratory symptoms associated with lead, arsenic, and manganese in total sample after multivariate logistic regression model.

Respiratory symptoms	**Total sample**		
	Arsenic (mg/kg)	**Lead (mg/kg)**	**Manganese (mg/kg)**
Wet cough			
Crude OR (95% C.I)	0.79 (0.43-1.49)	1.36 (0.65-2.85)	0.60 (0.32-1.14)
Adjusted OR[a] (95% C.I)	0.81 (0.14-1.61)	1.30 (0.54-3.11)	0.62 (0.31-1.22)
Adjusted OR[b] (95% C.I)	0.86 (0.43-1.73)	1.13 (0.44-2.86)	0.67 (0.32-1.37)
Dry cough			
Crude OR (95% C.I)	0.74 (0.42-1.33)	1.05 (0.51-2.15)	**0.39 (0.21-0.73)** *
Adjusted OR[a] (95% C.I)	0.86 (0.46-1.61)	0.93 (0.41-2.09)	**0.31 (0.16-0.64)** *
Adjusted OR[b] (95% C.I)	0.96 (0.49-1.87)	0.68 (0.29-1.59)	**0.31 (0.15-0.63)** *
Runny nose			
Crude OR (95% C.I)	0.75 (0.43-1.30)	1.00 (0.62-1.60)	0.58 (0.33-1.01)
Adjusted OR[a] (95% C.I)	0.90 (0.49-1.64)	0.95 (0.43-2.09)	0.55 (0.29-1.02)

Adjusted OR[b] (95% C.I)	1.0 0.58-1.72)	0.79 (0.34-1.81)	0.55 (0.28-1.05)
Rapid breathing			
Crude OR (95% C.I)	0.82 (0.35-1.90)	1.11 (0.39-3.08)	0.84 (0.36-1.93)
Adjusted OR[a] (95% C.I)	0.72 (0.29-1.75)	1.12 (0.36-3.39)	0.69 (0.27-1.79)
Adjusted OR[b] (95% C.I)	0.74 (0.29-1.89)	0.89 (0.28-2.88)	0.75 (0.27-2.04)
Sore throat			
Crude OR (95% C.I)	0.77 (0.38-1.54)	1.17 (0.51-2.69)	0.65 (0.33-1.31)
Adjusted OR[a] (95% C.I)	0.76 (0.36-1.62)	1.29 (0.52-3.22)	0.67 (0.31-1.42)
Adjusted OR[b] (95% C.I)	0.78 (0.36-1.68)	1.23 (0.46-3.24)	0.73 (0.33-1.62)
Sneezing			
Crude OR (95% C.I)	0.96 (0.53-1.76)	0.80 (0.38-1.66)	**2.05 (1.09-3.83)** *
Adjusted OR[a] (95% C.I)	0.84 (0.44-1.62)	1.16 (0.48-2.74)	**2.18 (1.06-4.48)** *
Adjusted OR[b] (95% C.I)	0.73 (0.36-1.43)	1.49 (0.61-3.63)	**2.23 (1.07-4.61)** *

* Significant at $p < 0.05$.

[a]Model for association of metal exposure with health symptoms adjusting with age, gender, educational status, dust, air pollution, smoking, mould, dampness, income, overcrowding.

[b]Model for association of metal exposure with health symptoms adjusting with age, gender, educational status, dust, air pollution, smoking, mould, dampness, income, overcrowding and heavy metals.

6. Odds ratio and 95% confidence interval for respiratory symptoms associated with lead, arsenic, and manganese in total sample after multivariate logistic regression model.

Acute ill health symptoms	**Total sample**		
	Arsenic (mg/kg)	**Lead (mg/kg)**	**Manganese (mg/kg)**

Fever			
Crude OR (95% C.I)	0.94 (0.59-1.51)	0.98 (0.53-1.79)	0.73 (0.45-1.17)
Adjusted OR[a] (95% C.I)	0.85 (0.51-1.42)	0.77 (0.38-1.54)	0.64 (0.37-1.07)
Adjusted OR[b] (95% C.I)	0.89 (0.52-1.52)	0.65 (0.31-1.36)	0.57 (0.33-1.00)
Chest pain			
Crude OR (95% C.I)	0.61 (0.33-1.11)	0.73 (0.32-1.63)	0.74 (0.41-1.33)
Adjusted OR[a] (95% C.I)	0.68 (0.36 1.31)	0.74 (0.30-1.84)	0.71 (0.36-1.38)
Adjusted OR[b] (95% C.I)	0.71 (0.36-1.41)	0.74 (0.28-1.91)	0.67 (0.33-1.35)
Earache			
Crude OR (95% C.I)	0.86 (0.35-2.11)	1.32 (0.46-3.76)	0.48 (0.19-1.23)
Adjusted OR[a] (95% C.I)	1.22 (0.46-3.24)	1.64 (0.46-5.81)	0.46 (0.16-1.31)
Adjusted OR[b] (95% C.I)	1.33 (0.48-3.67)	1.30 (0.36-4.71)	0.48 (0.16-1.42)
Headache			
Crude OR (95% C.I)	1.33 (0.80-2.19)	0.83 (0.42-1.61)	0.91 (0.55-1.50)
Adjusted OR[a] (95% C.I)	1.35 (0.77-2.36)	0.70 (0.33-1.48)	1.02 (0.57-1.80)
Adjusted OR[b] (95% C.I)	1.50 (0.85-2.67)	0.62 (0.28-1.37)	0.94 (0.52-1.70)
Watery eye			
Crude OR (95% C.I)	1.68 (0.85-3.33)	0.68 (0.32-1.48)	**3.35 (1.58-7.08)** *
Adjusted OR[a] (95% C.I)	1.56 (0.75-3.25)	0.75 (0.31-1.82)	**3.71 (1.63-8.48)** *
Adjusted OR[b] (95% C.I)	1.48 (0.69-3.20)	1.01 (0.38-2.68)	**3.57 (1.52-8.37)** *

* Significant at $p < 0.05$.

[a]Model for association of metal exposure with health symptoms adjusting with age, gender, educational status, dust, air pollution, smoking, mould, dampness, income, overcrowding.

[b]Model for association of metal exposure with health symptoms adjusting with age, gender, educational status, dust, air pollution, smoking, mould, dampness, income, overcrowding and heavy metals.

7. Odds ratio and 95% confidence interval for chronic diseases and mental illness associated with lead, arsenic, and manganese in total sample after multivariate logistic regression model.

Chronic diseases and mental illness	**Total sample**		
	Arsenic (mg/kg)	**Lead (mg/kg)**	**Manganese (mg/kg)**
Cancer			
Crude OR (95% C.I)	0.38 (0.04-3.75)	0.00	3.05 (0.31-29.77)
Adjusted OR[a] (95% C.I)	0.35 (0.03-3.73)	0.00	4.53 (0.36-57.26)
Adjusted OR[b] (95% C.I)	0.35 (0.03-3.67)	0.00	4.86 (0.34-68.79)
Hypertension			
Crude OR (95% C.I)	0.84 (0.48-1.45)	1.23 (0.59-2.57)	0.99 (0.55-1.78)
Adjusted OR[a] (95% C.I)	0.89 (0.45-1.78)	1.39 (0.55-3.54)	1.01 (0.48-2.09)
Adjusted OR[b] (95% C.I)	0.77 (0.37-1.55)	1.51 (0.54-4.19)	1.00 (0.38-2.67)
Heart disease			
Crude OR (95% C.I)	0.00	0.00	0.00
Adjusted OR[a] (95% C.I)	0.00	0.00	0.00
Adjusted OR[b] (95% C.I)	0.00	0.00	0.00
Mental illness			
Crude OR (95% C.I)	1.16 (0.23-5.86)	0.83 (0.09-7.31)	2.03 (0.36-11.28)
Adjusted OR[a] (95% C.I)	1.79 (0.27-11.52)	0.68 (0.06-8.17)	3.67 (0.51-26.30)
Adjusted OR[b] (95% C.I)	1.67 (0.26-10.82)	0.64 (0.04-9.89)	3.43 (0.47-24.74)

* Significant at $p < 0.05$.

[a]Model for association of metal exposure with health symptoms adjusting with age, gender, educational status, dust, air pollution, smoking, mould, dampness, income, overcrowding.

[b]Model for association of metal exposure with health symptoms adjusting with age, gender, educational status, dust, air pollution, smoking, mould, dampness, income, overcrowding and heavy metals.

8. Odds ratio and 95% confidence interval for gastrointestinal symptoms associated with lead, arsenic, and manganese in total sample after multivariate logistic regression model.

Gastrointestinal symptoms	Total sample		
	Arsenic (mg/kg)	Lead (mg/kg)	Manganese (mg/kg)
Diarrhoea			
Crude OR (95% C.I)	0.65 (0.18-2.29)	0.41 (0.05-3.27)	1.21 (0.36-4.05)
Adjusted OR[a] (95% C.I)	0.73 (0.19-2.82)	0.31 (0.03-3.41)	0.97 (0.25-3.77)
Adjusted OR[b] (95% C.I)	0.94 (0.24-3.75)	0.31 (0.03-3.61)	0.90 (0.23-3.59)
Vomiting			
Crude OR (95% C.I)	0.23 (0.03-1.98)	0.83 (0.09-7.28)	0.49 (0.08-2.76)
Adjusted OR[a] (95% C.I)	0.52 (0.04-7.02)	0.45 (0.02-8.68)	0.19 (0.01-7.14)
Adjusted OR[b] (95% C.I)	0.60 (0.04-9.30)	0.46 (0.02-10.57)	0.19 (0.01-6.12)

* Significant at $p < 0.05$.

[a]Model for association of metal exposure with health symptoms adjusting with age, gender, educational status, dust, air pollution, smoking, mould, dampness, income, overcrowding.

[b]Model for association of metal exposure with health symptoms adjusting with age, gender, educational status, dust, air pollution, smoking, mould, dampness, income, overcrowding and heavy metals.

Appendix 7: Odds ratio and 95% confidence interval for confounding variables after multivariate logistic regression

1. Odds ratio and 95% confidence interval for confounding variables after multivariate logistic regression for dry cough

Variables	Walmer Township		Wells Estate		Total sample	
	Crude OR (95% C.I)	**Adjusted OR (95% C.I)**	**Crude OR (95% C.I)**	**Adjusted OR (95% C.I)**	**Crude OR (95% C.I)**	**Adjusted OR (95% C.I)**
Age	0.69 (0.32-1.49)	0.51 (0.21-1.27)	0.93 (0.39-2.26)	1.01 (0.39-2.63)	1.25 (0.67-2.31)	1.49 (0.81-2.77)
Gender	0.81 (0.37-1.76)	0.79 (0.32-1.94)	0.94 (0.39-2.24)	0.95 (0.37-2.38)	1.10 (0.62-1.96)	1.05 (0.57-1.93)
Education status	1.37 (0.62-3.06)	1.81 (0.72-4.50)	0.66 (0.27-1.58)	0.57 (0.21-1.59)	0.75 (0.42-1.34)	0.57 (0.31-1.06)
Smoking	1.46 (0.65-3.29)	1.31 (0.49-3.54)	1.87 (0.75-4.66)	1.42 (0.52-3.91)	1.02 (0.57-1.85)	1.15 (0.61-2.19)
Income	0.54 (0.23-1.32)	0.61 (0.19-0.19)	0.55 (0.07-4.40)	0.82 (0.08-8.18)	1.61 (0.75-3.45)	1.58 (0.62-3.97)
Mould	**0.31 (0.14-0.71)** *	**0.23 (0.07-0.73)** *	0.80 (0.33-1.96)	0.69 (0.23-2.01)	1.44 (0.80-2.58)	1.61 (0.79-3.26)
Dust	0.71 (0.32-1.56)	1.87 (0.61-5.71)	0.73 (0.29-1.79)	0.48 (0.14-1.53)	1 (0.55-1.80)	0.61 (0.30-1.25)
Dampness	0.62 (0.29-1.34)	1.43 (0.49-4.19)	1.18 (0.49-2.84)	1.11 (0.31-4.01)	1.42 (0.80-2.54)	1.11 (0.55-2.26)
Overcrowding	**0.41 (0.19-0.92)** *	**0.19 (0.05-0.63)** *	1.16 (0.40-3.37)	1.77 (0.45-6.95)	**1.92 (1.04-3.57)** *	**2.23 (1.11-4.48)** *
Air pollution	0.57 (0.26-1.25)	1.05 (0.38-2.94)	0.82 (0.34-2.02)	0.85 (0.29-2.49)	1.18 (0.65-2.12)	1.14 (0.59-2.21)

*Significant at $p < 0.05$.

2. Odds ratio and 95% confidence interval for confounding variables after multivariate logistic regression model for wet cough

Variables	**Walmer Township**		**Wells Estate**		**Total sample**	
	Crude OR (95% C.I)	**Adjusted OR (95% C.I)**	**Crude OR (95% C.I)**	**Adjusted OR (95% C.I)**	**Crude OR (95% C.I)**	**Adjusted OR (95% C.I)**
Age	1.69 (0.67-4.28)	2.35 (0.82-6.71)	0.96 (0.41-2.24)	1.42(0.54-3.73)	1.25 (0.67-2.31)	1.47 (0.77-2.81)
Gender	1.38 (0.54-3.53)	1.18 (0.42-3.36)	0.77 (0.33-1.79)	0.98(0.39-2.43)	1.00 (0.75-1.33)	0.99 (0.52-1.88)
Education status	1.56 (0.54-4.51)	2.03 (0.64-6.72)	0.55 (0.23-1.28)	0.36(0.13-1.01)	0.84 (0.45-1.58)	0.80 (0.41-1.56)
Smoking	0.79 (0.31-2.04)	1.87 (0.51-6.79)	1.77 (0.74-4.25)	1.27(0.47-3.43)	1.23 (0.66-2.28)	1.56 (0.78-3.11)
Mould	1.71 (0.64-4.58)	2.39 (0.63-9.15)	0.56 (0.23-1.37)	0.87(0.27-2.18)	0.91 (0.47-1.75)	1.11 (0.51-2.40)
Dust	0.56 (0.22-1.41)	0.31 (0.09-1.14)	1.04 (0.42-2.56)	0.62(0.19-2.00)	0.78 (0.42-1.46)	0.78 (0.38-1.63)
Dampness	1.22 (0.49-3.05)	1.26 (0.35-4.56)	1.21 (0.52-2.82)	0.94(0.27-3.29)	1.21 (0.65-2.25)	1.21 (0.52-2.41)
Income	1.34 (0.45-3.99)	0.87 (0.24-3.14)	2.93 (0.85-10.09)	**6.19 (1.15-41.29)** *	1.77 (0.79-3.93)	0.86 (0.43-1.73)
Overcrowding	0.58 (0.18-1.82)	0.84 (0.18-3.91)	0.15 (0.02-1.16)	0.17 (0.02-1.52)	**0.36 (0.14-0.96)** *	0.38 (0.14-1.04)
Air pollution	1.06 (0.42-2.65)	1.16 (0.38-3.57)	1.17 (0.48-2.88)	0.73 (0.23-2.28)	0.12 (0.59-2.11)	1.07 (0.53-2.15)

* Significant at $p < 0.05$.

3. Odds ratio and 95% confidence interval for confounding variables after multivariate logistic regression for sneezing

Variables	**Walmer Township**		**Wells Estate**		**Total sample**	
	Crude OR (95% C.I)	**Adjusted OR (95% C.I)**	**Crude OR (95% C.I)**	**Adjusted OR (95% C.I)**	**Crude OR (95% C.I)**	**Adjusted OR (95% C.I)**
Age	0.94 (0.43-2.03)	0.92 (0.37-2.26)	**0.31 (0.10-0.91)** *	**0.24 (0.07-0.79)** *	0.63 (0.35-1.16)	0.62 (0.33-1.17)
Gender	0.69 (0.31-1.51)	0.68 (0.27-1.70)	0.61(0.21-1.72)	0.57 (0.18-1.82)	0.65 (0.35-1.22)	0.76 (0.39-1.45)
Education status	1.62 (0.73-3.58)	1.98 (0.83-4.91)	1.55(0.57-4.23)	2.04 (0.58-7.11)	1.41 (0.77-2.59)	1.59 (0.83-3.07)
Income	1.06 (0.39-2.83)	0.74 (0.21-2.49)	0.56(1.11-2.73)	0.14 (0.02-1.20)	0.73 (0.32-1.67)	0.47 (0.18-1.20)
Smoking	1.32 (0.59-2.92)	0.80 (0.29-2.24)	2.08(0.71-5.90)	2.43 (0.71-8.30)	1.67 (0.89-3.11)	1.35 (0.69-2.62)
Mould	**0.37 (0.16-0.84)** *	**0.21 (0.06-0.70)** *	1.13(0.41-3.11)	0.75 (0.19-3.00)	0.73 (0.39-1.36)	0.61 (0.28-1.27)
Dust	1.13 (0.52-2.44)	1.87 (0.60-5.76)	0.61(0.19-1.96)	0.45 (0.11-1.86)	1.03 (0.56-1.89)	0.92 (0.44-1.89)
Dampness	**0.45 (0.21-0.99)** *	0.96 (0.32-2.83)	0.95(0.34-2.62)	0.82 (0.22-3.06)	0.59 (0.32-1.07)	0.64 (0.34-1.40)
Overcrowding	0.81 (0.35-1.88)	0.31 (0.08-1.17)	4.18(0.53-32.96)	**13.75 (1.25-150.67)** *	1.06 (0.52-2.18)	0.97 (0.44-2.12)
Air pollution	1.96 (0.89-4.32)	**3.43 (1.15-10.20)** *	2.23(0.82-6.10)	3.07 (0.93-10.17)	**2.27 (1.23-4.19)** *	**2.76 (1.39-5.50)** *

* Significant at $p < 0.05$.

4. Odds ratio and 95% confidence interval for confounding variables after multivariate logistic regression model for watery eye

Variables	Walmer Township		Wells Estate		Total sample	
	Crude OR (95% C.I)	**Adjusted OR (95% C.I)**	**Crude OR (95% C.I)**	**Adjusted OR (95% C.I)**	**Crude OR (95% C.I)**	**Adjusted OR (95% C.I)**
Age	0.89 (0.38-2.09)	0.82 (0.32-2.14)	0.52 (0.18-1.52)	0.39 (0.11-1.32)	0.72 (0.37-1.39)	0.57 (0.28-1.15)
Gender	0.64 (0.27-1.57)	0.59 (0.22-1.56)	1.01 (0.34-2.99)	1.03 (0.32-3.06)	0.77 (0.39-1.50)	0.85 (0.42-1.71)
Education status	1.02 (0.42-2.47)	1.14 (0.42-3.10)	0.88 (0.29-2.58)	1.36 (0.41-4.51)	0.88 (0.44-1.75)	1.03 (0.49-2.14)
Smoking	0.95 (0.41-2.45)	0.54 (0.17-1.64)	0.93 (0.32-2.69)	1.37 (0.41-6.41)	1.01 (0.58-1.76)	0.81 (0.39-1.69)
Mould	0.49 (0.20-1.23)	**0.24 (0.06-0.87)** *	0.88 (0.31-2.56)	1.23 (0.35-4.29)	0.77 (0.39-1.51)	0.58 (0.26-1.29)
Dust	1.42 (0.61-3.34)	2.68 (0.78-9.19)	0.73 (0.22-2.41)	1.35 (0.28-6.42)	1.22 (0.63-2.38)	1.67 (0.75-3.72)
Dampness	0.80 (0.34-1.88)	1.36 (0.40-4.59)	0.42 (0.14-1.22)	0.81 (0.16-4.15)	0.61 (0.32-1.18)	0.86 (0.38-1.95)
Income	0.73 (0.27-2.00)	0.77 (0.23-2.59)	1.11 (0.13-9.23)	0.86 (0.07-11.06)	0.67 (0.28-1.62)	0.77 (0.28-2.17)
Overcrowding	0.98 (0.39-2.51)	0.45 (0.11-1.83)	1.63 (0.35-7.58)	0.97 (0.17-5.66)	1.06 (0.48-2.31)	0.92 (0.39-2.14)
Air pollution	1.39 (0.59-3.28)	1.19 (0.64-5.73)	0.44 (0.12-1.62)	0.41 (0.09-1.82)	1.04 (0.54-2.03)	1.02 (0.48-2.16)

* Significant at $p < 0.05$.