SHALLOW GROUNDWATER CONTAMINATION EVALUATION AT LANDFILL SITES USING GEOPHYSICS, HYDROCHEMISTRY AND ISOTOPE HYDROLOGY TECHNIQUES

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by

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LIST OF ABBREVIATIONS

2D	2 dimension
3D	3 dimension
APHA	American Public Health Association
As	Arsenic
ASTDR	Agency for Toxic Substances and Disease Registry
BOD	Biological Oxygen Demand
Cd	Cadmium
COD	Chemical Oxygen Demand
Cr	Chromium
Cu	Copper
DIC	Dissolved Inorganic Carbon
DWAF	Department of Water Affairs and Forestry
EC	Electric Conductivity
Fe	Ferum
GRA	Groundwater Resources Association,
Hg	Mercury
IRMS	Isotope Ratio Mass Spectrometer
MHLG	Ministry of Housing and Local Government
Mn	Manganese
MODFLOW	Modular Three-Dimensional Finite Difference Groundwater Flow
MSW	Municipal Solid Waste
NH_3-N	Ammoniacal nitrogen

Ni	nickel
NSWMD	National Solid Waste Management Department
Pb	Lead
RIP	Resistivity Image Profiling
TDS	Total dissolved solids
TU	Tritium Value
UNSW	University of New South Wales,
US EPA,	United States Of America, Environmental Protection Agency
VFA	Volatile fat acids
VOC	Volatile organic compound
VSMOW	Vienna Standard Mean Ocean Water
Zn	Zinc

LIST OF SYMBOLS

$\delta^{11}B$	Boron-11
$\delta^{81}Br$	Bromide-81
$\delta^{13}C$	Carbon-13
$\delta^{12}C$	Carbom-12
$\delta^{13}C$	Carbon-13
$\delta^{37}Cl$	Chloride37
δD	Deutrium
$\delta^{2}H$	Hydrogen-2
$\delta^{15}N$	Nitrogen-15
$\delta^{18}O$	Oxygen-18
$\delta^{16}O$	Oxygen16
$\delta^{6}Li$	Litium-6
$\delta^{34}S$	Sulphate-34
Ca^{2+}	Calcium ion
Cl^{-}	Chloride ion
K^{+}	Potassium ion
Mg^{2+}	Magnesium ion
Na^{+}	Sodium ion
NO_3^{-}	Nitrate ion
PO_4^{3-}	Phosphate ion
SO_4^{2-}	Sulphate ion

KAJIAN PENCEMARAN AIR BAWAH TANAH DI TAPAK PELUPUSAN SISA PEPEJAL MENGGUNAKAN TEKNIK GEOFIZIK, HIDROKIMIA DAN ISOTOP HIDROLOGI

ABSTRAK

Kaedah gabungan geofizikal, hidrokimia dan isotop hidrologi telah digunakan dalam penyelidikan ini untuk mengkaji ciri-ciri, punca dan perpindahan pencemaran di tapak pelupusan sampah Matang dan Beriah. Penyelidikan ini adalah untuk membandingkan pencemaran air bawah tanah untuk dua tapak pelupusan sampah iaitu Matang (tahap 3) yang merupakan tapak pelupusan sampah terkawal dan Beriah (tahap 0) yang merupakan tapak pelupusan sampah tidak terkawal. Kaedah profil pengimejan keberintangan berserta data ciri-ciri tanah yang diperolehi daripada telaga menunjukkan gambaran subpermukaan dan membuktikan dengan jelas kawasan-kawasan bawah tanah yang tercemar. Nilai keberintangan yang rendah telah dikesan di garisan 1 untuk Beriah dimana ia terletak di selatan barat tapak pelupusan sampah. Nilai keberintangan berada dalam julat 20 hingga 50 Ωm (sederhana rendah) untuk kedalaman 10 m dan kurang daripada 10 Ωm (sangat rendah) untuk kedalaman lebih daripada 10 m. Untuk Matang pula, nilai keberintangan yang sangat rendah ditunjukkan pada garisan 3 dengan nilai kurang daripada 10 Ωm pada jarak 100 hingga 180 m daripada garisan dan pada kedalaman 0 hingga 5 m. Keputusan geofizik ini kemudiannya dibandingkan dengan analisis hidrokimia untuk air bawah tanah dan air permukaan. Ciri-ciri hidrokimia seperti ciri fizikal (EC, TDS, pH dan DO), ion-ion utama (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, NH_4^{+},Cl^{-}, HCO_3^{-} dan SO_4^{2-}) dan logam berat (Fe, Ni, Cu dan Cr) telah digunakan untuk pengesanan pergerakan dan perpindahan larut lesap. Keputusan menunjukkan kepekatan Cl^{-}, Na^{+}, K^{+} and HCO_3^{-} adalah tinggi di sesetengah telaga di mana ia sejajar dengan ciri-ciri larut lesap. Oleh

itu, perpindahan larut lesap boleh diramalkan. Kemudian, analisis isotop stabil dilakukan di mana pengkayaan $\delta^{18}O$, $\delta^{2}H$ dan $\delta^{13}C$ di sesetengah telaga adalah seiring dengan ciri-ciri air sampah dan juga analisis hidrokimia. Daripada keputusan yang diperolehi, sampel air sampah untuk kedua-dua pelupusan sampah adalah sederhana banyak dengan $\delta^{18}O$- H_2O di mana untuk tapak pelupusan Matang, nilainya adalah daripada -5.98 $^{o}/_{oo}$ hingga -4.51 $^{o}/_{oo}$ dan tapak pelupusan Beriah adalah daripada 5.85 $^{o}/_{oo}$ and -4.52 $^{o}/_{oo}$. Tambahan pula, Visual MODFLOW telah digunakan untuk menentukan pergerakan air bawah tanah, kelajuan, pergerakan zarah dan pengangkutan bahan cemar. Keputusan yang diperolehi daripada gabungan semua teknik dan simulasi pemodelan air bawah tanah dapat menunjukkan dan menyelesaikan masalah yang timbul daripada teknik yang konvensional.

SHALLOW GROUNDWATER CONTAMINATION EVALUATION AT LANDFILL SITE USING GEOPHYSICS, HYDROCHEMISTRY AND ISOTOPE HYDROLOGY TECHNIQUES

ABSTRACT

Integrated geophysical, hydrochemistry and isotope hydrology have been used in this research to study the characteristics, origin and migration of contamination at Matang and Beriah landfill. Comparison studies of groundwater contamination for both landfill site categories were conducted for Matang landfill, level 3 (controlled landfill) and Beriah landfill, level 0 (uncontrolled landfill). The Electrical Resistivity Imaging method, supported by soil well logging data shows a subsurface image that provides clear indication of ground contamination zone. Low resistivity values were detected at line 1 in Beriah which is at the south west of the landfill. The resistivity value ranges indicate that the value ranges are from 20 to 50 Ωm (moderately low) at a depth of 10 m and less than 10 Ωm (very low) at a depth of greater than 10 m. Meanwhile, for Matang landfill, a significantly low resistivity value was observed in line 3 with a value <10 Ωm at 100 to 180m distance of the line and at the depth of 0 to 5m. The geophysical results were then compared with hydrochemical analysis of groundwater and surface water. The hydrochemical characteristics such as physical (EC, TDS, pH, and DO), major ions (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, NH_4^{+},Cl^{-}, HCO_3^{-} and SO_4^{2-}) and heavy metal (Fe, Ni, Cu and Cr) were used to fingerprint the leachate flow and migration. The results show that the high concentration of Cl^{-}, Na^{+}, K^{+} and HCO_3^{-} in certain boreholes indicate a strong correlation with leachate characteristics. Therefore, the migration of leachate plume can be predicted. The stable isotopes ($\delta^{18}O$, $\delta^{2}H$, $\delta^{13}C$) results show that when an enrichment of $\delta^{18}O$, $\delta^{2}H$, $\delta^{13}C$ in certain boreholes occur, it can be proved to be in good correlation with leachate characteristics. The leachate samples of both landfills are moderately enriched in $\delta^{18}O$- H_2O where in Matang landfill, the value ranging from -5.98 $^{o}/_{oo}$ to -4.51 $^{o}/_{oo}$ and for Beriah landfill, from -5.85 $^{o}/_{oo}$ and -4.52 $^{o}/_{oo}$. In addition, Visual MODFLOW was used to determine groundwater flow direction, velocity, particle flow and contaminant transport. The results of all the integrated techniques and groundwater modeling simulations prove to provide a good fingerprinting tool that can overcome the limitations posed by conventional techniques.

CHAPTER ONE

INTRODUCTION

1.1 Background

Malaysia is a developing country with a growing economy but still struggling to overcome the Municipal Solid Waste (MSW) problem. Overall, there is about 17,000 tonnes of waste being generated daily and this amount is estimated to increase up to 30,000 tonnes/day by the year of 2020 as a result of the increase in population, rapid economy growth, industrialisation and urbanisation process (Ministry of Housing and Local Government, 2005). All these wastes came from various sources such as, residential areas, industrial areas, commercial areas and institutional areas. Each of these sources contributes to different types of waste. Manaf et al. (2009) reveals that about 45% of the future waste will be made up of food waste, 24% of plastic, 7% of paper and 6% of iron and glass with the remainder being made up of other materials.

In Malaysia, landfilling is the most used method for solid waste disposal which employed an open dumpsite system. This method is favoured because it is considered to be the most reliable and cost effective (Chiemchaisri et al., 2002; Vasanthi et al., 2008). Statistics shows that to date, there are 190 disposal sites still in operation. However, only ten can be classified as sanitary landfills (Ministry of Housing and Local Government, 2005). The difference between open dumpsites and landfills lie in the design. A landfill is an engineered waste disposal site facility that is well equipped with specific pollution control technologies to reduce and minimise the potential impacts (Sabahi et al., 2009). An open dumpsite on the other hand, does not have all of the design aspects and poses potential threats to health, safety and environment (Idris et al., 2004).

The major potential environmental impact associated with landfilling activities is leachate generation.Leachate is a polluted liquid that emanates from the base of the landfill (Papadopoulou et al., 2006). It may be produced from precipitation, surface run-off and infiltration or intrusion of groundwater percolating through a landfill (Wang et al., 2002). Generally, the leachate produced contains organic (BOD, COD), ammoniacal-nitrogen, total suspended solids and inorganic pollutant (toxic metals) (Halim et al., 2009; Bashir et al., 2009). However, the quality of leachate will differ from one landfill site to another because it is dependent on the nature of wastes buried and the condition of disposal sites.

Thus, improper landfill management (without landfill liner and soil cover) can lead to excessive generation of leachate and the possibility for leachate migrating into groundwater is a major concern. In addition, insufficient equipment and facilities in landfill sites (leachate collection system and leachate treatment) will result in leachate being discharged into the nearest bodies of water without proper treatment. As a consequence, it will cause groundwater and surface water contamination which might pose serious threat to the environment, human health and other living organisms (Kjeldsen et al., 2010).

In order to assess whether groundwater is contaminated due to the leachate migration, geophysical hydrochemistry and isotope analysis can be conducted. There are two types of geophysical methods that are based on the physical properties of materials below the earth's surface. Surface geophysical methods are commonly used in mapping features of the geological settings meanwhile; borehole geophysical provides useful stratigraphic and hydrogeologic data (Shcwartz and Zhang, 2003). 2-D Electrical Resistivity Imaging (ERI) was developed to elucidate complex subsurface structure and uncover hidden water in a geophysical survey due to their different electrical properties. Since it is a non-destructive method and it is sensitive to the water content of each layer, it offers an attractive tool for describing subsurface properties without digging (Turesson, 2006). ERI can be measured using 1-dimensional (1D), 2-dimensional (2D) and 3-dimensional (3D) techniques. The measurements from the 1D technique displays the variation of soil resistivity in-depth without taking into account the horizontal variation (Loke, 2000). In the last decades, 2D and 3D techniques have been fairly developed so that the resistivity imaging has progressed to become a more applicable exploration technique. The advantages of using 2D/3D techniques are:

i. The ability to construct highly accurate resistivity imaging of the subsurface using a large number of measured points
ii. Provides beneficial results that are complementary to the information acquired through the use of other geophysical methods **(**Abbas et al., 2009).

The differences between 2D and 3D techniques are that the results from using 2D techniques will give a simultaneous display of both horizontal and vertical variations in resistivity (Edwards, 1977), while 3D techniques are able to show the direction of water flow. There are two methods to obtain a 3D ERI:

i. The reconstruction of a 2D network of parallel pseudo section
ii. Using a square array of four electrodes (Samouelian et al.,2005).

Besides, the hydrochemistry method is a subdivision of hydrology studies where its function is to detect the chemical properties of water by detecting the mineral ions that are present in the water sample and comparing it with existing water standards to determine the potential of the water. It is a very common method nowadays mostly for environmental studies such as determining the pollution of water, infiltration of leachate water into groundwater resources or salinity of water. The types of ions present are grouped into two (2) types, i.e. major ions and minor ions. The focus is to detect mineral ions that are present in the water sample and compare it against existing water standards to determine the potential of the water.

Environmental isotopic ratio of $\delta^{2}H$, $\delta^{13}C$ and $\delta^{18}O$ can be used distinctly to identify municipal solid waste landfill leachate as a source of surface waters and groundwater contamination in the study area. In this project, surface water samples from upstream and downstream of landfill related rivers, ponds and groundwater samples within the landfill site together with leachate samples were analysed to study the applicability of the stable isotope ratios as a tool for monitoring leachate contamination in surface waters and groundwater. All the water samples measured for $\delta^{2}H$–water, $\delta^{18}O$–water and $\delta^{13}C$–DIC (Dissolved Inorganic Carbon) values as derived from previous studies have demonstrated that the biogeochemical processes within the landfill environment has ability to produce a unique isotopic composition for these isotopes (Hackley et al., 1996; North et al., 2006). Value of the stable isotopes obtained from surface waters and groundwater samples were studied and correlated with the leachate to clearly fingerprint the possibility of contamination. The application of nuclear related technology in this study was conducted with the aid of Isotope Ratio Mass Spectrometer (IRMS) to analyse water samples for isotopic ratio. One of the significant objectives in this project is to develop an effective way to fingerprint surface waters and groundwater contamination caused by landfill leachates.

1.2 Problem Statement

Today, solid waste is among the major environmental problems faced by most municipal councils in Malaysia. As the amount of waste generation increases rapidly, landfills, in turn, are filling up at staggering rates resulting in a high demand for new landfill sites. However, due to the scarcity of land and expensive land prices especially in urban areas and elevated costs of constructing and operating a landfill, most of the landfills in Malaysia are developed and operated on an ad-hoc basis and located close to surface water and water catchment's areas.

Even though the potential for surface and groundwater contamination from landfills is due to the landfill leachate and has been recognised several decades ago especially in developing countries, there are few efforts being done to mitigate this problem in present landfill sites particularly in Malaysia. Studies have shown that majority of the 230 official dumping sites in Malaysia have no leachate treatment, no gas management facilities, no daily covering materials and are without proper liners or barriers (Chenayah and Takeda, 2005). The approach of managing solid waste eventually contributes severe impacts to groundwater and surface water contamination problems (Tadza et al., 2001). This is because leachate will always find a way to enter groundwater (leachate leakage owing to improper lining in landfills) and surface water (leachate run-off due to poor or no drainage facility and improper leachate treatment thanks to the lack of leachate treatment facilities).

There are many sources that can contribute to groundwater pollution namely the application of fertilisers, pesticides, disposal of treated industrial and municipal waste water, accidental spills and the impact of septic tank effluent (Paras et al., 2007; Mustafa et al., 2005). However, landfill leachate is believed to be the most potential threat to groundwater because it contains various types of substances and contaminants that are resistant to chemical and biological degradation (Fatta et al., 1999). A study reveals that groundwater contaminated with leachate might contain high conductivity, total dissolved solids, ammonia, chloride and toxic metals that might pose threat to human health (cancer risk, birth defect, damage to nervous system and death) and any other living organisms (Sabahi et al., 2009; Singh et al., 2008; Adeyemi et al., 2007).

Aware of these problems, Ministry of Housing and Local Government has conducted a study on safe closure and rehabilitation of landfill sites in Malaysia and suggested that 16 landfills located near water intake points (posing a threat to the safety and health of the people) to be closed using safe and acceptable methods. However, because of the fact that there are no replacement or alternative sites for solid waste disposal, four of the landfills were allowed to continue operations under the condition that these landfills be upgraded to an acceptable level (Level 3 for environmentally non–sensitive area and Level 4 for environmentally sensitive area or located near the intake of the water treatment plant for domestic supply) that will not damage the environment (Ministry of Housing and Local Government, 2005).

Consequently, detection of groundwater pollution and determination of pollutant sources are important when considering a clean-up or containment programme as well as legal issues that are frequently associated with polluted groundwater. In landfill areas with the presence of multiple sources of anthropogenic pollutants such as, hazardous waste disposal facilities, chemical industries, sewage treatment facilities, agriculture, housing and also geogenic factors such as, seawater intrusions that could possibly contribute to groundwater pollution cause difficulties in differentiating the source of the pollution and thus, complicates the interpretation of chemical data from monitoring wells around the landfill. By using the advantages of all the methods (resistivity imaging, hydrochemical and stable isotopes), it should be sufficient to overcome the limitationof inability to differentiate sources of pollution posed by conventional techniques.

1.3 Objectives

The purpose of this study is to develop an integrated environmental forensics tool in groundwater and surface water using hydrochemical, geophysical and isotope techniques. The information and results obtained from all the tools will map the contamination flow, direction, flow rate in the groundwater. Moreover, the information obtained could possibly be used for cost estimate, maintenance and monitoring activities of a landfill disposal site in time to come. The specific objectives of this study are to:

1. Determine the sub-surface pollutant flume by using geophysical techniques.
2. Evaluate the characteristics (physical, major ions, heavy metals, and D, O-18, C-13) of the landfill sites by using the hydrochemical method and stable isotopic composition as a tool.
3. Identify groundwater, surface water and leachate interaction at landfill sites through the use of geophysical techniques, hydrochemical and stable isotopic composition.
4. Verify the plume movement by using the groundwater model for landfill disposal sites.

1.4 Scope of Work

This research mainly focuses on two different levels of dumpsites in Perak, the Matang and Beriah landfills. Using the advantages of each method to compliment the other methods will give more accurate collaboration of results to fingerprint the contamination in shallow groundwater and surface water. To study the interaction of leachate, groundwater, and surface water at both landfill sites, leachate samples were collected from a leachate pond while groundwater and surface water were collected from the constructed borehole and nearest stream, respectively to monitor the leachate contamination of groundwater and surface water. All these samples were tested and examined for the physical, major ions, heavy metals and environmental isotopes (deuterium, oxygen-18 and carbon-13) to evaluate their characteristics. Meanwhile, geophysical techniques by using resistivity imaging were carried out to obtain the sub-surface profile of the landfill sites. MODFLOW software was used to study the movement and direction of groundwater flow as well as contaminant transport.

1.5 Thesis Outline

This thesis comprises of five chapters as follows:

Chapter 1 Introduction: This chapter introduces the background of the study and presents the problem statements, objectives and scope of work.

Chapter 2 Literature Review: Chapter 2 discusses the landfill, leachate and groundwater system. This chapter also emphasises on hydrochemical, stable isotopes, electrical resistivity imaging and groundwater modelling.

Chapter 3 Methodology: This chapter presents the electrical resistivity imaging method used, laboratory experiments for hydrochemical and stable isotope analysis including methods of groundwater modelling using visual MODFLOW.

Chapter 4 Results and Discussion: This chapter contains analytical data obtained from experimental and field works. The results include resistivity pseudo-section imaging of sub-surface, hydrochemical characteristics and isotopic composition analysis of leachate, groundwater and surface water for both Matang and Beriah landfill sites. This chapter also includes groundwater modelling.

Chapter 5 Conclusion and Recommendations: This chapter summarises all results and discussion for the integrated method (resistivity imaging, hydrochemical and isotope) and ultimately, draws a conclusion based on it.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter provides background information of landfill, landfill leachate characteristics, the impact of landfill leachate and groundwater contamination, geophysical techniques, environmental isotopes ratio, the hydrochemical method and MODFLOW software. It also includes the findings from previous works that related to this study.

2.1.1 Waste generation and types of waste

Malaysia is a developing country with rapid economy growing but still struggling finding the ideal solution to dispose Municipal Solid Waste (MSW) in a sustainable approach. The average municipal solid waste generated in Malaysia ranges between 0.5 to 0.8 kg/capita/day and increases to 1.7 kg/capita/day in major cities (Kathirvale et al., 2004). The current Malaysian population is 28 million and will keep rising over the years. Therefore, more waste is expected to be generated and substantial land will be needed in the future even if, the waste generation remains at the same level. The disadvantage of having too many landfills is that more leachate will be produced.

There are various types of waste stemming from residences, industries, clinical and municipals that will continue to be disposed of on the land (James, 1977). Hence, different types of waste require different types of landfill management. This is because some amount of generated waste is hazardous and poses potential threats to the environment and needs to be treated properly as well as safely disposed (Latifah et al., 2009). As a result, a classification system has been developed whereby landfills can be differentiated. According to the Department of Water Affairs and Forestry, DWAF, South Africa (1998), landfills can be classified into two types: sanitary landfill that receives general waste and secure landfill that receives hazardous waste. Besides, the nature of solid waste buried in the landfill will influence the leachate characteristics and its composition. Manaf et al., (2009) revealed that about 45% of waste in future will be made up of food, 24% of plastic, 7% of paper and 6% of iron and glass with the balance being (made up) of other materials.

2.1.2 Waste disposal site

All municipal solid waste produced are disposed in landfills and open dumpsites. The difference between open dumpsites and landfills are in terms of design. A landfill is an engineered waste disposal site facility that is well equipped with specific pollution control technologies to reduce and minimise the potential impacts (Sabahi et al., 2009). An open dumpsite, however, does not has appropriate landfill management aspects and poses potential threats to health, safety and the environment (Idris et al., 2004). Open dumpsites remain the most favoured method to dispose solid waste followed by lower levels of landfills due to technological and financial constraints (Chong et al., 2005). In Malaysia, landfills can be categorised into five levels that are, Level 0 (open dumpsite), Level 1 (controlled tipping), Level 2 (sanitary landfill with bund and daily soil cover), Level 3 (sanitary landfill with leachate recirculation system) and Level 4 (sanitary landfill with leachate treatment system) (Manaf et al., 2009; Pauzi et al., 2011). Table 2.1 clearly defines and differentiates the levels of landfills (Ministry of Housing and Local Government, Malaysia, MHLG, 1990).

Table 2.1 Classification of sanitary landfills in Malaysia (Ministry of Housing and Local Government, Malaysia, MHLG, 1990)

Items	Level 1	Level 2	Level 3	Level 4
Enclosing bund		√	√	√
Divider		*	√	√
Surrounding drain		√	√	√
Approach road	√	√	√	√
On-site road	√	√	√	√
Buffer zone		√	√	√
Litter control facility		*	√	√
Gas removal facility		*	√	√
Leachate collection facility			√	√
Leachate cycling facility			√	√
Seepage control facility			√	√
Leachate treatment facility				√
Site office	*	*	√	√
Weighbridge	√	√	√	√
Safety facility		√	√	√
Fire prevention facility		*	√	√
Monitoring facility			√	√
Wheel wash facility				√
Landfill equipment	√	√	√	√
Personnel (management)	√	√	√	√
Cover material	*	√	√	√
Water supply		√	√	√
Electricity			√	√
Insecticide	√	√	√	√
Monitoring chemicals			√	√
Environmental protection facility		√	√	√
Maintenance equipment	√	√	√	√

√: sufficient item
*: insufficient item

In 2002, Ministry of Housing and Local Government (MHLG) reported that there were 171 landfill operations in Malaysia where 83 are Level 0 (open dumpsite), 51 are Level 1 (controlled tipping) and 38 are Level 2, 3 and 4. Idris et al., (2004) revealed that in 2002, the number of landfills in operation is 161 where 77 are open dumps, 49 are Level 1 (controlled tipping), and only 37 are Level 2, 3 and 4. Following that, up till April 2012, there were a recorded total of 165 landfills that are still operation while 131 are closed landfills (as shown in Table 2.2) (Jabatan Pengurusan Sisa Pepejal Negara, JPSPN, 2012).

Table 2.2 Summary of total landfills in Malaysia (JPSPN, 2012)

State	Number of Operation Landfill	Number of Closed Landfill	Total
Johor	14	23	37
Kedah	8	7	15
Kelantan	13	6	19
Melaka	2	5	7
Negeri Sembilan	7	11	18
Pahang	16	16	32
Perak	17	12	29
Perlis	1	1	2
Pulau Pinang	1	2	3
Sabah	19	2	21
Sarawak	49	14	63
Selangor	8	14	22
Terengganu	8	12	20
WP Kuala Lumpur	0	7	7
WP Labuan	1	0	1
Total	165	131	296

2.1.3 Landfill phases

The decomposition of the readily organic matter begins as soon as the new landfill cell receives it municipal solid waste (MSW). The decomposition of the waste consists of a few phases and it varies from one site to another. This is because it is dependent on various factors such as, the composition of the solid waste, landfill operations, weather, seasonal changes, hydrological conditions of the landfill site, temperature, moisture content, pH and the age of the landfill site. According to previous works, Augenstein (1990) suggested that the stabilisation of waste proceeds in five sequential and distinct phases (aerobic, anaerobic, acidogenic, methanogenic and maturation) while Selberg et al., (2005); Agency for Toxic Substances and Disease Registry, ASTDR (2011) stated that bacteria decomposes landfill waste in four phases (aerobic, anaerobic, acidogenic and methanogenic). In spite of the varying opinion, they agreed that the decomposition of landfill waste undergoes three main stages that are: the aerobic phase followed by the anaerobic phase and lastly, methane formation. Figures 2.1 and 2.2 show the phases involved in landfills according to gas and leachate generation.

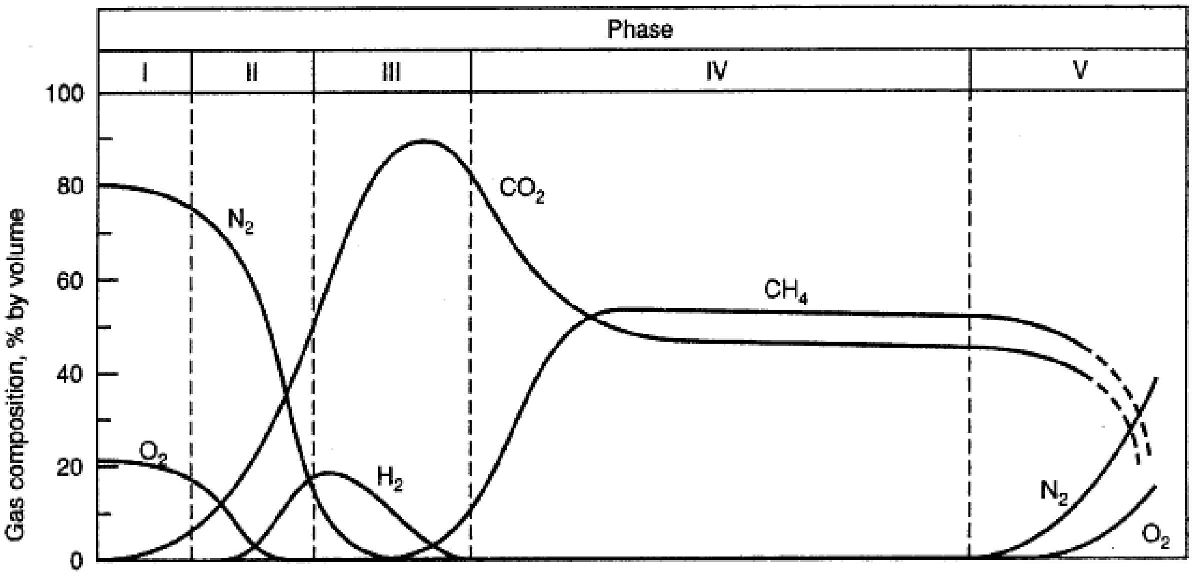

Figure 2.1 Phases in generation of landfill gas (Augenstein, 1990)

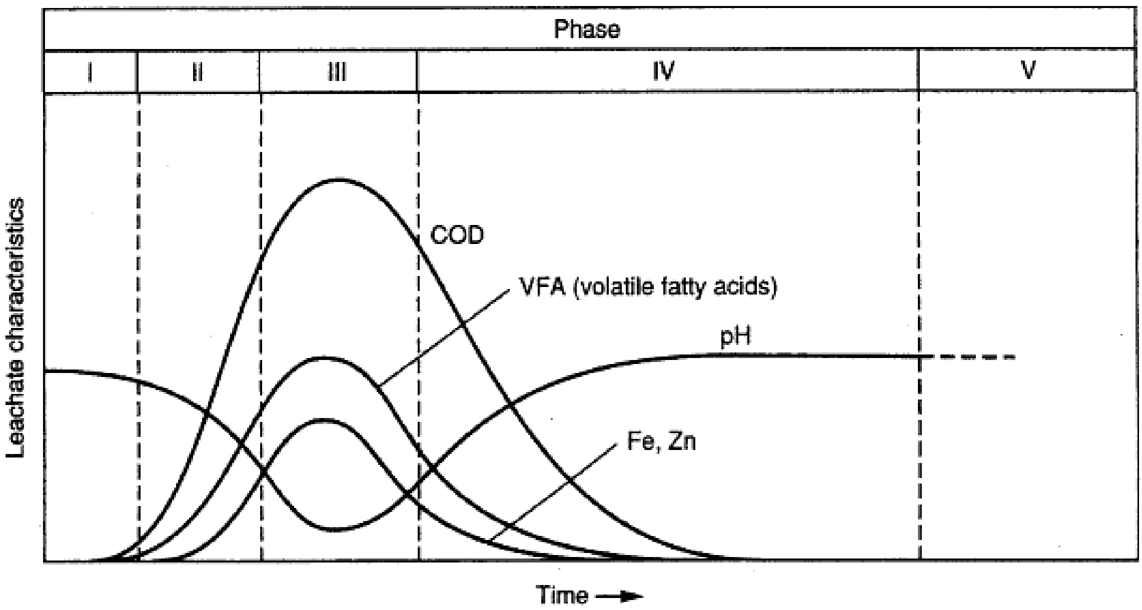

Figure 2.2 Phases in generation of landfill leachate (Augenstein, 1990)

The characteristics and rates of leachate generation from the landfill site are different from each phase and closely related to the microbiological response that occurs at each phase of the landfill site.

Aerobic phase is the first stage of waste decomposition. In this stage, the oxygen present in the void spaces decomposes the solid waste via biological process. Normally, the aerobic phase is quite short and no substantial leachate generation takes place (Jordening and Winter, 2005).

The second phase is known as transition stage where the transition from aerobic phase to anaerobic phase occurs. Within this time period, leachate formation occurs simultaneously. As the anaerobic bacteria take over, they produce wide range of acids including acetic, lactic, formic and alcohol that results in a decrease of pH in leachate. At the end of this stage, the concentration of COD and volatile organic acid will reduce (Chirtensen et al., 2001).

Next, is the acidogenic phase; where a high concentration of volatile organic acid, ammonia, hydrogen, and carbon dioxide is produced. The pH continues to reduce which increases the solubility of many compounds such as heavy metals, BOD and COD (Tchobanoglous, 2002).

In the fourth phase known as the methanogenic phase, methane formation will take place. Methane formation results in increased pH, thus influences the concentration of heavy metals present in the leachate. The concentration of BOD and COD are also reduced during this phase (Kjeldsen et al., 2010). The final phase is maturation. In this phase, the pH continues to increase as carboxylic acid concentration reduces (Warith, 2003).

2.2 Leachate

Undoubtedly, landfills are an indispensable part of our living. However, the leachate production from the landfill site may present long-term threats to groundwater and surface water that are hydrologically linked. This sub-topic will discuss in detail about the leachate formation, characteristics, and factors affecting leachate quality and quantity, as well as the impact of leachate towards groundwater.

2.2.1 Leachate Formation

Leachate is a solution of material leached from a solid. In a landfill site, leachate is polluted liquid that emanates from the base of a landfill (Papadopoulou et al., 2006) Landfill leachate is normally known as high-strength wastewater that is difficult to deal with because it generally contains high strength pollutants that have an adverse effect on the environment (Tengrui et al., 2007). Leachate is produced when percolating water moves through the landfill where it reacts chemically and biologically with the solid waste then, extracts the contaminants into the liquid phase and produces a moisture content sufficiently high to initiate liquid flow before it moves out of the landfill (Fatta et al., 1999).

The major sources of water for leachate formation are the infiltration of rain fall, groundwater that may flow laterally from the geologic formation surrounding the landfill, water contained within the solid waste deposited in the landfill and surface run-off into the landfill from exterior areas (Baker, 2005). Figure 2.3 explains in detail the formation of leachate from various sources. When the rain falls on the surface, it will eventually end up in one of three places:

i. Running off the surface into the drainage systems (RO)

ii. Infiltrating the surface and being evapotranspired back into the atmosphere (ET)

iii. Infiltrating into the landfill and seeping as deep percolation down into the solid waste below

iv. Percolation may be augmented by the infiltration of groundwater (G).

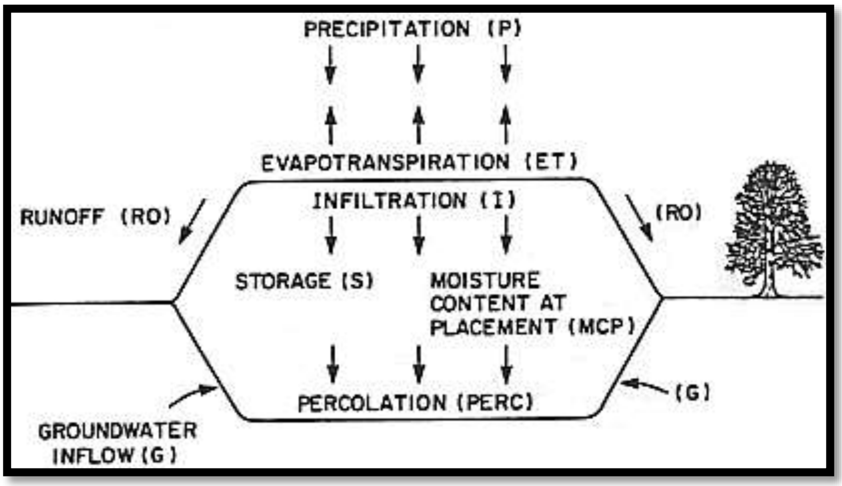

Figure 2.3 Leachate formation (Farquhar, 1989)

Once the leachate reaches the bottom of the landfill or an impermeable layer within the landfill, it either travels laterally to a point where it discharges to the ground's surface as a seep or it will move through the base of the landfill and into the sub-surface.

2.2.2 Leachate composition and characteristics

Generally, leachate can be classified into young leachate, intermediate and old or mature leachate. Ragle et al. (1995) reported that the composition of leachate and its emission rates differ between the old and the new areas of the fill. Young leachate indicates the landfill is in the acetic phase while old leachate indicates methanogenic phase (Maximova and Koumanova, 2006). Young or old leachate can be identified through colour and smell. Young leachate is known to have a slight smell and is brown or golden coloured. As for old or mature leachate, it is often black in colour and has a strong smell alike to the odour of a rotten egg. This colour and odour comes from the availability of oxygen in the landfill. Insufficient or depleted amounts of oxygen will alter the process from aerobic to anaerobic. Within the anaerobic process, the bacterium produces gas known as methane. In addition, leachate can also be classified as young, intermediate and old based on the years the landfill is in operation. These types of leachate can be defined according to landfill age and the value of pH, BOD_5, COD and BOD_5/COD ratio as summarised and shown in Tables 2.3 and 2.4.

Table 2.3 Leachate classification with age of landfill

	Young	**Intermediate**	**Old**
Ngo et al., (2008)	<5	5-10	>10
Tchobanoglous (2002)	<2	2-10	>10
Alvarez et al., (2004)	3-12 months	1-5	>5

Table 2.4 Typical values for landfill leachate classification (Ngo et al., 2008)

Parameter	**Young**	**Intermediate**	**Old**
pH	6.5	6.5-7.5	>7.5
BOD5	10000-20000		50-100
COD	>10000	4000-10000	<4000
BOD5/COD	>0.3	0.1-0.3	<0.1
Organic Compounds	80% volatile fat acids (VFA)	5-30% VFA+ humic and fulvic acids	Humic and fulvic acids
Heavy metals	Low-medium	Low	Low
Biodegradability	Important	Medium	Low

From Table 2.4, the pH value for young leachate is more acidic when compared to the pH value of old leachate. A lower pH is caused by the high concentrations of organic compounds (VFAs) in a young landfill. Over time, the bacterium degrades the VFA and reduces the organic strength of leachate thus, causing a rise in pH value (Timur and Ozturk, 1999). Besides, the high amount of readily degradable volatile acids account for the bulk of the BOD and COD of young leachate. As the waste ages, the organic matter gradually decreases as they are converted into gas (Shahin, et al., 2005). A variety of heavy metals are frequently found in landfill leachates and usually, a significant amount of heavy metals found in young leachate are slowly removed by complexation and precipitation in old leachate (Calli et al., 2006). With all these compositions, young leachate proves more polluted than old leachate (Tatsi and Zouboulis, 2002).

2.2.3 Factors Affecting Leachate Quality

Leachate composition or chemical quality varies significantly among landfills and it is known that different landfills will produce different qualities of leachate (Ngo et al., 2008). Research has shown that the composition of landfill leachate from the same source as well as from different sources is extremely varied. Hence, the leachate composition for a given landfill cannot be predicted from literature data since it is influenced by many parameters that are not easy to justify (Chian and DeWalle, 1976).

There are many parameters or factors that influence the quality of the leachate such as:

i. Age of the landfill
ii. The nature of the waste

iii. The source of waste

iv. The method of burial

v. The geological nature of the site (Tengrui et al., 2007; Sabahi et al., 2009; Rouhallah et al., 2011).

Age of the landfill dominantly governs the leachate's characteristics since waste placement. The older the landfill, the more the landfill waste is biodegraded because organic compounds decrease far more rapidly in comparison to inorganic compounds (Calli et al., 2006). This is the explanation why leachate from new landfills will be higher in BOD and COD then steadily decline, levelling off after 10 years (Akyurek, 1995). Moreover, the type or nature of the waste is also a significant factor. Initial waste normally consists of finite and varying types of chemicals where the leachate will inherit the properties of the waste it flows through. Besides, leachate quality reaches a peak after two or three years followed by a gradual decline in following years (McBean et al., 1995). Table 2.5 summarises the findings of leachate characteristics from various landfills according to the age of the landfill.

Table 2.5 Landfill leachate characteristics vs. age

Findings / **Parameter**	**Lee et al., 2010**	**Bahaa-eldin et al., 2010**	**Sanjay et al., 2009**	**Lee et al., 2010**	**Fatta et al., 1999**	**Umesh et al., 2008**
Landfill Age (years)	5	9	>10	15	20	>20
pH	6.8	6.7	8.33	7.3	8.44	8.35
BOD_5	6350	NA	4122	870	138	NA
COD	9600	NA	6834	1510	655	NA
BOD_5/COD	0.66	NA	0.6	0.5	0.13	
TOC	NA	NA	5434	NA	NA	NA
Conductivity (µS/cm)	NA	31.68	99510	NA	24038	26500

SS	NA	NA	NA	NA	245	NA
TDS	NA	28190	NA	NA	11618	1758
NH_3-N	520	3.96	NA	523	1216	NA
Org-N	880	NA	NA	663	NA	NA
NO_3	2	1.41	115	2	NA	178
F^-	NA	0.27	21.37	NA	NA	NA
Cl^-	1410	2047	4485	1100	4149	837
PO_4^{3-}	NA	ND	188.6	NA	13.6	13.6
SO_4^{2-}	509	12.95	796	771	356	287
Ca^{2+}	1060	155.8	340.5	405	57.1	89
Mg^{2+}	179	28.98	110.5	215	NA	306
K^+	NA	1.62	186.5	NA	1676	135
Na^+	1370	808.06	2550	1030	1984	470
As	NA	0.01	NA	NA	NA	NA
Cu	NA	0.05	0.9	NA	0.22	55.6
Cd	NA	0.001	0.93	NA	0.03	100
Cr	NA	0.01	2.87	NA	1.45	21.5
Fe	73.8	1.29	78.75	32.5	6.76	365
Pb	NA	0.05	0.84	NA	0.32	120
Mn	NA	0.63	4.15	NA	NA	423
Hg	NA	NM	NA	NA	NA	NA
Ni	NA	0.03	2.05	NA	0.67	60
Zn	NA	0.09	1.63	NA	0.53	201

*NA is Not Analysed

*ND is Not Detected

2.2.4 Factors Affecting Leachate Quantity

As previously discussed, the amount of infiltration from precipitation that falls on a landfill is a major factor that affects the quantity of leachate potentially generated. However, the amount of leachate produced also depends on the landfill's age, quantity of waste and the level of solid waste compaction. According to Kulikowska and Klimiuk (2008), the production of leachate in a young landfill is usually minor—around 30-40mm/year. Ehrig and Stegmann (1992) reported that the amount of leachate generated in a young Germany landfill is 15 to 25% from the annual rainfall whilst the amount for an old landfill is 25 to 50% of the annual rainfall. The level of the solid waste compaction also influences the amount of leachate generation. Rosik (2005) explained that landfills with low waste compaction would produce leachate about 40% of rainfall compared to 25% of rainfall for landfills with high waste compaction.

The amount of leachate produced from an active phase of a landfill under operation to a passive phase after closure has significant dissimilarity. This is because, after closure, the construction of the final cover will minimise the amount of water that can infiltrate through the final covers. This amount of water will percolate through the waste and generate leachate. Hence, the leachate volume generated in an active area and after closure can be obtained from the Equations 2.1 and 2.2 (Farquhar, 1989). For landfills, the free leachate retained on site, L_o must be a negative or zero value in order to ensure that there is no excess leachate produced. The amount of L_o can be obtained using the water balance equation Equation 2.3).

Leachate volume (active phase) =	(volume of precipitation) + (volume of pore squeeze liquid) – (volume lost through evaporation) – (volume of water absorbed by the waste) (2.1)
Leachate volume (after closure) =	(volume of precipitation) - (volume of surface run-off) – (volume lost through evapotranspiration) – (volume of water absorbed by the waste and intermediate cover) (2.2)
Lo=	(total liquid input) - (volume lost through evapotranspiration) – (absorption capacity of waste X weight of waste disposed) (2.3)

2.3 Groundwater Formation

According to the earth's water distribution, groundwater makes up more than one-fifth of earth's total fresh water supply (Liu et al., 2011). Groundwater is replenished by rain, snow, sleet and hail that infiltrates into the ground's solid materials that are actually porous. Materials with high porosity and permeability such as gravel, rock soil, sand and limestone can contain and transmit a large amount of water compared to materials with low porosity such as clay (University of New South Wales, UNSW, 2011). An area or a depth where the ground is filled or saturated with water is known as aquifer. Aquifer can transmit groundwater from an area of recharge to an area of discharge and provide a storage medium for usable quantities of groundwater.

2.3.1 Groundwater Quantity and Quality

In most countries, groundwater contamination is one of the least recognised environmental problems. This is due to the fact that the amount of groundwater used for water supply is minor compared to surface water. Thus, groundwater problems are not readily detected and pathways for contamination are not nearly as noticeable as those affecting surface water (Adeyemi et al., 2007).

However, for certain rural areas that are not connected to water distribution systems and lacking in clean water, they highly utilise groundwater as the main water supply (Mohamad Roslan et al., 2007). In addition, it has been reported that some states in Malaysia such as Kelantan, Perlis, Terengganu, Pahang, Kedah, Sabah and Sarawak have taken groundwater as an alternative for clean water (Mohamed Azwan, 2000). Moreover, during water crises and dry spells, groundwater is used as a source for emergency water supply. As it is being used for portable purposes, its quantity and quality remains an issue of concern (Noraini, 2003). The groundwater quantity and quality can be affected by increased demands for water (Steinman et al., 2007). Large-scale pumping caused water levels in wells to decline and when the groundwater levels are drawn down below the confining layer, it can lead to water quality impairments (Islam and Bernuth, 2003).

For surface water like rivers, there is a standard known as the National Water Quality Standard for Malaysia that can be referred to in order to classify the river's water quality. Unfortunately, the suitable index to assess groundwater is yet to exist in Malaysia (Mohamad Roslan, 2007). Hence, some researchers evaluate the quality of groundwater according to the Guidelines of Raw Drinking Water Quality Benchmark for Groundwater Quality (as shown in Table 2.6) and Malaysian Environmental Impact Assessment Guidelines for Groundwater (Taha et al., 2011).

Table 2.6 National Guidelines for Raw Drinking Water Quality (Ministry of Health, 2000)

Parameter	Symbol	Benchmark
Sulphate	SO_4	250 mg/l
Hardness	$CaCO_3SO$	500 mg/l
Nitrate	NO_3SO	10 mg/l
Coliform	-	Must not be detected in any 100 ml sample
Manganese	Mn	0.1 mg/l
Chromium	Cr	0.05 mg/l
Zinc	Zn	3 mg/l
Arsenic	As	0.01 mg/l
Selenium	Se	0.01 mg/l
Chloride	Cl	250 mg/l
Phenolics	-	0.002 mg/l
TDS	-	1000 mg/l
Iron	Fe	0.3 mg/l
Copper	Cu	1.0 mg/l
Lead	Pb	0.01 mg/l
Cadmium	Cd	0.003 mg/l
Mercury	Hg	0.001 mg