A STUDY ON QUANTITY AND QUALITY OF LEACHATE OF MATUAIL SANITARY LANDFILL

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It is hereby declared that this thesis or any part of it has not been submitted elsewhere for the award of any degree or diploma.

October, 2010 Md. Sufiullah Siddik Bhuyan

Dedicated To

My Parents

Mohammed Ullah Bhuiyan
Mrs Amena begum

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Abstract

Municipal solid waste management, from 2005 Dhaka City Corporation has given emphasis on introducing sanitary landfill technology rather than open dumping. A master plan was formulated by Dhaka City Corporation, with the technical assistance of Japan International Cooperation Agency (JICA) in 2005 for a target year of 2015 to make Dhaka City Clean. Under the Landfill Improvement project, Dhaka City Corporation (DCC) transformed an open dump to in a sanitary landfill at Matuail; the construction period was March 2006 to October 2007. It is the first sanitary landfill site in Bangladesh. Semi-aerobic system of waste decomposition has been installed at the landfill site. Aerated lagoons have been also constructed to treat the leachate. To operate the leachate treatment system efficiently, it is essential to know about the variations in the quantity and quality of leachate throughout the year. As a result, a study was conducted to monitor the effectiveness of the installed semi-aerobic system on leachate quality and differentiate between semi-aerobic system and boundary system for both in dry and wet season. The estimation of quantity of leachate from rainfall and find out relationship between leachate flow rates with rainfall intensity were also important to analyze both for semi-aerobic and boundary system.

For completing the study objectives, a rain gauge (18 in x 8 in) was placed at landfill site to record rainfall data and leachate production was estimated on monthly basis by using water balance method (Fenn *et al.* 1975). To obtain a relationship between leachate flow rate and rainfall intensity; leachate flow was also measured for a number of rainy days and dry period both in semi-aerobic and boundary system. Semi-aerobic system involves installation of a combined use of the perforated pipe network and gravel pack below the solid wastes layers for collection of leachate produced in the landfill as well as supply of oxygen into the deposited waste. Oxygen in air is led into the landfill through the leachate collection pipe by heat convection resulting from differences between the inner temperature and outside air temperature (Hanashima *et al.* 1981a). In boundary system depletion of oxygen supply biodegradable organic matter eventually is subjected to anaerobic breakdown. This anaerobic decomposition is biologically much the same as that in the anaerobic digestion of sewage sludge. Microbial organisms responsible for anaerobic decomposition include both facultative and obligate anaerobes.

In the study total rainfall was found 1816 mm for wet season and maximum rainfall and intensity were 650 mm and 55.90 mm/hr in August and September, 2008 respectively. The higher leachate flow rate occurred in rainy months of June, July and August, 2008 and maximum value of total leachate flow rate was 26.90 m^3/hr on 27th August, 2008 with rainfall intensity of 34.60 mm/hr. It was observed that in dry period collection efficiency of leachate was more than wet period at Matuail and the flow rates were within the range 3.2 – 5.0 m^3/hr for dry period and 12.7- 19.49 m^3/hr in rainy season.

Two regression equations were obtained to correlate flow rate with rainfall intensity. A linear relationship was found both for semi-aerobic and boundary system. The equations were $y = 0.245x + 3.214$, $r^2 = 0.856$ and $y = 0.325x + 5.153$, $r^2 = 0.784$ for semi-aerobic and boundary system respectively. From regression analysis it was also seen that during dry period leachate flow occoured 3.20 m^3/hr in semi-aerobic system and 5.0 m^3/hr in boundary system which was approximately similar to flow rate found from field observations.

Production of leachate was increased with the increasing rainfall but collection efficiency degraded in wet period. For the existing operating landfill area of 31.12 acres it was estimated that maximum leachate production was 70,819 m^3 in August, 08 generated from waste and rainfall. In dry period contribution of leachate generation from waste was 4795 m^3 and observed flow was 5.32m^3/hr in November, 2008. Total excess leachate generated from rainfall was not collected through installed leachate pipe networks due to unmanaged cleaning operation during rainy days as well as number of leachate pipes might not sufficient to carry the excess generated leachate lead to contaminate soil and ground water. For the month of May, June, July, September, October, November, 2008 and January 09, the leachate productions were 19,400 m^3, 24,634 m^3, 52,130 m^3, 20,218 m^3, 24,314 m^3 , 4795 $m^3$and 4717 m^3 respectively.

For monitoring seasonal variations of leachate quality parameters, two types of leachate samples; one from semi-aerobic and another from boundary system were collected for laboratory tests. The characterization of leachate at Matuail has shown that the concentation of different parameter varies within a wide range. It was due to non homogeneity of wastes. It typically contains a wide range of dissolved organic and inorganic contaminants, including heavy metals. Seasonal variations of COD, BOD, EC, NH_3-N, alkalinity, Cl^- and heavy metals contents were less in semi-aerobic system than boundary system except pH. The ratios of BOD to COD of the collected samples were 0.51–0.72 and 0.16–0.40 in semi-aerobic system and 0.56–0.72 and 0.14–0.42 in boundary system for the rainy and dry seasons respectively. The collected effluent suitable to be treated only by biological treatment methods in rainy season and in dry period effluent needs to be treated by physical or chemical treatment. Semi-aerobic system is effective in improving leachate quality compared with boundary system.

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LIST OF ABBREVIATIONS

BADC = Bangladesh Agricultural Development Corporation

BBS = Bangladesh Bureau of Statistics

BMD = Bangladesh Meteorological Department

BOD = Biochemical Oxygen Demand

BRTC = Bangladesh Research and Testing Corporation

BUET = Bangladesh University of Engineering and Technology

BWDB = Bangladesh Water Development Board

CEC = Cation Exchange Capacity

COD = Chemical Oxygen Demand

DAP = Detailed Area Plan

DCC = Dhaka City Corporation

DND = Dhaka-Narayanganj-Demra

DO = Dissolved Oxygen

DWASA= Dhaka Water Supply and Sewerage Authority

EC = Electrical Conductivity

EMP = Environmental Management Plan

EPA = Environmental Protection Agency

EPM = Environmental Protection Measures

EQS = Environmental Quality Standards

FML = Flexible Membrane Liner

HELP = Hydrologic Evaluation of Landfill Performance

IBI= Indices of Biological Integrity

IWM= Institute of Water Modeling

JICA= Japan International Cooperation Agency

MC= Moisture Content

NTU= Nephelometric Turbidity Unit

PERC = Percolation

RO = Reverse Osmosis

SWM = Solid Waste Management

TDS = Total Dissolved Solids

TSS = Total Suspended Solids

WBM = Water Balance Method

Chapter 1

INTRODUCTION

1.1 Background

The jurisdiction of Dhaka City Corporation (DCC) has an area of 360 km^2 and a population of 7.00 million (BBS, 2008). City Metropolitan Areas covers 1528 Sq.km area (DAP, 2010) and a population of 1, 27, 97,394 (BBS, 2008). Because of the scarcity of flood-free land, the population density exceeds 40000 per km in highly urbanized areas have gradually been expanding towards suburban areas. The greater Dhaka today occupying several urban areas in the out skirts such as Narayangonj, Demra, Uttara, Baridhara, Tongi, Gazipur, Mirpur and Savar. As one of the significant environmental issues in such a growing mega city, solid waste management issue is critical and to be urgently tackled for a sustainable solution.

To improve solid waste management in Dhaka, Dhaka City Corporation with financial support from Japan International Cooperation Agency (JICA) conducted a study on Solid waste Management (SWM) of Dhaka City under CLEAN DHAKA MASTER PLAN (2005-2015). The study recommended implementation of project and programs with focus on community- based SWM, doubling cleaning capacity, improvement of final disposal and enhancing management capacity of DCC. The implementation of the program/projects included in the Master Plan will contribute to achieve the goal of “Clean Dhaka”. There are priority projects and programs in the Master Plan for Improvement of Solid Waste Management in Dhaka City. The Landfills Improvement project at Matuail is one of the priority projects included in the Master Plan.

In accordance with the recommendation of the Master Plan for Improvement of Solid Waste Management of Dhaka city, the Dhaka City Corporation planned to convert the existing solid waste dump site at Matuail into sanitary landfill site and acquired land adjacent to this site to design a new model sanitary landfill. Crude dumping was practiced at this site since the beginning of its operation, converting the existing dump site into a sanitary landfill was a major challenge. Considering the situation, the DCC planned to improve the operational and environmental conditions of the existing dump site through adaptation of a series of design and operational interventions. These interventions were aimed at preventing further degradation of the surrounding environment as much as possible. At the same time the DCC acquired a 1, 95, 430 sq.m (53 acres) land to construct a new sanitary landfill adjacent to the existing dump site which has an area of, 189,990 sq.m (50 acres). Thus the Matuail landfill project of the DCC has two major components:

1) Improvement of the conditions of the existing open solid waste dump site and upgradation of the operation of the landfill, and
2) Construction of a sanitary landfill at the acquired land adjacent to the existing dump site.

DCC uses two landfill sites namely, Matuail (40 ha) and Aminbazar (20 ha) are under implementation process for sanitary condition (DCC, 2009). Matuail has been collecting solid waste 1150 ton/day to 1450 ton/day on an average daily (DCC, 2009) which officially recorded almost carrying ¾ th of coverage of the city. The rest of the wastes are disposed of at Aminbazar. The landfill site is using mainly collection of household wastes. But in practices, city dwellers of different income groups as well as other sources such as commercial, construction debris, industrial and uncontrolled clinical wastes have chance to mix at DCC waste collection point which is finally disposed to sanitary landfill. The hospitals and clinics of the city produce waste containing dangerous toxic chemicals, radioactive elements and pathological substances, heavy metal coming from small and medium industries of Dhaka City are also mixed with general wastes. Pet bottle and polythene also cause health hazard to environment and drainage system. One of the important aspects is that many of unorganized different recycling industries in the city are reducing waste load to the landfill site. These landfilling wastes are decomposed with the help of microbial action under anaerobic and semiaerobic conditions that produces leachate. To avoid contamination of ground and surface water by leachate road networks, underground leachate collection system, leachate treatment and recirculation process are introduced in Matuail sanitary landfill. Due to introduction of semi-aerobic system, decomposition rate has been increased resulting in higher generation of leachete that is percolated through semiaerobic layer and boundary system has been established to collect leachate that flows to the boundary.

During site investigation done by BRTC, BUET it was found that 15 to 40 m depth of clay layer exists at the landfill site which acts as a natural liner above ground water table and made the landfill free of ground water contamination. The success of the landfill mostly depends on operation and maintenance guide line to be followed by Dhaka City Corporation (BRTC, 2009) which reflects functioning of leachate drainage facilities, leachate quality assessment in different outlet points and monitoring ground water contamination.

1.2 Objectives of the study

The main objective of this study is to monitor the effectiveness of the installed semi-aerobic system on leachate quality and differentiate between semi-aerobic system and boundary system for both dry and wet season. The specific objectives are as follows:

- To measure rainfall intensity
- To measure the total leachate flow rates for both dry and wet season
- To measure the variation in the leachate flow rate with rainfall intensity
- To find the correlation between the leachate flow rate and rainfall intensity
- To estimate the leachate generation and compare with the measured flow
- To analyze the leachate quality and find the effectiveness of the semi-aerobic system

1.3. Methodology

For conducting the study a rain gauge (18 in x 8 in) was set up at landfill site to record rainfall data and leachate production was estimated for monthly basis by using it. To obtain a relationship between leachate flow rate and rainfall intensity the leachate flow was measured for a number of rainy and dry days both in semi-aerobic and Boundary system. For monitoring seasonal variations on leachate quality parameters two types of leachate samples; one from semi-aerobic and another from Boundary system were collected for laboratory tests.

1.4. Outline of the Thesis

Apart from this Chapter, the remainder of the thesis has been divided into five (4) chapters.

Chapter 2 presents literature review concerning sanitary landfill, landfill process, site selection, quantity and sources of waste generation, technology of landfill, development and management of landfill. The leachate generation, collection and treatment process, recirculation and recycling are also discussed in this chapter. It also explains construction of semi-aerobic system and boundary drainage system.

Chapter 3 represents the methodology of the work which includes method of sample collection, measuring and method of field leachate flow rate, procedure of recording rainfall data and quantitative analysis of leachate sample. It also describes laboratory test procedures of leachate samples.

In chapter 4, the results of monthly and daily variation of rainfall, rainfall intensity and runoff calculation and field leachate generation and comparison of flow and collection efficiency of leachate are provided. It also presents the laboratory experimental results of leachate samples and discusses the results.

Chapter 5 presents the concluding remarks and recommendations for the future studies.

Leachate flow rate and laboratory test results of leachate samples are shown in Appendix-I and II.

Chapter 2

LITERATURE REVIEW

2.1 Introduction

When solid wastes are openly dumped without control on the land two major disadvantages: 1) generate liquid and gaseous emissions (leachate and landfill gas) that can pollute the environment and 2) represent a breeding ground for disease-bearing animals and microorganisms. Other risks to the public health and safety and to the environment are also posed by the uncontrolled land disposal of solid wastes.

Sanitary landfilling, which is the controlled disposal of waste on the land, is well suited to developing countries as a means of managing the disposal of wastes because of the flexibility and relative simplicity of the technology. Sanitary landfilling controls the exposure of the environment and humans to the detrimental effects of solid wastes placed on the land. Through sanitary landfilling, disposal is accomplished in a way such that contact between wastes and the environment is significantly reduced, and wastes are concentrated in a well defined area. The result is good control of landfill gas and leachate, and limited access of vectors (e.g., rodents, flies, etc.) to the wastes. The practice of sanitary landfilling, however, should be adopted in accordance with other modern waste management strategies that emphasise waste reduction, recycling, and sustainable development.

In Matuail study area collection, treatment and safe disposal of excess leachate from the landfill site had been given top priority to mitigate possible impacts on environment. A network of perforated pipes with gravel pack system was installed within and around the waste cells for ventilation-cum-leachate collection in order to make semi-aerobic condition in the landfill for rapid stabilization of waste with minimum odor to convey the excess leachate into a pond system located between old dump site and newly acquired land for landfill. Incorporating the technology provides ease of collection and improving the quality of leachate. The leachate will then be treated by aerated lagoon method in the ponds to reduce the pollution load to acceptable levels and the effluent from the treatment plant will be discharged with surface drainage while the excess sludge will be put into the landfill for biodegradation with solid wastes. It will also reduce the discharge of methane, a highly potential greenhouse gas, in the environment.

As a result the study work needs to review the literatures that include land fill process, environmental factors, density and settlement of waste, types and composition of waste, topography, geology, hydrogeology, soil characteristics, operation and maintenance of landfill site, vegetation, water management, mechanism of leachate formation, composition and analysis of leachate flow, liners, leachate migration, collection, treatment and disposal of leachate.

2.2 Landfill Processes

Physical, chemical, and biological processes are discussed in this section. Of the three types, the biological processes probably are the most significant. However, the biological processes are strongly influenced by the physical and chemical processes.

2.2.1 Physical Process

In general, significant physical reactions in the fill are in one of three very broad forms: compression (compaction), dissolution, and sorption. Because settlement is an invariable accompaniment of compression, the two usually are discussed together. Similarly, dissolution and transport are closely associated phenomena, although not to the same degree as compression and settlement. All components of the buried fill are subjected to the three processes.

Compaction is an ongoing phenomenon that begins with compression and size reduction of particles by the compacting machinery and continues after the wastes are in place. The continuing compression is due to the weight of the wastes and that of the soil cover (burden). Sifting of soil and other fines is responsible for some consolidation. Settling of the completed fill is an end result of compression. This settling is in addition to the settlement brought about by other reactions (e.g., loss of mass due to chemical and biological decomposition).

The amount of water that enters a fill has an important bearing on physical reactions. Water acts as a medium for the dissolution of soluble substances and for the transport of unreacted materials. The unreacted materials consist of animate and inanimate particulates. Particle sizes range from colloidal to several millimetres in cross-section.

In a typical fill, the broad variety of components and particle sizes of the wastes provides conditions that lead to an extensive amount of adsorption, which is the adhesion of molecules to a surface. Of the physical phenomena, adsorption is one of the more important because it brings about the immobilisation of living and non-living substances that could pose a problem if allowed to reach the external environment. It could play an important part in the containment of viruses and pathogens and of some chemical compounds. Adsorption does have its limits, one of which is its questionable permanency. One or several factors can alter permanency. For example, it can be altered by the effect of biological and chemical decomposition on adsorption sites.

Absorption is another of the physical phenomena that takes place in a fill. It is significant in large part because it immobilises dissolved pollutants by immobilising the water that could transport them and suspended pollutant particulates out of the confines of the fill. Absorption is the process whereby substances are taken in by capillarity. Most of the absorption potential of landfilled municipal waste is attributable to its cellulosic content. However, it should be recognised that, excepting fills located in arid regions, eventually all absorbent material in a fill becomes saturated. Consequently, absorption may be regarded as being only a delaying action as far as pollutant release is concerned.

2.2.2 Chemical Process

Oxidation is one of the two major forms of chemical reaction in a fill. Obviously, the extent of the oxidation reactions is rather limited, inasmuch as the reactions depend upon the presence of oxygen trapped in the fill when the fill was made. Ferrous metals are the components likely to be most affected.

The second major form of chemical reaction includes the reactions that are due to the presence of organic acids and carbon dioxide (CO_2) synthesised in the biological processes and dissolved in water (H_2O). Reactions involving organic acids and dissolved CO_2 are typical acid-metal reactions. Products of these reactions are largely the metallic ions and salts in the liquid contents of the fill. The acids lead to the solubilization and, hence, mobilisation of materials that otherwise would not be sources of pollution. The dissolution of CO_2 in water deteriorates the quality of the water, especially in the presence of calcium and magnesium.

2.2.3 Biological Process

The importance of biological reactions in a fill is due to the following two results of the reactions:

1. The organic fraction is rendered biologically stable and, as such, no longer constitutes a potential source of nuisances.

2. The conversion of a sizeable portion of the carbonaceous and proteinaceous materials into gas substantially reduces the mass and volume of the organic fraction.

At this point, it should be remembered that a fraction of the nutrient elements in the waste is transformed into microbial protoplasm. Eventually, this protoplasm will be subject to decomposition and, hence, it makes up a reservoir for breakdown in the future.

The wide varieties of fill components that can be broken down biologically constitute the biodegradable organic fraction of MSW. This fraction includes the garbage fraction, paper and paper products, and “natural fibres” (fibrous material of plant or animal origin). Biological decomposition may take place either aerobically or anaerobically. Both modes come into play sequentially in a typical fill, in that the aerobic mode precedes the anaerobic mode. Although both modes are important, anaerobic decomposition exerts the greater and longer lasting influence in terms of associated fill characteristics.

2.2.3.1 Aerobic decomposition

The greater part of decomposition that occurs directly after the wastes are buried is aerobic. It continues to be aerobic until all of the oxygen (O_2) in the interstitial air has been removed. The duration of the aerobic phase is quite brief and depends upon the degree of compaction of the wastes, as well as the moisture content since the moisture displaces air from the interstices. Microbes active during this phase include obligate as well as some facultative aerobes.

Because the ultimate end products of biological aerobic decomposition are CO_2, and H_2O, adverse environmental impact during the aerobic phase is minimal. Although intermediate breakdown products may be released, their amounts and contribution to pollution usually are small. It requires supply of oxygen to be pumped into the landfill. This is a costly system in terms of construction and operation.

2.2.3.2 Anaerobic decomposition

Because the oxygen supply in a landfill soon is depleted, most of the biodegradable organic matter eventually is subjected to anaerobic breakdown. This anaerobic decomposition is biologically much the same as that in the anaerobic digestion of sewage sludge. Microbial organisms responsible for anaerobic decomposition include both facultative and obligate anaerobes.

Unfortunately, the breakdown products of anaerobic decomposition can exert a highly unfavourable impact on the environment unless they are carefully managed. The products can be classified into two main groups: volatile organic acids and gases. Most of the acids are malodorous and of the short-chain fatty-acid type. In addition to chemical reactions with other components, the acids serve as substrates for methane-producing microbes.

The two principal gases formed are methane (CH_4) and CO_2. Gases in trace amounts are hydrogen sulphide (H_2S), hydrogen (H_2), and nitrogen (N_2).

2.2.3.3 Semi-aerobic decomposition

Decomposition of the organic matter generates heat and increase the temperature to about 50-70^o C in the waste layers. The warm air and gases generated in the decomposing landfill tend to rise up and construction of venting system in the landfill helps supply of air in the system and thus oxygen is supplied at least in the surrounding areas of vent pipes and a semi-aerobic system of solid waste stabilization is established. It involves installation of a pipe network below the solid wastes for collection of leachate produced in the landfill as well as supply of oxygen into the deposited waste. Perforated vertical pipes are connected to the pipe network at definite intervals for supply of oxygen to the surrounding wastes and for gas venting. The relative advantages and disadvantages of the anaerobic and semi-aerobic systems of waste decomposition are presented in Table 2.1.

Table 2.1: Advantages and disadvantages of anaerobic and semi-aerobic processes.

Anaerobic Process	**Semi-aerobic Process**
Anaerobic process is very slow and takes years to fully stabilize the waste in the landfill;	The semi-aerobic process is faster than anaerobic process and hence the stabilization process is rapid;
The anaerobic process is associated with bad smell and methane gas generated in the landfill may causes fire hazard;	The odour and fire hazards problems are greatly reduced due to venting of gases and circulation of air in the landfill;
Ground and surface water pollution is caused by highly polluting leachate produced due to long contact between waste and leachate;	Rapid drainage of leachate from landfill reduces possibility of infiltration of leachate in the deeper layers;
Operation of the landfill is easier;	The BOD and COD of the leachate produced are significantly reduced;
The anaerobic system does not require special attention;	The surface and ground water pollution potentials are greatly reduced;
The methane can be collected for use as a fuel.	Emission of carbon dioxide instead of methane reduces global warming potential.

Source. Matsufuji, Y., Sinha, K., 1990

Waste stabilization takes places mainly through physical, chemical and biological process in landfill which produces end products ash, gases (CH_4, CO_2 H_2S) and liquid substances named as leachate containing heavy metals. Anaerobic process of decomposition is a slow process associated with bad smell and methane gas generated may causes fire hazard in landfill where as produces highly polluting leachate due to long contact between waste and leachate. In aerobic condition requires supply of oxygen to be pumped into the landfill which is a costly system in terms of construction and operation. For rapid stabilization process and reduction of odor and fire hazard by gas venting and circulation of air through pipe networks semi aerobic system is useful. Drainage of leachate in a systematic manner reduces possibility of infiltration and pollution of surface and ground water and also influences to produce less amount of green house gases. As a result leachate quality is improved and treatment cost would be lesser.

2.2.3.4 Environmental factors

The nature, rate, and extent of biological decomposition in a fill are greatly influenced by the environmental factors that affect all biological activities. The nature of biological decomposition determines the nature of the decomposition products. Among other things, rate determines the length of time during which the completed fill must be monitored and which must pass before the “reclaimed” area (i.e., completed fill) can be put to use whether it be for recreation, agriculture, construction, or other purposes.

One of the ways in which decomposition affects use of the completed fill is through its effect on the rate and amount of settlement (reduction in elevation), in that settlement is a major constraint on the use of the completed fill. Settling continues until biological decomposition has run its course. Therefore, the higher the rate of decomposition, the sooner the site can be put to use. Both research and demonstration studies have been performed over the past 5 to 10 years to accelerate biological decomposition of landfilled waste.

The principal factors that influence biological decomposition in a conventional fill are moisture, temperature, and the microbial nutrient content and degree of resistance of the waste to microbial attack. Moisture is a limiting factor in a fill at moisture content levels of 55% to 60% or lower, because microbial activity is increasingly inhibited as the moisture drops below the 55% level. For practical purposes, it ceases at 12%. Therefore, decomposition can be expected to proceed very slowly in fills located in arid regions.

The activity of most microbes increases with rise in temperature until a level of about 40°C is reached. For some types of microbes, the upper temperature is on the order of 55° to 65°C. Because temperatures in tropical regions are more favourable, decomposition can be expected to proceed more rapidly and to a greater extent in those regions.

With respect to nutrients, wastes characterised by a high percentage of putrescible matter approach the ideal in terms of decomposition. Among the wastes that fall into such a category are green crop debris, food preparation waste, marketplace produce waste, and animal and human manures. It is likely to find such a combination of ideal decomposition factors in developing countries in humid tropical regions of the world.

The nature, rate of deposition and extent of biological decomposition through moisture, temperature and microbial nutrients in waste control the stabilization process. Microbes activity dominates in high temperature in tropical regions expected to decompose rapidly whereas in arid zone vice versa. Thus the slower the degradation process produces less amount of leachate deteriorate the quality of lechate as long contact with waste.

2.2.4 In-Place density and settlement

2.2.4.1 Density

Among the factors that determine or influence in-place density (i.e., density after the wastes have been deposited and compacted in the fill) are composition of the wastes and operational procedures. Progressive settlement of the entire mass of the fill occurs as a consequence of decomposition and weight of overburden.

Because of the effect of settlement, increase in density becomes a continuing phenomenon. The in-place density of a properly operated, relatively deep fill can be on the order of 900 kg/m3; whereas that of a poorly compacted fill would be only about 300 kg/m3. In the United States, the usual range of density directly after compaction is on the order of 475 to 712 kg/m3.

2.2.4.2 Settlement

Settlement is manifested by a decrease in volume of the affected mass and subsequent reduction in elevation. For several reasons, the drop in elevation is not uniform throughout the fill. The lack of uniformity may be a serious constraint on the use of the completed fill. Undoubtedly, the greater the organic fraction and the deeper the fill, the greater will be the extent of settling. Rate of settling depends in large part upon that of the decomposition of the wastes and, hence, upon the factors that affect decomposition.

Because of the variations in the above factors and wide differences between operational procedures encountered in sanitary landfill practice, it is not surprising that a similarly wide variation exists between reported rates and the extent of settlement. Of the total settling, usually about 90% takes place during the first year. In arid regions, settlement may be only 3% after three years, while that in subtropical region may be as much as 20% after the first year. It indicates that whereas no physical settlement may occur if the initial density exceeds 1,060 kg/m3, nevertheless a theoretical settlement of 40% due to waste decomposition is possible (Cheney, A.C., 1983). However, it points out that with placement densities between 650 and 1,200 kg/m3, annual rates of 0.55% to 4.7% have been measured.

Progressive settlement of the entire mass of the fill occurs as a consequence of decomposition and weight of overburden. It depends on operation of landfilling of waste. Undoubtedly, the greater the organic fraction and the deeper the fill, the greater will be the extent of settling. Of the total settling, usually about 90% takes place during the first year. Type of waste mix, degree of compaction, moisture content and decomposition process affect the settling. At matuail municipal solid waste the placement density would be about 240 kg/m^3. After a course of time density of deposited waste getting more produces greater overburden pressure responsible for settlement. As semi-aerobic condition exists that provides air circulation as well as releases generated gas by venting system ease the settlement and increases decomposition rate. Hence entrapped moisture flowing more to enhance quantity and quality of leachate.

2.3 Types of solid wastes

2.3.1 Significance of waste types

Generally, sanitary landfills are considered to be land disposal facilities that receive solid wastes from residential, commercial, and industrial sources. The quantities and characteristics (e.g., composition, etc.) of the solid waste define the general procedures to be employed in the landfill operation. Furthermore, the type and composition of the wastes buried in the fill affect the quantity and composition of leachate generated and of the gases generated within the fill. Other considerations related to types of solid waste that affect the design and operation of landfills include the risks and hazards to personnel arising from the corrosivity, severe toxicity, or other dangerous property had by a particular waste.

2.3.2 Acceptable wastes

Most solid wastes generated by residential, commercial, industrial, and agricultural sources may be disposed in a sanitary landfill of modern design without necessarily directly or indirectly endangering the well being of the public and the quality of the environment. For convenience of reference, such wastes are referred to as “acceptable wastes”. In contrast, many types of industrial process wastes (as opposed to the wastes generated in the offices of industrial facilities) should not be disposed in sanitary landfills but should be handled in specially designed landfills. These wastes are referred to as “unacceptable wastes”. Wastes that are unacceptable should receive special evaluation to assess the particular risks associated with their disposal.

With very few exceptions, only those wastes for which a given facility has been specifically designed should be accepted by that facility. An exception might be a waste that has been shown to fit within the existing or appropriately modified design capacity of the facility and that has the appropriate biochemical characteristics. Unfortunately, in many of the poorer developing nations, separation of wastes into acceptable and unacceptable categories is not practiced, nor is separation feasible in the foreseeable future. In many developing countries, circumstances are likely to be such that the only feasible course of action to gain some degree of control over land disposal is to accept all solid wastes without exception. The very act of removing the wastes from the open environment and placing them in a controlled land disposal facility would represent advancement over the indiscriminate disposal practices currently in existence.

Dewatered solids (i.e., sludges or, synonymously, biosolids) from municipal wastewater treatment plants and water supply treatment plants (excepting raw sludge) can be regarded as being acceptable wastes.

2.3.3 Unacceptable wastes

Ideally, the decision as to which wastes are to be deemed unacceptable should be made during the planning process, should be made jointly by the responsible governmental agency and the disposal site designer and operator, and should take into account the results of surveying large waste generators (in particular, industrial waste generators) in terms of the quantities and characteristics of their wastes. The wastes should be identified in the landfill development plans and frequent users of the disposal facility should be provided with a list of such wastes. Criteria recommended for use in decisions regarding acceptability should include the hydrogeology of the site; the chemical and biological characteristics of the waste; availability of alternative methods for disposal, reuse, or recycling; environmental risks; and the risks to the health and safety of the operating personnel and to the public.

Wastes that should require specific approval of the responsible government agency for acceptance at the disposal site should include those that are legally defined as **"hazardous waste"** or wastes that contain materials that are defined as "hazardous materials" -- medical wastes, bulk liquids and semi-liquids, sludges containing free moisture, highly flammable or volatile substances, raw animal manures, septic tank pumpings and raw sludge, and industrial process wastes. It should be noted that some animal wastes may be infectious because they contain animal disease organisms that can be transmitted to humans.

The United States Environmental Protection Agency (EPA) promulgated a definition of "hazardous waste" that is appropriate for industrialised and developing nations. According to the definition, a waste is hazardous if it poses a substantial present or potential hazard to human health or living organisms because: the waste is non-degradable or persistent in nature, it can be biologically magnified, it can be lethal, or it may otherwise cause or tend to cause detrimental cumulative effects.

2.3.4 Special wastes

There are several types of wastes that are commonly termed "special wastes", as medical (infectious) wastes and various types of sludges are commonly generated and disposed on the land in developing nations, and therefore, should receive special attention. Quantities of other types of special wastes will be considerably reduced through extensive scavenging and recycling activities characteristic of developing nations. Some of these wastes include institutional wastes, construction and demolition debris, animal manures, and animal carcasses.

The type and composition of the wastes buried in the fill affect the quantity and composition of leachate generated and of the gases generated within the fill. In many developing countries, circumstances are likely to be such that the only feasible course of action to gain some degree of control over land disposal is to accept all solid wastes without exception. Medical (infectious) wastes and various types of sludges are commonly generated and disposed on the land in developing nations. Criteria recommended for use in decisions regarding acceptability should include the hydrogeology of the site; the chemical and biological characteristics of the waste; availability of alternative methods for disposal, reuse, or recycling; environmental risks; and the risks to the health and safety of the operating personnel and to the public. Thus leachate quality and quantity mostly depends on waste mix situation. In Matuail small scale incineration plant is being used for unacceptable waste. But there is a great chance of mixing industrial or hazardous and hospital wastes with domestic waste that may produce leachate containing heavy metals, infectious organism which detoriate the quality and need high treatment cost.

2.4 Quantity and composition of the wastes

The need for conducting a reliable waste characterisation program (accurate determination of generation rates and composition) arises from the fact that rational planning and sound decision-making in solid waste management depends upon access to accurate and representative data regarding generation rates and composition. Unfortunately for planners and decision-makers, the quantity and composition of urban wastes vary not only from country to country, but also from city to city and even from neighbourhood to neighbourhood within a city. As a country like Bangladesh in South Asia almost produces 80% of kitchen waste contains 65% - 80% moisture content which greatly affect the leachate production. Not practicing of source separation of waste mix contributes the bad quality of leachate and landfill to carry large amount of waste load.

2.5 Site Condition

2.5.1 Topography

The city area, the central part of the of the Dhaka district, lies on the southern half of the Madhupur Tract. The rest of the area is covered by the floodplains of the Jamuna, Padma, and Meghna rivers. The Pleistocene Madhupur clay forms the surface of the Madhupur

Tract, which stands higher than the surrounding floodplain. There is a great difference in the elevation throughout the Dhaka city. The outcome of the elevation difference is reflected by the distinct landforms: highlands, low lands and abandoned channels and depressions vary from 1.5 to 3.5 meters, which is vulnerable to monsoon flooding.

The Matuail waste disposal site is located in the south-eastern fringe of the Madhupur tract. The surface topography of the area is slightly undulated due to the underlying Madhupur tract, which is exposed in some places as isolated faintly elevated land. The floodplain is a low-laying area and remains water logged and swampy over a significant time of the year. The area is usually flooded in every year and the extent of the flooding is significant. Seasonal floods, siltation, as well as expanding anthropogenic activities govern the land development and modification of the area.

2.5.2 Geology

Information on the geology of a site is required for properly engineering a facility. Such information serves three important purposes: 1) identification of geological hazards, 2) provision of information for facility design, and 3) assessment of vulnerability of the site to groundwater contamination due to the hydrogeology of the site.

Geological information is difficult to acquire when an unstable terrain is involved. The integrity of the structures on unstable terrain is especially vulnerable to natural or man-induced forces, such as floods, seismic displacement and deformation, volcanic activity, landslides, subsidence, and weak or unstable soils.

The Matuail landfill site broadly is a part of the geologic framework within which the city of Dhka is located. This is comprised of the Madhupur Tract which is an uplifted fault block chiefly made up of dense reddish clay of Pleistocene age. This uplifted block is surrounded on all sides by the immediate floodplains of the active river systems of Buriganga, Daleswari, Turag and Sitalakhya which in turn are part of the larger Ganges, Jamuna, Brahmaputra and Meghna floodplains. Though Dhaka city extends over both of these clay and floodplain deposits, the project site is located within the floodplain deposits.

The Madhupur clay unit mainly consists of reddish-brown to yellowish-brown clay. It is generally assigned a Pleistocene age, which is underlain by Dupitila sand unit Mio-Pliocene age. These clays occur in the surface across the uplifted fault block called the Madhupur Garh and in the floodplains it is overlain by the floodplain deposits. The clays are very dense and highly oxidized producing the reddish to brownish colour. The thickness of this clay unit varies and averages to about 8 m. Within the Garh area it forms low ridges reaching a maximum height of about 30m above the surrounding floodplains. The project site at Matuail has outcrops of this clay unit in the west. The clay-dominated liyhology makes this unit an ideal impermeable layer and that can be expected to deter groundwater flow through it. (BRTC, 2008)

2.5.3 Hydrogeology

The potential to pollute the groundwater at the landfill depends, to a considerable extent, on the hydrogeological characteristics of the site, such as:

- depths to groundwater,
- nature and approximate thickness of water-bearing formations or aquifers near the landfill,
- quality of the groundwater upgradient of the landfill,
- site topography and soil type,
- soil infiltration rates at the site,
- effects of nearby pumping wells on groundwater beneath the site,
- hydraulic conductivity and its distribution at and near the site,
- depth and nature of bedrock,
- horizontal and vertical components of groundwater gradients, and
- groundwater velocity and direction.

Hydrogeologic system of Dhaka region is characterized by unconsolidated multiple aquifer system mostly composed of clay aquitard and sandy aquifer units. Generally, the sandy main aquifer is lying at a depth of 50-70m depth underlain by a clayey aquitard of varying thickness throughout the city. Matuail site has similar characteristics, but the sub-surface hydrogeology of the site has not been investigated in the past in great detail. Detailed information on hydrostratigraphy and aquifer system delineation for Dhaka city could be found in IWM-DWASA (2006). The general direction of ground water flow is from north to south; however since the main aquifer beneath Dhaka is heavily used for water supply by Dhaka Water Supply and Sewerage Authority (DWASA), the local ground water flow dynamics in the main aquifer is significantly influenced by the operation of about 426 production wells (deep tubewells) by DWASA.

A recent study was conducted IWM-DWASA (2006) provides an assessment of ground water level (piezometric head) of the main aquifer (upper Dupitila aquifer) beneath Dhaka. The groundwater level at north (Uttara and surrounding areas) and south (parts of Narayangonj district within the Boundary rivers) of Dhaka are at similar level and lies within 15 m of ground surface. The ground water level varies significantly in the central part of the city (e.g., Banani, Tejgaon, Khilgaon, Mirpur and Motijheel) with piezometric levels ranging from 50m to 71m (IWM-DWASA, 2006). Available information suggests that the maximum depth to ground water level (piezometric head) of the main aquifer at the project site at Matuail is over 30 m.

Being closer to the center of Dhaka, areas adjacent to the Matuail site have been studied by different agencies/organizations and reports and borehole log of this area is available with Bangladesh Water Development Board (BWDB) and some other organizations. The regional studies have done Bangladesh Agricultural Development Corporation (BADC) under the deep tubewells project provide important insights and allows for some reasonable interpretation of this site characteristic. Table 2.2 lists some hydrogeological parameters for the site as derived from the Deep Tubewell project maps of BADC.

Table 2.2: Aquifer Characteristics at Matuail Site

Aquifer Parameters	**Typical Value**
Thickness of Upper Clay	< 20 m
Thickness of Upper Sand	30-40 m
Depth to Main Aquifer	60-70 m
Permeability of Main Aquifer	250-500 mm/day
Specific Drawdown	3.0-4.5 m/cusec
Depth of Water in April, 1989	9-12 m

Source: BRTC, 2008

It is apparent that the focus of the Deep Tubewell Project was to characterize the deeper aquifer (lebelled as the main aquifer) which bears the burden of providing most of the ground water for Dhaka City. However, the waste disposal facilities will be placed at a much shallower depth above this main aquifer and the environmental concern is directed in delineating the hydrogeological characteristics of any shallower aquifer that might be present and the risk of contamination of such aquifers by the landfill leachate.

A study by Hoque (2004, unpublished PG Diploma project) reported on the shallower aquifer and stratigraphic characteristics of Dhaka city and adjacent areas. Table 2.3 shows his finding, which indicates that beneath the floodplains there is a shallow sand unit (Dhamrai formation) which must be considered as a potential aquifer. This type of stratigraphy is present beneath the Matuail site.

Table 2.3: Stratigraphy of Dhaka City Region

Stratigraphic Age	Stratigraphic Name	Lithology	Thickness (m)	Function System in Aquifer
		The Floodplain		
Holocene	Floodplain	Alluvial silt, Sand and Clay	6-15	Upper aquitard
Late Pleistocene to Holocene	Dhamrai Formation	Alluvial sand	100-200	Potential aquifer
Pre- Pleistocene	Not Named	Unknown		
		The Modhupur Tract		
Recent	Lowland alluviam	Swamp, Lavee and Riverbed sediments	0-5	Upper aquitard
Holocene	Bashabo Formation	Sand (discontinuous)	3-25	Aquifer
Pleistocene	Madhupur Clay Formation	Silty Clay member Fluvio-deltaic sand	6-25	Upper aquitard

Plio-Pleistocene	Dupi Tila Formation	Dupitila Clay Stones Fluvio-deltaic sand	100-180	Potential aquifer
Miocene	Girujan Clay	Bluish Clay	500-100	Known lower aquitard

Source: Hoque (2004)

To precisely delineate the thickness of the clay layer and the fine sand unit below, a more detailed study was carried out as a part of Matuail landfill project, in which a total of 20 boreholes were drilled in areas within the existing dumpsite and the site adjacent to it which has been acquired for construction of sanitary landfill. In general, the result from this study on subsurface hydrogeology reveals significant heterogeneity of the subsurface characteristics within the project area.

2.5.4 Climate

Bangladesh has a tropical climate with main three seasons- the hot and humid summer (March-May), the rainy season (June-September) and the mild and the dry winter (December-February). Bangladesh has been divided into seven climatic zones and Dhaka falls under the south-central climatic zone characterized by moderate rainfall and temperature. Relevant climatic data for the Matuail area were collected from the meteorological station located at Banani and Nawabgonj in Dhaka.

The general pattern of precipitation (which consists entirely of rain) follows the monsoon Pattern with the cooler, drier months from November to March, increasing rainfall in April and May, and highest rainfall in the summer months June to September, when the prevailing wind direction from south-west brings moisture with laden air from the Bay of Bengal. Average climatic variations in Bangladesh are shown in Table 2.4. It was recorded 1864 mm rainfall in 2008 occurred in Dhaka (BMD, 2008).

Table 2.4: Average climatic variations in 2008

Season	Temperature		Rainfall	Relative Humidity
	maximum	minimum		
Pre monsoon	32.6C	22.4 ^{o}C	453 mm	74%
Monsoon	31.5 ^{o}C	25.5 ^{o}C	1733 mm	86%
Post Monsoon	30.5 ^{o}C	21.4 ^{o}C	210 mm	80%
Winter	26.5 ^{o}C	13.9 ^{o}C	44 mm	73%
Annual	30.4 ^{o}C	21.2 ^{o}C	203 mm	78%

Source: BMD, 2008

2.5.5. Drainage

Most of the areas surrounding the matuail site are low land and located outside the Dhaka-Narayanganj-demra(DND) canal. Sitalakhya river flows 5 km east from the site. Bhalu River connects to the Sitalakhya River near Demra *ghat*. Dholain river/Debdulal *khal* (locally known as kajla *khal*) passes 500 m west of the Matuail. The *khal* connects with underground drainage/box-culverts that receive drainage water from south-eastern Dhaka. Due to blockages at the downstream part of the canal, most of the drainage water falls in the low lands surrounding the Mauail area. Illegal encroachment is rampant on the DND canal, which results in severe water logging during the rainy season affecting people living within the DND protection area. The stagnant polluted water causes serious odour problem in the area during the dry period. According the drainage zone of Bangladesh, the study area is defined as poorly and very poorly drained.

2.5.6. Geology and soil characteristics

Knowledge of the geological structure and history of an area is needed to predict groundwater behavioural characteristics. If sedimentary units are present or suspected, knowledge of the depositional history of the region may reveal unsuspected discontinuities in apparently uniform units (e.g., permeable channel deposit in a low permeability unit).

Permeability of the surrounding rocks and soils is an important factor in evaluating the suitability of an area as a potential site for a landfill. Although the primary permeability of a soil formation generally refers to groundwater intergranular flow (flow along the primary porosity), rate and direction of flow are controlled by the flow along fractures, joints, bedding planes, and solution cavities (secondary porosity). Secondary porosity may prevail when subsurface flow takes place in carbonate terrains, metamorphic and igneous rocks, and folded and faulted sedimentary rocks. Short circuiting may occur in situations in which secondary porosity is prevalent, inasmuch as low permeability (secondary porosity) is less an obstacle to contamination than is high permeability (primary porosity).

Unless control measures such as liners and leachate collection systems are implemented, a high permeability near the ground surface allows contaminants to move relatively quickly to the groundwater. Conversely, contaminants move slowly due to low permeability near the surface. Consequently, more time is allowed for attenuation or for instituting remedial measures before the groundwater becomes extensively contaminated. However, in such a situation, runoff of contaminated water may increase surface and subsurface water contamination.

2.5.6.1. Groundwater recharge

The potential for groundwater recharge to significant aquifers is one of the most important considerations in the evaluation of a potential landfill site. Areas of natural recharge must be avoided. Accordingly, the location of a site with respect to a regional groundwater flow system must be defined, particularly if the site is in or close to a primary recharge area. The introduction of contaminants in certain recharge areas may bring about migration of a contaminant over considerable distance and long residence times for a contaminant within the aquifer before reaching a discharge area.

Recharge areas are usually in topographically high areas where the water table may be relatively deep. Conversely, the water table is either near or at the land surface in discharge areas. Because of a decrease in potential energy with depth, the flow component is primarily downward in upland recharge areas; whereas, upward flow is the usual course in surrounding lowland discharge areas. The groundwater flow may be mostly horizontal in locations between the major recharge and discharge areas in laterally extensive regional flow systems. Moreover, significant recharge can take place between the major recharge and discharge areas. Finally, an adequate prediction of pathways of contaminant migration and determination of the recharge potential to underlying aquifers presupposes the making of an assessment of vertical gradients at the site under consideration.

The soil infiltration potential should be evaluated on a site-specific basis. Doing so may involve making determinations of the unsaturated hydraulic activity of the soil, particularly the soil that separates the bottom of the landfill from the uppermost aquifer. Such determinations are useful in determining the protective potential of the site against groundwater contamination by a landfill.

2.5.6.2. Vadose zone

The vadose zone is the zone that lies between the surface of the land and the principal water table (Figure 2.1). Although the vadose zone is generally known as the "unsaturated zone", saturated regions may be found in some vadose zones. Examples of such regions are perched water tables and tension-saturated zones. Vadose zone characteristics are important in arid regions because the water table may be located fairly deeply in those regions. Characteristics are less important in vadose zones in humid regions where the water table is shallow or in areas where fractured rock media occur near the ground surface.

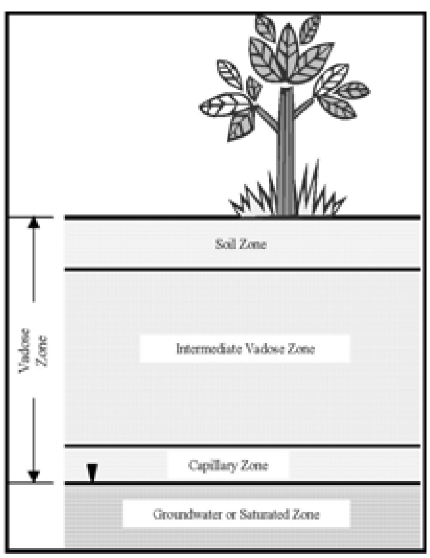


Figure 2.1: Diagrammatic sketch of vadose and groundwater zones (General Engineering and Radiological Health, USA, 1968)

A vadose zone that offers substantial protection against groundwater contamination should have the following characteristics: substantial thickness, a large capacity for adsorption and degradation of potential pollutants, a uniform soil structure, and consisting of a material characterised by low hydraulic conductivity.

The large sorption capacity of strata containing clay-rich soils is counterbalanced by the tendency of contaminants to move around them rather than through them. This tendency minimises the attenuation potential that may come from the presence of such strata. On the other hand, poor sorption materials (sands) are usually very permeable.

2.5.6.3. Uppermost aquifer

The term "aquifer" refers to a geological formation in which the amount of saturated permeable material is sufficient to result in a significant amount of water in wells and springs. An aquifer is classified as a "confined aquifer" if its top is covered by an impermeable layer. If the top of the water table represents the top of the aquifer, such an aquifer is classified as "unconfined".

The uppermost aquifer should be carefully monitored because it is the portion of the saturated zone that has the highest probability to be contaminated. It may be confined or unconfined. Certain uppermost aquifers may not represent a threat to groundwater quality, for example, those that do not have underlying aquifers, are not used for water supply, contain sorptive materials to attenuate potential contaminants, are deep, and are under a vadose zone that contains sorptive materials.

2.5.6.4. Underlying aquifers

The occurrence, characteristics, and usage of sources of groundwater that may underlie uppermost aquifers are factors to be considered in evaluating the potential of a landfill to contaminate groundwater. Considerations discussed for uppermost aquifers are applicable to underlying aquifers. Factors of particular importance are type of existing and potential usage, flow components, ambient water conditions, and the thickness and properties of materials that separate the aquifers. Among the factors that are the more effective in the prevention of contamination of groundwater resources are aquifers that are separated by a very thick layer of low permeability, sorptive materials or that lack direct hydraulic connections with the uppermost aquifer.

2.5.6.5. Summary of relationship between geological and hydrogeologic characteristics and groundwater contamination (Brunner, D.R. and D.J. Keller, 1972)

The combination of characteristics that would limit the risk of groundwater contamination is the following:

- The distance between the ground surface and the surface of the water in an unconfined aquifer or the top of a confined aquifer is greater than 30 m.
- The net recharge rate is less than 5 cm/yr.
- The water bearing unit is massive, dense, and unfractured.
- The soils are moderately hard or impervious.
- The topographic gradient is steeper than 18%.
- The vadose zone is comprised of dense, impervious media.
- The hydraulic conductivity for the water-bearing unit is less than about 0.4 $m^3/day/m^2$.

The greatest risk of groundwater contamination would be represented by the existence of the following set of conditions:

- The depth from ground surface to the water table is less than about 3 m.
- The groundwater recharge is greater than 25 cm/yr.
- The aquifers and vadose zones consist of irregular limestone or fractured basalt.
- The topographic gradient is less than 2%.
- The hydraulic conductivity is greater than about 80 $m^3/day/m^2$.

A fairly concise grasp of the interrelation between the various geologic and hydrogeologic factors, direction of leachate travel, and contamination of water resources may be gained from a review of Figure 2.2.

The Matuail landfill site broadly lies within the geological framework of Dhaka city characterized by multiple aquifers overlain by thick clay layer of varying thickness. Unlike Dhaka city, the surface clay layer is unconsolidated, gray to brown in color and varying from 8 to greater than 45m in depth, with pockets of silt and fine sand. An aquifer at a minimum R.L. of -16.5 m was encountered in the central part of the existing landfill. The ground level elevation of low lands and depressions at the landfill site vary from 1.5 to 3.5 meters and the area is vulnerable to monsoon floods. (BRTC, 2008)

2.5.7. Vegetation

Vegetation of concern ranges from the native types growing at the site to types planted as a part of site preparation and maintenance. The types of vegetation include small trees, shrubbery, herbaceous annuals, perennials, and groundcovers.

Trees and shrubs are planted to serve as a buffer; to reduce dust, noise, door, and visibility problems; and for site beautification. A groundcover reduces or even eliminates wind and rain erosion of the landfill cover, improves aesthetic quality, and enhances moisture removal by way of evapotranspiration. The amount of water removed through evapotranspiration is significant. A groundcover is especially important because of its role in ensuring the long-term stability and performance of the final landfill cover system.

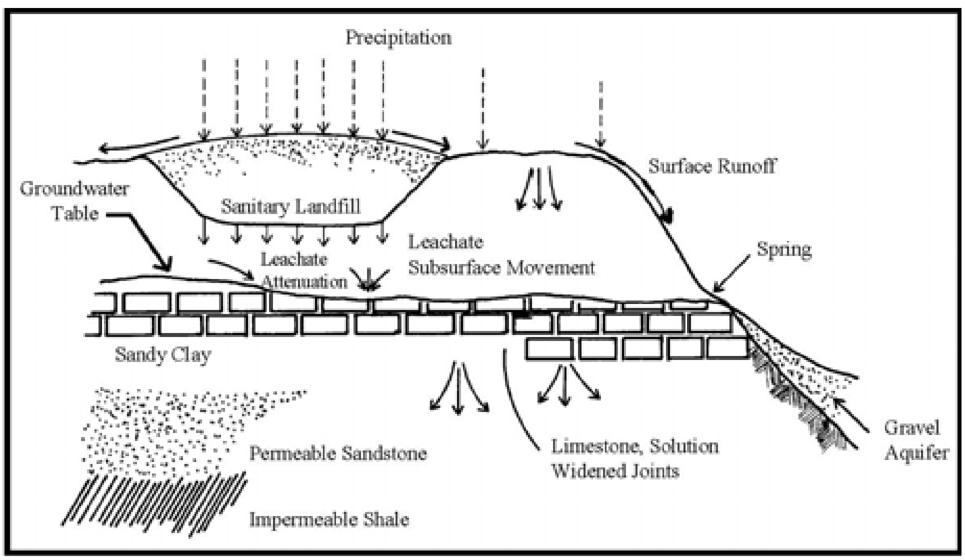


Figure 2.2: Interrelation between climatic, topographic, hydrologic, and geologic factors in terms of leachate travel and groundwater contamination (Boca Raton, Florida, USA, 1982)

In the study area Matuail old decomposed waste is using as suitable covere material reduces operation cost and extend the area on which waste to be disposed off further. The soil cover facilitated the drainage of storm water, prevented entry of rain water, and reduced the generation of leachate. Moreover, it enhanced the aesthetic of the landfill site and supported growth of vegetation.

2.6. Operation of Site

2.6.1. Introduction

This section presents an approach for the efficient operation of a solid waste landfill. A detailed outline of all daily activities is the basis of an effective operating plan. The plan must be sufficiently flexible to encourage managerial ingenuity in reaching the objectives, and sufficiently rigid to support proper operations. An efficient operating plan implies equipment that is compatible with the characteristics of the solid waste, the site conditions, and the method of landfilling.

In this section, site operation is divided into two parts: 1) operational procedures that do not depend upon the method employed for landfilling, and 2) operational procedures that are specific to the method of landfilling.

2.6.2. General operating procedures

Operation of a sanitary landfill requires a series of activities, some of which are normally conducted continuously while others are conducted at a fixed frequency. Some of the more important operational procedures that must be considered for all methods of landfilling include:

- preparation and maintenance of the site,
- environmental control,
- hours of operation, and
- procedures during inclement climate.

A discussion of each of these key items is presented in the following sections.

2.6.2.1. Site Preparation and maintenance

a) Site preparation

Site preparation is an important aspect of the general operating procedures of a sanitary landfill. As a particular cell is completed, new areas must be cleared, excavated, and lined (if necessary). Similarly, as the working areas are filled, a final cover should be applied on them as soon as possible.

b) Road maintenance

Maintenance of access roads at landfill sites is one of those activities that should be conducted on a continuous basis. If performed well, road maintenance often is an expensive operation. Regardless of the type of surface (soil, gravel, or pavement), the roads must be inspected and repaired frequently. Typical repairs include cleaning, adding or grading soil and gravel, filling holes, and cleaning drainage ditches. Since road maintenance is a costly operation, typically it is neglected. Unfortunately, lack of proper road maintenance leads to equipment damage, unnecessary delays in operations, and safety problems. It may be advisable to leave a few sections of well marked rough areas on some roads in order to control excessive speed by vehicles using the site.

c) General Maintenance

All waste treatment and disposal sites require continuous care. The site manager is the person responsible for the preparation of a detailed maintenance schedule. Specific dates should be scheduled for the performance of the following tasks:

- collection and disposal of litter;
- relocation of portable fences for the management of litter;
- maintenance of gates, fences, and structures;
- maintenance of drainage system and final cover; and
- preparation and upkeep of final site maps.

As areas of the site are completed, a series of maps indicating the status of filling phases should be updated. The maps should identify areas used for special wastes, the fill depth of the various areas, the type of waste disposed, as well as other site-specific features.

2.6.2.2. Environmental control

In most situations, regulations are established that require the inclusion of environmental controls in the design and operation of a landfill in order to protect the public health and the environment from potential negative impacts of landfills. The most commonly used types of environmental controls include impermeable barriers (liners), leachate collection and treatment systems, landfill gas management systems, and cover systems. Environmental controls are necessary to protect the environment during landfill operation and during the closure and post-closure periods. These practices are described in the following sections.

a) Siltation and erosion

Runoff having relatively high concentrations of silt usually is brought about by improper grading. Grades with a slope of 2% to 5% should be maintained, where feasible, to promote surface drainage but at the same time to control flow velocities to acceptable levels. Denuded areas should be kept to a minimum during site operation. Ongoing construction and maintenance of sediment control devices (e.g., diversion ditches, rip-rap, sediment basins) are critical for an environmentally sound operation. During final closure and the post-closure period, proper final grading, seeding, and maintenance of a final cover system help prevent long-term problems as a consequence of erosion and siltation.

b) Vectors

Flies, mosquitoes, rodents, birds, dogs, and other animals are an occurrence at landfill sites. Vectors can be controlled by frequently placing an adequate quantity of compacted soil over the wastes or by chemical means, and by maintaining the smallest possible working face. It has been demonstrated that a daily cover consisting of 15 cm of compacted soil having a low clay content will prevent the emergence of flies. However, even under the best program of prevention and site conditions, a landfill should have a regular inspection and fly control program. Mosquito control is best accomplished by preventing the accumulation of stagnant water anywhere on the site (e.g., in old tires and depressions). The accumulation of stagnant water on the surface can be prevented by properly grading the surface, by filling depressions, and by placing cover soil over waste materials.

Occasionally, rats and mice may be delivered to the site with the solid waste. If harbourage occurs in areas adjacent to or in some neglected portion of the site, extermination by the local health department will be necessary. Employees at the landfill should be trained to recognise burrows and other signs of the presence of rats and mice so that appropriate management procedures can be put into force. Access to wastes by animals such as pigs, cattle, sheep, and others should be strictly prohibited because of their ability to transmit pathogens directly or indirectly to humans.

c) Odours

Several potential sources of unpleasant odours exist at landfill facilities. Odours may be generated in the following situations:

• at the time the waste is delivered,
• from decomposing waste in place at the landfill, and
• from storage ponds and leachate treatment systems.

Odours generated at the time the waste is delivered can usually be mitigated by rapidly covering the wastes and ensuring that the cover is maintained intact.

Occasionally, loads of particularly malodorous materials (e.g., market or fish processing wastes) may be delivered to the landfill. If at all possible, deliveries of these materials should be scheduled such that sufficient workers and equipment are available to immediately cover the waste. If not possible, malodorous loads can be mixed or covered with other wastes in order to control the problem. In some cases, the application of lime and/or chemical masking agents to the wastes can achieve some degree of door control.

d) Litter

One of the most frequent complaints from residents living near landfills concerns blowing litter, particularly light materials such as papers and plastics. Blowing litter can be substantially reduced by:

• discharging the waste at the toe of the working face,
• application of water or damp waste to loads containing a high concentration of paper and/or plastics, and
• installation of portable or stationary fencing around the working face.

In addition, if soil cover or another material is available, frequent and thorough covering of the face and completed portions of the cell can play an important role in the control of litter. Generally, despite the operators' best efforts and control measures, the accumulation of some litter is inevitable at a landfill site. The installation of a fence around the site or downwind from the site will help to contain litter and keep it from reaching adjacent property. Daily cleanups, particularly at the end of the working day, can limit the quantity of litter that can eventually reach other property.

e) Fires

Potential sources of fires at landfills include receipt of wastes containing hot embers, sparks from vehicles, equipment fire, and vandalism. A good security program, combined with alert vehicle spotters, can control most of the problem. Hot and highly flammable wastes should be directed to special areas in the landfill and moistened or smothered with soil prior to disposal. All landfill vehicles should be equipped with fire extinguishers to limit damage in the event of an equipment fire.

If a water line is not available, a water truck or trailer equipped with a gas-powered pump should be always be on-hand at all but the smallest landfills. There are several techniques available for managing landfill fires. Fires near the surface of the fill can be excavated and extinguished with soil and/or water. Deep fires can sometimes be extinguished by placing damp soil on the surface of the fill, by injecting water into the burning section of the fill, or by excavating and extinguishing the waste. Deep landfill fires are very difficult to extinguish completely.

If landfill gas collection systems are present in a landfill where waste is burning, their continued operation must be given due consideration. Gas extraction wells can draw air into the fill and thus be a source of additional oxidiser (oxygen). Additionally, the wells can collect the byproducts of the waste combustion products, which can lead to degradation or destruction of the wells, piping, and control systems.

Open burning of combustible materials should be strictly prohibited at all disposal sites. The common practice of open burning for volume reduction or for salvaging (i.e., removal of insulation from aluminium and copper wire) should not be allowed at any type of waste disposal facility.

2.6.3 Inclement climate

Climatic conditions can significantly affect the operation of a landfill. Long periods of excessive rainfall, freezing temperatures, or extreme heat can disrupt routine operation of a landfill. The relative amount of rainfall during site preparation has a direct impact on the moisture content of the soil, as well as on groundwater saturation levels. Both of these parameters are important in the control of soil strength and permeability during construction of a clay liner or other compacted soil components. Extremely low temperatures (i.e., freezing conditions) during construction of the landfill site also impact soil workability and permeability. Temperature levels also affect the installation of flexible membrane liners, in particular seaming requirements.

Weather conditions also have an impact on the performance and operation of the facility. This is particularly true in economically developing countries where heavy rainfall often results in extremely muddy access roads and unloading areas, thus leading to long delays. Extremely high precipitation also has an impact on the water table. An excessively high water table may increase the groundwater pressure on the sidewalls of a trench operation, resulting in unstable conditions and landslides. One of the more effective means of managing high rainfall is to construct and maintain drainage canals on the periphery of the site to divert water from the wastes. In the event that the site is relatively flat, one option is to design relatively small and well contained cells properly sloped for the collection of the leachate. Another alternative is to install leachate collection systems to control some of the problems associated with copious precipitation. However, the leachate collection system also must have the capacity to absorb the high flow rates, otherwise the liquid pressure in the facility will increase. High liquid pressure may result in migration of water and leachate from the site. Decreased soil density, which may cause liner instability, may also result from heavy precipitation.

On the other hand, very dry environmental conditions may make the soil hard to excavate or compact. Furthermore, in the absence of moisture, organic matter does not readily decompose. In arid areas, evaporation generally is greater than rainfall. Consequently, very little or no leachate is formed from the waste after disposal. Landfills in arid and semi-arid regions may be operated without liners and leachate collection systems. In fact, it has been suggested that the best sites for landfills are in arid regions. Excessive drying of the soil used in the cover or bottom liner during construction can lead to the unwanted formation of cracks and increase the permeability of the soil.

Freezing temperatures may cause stockpiles of soil to freeze and become unusable. In extreme cases, very low temperatures may affect the proper operation of site equipment as well as the main components of the leachate collection system that are located above the frost line. Efficient operations require that operational problems of this nature be anticipated and contingency plans be developed in order to address the problems satisfactorily. Table 2.5 lists problems due to inclement weather and potential means of managing them.

Table 2.5: Inclement weather practices

Problem	**Method of Management**
Wet Weather	
Access roads are muddy	• Add cinders, crushed stone, or demolition debris • Maintain a special working area that has permanent roads
Unloading area is muddy	• Stockpile well drained soils and apply as necessary • Keep compactive equipment off area by unloading and moving refuse perpendicular to area • Grade unloading area slightly to permit runoff
Soil is wet/unworkable	• Maintain compacted, sloped stockpiles and/or cover with tarpaulin
Soil permeability/density varies from design	• Do not compact soils in overly wet weather • Cover the soil
Leachate collection system clogging from runoff and sedimentation	• Add barriers for fines • Periodic cleaning of pipe network
Dry Weather Soil is dry -- unable to excavate and increased permeability	• Cover the soil to prevent drying • Moisten the soil

Cold Weather Soil freezes	• Insulate stockpiles with leaves, snow, or straw • Add salt to the soil • Continually strip and cut soil • Maintain well drained soil/sand • Use hydraulic rippers on frozen soil

Source: Wilson, D.C., 1981.

2.6.4 Salvage/scavenging

Scavenging or uncontrolled sorting through raw wastes to recover materials that may be reusable is a common practice in most developing countries. This practice is strictly prohibited at the working face of a landfill in industrialised countries because there is a high risk of injury and a potential health hazard to the scavenger. In locations where regulations allow controlled salvaging, the practice can be conducted (as discussed in another subsection) away from the working area by individuals under direct supervision of the operator. Salvaging operations and storage must be confined to a specific area or facility so that they will not interfere with landfill operation. Strict controls must also be established on the types of materials that can be recovered, location and type of storage, and removal frequencies so that nuisance conditions do not develop. The individuals working in the salvaging area should be provided with uniforms, hard hats, masks, boots, and basic sanitation services.

In matuail it has important impact on decomposition process of waste. Scavengers are allowed in a controlled manner at Matuail site to recover reusable materials like pet bottle, plastic paper, steel can and metallic substances etc. It reduces heavy metal content which pollutes soil and water finally detoriates the leachate quality.

2.7 Water management

The two primary types of water resources to be protected from landfill operations are surface waters and groundwater. Surface waters may be contaminated by runoff or leachate from the landfill; whereas, groundwater may be polluted by leachate. The primary objective is to directly and indirectly prevent the landfill from adversely influencing flows to the water resource. This is best accomplished by excluding from the water resources any inputs that originate in the landfill.

2.7.1 Surface water

The first step in proper water management is to minimise surface waters entering the sanitary landfill. Upland drainage can be accomplished by means of pipes through fills that are located in gullies, ravines, and canyons. Runoff from areas surrounding the fill can be excluded by excavating a series of channels or shallow ditches to collect and divert the runoff.

All runoff from the disposal site and the fill itself must be excluded from all unaffected water resources. This is done by channelling the runoff to a collection and storage site, where the runoff can be treated. Ultimately, however, the best recourse is to exercise careful control over the amount of water subsequently retained on the fill site and the length of time the runoff is retained there. The longer the retention time, the greater the opportunity for the water to be contaminated before it leaves the site. Since runoff from the fill itself occurs only when the upper surface of the fill is as high or higher than the level of the surrounding land, an effective means of minimising the extent of degradation of the runoff is to shorten the time it is retained at or on the fill. Grading the landfill cover promotes efficient runoff of rainfall. The grade of the cover should be determined on the basis of the planned use of the completed site and of the ability of the cover material to resist erosion.

Surface water that runs off stockpiled cover material should not be allowed to enter watercourses without having been previously intercepted and ponded to remove settleable solids. A complete surface water plan must be developed with other preparatory planning for the site.

2.7.2 Ground Water

The basic premise of the protection of groundwater quality is that landfilled solid wastes and any leachate from the wastes not be allowed to come into contact with and, thus, contaminate groundwater. Leachate and leachate formation are described later in this chapter. In short, leachate is generated by the passage of water through the solid waste in a fill. If moisture is already present in the fill, it is termed primary leachate. If the moisture comes from rainfall infiltrating into and percolating through the fill, the leachate is termed secondary leachate. In both cases, the eventual composition of leachate is a function of the type of solid wastes deposited in the fill, age of the fill, and several other factors.

The degree of required separation of waste from the groundwater is determined by the potential of the leachate for contaminating the groundwater. The risk of contamination is greatest when the leachate contains toxic and hazardous compounds and/or when underlying material is highly permeable. The degree of separation necessary to protect groundwater quality increases with the potential for contamination. One should not plan on the leachate being diluted in the groundwater because the usually laminar pattern of groundwater flow allows very little mixing to occur in an aquifer.

A preliminary step in protecting groundwater quality is to ensure that a suitably thick layer of soil is between the bottom of the fill and the groundwater. The interposition of the layer permits some attenuation of leachate that percolates through the layer. However, in recent years, the fund of knowledge and the depth of the understanding of leachate and its contaminating characteristics have revealed the limitations of natural attenuation that takes place in the soil layer.

Leachate generated in the landfill has potential for the pollution of groundwater and surface water sources in the study area of matuail Groundwater pollution potentials have been assessed by estimating the time required to penetrate the natural clay layer beneath the landfill site. The travel time required by the leachate to reach the shallow aquifer is too high as compared to the time required for complete degradation of leachate. Hence the risk of groundwater pollution is very low, provided the clay layer is continuous and there is no local short-circuit through sand layer.

Although, dikes have been constructed around the landfills to confine the waste and its degraded products, oozing out of leachate is common during high rainfall, which can cause severe surface water pollution around the landfill site leading to damages to fishery, agriculture and aquatic environment. Local drainage congestion, fire hazards, air and noise pollution are some of the potential adverse environmental impacts during the construction and operation phases of the Matuail landfill project

To overcome those problems collection, treatment and safe disposal of excess leachate from the landfill site have been given top priority. A network of pipe system was installed within and around the waste in the landfill to convey the excess leachate into a pond system located between old dump site and newly acquired land for landfill. The leachate will be then treated by aerated lagoon method in the ponds to reduce the pollution load to acceptable levels and the effluent from the treatment plant will be discharged with surface drainage while the excess sludge will be put into the landfill for biodegradation with solid wastes.

The main drainage canal of the area is located on the western side of the landfill site, which also runs along the western side of the newly developed Green Model Town. A 20 feet wide drainage channel on the northern side of the landfill site has been kept and maintained as a tributary to the main canal for the local drainage of the area. Separate storm water surface drains has been constructed around the landfill for efficient drainage of rainwater away from the landfill site.

The Boundary slopes and steps at the landfill site will be covered with a thick clay layer. The decomposable fresh wastes in a cell will be covered by stabilized solid wastes from the landfill site to avoid bad smell. The vertical ventilation pipes connected to leachate pipes at certain intervals will prevent accumulation of gases in the landfill and keep the system semi-aerobic and free from bad odor.

2.7.3 Mechanisms of leachate formation

Leachate is produced when moisture enters the refuse in a landfill, extracts contaminants into the liquid phase, and produces moisture content sufficiently high to initiate liquid flow. Sources of moisture entering the landfill include liquid present in the refuse at placement, precipitation falling on refuse at placement and infiltrating after cover application, and intrusion of surface water from outside into the landfill.

2.7.3.1 Physico-Chemical Composition of MSW Landfill Leachates

Leachates arise as a result of the infiltration of precipitation to the interior of landfills, but at the same time water present in the wastes and released in different processes taking place in a landfill also contributes to the generation of leachates. There are several factors affecting the composition of leachates and their production. According to Johansen and Carlson; the most important of these are: solid wastes composition, operation mode of a landfill, climate and hydrogeological conditions as well as those inside the landfill (biochemical activity, moisture, temperature, pH and age of landfill). The above-mentioned factors vary considerably from landfill to landfill.

The breakdown of organic compounds in wastes may occur under aerobic, anaerobic or mixed aerobic-anaerobic conditions. Degradation in aerobic or aerobic-anaerobic conditions leads to the rapid stabilization of organic components and relatively low concentrations of organic and inorganic substances in the leachates (JĘDRCZAK A., HAZIAK K ,1994).

Leachates generated in the initial period of waste deposition (up to 5 years) on landfills have pH 3.7-6.5 that reflects the presence of carboxylic acids and bicarbonate ions. With time the leachates become neutral or weakly alkaline (pH 7.0-7.6). Landfills exploited for a long period of time give rise to alkaline leachates (pH 8.0--8.5) (TAŁAŁAJ I, 1998).

2.7.3.2 Stabilization processes of leachate in landfills

Landfills have been controlled and monitored for about 30 years. Throughout this period an increasing understanding of the complex series of chemical and biological reactions that initiates with the burial of refuse in a landfill has been developed. Figure I shows the gas and leachate composition as refuse decomposes. The figure is developed from the first description of the landfill phases given by Farquhar and Rovers (1973). The first four phases shown in the figure are referred to as the aerobic phase, the anaerobic acid phase, the initial methanogenic phase,and the stable methanogenic phase. Subsequent phases of decomposition, in which the waste cell begins to turn aerobic are based on theory and are somewhat speculative because no field data are available to document the onset of aerobic conditions (Christensen and Kjeldsen, 1995). This is due to the fact that most well monitored landfills are less than 30 years old and are still in the stable methanogenic phase. During the initial aerobic phase, oxygen present in the void spaces of the freshly buried refuse is rapidly consumed, resulting in the production of CO2 and

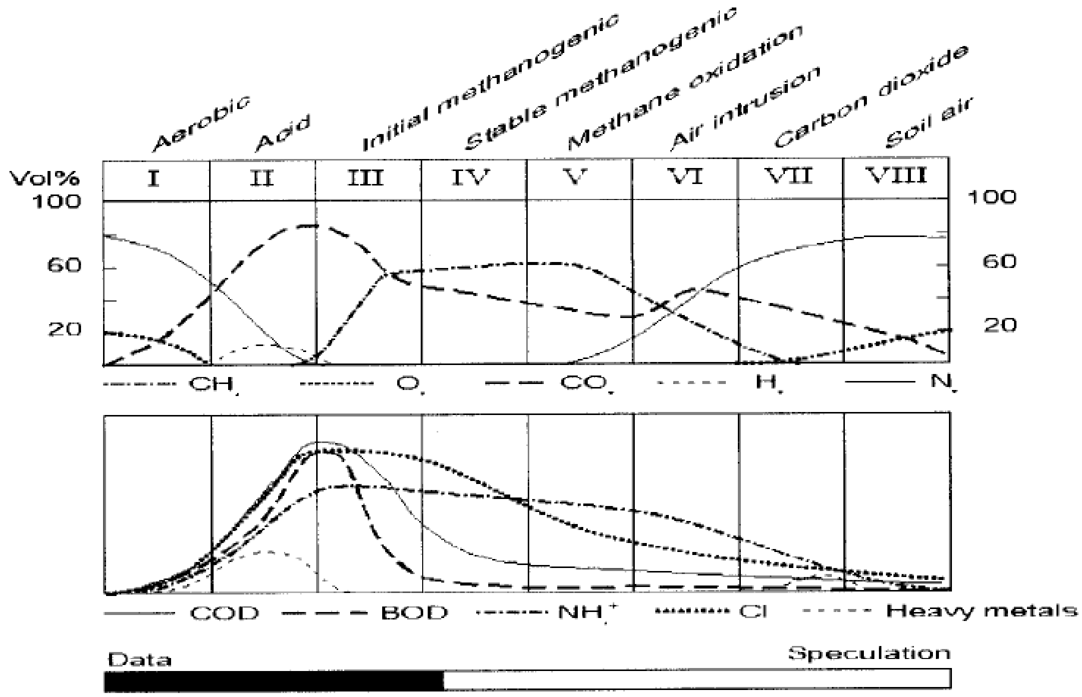


Figure 2.3. The lifetime of a landfill showing general trends in gas and leachate quality development.

maybe an increase in waste temperature. The aerobic phase in a landfill lasts only a few days because oxygen is not replenished once the waste is covered. During the aerobic phase, the waste is not typically at field capacity (Barlaz and Ham, 1993). Most leachate produced during this phase results from the release of moisture during compaction as well as short-circuiting of precipitation through the buried refuse. As oxygen sources are depleted, the waste becomes anaerobic, which supports fermentation reactions. Cellulose and hemicellulose comprise 45 to 60% of the dry weight of MSW and are its major biodegradable constituents (Barlaz et al., 1989b). The decomposition of these compounds to methane and carbon dioxide in landfills under anaerobic conditions is well documented (Barlaz et al., 1990; Pohland and Harper, 1986; Bookter and Ham, 1982). Cellulose and hemicellulose biodegradation is carried out by three groups of bacteria: (I) the hydrolytic and fermentative bacteria that hydrolyze polymers and ferment the resulting monosaccharides to carboxylic acids and alcohols; (2) the acetogenic bacteria that convert these acids and alcohols to acetate, hydrogen, and carbon dioxide; and (3) the methanogens that convert the endproducts of the acetogenic reactions to methane and carbon dioxide (Zehnder, 1982). This process proceeds efficiently over a relatively narrow pH range around neutral. In the second phase the hydrolytic, fermentative, and acetogenic bacteria dominate, resulting in an accumulation of carboxylic acids, and a pH decrease. The highest BOD and COD concentrations in the leachate will be measured during this phase (Barlaz and Ham, 1993; Reinhart and Grosh, 1998). The BOD:COD ratio in the acid phase has been reported to be above 0.4 (Ehrig,1988) or 0.7 (Robinson, 1995). As the pH is acidic, acid phase leachate is chemically aggressive and will increase the solubility of many compounds.

The onset of the initial methanogenic phase (3) occurs when measurable quantities of methane are produced. The onset of this phase is likely associated with the pH of the refuse becoming sufficiently neutralized for at least limited growth of methanogenic bacteria. During this phase the acids that accumulated in the acid phase are converted to methane and carbon dioxide by methanogenic bacteria, and the methane production rate will increase (Christensen and Kjeldsen, 1989, Barlaz et a]., 1989a). Cellulose and hemicellulose decomposition also begins. COD and BOD concentrations begin to decrease and the pH increases as acids are consumed. The BOD to COD ratios will also decrease as carboxylic acids are consumed.

In the stable methanogenic phase, the methane production rate will reach its maximum, and decrease thereafter as the pool of soluble substrate (carboxylic acids) decreases. In this phase, the rate of CH4 production is dependent on the rate of cellulose and hemicellulose hydrolysis. The pH continues to increase to steady state pool concentrations that are on the order of a few mg/L. Some COD is presentin the leachate, but it is mostly recalcitrant compounds such as humic and fulvic acids (Barlaz and Ham, 1993; Christensen et al., 1994). As discussed in the following section, the BOD:COD ratio generally will fall below 0.1 in this phase because carboxylic acids are consumed as rapidly as they are produced.

The four phases of refuse decomposition described above have been defined on the basis of both field and laboratory-scale data that have been summarized in earlier reviews (see Barlaz et al., 1990). However, environmental conditions in the landfill will have a significant impact on the rate of refuse decomposition, and subsequently the time required for decomposition to proceed to the point where methane production decreases to zero. Studies on the effect of a number of factors on refuse decomposition have been summarized (Barlaz et al., 1990; Christensen et al., 1992). The factor that has most consistently been shown to affect the rate of refuse decomposition is the moisture content, and it is generally accepted that refuse buried in and climates decomposes more slowly than refuse buried in regions that receive greater than 50 to 100 cm of annual infiltration into the waste. Refuse decomposition can also be accelerated during the operational phase of the landfill. The most common enhancement technique is the use of leachate recycle, whereby leachate is recirculated through the refuse as opposed to it being treated and released to the environment. By recirculating leachate, the refuse moisture content is increased from its initial value, which is typically 15 to 25% (wet weight basis) to 40 to 50%. In addition, leachate recirculation results in better distribution of nutrients, substrates, and bacteria. Other factors that can be used to accelerate decomposition include shredding and an initial aeration step in which the refuse is aerated for a period of 1 to 2 months after burial to increase the temperature and allow for the aerobic biodegradation of the initial accumulation of soluble organic carbon (Komilis et al., 1999a,b). However, field experience with shredding and aeration are considerably more limited. Wheras the authors are not familiar with any landfills that have progressed beyond the stable methanogenic phase, in theory refuse will continue to decompose until no more degradation occurs and the landfill becomes aerobic. This process can be described as a series of four phases in which the methane production rate continues to decrease to a point at which air begins to infiltrate into the waste cell (Christensen and Kjeldsen, 1995). The four phases are discussed in detail in Section IV on long-term landfill stabilization.

I. MSW landfill leachate composition

This section presents data on the composition of landfill leachate, and further discuss the importance of the landfill phases presented in the previous section on compositional changes. Pollutants in MSW landfill leachate can be divided into four groups:

- Dissolved organic matter, quantified as Chemical Oxygen Demand (COD) or Total Organic Carbon (TOC), volatile fatty acids (that accumulate during the acid phase of the waste stabilization, Christensen and Kjeldsen, 1989) and more refractory compounds such as fulvic-like and humic-like compounds.

- Inorganic macrocomponents: calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), potassium (K^+), ammonium (NH_4^+), iron (Fe^{2+}), manganese (Mn^{2+}), chloride (Cl^-), sulfate (SO_4^{2-}) and hydrogen carbonate **(HCO_3^-).**

- Heavy metals: cadmium (Cd^{2+}), chromium (Cr^{3+}), copper (Cu^{2+}), lead (Pb^{2+}), nickel (Ni^{2+}) and zinc (Zn^{2+}).

- Xenobiotic organic compounds (XOCs) originating from household or industrial chemicals and present in relatively low concentrations (usually less than I mg/l of individual compounds). These compounds include among others a variety of aromatic hydrocarbons, phenols, chlorinated aliphatics, pesticides, and plastizers.

Other compounds may be found in leachate from landfills: for example, borate, sulfide, arsenate, selenate, barium, lithium, mercury, and cobalt. However, in general, these compounds are found in very low concentrations and are only of secondary importance. Leachate composition may also be characterized by different toxicological tests, which provide indirect information on the content of pollutants that may be harmful to a class of organisms.

II. Sampling of leachate

A landfill contains areas of refuse of varying ages and states of decom-position. Thus, where leachate from older methanogenic refuse is mixed with leachate from fresher refuse in the acid phase, it is not possible to relate leachate composition to processes within the waste layers. Furthermore, where leachate from refuse in the acid phase percolates through well-decomposed refuse, the leachate can be expected to reflect the composition of methanogenic leachate. This is because the high COD of the acid phase leachate will be consumed as the leachate passes through the well decomposed, and thus carbon limited refuse. In cases where leachate is released to groundwater, such as in the case of older landfills that are not lined, the spatial distribution of the leachate quality is especially important to evaluate the leaching to the underlying strata. This, how-ever, require a large number of sampling points (Kjeldsen et al., 1998; Assmuth, 1992).

Leachate composition varies significantly among landfills depending on waste composition, waste age, and landfilling technology. Leachate sampling methods and sample handling routines may also influence the measured leachate quality. For example, colloids have a high affinity for heavy metals (Gounaris et al., 1993), thus the concentration of heavy metals measured in a leachate sample may depend strongly on the amount of colloidal matter present in the sample and the handling of the sample (see also the section on heavy metals). No standard protocols for sampling, filtration, and storage of leachate samples exist. The content of colloidal matter in a sample depends to a large extent on the sampling technique used (e.g.,McCarthy and Zachara, 1989; Backhus et al., 1993). Where samples are obtained from groundwater monitoring wells, a high pumping rate will increase the colloid content of the sample significantly (Backhus et al., 1993), and the heavy metal concentration may also be increased. Therefore, leachate samples should be filtered in the field before analysis of heavy metals, especially if the sampling is done quickly. Alternatively, samples could be withdrawn under very low pumping rates and after sufficient purging of the well. Sampling and sample handling may explain part of the variation seen among landfills with respect to the heavy metal concentration in leachates. Maintaining leachate samples under anaerobic conditions until they are preserved is also important because metal solubility varies with their oxidation stage.

Leachate analysis for XOCs may be biased by loss of pollutants due to volatilization or sorption to the sampling equipment. However, recent studies have shown that the quality of leachate analysis for XOCs is seriously jeopardized only if very poor sampling protocols are used (Parker, 1994).

III. Variation of Leachate Composition

In general, landfill leachates may contain very high concentrations of dissolved organic matter and inorganic macro components. The concentrations of these components may typically be up to a factor 1000 to 5000 higher than concentrations found in groundwater.

Several parameters change dramatically as the landfill stabilizes. During the acid phase, the leachate may show low pH values and high concentrations of many compounds, in particular high concentrations of easily degradable organic com-pounds as volatile fatty acids. In the later stable methanogenic phase, the pH increases and the BOD5/COD ratio (biological oxygen demand measured over 5days divided by chemical oxygen demand), reflecting the degradability of the organic carbon is lowered dramatically (Ehrig, 1988). The increased pH also affects many of the inorganic parameters as illustrated in Table 2, where data are presented for acid phase leachate and methanogenic leachate. For parameters not significantly affected by landfill stabilization, only average values are given.

Besides the time dependency in relation to change from acid to methanogenic phase, short-term variations in leachate quality are also expected. Seasonal varia-tions in leachate composition have been observed in several cases. Akesson and Nilsson (1997) observed lower leachate concentrations in the wet season in a Swedish landfill test cell. Similar observations were found by Chu et al. (1994) ina Hong Kong landfill.

A. Dissolved Organic Matter

As described previously, several bulk parameters are used to describe the content of dissolved organic matter in leachate; TOC (Total Organic Carbon), COD (Chemical Oxygen Demand), and BOD (Biological Oxygen Demand). Table 3 gives further details on observed BOD and COD values and the ratio BOD/COD in leachates from older landfills that are well into their methane phase. The table shows that the BOD/COD ratio in most cases is below 0.10 for methanogenic leachates.

One source of variability of the COD measurement that may have some effect on the values presented in Table I is the presence of inorganic constituents that may contribute to COD. For instance, Kylefors et al. (1999) found that Fe(II), Mn(II), and sulfide contributed up to one-third of the COD in the leachates they tested. Chloride may also contribute to COD if not accomodated for in the procedure.

In addition, poor sampling methods that expose anaerobic leachate to oxygen may cause Fe(II) to oxidize to Fe(III) and precipitate out of the leachate. This would result in a decreased COD relative to a study in which Fe (II) was oxidized as part of the COD analysis. This would occur when the sample was maintained under anaerobic conditions until after filtration, at which point it could be acidifiedto reduce iron oxidation.

Dissolved organic matter in leachate is a bulk parameter covering a variety oforganic degradation products ranging from small volatile acids to refractory fulvic and humic-like compounds (Chian and DeWalle, 1977). Dissolved organic matter can affect leachate composition in relation to other constituents through the complexing properties of the high-molecular-weight component of the dissolved organic matter. Unfortunately, we usually have very little information on the composition of the dissolved organic matter in landfill leachate. At the most general level, a low BOD/COD ratio suggests a leachate with low concentrations of volatile fatty acids and relatively higher amounts of humic and fulvic like compounds. A few investigations concerning DOC in landfill leachate are available.

Harmsen (1983) analyzed an acid-phase leachate and a methanogenic-phase leachate. In the acid-phase leachate, more than 95% of the DOC content of 20,000mg/l consisted of volatile fatty acids and only 1.3% of the DOC consisted of high-molecular-weight (MW) compounds (MW> 1000). In addition, volatile amines and alcohols were detected. In the methanogenic-phase leachate; however, no volatile acids, amines, or alcohols were detected, and 32% of the DOC (2100 mg/l) consisted of higher-molecular-weight compounds (MW>1000). Also in a methanogenic-phase leachate, Artiola-Fortuny and Fuller (1982) described more than 60% of the DOC content as humic-like material. Investigating anaerobic and aerobic leachates and leachates that have passed a model aquifer, Frimmel and Weis (1991) found that only 6 to 30% of the DOC could be described as fulvic acids.

More detailed characterization of the DOC in leachate and leachate polluted groundwater is based on isolation and purification of the DOC. These procedures may potentially change the properties of the organic matter because it is necessary to purify the material to obtain results. Weis et al. (1989) compared fulvic acids from landfill leachates with those from soil and bog lake water. The fulvic acids isolated from landfill leachate had higher carbon, hydrogen, and sulfur content, lower quantities of phenolic groups, lower complexation capacities for copper and lower molecular weight. Christensen et al. (1998a) characterized 82% of the DOC in leachate polluted groundwater sampled less than 10 m downgradient from the Vejen Landfill (DK) and found 49% fulvic acids, 8% humic acids, and 25%hydrophilic fraction. Based on molecular weight, elemental composition, and acidity, the fulvic acid fraction and the hydrophilic fraction resembled fulvic acidsfrom other origins, whereas the humic acid had rather low molecular weight. This analysis showed that the three fractions of DOC were rather similar with respect to the features of importance to complexation of metals.

Table 2.6 Composition of Landfill Leachate' (Values In mg/l unless otherwise stated.)

Parameter	Range
pH	4.5-9
Spec. Cond. ($\mu S\ cm^{-1}$)	2500-35000
Total Solids	2000-60000
Organic Matter	
Total Organic Carbon (TOC)	30-29000
Biological Oxygen Demand (BOD_5)	20-57000
Chemical Oxygen Demand (COD)	140-152000
BOD_5/COD (ratio)	0.02-0.80
Organic nitrogen	14-2500
Inorganic macrocomponents	
Total phosphorous	0.1-23
Chloride	150-4500
Sulphate	8-7750
Hydrogenbicarbonate	610-7320
Sodium	70-7700
Potassium	50-3700
Ammonium-N	50-2200
Calcium	10-7200
Magnesium	30-15000
Iron	3-5500
Manganese	0.03-1400
Silica	4-70[a]
Heavy metals	
Arsenic	0.01-1
Cadmium	0.0001-0.4
Chromium	0.02-1.5
Cobolt	0.005-1.5
Copper	0.005-10
Lead	0.001-5
Mercury	0.00005-0.16
Nickel	0.015-13
Zinc	0.03-1000

The ranges are based on Andreottola and Cannas (1992), Chu etal.(1994), Robinson (1995), Ehrig (1980), Ehrig (1983), Ehrig (1988),Garland and Mosher (1975), Johansen and Carlson (1976), Karstensen(1989), Krug and Ham(1 997), Lu et al. (1985), NaturvArdsverket (1989),Owen and Manning (1997), and Robinson and Maris (1979).a Values based on Owen and Manning (1997).

Table 2.7 Leachate Composition in Terms of Average Values and Ranges for Parameters
with Differences between Acid and Methanogenic Phase(Ehrig, 1988) and Average Values for Parameters with No Observed Differences between Acid and Methanogenic Phase (Ehrig, 1983) (Allvalues in mg/I except pH and BOD5/COD)

Parameter	Acid phase		Methanogenic phase		Average
	Average	Range	Average	Range	
pH	6.1	4.5-7.5	8	7.5-9	
Biological Oxygen Demand (BOD_5)	13000	4000-40000	180	20-550	
Chemical Oxygen Demand (COD)	22000	6000-60000	3000	500-4500	
BOD_5/COD (ratio)	0.58		0.06		
Sulfate	500	70-1750	80	10-420	
Calcium	1200	10-2500	60	20-600	
Magnesium	470	50-1150	180	40-350	
Iron	780	20-2100	15	3-280	
Manganese	25	0.3-65	0.7	0.03-45	
Ammonia-N					740
Chloride					2120
Potassium					1085
Sodium					1340
Total phosphorus					6
Cadmium					0.005
Chromium					0.28
Cobalt					0.05
Copper					0.065
Lead					0.09
Nickel					0.17
Zinc	5	0.1-120	0.6	0.03-4	

Table 2.8 Observed Values of BOD, COD and BOD/COD-Ratio for Landfill Leachates Samples from Landfills in the Methanogenic Phase

BOD (mg/l)	COD (mg/l)	BOD/COD	Reference
5.7-1100	76-6997	---	Concentration ranges from 21-30 year old German landfills (Krumpelbeck and Ehrig, 1999)
290	1225	0.24	Average concentrations from 21-30 year old German landfills (Krumpelbeck and Ehrig, 1999)
44	320	0.11	Average concentrations from old, Danish landfills (Kjeldsen and Christophersen, 2001)
39	398	0.10	Composite results at Sandsfarm Landfill, (Robinson, 1995)
11	190	0.06	Composite results at Bishop Middleham Landfill, (Robinson, 1995)
38	517	0.07	Composite results at Odsal Wood Landfill, (Robinson, 1995)
1.0	53	0.02	Composite results at East Park Drive Landfill, (Robinson, 1995)
2.5	64	0.04	Composite results at Marton Mere Landfill, (Robinson, 1995)
180	3000	0.06	Average concentrations in methanogenic leachate (Ehrig, 1988)

B. Inorganic Macrocomponents

The concentrations of some inorganic macrocomponents in leachate depend,as in the case of the dissolved organic matter, on the stabilization of the landfill.Table 2.8 shows that the cations calcium, magnesium, iron, and manganese are lowerin methanogenic phase leachate due to a higher pH (enhancing sorption andprecipitation) and lower dissolved organic matter content, which may form com-plexes with the cations. Sulfate concentrations are also lower in the methanogenic phase due to microbial reduction of sulfate to sulfide.

Table 2.8 also presents average concentrations for parameters with no observed difference between acid and methanogenic phase. These are the macro components chloride, sodium, and potassium for which the effects of sorption, complexation, and precipitation are minor. Decreasing trends in concentration with time of these pollutants could be due to wash out by the leaching, although Ehrig (1983, 1988) did not observe any decrease in concentration for these parameters after up to 20years of leaching.

Table 2.8 is based on detailed studies (Ehrig 1983, 1988) on a large number of landfills in Germany. Similar findings are presented in a study of 13 sanitary landfills in Wisconsin, USA (Krug and Ham, 1997), where equivalent concentration ranges and time dependency of the selected parameters were found.

Many investigations report concentrations of ammonia-nitrogen in the range of 500 to 2000 mg/I, and no decreasing trend in concentration with time. Ammoniais released from the waste mainly by decomposition of proteins. The only mechanism by which the ammonia concentration can decrease during refuse decomposition is leaching because there is no mechanism for its degradation under methanogenic conditions (Robinson, 1995; Burton and Watson-Craik, 1998). Forthis reason, several researchers have identified ammonia as the most significant component of leachate for the long term (Robinson, 1995; Krumpelbeck and Ehrig, 1999; Christensen et al., 1994; Christensen et al., 1999). In a study of 50 German landfills, ammonia concentrations did not show a significant decrease even 30 years after landfill closure (Krumpelbeck and Ehrig, 1999). Ehrig (1988) reports that there is no significant change in ammonia concentrations from the acidic to methanogenic phase, and that the average value is 740 mg-N/L (Table 2). Ammonia concentration data from several studies is given in Table 4. These data document that ammonia concentrations will remain high even in leachate from older landfills that is otherwise low in organic content.

C. Heavy Metals

There is wide variation in the reported concentrations of heavy metals from different landfills (Table 1). However, average metal concentrations are fairly low. This has been shown by several studies in which researchers have reported metals concentrations from full-scale landfills, test cells, and laboratory studies. The ultimate conclusion of all of these studies is that heavy metals in landfill leachateat present are not at major concern (Christensen et al., 1999; Robinson, 1995; Reinhart and Grosh, 1999; Revans et al., 1999; Kjeldsen and Christophersen, 2001; Christensen et al., 1994). Table 5 gives more details of observed heavy metal concentrations. For comparison, the U.S. Drinking Water Standards are presented as well. The table shows that most heavy metal concentrations in landfill leachate are at or below the US drinking water standards.

Table 2.9: Ammonia Concentrations in Landfill Leachate (All values are from older landfills in the methanogenic phase)

Ammonia-N (mg/l)	Reference
110	Average ammonia concentration from 104 old, Danish landfills (Kjeldsen and Christophersen, 2001)
233	Composite results at Sandsfarm Landfill, (Robinson, 1995)
282	Composite results at Bishop Middleham Landfill, (Robinson, 1995)
399	Composite results at Odsal Wood Landfill, (Robinson, 1995)
43	Composition results at East Park Drive Landfill, (Robinson, 1995)
30	Composition results at Marton Mere Landfill, (Robinson, 1995)
12-1571	Range of concentrations from 21-30 year old, German landfills (Krumpelbeck and Ehrig, 1999)
445	Average concentration from 21-30 year old, German landfills (Krumpelbeck and Ehrig, 1999)
740	Average concentration (Ehrig, 1988)

TABLE [illegible]

Heavy Metal Concentrations in Leachate[a]

Reference	1	2	3	4	5	6	7	8	9	10	US Stand.[b]
Metal											
Cd	0.006	0.005	0.006	0.0002	0.0004	0.0003	0.0036	0.002 - 0.008	0.0002 - 0.018	< 0.01 - < 0.04	0.005
Ni	0.130	0.17	0.05	0.028	0.084	0.054	0.062	0.01 - 0.08	0.0036 - 0.348	< 0.01 - 0.1	---
Zn	0.67	0.6	2.2	0.2	0.36	0.085	5.31	0.003 - 0.011	0.05 - 9	< 0.01 - 0.47	5.0
Cu	0.07	0.065	0.04	0.002	0.007	0.034	0.002	---	0.004 - 0.27	< 0.02 - 0.17	1.3
Pb	0.07	0.09	0.02	< 0.005	< 0.005	0.056	0.188	0.016 - 0.067	0.005 - 0.019	< 0.04 - 0.13	0.0
Cr	0.08	0.28	0.01	0.003	0.016	0	0.002	0.033 - 0.085	0.005 - 1.62	< 0.01 - 0.05	0.1

1. Average (undiluted) leachate concentration from 106 old, Danish landfills (Kjeldsen and Christophersen, 2001).
2. Average leachate concentration in 20 German landfills in the methanogenic phase (Christensen et al., 1999).
3. Average leachate concentration in a full-scale test cell operated with leachate recirculation (Flyhammar et al., 1998).
4-7. Average leachate concentrations at four Danish landfills. Only site 4 has been closed (Jensen and Christensen, 1999).
8. Ranges of leachate concentrations in the most contaminated groundwater wells at North Bay Landfill, Canada (Christensen et al., 1999).
9. Ranges of typical leachate concentrations in a study of 21-30 year old, German landfills (Krumpelbeck and Ehrig, 1999).
10. Ranges of typical leachate concentrations at six old landfills in the UK (Robinson, 1995).
--- Data not available

a. Data listed are either the average or range for a given study in mg/l.

b. National primary drinking water regulations, USA (http://www.epa.gov/OGWDW/wot/appa.html).

D. Xenobiotic Organic Compounds (XOCs)

Table 10 presents concentration ranges of some xenobiotic organic compounds (XOCs) found in landfill leachate. The table is based mostly on observations from landfills containing municipal solid waste. The amount of hazardous waste that has been allowed into MSW landfills has decreased significantly over the last 20 years. However, many of the landfills for which data are reported in Table 6 may contain waste from a time period when there were fewer restrictions on the disposal of hazardous waste in MSW landfills. Very broad ranges are observed, reflecting differences in waste composition, landfill technologies, and waste age.

The most frequently found XOCs are the monoaromatic hydrocarbons (ben-zene, toluene, ethylbenzene, and xylenes) and halogenated hydrocarbons such as tetrachloroethylene and trichloroethylene (Table 10).

Table-2.10 Xenoblotic Organic Compounds (XOCs) Observed in Landfill Leachates

Compound	Range (μg/l)	References[5]
Aromatic hydrocarbons		
Benzene	0.2-1630	a,b,d,f,h,i,k,l,m,n,o,p,q, t, x
Toluene	1-12300	a,b,d,f,h,i,k,l,m,n,o,p,q, t, x
Xylenes	0.8-3500	a,b,d,f,h,i,k,l,m,n,o,p,q, t, x
Ethylbenzene	0.22329	a,b,d,f,m,n,o,p,q, t, x, y
Trimethylbenzenes	0.3-250	b,f,o,p, t, x
n-Propylbenzene	0.3-16	T, x
t-Butylbenzene	2.1-21	T
o-Ethyltoluene	0.5-46	t
m-Ethyltoluene	0.3-21	T
p-Ethyltoluene	0.2-10	T
Naphthalene	0.1-260	c,d,f,m,n,o,p, t, x
Halogenated hydrocarbons		
Chlorobenzene	0.1-110	a,d,f,m,o, t
1,2-Dichlorobenzene	0.1-32	a,c,d,f,o, t
1,3-Dichlorobenzene	5.4-19	Y
1,4-Dichlorobenzene	0.1-16	a,c,d,f,m, t
1,2,3-Trichlorobenzene	I	Y
1,2,4-Trichlorobenzene	4.3	Y
Hexachlorobenzene	0.025-10	Z
1,1-Dichloroethane	0.6-46	a,i, t, v
1,2-Dichloroethane	<6	a,b,d
1,1,1-Trichloroethane	0.01-3810	a,b,d,f,m,o,p,q, t, x
1,1,2-Trichloroethane	2.5-16	Y
1,1,2,2,-Tetrachloroethane	I	Y
trans-1,2-Dichloroethylene	1.6-6582	a,b, v
cis-1,2-Dichloroethylene	1.4-470	a,b, t
Trichloroethylene	0.05-750	a,b,d,f,l,m,n,o,p, t, x, y
Tetrachloroethylene	0.01-250	a,b,f,i,l,m,n,o,p,q, t, x
Dichloromethane	1.0-827	a,b,d,k,m, t, y
Trichloromethane	1.0-70	a,b,d,h,i,k,o,p,q,
Carbontetrachloride	4.0-9.0	h,o,p
Phenols		
Phenol	0.6-1200	c,f,g,k,m,n, x
Ethylphenols	<300	k,l
Cresols	1-2100	c,g,i,k,l,m,n, t, x
Bisphenol A	200-240	t
3,5-Dimethylphenol	0.7-27.3	x
2,5-Dimethylphenol	0.4-4.5	X
2,4-Dimethylphenol	0.1-12.5	x
3,4-Dimethylphenol	0.03-10.4	x
2,6-Dimethylphenol	0.3-1.9	X
2-Methoxyphenol	I[a]	x
2/3-Chlorophenol	0.03-1.6	x
4-Chlorophenol	0.2-1.3	x
4-Chloro-m-cresol	1.2-10.2	x
3,5-Di-chlorophenol	0.08-0.63	x
2,3,4,6-Tetrachlorophenol	0.079-3.0	z

Alkylphenols		
Nonylphenol	6.3-7	x
Nonylphenolmonocarboxylate	0.5-3	x
Pesticides		
Ametryn	0.12	X
AMPA	3.8-4.3	X
Atrazin	0.16	X
Bentazon	0.3-4.0	X
Chloridazon	1.6	X
Chlorpropham	26	X
Dichlobenil	0.1-0.3	X
Fenpropimorf	0.1	X
Glyphosat	1.7-27	X
Hexazinon	1.3	X
Hydroxyatrazin	0.7-1.7	X
Hydroxysimazin	0.6-1.7	X
Isoproturon	1.2	x
Lindane	0.025-0.95	Z
Mecoprop[1]	0.38-150	c,e,l, u, x
MCPA	0.2-9.1	U, x
Propoxuron	2.6	X
Simazine	2.3	X
Tridimefon	2.1	X
4-CPP	15-19	X
2,4-D[2]	1.0-5	c,l
2,4,5-T	1[4]	U
2,4-DP	0.3-5.2	U, x
2,6-DCPP	0.7-1.3	X
Phthalates		
Monomethyl phthalate	1	X
Dimethyl phthalate	0.1-7.7	S
Diethyl phthalate	0.1-660	c,g,j,m, t, x
Methyl-ethyl phthalate	2-340	X
Mono-(2-ethylhexyl) phthalate	4-14	V, x
Di-(2-ethylhexyl) phthalate	0.6-235.9	s, t, u, v, x
Mono-butylphthalate	4-16	V, x
Di-n-butylphthalate	0.1-70 5.0-15	c,g,i,j,m, t
Di-isobutylphthalate	3-6	T
Mono-benzylphthalate	6-16	V, x
Butylbenzyl phthalate	0.2-8	c,g,j, v
Dioctylphthalate	1-6	T
Phthalic acid	2-14000	V, x
Aromatic sulfonates		
Naphtalene-1-sulfonate	506-616	r
Naphtalene-2-sulfonate	1143-1188	r
Naphtalene-1,5-disulfonate	<2.5-51	r
Naphtalene-1,6-disulfonate	366-397	r
Naphtalene-2,7-disulfonate	129-145	r
2-aminonaphtalene-4,8-disulfonate	73-109	r
p-toluenesulfonate	704-1084	r

Phosphonates		
Tri-n-butylphosphate	1.2-360	c,f,i,l,m
Triethylphosphate	15	f,i,l
Miscellaneous		
Acetone	6-4400	a,i,k,o
2(3H)-Benzothiazolone	10-50	t
Camphor[3]	20.6-255.2	c,f,i,n, t, x
Cumen	0.3-7.4	
Fenchone	7.3-83	c,f,n, x
Tetrahydrofuran	9-430	a,i,k,o
Indane	0.2-20	t
Methylethylketone	110-6600	a,k, aa
Methyl-iso-butylketone	1.1-176	t, aa
Dimethoxymethane	1.1	t
MTBE	0.8-35	t
Styrene	0.5-1.6	t

The main reason for the relatively large number of investigations focusing on these two groups of pollutants is their well documented negative effects in the aquatic environment. In addition, these nonpolar organic compounds are relatively easy to analyze for, in spite the very complicated matrix of leachates from landfills. Finally, several of these compounds have been designated as priority pollutants by the U.S. Environmental Protection Agency. Data on polar and ionic organic pollutants is scarcer, although the number of investigations including these more water-soluble pollutants is increasing. This can be exemplified by the group of phenols, where the older studies usually only were analyzing for phenol and the cresols, while some newer investigations also cover, for example, chloro- and nonyl-phenols (Table 10). The observed quantities of these phenols are generally in the tg/l level. Twenty-one different pesticides were identified from a screening for a total of pesticides in 10 Danish landfills (Ledin et al., 2001). The most common ones were MCPP (or Mecoprop; present in nine landfills), Bentazon (six landfills), and MCPA (three landfills). These phenoxyalkanoic acid herbicides have been identified in leachates from other landfills as well. Especially MCPP has been observed frequently (Schultz and Kjeldsen, 1986; Gintautas et al., 1992; Kjeldsen, 1993; Oman and Hynning, 1993; Oman, 1999). However, other types of pesticides were also identified, for example, Ametryn, Atrazine, Chlorpropham, Dichlobenil, and Hexazinon (Table 9). These findings indicate that pesticides could be of importance when evaluating the impact from landfill leachates on groundwater quality. Measurements for benzene and naphthalene sulfonates have been carried out in leachates from four Swiss landfills (Riediker et al., 2000). The results showed that benzenesulfonates (p-toluenesulfonate) and naphthalenesulfonates (Naphtalene- I -sulfonate, Naphtalene-2-sulfonate, Naphtalene- 1,5-disulfonate, Naphtalene- 1,6- disulfonate, Naphtalene-2,7-disulfonate, and 2-aminonaphtalene-2,7-disulfonate) were present in the leachates, at a concentration range shown in table 10. The sulfonates include some of the surfactants used in laundry detergents and shower soaps. Another type of surfactant that could be expected to be present in landfill leachates are the alkylphenol polyethoxylates. Ledin et al. (2001) analyzed for two of these, nonylphenol mono- and di-ethoxylate, as well as two degradation products, nonylphenol mono- and di-carboxylate. They found nonylphenol monocarboxylate in leachates from two landfills, although no nonylphenol polyethoxylates were observed. The phthalates are also pollutants of concern. The most frequently observed phthalates are di-(2-hexylethyl) phthalate, di-ethyl-phthalate, di-n-butyl-phthalate, and butyl-benzyl-phthalate (Table 10). The highest concentrations are, however, observed for the degradation product phthalic acid (up to 14 mg/l) (Ejlertsson et al., 1999). It could also be noted that MTBE (methyl-tert-butyl-ether), which is used as a gasoline additives, has been found in concentrations up to 35 jig/l in the leachates from eight Swedish landfills (Greenpeace, 1999). More that 200 individual compounds or classes of compounds were identified in a screening for XOCs in three Swedish landfills (Paxeus, 2000). Among the compounds identified were dioxanes and dioxolans, which have not been reported previously in landfill leachates. These are synthetic cyclic ethers and are known to have very low odor threshold and high odor intensity. They originates form waste disposal from alkyd resin production and from disposed products from painting and coating (Paxeus, 2000). AOX (Adsorbable Organic Halogen) has in some cases been used as an aggregated parameter for the content of XOCs containing halogens. Robinson (1995) reviewed concentration ranges of AOX in landfill leachates reported in the literature and performed additional analysis on 30 landfill leachate samples. The total range given by Robinson (1995) was 30 to 27,000 ,ug/l, but in most cases AOX results were in the range of 200 to 5000 ug/l. The usefulness of AOX measurements is limited by the lack of information on identities and concentrations on individual compounds, often with quite different health effects, and also by poor correlation between the measured AOX in the leachate, and the concentrations of identified, halogenated pollutants (Robinson, 1995). Gr0n et al. (2000) saw the same problems using the related parameter

TOX (Total Organic Halogens) in leachate from two Danish landfills. With commonly used screening procedures for organic pollutants, the individual halogenated compounds behind the TOX could not be found.

The results for halogenated aliphatics and the aromatics from two studies are compared in Table 11. The data presented by Krug and Ham (1997) originate from 13 municipal sanitary landfills in Wisconsin, USA, while the data from Kjeldsen and Christophersen (2001) is from 104 old Danish MSW landfills. In both studies, BTEX were the most frequently found compounds and concentrations were generally lower at the Danish landfills. Krug and Ham (1997) also reported the frequent presence of halogenated hydrocarbons at relatively high concentrations, reflecting the co-disposal of hazardous waste at some of the sites. At the old Danish sites the concentrations of the halogenated hydrocarbons were very low, probably reflecting that intense co-disposal has not been practiced on the Danish sites. Table 8 shows the results of a recent study comparing detection frequency and concentrations from old and new MSW landfills (Gibbons et al., 1999). The table shows that the concentrations of xenobiotic organic compounds at the old MSW landfills were generally higher than concentrations at the newer landfills, probably reflecting a lower acceptance of organic chemicals at the newer landfills. These data are in good accordance with an investigation of leachate concentrations over a I-year period from 40 landfills with no co-disposal (Ecobalance, 1999).

E. Toxicity of Landfill Leachate

Risk assessment of landfill leachate is traditionally based on chemical analyses of specific compounds present in the leachate. However, risk assessment is not sufficiently developed to take into account interactions among chemicals or toxic degradation products for constituents in a complex mixture. In contrast to chemical analysis, bioassays can be used to characterize the toxicity of landfill leachate to integrate the biological effect of all its constituents. Thus, factors like bioavailability, synergistic, antagonistic, or additive effects can be assessed directly without the need for assumptions and extrapolations made from chemical analysis. Until about 1980, there were only a few published studies on the toxicity of landfill leachate (Cameron and Koch, 1980), but since then the toxicity of landfill leachate has been assessed by several authors using a number of different organisms (Table 9). Single species or test batteries consisting of several different species or organisms from different trophic levels have been applied to landfill leachate to detect both specific and general toxicity. Fish (usually fathead minnow or rainbow trout), crustaceans (daphnids), and luminescent bacteria (commercially available as Microtox test kits) are among the most frequently used methods. Considerable differences in the sensitivities of different test organisms have been observed in most studies (for example, Plotkin and Ram, 1984; Clement et al.

2.7.3.3 Leachate characteristics

The chemical characteristics of leachate depend on waste composition and conditions within the landfill such as temperature, moisture, stage of decomposition, landfill depth and so on. As a whole, COD, BOD and NH_3-N of leachate of a typical sanitary landfill will change with time as shown in Fig 2.4. BOD decreases more rapidly than COD because BOD is attributed to more easily biodegradable substances in waste and these are attacked by variety of bacteria at early stage of filling.

Landfill types or landfill techniques help to create a certain environment mentioned above which affects both the rate of waste decomposition and stabilization. Based on varying metabolic function of microorganism within landfills, landfill type has been classified into five categories, as shown in Table 2.11 and Fig 2.4.

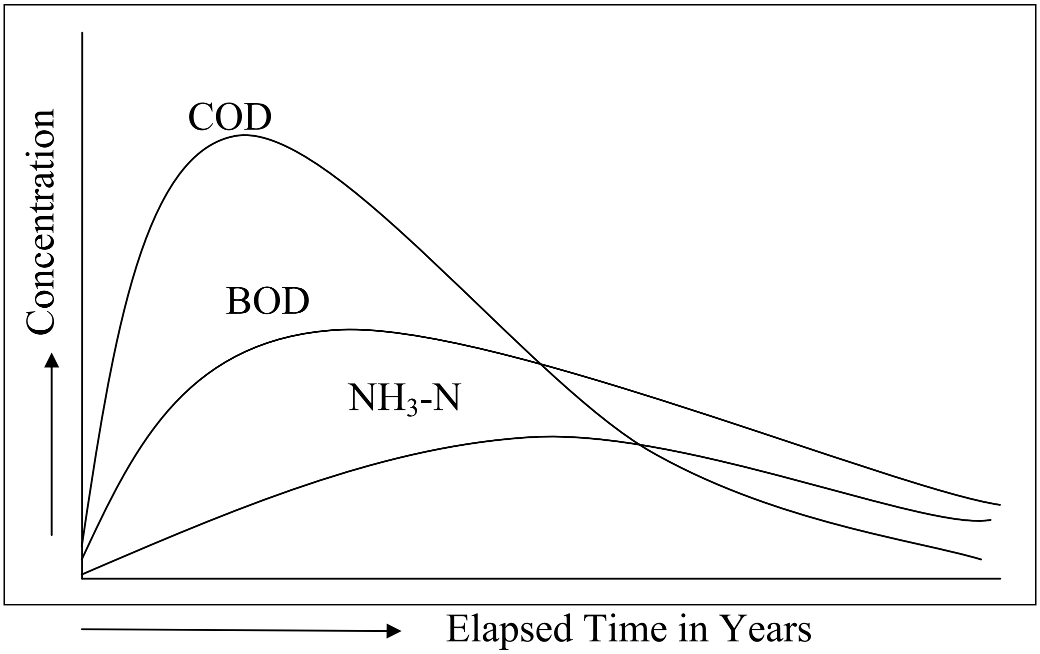


Figure 2.4: Change of leachate concentration with time (Matsufuji, Y., Sinha, K., 1990)

Table 2.11: Classification of Landfill Type		
1	Anaerobic landfill	Wastes are filled in dug area of plane field or valley. Wastes are filled with water and decomposition occurs in aerobic condition
2	Anaerobic sanitary landfill	Anaerobic landfill with cover like sandwich shape. Condition inside the landfill is same as anaerobic landfill.
3	Improved anaerobic sanitary landfill	It has leachate collection system in the bottom of the landfill site. Other conditions are same as in anaerobic sanitary landfill. The conditions are still anaerobic but moisture content is much less than anaerobic sanitary landfill.
4	Semi-aerobic landfill	Leachate collection pipe is bigger than the one in improved sanitary landfill. The opening of the pipe is covered with small crushed stones. Moisture content in solid waste is small. Oxygen is supplied to waste from leachate collection pipe.
5	Aerobic landfill	In addition to the leachate collection pipe, air supply pipes are attached and air is forced into the landfill due to which condition becomes more aerobic than semi-aerobic landfill.

Source. Matsufuji, Y., Sinha, K., 1990

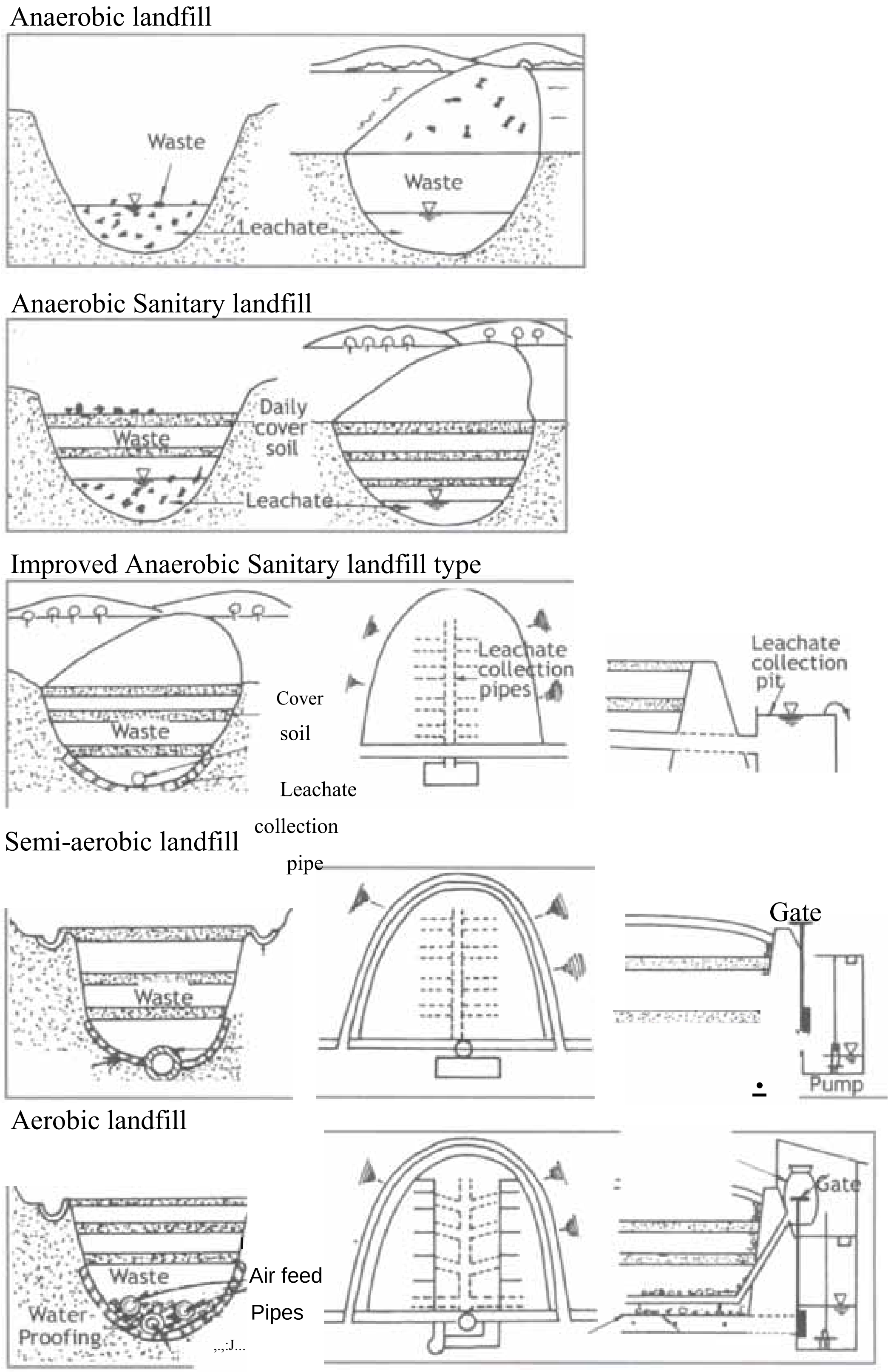


Figure 2.5: Classification of landfill types (Matsufuji, Y., Sinha, K., 1990)

2.7.3.4. Method of Leachate Estimation

A. Water Balance

The various components of a water balance for a landfill are presented in Figure 2.5. As shown in the Figure, the primary sources of water are: water entering the fill through the cover (precipitation), moisture in the cover material, groundwater inflow, and inherent moisture in the solid waste. In addition, a small amount of water is formed as a byproduct of decomposition of the wastes. Water leaves the landfill in the form of saturated vapour in the landfill gas, and through transpiration. The remainder of the water is either stored by the waste or becomes leachate.

The algebraic statement of this form of water balance is

PERCOLATION = P - RO - ET - AS + G proposed by **Fenn *et al.* (1975)**

A generalized pattern of leachate formation is presented in Fig. 2.5. The components shown include the following steps:

i. Precipitation (P) falls on the landfill and some of it becomes runoff (RO).
ii. Some of P infiltrates (I) the surface (uncovered refuse, intermediate cover, or final cover).
iii. Some of I evaporates (E) from the surface and (or) transpires (T) through the vegetative cover if it exists.
iv. Some of I may make up a deficiency in soil moisture storage (S) (the difference between field capacity (FC) and the existing moisture content (MC)).
v. The remainder of I, after E, T, and S have been satisfied, moves downward forming percolate (PERC) arid eventually leachate (L) as it reaches the base of the landfill.
vi. PERCOLATION may be augmented by infiltration of groundwater (G). The procedure used to analyze these processes is referred to as a water balance (WB), various forms of which are commonly used for the simulation of surface water hydrology.

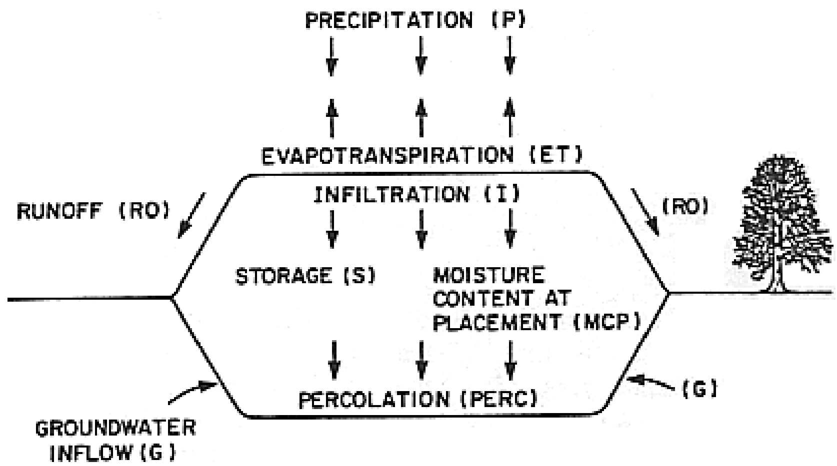


Figure 2.6: Components of water balance (FENN, D.G., HANLEY, K. J., and DEGEARE, T.V. 1975)

The field capacity of a landfill varies as a function of the weight of the overburden, as well as of other variables, e.g., soil and waste characteristics. The field capacity of a landfill can be estimated (Garland, G.A. and D.C. Mosher, 1975) approximately using the following equation:

where:

FC = 0.6 x 0.55 (W/ (10,000+W))

Where

- FC = field capacity, and
- W = weight of overburden calculated at the middle of the lift.

If MC > FC then Leachate generated.

Alternatively, the field capacity of compacted solid waste, as well as other materials, can be determined experimentally. Calculated estimates of field capacity should be confirmed through measurements whenever possible.

B. HELP Model

HELP: Computer models have been developed subsequently using the WBM as a basis with various modifications. The hydrologic simulation of solid waste disposal sites (HSSWDS) model developed by Perrier and Gibson (1981) and the hydrologic evaluation of landfill performance (HELP) model reported by Schroeder (1983) are two of the more widely accepted of these computer models. The HELP model is perhaps the best of the available computer models. Its use has become compulsory for Superfund Site evaluation.

Components of the WBM and the HELP model.

The component steps of the WBM used to calculate landfill leachate flow are presented in flow chart form in Fig.2.7. Table 2.7 provides a summary description of each step and compares the steps with those of the HELP model. More detailed information about the methods is given in Kmet (1982, 1986). The components are generally calculated in units of height of water per unit time (e.g., centimeters (or inches) per month).

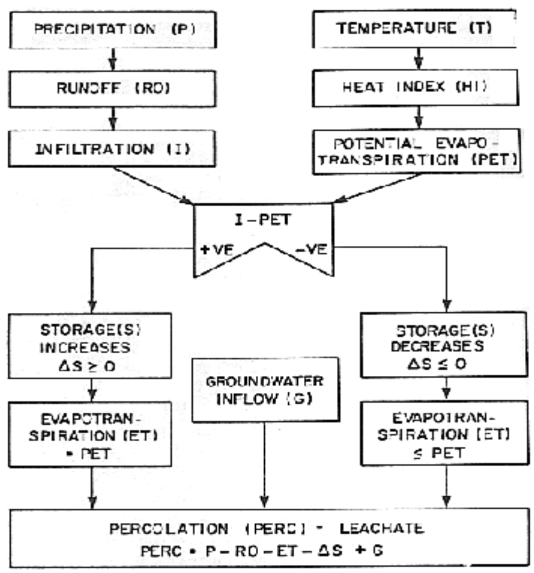


Figure 2.7: Components of the WBM and the HELP model **(Kmet, 1982, 1986).**

The time of leachate arrival at the base of the landfill is handled differently in the two methods. The WBM does not account for the period of time required for the refuse to be brought up from its moisture content (MC) at placement (e.g.15 $cm.m^{-1}$) to field capacity (FC) (e.g.35 $cm.m^{-1}$) at which point liquid flow begins. This can take several months depending on the refuse type, compaction, and depth in addition to the percolation rate. The WBM assumes that the refuse is already at FC and that a unit of PERC at the top produces an equivalent unit of leachate at the bottom. The method is therefore applicable only after FC has been reached in the landfill. It is possible to estimate the time of first leachate production using PERC and allowing it to increase the MC until FC is reached. However, Kmet (1986) has shown that the actual time at which leachate first appears at a landfill is much less than that predicted with this method. He attributed this to channelling and nonhomogeneous MCs and flow properties within the refuse. This would result in FC in the region of channels much less than FC at other locations within the refuse.

The HELP model, in addition to performing a water balance, also calculates a flow rate through the refuse and therefore estimates the time of first leachate appearance. However, channeling due to heterogeneities within the refuse reduces the accuracy of these flow rate calculations and tends to overestimate leachate arrival times.

Table 2.12 Components of the WBM and comparison with the HELP model (FARQUHAR, G. J, and Rovers, F. A. 1973)

WBM	HELP model
1. Pontential evapotranspiration (PET)-the potential amount of moisture that can evaporate soil and (or) refuse and transpire from vegetative cover depending upon temperature (T) and solar radiation	
Thornthwate method	Penman method (Penman 1948)
(Thornthwaite and Mather 1957)	
Data input	
Temperature: Monthly	Daily
Heat index: Monthly	Monthly
2. Precipitation (P) - the precipitation in all forms falling on the site	
Monthly averages	Daily averages (choice available)
3. Runoff (RO) - that portion of precipitations which runs off the site and does not infiltrate	
Thornthwaite and Mather (1957)	U.S.Department of Agriculture (1975)
Fenn et al. (1975)	
RO = CROP	Same as WBM
(C_{RO} is a runoff coefficient)	
Data input	
Vegetation	
Slope	
Soil types	
Surface treatment	

4. Infiltration (1) - that portion of precipitation which infiltrates the site

I = P - RO Same as WBM

5. Soil moisture storage (S) -the amount of infiltration which is retained in the soil and (or)
refuse up to field capacity and thus does not percolate as leachate (SMAX is the maximum S for soil or refuse)

Thornthwaite and Mather (1957) Same as WBM
Data input

Soil type

Depth

Field capacity

Moisture content (MC)

Wilting point (WP)

AS (change in S)

= + ve when 1> 0 and MC < SMAX

= - ve when (1 - PET) <0 and

MC> WP

6. Actual evapotranspiration (ET) - the actual amount of evapotranspiration (ET ≤ PET) which occurs; depends on the soil types and depths, vegetation type, root depth, MC

ET ≤ PET - [(I - PET) - S]

7. Percolation (PERC) - the amount of liquid which reaches the base of the landfill to become leachate PERC = P -RO - ET - S + G

Output of the WBM

The output from the WBM and also the HELP model (although the Iatter is more comprehensive) is represented in Figure 2.7. The data are given as monthly averages and thus some seasonality is evident. Leachate production (PERC) exists in the months from February to May inclusive and is zero during the remaining months. Seasonality in the other components such as P and ET is also shown. When PET exceeds I, S is reduced by evapotranspiration as shown in the months of June, July, and August. In November and December, although I exceeds PET no PERC occurs since l is used to make up the deficit in S (SMAX = 9 cm in this illustration). The output therefore provides estimates of leachate flow and its variability throughout the year. Such information is essential when assessing the impact of the leachate on either the soil environment or a treatment facility to which the leachate is being discharged.

HELP model is more accurate to measure leachate production and flow rate on the basis WBM with various modifications by computer model which use hydrologic simulation of solid waste disposal sites (HSSWDS). Here HELP model is not readily available and not been yet practicing in research projects. As a result WBM model is used as customary tools for calculating leachate production in the area of study.

2.7.3.5 Analysis of leachate Flow

While water balance equation is conceptually correct and comprehensive, accurate predictions of leachate flow are difficult to achieve because of the uncertainties associated with estimating the various terms. Most formulae and methods in use are empirical. Some of the data base required is stochastic in nature (temperature, heat index, precipitation, wind, vegetative growth). Other data are poorly defined (runoff coefficients, refuse and cover density and compaction, moisture storage capacities).

Analyses have been performed to compare water balance predictions of leachate flow with actual measurements made in the field. Gee (1981) used two variations of the water balance method to predict leachate flow at the GROWS Landfill in Bucks Co., Pennsylvania. These predictions were too high by a factor of approximately 2 when compared with measured leachate flows. Lu *et* al. (1981) performed similar comparisons at 5 landfills using 25 different methods to estimate the various terms of WBM equation. On average, leachate flow estimates were in error by a factor of 2. However, the poorest estimates were as much as 100 times greater than the measured leachate flows.

In contrast, Kmet (1982) had excellent success using a water balance method to simulate leachate production in Ham's (1980) eight field lysimeters. Leachate flows ranged from 16.6 to 22.1% of precipitation on an annual average basis. Water balance methods predicted an average of 22% of precipitation, providing excellent agreement with measured values. Kmet used the water balance method (WBM) proposed by Fenn *et al.* (1975) with modifications to account for infiltration and runoff from the landfill during winter conditions. This appears to be an acceptable procedure to predict leachate flow.

The WBM as proposed by Fenn *et al.* (1975) is a manual procedure solved generally with monthly averaged values.

2.7.3.6 Leachate migration

In "typical sanitary landfills" in most industrialised countries, leachate is found at the bottom of the fill. In developing countries, where most landfills are not lined, the leachate will have the tendency to migrate in a downward motion through the underlying soils. Only a limited amount of research has been carried out on the movement of fluids through solid waste. Depending upon the type of material surrounding the fill, it is possible that a certain amount of lateral migration will take place.

One of the major concerns associated with the uncontrolled vertical migration of leachate is the potential contamination of the groundwater. The rate of migration of leachate can be estimated by using Darcy's law:

$$Q = - K A\, dh/dl$$

where:

- Q = leachate flow rate (m3/day);
- K = hydraulic conductivity (m3/m2 - day);
- A = cross-sectional area through which the leachate flows (m^2);
- dh/dl = hydraulic gradient;
- h = head loss (m); and
- l = vertical depth (m).

The negative sign in Darcy's law is due to the fact that head loss (dh) is always negative. Typical values for the hydraulic conductivity (i.e., permeability) for various soils are provided in Table 2.7 (Ettala, M., 1987).

Table 2.13: Typical values for the hydraulic conductivity for various soils

Soil Type	**Hydraulic Conductivity, K (m3/m2 - d)**
Uniform coarse sand	407
Uniform medium sand	102
Uniform fine sand	4
Silty sand	0.09

Sandy clay	0.005
Silty clay	0.0009
Clay	0.00009

Source: Ettala, M., 1987

In Matuail it was studied that the thickness of this clay unit varies and averages to about 8 m (BUET, 2008). Within the Garh area it forms low ridges reaching a maximum height of about 30m above the surrounding floodplains. The project site at Matuail has outcrops of this clay unit in the west. The clay dominated lithology makes this unit an ideal impermeable layer and that can be expected to avoid migration of leachate and deter groundwater flow through it.

2.7.3.7 Attenuation of leachate characteristics in soil

Attenuation by soil is an adsorption process in which contaminants are removed from leachate moving through the soil. Attenuation is an important mechanism to consider in the design of a bottom liner and particularly if a bottom liner is not incorporated into the design of a sanitary landfill. The mechanism of removal is the adsorption of the contaminants on the surface of active soil particles (e.g., clay minerals). The fact that attenuation is an adsorption process places a high upper limit on the attenuation capacity of a soil. Hence, soil attenuation is only a short-term means of controlling contaminant migration and protecting groundwater resources from leachate. Moreover, having been contaminated by the adsorbed chemicals, the soil constitutes another source of contaminants to water percolating through the soil. In case of a need to institute corrective or remedial action, contaminated soil would have to be cleaned.

Among the chemical properties that exert an influence on the capacity of a soil for attenuating contaminants are cation exchange capacity (CEC), pH, clay content, mineralogy, free iron oxide content, and lime concentration. The attenuation capacity of a soil generally increases with increase in clay content, free iron oxide content, and lime concentration. Cation exchange capacity is largely a function of clay content and clay mineralogy of the soil. The higher its CEC value, the more efficient a soil becomes at attenuating cations and polar organics. Heavy metals frequently are held by alkali soils.

2.7.3.8 Leachate formation in arid areas

The rate of leachate generation from landfills in developing countries located in arid regions may be relatively low if the results of a research project conducted in Lima, Peru are typical. The project was commissioned for the purpose of assessing the potential environmental impacts, including leachate production, associated with the operation of land disposal sites. The average rainfall in Lima (and generally in the entire coastal area of Peru) is less than 10 mm/yr; thus the results would be applicable to dry (arid) regions. Three micro-landfills that had been operated as sanitary landfills using sand as intermediate and final cover material and an old disposal site operated simply as an open dump were monitored and analysed.

2.7.3.9 Environmental Impact

The major environmental problems experienced at landfills have resulted from the loss of leachate from the site and the subsequent contamination of surrounding land and water. Improvements in landfill engineering have been aimed primarily at reducing leachate production, collecting and treating leachate prior to discharge, and limiting discharge to the assimilative capacity of the surrounding soil. Whether leachate is to be collected and treated or is allowed to discharge to the soil, it is essential to have estimates of leachate flow and strength and variation of this with time as the site develops through closure and after closure. While these estimates are essential to proper landfill design, their preparation is difficult and uncertain process.

The mitigation measures, environmental monitoring and institutional arrangement are the main components of the environmental management plan (EMP) for matuail sanitary landfill. An effective environmental monitoring program has been developed as part of the EIA to ensure that the environmental protection measures (EPMs) specified for the construction and operation phases are implemented, Environmental Quality Standards (EQS) are strictly maintained and to observe the effectiveness of the EPM. The monitoring program is designed to measure the actual impacts and adopt correcting measures to reduce unacceptable level of environmental impacts, if any. Important surface and groundwater quality parameters, leachate quality, air quality and noise levels will be measured at regular intervals. Few observation wells have been installed in the shallow aquifer around the landfill area to monitor the change in groundwater quality.

The Landfill Management Unit of the DCC is implementing the Environmental Management Plan of the project. A manual with step by step guidance for operation and management of the landfill has been developed. The monitoring results are analyzed to observe the trend and compliance with the Environmental Quality Standards and adopt appropriate measures as necessary. The new landfill adjacent to the existing one will be an example of sound environmental management of landfill operations in Bangladesh.

2.8 Liners

2.8.1 Soil liners

To form a bottom liner for the landfill, soil can be used in one layer (i.e., a single-liner system) or in conjunction with layers of other materials (i.e., as one or more layers of a multi-layer, or composite, liner system). Hazardous wastes, due to their hazardous characteristics, require secure containment and should be disposed in sites equipped with double, or composite, liner systems. When a soil liner is used as a single liner, it reduces or may even keep the leachate from leaving the fill and reaching the subsurface environment. In the event that the soil liner is placed underneath a flexible membrane liner (FML), the soil liner serves as a protective layer for the overlying flexible membrane liner (FML). In addition, the soil liner constitutes an additional barrier to leachate migration. A soil liner must be properly designed and constructed so that it forms a long-term, structurally stable base for overlying facility components.

2.8.1.1 Materials

To adequately serve as a liner, a soil must have a low permeability (preferably less than 1×10^{-6} cm/sec) when compacted under field conditions. After compaction, the liner should be able to support itself and the overlying facility components. The liner material should yield to handling by construction equipment. Finally, a liner constructed of the material (i.e., the soil) should suffer no significant loss in permeability or strength when exposed to waste or leachate from the waste. A soil that is deficient in a required characteristic may be rendered suitable by blending it with another soil or with a soil additive. An example is the addition of bentonite cement to decrease permeability. Ideally, the compaction and permeability characteristics of the selected soil liner material should be determined by laboratory tests, so as to provide necessary information regarding the interrelationship between moisture content, density, compactive effort, and permeability.

Of the common types of soils, a well compacted mixture containing clay is one of the more commonly used soils for a bottom liner. Clay generally refers to all soils having a particle size smaller than a given size (typically less than 2 microns). Pore-size distribution, fluid viscosity, effective porosity, and fluid density determine the permeability of clay soils to fluids. A clay liner usually is constructed as a layer 0.3 to 1 m thick. To function as an effective liner, the clay must be mixed with other granular soils and placed with the proper moisture content. The density of the liner can be increased through compaction in order to decrease the material's permeability. During installation of a clay liner, compaction is controlled by measuring moisture content and density in each lift. If sufficient clay is not available locally, natural clay additives (e.g. montmorillonite) may be added to the mixture of clay soil to form an effective liner. The use of additives requires evaluation to determine optimum types and mixing ratios.

If it meets the necessary specifications for a liner, the native soil at the facility site would best satisfy cost and convenience considerations. Otherwise, a suitable soil must be imported from another location. Obviously, cost becomes an important consideration when offsite material is used. In developing countries, the maximum distance would depend upon local conditions. In most cases, a haul of any appreciable distance would be impractical. The liner material, whether excavated locally or imported, usually is stored as a borrow pile established at the site.

2.8.2 Flexible membrane liners

The constituent material of a flexible membrane liner (FML) is pre-fabricated polymeric sheeting. A flexible liner may be used in many ways. For example, it may be used as a single liner installed directly over the foundation soil; as part of a composite liner placed upon a soil liner, or as a layer of a multi-element leak detection system in a double-lined landfill. In general, flexible membrane liners may be too costly to be installed in developing countries. However, should they be required, attention must be given to specifications and cost, as well as to installation.

Major steps to be taken in the use of a flexible membrane liner are selection of the FML material, designing of the subgrade, and planning the installation. The last step includes the design of subcomponents, such as sealing and anchoring systems and vents. Among the types of membranes commonly used for lining sanitary landfills are high-density polyethylene, chlorinated polyethylene, and chlorosulfonated polyethylene. Important criteria to follow for selecting an FML include chemical compatibility with the characteristics of the leachate to be contained; possession of appropriate physical properties such as thickness, flexibility, strength, and degree of elongation; resistance to weathering and biological attack; availability; and cost.

If testing facilities are not available, judgments about compatibility of the synthetic material with wastes and leachates will have to be made on the basis of specifications provided by the manufacturer. With respect to mechanical properties, FMLs having high strength and low elongation are best suited in applications where high stresses are expected (e.g., sidewalls steeper than 2.5:1). Lower strength and higher elongation FMLs (e.g., chlorosulfonated polyethylene) are best used for applications likely to involve large deformations such as differential settlement and local subsidence. Other important mechanical properties that should be considered include: flexibility at various temperatures, resistance to puncture, thermal expansion, seaming characteristics, resistance to weathering, and resistance to biological attack and environmental conditions (e.g., sunlight and atmospheric ozone). Information on FMLs can be sought from manufacturers. Although some published literature is available, such information may be difficult to obtain in a developing nation.

The subgrade upon which an FML rests is a key factor in the maintenance of its integrity. The reason is that it serves as a supporting structure and it controls the accumulation of gas and liquid beneath the liner. Consequences of the accumulation can be uplift stress and reduction of the strength of underlying soils. In addition to those resulting from gas and liquid accumulation, mechanical stresses may be caused by subsidence beneath the liner and other stresses due to differential movements of the subgrade, etc. All of these failure mechanisms can be prevented or minimised by employing common foundation design measures to prevent settlement, subsidence, slope failure, and other undesirable occurrences, as well as other engineering design measures related to soil and liner materials.

Important design features of protective bedding layers are the provision of drainage to prevent the accumulation of gas or liquid and the protection of the liner from being punctured. The drainage layer may consist of sand, gravel, or other comparable granular material. Alternatively, it may take the form of a geotextile (a fabric designed to provide tensile strength and serve as a filter). Granular drainage layers have some substantial limitations, including difficult installation and maintenance of stability on steep slopes, and vulnerability to disturbance by workers and to erosion wind or water during construction. These problems are avoided by resorting to geotextiles. Moreover, geotextiles protect the liner from mechanical stresses.

Surface preparation for FMLs should include: 1) removal of rocks (larger than 25 mm), roots, and other debris from the surface; and 2) removal of organic materials so as to minimise settlement and gas production under the liner. Soils that expand or shrink excessively should be avoided. Finally, the substrate soil surface should be compacted to provide a firm and unyielding base for the liner. Because the actual installation of a flexible membrane liner is a complex and critical task, it should be conducted by a qualified and competent company under the supervision of the manufacturer or an engineer of the manufacturer.

2.9 Leachate collection and treatment

2.9.1 Introduction

The decision to incorporate a leachate collection and treatment system as part of a sanitary landfill system in a developing country is, in many cases, a very difficult one due primarily to the expense. Obviously, the consideration only applies in those instances in which a bottom liner has been incorporated into the design of the landfill. If a leachate treatment and collection system is to be installed, funds must be available for operation as well as for capital expenses. If a thorough analysis of the situation indicates that a bottom liner and a leachate collection and treatment system should be installed, every effort should be made to implement the systems such that their construction and operation do not result in the contamination of the surrounding land resources or potential sources of water supply. The implementation of a leachate collection and treatment system involves the following design steps: 1) selection of the type of bottom liner to be applied; 2) preparation of a grading plan (i.e., channels, pipelines, and others); 3) design of the system for the collection, removal, and storage (if required) of the leachate; and 4) identification, selection, and design of the treatment system.

2.9.2 Prerequisities

There are two key steps that must be carried out before a leachate collection and treatment system can be designed. The first one involves the selection of the bottom liner and the second involves the estimation of the quantity and quality of the leachate.

2.9.2.1 Bottom liner

The processes involved in the selection, design, and installation of a bottom liner have been discussed in previous sections.

2.9.2.2 Quantity and quality of leachate

The quantity of leachate waters generated in landfills depends mainly on the climatic factors in its vicinity, that is the above all on the water balance in the layer covering wastes. The volume of leachates is also affected by: initial moisture content of the wastes, solid waste composition, biochemical and physical transformations taking place in them and causing changes in their humidity and by the inflow of water from outside a landfill. The amount of leachates in the scale of a year is not constant. The age of a landfill also significantly affects the quantity of leachates formed. The ageing of a landfill is accompanied by increased quantity of leachates, which according to Szpadt should be ascribed to the water--retaining capacity of wastes with simultaneous reduction of their water capacity as a result of the mineralization of organic substances.The quality of the leachate from a landfill depends primarily on the type of waste placed in the fill, degree of compaction, depth of fill, and age of the waste. For example, leachate produced during the first phase of decomposition of MSW characteristically has an acidic pH resulting from a high concentration of organic acids. Some characteristics of leachate from municipal solid wastes are presented in Table 2.14. The range of values given in the table reflects leachates generated during the acid and methanogenic phases of decomposition.

Table 2.14: Characteristics of leachate generated from decomposition of municipal solid wastes

Parameter	**Range of Values (mg/L)**
pH	4.5 to 9
Alkalinity (CaCo3)	300 to 11,500
BOD (5-day)	20 to 40,000
Calcium	10 to 2,50
COD	500 to 60,000
Copper	4 to 1,400
Chloride (Cl-)	100 to 5,000
Hardness (CaCo3)	0 to 22,800
Iron - Total	3 to 2,100
Lead	8 to 1,020
Magnesium	40 to 1,150
Manganese	0.03 to 65
Ammonia- NH3	30 to 3,000
Organic N	10 to 4,250
Nitrogen-NO2	0 to 25
Nitrogen-NO3	0.1 to 50
Nitrogen-Total	50 to 5,000
Potassium	10 to 2,500
Sodium	50 to 4,000
Sulphate (SO4=)	20 to 1,750
Total Dissolved Solids	0 to 42,300
Total Suspended Solids	6 to 2,700
Total Phosphate	0.1 to 30
Zinc	0.03 to 120

Source: Ehrig, H.-J. and T Scheelhaase, 1993.

A Range of values encompasses both acid and methanogenic phases of waste decomposition.

2.9.3 Leachate collection systems

The basic purpose for installing a leachate collection system in a landfill is to remove leachate and water that may have penetrated the waste or may have come in contact with it. The capacity of the leachate collection system depends upon the quantity of leachate expected to be generated. The system should be installed such that it is compatible with the type and shape of the bottom liner. The design of the system should incorporate every measure to minimise or prevent clogging.

One of the critical components of the leachate collection system is its drainage layer or system. The drainage layer provides a path for the leachate to flow through, thus enabling collection and removal of the leachate. In addition, the drainage layer provides protection to the bottom liner from both the waste and the heavy equipment operating on top. The drainage system typically consists of a mixture of porous materials such as sand and gravel. The materials for the drainage system should be carefully selected and graded so that they do not clog the collection pipes. Some of the more sophisticated drainage systems include more than one drainage layer. In addition, clogging between filter layers can be reduced by including a filter fabric between them.

The efficiency of the leachate collection system is partly controlled by the characteristics of the drainage layer. In particular, the hydraulic conductivity of the drainage system reduces the efficiency of the collection system. Drainage layers also are prone to clogging. Clogging of the drainage layer (i.e., a reduction in the hydraulic conductivity) results in a reduction in the quantity of leachate removed from the site.

2.9.4 Design of the leachate collection system

There are a number of proposed designs for leachate collection systems. Two of the more common systems are the sloped terrace and the piped bottom. They are described below.

The sloped terrace design involves the sloping of the bottom of the fill into a series of terraces. Generally, the recommended slopes for the terraces are in the range of 1% to 5%. This degree of inclination promotes migration of the leachate in the direction of collection pipes or channels. The collection channels typically include perforated collection pipes in a bed of packed gravel. The gravel should have a size of in the range of 3.5 to 5 cm. The gravel itself can become clogged with fine particulates; consequently, the gravel typically is enclosed within a layer of geotextile filter fabric. Usually, the inclination of the drainage channels is in the range of 0.5% to 1.0%.

The piped bottom collection system design includes the placement of clay barriers and perforated leachate collection pipes at the bottom of the site. Typically, the barriers have a defined form and a width similar to that of the solid waste cell. A geomembrane is placed on top of the clay surface. After the barriers have been installed, slotted pipes are placed on top of the geomembrane. The leachate collection pipes usually have a diameter of about 10 cm, and the perforations usually cover about 50% of the pipe's circumference. The collection pipes are placed about 10 to 20 m apart and are covered with a drainage layer of sand and gravel. As a precaution against clogging of the pipe perforations, a fabric filter can be placed on top of the drainage layer. The separation between the pipes will control the amount of leachate that will accumulate at the bottom of the fill. In a typical operation, the layer of sand and gravel is about 60 cm thick and is placed on top of the collection pipes a few weeks before the first load of waste is discharged on the cell. It is advisable not to compact the first layer of waste in order to protect the integrity of the piping network. The slope of the unit should be on the order of 1% to 2% in order to promote the migration of leachate toward the collection points. The designs of these facilities should promote drainage by gravity.

2.9.5 Removal and storage of the leachate

Removal of leachate from a landfill can be carried out in either of two manners: by installing a pipe through the side of the fill or by placing a sloped collection pipe inside the fill. If a pipe is placed through the side of the landfill, the construction should be conducted with due caution in order to avoid damaging the liner system. Most leachate collection systems will clog at some point in time. Consequently, manholes and vertical and/or horizontal cleanouts should be provided in strategic locations in order to conduct periodic maintenance and inspection (McGraw-Hili Kogakusha, Ltd., Tokyo).

Once the leachate is captured in a particular section of the landfill, it usually is routed to storage in tanks, vaults, or ponds. The type and size of the storage device will depend upon the quantity and characteristics of the leachate, proximity to inhabited areas, and the type of treatment required.

2.9.6 Leachate management alternatives

The type and degree of treatment afforded to leachate from a sanitary landfill will have an impact on the level of pollution of any nearby groundwater and of the surrounding environment. The best approach to leachate management is to avoid generating it in the first place. However, this condition usually can be achieved or closely approached only under dry climatic conditions. If conditions are such that leachate is generated, there are several options for managing it:

- evaporation (natural or forced),
- recirculation and recycling,
- discharge to an offsite wastewater treatment facility, and
- onsite treatment.

A discussion of each of the approaches follows.

2.9.6.1 Evaporation

Evaporation of the leachate, by natural means, is one of the more appropriate solutions for managing the leachate generated in developing countries whose climatic conditions would be compatible with the technique (i.e., high temperatures and low relative humidity). In this technique, once the leachate is collected, it is transported to an evaporation pond. The pond should be constructed using an impermeable material and should have sufficient capacity to hold the leachate plus any incident precipitation. If the pond is relatively small, it may be feasible to place a cover over the pond permanently or during the rainy season. The rate of evaporation depends upon climatic conditions; however, the evaporation rate can be enhanced by spraying the leachate either on the pond or on the surface of parts of the completed fill. Spraying on the surface may lead to generation of unpleasant odours and of aerosols that may contain pathogens and micron-size particulates, which may be of consequence if sensitive receptors are located nearby.

The rate of evaporation can be increased by heating the leachate. Heating the leachate can be a costly undertaking, although landfill gas could be used for this purpose.

2.9.6.2 Recirculation and recycling

Recirculation of the leachate through the landfilled wastes has been applied in several facilities throughout the world as a method of leachate management. Relatively high concentrations of BOD, COD, and, in some cases, heavy metals generally are found in the leachate soon after the waste is placed in the landfill. Under certain conditions, the potentially polluting characteristics of organic compounds in the recirculated leachate can be attenuated by the chemical and biological processes occurring in the landfill and, thus, substantial savings can be achieved in terms of the capital and operational expenses of treatment.

Published results indicate that a substantial reduction of the organic compounds in the leachate can occur over a short time if recirculation is employed, although many landfills that have a high rate of refuse placement have not experienced any appreciable long-term effect due to recirculation.

There are some disadvantages associated with the application of recirculation, including: 1) the potential of polluting the surrounding environment due to migration of the leachate through the sides or through the bottom of the fill, and 2) a buildup of heavy metals, salts, and other undesirable compounds in the leachate that eventually will have to be disposed.

If the landfill has two or more lifts and the lifts are capped with relatively impermeable covers, the application of recirculation should be considered very carefully. This is because intermediate covers can act as more or less impenetrable barriers, thereby leading to the accumulation of leachate on the top of the cover. Accumulation can be sufficient either to establish zones of saturated wastes, or to form water tables within the fill. Saturation of portions of the waste can result in the material prematurely reaching anaerobic conditions and, thereby, yielding large variations in the quality of the leachate that is produced. Furthermore, the generation of areas of saturated waste above the intermediate cover can also lead to the leachate migrating to and emerging from the sides of the landfill.

2.9.6.3 Treatment

In the event that minimisation, evaporation, or recirculations are not viable alternatives, the next viable alternative is to implement some type of treatment system. The type and capacity of the treatment system are functions of the quantity and characteristics of the leachate. As opposed to municipal wastewater, the quantity and characteristics of leachate undergo substantial variations over time. Furthermore, climatic conditions also have an impact on the quantity and quality of the waste liquid.

There are various alternatives available for the treatment of leachate. Most of these alternatives have been adapted from conventional methods of wastewater treatment. Some of the processes include physical, chemical, and/or biological steps. There are very few full-scale leachate treatment systems in operation in developing countries. A conventional design in industrialised countries would be as follows: 1) pre-treatment, 2) physical and/or chemical treatment, and 3) biological treatment. The pre-treatment step, as its name implies, generally involves a series of processes designed to prepare the leachate for further processing. Pre-treatment may include: screening, sedimentation, and pH adjustment. The second stage of the treatment includes several steps designed to remove heavy metals, suspended solids, and colour. These processes may involve flocculation, sedimentation, sand filtration, and others. The third and final general step may include a series of basically biological processes. These processes are designed to remove the organic loading (BOD and COD), as well as ammonia, from the leachate. Typical processes include: oxidation ponds, aerated lagoons, activated sludge, and others. Following are brief descriptions of some of these processes. Complete descriptions of these processes can be found in standard texts on wastewater treatment.

Biological treatment

There are several characteristics of the leachate that will dictate the advisability of using some type of biological treatment. Some of the more important characteristics involve the relatively high organic and inorganic loads, fluctuations in the quantity, changes in the concentration of organic matter, and others. One relatively simple approach to evaluating the biodegradability of leachate is by checking the ratio of BOD to COD. If the ratio is about 0.5, then it may be possible to treat the leachate biologically. On the other hand, if the BOD: COD is less than 0.5:1, a biological system may not be appropriate as a treatment process. Ratios of BOD to COD over the course of decomposition of MSW can range from an average of about 0.6 during the acid phase to about 0.1 during the methanogenic phase.

Leachate contains several compounds that, in some concentrations, are known to have a negative impact on the performance of biological treatment processes. Some of these compounds are: chlorides, sulphides, ammonia, metals, and others.

Even though biological treatment processes can withstand most of the characteristics of leachate, if inhibition is observed during tests, it may be necessary to include a pre-treatment stage in the overall treatment process.

A. Aerated lagoons

Aerated lagoons are applicable to landfills that generate relatively small quantities of leachate. In this case, the leachate is transported to a lagoon, where it is aerated by mechanical means (surface aerators or air pumps). Both aeration and the mixing brought about by the aeration enhance the degradation of organic substances by introducing atmospheric oxygen into the leachate. Retention times on the order of 10 days have produced relatively large reductions in the concentrations of BOD and COD.

B. Activated sludge

This particular process is similar to the aerated lagoons excepting that, in this case, a certain percentage of the sludge produced in the process is recycled. As such, a settling tank is needed in the system.

C. Facultative ponds

Facultative ponds are used to treat various types of wastewaters. The ponds generally are between 1 and 1.5 m deep and are not aerated by artificial means. In the process, the top layer of the pond behaves as an aerobic lagoon due to wind aeration and the oxygen generated by algae. On the other hand, the bottom layer is not impacted by the conditions at the surface and thus becomes anaerobic. Facultative ponds typically remove ammonia-nitrogen through nitrification processes.

Properly designed aerobic lagoons and facultative ponds may be suitable for leachate treatment in a number of developing countries.

D. Other biological processes

In addition to the processes described in the preceding paragraphs, there are several other alternatives for the biological treatment of leachate. Some of the processes include: anaerobic digestion, anaerobic lagooning, and anaerobic filters. In general, aerobic processes require relatively long detention times in order to be effective. Aerobic processes remove ammonia-nitrogen by nitrification or by conversion to biomass. Anaerobic treatment processes, on the other hand, probably are most applicable as a pre-treatment process since these types of processes do not remove ammonia and the effluents generally have a relatively high turbidity.

Reverse osmosis

The application of reverse osmosis (RO) is relatively new in the solid waste management field. In the process, the liquid to be treated is forced, at high pressures, through membranes. The membranes retain impurities and a treated effluent is discharged. Due to the characteristics of the leachate, membrane fouling has been a common problem. Development of new types of membranes is addressing some of these problems. If RO is going to be used in the treatment of leachate, it is recommended that the leachate undergo some form of pre-treatment in order to reduce membrane fouling and to prolong the useful life of the system.

2.9.6.4 Environmental monitoring

Ultimately, the rationale for monitoring is to detect adverse impacts of the landfill on the adjacent air, water, and soil environments so as to be able to take the remedial measures needed to counteract the impacts. The process consists of: 1) establishing baseline environmental data and characterising the nature, extent, and magnitude of the impact; and 2) developing a remedial course of action. Impacts are indicated and identified by differences between the pre-landfill and post-landfill qualitative and quantitative characteristics of the air, water, and soil environments, or by the existence of gradations in quality and quantity with respect to proximity to the fill. Programs and methods for monitoring can range from minimal to quite extensive in terms of extent, complexity, type, and costs. The minimal category would be sufficient for situations in which the need for monitoring does not warrant an extensive program.

a. Ground Water

According to the general principles mentioned in the preceding paragraph, impact on groundwater quality can be evaluated on the basis of difference between groundwater quality (e.g., pH; dissolved solids concentration; chemical composition; and presence, identity, and concentration of microorganisms before and after construction and completion of the fill). Impact of an existing fill on groundwater flowing under and around the fill can also be evaluated on the basis of difference between the quality of the groundwater before it reaches the vicinity of the fill and after it has moved beyond the fill. Estimates depending upon groundwater flow pre-suppose aknowledge of the direction and velocity of the groundwater flow.

Potential impact on groundwater quality can be estimated on the basis of the composition and quantity of leachate generated in the fill. Knowledge of leachate composition and rate of production would also be of use in the identification of contaminants attributable to the landfill and in predicting the intensity of the contamination. To obtain such knowledge, it is necessary that the fill be provided with a leachate collection and sampling system. The problem is that in developing nations, such installations are rare and the fund of accumulated data under controlled conditions is sparse. The applicability of leachate data collected for landfills in industrialised countries must be analysed prior to considering them representative of a given location in a developing country. If a leachate collection system is available, then monitoring would consist of measuring rate of leachate production and analysing the leachate for items of interest. Examples of such items are physical characteristics, the identity and concentration of toxic chemicals and chemical constituents adverse to water quality, and pathogenic organisms.

a1. Monitoring wells

Because sampling (collection and analysis) is a key element in a groundwater monitoring program, the method of sampling must be carefully considered. In this connection, networks of monitoring wells play an important role. The extent and sophistication of this network are determined in part by the purpose of the program and by the economic and technological resources of the region that is to be served by the network. With regard to purpose, a monitoring well network for gross groundwater quality indicators differs drastically from wells intended for detecting toxic organic compounds or heavy metals. The wells must be installed at proper horizontal and vertical positions near the landfill.

Appropriate methods for installing the wells are determined on the basis of anticipated nature of subsurface aquifer materials, site accessibility, availability of drilling water, desired diameter and depth of the well, nature of subsurface contaminants, and economic and time constraints. A list and evaluation of the many methods may be found in "Guidelines for the Land Disposal of Solid Wastes".

Of the various applicable criteria, all wells should, at least, meet the following two criteria: 1) water must flow freely into the well; and 2) downward migration of surface water or upward migration of undesired groundwater to the well-intake zone must be prevented. Basic elements in the design of monitoring wells are the casing, filter pack, seal, annulus backfill, and grouting. The elements are indicated in Figure 2.8. Installation is completed by well development. Well development accomplishes two tasks: 1) the well is cleared of foreign materials introduced during drilling, and 2) the natural formation adjacent to the well screen is restored. Development may be accomplished by way of bailing, pump surging, air lifting, and combined air lifting and bailing.

Among the several methods for drilling a monitoring well are hand-augured boring, auger drilling, mud-rotary drilling, air-rotary drilling, and cable-tool percussion drilling. Of these methods, hand-augured boring is the least expensive. However, it is best suited for shallow borings (less than 4 m deep) that are only 5 to 15 cm in diameter. Auger drilling is suitable for depths of about 45 to 50 m.

a1.2. Collection and analytical methods

With the use of the installed and developed wells, it is possible to obtain samples that are chemically representative of the water taken in by the well. Consequently, attention must be directed to: 1) the physical extraction of the water from the well, 2) the preservation of the chemical integrity of the sample in transit to the place where it will be analysed, and 3) the attainment of analytical results that are accurate and have a high degree of precision.

Among the several means of collecting samples from the wells are: down-hole collection devices; suction-lift, positive displacement, gas-lift, and gas-drive methods; gas squeeze or bladder pumps; and jet or venturi pumps.

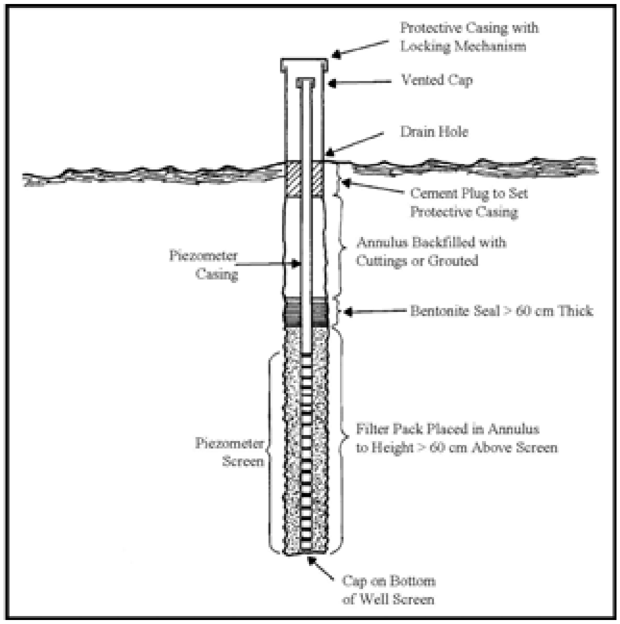


Figure 2.8 Groundwater monitoring well (Diaz, L.F., G.M. Savage, and C.G. Golueke, 1982)

The following water quality parameters are recommended for analytical determination and monitoring due to the fact that the presence of them is a potential indicator of contamination by landfill leachate:

• pH,
• specific conductance,
• alkalinity,
• biological oxygen demand,
• chemical oxygen demand,
• nitrate/nitrite nitrogen,
• total (Kjeldahl) nitrogen,
• chloride,
• iron,
• sodium,
• manganesedium, and
• sulphate.

The pH level and specific conductance should be determined in the field, while the other sample analyses can be carried out by laboratories at universities or those that typically analyse the characteristics of potable water. The recommended frequency of sample collection and analysis is at least twice per year.

In addition to the water quality parameters listed above, analyses and monitoring for other metals and some organic chemicals should be considered for the groundwater testing program depending on the availability of financial resources and analytical testing capability. The additional lists of parameters are listed below:

- arsenic,
- barium,
- cadmium,
- chromium,
- mercury,
- lead,
- selenium,
- total phenols, and
- volatile organic compounds.

These parameters can be monitored less frequently than twice per year and depending on site-specific conditions.

b2. Surface water

The necessity or advisability of monitoring surface water quality depends upon: 1) the proximity of the landfill to surface water, and 2) the drainage patterns between the fill and the surface water. The approach followed in the selection of sampling stations, equipment, and procedures should be similar to the approach used in the selection process for groundwater monitoring. The stations should be located in areas that have the greatest potential for contamination. These areas include the pathways through which leachate can enter a surface body of water. Flow patterns and seasonal variations should also be taken into consideration. Equipment used for sampling surface water and the methods used to analyse the samples should be consistent with procedures selected for testing groundwater samples.

2.10. A case study in Malaysia in 1990

It was in Malaysia when the first low-cost re-circulatory semi-aerobic landfill was developed in 1990. It was the first and the successful technology transfer of semi-aerobic landfill in a developing country. A comparison on leachate quality of semi-aerobic and anaerobic landfills in Malaysia is shown below:

Table 2.15: Leachate quality of semi-aerobic and anaerobic landfills in Malaysia

Parameter	Anaerobic	Semi-aerobic
pH	7.70	7.30
DO	0.28	0.42
Temperature	30.30	32.90
Conductivity	36.60	21.90
BOD	5293	117
COD	9650	4020
Zinc	0.03	0.01
Iron	6.41	2.91

2.11 Semi-aerobic landfill construction at Matuail

2.11.1 Construction of Boundary Leachate Drainage System

Boundary leachate drainage system was constructed to collect the leachate of the existing landfill and carry it to the 1st leachate treatment pond. The construction started from the south-east corner of the on-going landfill operational area. Since the system was designed to ensure gravity flow and removing soft soil below the system, the depth of excavation reached nearly 3m from the existing concrete road surface. It made the construction very difficult and stability of the adjacent concrete road was in jeopardy at some locations.

At first the waste and soft soil were removed from the route using an excavator. Hard soil was also removed where needed to provide the required slope. Leachate and storm water accumulated in the trench was pumped out for proper construction of the drainage system. Sand filling was carried out in 150mm layers where required and each layer was compacted manually to obtain a stable base. Then construction debris (6mm-40mm size) was placed and compacted to obtain a 200mm layer. Above it the 3-line perforated UPVC pipe was placed with the openings at the top. The construction debris was placed surrounding the lowest quarter depth of the pipe. Then 20mm-50mm screened gravel was placed in the trench up to at least 300mm height above the crown of the pipe. The lateral thickness of the gravel pack was at least 200mm. Old waste was placed in the trench as per supplied drawing and was compacted manually. A clay layer of 500mm in thickness was placed over the compacted old waste. Brick manholes of adequate size were placed at 30m interval. A view of the under construction boundary leachate drainage system is shown in figure 2.8.

Figure 2.9: Boundary Lechate Drainage System under Construction (BRTC, 2008)

At some locations of deep trench, the soil below the adjacent concrete road was displaced due to movement of heavy equipment. Sand bags were placed at those locations to prevent collapse of the road as shown in figure 2.9.

Figure 2.10: Prevention of collapse of Road (BRTC, 2008)

2.11.2 Construction of Semi-Aerobic System of Waste Decomposition

The construction of semi-aerobic system of waste decomposition was initiated when the existing landfill operational area attained a waste dump height of approximately 5 m above the boundary road level. At first the waste dump was excavated along the route of the main leachate pipe. The excavation was started from the south end of the route. The bottom of the trench was compacted manually to attain a stable bed. Then construction debris (6mm-40mm size) was placed in the trench and compacted to obtain a final depth of 300mm. A down slope of 0.5% of the compacted bed was ensured. Then the main leachate pipe (perforated uPVC pipe of 400 mm in diameter, no. of hole line is 5) was properly placed on the bed. Then screened brick chips (20mm-50mm size) were placed in the trench up to a height of 1 m above the compacted bed. Junction boxes were constructed at 40m-50m intervals to connect the main leachate pipe, branch leachate pipe and gas vent pipe. Then trenches were excavated to install branch leachate pipes. The bed of each of the trenches was compacted manually and proper slope of the bed was ensured. Then construction debris (6mm-40mm size) was placed in the trench and compacted to obtain a final depth of 300mm. After that perforated UPVC pipe (200mm in diameter, no. of hole line is 4) was placed properly on the compacted base. Crushed brick chips (20mm-50mm) were placed in the trench for a depth of 300 mm. Gas vent pipe (UPVC pipe 200mm in diameter, no. of hole line is 4) was then connected to the branch leachate pipe at an interval of 35m-45m. The upper end of the leachate pipe was then connected to an air inlet pipe of 200mm in diameter. The lower end of the main leachate pipe was then connected to a boundary leachate manhole ensuring free fall of the collected leachate and enough air circulation.

Each gas vent pipe was gravel packed using crushed brick chips (20mm-50mm size). The thickness of the pack was 300 mm and confined by suitable bamboo casing. The old waste was used for back filling of the trenches. A view of the under construction semi-aerobic system is presented in figure 2.10. The height of the vent pipe was gradually increased as the waste dump attained higher level.

Figure 2.11: Semi-Aerobic System under Construction (BRTC, 2008)

It was observed that the remaining open drains were constructed having 150 mm wall and bottom slab thickness. To arrest further deflection of the completed drains, lateral struts were place inside the drain. Moreover, lateral struts were also provided in the new open drains for additional safety. For safety, at some places, covered drain and storm sewerage system were constructed. A view of the completed storm water drainage system in front of the control area is shown in figure 2.11.

Figure 2.12: Storm Water Drainage System In front of the Control Area (BRTC, 2008)

2.12 Summary of the literature review

The release of leachate to the environment is one of the major environmental impacts related to disposal of waste. Disposed waste in landfills undergoes a series of phases where the waste is decomposed. Leachates arise as a result of the infiltration of precipitation to the interior of landfills, but at the same time water present in the wastes and released in different processes taking place in a landfill also contributes to the generation of leachates. There are several factors affecting the composition of leachates and their production. According to Johansen and Carlson the most important of these are: solid wastes composition, operation mode of a landfill, climate and hydrogeological conditions as well as those inside the landfill (biochemical activity, moisture, temperature, pH and age of landfill). The above-mentioned factors vary considerably from landfill to landfill. Leachates generated in the initial period of waste deposition (up to 5 years) on landfills have pH 3.7-6.5 that reflects the presence of carboxylic acids and bicarbonate ions. With time the leachates become neutral or weakly alkaline (pH 7.0-7.6). Landfills exploited for a long period of time give rise to alkaline leachates (pH 8.0--8.5) (TALALAJI, 1998).

The leachate contains four groups of pollutants: dissolved organic matter, inorganic macrocomponents, heavy metals, and xenobiotic organic compounds. Existing data show that the composition of leachate is highly dependent on the degradation stage of the waste. In the acid phase, concentrations are generally higher due to enhanced formation of dissolved organic matter and release of ammonia. In the methanogenic phase, the content of dissolved organic matter significantly decreases and the composition of the organic matter changes indicated by BOD: COD ratios below 0.10. The ammonia concentration seems not to follow the same decreasing trend and may constitute one of the major long-term pollutants in landfill leachate. The content of heavy metals in the leachates is generally very low as a result of attenuating processes (sorption and precipitation) that take place within the disposed waste. Leachate contains a broad variety of xenobiotic organic compounds. A very broad concentration range for each pollutant is observed in most cases. The most frequently observed compounds are aromatic hydrocarbons and chlorinated aliphatic compounds. A landfill will in a long time frame undergo several phases in which oxygen from the atmosphere will penetrate deeper and deeper into the waste. The oxidation of residual organic matter not decomposed an aerobically, and oxidation of sulfur, nitrogen, and iron-containing compounds may lead to lower pH and higher redox potentials, which may result in enhanced long-term releases of heavy metals. However, model calculations and a few laboratory experiments suggest that the enhanced release might not occur within a time frame of several thousands of years.

The breakdown of organic compounds in wastes may occur under aerobic, anaerobic or mixed aerobic-anaerobic conditions. Degradation in aerobic or aerobic-anaerobic conditions leads to the rapid stabilization of organic components and relatively low concentrations of organic and inorganic substances in the leachates (JĘDRCZAK A., HAZIAK K, 1994). Anaerobic process of decomposition is a slow process associated with bad smell and methane gas generated may causes fire hazard in landfill. It is facilitated fermentation reactions in methanogenic phase and more reaction time available for degradation of waste increased the solubility of pollutant. In aerobic condition requires supply of oxygen to be pumped into the landfill which is a costly system in terms of construction and operation. Semi-aerobic process is involved a gas venting and perforated pipe networks system which provides circulation of air in the waste layers. Thus a rapid stabilization process occurs which reduces odor and fire hazard (Hanashima et al. 1981a). Drainage of leachate in a systematic manner reduces possibility of infiltration and controls surface and ground water pollution. It also influences to produce small amount of green house gases. As a result, leachate quality is improved and treatment cost would be less in semi-aerobic process.

The removal of leachate from a landfill can be carried out in either of two manners: by installing a pipe through the side of the fill or by placing a sloped collection pipe inside the fill. Most leachate collection systems will clog at some point in time. Consequently, manholes and vertical and/or horizontal cleanouts should be provided in strategic locations in order to conduct periodic maintenance and inspection (McGraw-Hili., Tokyo). Once the leachate is captured in a particular section of the landfill, it usually is routed to storage in tanks, vaults, or ponds. The type and size of the storage device will depend upon the quantity and characteristics of the leachate, proximity to inhabited areas, and the type of treatment required. The type and degree of treatment afforded to leachate from a sanitary landfill will have an impact on the level of pollution of any nearby groundwater and of the surrounding environment. There are several options for managing it such as evaporation (natural or forced), recirculation and recycling, discharge to an offsite wastewater treatment facility, and onsite treatment.

In Matuail landfill for collection, treatment and safe disposal of excess leachate from the landfill site; a network of perforated pipes with gravel pack system was installed within and around the waste cells for ventilation-cum-leachate collection in order to make semi-aerobic condition (Fukuoka Method). For rapid stabilization of waste with minimum odor it is to convey the excess leachate into a pond system located between old dump site and newly acquired land for landfill (BRTC, 2008). A long term operation of semi-aerobic landfill depends on proper functioning of the installed semi-aerobic system which will improve the leachate quality. A lack of routine and periodic operation and maintenance especially in wet season may cause ineffectiveness of the system. Consequently, it is absolutely necessary to introduce the large scale monitoring of toxicity of leachates flowing from municipal landfills with regard to aquatic organisms.

Chapter 3

METHODOLOGY

3.1 Introduction

Municipal solid waste management, from 2005 Dhaka City Corporation has given emphasis on introducing sanitary landfill technology rather than open dumping. A master plan was formulated by Dhaka City Corporation, with the technical assistance of Japan International Cooperation Agency (JICA) in 2005 for a target year of 2015 to make Dhaka City Clean. Under the Landfill Improvement project transforming open dump to sanitary landfill; the construction period was March 2006 to October 2007. On 3rd October 2007, Dhaka City Corporation inaugurated for the first time semi-aerobic sanitary landfill located at Matuail in Bangladesh. As a result of public awareness, solid waste collection, transportation and disposal have improved which provide mitigation of pollution of soil, surface and ground water. The study covers the leachate generated in landfill site after introducing semi-aerobic system, quality of leachate throughout the year and flow collection efficiency of leachate pipes. This chapter presents the description of the study area, sampling type, location and collection procedure, field rainfall data, and measurement of flow and estimation, laboratory analysis of various parameters of different types of collected samples.

3.2 The Study Area

Dhaka City Corporation (DCC) started crude dumping of solid wastes from Dhaka City at Matuail landfill sites from the very beginning. For leachate management, leachate collection systems have been constructed and leachate treatment system has recently been completed. Semi-aerobic system of waste decomposition has been installed at the landfill site. Aerated lagoons have been also constructed to treat the leachate (DCC, 2009). To operate the leachate treatment system efficiently, it is essential to know about the variations in the quantity and quality of leachate throughout the year. Moreover, it is important to know the effectiveness of the installed semi-aerobic system on the leachate quality. The obtained data will be very useful in the design of future sanitary landfills in similar environments. Hence, it is high time to undertake a study for a detail investigation of the quality and quantity of leachate at Matuail sanitary landfill.

Aerial image of the study area and layout diagram of sanitary landfill have been given in Figure 3.1 aerial image explains the surrounding physical condition of existing landfill site. The site was surrounded by low laying marshy land; north side of the existing landfill was acquired for future extension. A private housing project also located at south side and other two sides, east and west were used as fishery and agricultural purposes respectively. So the surroundings of study area were more vulnerable to soil and water pollution which detrimental to public and aquatic life. The figure 3.2 describes a sanitary landfill design plan for different facilities such as old waste dumping depot, leachate pipe networks, gas vent pipe system, leachate flow direction, internal access roads, boundary completed roads, landfill control and hospital waste management facilities, car wash pool, leachate treatment pond and acquired land for future uses at Matuail.

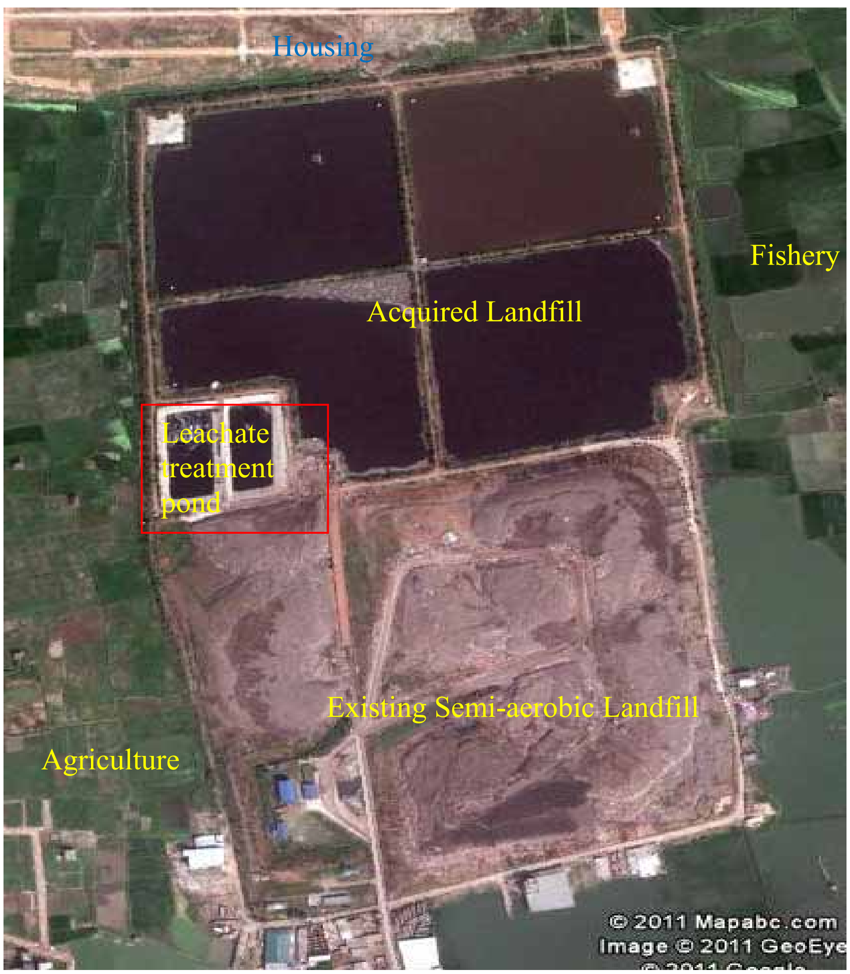


Figure 3.1: Aerial image Google Earth satellite image (2011)

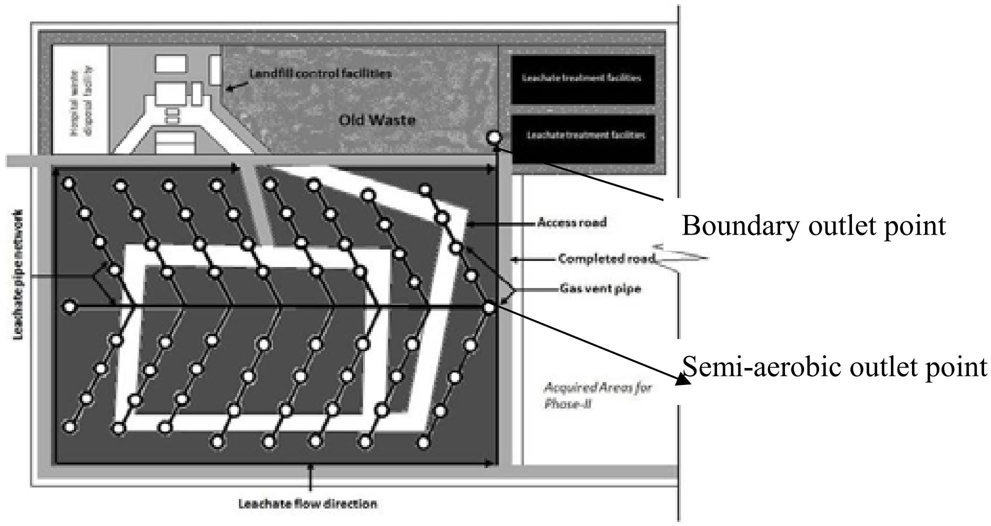


Figure 3.2: Layout plan of Sanitary Landfill (DCC,2008)

3.3 Types of sample and sampling location:

Leachate samples were collected in dry and wet period from two different systems known as semi-aerobic and the Boundary collection system. Two types of samples were collected one from semi- aerobic layer collection pit (the discharge point of semi-aerobic system) and another from the north-east pit of the Boundary layer (boundary collection system) in each month.

3.3.1 Method of Sample Collection:

Leachate samples were collected for a number of months started from April 2008 to April 2009 which cover both summer and rainy seasons. Two types of samples were collected one from semi-aerobic system collection pit (the discharge point of semi-aerobic system) and another from Boundary system (the north-east pit of the Boundary layer) in each month respectively. For collection of leachate samples a bucket was hold below the two different outlet points and then stored in a pet bottle. After that pet bottles were marked with different identification names presenting drainage layer name, date and time of collection. After completing the sampling it was carried to BUET Environmental Engineering Laboratory for testing. In rainy days, the samples were collected both before and after the rainfall occurred depending upon field conditions. As the outlet pipe was connected temporarily to future landfill area during the construction of newly acquired area and leachate ponds, the samples collection in the month of July, 2008 was hampered due to backflow of diluted leachate to semi-aerobic system collection point from waste retention pond. At that time leachate samples were collected from outlet pit rather than outlet pipe. The method of collection of leachate at Matuail landfill site has given below with some photographs.

Figure 3.3: Method of leachate collection from semiaerobic system and Boundary system of Matuail Landfill site

3.4 Measurement of leachate flow rate

During collection of samples leachate flow rate was measured from two different outlet points. Two eight (8) litre capacity of plastic buckets were kept below outlet points for accumulation of leachate and the collection time was recorded by stopwatch in each month (depending on favorable field condition). The outlet pipe from collection pit of semi-aerobic system was connected temporarily to future landfill area during the construction of newly acquired area and leachate ponds; the rainy period in July submerged situation created overflowing the pit due to backflow of leachate hampered the flow measurement in semi-aerobic system. Besides that the leachate flow from the south direction of Boundary system could only measured as the connection pipe between semi-aerobic system and Boundary system was damaged during the time of measurement period. As both sides of the landfill area were almost same, so the total measurement of Boundary systems was considered twice of the flow measured in south direction. The flow measurement was not possible to take at night time due to lack of lighting facilities in landfill area. Frequency of measurement of flow rate and measurement during rainfall were not taken due to unfavorable climatic and field conditions. In the study the time ranges of leachate flow measurement were within 20 minutes to 6 and ½ hrs after the end of rainfall. The measurement of leachate flow rate data is given below in Table 3.1.

Table 3.1: Time record of leachate flow rate

Date	Daily Flow (m^3/hr)			
	Semi-aerobic system	Boundary system	End of Rainfall Time	Time of Flow Measurement
19-May-08	2.10	3.90	1:50:00 AM	6:10:00 AM
22-May-08	5.50	9.34	2:49:00 PM	4:35:00 PM
26-May-08	4.62	7.60	4:39:00 PM	5:34:00 PM
29-May-08	8.60	9.12	8:10:00 AM	10:15:00 AM
18-Jun-08	9.50	13.60	7:22:00 AM	9:40:00 AM
20-Jun-08	8.18	11.46	5:22:00 PM	5:55:00 PM
30-Jun-08	6.80	7.00	11:26:00 AM	1:20:00 PM
09-Jul-08	5.10	9.70	8:22:00 AM	10:55:00 AM
15-Jul-08	8.53	13.32	9:35:00 AM	10:15:00 AM
20-Jul-08	7.86	12.46	1:50:00 PM	3:44:00 PM
03-Aug-08	5.67	8.78	3:20:00 PM	5:10:00 PM
20-Aug-08	7.49	9.60	3:32:00 AM	9:34:00 AM
27-Aug-08	10.50	16.42	6:55:00 PM	7:18:00 PM
18-Sep-08	3.30	6.40	12:20:00 PM	2:35:00 PM
27-Sep-08	6.67	9.70	9:15:00 PM	9:45:00 PM
03-Oct-08	5.24	7.52	6:30:00 AM	8:44:00 AM
06-Oct-08	6.80	8.26	9:45:00 AM	10:20:00 AM
9-Nov-08	1.85	2.20	--	--
17-Nov-08	1.98	3.60	--	--
18-Dec-08	1.82	3.10	--	--
29-Dec-08	1.65	3.04	--	--
8-Jan-09	1.70	2.90	--	--
17-Jan-09	1.50	2.60	--	--

3.5 Recording Rainfall Data

Field rainfall data was recorded at landfill site to find out production of leachate. In this study an indigenous stainless steel made rain gauge (18 in x 8 in) inside with a 2(two) liter capacity of plastic beaker was used. Site selection for rain gauge setup was important to record rainfall data with minimum disturbance. Therefore, roof of the sub-station of Matuail landfill site was selected. The rain gauge was set at center of the roof with brick wall support for wind protection and rainfall data were recorded in daily for wet season. The gauge was set at the end of March, 2008 and rainfall occurred from the month of May, 2008.

The beginning and ending time of rainfall were recorded by using stop watch to find out the duration of each rainfall data. Volumetric measurement of rainfall in milliliter was taken from the cylinder. When duration and intensity of rainfall was more, rain water was spilled out from the cylinder to the outer cylinder. Hence, total volume of rainfall was taken as summation of the volume of the cylinder and water present in the outer cylinder. It was difficult to record data at night for worse weather condition, and then it was measured in morning that might give some erroneous readings. The daily recorded rainfall data photographs of the rain gauge was used in landfill site has shown below.

Rain Gauge, Plastic Beaker (2 ltr), Funnel

S .S Cylinder(18 in x 8 in) with Funnel

Rain Gauge and placement platform located at roof of Substation room

Figure 3.4: Rain gauge

Table 3.2: Rainfall Data

					At Matuail Landfill site
S.l. No	Date	Starting time	Ending time	Duration (min)	Rainfall (mm)
1	18-May-08	10:45:00 PM	12:30:00 AM	105	28.03
2	19-May-08	11:30:00 PM	1:50:00 AM	140	1.27
3	22-May-08	2:16:00 PM	2:49:00 PM	33	4.94
4	24-May-08	4:33:00 PM	4:49:00 PM	16	3.38
5	24-May-08	5:25:00 PM	5:57:00 PM	32	4.62
6	25-May-08	12:51:00 PM	1:24:00 PM	33	22.61
7	25-May-08	11:37:00 AM	12:42:00 PM	65	49.84
8	26-May-08	1:50:00 PM	4:39:00 PM	169	17.83
9	26-May-08	2:00:00 AM	2:17:00 AM	17	0.64
10	26-May-08	3:01:00 AM	3:47:00 AM	46	5.25
11	29-May-08	7:38:00 AM	8:10:00 AM	32	9.24
12	18-Jun-08	4:10:00 AM	7:22:00 AM	192	56.05
13	19-Jun-08	6:21:00 AM	7:05:00 AM	44	13.06
14	19-Jun-08	7:02:00 PM	8:22:00 PM	80	23.73
15	19-Jun-08	2:09:00 AM	2:49:00 AM	40	11.46
16	20-Jun-08	3:31:00 PM	5:22:00 PM	106	40.76
17	22-Jun-08	12:42:00 AM	12:59:00 AM	17	1.27
18	30-Jun-08	7:30:00 AM	8:22:00 AM	52	2.55

S.l. No	Date	Starting time	Ending time	Duration (min)	Rainfall (mm)
19	30-Jun-08	10:16:00 AM	11:26:00 AM	70	7.64
20	30-Jun-08	8:30:00 PM	9:30:00 PM	60	13.54
21	30-Jun-08	10:25:00 PM	11:15:00 PM	50	26.75
22	01-Jul-08	6:50:00 AM	9:25:00 AM	95	37.90
23	01-Jul-08	9:40:00 AM	3:15:00 PM	335	21.34
24	02-Jul-08	7:26:00 AM	9:10:00 AM	104	15.13
25	02-Jul-08	11:40:00 AM	3:22:00 PM	222	2.87
26	03-Jul-08	7:22:00 AM	2:37:00 PM	435	62.74
27	04-Jul-08	11:35:00 AM	1:15:00 PM	100	1.27
28	09-Jul-08	1:15:00 AM	8:22:00 AM	427	68.79
29	10-Jul-08	10:25:00 AM	11:00:00 AM	35	5.73
30	11-Jul-08	9:35:00 AM	11:20:00 AM	95	0.64
31	11-Jul-08	4:15:00 PM	4:50:00 PM	35	0.96
32	12-Jul-08	8:20:00 AM	9:20:00 AM	60	5.10
33	12-Jul-08	3:20:00 AM	4:30:00 AM	70	16.40
34	14-Jul-08	4:25:00 AM	7:45:00 AM	200	28.50
35	15-Jul-08	1:50:00 AM	2:45:00 AM	55	41.08
36	15-Jul-08	5:55:00 AM	6:55:00 AM	60	26.91
37	15-Jul-08	7:00:00 AM	9:35:00 AM	155	35.67
38	15-Jul-08	2:45:00 PM	4:10:00 PM	85	28.34
39	20-Jul-08	11:14:00 AM	1:50:00 PM	156	37.58
40	20-Jul-08	4:45:00 PM	5:15:00 PM	30	19.90
41	01-Aug-08	5:30:00 AM	12:50:00 PM	440	54.94
42	03-Aug-08	1:30:00 PM	3:20:00 PM	110	13.38
43	09-Aug-08	6:16:00 AM	12:55:00 PM	399	32.64
44	09-Aug-08	8:35:00 PM	11:20:00 PM	165	22.77
45	10-Aug-08	9:25:00 AM	3:10:00 PM	345	31.21
46	11-Aug-08	11:20:00 PM	6:45:00 AM	445	17.83
47	12-Aug-08	7:10:00 AM	9:35:00 AM	145	10.19
48	14-Aug-08	6:45:00 AM	9:20:00 AM	155	38.85
49	14-Aug-08	4:10:00 PM	5:35:00 PM	85	10.19
50	14-Aug-08	11:20:00 PM	1:30:00 AM	130	7.64
51	15-Aug-08	8:20:00 AM	10:15:00 AM	105	18.15

S.l. No	Date	Starting time	Ending time	Duration (min)	Rainfall (mm)
52	15-Aug-08	9:10:00 PM	11:50:00 PM	160	27.39
53	16-Aug-08	6:25:00 AM	10:55:00 AM	270	35.67
54	16-Aug-08	3:45:00 PM	5:50:00 PM	125	19.59
55	16-Aug-08	4:15:00 AM	7:20:00 AM	185	28.34
56	18-Aug-08	5:30:00 PM	7:40:00 PM	130	17.83
57	18-Aug-08	9:15:00 AM	12:15:00 PM	180	21.34
58	19-Aug-08	5:10:00 AM	9:10:00 AM	240	51.59
59	20-Aug-08	1:35:00 AM	3:32:00 AM	107	24.84
60	23-Aug-08	4:20:00 PM	5:15:00 PM	55	20.54
61	25-Aug-08	8:10:00 AM	11:50:00 AM	220	35.67
62	27-Aug-08	5:20:00 PM	6:55:00 PM	95	54.78
63	28-Aug-08	7:25:00 AM	9:10:00 AM	105	10.19
64	29-Aug-08	1:20:00 AM	2:30:00 AM	70	6.37
65	29-Aug-08	7:45:00 AM	3:20:00 PM	455	38.06
66	15-Sep-08	4:20:00 AM	9:45:00 AM	325	16.40
67	17-Sep-08	9:27:00 PM	11:05:00 PM	98	22.61
68	18-Sep-08	10:30:00 AM	12:20:00 PM	110	6.69
69	26-Sep-08	6:50:00 PM	7:30:00 PM	40	37.26
70	27-Sep-08	8:20:00 PM	9:15:00 PM	55	13.38
71	28-Sep-08	6:35:00 AM	11:30:00 AM	295	23.09
72	28-Sep-08	8:00:00 PM	7:50:00 AM	710	41.08
73	01-Oct-08	6:30:00 AM	12:13:00 PM	343	19.75
74	03-Oct-08	10:25:00 PM	6:30:00 AM	485	64.49
75	04-Oct-08	9:55:00 AM	1:05:00 PM	190	15.29
76	05-Oct-08	2:40:00 PM	5:25:00 PM	225	46.82
77	06-Oct-08	6:10:00 AM	9:45:00 AM	215	57.80

3.6 Quantitative analysis of leachate flow

For a number of rainy days, the recorded rainfall data were used to estimate leachate generation and leachate flow was measured in two locations, the discharge point of semi-aerobic system and the entrance of leachate pond of boundary leachate collection system. The data were used to compare the variation of leachate flow and find out the graphical relationship of leachate flow with rainfall intensity. The variation of leachate generation and observed flow rates are shown below:

Table 3.3: Daily Leachate Flow Rate with Rainfall Intensity

Date	Daily Flow (m^3/hr)			
	Rainfall intensity I(mm/hr)	Flow In Semi-aerobic system	Flow In Boundary system	Total Flow
19-May-08	0.55	2.10	3.90	6.00
22-May-08	8.98	5.50	9.34	14.84
26-May-08	6.14	4.62	7.60	12.22
29-May-08	17.33	8.60	9.12	17.72
18-Jun-08	17.52	9.50	13.60	23.10
20-Jun-08	23.07	8.18	11.46	19.64
30-Jun-08	13.06	6.80	7.00	13.80
09-Jul-08	9.67	5.10	9.70	14.80
15-Jul-08	22.31	8.53	13.32	21.85
20-Jul-08	18.54	7.86	12.46	20.32
03-Aug-08	7.30	5.67	8.78	14.45
20-Aug-08	13.93	7.49	9.60	17.09
27-Aug-08	34.60	10.50	16.42	26.92
18-Sep-08	3.65	3.30	6.40	9.70
27-Sep-08	14.60	6.67	9.70	16.37
03-Oct-08	7.98	5.24	7.52	12.76
06-Oct-08	16.13	6.80	8.26	15.06
9-Nov-08	--	1.85	2.20	4.05
17-Nov-08	--	1.98	3.60	5.58
18-Dec-08	--	1.82	3.10	4.92
29-Dec-08	--	1.65	3.04	4.69
8-Jan-09	--	1.70	2.90	4.60
17-Jan-09	--	1.50	2.60	4.10

3.7 Laboratory Analysis of Leachate Quality

Collected leachate samples were analyzed in the Environmental Engineering Laboratory of Civil Engineering Department of BUET to determine their characteristics.

3.7.1 Analysis of leachate samples

Leachate samples were collected from upper layer collection pit known as the discharge point of semi-aerobic system and Boundary system (boundary collection system) known as the entrance of leachate pond in each month respectively from Matuail landfill site. The samples were analysed to determine the concentration of pH, Temperature, Electrical Conductivity (EC), Alkalinity, Cl^- , NH_3-N, BOD_5, COD, DO and common metal ions Cr, Cd, Pb, Zn, Ni and Cu. In this study, pH was measured using pH meter and Temperature and EC (Electric conductivity) were measured by EC (Electric conductivity) meter. Alkalinity was measured by titration. Chloride (Cl^-) was determined by Mohr Method and COD, NH_3-N were measured with Portable Spectrophotometer (MODEL- HACH, DR4000U).

BOD_5 test was conducted by an empirical test in which standardized laboratory testing procedures were followed to determine the oxygen requirements of leachate.

The concentration of heavy metals such as Cr, Cd, Pb, Zn, Ni, Cu and some dissolved metals such as Na, K were determined by Atomic Absorption(flame) Spectrophotometer(Shimadzu Model No. AA680). Photographs of some of the laboratory equipments that were used in lab tests have given below.

Atomic Absorption (flame) Spectrophotometer (Shimadzu Model No. AA680).

Portable Spectrophotometer (MODEL- HACH, DR4000U).

EC (Electric conductivity) meter.

COD Digester

Figure 3.50: Laboratory test equipments

Chapter-4

Results and Discussion

4.1 Introduction

The assessment of leachate quantity and quality is important for monitoring the effectiveness of semi-aerobic system for a long-term landfill operation and leachate treatment. To secure long-term dewatering of landfills and reduce treatment costs it is necessary to know the seasonal variations of leachate quantity and quality. In the study it was observed the contribution of precipitation for leachate production and collection efficiency for leachate pipes. The rainfall-flow relationship was established by linear regression analysis. Leachate containing organic, inorganic and heavy metal contents were also analyzed by the laboratory test of leachate samples both in semi-aerobic and boundary system. The test results and discussion have been presented in the following sections of this chapter.

4.1.1 Measurement of Rainfall Intensity

The daily rainfall data was recorded by a rain gauge at Matuail landfill site for the period of May, 2008 to October, 2008. The rainfall data have presented in Table 3.2 in chapter 3.

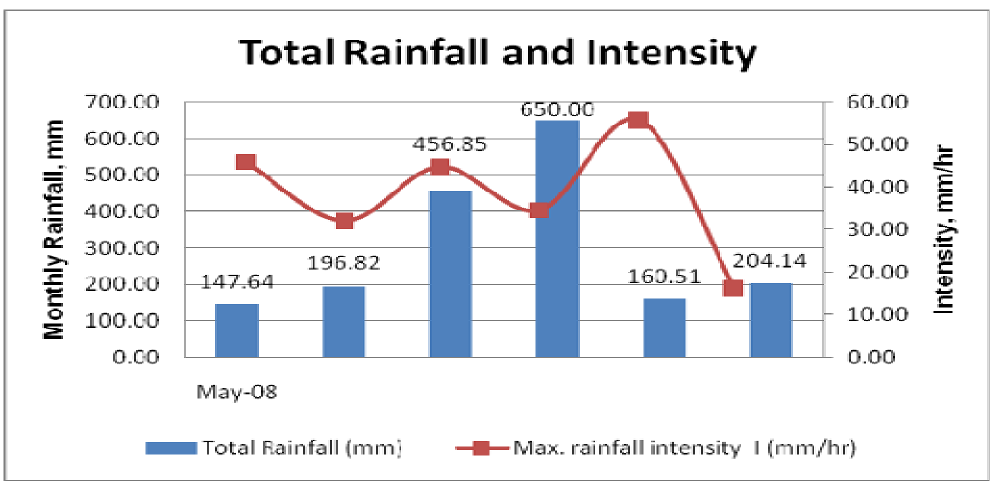
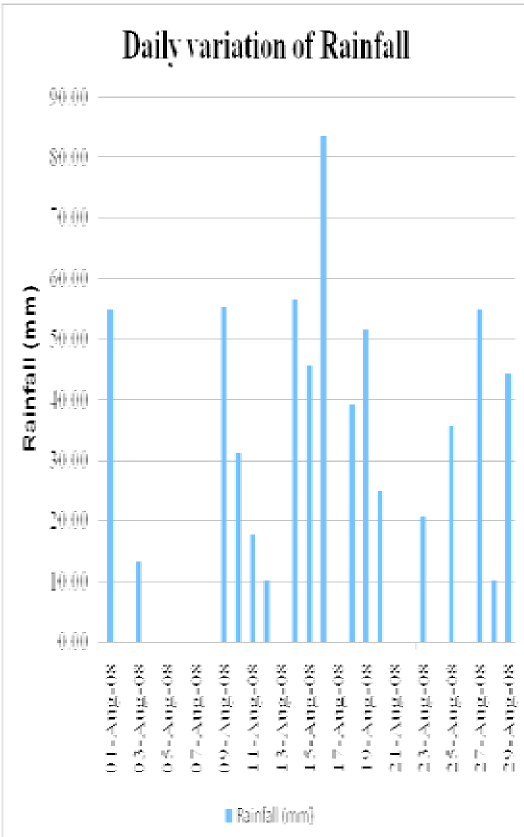


Figure 4.1: Variation of Monthly rainfall and Maximum intensity.

In the study it was observed that the total rainfall was found 1816 mm for the six month of pre monsoon and monsoon period. In july and august most of the rainfall was occurred. The contributions of rainfall were found in july 25 percent and in august 36 percent of the total rainfall. The maximum rainfall was recorded 650 mm in august and the rainfall intensity was 34.60 mm/hr. But the maximum intensity of rainfall was occurred in September, 2008 and the value was 55.89 mm/hr. Daily variation of rainfall was also observed and for the month of august 2008, it was seen that on 16th august found maximum rainfall and 27th august the rainfall intensity was maximum throughout the month. The data of daily variation of rainfall are shown below:



Day	Rainfall (mm)	Duration (min)
01-Aug-08	54.94	440
03-Aug-08	13.38	110
09-Aug-08	55.41	564
10-Aug-08	31.21	345
11-Aug-08	17.83	445
12-Aug-08	10.19	145
14-Aug-08	56.69	370
15-Aug-08	45.54	265
16-Aug-08	83.60	580
18-Aug-08	39.17	310
19-Aug-08	51.59	240
20-Aug-08	24.84	107
23-Aug-08	20.54	55
25-Aug-08	35.67	220
27-Aug-08	54.78	95
28-Aug-08	10.19	105
29-Aug-08	44.43	525

Figure 4.2: Variation of Daily rainfall

4.1.2 Measurement of Leachate flow rate

The leachate flow in semi-aerobic and boundary collection system was measured for both dry and rainy seasons cover the months from May, 2008 to January, 2009.

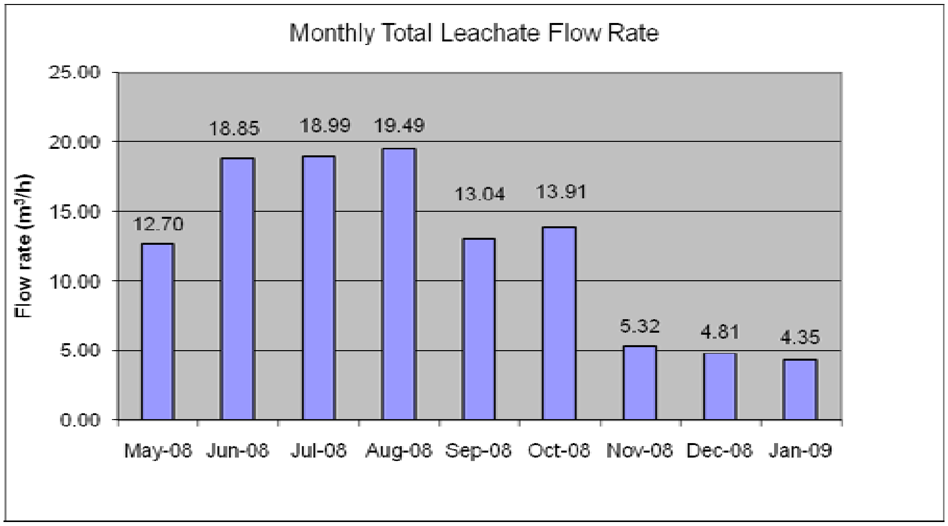


Figure 4.3: Monthly Total leachate flow

From the above graph it was found that the higher leachate flow rate occurred in June, July and August and increased with the increasing rainfall. The maximum leachate flow was 19.49m^3/hr in the month of August 08 and the collection efficiency was derived approximately 25% which was minimum among the observed data. The minimum value of leachate flow was found 4.35m^3/hr in January, 2009 during winter. The trend of flow rate declined from rainy season to dry period. During boundary leachate flow measurement the flow from the south direction was possible to measure. As the whole boundary drainage system cover the total operational drainage area, the total boundary flow was taken as twice of the measured flow. Hence the flow rates of semi-aerobic and boundary systems were combined to get the total discharge rate. The monthly variation of leachate flow rate corresponding monthly collection efficiency data has shown in Table 4.2 in Appendix I.

According to the field observations, it had been seen that some poor maintenance of leachate pipes and dumped waste into the intermediate pit in between semi-aerobic and boundary system resulted flow in slow condiion at boundary discharge point. Hence the total flow became the summation of semi-aerobic and boundary flow. The presence of iron in leachate formed a hard layer inside the pipe and during rainy season broken pipe was found in connection between semi-aerobic system and boundary system. Lack of cleaning operations it was affected the flow rate. During leachate pond construction, the future landfill facilities were using as final disposal point that posed the back flow; submerged the collection pit especially in rainy season which also affected on the actual flow measurement. A number of frequencies of flow measurement were not possible to take in regular interval due to unfavorable weather condition at site.

The flow measurement was affected by some worse situation in field that has given below.

Deposited iron shell in leachate pipe

Submerged condition of leachate pond

Poor maintenance of drainage pit

Boundary pipe under submerged condition

In the study, it was also observed that leachate drained out from the leachate pipe of semi-aerobic system in quarter full flowing during dry period and half full in rainy season. During some rainy days boundary system was remained under submerged condition. The situations were gone worse situation when adjacent leachate ponds as well as retention ponds were inundated. At that time waste disposal operation and regular cleaning activities were hampered causing stagnant of leachate in zero flow condition.

4.1.3 Variation of Leachate flow rate

Observed leachate flow rate variation with time during rainy days was analyzed in the study which was reflected by giving the performance behaviour of installed leachate collection pipes both in semi-aerobic and boundary system.

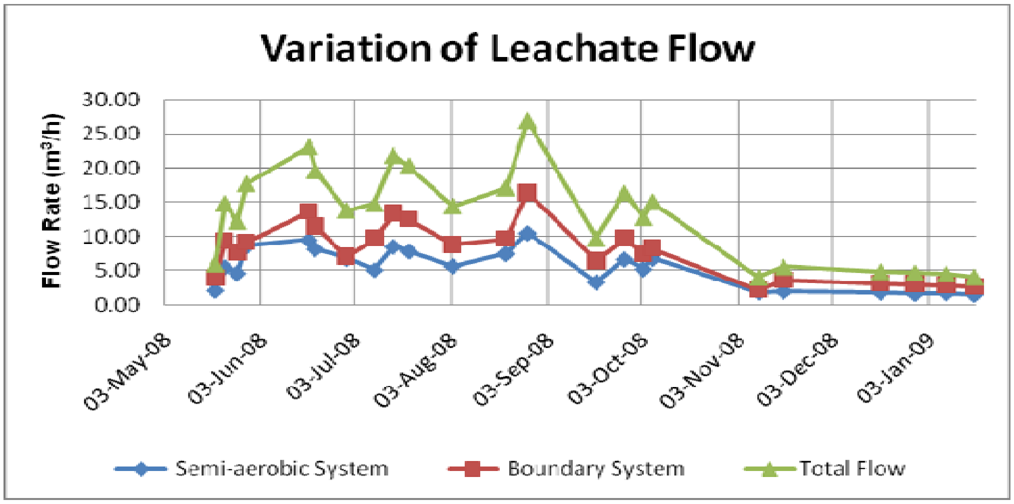


Figure 4.4: Variation of leachate flow rate

The maximum value of the total leachate flow was found 10.50m^3/hr and 16.452m^3/hr in semi-aerobic and boundary system respectively on 27th August, 2008 and the rainfall intensity occurred 34.60 mm/hr on that day under the twenty third observations. The ranges of leachate flow were 3.30 – 10.50 m^3/hr and 1.50 to 9.50 m^3/hr in semi-aerobic system and 3.90-16.42 m^3/hr and 2.2-9.12 m^3/hr in boundary system for the rainy and dry seasons respectively (Table 4.1, appendix-I) .The trend lines of leachate flow were similar to semi-aerobic and boundary system.

4.1.4 Correlation of leachate flow with change in rainfall

Two regression equations were generated in the study to correlate leachate flow with rainfall intensity. It was developed by Microsoft Excell Software. The regression analysis assumes that the relationship between rainfall and leachate flow can be approximated through a linear function. By analyzing the data and determining the results over a relatively small change in rainfall, any errors introduced through the linear approximation should be small. Based on the slope of each regression, a correlation was developed between flow and rainfall intensity for both semi-aerobic and boundary system.

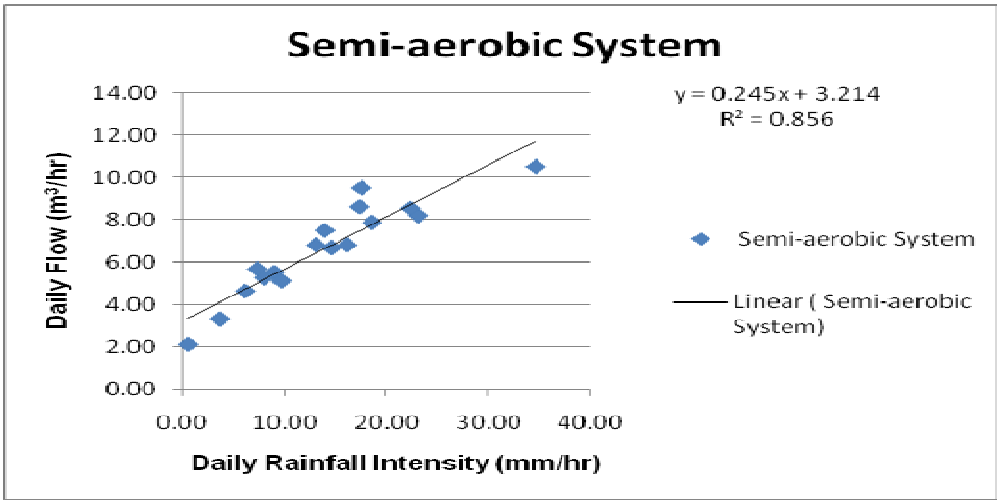


Figure 4.5: Regression of daily rainfall intensity versus flow in semi-aerobic system

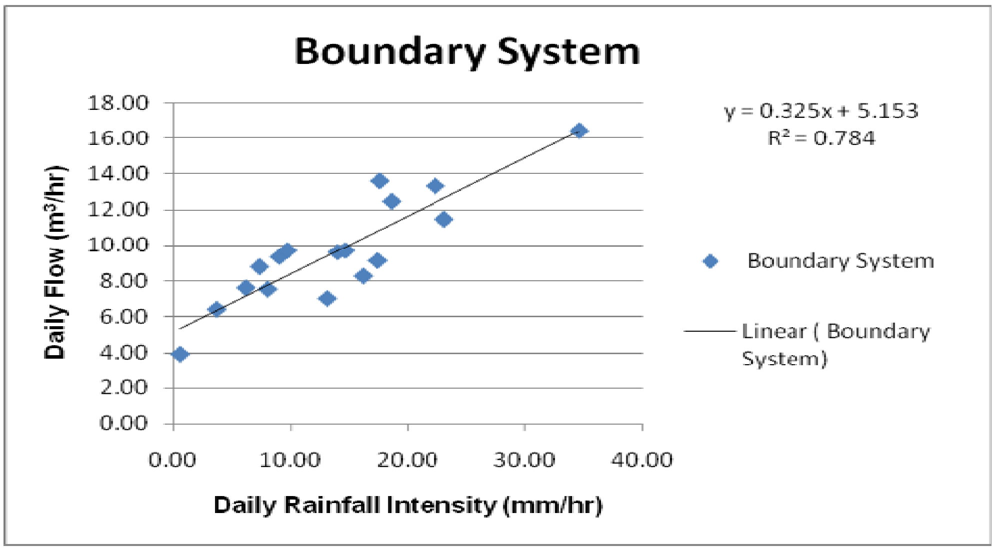


Figure 4.6: Regression of daily rainfall intensity versus flow in boundary system

The SSE (sum of squared error) value for the regression equation of semi aerobic system was 11.16 and R^2 (coefficient of determination or variance) was 85.60 percent and the SSE (sum of squared error) for the regression equation of Boundary system was 32.06 and R^2 (coefficient of determination or variance) was 78.40 percent. Less SSE value interpreted that semi-aerobic system was more linearly dependent than Boundary system for same rainfall intensity. For 1 mm/hr changes of rainfall intensity the changes of flow were 1.375m^3/hr and 0.958 m^3/hr for semi-aerobic and Boundary system respectively which determined the leachate pipes in semi aerobic layer collect more leachate. The Y intercept value of semi-aerobic system was less than the boundary system and a declining trend was found. In the study the time ranges of leachate flow measurement were within 20 minutes to 6 and ½ hrs after the end of rainfall. If the flow would measure during rainfall the regression analysis would obtain more linear characteristics and the R^2 value would also get more. From the two regression analysis it was also seen that during dry period leachate flow occurred $3.20m^3$/hr in semi-aerobic system and $5.0m^3$/hr in boundary system.

Justification of the result

Hammett (1990) determined a statistically significant decline in annual mean discharge for the Peace River at Bartow, Zolfo Springs, and the Arcadia gaging stations from the 1930s to 1984.Stream flow at Bartow, Zolfo Springs, and Arcadia was graphed against rainfall (averaged from six stations) on an annual basis for the period-of-record for each station. Simple linear regression was applied to each station to develop an equation that relates annual rainfall to flow volumes. Based on the slope of each regression, a correlation can be developed between flow and rainfall. R-squared values (coefficient of determination) were greater than 0.7 other than Bartow. The linear regression equations were found for the study that is shown below:

For Bartow, $y = 15.7x-580$, $r^2 = 0.66$
Zolfo springs, $y = 34.4x-1160$, $r^2 = 0.74$
Arcadia, $y = 61x-2075$, $r^2 = 0.77$

Comparing with the above research the regression equations obtained from the study found similar nature of result. The rainfall-flow relationship was influenced by the factors such as frequency and time of of flow measurement, coefficient of drainage area, side slope, cover condition, climatic characteristics and base flow loss through infiltration.

4.1.5 Estimation of Leachate Generation:

For Matuail Landfill

To estimate leachate the widely used water balance method was followed which derived details in chapter 2, page 46, and article 2.7.3.3.

<u>Formula of leachate production</u>

$$V_L = (P.A + V_{waste\ water}) – Runoff – Evaporation$$

<u>Area of operation landfill</u>

A_1 = 420 m*300 m = 126000 m^2 = 31.12 acre

In August 08 the total rainfall was P = 650 mm

a) Moisture from rainfall, P.A = 126000 x 650/1000 = 81900 m^3

b) Moisture from dumped waste = Vw

i) Existing condition:

Total operational measured area of landfill A = 126000 m^2

Existing waste height, H = 5 m,

Apparent bulk avg. density ϒ = 240 kg/ m^3, source- JICA study team

Vol^m = 126000* 5 = 630000 m^3

W’ = 630000*240 =1.50*10^8 kg = Overburden waste

W = 0.5 * W’ = 7.6*10^7 kg = middle lift of Overburden waste

FC = 0.6*0.55(W/ (10000+W)) = 0.329 = 33 % (33 % space fill up by water due to action of capillary force & adsorption of wastes after drain out of water by gravity force)

ii) For Collected waste

On avg. collected waste in Matuail landfill, 1450 ton/day from weigh bridge data.

Apparent bulk avg. density ϒ = 0.24 ton/ m^3,

Vol of waste V = 1450 x 31 / 0.24 m^3 = 187292 m^3

Mc of waste = The moisture content analyzed ranges from 65% to 80% for the mixture of waste on average collected from primary sources (DCC and JICA, 2005).

During carrying raw waste by Van or trolley from primary sources to secondary collection points, vibration takes places for movement of primary van accelerates compaction that reduces moisture content. Again unloading of waste to secondary point, scavenging and reloading of waste to CC (container carrier) or OT (Open truck) also reduce moisture by leaching out moisture to adjacent surface drain.

Let wastage of moisture = ½ of moisture in waste = 80 x 0.5= 40%

So the available moisture content Mc = 40%

As MC > FC then Leachate generated from waste = Mc – Fc = (40 – 33) % = 7 %

$\mathbf{V}_{\textbf{waste water}}$ = 187292x 7% = 13110 m^3

c) Runoff

<u>Runoff flow calculation:</u>

Q = (1/1000). CIA = (1/1000) x 0.10 x 20.97 x 126000 = 264.22 m^3/day

Avg. Leachate Runoff flow in both side of the Area = 2x264.22 m^3/day = 528.39 m^3/day, say 529 m^3/day for Avg. daily rainfall, I = 20.97 mm/day.

In August 08,

Total runoff volume Vr = 529 x 31 = 16399 m^3

d) Observed flow

Collected flow = 19.49 m^3/h

Vol of Observed flow of Leachate in Aug-08, Vo = 19.49 x 31x24 = 14500 m^3

e) Evaporation

In Asian countries like Malaysia, evaporation rate for agricultural land surface 3mm-5 mm/d on average (Agromet Bulletin, 2010), Here 2mm/day evaporation rate was considered for Matuail Landfill.

Evaporation vol, Ve = 2/1000 x 126000 x 31 = 7812 m^3

1) **<u>Leachate Production for rainy month of August</u>**

$$V_L = (P.A + V_{\text{waste water}}) - \text{Runoff} - \text{Evaporation}$$

$= 81900\ m^3 + 13110\ m^3 - 16399\ m^3 - 7812\ m^3$
$= 70819\ m^3$

Collection efficiency = collected leachate / generated leachate x 100%

= 14500 / 70819 x100 % = 20.47 ≈ 21 %

2) **<u>Leachate Production for dry month of December</u>**

$$V_L = (P.A + V_{\text{waste water}}) - \text{Runoff} - \text{Evaporation}$$

$V_{\text{waste water}} = 187292 \times 7\% = 13110\ m^3$
Evaporation vol, Ve = $2.2/1000 \times 126000 \times 31 = 8593\ m^3$
$= 0\ m^3 + 13110\ m^3 - 0\ m^3 - 8593\ m^3$
$= 4517\ m^3$

Collection efficiency = collected leachate / generated leachate x 100%
= 3579 / 4517 x100 % = 79.22 ≈ 80 %

For the existing operating landfill area of 31.12 acres it was estimated that the production of leachate was 70,819 m^3 where runoff was 16399 m^3 for avg rainfall 20.97 mm/day occurred in August 08 and the collection efficiency was approximately 21% and in dry season of December, 2008; leachate production was 4517 m^3 and the collection efficiency was 80%. For the month of May, June, July, September, October, November, 2008 and January 09, the leachate productions were 19,400 m^3, 24,634 m^3, 52,130 m^3, 20,218 m^3 , 24,314 m^3 , 4795 $m^3$and 4717 m^3 respectively, while the observed flow were 9445 m^3, 1357 m^3, 14129 m^3, 9385 m^3, 10349 m^3, 3830 $m^3$and 3214 m^3. The results determined that the production of leachate generation increased with the increasing rainfall but collection efficiency degraded in rainy period. It was also given the information that uncollected leachate stored in the waste layer might slower the decomposition rate by reducing the air in waste mass and chance to contaminate the ground water. The results were mostly affected by the factors regarding field waste characteristics, run-off coefficient, evaporation rate, cover materials, number of collection pipes installed, maintenance of pit and pipes, outlet conditions as well. The variation of monthly leachate production has shown in Table 4.2 in Appendix I and Figure 4.7.

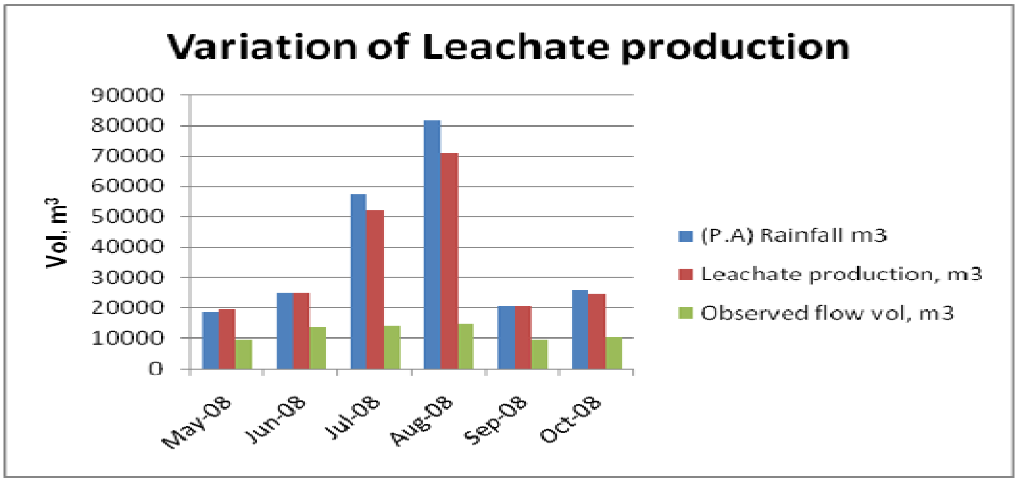


Figure 4.7: Monthly variation of leachate production during rainy season

4.2 Results of Leachate Samples

The quality of leachate samples were analyzed both for semi-aerobic and boundary system as well as observed rainfall effect on the organic, inorganic and heavy metal contents present in leachate. For this samples were tested in monthly at laboratory and determined the variation of various parameters throughout the year. The concentration of heavy metals such as Cr, Cd, Pb, Zn, Ni, and Cu was monitored for dry and rainy season. The test results are given Table 4.4 in Appendix II.

4.2.1 COD (mg/l)

The chemical oxygen demand (COD) test is widely used as a means of measuring the organic strength of domestic and industrial waste. It provides measurement of a waste in terms of the total quantity of oxygen required for oxidation to carbon dioxide and water. In this test strong oxidizing reagent; High range vial solution with 2.5 ml diluted sample was used under acidic condition and digested for two hours. The chemical oxygen demand (COD) test was done in the laboratory by Portable Spectrophotometer (HACH, DR2600U). The COD corresponding time graph has shown in Figure 4.8.

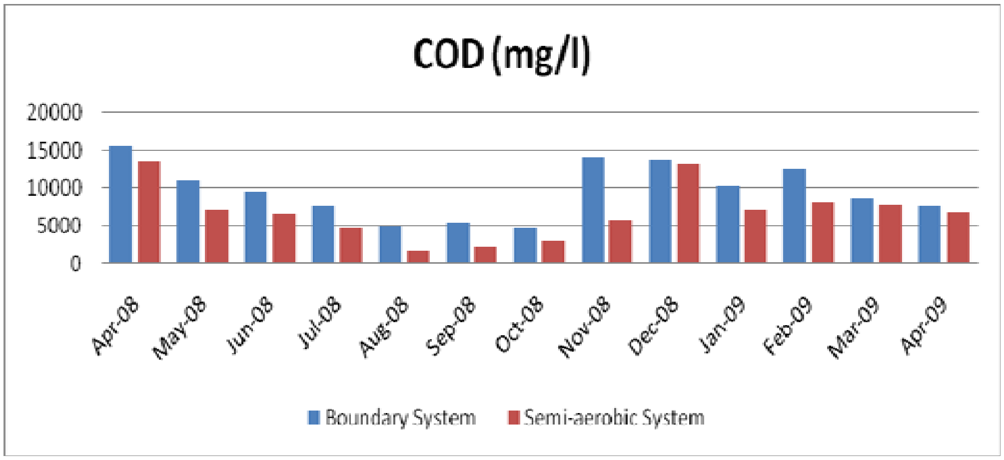


Figure 4.8: **COD (mg/l) variation with time**

From the experimental data it was observed that in April-08 the COD concentrations were 15580 mg/l (boundary system) and 13730 mg/l (semi-aerobic system) and gradually decreased from dry season to rainy season. The minimum value was also found 5020 mg/l (boundary system) and 1820 mg/l (semi-aerobic system) during August-08 when the maximum flow occurred. After that the COD concentrations began to increase rapidly when the dry period was started. The ranges for COD values were 3080–6620 mg/l and 5900–13730 mg/l in semi-aerobic system and 4820–9620 mg/l and 7700–15580 mg/l in boundary system for the rainy and dry seasons respectively. Concentration of pollutants was maximum during summer and get diluted during monsoon. In boundary system the waste became anaerobic, which facilitated fermentation reactions in methanogenic phase and more reaction time available for degradation of waste increased the solubility of pollutant.

4.2.2 BOD (mg/l)

The BOD_5 is the amount of oxygen consumed by the micro-organisms during the first 5 days biodegradation and BOD determination is based on micro-organisms activity. The BOD_5 (mg/l) corresponding time graph has shown in Figure 4.9**.**

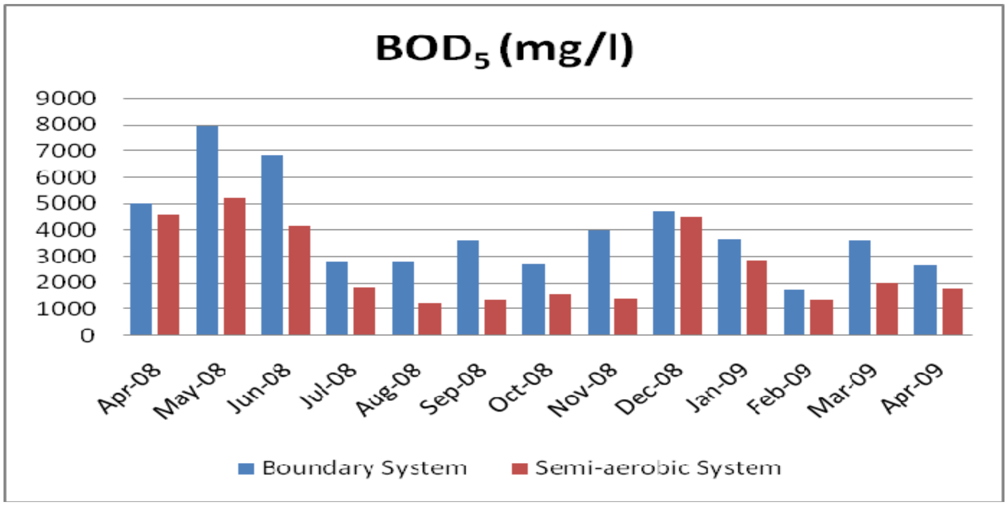


Figure 4.9: **BOD_5 (mg/l) variation with time**

All samples showed the BOD values beyond the permissible limits which implied that leachate contained high bacterial load needing more oxygen to degrade the organic matter. Seasonal variations in BOD values appears to be a function of changes in the degree of dilution, quantity of organic matter and the activities of microorganisms carrying out decomposition of carbonaceous and nitrogenous matter. The minimum value was observed in the month of August, 2008 where maximum rainfall was occurred producing diluted leachate. In boundary system the waste became anaerobic, which facilitated fermentation reactions and offer greater contact time and longer travel distance, thus higher concentration resulted. The ranges for BOD values were 1233–4156 mg/l and 1348–5200mg/l in semi-aerobic system and 2700–6831 mg/l and 1713–8000 mg/l in boundary system for the rainy and dry seasons respectively.

The effectiveness of biological treatment methods can be determined by using the BOD to COD ratio. Effluent can be suitably treated using biological treatment methods if the BOD to COD ratio is above 0.6 (Rao and Datta, 1987). The ratios of BOD to COD of the collected samples were 0.51–0.72 and 0.16–0.40 in semi-aerobic system and 0.56–0.72 and 0.14–0.42 in boundary system for the rainy and dry seasons respectively. Therefore, the collected effluent suitable to be treated only by biological treatment methods in rainy season and in dry period effluent needs to be treated by physical or chemical treatment.

4.2.3 EC (ms/cm)

The EC (ms/cm) variation with time graph has shown in Figure 4.10.

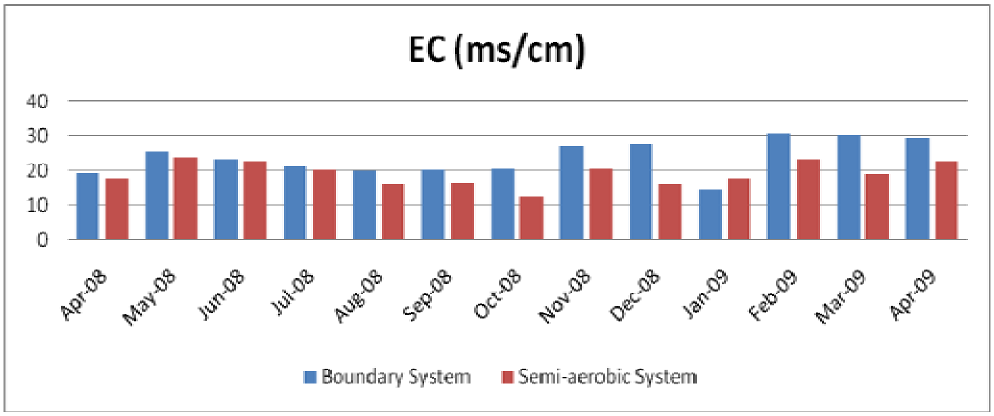


Figure 4.10: **EC (ms/cm) variation with time**

The Electric Conductivity of leachate depends upon the dissolved ions present in the leachate sample. The higher conductivity values of leachate sample were during dry season than the rainy season. It was due to dilution of these ions after heavy rainfall. In dry season having no rainfall so the minerals accumulated and remained in the stagnant leachate in dissolved form increased conductivity. In boundary system it was observed that EC values were more than semi-aerobic systems due to leachate remained for greater contact time and longer distance to travel within the waste layers. The higher conductivity values of leachate sample were almost equal in December, February, March and April, while lowest in the month of July, August, September and October due to dilution of samples after heavy rainfall. The ranges of EC values were 12.35-22.70 (ms/cm) and 16.10-24.10 (ms/cm) in semi-aerobic system and 19.8-23.30 (ms/cm) and 14.50–30.60 (ms/cm) in boundary system for the rainy and dry seasons respectively.

4.2.4 pH

The variation of pH of the leachate with time has given in Figure 4.11.

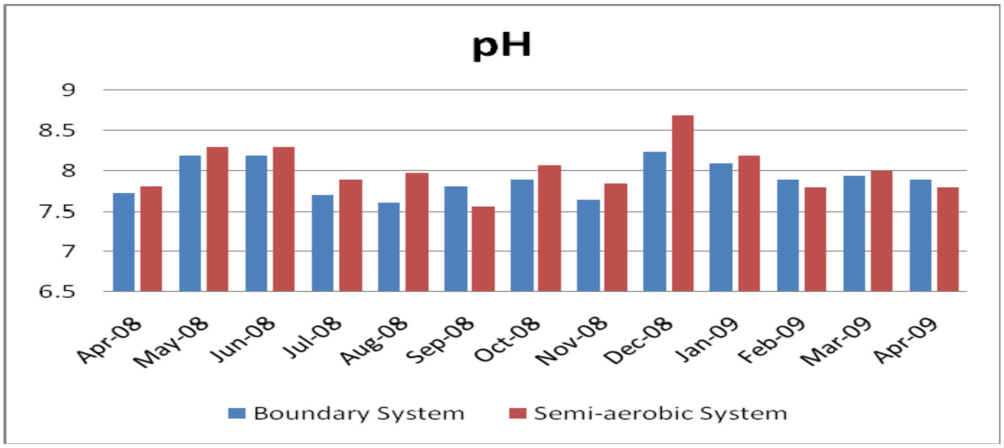


Figure 4.11: pH variation with time

In Matuail landfill leachate, which typically have pH values ranging from 7.6 to 8.7. Here methanogenic bacteria active for carbon dioxide phase. It was due to mineralization of carbonates, bicarbonates and hydroxides. These chemical species might have contributed towards higher alkalinity. pH tended to increase gradually with time showed alkaline in nature. Stabilized leachate shows fairly constant pH with little variations and it may range between 7.5 and 9 (Kulikowska and klimiuk, 2008). From the observed data it was found that semi-aerobic system pH values were higher than boundary system both in rainy and dry season. As a result, stabilization of leachate was occurred more in semi-aerobic system. The ranges for pH values were 7.55–8.30 and 7.80–8.70 in semi-aerobic system and 7.61–8.2 and 7.64–8.24 in boundary system for the rainy and dry seasons respectively.

4.2.5 NH_3-N (mg/l)

The variation of NH_3-N (mg/l) of the leachate with time has given in Figure 4.12.

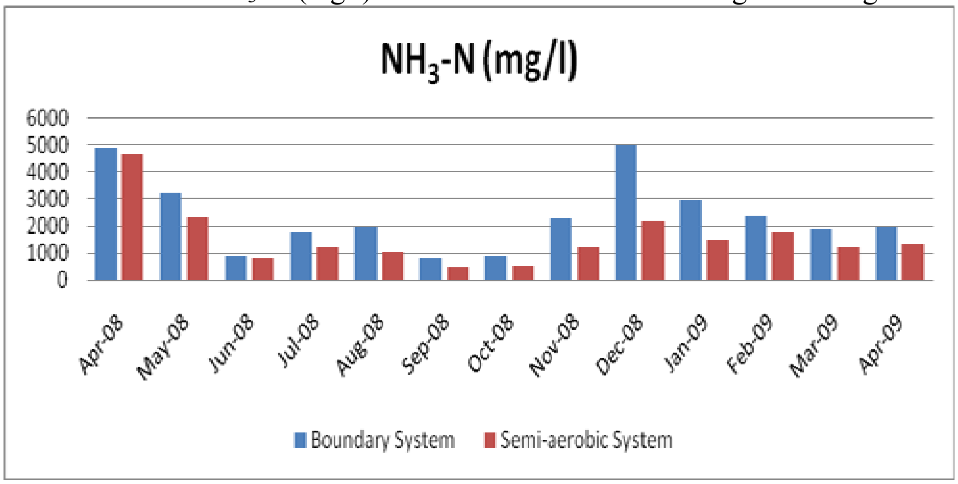


Figure 4.12: NH_3-N (mg/l) variation with time

The most of the nitrogen in landfill is in the ammonia forms following the degradation of protein and amino acids. In dry period NH_3-N(mg/l) concentration was observed more than rainy period and also showed higher values in boundary system. During beginning of rainy season sharp drop of NH_3-N(mg/l) concentration occurred due to dilution of leachate. In boundary system the waste became anaerobic, ammonia is considered as a major long-term pollutant because of its stability under anaerobic conditions. In comparison to soluble organics, the release of soluble nitrogen from waste into leachate continues over longer period (Kulikowska and klimiuk, 2008). The only mechanism by which the ammonia concentration can decrease during refuse decomposition is leaching because there is no mechanism for its degradation under methanogenic conditions (Robinson, 1995; Burton and Watson-Craik, 1998). Ehrig (1988) reports that there is no significant change in ammonia concentrations from the acidic to methanogenic phase. The ranges for NH_3-N values were 485-1234 mg/l and 1240-4675 mg/l in semi-aerobic system and 807.50-1950 mg/l and 1897.50–5000 mg/l in boundary system for the rainy and dry seasons respectively.

4.2.6 Alkalinity (mg/l)

The variation of alkalinity (mg/l) with time has given in Figure 4.13:

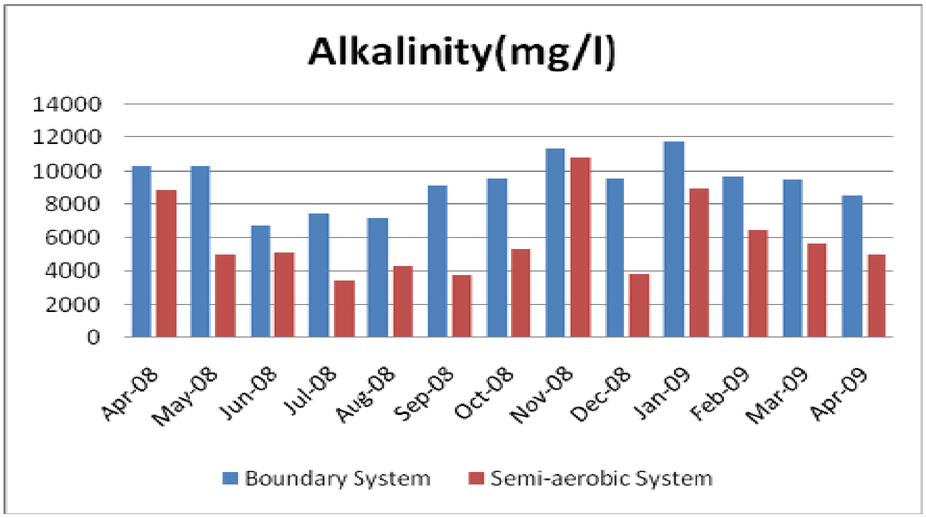


Figure 4.13: **Alkalinity (mg/l) variation with time**

During beginning of rainy season, higher discharge followed the decrease in concentration of alkalinity and higher concentrations were observed in dry or winter time for low flow rate condition. From the observed data it was found that the alkalinity (mg/l) values of boundary system were higher than semi-aerobic system which signified the aerobic degradation dominated in semi-aerobic system. The least values of alkalinity 3450, 4300 and 3820 mg/l were observed in the month of july, august and september respectively in semi-aerobic system as more organic matter decomposed to organic acid. On the other hand more reaction time increased the alkalinity values in boundary system during dry season than the rainy season. The ranges for alkalinity values were 3450-5300 mg/l and 3900-10880 mg/l in semi-aerobic system and mg/l and 6700–9600 mg/l and 8590-11780 mg/l in Boundary system for the rainy and dry seasons respectively.

4.2.7 Chloride

The variation of Cl^- (mg/l) with time has given in Figure 4.14.

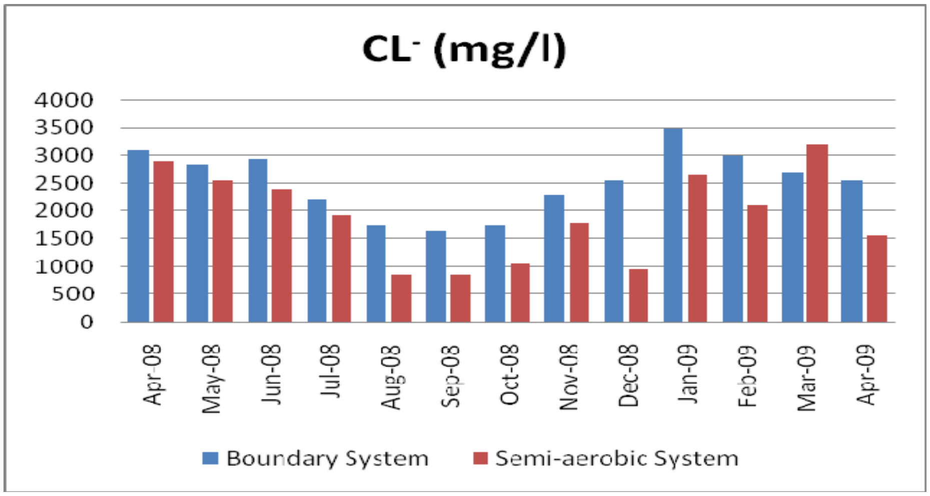


Figure 4.14: Cl^- (mg/l) variation with time

The chloride values were increased rapidly from rainy days to dry period both in boundary and semi-aerobic system, while the peak value was 3500 mg/l in the month of January, 2009 for boundary system. It was observed that the pH (Figure: 4.11) and Cl^- concentrations began to increase simultaneously both in the boundary and semi-aerobic system. As a result of the increase in pH, the dissolution of chloride increases and thus the chloride concentration in leachate increased. The ranges for Cl^- values were 850-2400 mg/l and 950-3200 mg/l in semi-aerobic system and 1650–2950 mg/l and 2300-3500 mg/l in Boundary system for the rainy and dry seasons respectively.

4.2.8 Heavy metals (ppm)

The studied dissolved metal concentrations in Matuail leachate during dry and wet period and their variation percentage are given in Table 4.3. The variation percentage was evaluated from the average values of the dissolved metal concentrations.

The concentration variations of heavy metals such as Cr, Cd, Pb, Zn, Ni, and Cu with time have shown in Figure 4.15 to 4.20.

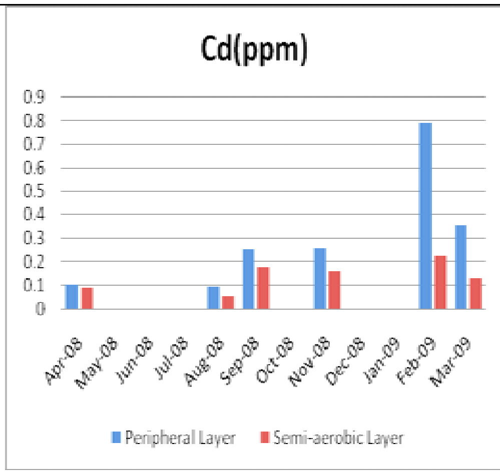


Figure 4.15: Cd (ppm) variation with time

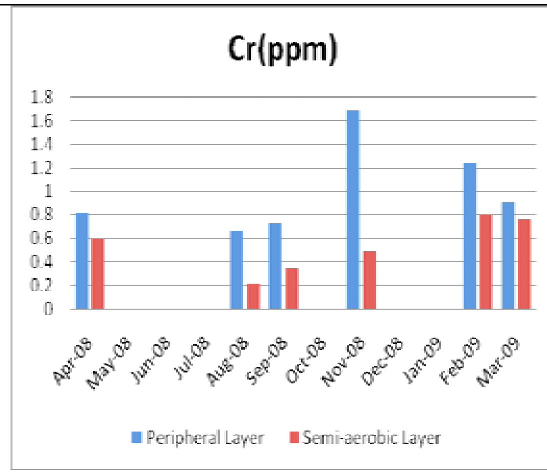


Figure 4.16: Cr (ppm) variation with time

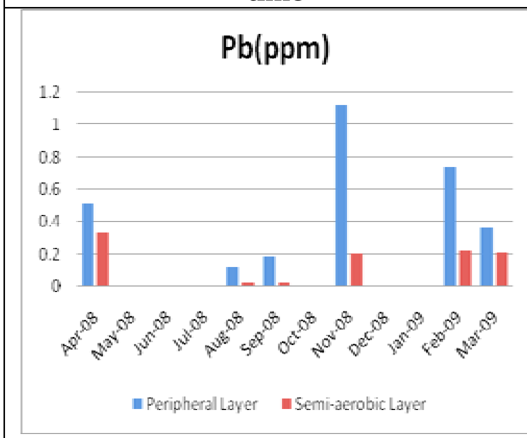


Figure 4.17: **Pb (ppm) variation with time**

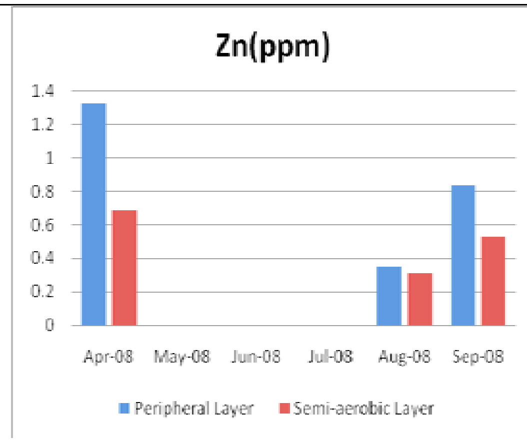


Figure 4.18: **Zn (ppm) variation with time**

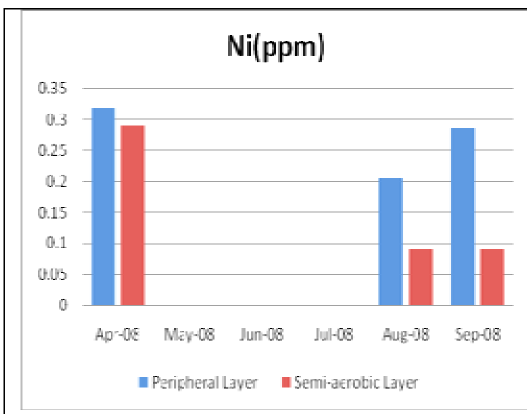


Figure 4.19: **Ni (ppm) variation with time**

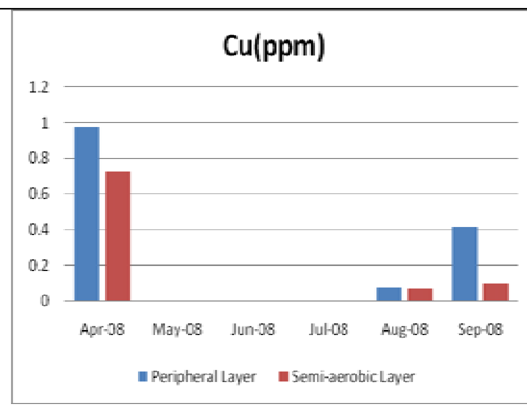


Figure 4.20: **Cu (ppm) variation with time**

In general, the concentration of heavy metals in landfill leachate is fairly low. Concentration of heavy metals in a landfill is generally higher at earlier stages because of higher metal solubility as a result of low pH caused by production of organic acids. As a result of decreased pH at later stages, a decrease in metal solubility occurs resulting in rapid decrease in concentration of heavy metals except lead because lead is known to produce very heavy complex with humic acids. However, the solubility and mobility of metals may increase in the presence of natural and synthetic complexing ligands such as EDTA and humic substances. Further, colloids have great affinity for heavy metals and a significant but highly variable fraction of heavy metals is associated with colloidal matter. According to Baun and Christensen, less than 30%, typically less than 10% of the total metal concentration is present in free metal ion forms and the rest is present in colloidal or organic complexes. The solubility of the metals can also increase because of the reducing condition of the leachate which changes the ionic state of the metals (i.e.,Cr(VI) □→ □Cr (III), and As (V) → □As (III).

It was seen from Table 4.3 that chromium (Cr) concentrations ranges 0.218 ppm – 1.689 ppm in leachate samples were significantly higher than other heavy metals and cadmium (Cd) concentrations ranges 0.056 ppm -0.789 ppm were lower than other heavy metals in leachate sample. It was also observed that the concentration of heavy metals were lower in rainy season other than dry period. In wet period the intense rains cause an increase in the leachate flow, producing a dilution of the contaminants. It was also observed that in November, 2008 and February, 2009 significant amount of Cr and Pb concentrations were accumulated in boundary system rather than semi-aerobic system. During those months Cr concentrations were 1.689 ppm, 1.237 ppm and Pb concentrations were 1.127 ppm, 0.741 ppm. The reason was that generated leachate rested on a long time in contact with waste. With the increase of the age of Matuail landfill there was a significant reduction of heavy metals in semi-aerobic system observed rather than boundary system. According to the variation percentage in Table 4.3 the maximum seasonal decrease observed for Pb and the minimum for Ni in boundary system and the maximum seasonal decrease observed for Pb and the minimum for Cd in semi-aerobic system.

4.2.9 Comparative Study of Test Results

Table 4.1: Comparative study of test results

Parameter, Unit	September 2008		January 2008, BUET Collected date	February 2009	
	Boundary	Semi-aerobic		Boundary	Semi-aerobic
COD, mg/l	5510	2280	8230	12480	8120
BOD_5 , mg/l	3600	1358	2700	3713	2348
EC, ms/cm	20.3	16.31	30.3	30.6	23.3
pH	7.81	7.55	7.9	7.9	7.8
NH_3-N , mg/l	807.5	485	2250	2375	1750
Temp, ^oC	29.7	29.8	20.7	26.4	26.2
Alkalinity , mg/l	9200	3820	12220	9750	6470
Cl^- , mg/l	1650	850	1900	3000	2100
Cd, ppm	0.253	0.178	0.0015	0.789	0.227
Pb, ppm	0.184	0.023	0.185	0.741	0.224
Cr, ppm	0.736	0.353	1.131	1.237	0.803
Zn, ppm	0.838	0.527	0.689	-	-
Cu, ppm	0.414	0.091	0.338	-	-
Ni, ppm	0.286	0.091	0.314	-	-
Na, ppm	2480	2523	-	-	-
K, ppm	3920	3540	-	-	-

The study on leachate quality parameter was analyzed by BUET in January, 2008 and found more or less same as the results obtained from leachate samples collected from boundary system of Matuail landfill site. Experimental parameters were found same as a case study on semi-aerobic landfill in Malaysia which was conducted by Matsufuji, Y., Sinha, K in 1990.

Chapter 5

Conclusions and Recommendations

5.1 Introduction

A study was conducted to investigate the performance of semi-aerobic system during different rainy days by collecting the leachate flow as well as correlate the rainfall intensity with the flow in Matuail sanitary landfill. A rain gauge (18 in x 8 in) was installed at study area for recording the rainfall data. The leachate flow was measured manually with a bucket of 8 (eight) liter volume for a number of rainy and dry days in different time interval from the two discharge points located at semi-aerobic and boundary system. To find out the seasonal variations of organic, inorganic strength and heavy metal contents in leachate samples, laboratory tests were performed in dry and wet seasons for both in semi-aerobic and boundary system. The following conclusions can be made from the study.

5.2 Conclusions

1. Total rainfall was 1816 mm for wet season. In July and August, percentages of the total rainfall were 25 % and 36% respectively. Maximum value of the total leachate flow rate was 26.92m^3/hr on 27th August, 2008 with rainfall intensity of 34.60 mm/hr.

2. The higher leachate flow rate occurred in rainy month of June, July and August and increased with the increasing rainfall. Although the maximum flow was 19.49m^3/hr in August 08, the collection efficiency was found approximately 21%. In dry period the collection efficiency was found about 80 percent. In the study it was observed that in dry period collection efficiency of leachate was more than wet period at Matuail and the flow rates were within the range 3.2 – 5.0 m^3/hr for dry period and 12.7- 19.49 m^3/hr in rainy season.

3. Two regression equations were obtained to correlate flow rate with rainfall intensity. A linear relationship was found both for semi-aerobic and boundary system. The equations are $y = 0.245x + 3.214$, $r^2 = 0.856$ and $y = 0.325x + 5.153$, $r^2 = 0.784$ for semi-aerobic and boundary system respectively where x denotes rainfall intensity and y denotes flow rate. From the two regression analysis it was also seen that during dry period leachate flow occoured 3.20 m^3/hr in semi-aerobic system and 5.0 m^3/hr in

boundary system which was approximately similar to flow rate found from field observations.

4. Production of leachate was increased with the increasing rainfall but collection efficiency degraded in wet period. For the existing operating landfill area of 31.12 acres it was estimated that maximum leachate production was 70,819 m^3 in August, 08 generated from waste and rainfall. In dry period contribution of leachate generation from waste was 4795 m^3 and observed flow was 5.32m^3/hr in November, 2008. Total excess leachate generated from rainfall was not collected through installed leachate pipe networks due to unmanaged cleaning operation during rainy days as well as number of leachate pipes might not sufficient to carry the excess generated leachate lead to contaminate soil and ground water.

5. The ratios of BOD to COD of the collected samples were 0.51–0.72 and 0.16–0.40 in semi-aerobic system and 0.56–0.72 and 0.14–0.42 in boundary system for the rainy and dry seasons respectively. The collected effluent suitable to be treated only by biological treatment methods in rainy season and in dry period effluent needs to be treated by physical or chemical treatment.

6. Seasonal variations of COD, BOD, EC, NH_3-N, alkalinity, Cl^- and heavy metals contents were less in semi-aerobic system than boundary system except pH. The experiment was found same as a case study conducted by Matsufuji, Y., Sinha, K., (1990) in Malaysia.

7. Semi-aerobic system is effective in improving leachate quality compared with boundary system.

8. Time and frequency of leachate flow measurement play an important role on flow rate and rainfall relationship.

9. In the study leachate contains significant amount of organic, inorganic and heavy metals should not be disposed off adjacent agricultural and fishery land without proper treatment.

5.3 Recommendations for Further Studies

i. Annual rainfall and evaporation data should be measured to get better estimation of leachate.
ii. Runoff coefficient should be determined for landfill site to get more accurate leachate estimation.
iii. Daily measurement of leacahte flow and flow measurement during rainfall are needed to obtain better relationship between flow rate and rainfall intensity.
iv. Leachate containing heavy metal contents should be tested monthly to observe better variations.
v. To setup several monitoring well at Matuail landfill site to analyze groundwater contamination by leachate.

Annexure-I

Table 4.2 : Variation of leachate production

Month	(P.A) rainfall m^3	Leachate production m^3	Avg. Monthly Observed Flow (m^3/hr)	Collection efficiency, %
May-08	18603.06	19399.66	12.70	48.69
Jun-08	24798.73	24633.40	18.85	55.09
Jul-08	57562.74	52129.81	18.99	27.10
Aug-08	81900.00	70818.42	19.49	20.47
Sep-08	20224.20	20217.78	13.04	46.42
Oct-08	25721.66	24313.34	13.91	42.57
Nov-08	--	4794.42	5.32	79.89
Dec-08	--	4517.22	4.81	79.22
Jan-09	--	4517.22	4.35	71.15

Table 4.3: Dissolved metal concentrations (ppm) and variation percentage (%)

Boundary system						Semi-aerobic system				
Dry period	Element	Min	Max	Avg	Variation %	Element	Min	Max	Avg	Variation %
Apr-08	Cd	0.105	0.789	0.377		Cd	0.093	0.227	0.153	
Nov-08	Pb	0.361	1.127	0.686		Pb	0.207	0.333	0.242	
Feb-09	Cr	0.822	1.689	1.165		Cr	0.495	0.803	0.666	
Mar-09	Zn	-	-	1.323		Zn	-	-	0.688	
	Cu	-	-	0.977		Cu	-	-	0.724	
	Ni	-	-	0.318		Ni	-	-	0.290	
Wet Period										
Aug-08	Cd	0.098	0.253	0.176	53.48	Cd	0.056	0.178	0.117	23.40
Sep-08	Pb	0.12	0.184	0.152	77.84	Pb	0.023	0.023	0.023	90.48
	Cr	0.663	0.736	0.700	39.94	Cr	0.218	0.353	0.286	57.15
	Zn	0.349	0.838	0.594	55.14	Zn	0.31	0.527	0.419	39.17
	Cu	0.074	0.414	0.244	75.03	Cu	0.067	0.091	0.079	89.09
	Ni	0.205	0.286	0.246	22.80	Ni	0.091	0.091	0.091	68.62

Annexure-II

Table 4.4: Laboratory Test Results for a period of April-08 to April-09

Date-19-04-08				
Time of Sample Collection-11.00 a.m				
		Weather		Dry
Sl no	Parameter	Unit	Sample	
			Boundary system	Semi-aerobic system
1	COD	mg/l	15580	13730
2	BOD_5	mg/l	5000	4600
3	EC	ms/cm	19.14	17.44
4	P^H	-	7.73	7.81
5	NH_3-N	mg/l	4925	4675
6	Temp	^oC	34.3	32.9
7	Alkalinity	mg/l	10300	8900
8	Cl^-	mg/l	3100	2900
9	Cd	ppm	0.105	0.093
10	Pb	ppm	0.515	0.333
11	Cr	ppm	0.822	0.607
12	Zn	ppm	1.323	0.688
13	Cu	ppm	0.977	0.724
14	Ni	ppm	0.318	0.29
15	Na	ppm	2733	2666
16	K	ppm	4715	4624

Date-17-05-08 Time of Sample Collection-10.20 a.m				
			Weather	Cloudy
Sl no	Parameter	Unit	Sample	
			Boundary system	Semi-aerobic system
1	COD	mg/l	11080	7180
2	BOD_5	mg/l	8000	5200
3	EC	ms/cm	25.7	24.1
4	P^H	-	8.2	8.3
5	NH_3-N	mg/l	3225	2350
6	Temp	^oC	33.3	33.2
7	Alkalinity	mg/l	10340	4960
8	Cl^-	mg/l	2850	2550

Date-28-06-08 Time of Sample Collection-10.20 a.m				
			Weather	Cloudy
Sl no	Parameter	Unit	Sample	
			Boundary system	Semi-aerobic system
1	COD	mg/l	9620	6620
2	BOD_5	mg/l	6831	4156
3	EC	ms/cm	23.3	22.7
4	P^H	-	8.2	8.3
5	NH_3-N	mg/l	900	800
6	Temp	^oC	32.5	32.3
7	Alkalinity	mg/l	6700	5100
8	Cl^-	mg/l	2950	2400

Date-30-07-08 Time of Sample Collection-12.20 p.m				
Weather			Cloudy	
Sl no	Parameter	Unit	Sample	
			Boundary system	Semi-aerobic system
1	COD	mg/l	7720	4950
2	BOD_5	mg/l	2800	1800
3	EC	ms/cm	21.1	20.3
4	P^H	-	7.7	7.9
5	NH_3-N	mg/l	1760	1234
6	Temp	^oC	31	31.5
7	Alkalinity	mg/l	7500	3450
8	Cl^-	mg/l	2228	1940

Date-31-08-08 Time of Sample Collection-10.20 a.m				
Weather			Cloudy	
Sl no	Parameter	Unit	Sample	
			Boundary system	Semi-aerobic system
1	COD	mg/l	5020	1820
2	BOD_5	mg/l	2800	1233
3	EC	ms/cm	19.8	15.85
4	P^H	-	7.61	7.98
5	NH_3-N	mg/l	1950	1025
6	Temp	^oC	30	30
7	Alkalinity	mg/l	7200	4300
8	Cl^-	mg/l	1750	850
9	Cd	ppm	0.098	0.056
10	Pb	ppm	0.12	0.023
11	Cr	ppm	0.663	0.218
12	Zn	ppm	0.349	0.31
13	Cu	ppm	0.074	0.067
14	Ni	ppm	0.205	0.091

Date-24-09-08 **Time of Sample Collection-1.20 p.m**				
			Weather	Cloudy
Sl no	Parameter	Unit	Sample	
			Boundary system	Semi-aerobic system
1	COD	mg/l	5510	2280
2	BOD_5	mg/l	3600	1358
3	EC	ms/cm	20.3	16.31
4	P^H	-	7.81	7.55
5	NH_3-N	mg/l	807.5	485
6	^oC			
7	Alkalinity	mg/l	9200	3820
8	Cl^-	mg/l	1650	850
9	Cd	ppm	0.253	0.178
10	Pb	ppm	0.184	0.023
11	Cr	ppm	0.736	0.353
12	Zn	ppm	0.838	0.527
13	Cu	ppm	0.414	0.091
14	Ni	ppm	0.286	0.091
15	Na	ppm	2480	2523
16	K	ppm	3920	3540

Date- 28-10-08 Time of Sample Collection-12.20 p.m				
			Weather	Cloudy
Sl no	Parameter	Unit	Sample	
			Boundary system	Semi-aerobic system
1	COD	mg/l	4820	3080
2	BOD_5	mg/l	2700	1560
3	EC	ms/cm	20.4	12.35
4	P^H	-	7.9	8.08
5	NH_3-N	mg/l	920	540
6	Temp	^oC	30.2	30
7	Alkalinity	mg/l	9600	5300
8	Cl^-	mg/l	1750	1050

Date- 30-11-08 Time of Sample Collection-10.35 a.m				
			Weather	Sunny
Sl no	Parameter	Unit	Sample	
			Boundary system	Semi-aerobic system
1	COD	mg/l	14180	14160
2	BOD_5	mg/l	4000	1400
3	EC	ms/cm	27.3	20.6
4	P^H	-	7.64	7.85
5	NH_3-N	mg/l	2275	1250
6	Temp	^oC	28.2	28
7	Alkalinity	mg/l	11380	10880
8	Cl^-	mg/l	2300	1800
9	Cd	ppm	0.257	0.16
10	Pb	ppm	1.127	0.202
11	Cr	ppm	1.689	0.495

Date- 18-12-08				
				Time of Sample Collection-12.20 p.m
			Weather	Sunny
Sl no	Parameter	Unit	Sample	
			Boundary system	Semi-aerobic system
1	COD	mg/l	13760	13380
2	BOD_5	mg/l	4740	4500
3	EC	ms/cm	27.7	16.1
4	P^H	-	8.24	8.7
5	NH_3-N	mg/l	5000	2200
6	Temp	^oC	21.3	21.4
7	Alkalinity	mg/l	9550	3900
8	Cl^-	mg/l	2550	950

Date- 28-01-09				
				Time of Sample Collection-9.10 a.m
			Weather	Sunny
Sl no	Parameter	Unit	Sample	
			Boundary system	Semi-aerobic system
1	COD	mg/l	10460	7200
2	BOD_5	mg/l	3650	2860
3	EC	ms/cm	14.5	17.6
4	P^H	-	8.1	8.2
5	NH_3-N	mg/l	2950	1490
6	Temp	^oC	20.6	20.5
7	Alkalinity	mg/l	11780	8940
8	Cl^-	mg/l	3500	2650

Date- 7-02-09 **Time of Sample Collection-12.20 p.m**				
			Weather	Sunny
Sl no	Parameter	Unit	Sample	
			Boundary system	Semi-aerobic system
1	COD	mg/l	12480	8120
2	BOD_5	mg/l	3713	2348
3	EC	ms/cm	30.6	23.3
4	P^H	-	7.9	7.8
5	NH_3-N	mg/l	2375	1750
6	Temp	^oC	26.4	26.2
7	Alkalinity	mg/l	9750	6470
8	Cl^-	mg/l	3000	2100
9	Cd	ppm	0.789	0.227
10	Pb	ppm	0.741	0.224
11	Cr	ppm	1.237	0.803
Date- 07-03-09 **Time of Sample Collection-10.35 a.m**				
			Weather	Sunny
Sl no	Parameter	Unit	Sample	
			Boundary system	Semi-aerobic system
1	COD	mg/l	8640	7740
2	BOD_5	mg/l	3600	2000
3	EC	ms/cm	30.5	18.81
4	P^H	-	7.95	8.00
5	NH_3-N	mg/l	1897.5	1240
6	Temp	^oC	26.4	26.4
7	Alkalinity	mg/l	9540	5650
8	Cl^-	mg/l	2700	3200
9	Cd	ppm	0.358	0.131
10	Pb	ppm	0.361	0.207
11	Cr	ppm	0.911	0.76

Date- 04-04-09 **Time of Sample Collection-12.20 p.m**				
			Weather	Sunny
Sl no	Parameter	Unit	Sample	
			Boundary system	Semi-aerobic system
1	COD	mg/l	7700	6750
2	BOD_5	mg/l	2650	1740
3	EC	ms/cm	29.3	22.7
4	P^H	-	7.9	7.80
5	NH_3-N	mg/l	1950	1320
6	Temp	^oC	32.4	32.3
7	Alkalinity	mg/l	8590	4950
8	Cl^-	mg/l	2550	1560

Table 4.5: Summary of Test Results

Leachate Quality Parameter	Unit	Concentration		Bangladesh Standard (ECR 97)
		Boundary system	Semi-aerobic system	
COD	mg/l	4820-15580	3080-13730	**4**
BOD_5	mg/l	1713-8000	1233-5200	**0.2**
EC	ms/cm	14.50-30.60	12.35-24.10	**--**
pH	-	7.61-8.24	7.55-8.70	**6.5-8.5**
NH_3-N	mg/l	807.50-5000	485-4675	**0.5**
Temp	^oC	26.4-34.30	26.20-32.90	**--**
Alkalinity	mg/l	6700-11780	3450-10880	**--**
Chloride	mg/l	1650-3500	850-3200	**600**
Cadmium	ppm	0.098-0.789	0.056-0.227	**0.005**
Lead	ppm	0.12-1.127	0.023-0.333	**0.05**
Chromium	ppm	0.663-1.689	0.218-0.803	**0.05**
Zinc	ppm	0.349-1.323	0.31-0.688	**5**
Copper	ppm	0.074-0.977	0.067-0.724	**1**
Nickel	ppm	0.205-0.319	0.091-0.290	**0.1**
Sodium	ppm	2480-2733	2523-2666	**--**
Potassium	ppm	3920-4715	3540-4624	**--**

Table 4.6 Formulation of regression equation for boundary system.

Annexure-III

$Y = \beta_0 + \beta_1 X + \varepsilon_i = 0.325x + 5.153$										Predicted dependable variable	True dependable variable	Error value		Variance
Boundary System (Yi)	Rainfall intensity I(mm/hr) (Xi)	Mean Y'	Mean X'	Y-Y'	X-X'	(Y-Y')(X-X')	$(X-X')^2$	β'_1 = \$(Y-Y')(X-X')/\$(X-X')2	β'_0 = Y'- β'_1X'	Y'i = $\beta'_0+\beta'_1$Xi	Yi	ε_i = Yi-Y'i	ε^2_i	R^2= SSE/(N-2)
3.90	0.55	9.66	13.84	-5.76	-13.30	76.56	176.81	0.325	5.153	5.331	3.90	-1.431	2.05	0.856
9.34	8.98			-0.32	-4.86	1.54	23.63			8.076	9.34	1.264	1.60	
7.60	6.14			-2.06	-7.70	15.85	59.34			7.151	7.60	0.449	0.20	
9.12	17.33			-0.54	3.48	-1.87	12.12			10.791	9.12	-1.671	2.79	
13.60	17.52			3.94	3.67	14.48	13.49			10.853	13.60	2.747	7.55	
11.46	23.07			1.80	9.23	16.63	85.17			12.661	11.46	-1.201	1.44	
7.00	13.06			-2.66	-0.79	2.09	0.62			9.401	7.00	-2.401	5.77	
9.70	9.67			0.04	-4.18	-0.18	17.45			8.298	9.70	1.402	1.96	
13.32	22.31			3.66	8.47	31.01	71.69			12.413	13.32	0.907	0.82	
12.46	18.54			2.80	4.70	13.17	22.08			11.187	12.46	1.273	1.62	
8.78	7.30			-0.88	-6.54	5.74	42.84			7.528	8.78	1.252	1.57	
9.60	13.93			-0.06	0.09	0.00	0.01			9.686	9.60	-0.086	0.01	
16.42	34.60			6.76	20.75	140.35	430.76			16.411	16.42	0.009	0.00	
6.40	3.65			-3.26	-10.19	33.21	103.90			6.341	6.40	0.059	0.00	
9.70	14.60			0.04	0.75	0.03	0.57			9.903	9.70	-0.203	0.04	
7.52	7.98			-2.14	-5.86	12.54	34.40			7.749	7.52	-0.229	0.05	
8.26	16.13			-1.40	2.29	-3.20	5.23			10.402	8.26	-2.142	4.59	
						357.958	1100.10				**Sum of Squired residual=SSE=**		32.06	

Table 4.7 Formulation of regression equation for semi-aerobic system.

$Y = \beta_0 + \beta_1 X + \varepsilon_i =$ 0.245x + 3.214										Predicted dependable variable	True dependable variable	Error value		variance
Semi-aerobic Syatem (Yi)	Rainfall intensity I(mm/hr) (Xi)	Mean Y'	Mean X'	Y-Y'	X-X'	(Y-Y')(X-X')	$(X-X')^2$	β'_1 = \$(Y-Y')(X-X')/\$(X-X')2	β'_0 = Y'- β'_1X'	Y'i= $\beta'_0+\beta'_1$Xi	Yi	ε_i = Yi-Y'i	ε^2_i	R^2= SSE/(N-2)
2.10	0.55	6.62	13.84	-4.52	-13.30	60.04	176.81	0.246	3.215	3.349	2.10	-1.249	1.56	0.744
5.50	8.98			-1.12	-4.86	5.42	23.63			5.421	5.50	0.079	0.01	
4.62	6.14			-2.00	-7.70	15.37	59.34			4.723	4.62	-0.103	0.01	
8.60	17.33			1.98	3.48	6.91	12.12			7.471	8.60	1.129	1.28	
9.50	17.52			2.88	3.67	10.59	13.49			7.517	9.50	1.983	3.93	
8.18	23.07			1.56	9.23	14.44	85.17			8.882	8.18	-0.702	0.49	
6.80	13.06			0.18	-0.79	-0.15	0.62			6.422	6.80	0.378	0.14	
5.10	9.67			-1.52	-4.18	6.33	17.45			5.589	5.10	-0.489	0.24	
8.53	22.31			1.91	8.47	16.21	71.69			8.695	8.53	-0.165	0.03	
7.86	18.54			1.24	4.70	5.85	22.08			7.770	7.86	0.090	0.01	
5.67	7.30			-0.95	-6.54	6.19	42.84			5.008	5.67	0.662	0.44	
7.49	13.93			0.87	0.09	0.08	0.01			6.636	7.49	0.854	0.73	
10.50	34.60			3.88	20.75	80.63	430.76			11.714	10.50	-1.214	1.47	
3.30	3.65			-3.32	-10.19	33.79	103.90			4.111	3.30	-0.811	0.66	
6.67	14.60			0.05	0.75	0.04	0.57			6.800	6.67	-0.130	0.02	
5.24	7.98			-1.38	-5.86	8.07	34.40			5.175	5.24	0.065	0.00	
6.80	16.13			0.18	2.29	0.42	5.23			7.177	6.80	-0.377	0.14	
						270.233	1100.10				**Sum of Squired residual=SSE=**		11.16	

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