# THE PERFORMA... VITH HORIZONTAL SUBSURFACE FLOW (HSF) WETLAND FOR LANDFILL LEACHATE TREATMENT

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# ABSTRACT

The effect of limestone filter with wetland in landfill leachate treatment was studied. The combination of these two systems was seen as a good way to eliminate organic and inorganic matters in wastewater because limestone filter offers an abiotic condition while wetland offers a biotic condition. Control system (limestone filter) and full-treatment system (limestone filter with HSF wetland) were used in this study. Before and after treatments concentrations of parameters for pH, COD, BOD, TSS, $NH_3$–N, oil and grease, lead (Pb), zinc (Zn), manganese (Mn), iron (Fe) and copper (Cu) in leachate taken from Jabor-Jerangau Landfill were studied in a continuous flow mode. The sample was pre-treated with aeration beforehand for 48 hours. The filter was filled with limestone of sizes 2mm, 5mm, 10mm and 14mm that were layered in ascending order from top to bottom with ratio 30:25:25:20. Horizontal subsurface flow (HSF) system was applied to the wetland. From the result generated, it was found that combination of limestone with HSF wetland shows higher average percentage removal with 72.5% COD, 42.9% BOD, 73% TSS, 68.3% $NH_3$–N, 62% oil and grease, 79% lead, 82.2% manganese and 40.6% zinc. Both systems have the same breakpoint which was at 12-day HRT. This study concludes that full-treatment system can improve leachate quality and has good efficiency within 12 days.

# ABSTRAK

Kesan penapis batu kapur dengan tanah bencah buatan dalam rawatan air larut resap telah dikaji. Gabungan kedua-dua system ini telah dilihat sebagai langkah yang baik untuk menyingkirkan bahan organic dan bukan organic di dalam air sisa kerana penapis batu kapur menyediakan keadaan abiotik manakala tanah bencah buatan menyediakan keadaan biotik. Sistem kawalan (penapis batu kapur) dan sistem rawatan lengkap (penapis batu kapur dengan tanah bencah buatan subpermukaan) telah digunakan dalam kajian ini, Kepekatan untuk parameter pH, COD, BOD, TSS, $NH_3$–N, minyak dan gris, Plumbum (Pb), Zink (Zn), Mangan (Mn), ferum (Fe) dan Kuprum (Cu) dalam air larut resap diambil dari Tapak Pelupusan Sampah Jabor-Jerangau telah dikaji dalam mod aliran berterusan. Sampel telah diberi pra-rawatan menggunakan proses pengudaraan terlebih dahulu. selama 48 jam. Penapis tersebut telah dipenuhi dengan batu kapur bersaiz 2mm, 5mm, 10mm dan 14mm yang berlapis menurut susunan dari atas ke bawah dengan nisbah 30:25:25:20. Sistem aliran sub-permukaan mendatar (HSF) telah diaplikasikan kepada tanah bencah buatan tersebut. Daripada keputusan yang diperolehi, didapati kombinasi penapis batu kapur dan tanah bencah buatan HSF mempunyai peratusan penyingkiran yang lebih tinggi dengan 72.5% COD, 42.9% BOD, 73% TSS, 68.3% $NH_3$–N, 62% minyak dan gris, 79% Plumbum, 82.2% Mangan dan 40.6% Zink. Kedua-dua system mempunyai breakpoint yang sama iaitu pada 13-hari HRT. Kajian ini menyimpulkan bahawa sistem rawatan lengkap dapat menambahbaikkan kualiti air larut resap dan mempunyai kecekapan yang baik dalam masa 12 hari.

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# LIST OF SYMBOLS

| | |
|---|---|
| % | percent / percentage |
| x | multiplication |
| $Al^{+}$ | Aluminium ion |
| $CaCO_3$ | Calcium carbonate |
| $H^{+}$ | Hydrogen ion |
| Ca2+ | Calcium ion |
| $CO_2$ | carbon dioxide |
| Fe | Iron (Ferum) |
| $Fe^{2+}$ | Ferrous ion |
| $Fe^{3+}$ | Ferric ion |
| $Fe(HCO)_2$ | Ferrous bicarbonate |
| $Fe(OH)_3$ | Ferric hydroxide |
| $H_2O$ | water |
| Mn | Manganese |
| mg/L | milligram per litre |
| $Mn(HCO_3)$ | Manganese bicarbonate |
| $MnO_2$ | Manganese oxide |
| $NH_3-N$ | Ammoniacal Nitrogen |
| $O_2$ | Oxygen |
| Pb | Lead (Plumbum) |
| Zn | Zinc |

## LIST OF ABBREVIATIONS

| | |
|---|---|
| AAS | Atomic Absorption Spectroscopy |
| AWTS | Aerated Wastewater Treatment Systems |
| BOD | Biochemical Oxygen Demand |
| COD | Chemical Oxygen Demand |
| DOE | Department of Environment, Malaysia |
| HRT | Hydraulic Retention Time |
| HSF | Horizontal Subsurface Flow |
| LPM | Litre per minute |
| TSS | Total Suspended Solids |

# CHAPTER 1

# INTRODUCTION

## 1.1 Introduction

Population that keeps on increasing gives changes to the amount of human needs. To cater the needs of people, industrialization grows rapidly that it alters the pattern of human consumption of products (Zainol et al., 2012). Malaysia as a developing country does not exempt to this situation. As of 2010, Malaysian population was 28.6 million and is expected to increase of another 35% in 2040 (DOS, 2013). It can be predicted that the amount of solid waste produced will eventually increase. Kuala Lumpur alone produces 3500 tons of domestic and industrial wastes per day where 50% of the total waste produced is organic waste (Abdul, 2010) (Mallak and Ishak, 2012).

This matter has made municipal and industrial waste generations grow in larger amount. With many available lands, landfilling seems to be the most common method for solid waste disposal. It is estimated that there are more than about 260 landfills throughout Malaysia (Zainol et al., 2012). Apart from Malaysia, most countries with tropical settlement also use landfill as the method for solid waste disposal (Saheri et al., 2009). Landfills, specifically sanitary landfills are the alternative method practiced worldwide due to its economic advantages (Kjeldsen et al., 2002) (Renou et al., 2008) (Alkassasbeh et al., 2009) (Zainol et al., 2012) (Aziz and Abu Amr, 2012). Based on comparative studies, sanitary landfill is also cost-effective and environmentally friendly as compared to incineration, composting and gasification while open dumping grounds give serious problems that contribute to the major environmental problem and social threats (Renou et al., 2008) (Zainol et al., 2012).

Sanitary landfilling is the common way to eradicate municipal solid wastes. The 'sanitary' itself is meant by the minimal potential pollution problems and exposure of waste to the environment a landfill could offer (Ghosh and Hasan, 2010). Wastes collected in sanitary landfill are spread in layers and compacted to reduce its volume and are then covered with soil. It has facilities to collect landfill leachate with appropriate bottom liners that prevent its infiltration to the ground as well as the infrastructure to exploit landfill gases (Alkassasbeh et al., 2009). However, having such technology could not stop the percolation of excess rainwater through the waste layers in the landfill where pollutants are transferred to the seeping water by the physical, chemical and microbial processes in the waste (Kjeldsen et al., 2002). Every landfill will have almost the same various leachate compositions regardless of its age and nature of solid waste which are categorized into four groups of pollutants that is dissolved organic matter, inorganic macro-components, heavy metals and xenobiotic organic compounds (Kjeldsen et al., 2002).

Leachate could be dangerous if it infiltrates into the water sources such as groundwater due to various pollutants transferred from waste material it has encountered (Salem et al., 2008). By improving landfill engineering, apart from aiming to reduce the production of leachate, it is also important to prioritise the treatment quality. The impacts of landfill leachate to the water sources and the nearby areas have raised the number of studies done by various researches (Mor et al., 2006). Researches were either on the leachate itself or the effective treatments to eliminate contaminants. Based on various previous researches, there have been a lot of treatment systems conducted to treat landfill leachate physically, chemically and biologically.

Leachate treatment should be convenience with the simplest and the most cost-effective method of constructing and maintaining, pleasing aesthetic appearance, flexible design using environmentally friendly technology as well as operating with minimum energy but still giving the best results of contaminants removal similar to other available wastewater treatment systems. Limestone and constructed wetland have the criteria mentioned above and based on previous studies, both medium are among the best to treat wastewater. Since the use of limestone filter and constructed wetlands are not a common practice in Malaysia, therefore, both systems are used to in this study to prove their effectiveness and aims to provide options to treat wastewater especially landfill leachate.

## 1.2 Problem Statement

The growing economic in developing countries especially in capital city bring about the increasing of solid waste generation. In Malaysia, landfilling is the widely used method of municipal solid waste disposal. However, landfill can cause leachate generation which is a type of wastewater produced when any liquid comes into contact with waste which will then flow away from the waste materials. Improper treated leachate can bring harm to the groundwater which has become our major source of drinking water worldwide if it leaks and enter the water aquifer due to improper design of landfill. Eventually, this is a threat to public health and environment. Since the use of constructed wetland and limestone filter are not a common practice in Malaysia, therefore, this study aims to provide options to treat wastewater here.

## 1.3 Objective

The objective of this project is:

a) To determine the parameters of leachate such as pH, biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), oil and grease, ammoniacal nitrogen ($NH_3-N$), and heavy metals of Iron (Fe), Manganese (Mn), Copper (Cu), Zinc (Zn) and Lead (Pb).

b) To study the effectiveness of limestone filter with horizontal subsurface flow (HSF) wetland to treat landfill leachate.

c) To obtain the breakpoint that is the limit of the contaminant removal efficiency of the treatment system.

## 1.4 Scope of Project

In this study leachate will be used as wastewater sample which will be taken from Jerangau-Jabor Landfill in Kuantan. Limestone filter and HSF wetland were used as mediums to treat the leachate. There were two systems used to compare their effectiveness. Limestone filter was the control system and combination between limestone filter with HSF wetland was the full-treatment system. Limestone of size 2mm, 5mm, 10mm and 14mm with river sand of 2.36mm will be used as a filter media. As for HSF wetland, granite gravel of 20mm, sand of 2.36mm in sizes will be used as the media for HSF constructed wetland. Emergent aquatic vegetation used on HSF wetland is cattails (*Typha latifolia sp.*). Parameters to be analysed are pH, COD, BOD, TSS, oil and grease, $NH_3$–N and metals such as iron (Fe), manganese (Mn), copper (Cu), zinc (Zn) and lead (Pb).

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Introduction

This chapter discusses the literatures that are related to leachate treatment using limestone filter and constructed wetland. It will review on landfill leachate starting from its generation, composition to its available treatment. Other than that, review is also made on the system of horizontal subsurface flow (HSF) wetland and limestone filter, as well as the mechanism of removal of both systems. This chapter will also cover on the previous studies done by various researchers regarding wastewater treatments.

## 2.2 Landfill Leachate

Landfill leachate can simply be interpreted as the contaminated liquid at the base of landfill. The liquid is contaminated by the dissolved organic matter, phenol, ammoniacal nitrogen, phosphate, heavy metals, sulphide, hardness, acidity, alkalinity, salinity, solids, inorganic salts, and other toxicants are among the organic matters present in landfill leachate (Zainol et al., 2012). **Figure 2.1** shows the leachate collected in a landfill.

With the contaminants present in the liquid, if it were to infiltrate into the soil and reach the groundwater, it will cause pollution which is very dangerous since groundwater is the major source of drinking water worldwide. This indirectly gives a threat to public health and the environment. A proper landfill design could hinder from such problem to occur. Improper landfill such as regular dumpsite could exhibit the problem mentioned above. **Figure 2.1** shows a layout of a modern engineered landfill.

**Figure 2.1**: Landfill leachate collected in a retention pond

Source: mikedavidsonet.com

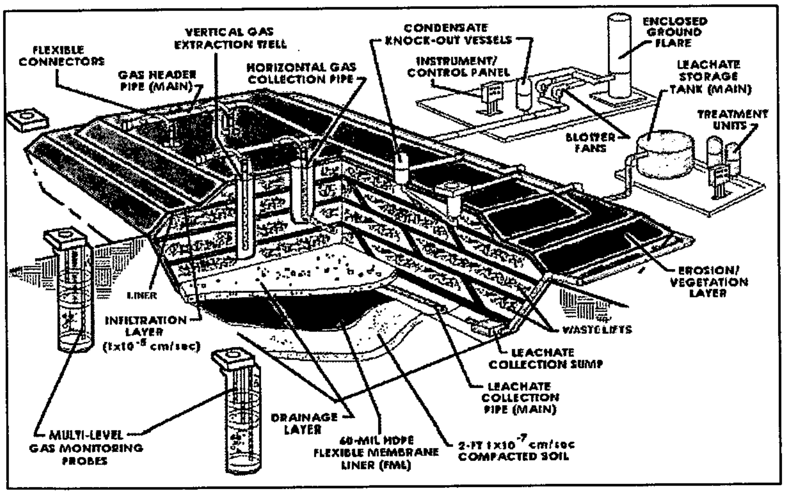


**Figure 2.2**: A layout of a modern engineered landfill

Source: CalRecycle.ca.gov

### 2.2.1 Leachate Generation

Leachate production involves with the elements of water balance. Precipitation and excess rainwater are the liquids that may run off from the landfill or infiltrates into it. The infiltration may cause the percolation of the liquids through the layers of waste deposited in a landfill which consists of organic matter in large amounts (Farquhar, 1988; Kjeldsen et al, 2002).

Othman (2009) reported that the composition and amount of leachate depend on many factors such as quality of wastes and its crumbling, techniques of landfilling and degree of waste compaction, age of landfill, biochemical and physical processes of waste decomposition, moisture and absorption capacity of wastes, precipitation, humidity, evapotranspiration rate, topography of landfill site, lining system, hydrogeology and vegetation.

**Figure 2.3** shows the conceptual process of leaching where rain water percolates through the deposit and dissolute by soluble substances contained in the solid waste materials. Apart from dissolution process of solid compounds as the mechanism to the release of contaminants to the percolating water, desorption of adsorbed species, chemical reactions such as oxidation and acid attack as well as complexation may also contribute to the present of contaminants in the water which is later called leachate (Petersen and Petrie, 2002).

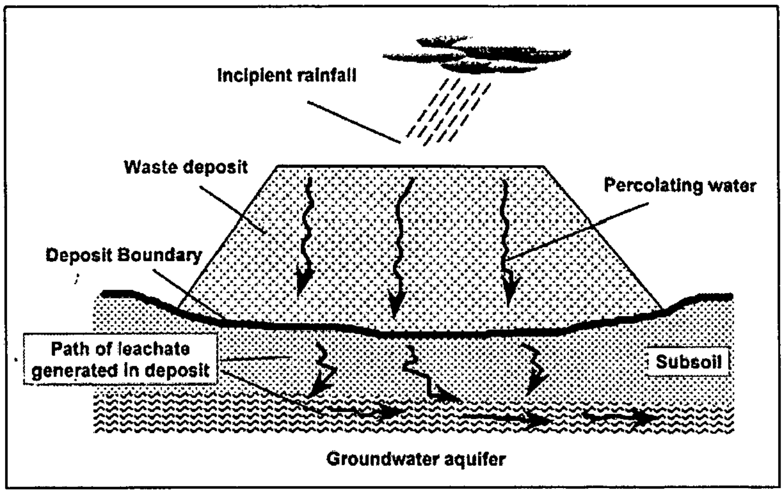


**Figure 2.3**: Conceptual leached process

Source: Petersen and Petrie (2000)

Li Rong (2009) also reported in her research that generation of leachate can also occur within the waste generated. It is due to the presence of solid wastes own excess moisture and adsorbed moisture coming from atmosphere or rainwater. The liquids generated by the waste itself are through the process of hydrolysis of solid waste and biological degradation as well as solubilisation of soluble salts contained in waste (Taylor and Allen, 2006).

### 2.2.2 Leachate Composition

Water percolated having contact with the solid wastes that undergo decomposition is leached by both biological and chemical constituents (Tchobanoglous et al., 1993). The compositions of landfill leachate are varies depending on the solid wastes composition, operation mode of a landfill, climate and hydrogeological conditions as well as those inside the landfill which is the biochemical activity, moisture, temperature, pH and age of landfill (Slomczynska and Slomcynski, 2004).

Vymazal and Kropfelova (2008) stated that leachate is coloured generally, anoxic and has high concentrations of total dissolved solids, COD, $BOD_5$, ammonia, phenols, benzene, toluene, chlorine, iron, manganese, arsenic, heavy metals such as lead, cadmium, zinc or chromium but little or no phosphorus. Aik et al. (2010) divided pollutants in leachate into three groups as shown in **Table 2.1**. Tchobanoglous et al. (1993) on the other hand outlined the typical physical, chemical and biological monitoring parameters used to characterize leachate as described in **Table 2.2**.

**Table 2.1**: Pollutants in leachate

| Group of pollutants in leachate | Components |
|---|---|
| Organic matters | Acids, alcohol, aldehydres, and others usually quantified as COD (chemical oxygen demand), BOD (biochemical oxygen demand), DOC (dissolved organic carbon), other volatile fatty acid and refractory compound include fulvic-like and humic like compounds |
| Inorganic matters | Sulphate, chloride, ammonium, calcium, magnesium, sodium, potassium, hydrogen carbonate and heavy metals such as iron, manganese, lead, nickel, copper, cadmium, chromium and zinc |
| Xenobatic organic compounds | Aromatic hydrocarbon, phenols, chlorinated aliphatics, pesticides and fertilizers include PCB, Dioxin, PAH, etc. |

Source: Aik et al. (2010)

**Table 2.2**: Leachate sampling parameters

| **Physical** | **Organic constituents** | **Inorganic constituent** | **Biological** |
|---|---|---|---|
| Appearance | Organic chemicals | Suspended solids (SS), total dissolved solids (TDS) | Biochemical oxygen demand (BOD) |
| pH | Phenols | Chloride | Coliform bacteria (total; fecal; fecal streptococci) |
| Oxidation-reduction potential | Chemical oxygen demand (COD) | Sulphate | Standard plate count |
| Conductivity | Total organic carbon (TOC) | Phosphate | |
| Colour | Volatile acids | Alkalinity and acidity | |
| Turbidity | Tannins, lignins | Nitrate-N | |
| Temperature | Organic-N | Nitrite-N | |
| Odour | Ether soluble (oil and grease) | Ammonia-N | |
| | Methylene blue active substances (MBAS) | Sodium | |
| | Organic functional groups as required | Potassium | |
| | Chlorinated hydrocarbons | Calcium | |
| | | Magnesium | |
| | | Hardness | |
| | | Heavy metals (Pb, Cu, Ni, Cr, Zn, Cd, Fe, Mn, Hg, Ba, Ag) | |
| | | Arsenic | |
| | | Cyanide | |
| | | Fluoride | |
| | | Selenium | |

Source: Tchobanoglous et al. (1993)

The reactions occurring in landfills do affect the composition in leachate. In biological reaction, organic material in solid waste leads to the development of landfill gases and liquids. With the presence of oxygen, biological decomposition process occurs aerobically until the oxygen depleted. During this stage, production of $CO_2$

occurs. However, the aerobic stage is short with no significant volumes of leachate produced. It is quickly replaced by anaerobic conditions (Taylor and Allen, 2006). Without the presence of oxygen, the decomposition process continues anaerobically with the organic matter is converted to $CO_2$, $CH_4$, ammonia and hydrogen sulphide (Tchobanoglous et al., 1993).

In anaerobic digestion, acetogenic (acid) fermentation, intermediate anaerobiosis and methanogenic fermentation are the main stages operate in different parts of the landfill (Taylor and Allen, 2006). In a younger landfill, leachate will undergo acetogenic stage which includes hydrolysis, formation of organic acids, hydrogen and carbon dioxide. An older landfill will undergo methanogenic stage where there will be formation of methane, carbon dioxide, etc. (Slomczynska and Slomcynski, 2004).

Variation in leachate composition also depends greatly on the age of landfill and the events that come before the sampling time. During the decomposition of acid, the concentration of $BOD_5$, TOC, COD, nutrients and heavy metals will be high with acidic pH values of 5 to 6 due to hydrolysis and fermentation of protein. In the fermentation of methane, the pH will be neutral within range of 6 to 8 and the concentrations of the parameters mentioned will be lower due to the majority organic components has almost solubilised. Leachate produced at this stage is characterised by relatively low BOD values and low ratios of $BOD_5/COD$ (Tchobanoglous et al., 1993) (Taylor and Allen, 2006). Stegmann et al. (2005) reported a study by Kruse (1994) that there are three characteristics periods according to the $BOD_5/COD$ ratio as follows:

| | | |
|---|---|---|
| Acid phase | : | $BOD_5/COD \geq 0.4$ |
| Transient phase | : | $0.4 > BOD_5/COD > 0.2$ |
| Methanogenic phase | : | $BOD_5/COD \leq 0.2$ |

Aik et al. (2010) also reported that composition of landfill leachate varies widely depending on the waste type and the waste age. In his study, samples of leachate from two cells of different ages within one landfill were studied. The results of parameters show higher contaminant concentrations in younger cell as compared to the older cell. This shows the correlation between leachate qualities with waste age where the acetogenic and methanogenic phases experienced by both organic and inorganic constituents in the waste affected their microbial degradation. **Table 2.3** below shows the range of the observed concentration values.

**Table 2.3**: Typical data on the composition of leachate from new and mature landfills

| | Value, mg/L | | |
|---|---|---|---|
| | New landfill (< 2 years) | | Mature landfill |
| **Constituent** | **Range** | **Typical** | **(> 10 years)** |
| $BOD_5$ (biochemical oxygen demand) | 2000-30000 | 10000 | 100-200 |
| TOC (total organic carbon) | 1500-20000 | 6000 | 80-160 |
| COD (chemical oxygen demand) | 3000-60000 | 18000 | 100-500 |
| Total suspended solids | 200-2000 | 500 | 100-400 |
| Organic nitrogen | 10-800 | 200 | 80-120 |
| Ammonia nitrogen | 10-800 | 200 | 20-40 |
| Nitrate | 5-40 | 25 | 5-10 |
| Total phosphorus | 5-100 | 30 | 5-10 |
| Ortho phosphorus | 4-80 | 20 | 4-8 |
| Alkalinity as $CaCO_3$ | 1000-10000 | 3000 | 200-1000 |
| pH | 4.5-7.5 | 6 | 6.6-7.5 |
| Total hardness as $CaCO_3$ | 300-10000 | 3500 | 200-500 |
| Calcium | 200-3000 | 1000 | 100-400 |
| Magnesium | 50-1500 | 250 | 50-200 |
| Potassium | 200-1000 | 300 | 50-400 |
| Sodium | 200-2500 | 500 | 100-200 |
| Chloride | 200-2000 | 500 | 100-400 |
| Sulfate | 50-1000 | 300 | 20-50 |
| Total iron | 50-1200 | 60 | 20-200 |

Source: Tchobanoglous et al. (1993)

### 2.2.3 Leachate Problems Towards Ecosystem

Landfills are identified as one of the major threats to groundwater resources. Groundwater has been the supply of fresh water covering about 95% worldwide. Leachate produced is considered as the liquid containing high concentration of decomposition by-products and hazardous matter that it carries resulting from mixing with waste materials on landfill (Mor et al., 2006). Uncontrolled landfills such as open dumps possess the ability to pollute the groundwater as it is not build with proper facilities such as geotextile lining for leachate collection.

The resulting leachate will leave the landfill by seeping into the soil through direct infiltration on site or by infiltration of leachate-laden runoff offsite (Taylor and Allen, 2006). Once the infiltration reaches the water aquifer it will directly pollute the groundwater. Leachate can also enter the groundwater directly without soil filtration due to the high position of groundwater table which is close to the ground surface (Al-Khateeb, no date.). **Figure 2.4** shows infiltration of leachate from landfill into the soil reaching the groundwater.

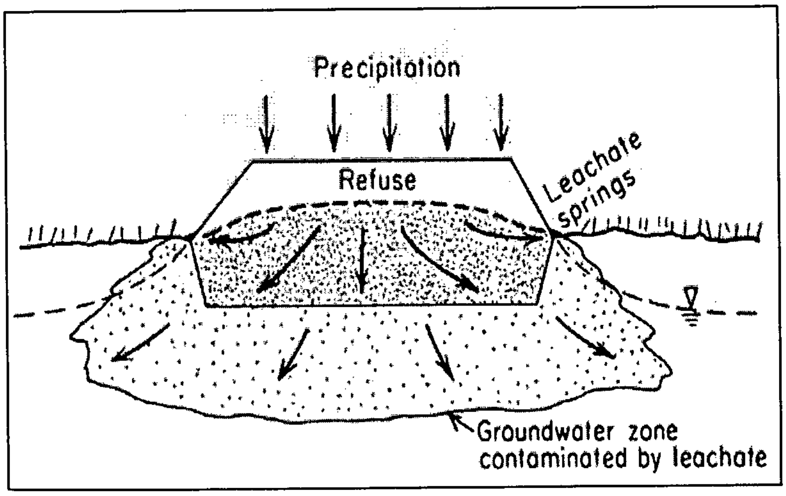


**Figure 2.4**: Landfill infiltrates into soil polluting the groundwater zone

Source: Taylor and Allen, 2006