

Evaluation of Contamination Potential and Treatment Techniques of Leachate Generated from Landfill Lysimeter

by

Md. Rafizul Islam

A thesis submitted in partial fulfillment of the requirements for the degree of
Doctor of Philosophy in Civil Engineering



Khulna University of Engineering & Technology

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August 2014

Declaration

This is to certify that the thesis work entitled "Evaluation of Contamination Potential and Treatment Techniques of Leachate Generated from Landfill Lysimeter" has been carried out by Md. Rafizul Islam in the Department of Civil Engineering, Khulna University of Engineering & Technology, Khulna, Bangladesh. The above research work or any part of the work has not been submitted anywhere for the award of any degree or diploma.



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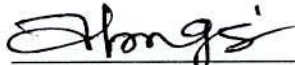
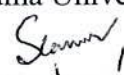
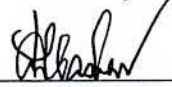
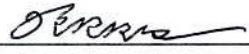


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Affectionately dedicated

To

my mother and beloved wife who taught me

honesty, simplicity and responsibility

and

my elder brother who promote me

for higher studies

Acknowledgements

The author conveys his thoughtful gratitude to his supervisor, Prof. Dr. Muhammed Alamgir, Department of Civil Engineering, Khulna University of Engineering & Technology (KUET), Bangladesh, for his constant supervision, constructive and caring appreciation as well as precious suggestions at every stage throughout this study period. It was a valuable experience to work under the guidance of Professor Alamgir, a person having highly disciplined life style, well behaved even in adverse situations and capable of giving right and prompt decision with philosophical opinion. He also would like to express his deeply grateful appreciations to Prof. Dr.-Ing. habil. Werner Bidlingmaier and Prof. Dr. Eckhard Kraft, Department of Waste management, Bauhaus University Weimer, Germany as well as Prof. Dr. Witold Stepniewski, Faculty of Environmental Engineering, Lublin University of Technology, Poland, for their valuable time and comments throughout this study.

Special thanks also go to Prof. Dr. Muhammed Alamgir advisees: Prof. Dr. Raffaello Cossu, IMAGE (Environmental Engineering), University of Padova, Italy and other friends for their helpful discussion and friendships. The author can not forget Prof. Dr. Quazi Hamidul Bari, and Associate Professor of Dr. Md. Rokonuzzaman, Department of Civil Engineering, KUET, for sharing his great ideas, correction and friendships.

Profound gratitude is also expressed to Professor Dr. Md. Saiful Islam, Head, Department of Civil Engineering, KUET, for all his valuable suggestions, supports and cooperation and for providing laboratory facilities during the period of this study. Appreciation is express to Asia Pro Eco II Programmer of the European Commission for the project of "WasteSafe II" entitled as "Safe and Sustainable Management of MSW through the Practical application of WasteSafe Proposal" funded for the completion this research work.

The author would like to give special thank to SK. Zahid Hassain (Technical Officer), Md. Monirul Islam (Lab Technician) and Kawser Alam Mia (Lab Attendant) for his helping hand in the construction of lysimeter. Furthermore thanks are anticipated all laboratory staffs in Geotechnical Engineering and Environmental Engineering for cooperation in the experimental set-up. Thanks are also conveyed to all the Environmental Engineering Program Secretarial staffs, DoE, Khulna division, for their cooperation.

Last but not least, his profound gratitude to his beloved wife Sumona Afroz and daughters Sanika Afroz and Takia Afroz, for their inspiration, patience and whole-hearted mental support throughout the study.

Abstract

In this study one open dump lysimeter with leachate detection and collection system as well as two sanitary lysimeter having two different types of cap liner were simulated. After designing a reference cell, construction of landfill lysimeter was started in January 2008 and completed in July 2008. In all construction process locally available civil construction materials were used. The municipal solid waste (MSW) of 2800 to 2985 Kg having the total volume of 2.60 m^3 (diameter 1.48 m; height 1.6m) as well as moisture and organic content of 65, 52 %, respectively, was deposited in each lysimeter by applying required compaction energy. This study endeavors to characterize leachate and investigate the tropical climatic influence on leachate characteristics under different seasonal variation. The leachate characteristics, leachate generation and climatic influence parameter had been monitored since June 2008 to Dec. 2010. These periods covered both the dry and rainy season. The leachate generation followed the rainfall pattern and open dump lysimeter-A without top cover demonstrated more leachate generation due to percolation of rainfall than that of sanitary lysimeter-B and C.

Open dump lysimeter-A showed lower concentration of TKN and $\text{NH}_4\text{-N}$ as well as TKN load, while both the concentration and load of COD higher in compared to sanitary lysimeter-B and C. Sanitary lysimeter-B, not only revealed lower leachate generation, but also produced reasonable lower concentration and load of COD in compared with open dump lysimeter-A. Result depicted that lysimeter operational mode had direct effect on leachate quality. In contrary, sanitary lysimeter-C showed higher composition of LFG in compared to sanitary lysimeter-B due to the providing of lower compaction of cap liner in sanitary lysimeter-C. In absence of compacted clay liner (CCL) and hence percolation of rainwater that facilitated rapid degradation of MSW in open dump lysimeter-A and resulted in higher settlement than that of sanitary lysimeter-B and C. In sanitary lysimeter-B and C, leachate generation showed lesser amount than that of open dump lysimeter-A due to the providing of cap liner in lysimeter-B and C, played an important role to reduce the percolation of rainwater. Study revealed leachate pollution index (LPI) and sub-pollution indices (sub-LPI) for lysimeter significantly higher and proper treatment to be necessary before discharging the leachate into the water bodies.

To meet the standard discharge condition lysimeter leachate was treated in the laboratory through the phytoremediation treatment process by using aquatic reactors of duckweed, snail, helencha and topapana, but the removal efficiency was not satisfactory. Then the leachate was treated through the chemical coagulation process by using FeCl_3 , PAC, FeSO_4 and $\text{Al}_2(\text{SO}_4)_3$ in various dosages and pH. Result revealed that FeCl_3 more effective for removing pollutant. In the laboratory, leachate was further treated by using FeCl_3 at optimum dosage and the concentration and consequently the values of LPI of treated leachate were found within the limit of maximum discharge standards. Finally, it can be concluded that leachate generated from lysimeter may be discharge after required level of chemical treatment into the natural streams to maintain the limit of maximum discharge standards.

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Nomenclature

All the notation and symbols are defined where they first appear in the text or figures. For convenience, the more frequently used symbols and their meanings are listed below.

$\text{Al}_2(\text{SO}_4)_3$	: Aluminum sulphate
AN_1, AN_2	: Anaerobic reactors
AOP	: Advanced oxidation processes
APHA	: American public health association
ASTM	: American Society for Testing and Materials
B	: Sanitary lysimeter-B
BOD_5	: Biochemical oxygen demand
c	: Cohesion
CaCO_3	: Calcium carbonate
CC	: Cement concrete
CCLs	: Compacted clay liners
Cd	: Cadmium
CEC	: Cation exchange capacity
CH_4	: Methane
CL	: Closed lysimeter
Cl^-	: Chloride
CO_2	: Carbon dioxide
COD	: Chemical oxygen demand,
Cr	: Chromium
Cu	: Copper
DoE	: Department of Environment
E	: Evapo-transpiration from the landfill
EB	: Electron beam
EC	: Electric conductivity
EPA	: Environmental protection agency
EPD	: Environmental protection department
ET	: Quantity of moisture lost through evapo-transpiration per unit area
Fe	: Total iron
FeCl_3	: Ferric chloride
FeSO_4	: Ferrous sulphate
FMLs	: Synthetic flexible membrane liners
GCL	: Geosynthetic clay liner
gm	: Gram
H_2SO_4	: Sulfuric acid

HCl	: Hydrochloric acid
HCV	: Higher calorific value
ISWA	: International solid waste association
k	: Intrinsic permeability
KUET	: Khulna University of Engineering & Technology
LCS	: Leachate collection systems
LCV	: Lower Calorific value
LDCs	: Least developed countries
LPI	: Leachate pollution index
LPI_{10}	: Root sum power additive form ($r=10$)
LPI_2	: Root sum power additive form
$LPI_{2.5}$	: Ambiguity and eclipsity free aggregation function
LPI_4	: Root sum power additive form ($r=4$)
LPI_{hm}	: Leachate pollution index for heavy metal fraction in leachate
LPI_{in}	: Leachate pollution index for inorganic fraction in leachate
LPI_{max}	: Maximum operator function
LPI_{mr}	: Weighted root sum square aggregation function
LPI_{or}	: Leachate pollution index for organic fraction in leachate
LPI_{rm}	: Root mean square additive form
LPI_{ua}	: Unweighted additive form
LPI_{um}	: And unweighted multiplicative aggregation function
LPI_{w10}	: Weighted root sum power additive form ($r=10$)
$LPI_{w2.5}$	: Weighted ambiguity and eclipsity free aggregation function
LPI_{w4}	: Weighted root sum power additive form ($r=4$)
LPI_{wa}	: Weighted linear additive form
LPI_{wm}	: Multiplicative aggregation function
MAP	: Magnesium ammonium phosphate
MBAS	: Methylene blue active substances
meq	: Milliequivalents
MSW	: Municipal solid waste
n	: Number of leachate pollutant parameter
NH_3-N	: Nitrate
NH_4-N	: Ammonia nitrogen
Ni	: Nickel
NMOCS	: Non-methane organic compounds
NTU	: Naffillometric turbidity unit
O_2	: Oxygen
O_3	: Ozonation

OC	: Organic content
OL	: Open lysimeter
OpCD	: Optimum coagulant dosage
PAC	: Poly-aluminum chloride
Pb	: Lead
PER	: Quantity of water which percolates through the cover per unit area of soil
PI	: Plasticity index
p_i	: Sub-index value
PL	: Plastic limit
PSSL	: Pilot scale sanitary landfill
R	: Precipitation
R^2	: Regression coefficient
RCC	: Reinforced cement concrete
RO	: Quantity of runoff per unit area
rpm	: Revolution per minute
SO_4^{2-}	: Sulfate
SPT	: Standard penetration test
Sub-LPI	: Sub-pollution indices
TCB	: Total coliform bacteria
TDS	: Total dissolve solid,
TKN	: Total kjeldahl nitrogen
TOC	: Total organic carbon
TS	: Total solid
TSS	: Total suspended solid
UV	: Ultraviolet
VDS	: Volatile dissolved solids
VFA	: Volatile fatty acids
VOC	: Volatile organic compounds
VS	: Volatile solid
VSS	: Volatile suspended solids
W	: Quantity of moisture either lost or retained in the waste
w/w	: Weight per weight
Wc	: Water in the cover material placed on the waste
W _{evp}	: Moisture loss due to evaporation
w_i	: Weight factor
Wleach	: Water leaving the landfill (control volume) as leachate
Wlfg	: Water utilized in the formation of landfill gas
Wp	: Water from precipitation and other outside sources (less runoff)

W_{sw}	: Moisture in the incoming solid waste
W_v	: Water lost as saturated vapor with the landfill gas
Z_n	: Zinc
γ	: Specific weight of water
ΔMC	: Change in the amount of moisture stored in a unit volume of landfill
μ	: Dynamic viscosity of water and

Chapter One

Introduction

1.1 Background of the Study

The best appropriate ways of managing of municipal solid waste (MSW) generated from different sources are source reduction, reuse and recycling, but beyond this, the remaining MSW still have to be effectively managed with environmentally sound technologies (Rafizul et al., 2012a). The key management tries of MSW are landfilling, composting, anaerobic digestion, combustion or incineration and gasification (Tchobanoglous et al., 1993). There are two options for disposal of MSW, one is open dumping and another one is sanitary landfill (Visvanathan et al., 2002). In South and Southeast Asia more than 90 % of MSW is disposed in an open dumping landfill (Trankler et al., 2005). Considering this issue, it is necessary to develop an approach to design and operate simple landfill with economic version, which are in-transition between an open dumping and sanitary landfill facilities (Visvanathan et al., 2002).

The term 'landfill' is used herein to describe a unit operation for final disposal of MSW on land, designed and constructed with the objective of minimum impact to the environment (Alamgir et al., 2005). This term encompasses the other terms such as 'secured landfill' and 'engineered landfills' which are also sometimes applied to MSW disposal units (Tubtimthai, 2003). The term 'landfill' can be treated as synonymous to 'sanitary landfill' of MSW, only if the latter is designed on the principle of waste containment and is characterized by the presence of a liner and leachate collection system to prevent ground water contamination (Visvanathan et al., 2007). Sanitary landfill is one of the secure and safe facilities for the disposal of MSW; however, it needs high standard of environment protection in the operation of landfill (Davis and Cornwell, 1998). Moreover, it is a well-suited method for managing of MSW and to investigate the performance of sanitary landfill, the behavioral patterns namely; leachate generation, landfill gas (LFG) emissions etc. are required (Visvanathan et al., 2002). Sanitary landfill is the most popular method of ultimate disposal of MSW. It is a land disposal site employing an engineered method of disposing of MSW on land in a manner that minimize

volume, and applying and compaction cover material at the end of each day (Davis and Cornwell, 1998; Qasim and Chaing, 1994).

Lysimeter is a simulate form of sanitary landfill in the sense of control device (Rafizul et al., 2011). The word lysimeter is a combination of two Greek words "*Lusis*" means *Solution* and "*Metron*" means *Measure* and the original aim is to measure soil leaching as stated by Rafizul et al. (2009). Three lysimeters were designed and hence constructed at KUET campus, to investigate the performance of both the base and cap liners. In order to restrict of leaching, both the cap and base liners made from compacted clay liners (CCLs) were used in landfill lysimeter. The base liner in lysimeter-A in terms of thickness and materials characteristics was the same as the pilot scale sanitary landfill (PSSL) situated at Rajbandh of Khulna city (Islam et al., 2011). However, two different types of cap liners were constructed in the experimental study; cap liner in lysimeter-B was exactly the same as PSSL and the one in lysimeter-C was a simple and economic version. The MSW deposited in landfill lysimeter was collected from Khulna city area as similar to that of deposited in PSSL. Moreover, the average composition of MSW and moderate compaction density were maintained during the deposition of MSW in lysimeter. The functionality of locally available civil engineering materials used for lysimeter construction will be judged through its proper characterization. Moreover, the emission of LFG and leachate from MSW in lysimeter depends on the characteristics of clay used as CCLs and the deposited MSW in landfill lysimeter. The principal components of LFG emissions from the landfill sites are methane, carbon dioxide, hydrogen, oxygen and nitrogen (Gendibien et al., 1992). Methane and carbon dioxide are the major gases produced in MSW from anaerobic decomposition of biodegradable organic waste (Ahn et al., 2002).

The leachate generated from MSW disposal sites is considered as one of the highly contaminated resources from physical, chemical and biological point of view (Rafizul et al., 2009). However, the best possible knowledge of leachate characteristics at a specific site is an essential management tool. This is not only important for new containment landfill needs designed in advance, where leachate will be extracted , but also important for the old landfill where the environmental safeguards rely on the natural attenuating properties of the geological strata, to reduce the level of contaminant to environment (Robinson et al., 1989 and Youcai et al., 2000). In that manner leachate may pose a severe pollution threat to ground water supplies (Kelly et al., 1976; Rafizul et al., 2012b). Chemically contaminated leachate is one of the byproducts in landfill degradation reactions (Alamgir et al., 2006). One of the severe problems

associated with the open dumping of MSW is percolation of leachate into the surrounding environment, subsequent contamination of the land and water bodies (Walker, 1969; Chian and DeWalle, 1976; Kelly, 1976; Masters, 1998; Kumar et al., 2002). El-Fadel et al. (2002) stated that composition of landfill leachate can exhibit considerable spatial and temporal variations depending upon the site, management practices, refuse characteristics (i.e. composition and age), and internal landfill processes (hydrolysis, adsorption, speciation, dissolution, ion exchange, re-dox reactions, precipitation etc.). Moreover, the variation of leachate quality in MSW landfill can be attributed to many interacting factors such as the composition and depth of MSW; decomposition and age of MSW; degree of compaction; landfill design and operation; liner (top and base) design and operation; MSW filling procedures; the availability of moisture content; available oxygen; rate of water movement (fluid addition) and temperature (Qasim and Chiang, 1994). Therefore, it is difficult to generalize the chemical composition of leachate that poses at a particular time of sampling. In addition, leachate quality may vary from time to time and site to site due to the variables such as waste composition, temperature, moisture content, climatic changes etc. (Alkalay et al., 1998; Lee, 2002; Rafizul et al., 2011). The present study was aimed to characterize the leachate and to investigate the tropical climatic influence on leachate characteristics generated from MSW deposited in open dump and sanitary landfill lysimeter. The generation of leachate is a result of percolation of rainfall through open landfill (Aziz et al., 2007). Moreover, the characteristics of leachate are highly variable depending on the wastes deposited in the landfill, composition of wastes, moisture content, the particle size, the degree of compaction, sampling procedures, landfill design and operation, the hydrology of the site, the climate, and age of the fill and other site-specific conditions including landfill design and type of liners used, if any (Rafizul et al., 2012a; Leckie et al., 1979). The concentrations of leachate contaminants may range over several orders of magnitude (Deng and Englehardt, 2006; Bashir et al., 2010; Halim et al., 2010).

Leachate can contaminate groundwater where landfills are not provided with liners and surface water if it is not collected and treated prior to its discharge. The overall pollution potential of landfill leachate can be calculated in terms of leachate pollution index (*LPI*) as proposed by Kumar and Alappat (2005). Because identification and quantification of pollutants in landfill leachate is the major limitation for its successful treatment (Trankler et al., 2005), *LPI* can be used as a mean to determine whether a landfill requires immediate attention in terms of introducing remediation measures. Most of the landfills in developing countries including Bangladesh are not designed with proper leachate collection mechanism. Moreover, the state

regulatory authorities in almost of the countries have framed regulations to safe guard against the contamination of groundwater sources from the leachate generated from the landfills (Umar et al., 2010). As the remedial and preventive measures are so expensive for most of the countries of the world, so it is to be taken up in a phased manner. Thus a system needs to develop to classify the landfill in the basis of their hazard potential (Urase et al., 1997; Rafizul et al., 2012c). Kumar and Alappat (2003) have developed a technique to find the leachate contamination potential of different landfills on a comparative scale in terms of *LPI*. *LPI* has many potential applications including ranking of landfill sites, resource allocation, trend analysis, enforcement of standards, scientific research and public information. In this study, the contamination potential of landfill lysimeter was evaluated by using *LPI* and sub-*LPI*s and the variability of leachate parameters involved in *LPI* were also analyzed.

Leachate is one of the major problems to overcome in managing the landfill. The collection and treatment of leachate has become common practice in order to prevent environmental pollution (Cara et al., 1974; Zouboulis, 1930). This study endeavors to characterize the leachate collected from leachate collection chamber of landfill lysimeter at KUET campus, through the biological as well as chemical treatment processes. The concentration of contaminants in leachate was compared to the maximum discharge standard from some selected countries available in the literature. Result revealed most of the parameters exceed the permissible limit of maximum discharge standard which indicates that treatment is required for reducing the leachate concentration. Leachate samples having the ratio of BOD_5 and COD is less than 0.30, should be treated by chemical treatment process; 0.30-0.60 by combined process of biological and chemical treatment process; greater than 0.60 which indicates for removing leachate concentration, it should be treated by biological process (Mahmud et al., 2012). In the pilot scale treatment scheme, the phytoremediation treatment through aquatic reactors by Duckweed (*Lemna minor*), Snail (*Pila globosa*), Helencha (*Enhydra fluctuans*) and Topapana (*Pistia stratiotes*) was carried out. In the laboratory, leachate samples at varying concentrated were prepared through the dilution of raw leachate with tap water. At such stage, the prepared 100 concentrations of leachate means 100 % of raw leachate was used and 50 concentration means 50 % of tap water was mixed with 50 % of raw leachate. Similarly 20 concentration of contaminants in leachate means 80 % of tap water was mixed with 20 % of raw leachate. In addition, the leachate samples subsequent to pre-treatment through different aquatic reactors were analyzed based on the elapsed period from the treatment, leachate concentration (conditioning system) and removal efficiency. Treating through phytoremediation treatment

process, the removal efficiency was not satisfactory. Then for removing the concentration in leachate, leachate was further treated by using chemical coagulants of ferric chloride (FeCl_3), poly-aluminum chloride (PAC), aluminum sulphate ($\text{Al}_2(\text{SO}_4)_3$) and ferrous sulphate (FeSO_4) at various dosages and pH. Results revealed FeCl_3 more effective coagulant in leachate treatment in compared to PAC, FeSO_4 and $\text{Al}_2(\text{SO}_4)_3$ because this chemical was able to give more reduction than PAC, FeSO_4 and $\text{Al}_2(\text{SO}_4)_3$. Result showed that by using FeCl_3 at optimum dosage, the concentration of contaminants in leachate and consequently the vales of LPI of treated leachate of landfill lysimeter was found within the limit of maximum leachate discharge standards. It can be concluded that leachate generated from lysimeter may be discharge without further treatment into the natural streams to maintain the limit of maximum discharge standards.

1.2 Objectives of the Study

As a principal output from dumping facilities, leachate is one of the major problems to overcome in managing the solid waste landfill and treatment has become common practice in order to prevent environmental pollution. The treatment that has low cost, need less maintenance and environmental friendly was the target on how to treat the leachate. This research mainly focused on the performance of base liner in open dump lysimeter and cap liner in sanitary lysimeter. Moreover, the variation of leachate parameters with the increasing of elapsed period of MSW deposited in lysimeter operated at varying operational conditions as well as the tropical climatic variation also highlighted. To reduce the pollutant concentration in leachate for meet the standard discharge condition, the performance of biological and chemical treatment were also investigated. The overall objectives can be summarized as follows:

1. To investigate the characteristics of leachate, LFG and settlement pattern of MSW deposited in lysimeter simulated at varying landfill operational condition.
2. To examine the influence of tropical climatic on leachate characteristics, generation pattern and cumulative loading of carbon and nitrogen in leachate.
3. To evaluate the contamination potential of landfill lysimeter by using a quantifying tool of leachate pollution index and sub-pollution indices.
4. To study the consequence/potential and effectiveness of different treatment processes for removing contaminations from lysimeter leachate.
5. To recommend appropriate design aspects and operational modes for sustainable landfill operation.

1.3 Scope of the Study

- (i) This study was adopted landfill lysimeter simulation through different operation modes using three lysimeters that were set up for study lysimeter experiments under tropical conditions in the Environmental Research Station backyard of Civil Engineering Department at KUET campus.
- (ii) The leachate characteristics, leachate generation, settlement variation and climatic influence parameter such as rainfall and temperature, has been continuously monitored from June 2008 to December 2010. The experiment parameters were monitored continuously and were also utilized this data to compare the leachate characteristic, leachate generation in the region, and to determine settlement variation of solid waste during operation.
- (iii) One open dump lysimeter with leachate detection and collection system as well as two sanitary lysimeter having two different types of cap liner were simulated.
- (iv) The experiments has been conducted in simulated landfill lysimeter. The three landfill lysimeter , were constructed using the brick wall of 250 mm thick having outer and inner diameter of approximately 1.98 m and 1.48 m, respectively, with a total height of 3.35 m, resting on a 250 mm thick of reinforced cement concrete mat foundation at a depth of 760 mm below the existing ground surface.
- (v) The biodegradation of MSW in landfill lysimeter was studied in terms of quantity and quality of LFG produced, leachate characteristics and changes in chemical characteristics of solid waste at the beginning until the completion of the study.
- (vi) To meet the standard discharge condition lysimeter leachate was treated in the laboratory through the phytoremediation treatment process by using aquatic reactors of duckweed, snail, helencha and topapana, but the removal efficiency was not satisfactory.
- (vii) Then the leachate was treated through the chemical coagulation process by using FeCl_3 , PAC, FeSO_4 and $\text{Al}_2(\text{SO}_4)_3$ in various dosages and pH.
- (viii) The contamination potential of landfill lysimeter was evaluated by using a quantifying tool of leachate pollution index and sub-pollution indices.

1.4 Organization of the Thesis

This report was written through eight chapters in the following sequence. The outline and relations between these eight chapters as depicts in Figure 1.1. The background, objectives as well as the research scope were presented in a comprehensive style in Chapter One.

Chapter Two presented the literature review of this work. This chapter describes the characteristics of MSW and dumping facilities, CCL used in the lysimeter and the leachate characteristics and management which generated in lysimeter as a potential output. This chapter also deals about the open dump, sanitary landfill lysimeter and overall significance of the landfill gas emissions from MSW deposited in Landfill. In addition, the contamination potential of landfill lysimeter through the concept of leachate pollution index (LPI), formulation of sub-pollution indices and variable aggregation has been described in this chapter.

Chapter Three discusses about the overall methodology of this study. The details of landfill lysimeters design, construction, monitoring and evaluation are also highlighted in this chapter. This chapter also discusses the procedure for the determination of physical, hydraulic, compaction properties as well as mineralogical compositions of clay used as compacted clay liner (CCL). Moreover, the physical and chemical characteristics of MSW deposited in lysimeter are also highlighted in this chapter. This chapter also deals about the laboratory procedure with model references for the determination of relevant parameters of contaminated leachate as well as measure the flow rate and composition of LFG generated from the MSW in lysimeter and hence discussed. In addition, the analyses of contamination potential of landfill lysimeter through LPI, chemical and phytoremediation treatment of leachate are also described by the author in this chapter.

Chapter Four describes the design, construction and evaluation of pilot scale landfill lysimeter in Bangladesh. Moreover, the design of reference cell, construction and monitoring of landfill lysimeter are also highlighted in this chapter. The monitoring of settlement of MSW in landfill lysimeter, quantification of leachate generated from MSW in landfill lysimeter, evaluation of contamination potential of landfill lysimeter using LPI and specific COD load of MSW in landfill lysimeter are also presented by the author in this chapter. In addition, this chapter describes the composition and production rate of landfill gas generated from MSW in sanitary landfill lysimeter.

Chapter Five represents the characterization and seasonal variation of lysimeter leachate. This chapter also describes the analytical methods for the assessment of leachate as well as the characteristics of leachate in terms of pH, chloride, nitrogen and carbon content. Moreover, the influence of tropical seasonal variations on landfill lysimeter operation in terms of variation of leachate generation, settlement, pH, COD concentration, chloride, total solid and conductivity are also described in this chapter. Chapter Five also describes the assessment of metal and heavy metal concentration in lysimeter leachate. The chapter represents the variation of metal concentrations in terms of calcium, potassium, sodium, magnesium and total iron as well as heavy metal concentration via cadmium, copper, nickel, zinc, chromium, lead and mercury in relation to the variation of elapsed time for the deposition of MSW in landfill lysimeter.

Chapter Six represents the selection of appropriate aggregation function. Chapter Six describes the evaluation of contamination potential of landfill lysimeter using leachate pollution index (LPI). Moreover, the concept of leachate pollution index, pollutant variables selection, development of pollutant variable rating curves and variable aggregation are also highlighted in this chapter. In addition the assessment of parameters involved in the LPI and their significance are also represented in this chapter. The formulation of sub-pollution indices and evaluation of LPI of landfill lysimeter was also highlighted in this chapter. In addition, chapter Six represents the possible errors involved in the estimation of LPI. Moreover, the errors introduced by ignoring pollutant data based on weight factor, removing pollutants with low weight factors, removing pollutants with high weight factors and errors introduced by ignoring pollutant data based on sub-index value are also highlighted in this chapter.

Chapter Seven describes the small scale phytoremediation treatment of lysimeter leachate. This chapter also represents the effect of phytoremediation treatment on leachate concentration as well as the removal efficiency of pollutant in leachate. This chapter also describes the chemical treatment of lysimeter leachate using coagulants. The analytical methods for the assessment of leachate and the coagulation and flocculation process of leachate treatment are also highlighted in this chapter. The chemical coagulant at varying concentrations, regression coefficient for optimum coagulant dosage, effect of pH on the optimum coagulation dose of coagulation, regression coefficient for optimum pH as well as optimum results of leachate treatment are also highlighted in this chapter.

Finally, the conclusions and recommendations of the findings were presented in Chapter Eight.

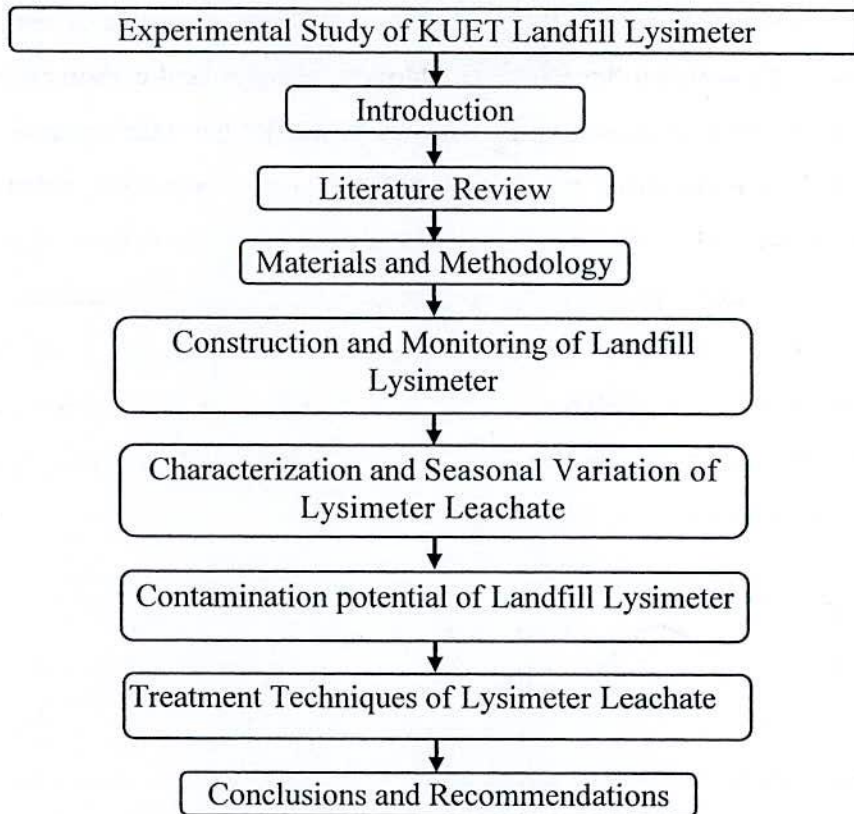


Figure 1.1: Outline and relations between eight chapters of this study

Chapter Two

Literature Review

2.1 General

This chapter describes the characteristics of MSW and dumping facilities, CCL used in lysimeter and the leachate characteristics and management which generated in lysimeter as a potential output. This chapter also deals about the open dump, sanitary landfill, lysimeter technology and overall significance of the landfill gas emissions from MSW deposited in landfill. In addition, this chapter also deals about the contamination potential of landfill lysimeter through the concept of leachate pollution index (LPI), formulation of sub-pollution indices and variable aggregation.

2.2 Municipal Solid Waste

Municipal solid waste (MSW) can be defined as useless, unused, unwanted or discarded material available in solid or semisolid form (Qasim and Chiang, 1994). It normally includes all the community waste such as durable good, non durable goods, containers and packaging, food waste, yard wastes and small amount of inorganic waste except industrial wastes (White et al., 1999; <http://www.wastekeysheets.net/>). Many changes of MSW generation and composition have taken place due to urbanization including increase in the population. The rate of consumption has risen and the lifestyle of the people, too, has changed (Margarida et al., 2007). Several studies have shown how increasing waste has affected society and the environment (nature) (Narisa, 2004). The amount of waste production is a sign of the level of industrialization or a degree of development of a country or a city (Grover et al., 2002; Ludwig, 2003).

2.2.1 Composition of MSW

Composition is the term used to describe the individual components that make up a MSW stream and their relative distribution, usually based on percent by weight (www.worldbank.org//solid_wm/). Most of the countries, in the world have a national aim to decrease the quantity of MSW in different ways such as by recycling, recovery and diversion

from landfill. In order to achieve those aims, information about the composition of MSW is required (Burnley et al., 2007). The successful planning of MSW management requires the availability of reliable information about the quantity and the type of material being generated (Gidarakos et al., 2006; Renbi and Mardina, 2002). Information on the composition of MSW is important in evaluating equipment needs, systems, management programs and plans. The actual percentage distribution of solid wastes will depend on: (i) the extent of the construction and demolition activities, (ii) the extent of the municipal services provided, and (iii) the types of water and wastewater treatment processes (www.lboro.ac.uk/WEDC; (www.epa.gov/non-hw/muncpl/index.htm)). A complete picture about the composition of MSW is an essential part for selection of the appropriate type of storage and transport system, determination of the potential resource recovery, choice of a suitable method of disposal, and the determination of the environmental impact exerted by MSW (Alam et al., 2008; Chan, 1993).

2.2.2 Physical Properties of MSW

Important physical characteristics of MSW include specific weight, moisture content, particle size and size distribution in the mass, field capacity and porosity. The discussion is limited to an analysis of residential, commercial, and some industrial solid wastes (Tchobanoglous et al., 1993). Additional details on physical, chemical, and microphytoremediation methods of testing for MSW may be found in various publications of the American Society for Testing and Materials (ASTM).

2.2.2.1 pH

pH is the numerical expression of the concentration of hydrogen ions in a solution. It depicts whether a solution is neutral ($\text{pH}=7$), acidic ($\text{pH}<7$) or alkaline ($\text{pH}>7$). Organic materials with a wide range of pH values from 3 to 11 can be composted, but the more desirable pH range for composting is between 5.5 and 8.5 (Tchobanoglous et al., 1993). A study conducted by WasteSafe (2005) and shows in Bangladesh the pH value for MSW varies from 7.71 to 8.69. It clearly shows that the MSW of Bangladesh suitable for composting.

2.2.2.2 Total Porosity

Total porosity at 100 % saturation, is defined as the volume water to total volume. For MSW, the typical value is 0.67. A typical compacted soil liner material has the total porosity of about 0.40.

2.2.2.3 Wilting Point

Wilting point is defined as the lowest volumetric water content that can be achieved by plant transpiration. The typical value for MSW is 0.084, while it is 0.29 for compacted clay liner in soil.

2.2.2.4 Moisture Content

One of the most important physical characteristics of MSW is moisture content. Moisture content is a property of particular importance to incinerator design and operation because of its effect on the calorific value and the ignition characteristics of the refuse (Zach et al., 2000)). Moisture content is also very important in composting, as there is a close relationship between moisture and aeration-particularly in windrow composting (Diaz et al., 1996). The moisture content completely depends on the composition of MSW. In case of MSW, it depends on the socio-economic condition, life style, geological location, weather conditions, seasons particularly rains and other parameters such as storage practice, collection method, etc. The moisture content in the developed country is much less than that of the developing and Least Developed Countries (LDCs). For most MSW in the United States, moisture content varies from 15 to 40 %. A study (WasteSafe 2005) shows that in Bangladesh it varies from 56 to 70%. In aerobic composting process, moisture content should be in the range between 50 and 60 % (Tchobanoglous et al., 1993). It depicts that the MSW of Bangladesh is suitable for composting.

2.2.2.5 Volatile Solid Content and Ash Residue

The portion of organic materials with respect to the solid wet of the sample that can be released as a gas when organic material is burned in a muffle furnace at the temperature of 550°C for 5 hours is known as volatile solid (VS) content (Tchobanoglous et al., 2002). VS is a useful parameter particularly in gas production. Gas production is usually expressed in two terms: i) per unit of total solid, and ii) VS introduced. The VS content depends on the composition of MSW and it is usually high in the LDCs. A study conducted in Bangladesh (WasteSafe 2005) shows that VS content varies from 43 to 71%, while ash residue varies from 29 to 57 %.

2.2.2.6 Bulk Density

Bulk density is the important physical characteristics of MSW for final sample size reduction operation. Density data is often required to obtain the mass and volume of waste that must be managed. Proper evaluation of this property is also important in designing the collection

equipment and treatment plant capacity. It should be noted that the different value between the compacted and uncompacted densities (Diaz et al., 1996). Diaz et al. (1996) reported that bulk density for Low, middle income developing and industrialized countries varies from 300 to 600, 200 to 300, 100 to 150 kg/m³, respectively. However, a study WasteSafe (2005) conducted in six major cities of Bangladesh shows that it varies from 549 to 1127 kg/m³.

2.2.2.7 Particle Size Distribution

The particle size and distribution of the component materials in MSW is an important consideration for a basic understanding of the nature of the wastes and potentiality of materials recovery, especially with mechanical means such as trammel screens and magnetic separators. It is also a nutrient-related factor, because the waste is the substrate in composting and the substrate is the source of nutrients. The relation to nutrition is the effect of size of the individual particles. Particle size also determines the ratio of mass-to-surface and hence amount of a particle's mass that is exposed to microbial attack (Diaz et al., 1996). The particle size distribution of waste is usually determined by sieve analysis. Air-dried wastes with the lumps are passed through a number of sieves and finally cumulative percent passing through a given sieve is determined. This is generally referred to as percent finer. The particle size distribution can be used to determine some of the basic waste parameter such as effective size, the uniformity coefficient and the coefficient of gradation. The screens can be easily made with lumber and wire and have square openings, and the sizes of the openings are 400, 300, 200, 100, 76.2, 38.2, 19.1, 9.52, 4.76 and 2.38mm. A study (WasteSafe, 2005) depict that the average percent finer in Bangladesh are 100% in 200 mm sieve openings whereas 83 % in 100 mm, 72 % in 76.2 mm, 53 % in 38.2 mm and 33 % in 19.1 mm and gradually decreases for smaller sieve openings. In 100 mm sieve opening, the average highest value is 92 % for Khulna city, while the lowest value is 78 % for Dhaka city.

2.2.2.8 Field Capacity

The field capacity of MSW is the total amount of moisture that can be retained in a waste sample subject to the downward pull of gravity. The field capacity of waste materials is of critical important in determining the formation of leachate in landfills (Tchobanoglous et al., 1993). Water in excess of the field capacity will be released as leachate. The field capacity varies with the degree of applied pressure and the state of decomposition of the waste. A field capacity of 30

percent by volume corresponds to 30in/100in. The field capacity of uncompacted commingled wastes from residential and commercial sources is in the range of 50 to 60 %.

2.2.3 Chemical Properties of MSW

The chemical properties of MSW are especially important to determine its possible environmental impacts. Information on the chemical composition of the components that constitute MSW is also important in evaluating alternative processing and recovery options (Jayabala, 2005; Mufeed et al., 2007; Agamuthu, 2001). The important chemical characteristics of MSW are: calorific value, carbon, nitrogen, hydrogen, oxygen, potassium, phosphorous, sulfur and boron. Among the above mentioned properties, the most important are described in the followings:

2.2.3.1 Calorific value

The term calorific value of waste is the quantitative estimation of heat energy released by burning (or modifying) a unit amount of the waste in a specified process (Fassett et al., 1994). Two types of energy values are usually ascertained; one is Higher Calorific Value (HCV) and another is Lower Calorific value (LCV). Depending upon the process, calorific value of a fuel may vary. The total heat released by complete burning of a fuel is called the HCV. Usually some fuel contains hydrogen, which produces water and heat during burning with oxygen. The water gets evaporated by absorbing this heat and escapes with exhaust. Higher calorific value of MSW will be estimated by using a bomb calorimeter in laboratory as oven dry basis (Jha et al., 2003; Jouraiphy et al., 2005). The term calorific value of waste is quantitative estimate of heat energy released by burning a unit amount of waste in a specific process. It is obvious that energy content in MSW depends on the composition, however, literature shows (Tchobanoglous et al., 1993) that range of energy is 4,000 to 6,000 Btu/lb (9304 to 13,956 kJ/kg). As reported (WasteSafe, 2005), calorific value of organic components of MSW collected from six major cities of Bangladesh was determined in laboratory by using a bomb calorimeter. The highest calorific values were 20,467 kJ/kg for rubber, 20,077 kJ/kg for plastics and 14,578 kJ/kg for wood and the lowest value was obtained as 5,907 kJ/kg for wood wastes.

2.2.3.2 Carbon

Carbon is one of the most important components in MSW. In aerobic composting of MSW, the higher concentrations of carbon are superior as bacteria use carbon as an energy source. In MSW

paper is the main source of carbon. Thus higher ratio of paper to vegetables/putrescible matters, higher the concentration of carbon can be obtained. In Bangladesh less percentage of paper is present in MSW. The report shows (WasteSafe, 2005) that percentage of paper and paper products varies from 7.2 to 10.7 % at source and 4 to 7 % at secondary disposal sites. From laboratory investigation, it was observed that average % of carbon varies from 2.67 to 15.15 in Bangladesh.

2.2.3.3 Nitrogen

In MSW, the main source of nitrogen is the vegetables/putrescible matter, which is very high percentage in MSW of Bangladesh. In aerobic composting of solid waste by Windrow Technique, the optimum value of nitrogen appears to be about 1.40% in compost (Enayetullah and Sinha, 2000). Nitrogen as inorganic nutrient needed by microorganism during composting of solid waste and bacteria use nitrogen for cell building in aerobic composting. A study shows (WasteSafe, 2005) that the percentage of nitrogen varies from 0.17 to 1.62% in Bangladesh as obtained from MSW samples collected from six major cities.

2.2.3.4 Potassium

Potassium is one of the principle inorganic nutrients needed by microorganism during the composting of solid waste. In aerobic composting of MSW by Windrow Technique, the optimum value of potassium appears to be about 0.66% in compost (Enayetullah and Sinha, 2000). A study shows (WasteSafe, 2005) that the percentage of potassium varies from 0.38 to 1.37% in Bangladesh as obtained from MSW samples collected from six major cities.

2.2.3.5 Phosphorous

Phosphorous is another principle inorganic nutrients needed by microorganism during the composting of MSW. In aerobic composting of solid waste by Windrow Technique, the optimum value of potassium appears to be about 0.36% in compost (Enayetullah and Sinha, 2000). A study shows (WasteSafe, 2005) that the percentage of phosphorous varies from 0.23 to 0.41% in Bangladesh as obtained from MSW samples collected from six major cities.

2.2.4 Mechanical Properties

The mechanical properties are especially important for the design of sanitary landfills and ancillary systems (Diaz et al., 1996). Analyses and testing of MSW are carried out using raw (fresh) MSW, fractions of MSW, as well as landfilled MSW generated in industrialized countries in Western Europe. Due to the sharp differences in the composition and characteristics between these wastes and those from economically developing countries, it is needed to modify to suit the conditions of the particular location (Diaz et al., 1996). However, there is no reliable reported data in Bangladesh. Major mechanical characteristics of MSW are described briefly in the followings:

2.2.4.1 Strength and Compressibility

Strength and compressibility for MSW are important engineering considerations because these characteristics are required for landfill stability and settlement analyses. Due to variability in MSW, reliance on conventional laboratory results is not prudent. In general, strength and compressibility characteristics of MSW are not yet well understood and need further evaluation. Triaxial compression test is generally conducted on raw MSW and on mixtures of MSW and incinerator bottom ash to determine the stress-strain behavior. The test result shows that ash has a considerable impact on the behavior of refuse (Diaz et al., 1996). The results also demonstrate that samples of the old refuse were able to reach substantially higher densities than the samples of fresh refuse. Besides this, vane shear test, standard penetration test (SPT) tests and back-calculated $c-\phi$ are used to get required data. Sharma et al. (2005) generally use the values of cohesion, $c=400 \text{ lb/ft}^2$ and angle of internal friction, $\phi=20^\circ$ in preliminary slope stability analysis.

Compressibility of a landfill is related to the settlement behavior of the landfill. The settlement behavior of MSW is complex and can be influenced by various factors such as movement of smaller particles into larger voids, chemical reactions, biodegradations of organics within the landfill, dissolving of soluble substances by percolating groundwater, creep, and changes in deformation properties with time (Sowers, 1968, Fassett et al., 1994). Generally, it has been observed that a new landfill may settle up to 50% of its thickness or depth, while a closed landfill will settle between 15 to 20% per year.

2.2.4.2 Permeability of Compacted Waste

The hydraulic conductivity of compacted waste is an important mechanical property that to a large extent, governs the movement of liquids and gases in a landfill. The coefficient of permeability is normally written as: $k = Cd^2 \gamma/\mu = k \gamma/\mu$; where, k =coefficient of permeability, C =dimensionless constant or shape factor, d =average size of pores, γ =specific weight of water, μ =dynamic viscosity of water and k =intrinsic permeability. The term Cd^2 is known as the intrinsic (or specific) permeability. The intrinsic permeability depends solely on the properties of the material, including pore size distribution, tortuosity, specific surface and porosity. The typical values for the intrinsic permeability for compacted MSW in a landfill are in the range between about 10^{-11} to 10^{-12} m^2 in the vertical direction and about 10^{-10} m^2 in the horizontal direction.

2.3 Dumping Facilities of MSW

Landfilling practices in developing countries differ from that of the developed countries, which follow advanced landfilling practices such as sanitary landfill (engineered landfill) as opposed to open dumping practiced in the developing countries. There are two methods for the final disposal of MSW, one is open dumping and the other is sanitary landfill (Visvanathan et al., 1999).

2.3.1 Open Dumping Facilities

Open dump is a solid disposal without waste compaction during placement; neither compacts nor covers with soil. The land is used without preparation of engineering planning (Chomsurin, 1997). Thus, the open dump site characteristic are unplanned heaps of uncover waste, burning waste at the dump site, pools of standing polluted water, rat and fly infestation and waste scavenging at dump site (Pugh, 1999). Open dump practice of MSW in Bangladesh (Alamgir et al. 2005) shown in Figure 2.1.



Figure 2.1: Open dump practice in Bangladesh

In South and South East Asia the open dump approach is the most predominant waste disposal option (Visvanathan et al., 1999; Ashford et al., 2000). Open dumping is the main disposal method of MSW in developing countries (Bulent et al., 2004). The toxic chemicals from open dump have negative effects on human life, wildlife, and environmental quality (Tanabe, 2002). Open dumping facilities have no longer acceptable from aesthetic, environment and sanitary points of view (Minh et al., 2003). Crude open dumping is being practiced in many developing countries as a means of final disposal of solid waste (Visvanathan et al., 2003). The bad effects of open dumping reveals as: (a) health hazard; (b) public complain; (c) bad image; (d) air and water pollution and (e) more space occupies.

2.3.2 Sanitary Landfill

Sanitary landfill is one of the most widely used MSW methods; however, it needs high standard of environment protection in the operation of landfill (Davis and Cornwell, 1998; Tchobanoglous et al., 1993). The changing from dumping to high standard of environment protection needed time change technology, change in thinking and behavior (Bodelius and Rydberg, 2000; Pugh, 1999). Figure 2.2 shows a cross-section of a typical engineered landfill constructed at Khulna city of Bangladesh, which has provisions for containing leachate and landfill gases generated from MSW deposited in pilot scale sanitary landfill (PSSL) stated by Islam et al. (2009).

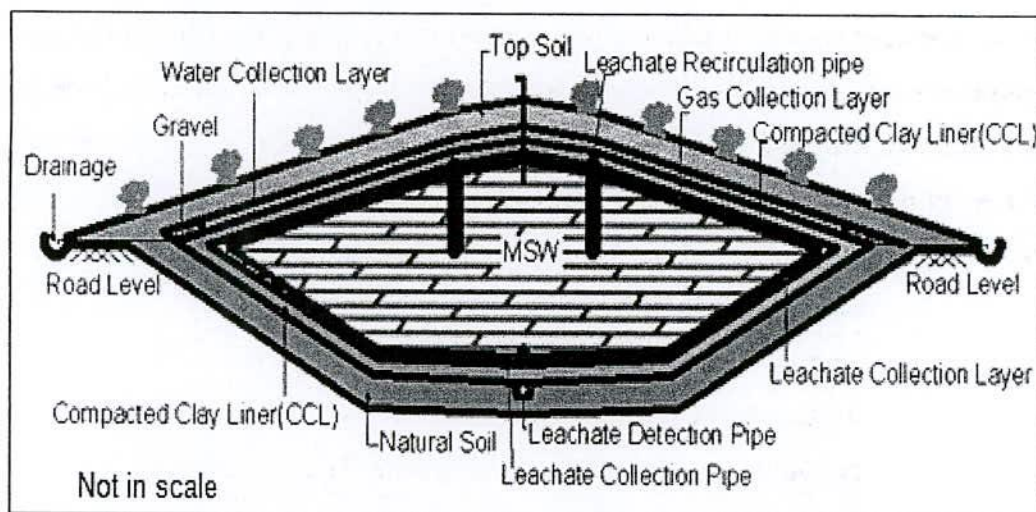


Figure 2.2: Cross section of PSSL at Rajbandh, Khulna (Source: Islam et al., 2009)

The base liner, the most important component, includes a leak detection sump system, compacted clay liner, leachate collection pipe system with a leachate collection layer. It was designed considering hydrological data of the site, the size of landfill, suitability of construction and locally available of material as shown in Figure 2.3. In addition, the final cover of PSSL as shown in Figure 2.4, consists of top soils, percolation water collection layer, compacted clay liner and gas collection pipe system with gas collection layer.

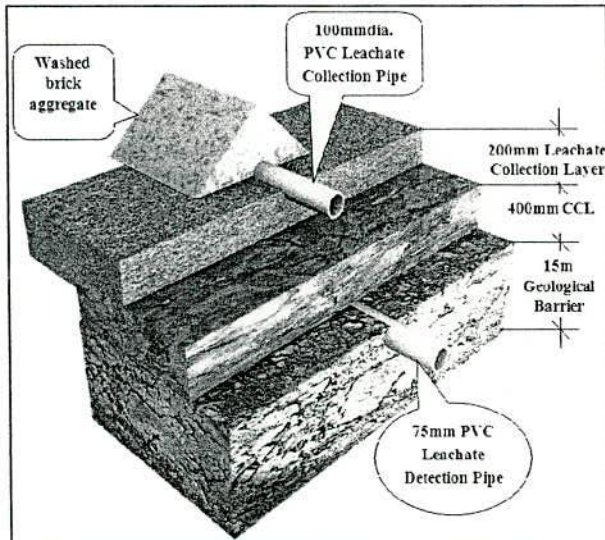


Figure 2.3: Schematic diagram of base liner

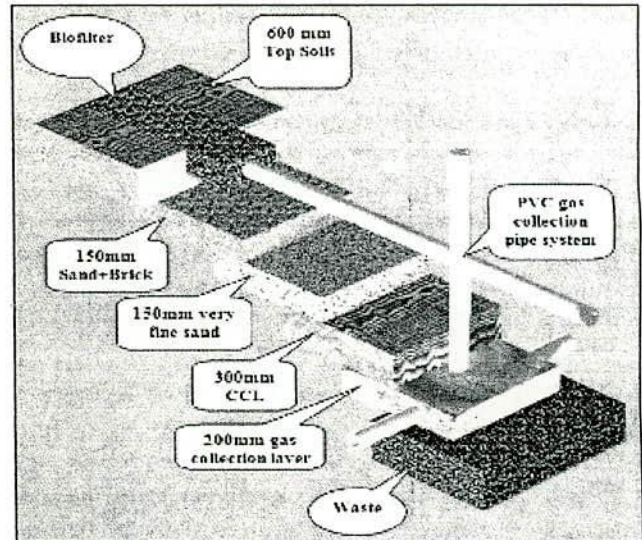


Figure 2.4: Schematic diagram of the cap liner

The main aim of a sanitary landfill is to use it for a longer time for disposal of MSW with less negative effect to the ecosystem (Agamuthu, 2001; Mohamed, 2004). There must be several monitoring wells around the landfill to monitor the movement of pollutants. There should also be a special drainage system which can help to reduce the flow over from the landfill surface. Thus, the amount of water that penetrates it will be reduced. Typically, impermeable clay cap located at the top of landfill can prevent the infiltration of water through the landfill (Figure 2.4) (Chiras, 2001). There are several types of landfills with or without engineering measures, leachate and landfill gas management and day-to-day operation measures, which are cited in Table 2.1. These are usually planned, located, designed and constructed in accordance with engineering specification to minimize ground water contamination (Sowers, 1968). The advantages of sanitary landfill given of: (a) no health hazard; (b) no public complain; (c) no smell; (d) gas and leachate control and (e) life of landfill extended. The progressive development of sanitary landfill plan as presented in Table 2.2.

2.1: Types of solid waste landfill

Type	Engineering measures	Leachate management	Landfill gas management	Operation measures
Open Dump	None	Unrestricted release of contaminants	None	Few, mostly scavenging
Controlled Dump	None	Unrestricted release of contaminants	None	Recording and placement of waste with compaction
Engineered Landfill	Infrastructure and placing of liners	Containment and some level of leachate management	Passive ventilation or flaring	Registration and placement of waste with compaction and daily use of soil cover
Sanitary Landfill	Proper siting and infrastructure; liner and leachate collection	Containment and leachate treatment (phytoremediation and physico-chemical)	Flaring	Registration and placement of waste with compaction and daily use of soil cover, and final top cover
Controlled Contaminant Release Landfill	Proper siting and infrastructure with low permeable liner; Low permeable final top cover	Controlled release of leachate based on assessment and proper siting and treatment	Flaring or passive Ventilation through top cover	Registration and placement of waste with compaction and daily use of soil cover and final top cover
Landfill Bioreactor	Proper siting and infrastructure with liner and leachate recirculation system	Controlled leachate recirculation for enhanced degradation and stabilization of wastes and leachate	Landfill gas recovery	Registration and placement with compaction, daily cover, closure, mining and material recovery

Source: Tubtimthai, 2003

Table 2.2: Progressive development of sanitary landfill

Date	Development	Problem	Improvement
1970	Sanitary landfill	Odors, fires	Daily cover, better compaction
Late 1980-early 1990	Engineered landfill recycling	Ground and ground water contamination	Engineered liners, cover, leachate and gas collection system, increasing regulation
Late 1990	Improve siting and containment waste diversion and reuse	Stability, gas migration	Incorporation of technical, development of new lining materials, increase post closure use
2000	Improved gas treatment	-	Increasing emphasis on mechanical and phytoremediation waste pretreatment, leachate recirculation and bioreactions

Source: Tubtimthai, 2003

2.4 Lysimeter Technology

The term lysimeter is a combination of the Greek words “*lusi*” means “*solution*” and “*metron*” means “*measure*” (Meima, 1997) and the original aim was to measure soil leaching. The first lysimeter was used by DE LA HIRE in 1688. The overall definition of lysimeter from various sources as reveals below:

- Lysimeter is a control device where the generated leachate and LFG are accumulated from deposited MSW in landfill then collected properly.
- A device which is used to measure the rate of downward water movement through a block of soil usually undisturbed or to collect such percolate water as referred as lysimeter.
- A type of evaporation gauge consisting of a tank or pan of soil placed in a field so that the soil, water and vegetative properties in the tank duplicate as closely as possible the properties of surrounding area.
- An instrument to collect water flowing through the vadose zone or unsaturated zone of soil. A lysimeter is a measuring device which can be used to measure the amount of actual evapotranspiration which is released for an area of woodland.

Typical view of lysimeter test cell constructed at AIT, Thailand for the treatment of MSW (WasteSafe, 2010) shown in Figure 2.5. In addition, four pilot-scale lysimeters of 3.0-m-height and 1.3-m-diameter were constructed outdoors using reinforced cement concrete rings at Centre for Environmental Studies, Anna University, Chennai, Tamil Nadu, India (Swati et al., 2011) shown in Figure 2.6. The laboratory-scale landfill lysimeter, which were constructed from 0.5 cm

polypropylene at Yildiz Technical University, Environmental Engineering Department, Yildiz, Besiktas, Istanbul (Sinan et al. 2006) is shown in Figure 2.7.

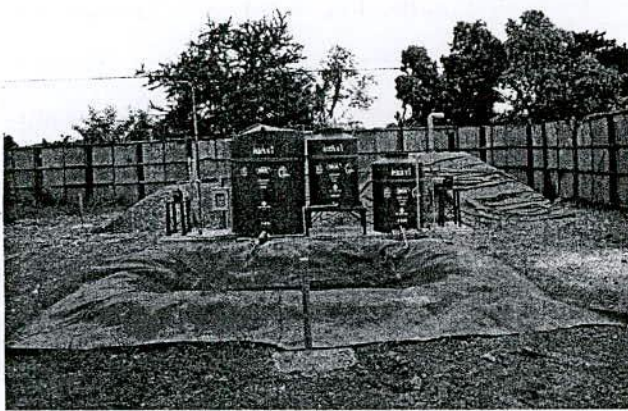


Figure 2.5: Lysimeter test cell at AIT, Thailand

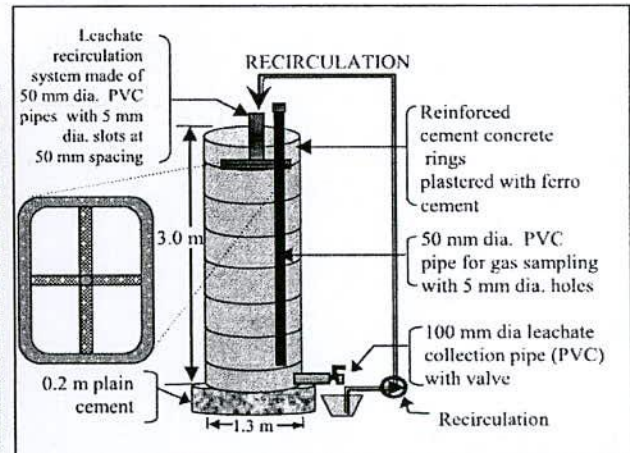


Figure 2.6: Pilot-scale lysimeter Chennai, India

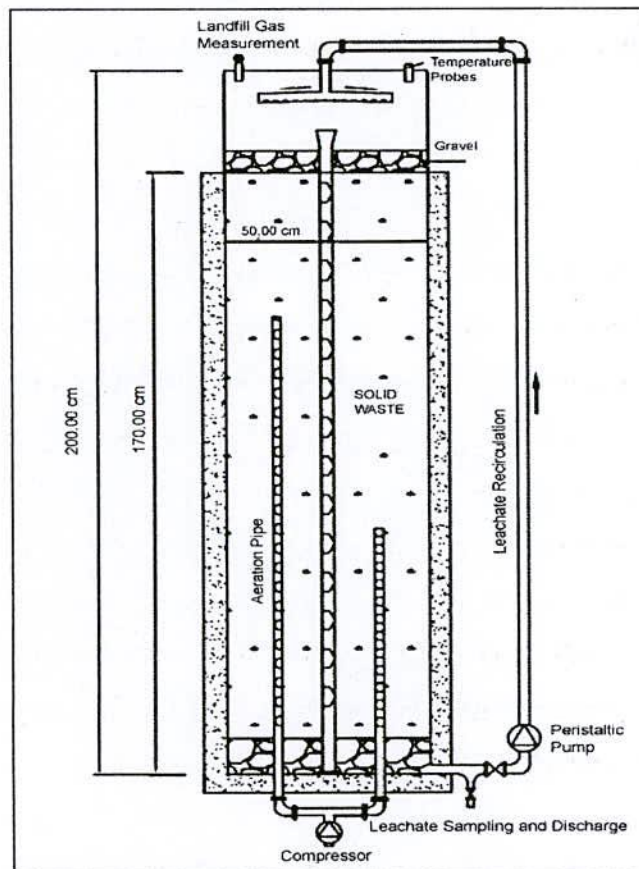


Figure 2.7: Laboratory-scale lysimeter Istanbul

2.4.1 Principles and General Considerations

Lysimeters have been developed for use in soil science and have been used for over 300 years to study the relations between soil, water and plants. Much knowledge and experience concerning

the use, design, and operation of lysimeters have been gathered in this scientific field. During the last decades, the use of lysimeters has been extended to other scientific fields as for example to quantitative and qualitative studies of the leaching of LFG and contaminated leachate from MSW products or contaminated soils in order to evaluate the environmental impact of these materials. Leaching results from lysimeter experiments may often be taken to represent results obtained under field-resembling conditions, and they may thus be very useful for different purposes. The results may provide information on the composition of the initial leachate at very low liquid to solid ratios, which is very important in environmental risk assessment.

Lysimeter leaching tests are, in principle, large-scale column leaching tests where the test material is placed in a container with an open surface. The container is supplied with a drainage system at the bottom, from where the leachate is conducted to a collection vessel. Then the contaminated leachate will be collected at the interval of time for laboratory investigations as well as to treat the leachate through different physical, chemical and phytoremediation treatment in sense of low cost effective (Diaz et al., 1996). Lysimeter experiments are often performed outdoors under "natural" conditions where the flow direction of the soil solution is downward. The formation of leachate is due to infiltration of precipitation but under special circumstances irrigation may be used in order to accelerate the leachate formation. Lysimeter experiments may also be performed indoors where the formation of leachate will be due to irrigation, and in that case the flow direction can be upwards as well as downwards. The duration of lysimeter tests is typically one to several years.

2.4.2 Classification of Lysimeter

Lysimeters may be classified according to different criteria such as type of soil block used (monolithic or reconstructed), drainage (drainage by gravity or vacuum or a water table may be maintained), or weighing or non-weighing lysimeters (Kohnke et al., 1940; Dugas et al., 1990). In addition, based on construction procedure and materials, the lysimeter categories as (Meij et al., 2000): (a) Weighable lysimeter; (b) Non weighable lysimeter; (c) Hydro lysimeter; (d) Meteo lysimeter; (e) Scientific field lysimeter; (f) Agro lysimeter; (g) Aerobic (open dump) lysimeter and (h) Anaerobic (sanitary landfill) lysimeter.

2.4.3 Design and Materials

The dimensions of a lysimeter will to a large extent be related to the time frame of the project involving the lysimeter. It should be possible to perform the desired measurements within the time frame of the lysimeter test, and the design of the lysimeter is often related to the amount of leachate that should be collected during the lysimeter experiment. Lysimeters most commonly are constructed with rectangular or circular surfaces, and they vary widely in sizes. A cylindrical container is often used for a “smaller” lysimeter (Cronan, 1978; McLay et al., 1992), whereas rectangular shapes generally are more practical for very large lysimeters (Humer et al., 2001). Rectangular lysimeters are also recommended for studies involving crops at the surfaces of the lysimeters due to the row crop geometry (Howell et al., 1991). In general the size of the lysimeter should be chosen keeping in mind that the results of the lysimeter tests must be representative for the material investigated. This means that if the material is very heterogeneous or if the particle size is large the lysimeter must be large enough to contain a representative sample of the material. It is of course of great importance to ensure that the material used for the construction of the lysimeter does not contaminate the leachate or the soil solutions, and that the material does not interfere with the parameters to be tested.

2.4.4 Design Consideration of Lysimeter

Lysimeter consists of collecting percolating water from the base of a test section, provides a direct measurement of the percolation rate, and can be used in equivalency demonstrations. The study of lysimeter how it's geometry & boundary conditions affect lateral diversion & percolation rates measured using lysimeter (Doerry, 1984). Lysimeters with various geometries were simulated with the constant meteorological & vegetation data. Simulations showed that sidewalls which are of 0.35 m high can minimize the lateral diversion of flow around the sides of the lysimeter. Up slope and down slope end walls need to extend to the surface of the lysimeter, especially when the lysimeter is inclined (4:1 or 3:1 slope). Modeling has shown that lysimeters underestimated percolation by 8 to 14 %. Based on these simulations in the design and construction of lysimeters recommended design of lysimeter is suggested.

2.4.5 Factors in Evaluating the Potential Site of Lysimeter Construction

The following factors may be affecting the site selection of lysimeter construction of: (a) Haul distance; (b) Location restriction; (c) Available land area; (d) Site access; (e) Soil condition and topography; (f) Surface-water hydrology; (g) Geologic and hydrologic conditions; (h) Existing land use patterns; (i) Local environmental conditions and (j) Potential ultimate uses for the completed site.

2.5 Compacted Clay Liners

Compacted clay liners (CCLs) are constructed primarily from natural soil materials that are rich in clay, although the liner may contain processed materials such as bentonite. CCLs are constructed in layers call lifts that typically have a thickness after compaction of 150 mm. On side slopes, the lifts in final cover systems are almost always placed parallel to the slope. However, parallel lift are very difficult or impossible to construct on side slopes steeper than 2.5 (H)-to-1(V) (Daniel et al., 1995).

2.5.1 Component of CCLs

A compacted soil component beneath, and in direct contact with, the geomembrane will: (a) Minimize, over the long term, liquid migration into the waste in the event of geomembrane failure or through imperfections (holes, tear, etc.) inadvertently left during the construction process; (b) Provide a firm foundation for the overlaying layers of the cover system; (c) Serve as bedding materials for protection of the overlaying geomembrane and (d) In junction with the geomembrane, satisfy the typical regulatory requirement for the cover to be no more permeable than the bottom liner of the facility. The design of CCL will depend on site-specific factors including the properties and engineering characteristics of the soil being compacted, the degree of compaction attainable, the total expected load, and the expected precipitation.

2.5.2 Design Criteria of CCL

The design criteria of CCL are as follows: (a) Hydraulic conductivity , $k < 10^{-9}$ m/sec; (b) Clay (<20-6 m) content > 15-20 %; (c) Plasticity index, PI >7 to 15%; (d) Water content must be

greater than plastic limit; (e) Must be as ductile as possible (by avoiding the use of dense, dry soils, which tends to brittle); (f) Minimum cation exchange capacity (CEC) of 10 meq (Milliequivalents)/100 gr. soil; (g) Leachate compatibility : (no k-value increase); (h) Minimum thickness for MSW: 1.0 m, 0.6 m with Geomembrane; (i) Minimum thickness for industrial /toxic waste: 3-4 m, alternatively Multiple Composite Liner Systems. These criteria are quite complex to investigate because the performance of the liner materials is influenced by many variables such as clay contents, liquate limit, plasticity index, activity, amount of fines, properties of the fines, grading, compaction level, water contents and mineralogy. The overall criteria of clay used as CCLs in sanitary landfill as shown in Figure 2.8.

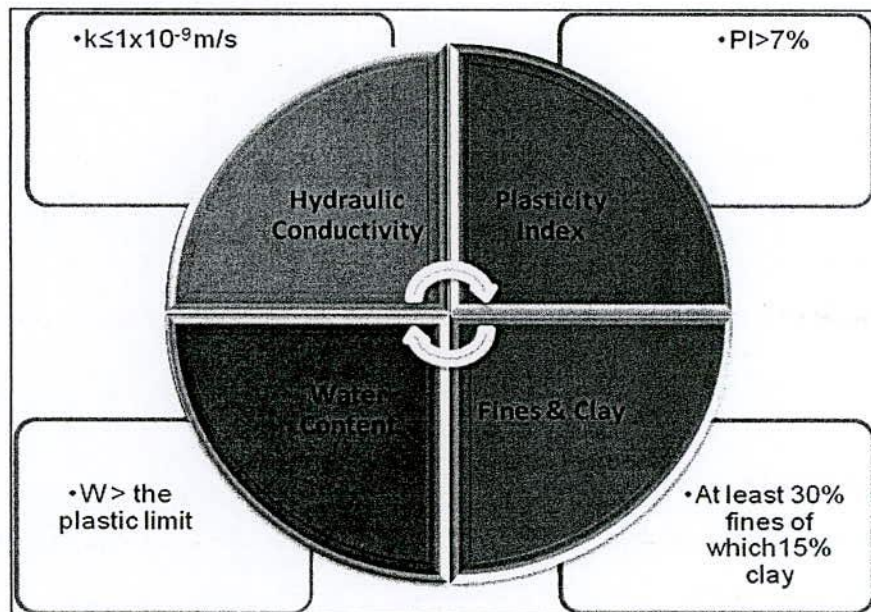


Figure 2.8: Criteria to satisfy the clay as CCL

2.5.3 Liner System of Landfill

The basic liner system used as a single composite barrier system (I) in the engineered landfill shown in Figure 2.9 (a) and serves as: (a) Clay liner and the geomembrane serve as a composite barrier to the movement of leachate and landfill gas; (b) Sand layer serves as the collection and drainage layer; (c) Geotextile layer is used as separation layer to minimize the intermixing of the soil and sand layers and (d) The final soil layer is used to protect the drainage and barrier layers. However, the basic liner system used as a single composite barrier system (II) in the engineered landfill shown in Figure 2.9 (b) and serves as: (a) Specifically designed geonet and geotextile filter cloth are placed over the geomembrane, which, in turn, is placed over a compacted clay

layer; (b) The protective soil layer is placed above the geotextile; (c) The geonet and geotextile function together as the drainage layer to convey leachate to the leachate collection system and (d) The permeability of drainage layer is equivalent to that of coarse sand/gravel.

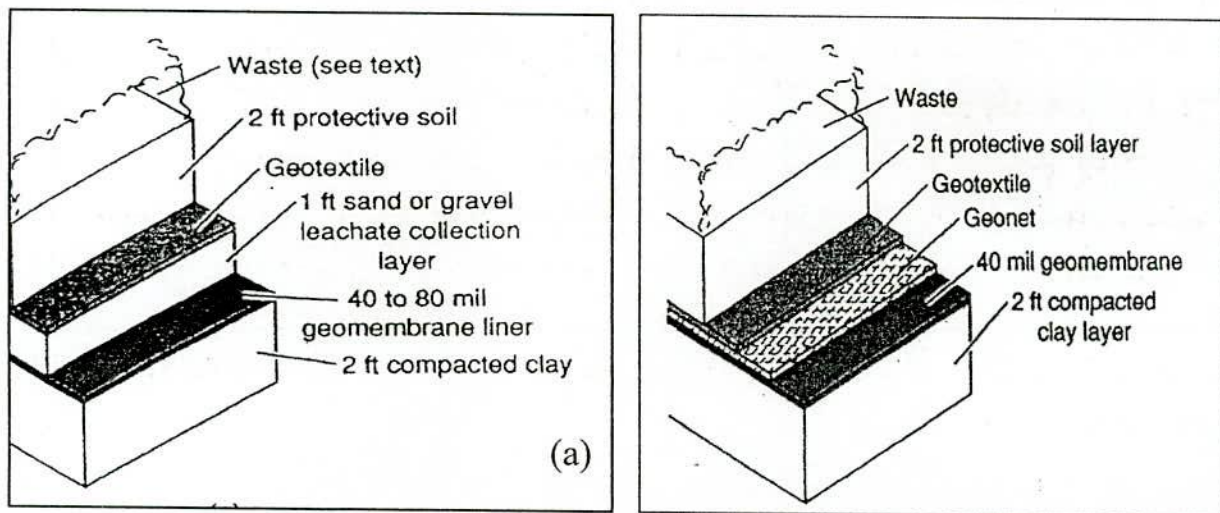


Figure 2.9: Basic liner used as a single composite barrier (a) system (I) and (b) system (II)
(Source: Diaz et al., 1996)

In addition, the basic liner system used as a double composite barrier system (I) in the engineered landfill shown in Figure 2.10 (a) as well as serves as: (a) Two composite liners, commonly identical as the primary and secondary composite liners consisting compacted clay, geomembrane, geonet and geotextile and (b) Primary composite liner is used for the collection of leachate, while the secondary liner serves as a leak detection system and a backup for the primary composite liner. Moreover, the basic liner system used as a double composite barrier system (II) in the engineered landfill shown in Figure 2.10 (b) as well as serves as: (a) Same as double layer composite system with PCL and SCL with exception that the clay layer below the first geomembrane liner is replaced with a geosynthetic clay liner (GCL) and (b) GCL is made from high-quality bentonite clay and an appropriate binding material.

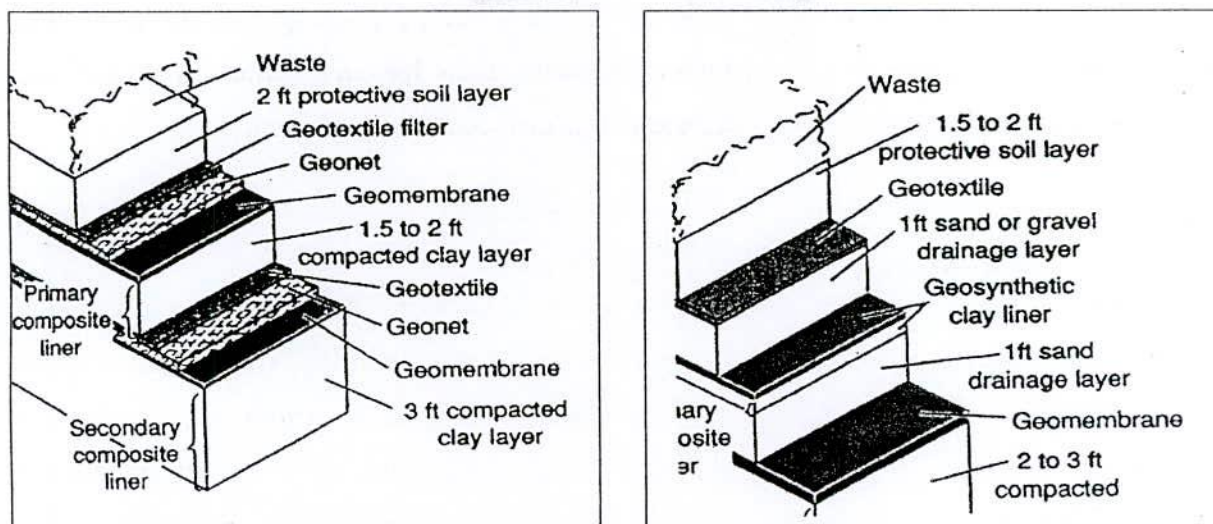


Figure 2.10: Basic liner used as a double composite barrier (a) system (I) and (b) system (II) (Source: Diaz et al., 1996)

2.6 Issues in the Solid Waste Landfill

2.6.1 Leachate as a Potential Output Element

Leachate may be defined as liquid that has percolated through solid wastes and has extracted dissolved and suspended materials. In most landfills, leachate is composed of the liquid that has entered the landfill from external sources, such as surface drainage and rainfall and the liquid produced from the decomposition of the wastes, if any. Landfill leachate is liquid that occasionally leaks from a landfill and enters the environment. This liquid may either exist in the landfill or it may be created after rainwater mixes with the chemical waste in a landfill (Tatsi and Zouboulis, 2002). Leachate is generated due to precipitation, surface run-off, and infiltration or intrusion of groundwater percolating through a landfill. It can cause great environmental problems if it gets into underground water, especially because it has organic matter (both biodegradable and non-biodegradable carbon) ammonia-nitrogen, heavy metals, chlorinated organic and inorganic salts. However, some of these pollutants can be degraded by microorganisms (Wang et al., 2002). The best method of leachate treatment depends on the characteristics of leachate. There are different methods of treatment of leachate, one of which is the phytoremediation process which is suitable for young or “freshly” produced leachates, but it is less efficient for the treatment of “older” leachate. Another method, the physical-chemical process is not suitable for treating young leachate (Ntampou et al, 2006).

Landfill leachate has an impact on the environment because it has very dangerous pollutants such as ammonium nitrogen (NH_4^+-N), biodegradable and refractory organic matter and heavy metals. In fact, the ammonium concentration in leachate found to be up to several thousand mg/L (Li et al., 1999; Wichitsathian et al., 2004). In addition, Landfill leachate cause serious pollution to groundwater and surface waters. It is important to note that the chemical characteristic of leachate varies significantly and is usually different from country to country and from residential to residential area as a function of a number of factors such as waste composition, the degradation degree of waste, moisture content, hydrological and climatic conditions (Wang et al., 2003). Depending on the type of wastes and the reactions between the percolated water and wastes, the leachate may become highly contaminated. The most common reaction process occurring within the wastes are: (a) Dissolution of certain solid forms of waste and subsequent precipitation; (b) Decomposition and disintegration of the solids and (c) Reactions between the original liquids contained in the waste and the percolating water.

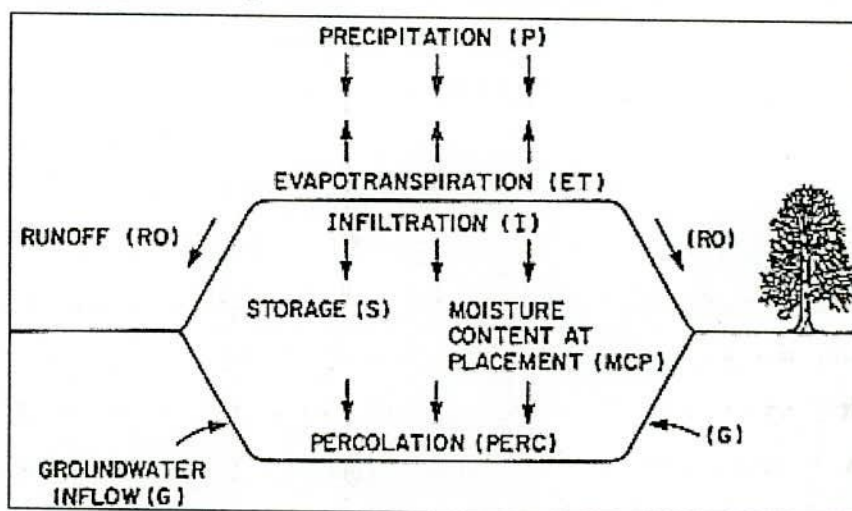


Figure 2.11: Pattern of leachate generation from solid waste landfill

2.6.2 Generation of Leachate and Water Balance

Landfill leachate is a high strength wastewater generated as a result of percolation of the rainwater and moisture through the waste resulting in the solubilization of nutrients and the contaminants within a landfill. Generally, the quantity of leachate is a direct function of the amount of external water entering the landfill. A general pattern of leachate generation is presented in Figure 2.11 (Farquhar, 1989). The leachate generation process consists of several

procedures which are illustrated as: (a) Precipitation falls on the landfill and some of it becomes runoff; (b) Some of the precipitation infiltrates the surface (uncovered refuse, intermediate cover, or final cover); (c) Some of the infiltration evaporates from the surface and (or) transpires through the vegetative cover if it exists; (d) The remainder of the infiltration, remaining after evaporation, and the storage water moves downward as forming percolate and which eventually becomes leachate as it reaches the base of the landfill and (e) Percolation may be increased by infiltration of groundwater. In addition, Figure 2.12 presents the various water inputs and its movement in the landfill leading to leachate production. Figure 2.13 gives the equations for leachate generation and water balance.

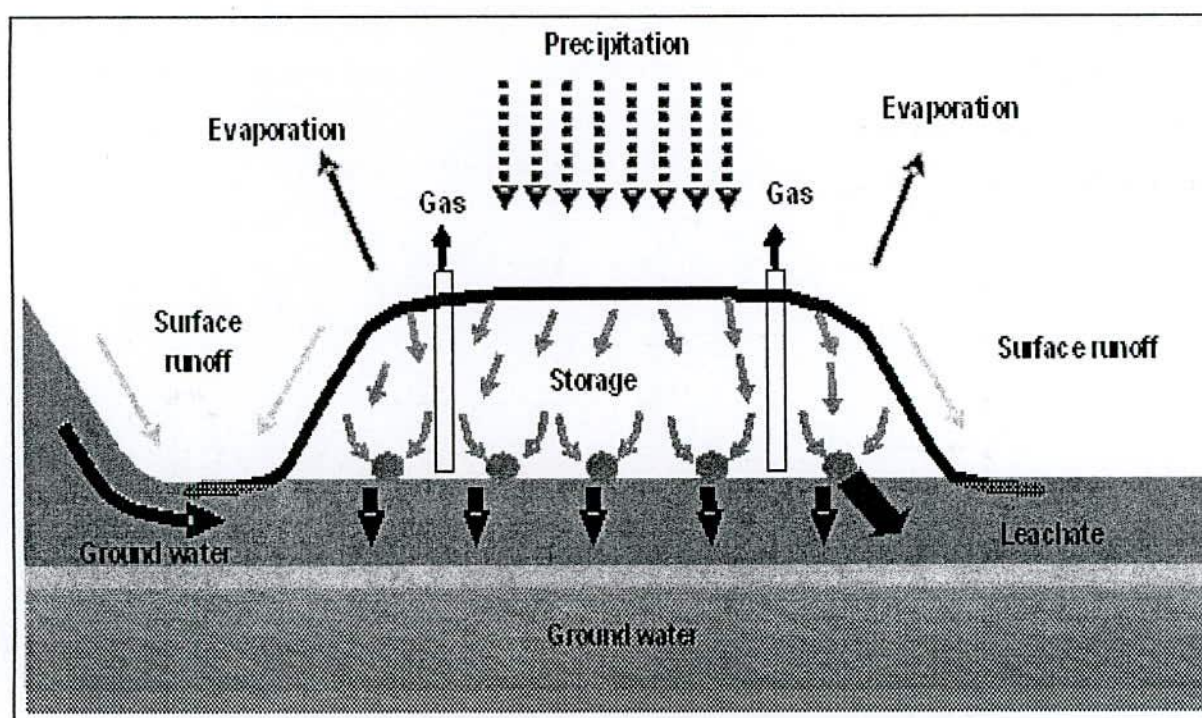


Figure 2.12: Movement of water in the landfill (Source: Tubtimthai, 2003)

The components, which contribute to leachate formation, follow a certain pattern based on the physical processes taking place within the landfill that can be summarized as follows: (a) Precipitation on the landfill initiates runoff while some amount infiltrates into the surface; (b) Some of the infiltration evaporates from the surface and/or transpires through vegetative cover while some part is retained as the soil moisture; (c) The remainder of the infiltration percolates within eventually forming leachate at the base of the landfill and (d) Percolation may be augmented by infiltration of groundwater. The most popular and easiest method employed for the

disposal of solid waste in least developing Asian countries is the landfill method. The composition of municipal solid waste will be changed physically-chemically and phytoremediation ly after landfilling directly, due to weathering conditions. When rain falls it will combine with waste and generate a high contaminant liquid called leachate. The waste in the landfill undergoes changes from a short acidic phase (aerobic) to much longer acidogenic and methanogenic phases (anaerobic decomposition) (Tonni et al, 2005).

Leachate Generation

$$W = R - E$$

W = Quantity of moisture either lost or retained in the waste [mm];

R = Precipitation [mm]; and

E = Evapo-transpiration from the landfill [mm].

Leachate Formation and Water Balance

$$\Delta MC = P - RO - ET - PER$$

ΔMC = Change in the amount of moisture stored in a unit volume of landfill [cm];

P = Quantity of net precipitation (incident precipitation less runoff) per unit area [cm];

RO = Quantity of runoff per unit area [cm];

ET = Quantity of moisture lost through evapo-transpiration per unit area [cm]; and

PER = Quantity of water which percolates through the cover per unit area of soil cover [cm].

Water balance

$$\Delta MC = W_{sw} + W_c + W_p - W_{lfg} - W_v - W_{evp} + W_{leach}$$

ΔMC = Change in the quantity of moisture stored in the landfill [kg/m³];

W_{sw} = Moisture in the incoming solid waste [kg/m³];

W_c = Water in the cover material placed on the waste [kg/m³];

W_p = Water from precipitation and other outside sources (less runoff) [kg/m³];

W_{lfg} = Water utilized in the formation of landfill gas [kg/m³];

W_v = Water lost as saturated vapor with the landfill gas [kg/m³];

W_{evp} = Moisture loss due to evaporation [kg/m³]; and

W_{leach} = Water leaving the landfill (control volume) as leachate [kg/m³].

Figure 2.13: Equations for water balance and leachate formation (Source: Tubtimthai, 2003)

2.6.3 Formation of Leachate

A water balance on the landfill can assess the potential for the formation of leachate. The principle components involved in the water balance are: (a) The water entering the landfill cell from above, the moisture in the solid wastes, the moisture in the cover material, and the moisture in the sludge, if the disposal of sludge is allowed and (b) The water leaving the landfill as part of the landfill gas, the saturated water vapor in the landfill gas, and as leachate. Landfill leachate

formation depends on several phases (Figure 2.14), which are related by changes in solid waste composition. These phases are hydrolysis and acidification (phase I), Initial methane generation (phase II), Stable methane (phase III), Slow-down (phase IV), and Final storage (phase V).

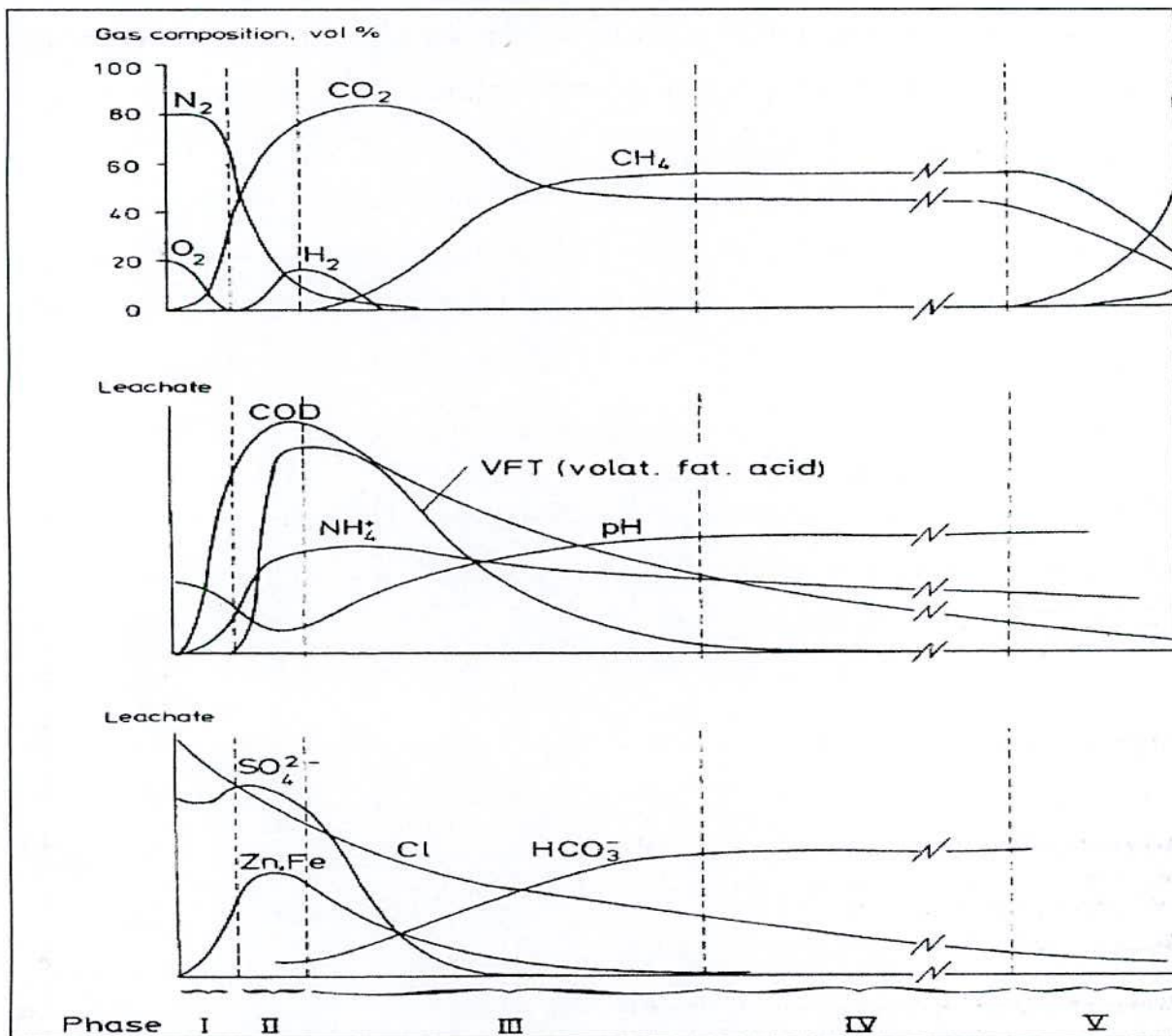


Figure 2.14: Development of gas and leachate in landfill (Source: Christensen and Kjeldsen, 1989)

In Phase I, the decomposition of solid waste by bacteria begin through aerobic process which requires oxygen. In the Phase II, the anaerobic process starts, while the amount of oxygen decreases. The presences of organic acids reduce the pH in the leachate. Also through this stage the methanogenic bacteria starts to grow slowly. Furthermore, the consumption of simple organic compounds helps to produce methane and carbon dioxide within the landfill. Waste decomposition can take many years. The transition from phase II to phase III may not be completed for decades. Phase III is called the acid phase due to the production of acids during the

phase. This stage includes many activities such as the beginning of methane production, growth of methanogenic bacteria which is responsible for degradation of soluble organic compounds in the leachate. Furthermore, the BOD₅, COD and conductivity of leachate will increase due to the dissolution of the organic acids in the leachate. Many inorganic constituents, in particular heavy metals, will be solubilized during this phase due to the low pH of the landfill leachate. The leachate that is produced in phase III has a lower value of pH as well as a lower ratio of BOD₅ to COD. Moreover, both ammonia and nitrogen will be present at higher levels in the leachate. A number of inorganic constituents, for example heavy metals and also many essential substances will be solubilized in this phase. The composition of phase III is distinguished by neutral pH; low concentration of volatile fatty acid, sharply decreasing redox potential, and higher refractory organic matter concentrations. The longest phase is the methanogenic phase which undergoes more stabilization than other phases.

In phase IV a group of microorganisms convert the acetic acids and hydrogen gas to methane and carbon dioxide. The microbes responsible for this reaction are called methanogenic or methanogens. The pH values, due to methanogenic reaction, will rise to more neutral range of 6.8-8. The BOD₅ and COD values of the landfill leachate and the concentration of heavy metals will reduce. Phase V which is the maturation phase starts after the biodegradable organic material. Leachates produced during this phase are characterized by relatively low BOD values and low ratios of BOD/COD. Also, heavy metal, organic compounds and fatty acids are depleted, while the ammonia-nitrogen remains at high level and pH will increase (Diego, 2003).

However, the amount of pollutants in the leachate varies with time. Generally, the biodegradable organics tend to reach peak concentrations in the leachate in the earlier period (months) of leaching and then decreased. On the other hand, some pollutants such as poorly biodegradable organics and heavy metals such as iron tend to persist in the leachate for several years. This is shown in Figure 2.15 (Farquar, 1989). It is also apparent from this data that contaminants are added to the leachate for many years even after the site is closed. Usually, the main reason for the presence of heavy metals in landfill leachate is the lack of awareness among the people. A lot of hazardous waste such as clinical bandages, batteries and medicine are found in the refuse sent to landfills (Hamidi et al, 2003). Heavy metals such as iron, manganese, zinc, chromium, lead, copper and cadmium are present in high concentrations. These minerals can cause pollution to groundwater, surface water and reservoirs (Schwarzbauer et al., 2002; Aziz et al., 2004).

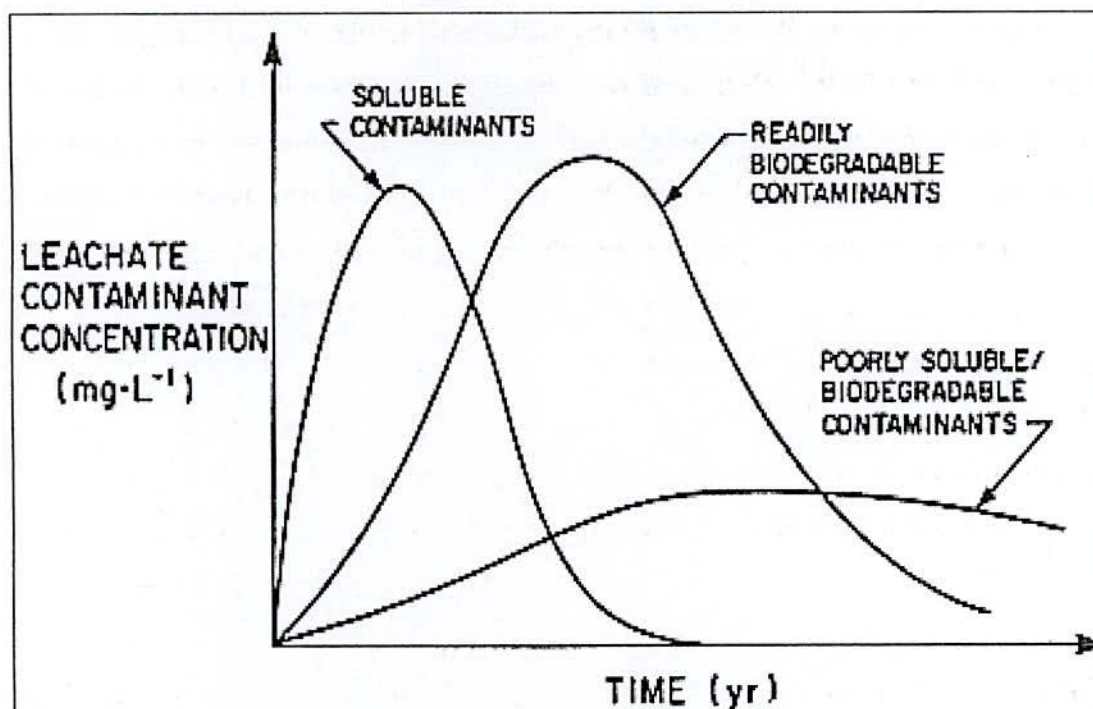


Figure 2.15: Illustration showing the amount of pollutants in the leachate (**Source:** Farquar, 1989).

2.6.4 Composition of Leachate

The composition of leachate is decided by many factors, for example waste composition, site hydrology, the availability of moisture and oxygen, design and operation of the landfill and its age. Many studies indicate that leachate is rich with minerals and many other resources (Christensen et al, 2001; Warith, 2002; Abanades et al., 2001; Rivas et al., 2004). Furthermore, leachate may contain large amounts of organic matter, but also refractory materials and biodegradation materials (Marttinen et al, (2002). Furthermore, leachate can contain hazardous organic substances, e.g. aromatic compounds, chlorinated aliphatic compounds, phenols, phthalates and pesticides (Paxéus, 2000; Baun et al., 2003, 2004).

The operation of landfills poses a great challenge in the production and management of the leachate especially if it is not properly collected, treated, and disposed. It is considered an environmental problem because it is one of the main sources of contamination of soil, ground water, and surface water. The environmental problem is created since leachate contain large quantities of materials like organic matter, ammoniacal - nitrogen, heavy metals, and chlorinated

organic and inorganic compounds (Al-Yaqout et al., 2003). A knowledge of leachate composition and its seasonal variation helps to choose the best method of treatment (Tatsi and Zouboulis, 2002). The old landfills which have a large quantity of organic matters use a combination of techniques because it is more efficient to do so. However, phytoremediation treatment is insufficient for old landfills (Silva et al., 2003). The Table 2.3 shows the typical data on the composition of leachate from new and maturation landfill.

Table 2.3: Typical data on the composition of leachate from new and maturation landfill

Constituent	Value mg/L		
	New landfill (<2 years)		Mature landfill (>10 years)
	Range	Typical	
BOD5 (5-day biochemical oxygen demand)	2,000-30,000	10,000	100-200
TOC (total organic carbon)	1,500-20,000	6,000	80-60
COD (chemical oxygen demand)	3,000-60,000	18,000	100-500
TSS (total suspended solids)	200-2,000	500	100-400
Organic nitrogen	10-800	200	80-120
Ammonia nitrogen	10-800	200	20-40
Nitrate	5-40	25	5-10
Total phosphorus	5-100	30	5-10
Ortho phosphorus	4-80	20	4-8
Alkalinity as CaCO ₃	1,000-10,000	3,000	200-1,000
pH	4.5-7.5	6	6.6-7.5
Total hardness as CaCO ₃	300-10,000	3,500	200-500
Calcium	200-3,000	1,000	100-400
Magnesium	50-1,500	250	50-200
Potassium	200-1,000	300	50-400
Sodium	200-2,500	500	100-200
Chloride	200-3,000	500	100-400
Sulfate	50-1,000	300	20-50
Total iron	50-1,200	60	20-200

Source: Tchobanoglous et al. (1993), Notation: pH has no unit.

Table 2.4 shows the difference in leachate quality which is dependent upon landfill age. The results of recent studies shows that even leachate from young landfills contain low organic concentration (Aziz et al., 2007). The reason for it may be the fact that leachate recirculation method is practiced in many landfills according to Chan et al., (2002). The concentration of chemical materials will change over time. Hence it is difficult to be specific as to concentration of a particular chemical in leachate at a given time. The composition and characteristics of leachate used to determine the kind of leachate treatment methods needed and appropriate.

Table 2.4: Characteristics of different types of landfill leachate

	Young	Intermediate	stabilized
Age of landfill (years)	<1	1-5	>5
pH	<6.5	6.5-7.5	>7.5
BOD/COD	0.5-1.0	0.1-0.5	<0.1
COD(g/L)	<15	3 – 15	<3
NH ₃ -N(mg/L)	<400	NA	>400
TOC/COD	<0.3	0.3 – 0.5	>0.5
Heavy metals (mg/L)	>2	<2	<2

Source: Tchobanoglous et al. (1993)

Table 2.5: Maximum discharge standard for landfill leachate from selected countries

	Maximum discharge standard (mg/L)						
	USA ⁽¹⁾	Germany ⁽²⁾	France ⁽³⁾	Hong Kong ⁽⁴⁾	South Korea ⁽⁵⁾	Malaysia standard (A) ⁶	Malaysia standard (B) ⁷
COD	NA	200	120	200	50	50	100
BOD ₅	NA	20	30	800	NA	20	50
NH ₃ -N	NA	NA	NA	5	50	NA	NA
Total nitrogen	NA	70	30	100	150	NA	NA
Phosphorus	NA	30	NA	25	NA	NA	NA
Cd (II)	0.01	0.1	NA	0.1	NA	0.01	0.02
Cr (III)	NA	0.5	NA	0.1	NA	-	0.05
Cr (VI)	0.05	0.1	NA	NA	NA	-	0.05
Ni (II)	0.013	1	NA	0.6	NA	0.2	1.0
Pb (II)	0.03	0.5	NA	NA	NA	0.1	0.5
Cu (II)	0.07	0.5	NA	1.0	NA	0.2	1.0
Zn (II)	0.3	2	NA	0.6	NA	0.2	1.0
Ag (I)	0.05	NA	NA	0.6	NA	-	-

Source: Imran et al. 2011

There are specific technologies which are used to reduce the concentration of contaminants in the leachate. Treatment methods like physio-chemical treatment, phytoremediation treatment, advanced oxidation process as well as natural systems such as constructed wetlands (Klomjek et al., 2005) and leachate recirculation (Warith 2002) have been developed in recent years. These treatments not only minimize the generation of toxic contaminants from leachate, but also comply with the increasingly stringent discharge standards in different countries (Table 2.5).

2.6.5 Characteristics of Leachate

The variation in leachate quality can be due to a variety of reasons based on the four aspects of andfills, which are: (a) Waste type - its grade of decomposition with possible seasonal variance in its deposal; (b) Landfill environment-waste degradation phase, humidity, precipitation, temperature, etc.; (c) Filling technique-waste compaction, landfill cover and height of landfill layers; and (d) Sampling-method of analysis and point of sample collection. These aspects are interlinked and a combination of the first three categories contributes to the overall variance in leachate quality and characterization, whereas the fourth aspect affects the analysis. Moreover, the changes in the BOD_5/COD , COD/TOC , VS/FS and VFA/TOC ratios of leachate depend greatly on the age of the landfill (Chian and DeWalle, 1976; Kylefors, 1997). Figure 2.16 represents the trend in the variation of leachate over the age. Figure 2.17 shows the trend of leachate quality over the lifetime of a landfill with its different phases.

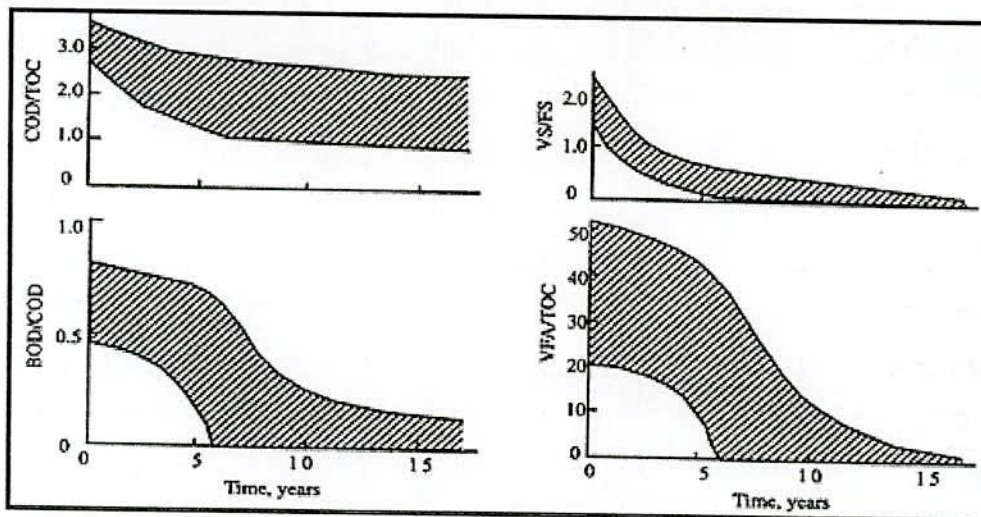


Figure 2.16: Variation of leachate characteristics over time in a landfill (Source: Kylefors, 1997)

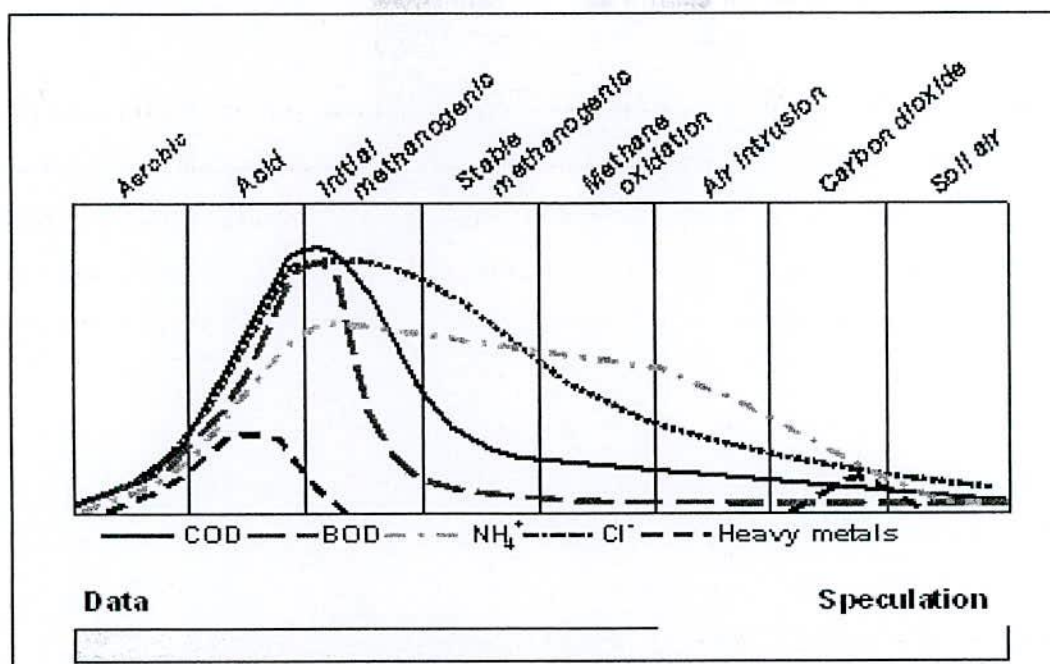


Figure 2.17: Trends in leachate quality over lifetime of a landfill (Source: Tubtimthai, 2003)

During the first few years (<5 years), the landfill is in acidogenic phase and the leachate generated is generally referred to as young or carbon-based leachate due to the higher concentration of organic carbon. Landfill greater than 10 years old are generally in the methanogenic phase and the leachate generated is referred to as old or nitrogen-based (Mavinic, 1988). Ehrig (1998) conducted an extensive study on leachate characterization of 15 landfills ranging from 0 to 12 years in Germany and found the characteristics of leachate in the acidogenic and methanogenic landfill leachate. Table 2.6 presents the general leachate characteristics with age and suitability of treatment options in terms of biodegradable, intermediate and stabilized landfill leachate. Table 2.6 aids in determining the appropriate leachate treatment options. Effectiveness of combined process for the treatment of a leachate produced at specific landfill age has not been considered. Individual treatment options cannot be a long-term solution for leachate as they are not effective in treating that generated at different periods of time and do not adapt to changing characteristics (Pohland et al., 1985). Moreover, the characteristics of leachate generated from deposited MSW in landfill as presented in Table 2.7.

Table 2.6: Relation between landfill age, leachate characteristics and treatment

Landfill Age (years)	< 5 (young)	5 to 10 (medium)	> 10 (old)
Leachate Type	I (Biodegradable)	II (Intermediate)	III (Stabilized)
pH	< 6.5	6.5 - 7.5	> 7.5
COD (mg/L)	> 10,000	< 10,000	< 5000
COD/TOC	< 2.7	2.0 - 2.7	> 2.0
BOD ₅ /COD	< 0.5	0.1 - 0.5	< 0.1
VFA (% TOC)	> 70	5 - 30	< 5
Process	Treatment Efficiency		
Phytoremediation Treatment	A	B	C
Chemical Oxidation	B-C	B	B
Chemical Precipitation	B-C	B	C
Activated Carbon	B-C	A-B	A
Coagulation-flocculation	B-C	A-B	A
Reverse Osmosis	C	A	A

Source: Amokrane et al., 1997; A=Good; B=Fair; C = Poor;

Table 2.7: Different characteristics of leachate generated from deposited MSW

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

Source: Tchobanoglous et al. (1993)

2.6.6 Control of Leachate Movement

Cleaning of polluted ground water is very expensive. Hence, using the best ways for leachate treatment in order to keep the ground water safe and clean is very essential. Currently, landfill management is governed by strict rule, design, and construction instructions in order to prevent the migration of leachate into the ground water. The design of the lining system offers less permeability in the movement of leachate into ground water. The lining materials are mostly made of low-permeability soils (typical clays) or synthetic materials (e.g. plastic). Sometimes the landfill design has more than one liner. Leachate collection systems (LCS) consist of several layers with different types of materials. Figure 2.18 shows the components of a collection system (listed from the solid waste layer downward) (Debra and Manoj, 2000).

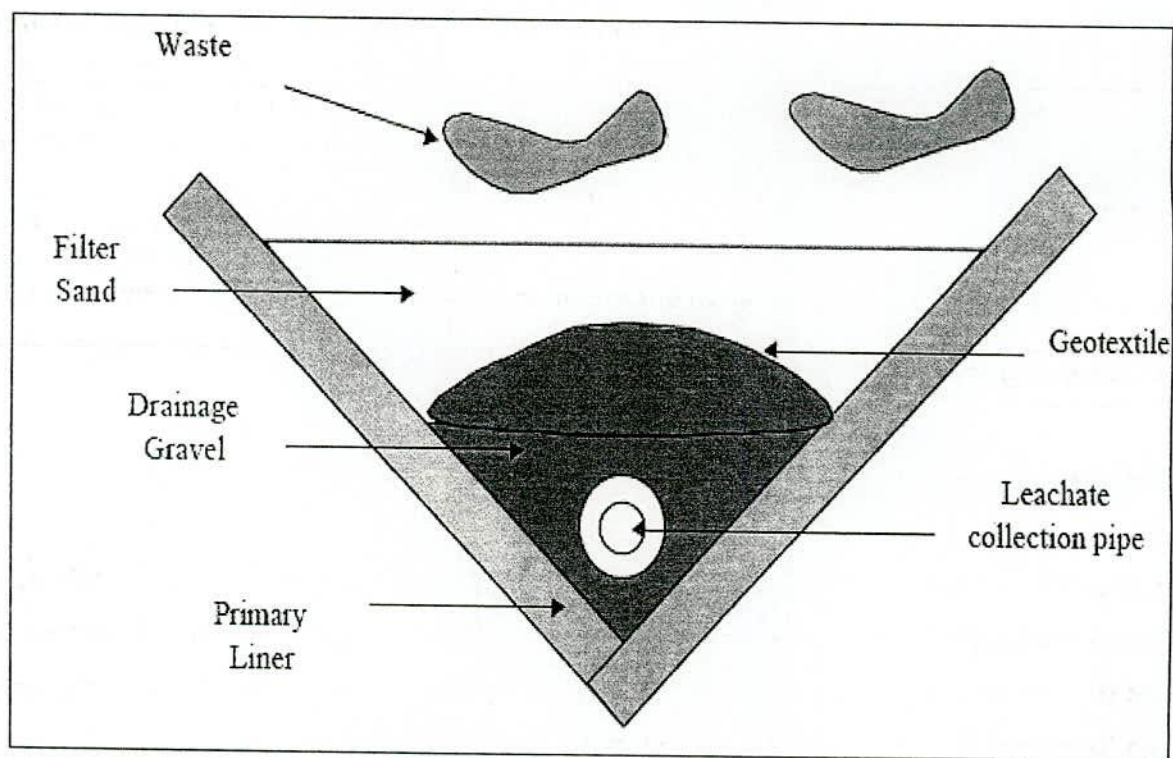


Figure 2.18: Schematic diagram showing a cross section of typical LCS

As leachate percolated through the underlying strata, many of the chemical and phytoremediation constituents are removed by the filtering and absorptive action of the material composing strata. In general, the extent of this action depends on the characteristics of the soil, especially the clay content. To prevent percolation, the best practice is elimination or containment. The use of clay as a liner is the favored method of reducing or eliminating of percolation of leachate from landfills

for its ability to adsorb and retain many of the chemical constituents and resistance to flow. The general guidelines for the control of leachate as presented in Table 2.8. The use of combination composite geosynthetic and clay liners is gaining popularity, especially because of the resistance afforded by geomembranes to the movement of both leachate and landfill gases.

Table 2.8: Guidelines for leachate control facilities

Item	Comments
Synthetic flexible membrane liners (FMLs)	Liners must be designed and constructed to contain fluids, which include wastes and leachates. These liners are installed to cover all natural geologic materials that are in contact with waste or leachate at a waste management unit.
Bottom seals	No specific regulations exist governing the application of bottom seals at MSW waste management units. Design, construction, and installation of bottom seals are subjected to the approval of local enforcement agencies.
Artificial earthen liners	Clay liners for MSW waste management units must be a minimum of 1 ft thick, relative compaction of at least 90 percent and hydraulic conductivity, $k < 10^{-9}$ m/sec.
Subsurface barriers	A subsurface barrier is intended to be used in conjunction with natural geologic materials to assure that lateral permeability standard are satisfied. It must be a minimum thickness of 2 ft for clay material or a minimum of 40 mils for synthetic materials.

Source: Tchobanoglous et al. (1993)

2.6.7 Factors Affecting Leachate Composition

The composition of leachate is influenced by various factors-seasonal variations, landfill age, waste composition, geological characteristics and landfilling techniques. These factors interlinked with one another have potential to influence the leachate quality, thereby producing an integrated effect on its composition. Some important factors are discussed in the sections below (Pohland et al., 1999).

2.6.7.1 Climatic Variation

The influence of climatic conditions over changes in leachate quality and quantity should be considered while designing a landfill for disposal of MSW and proposing a treatment scheme for leachate. Rainfall acts as a medium of transportation for leaching and migration of contaminants from a landfill. It also provides the required moisture for methane production and phytoremediation activity. Normally, leachate is produced when the moisture content in the

landfill exceeds the field capacity. The quantity is found to be comparatively low during the dry season. When the rainfall begins, initially it takes some time to reach the field capacity, which once reached, leachate production increases. In hot and humid climates, leachate production is much higher than that experienced in hot arid regions. On the other hand, high rainfall leads to increased leachate production and reduced leachate strength due to dilution. The quality of leachate produced may be regarded as proportional to the volume of water percolating through the landfilled waste. Reduction in the quantity of water entering a landfill cell is therefore of great importance in reducing the rate of leachate generation (Tatsi and Zouboulis, 2002). Researchers have measured the temporal variation in leachate production to be 2-45 L/s which depends largely on the precipitation over the landfill (Martin et al., 1995). The influence of seasonal variation in the leachate quality and quantity varies from place to place and is also influenced by other factors. It is necessary to consider the hydrological factors and leachate quality data while proposing a treatment scheme to avoid problems of environmental deterioration caused by direct disposal.

2.6.7.2 Landfill Age

Sampling and analysis of leachate are important for assessing changes in its quality over a period of time. The differentiation of landfill age can be made based on dominating degradation phase and the composition of the resultant leachate (Leikam and Stegmann, 1999). The climatic variation of leachate quality and quantity depends on its age. The BOD₅/COD ratio that depicts the biodegradability of the leachate has a decreasing trend with age from a readily biodegradable ratio of 0.5 to a higher fraction of poor degradability with a value of 0.1 or less. Table 2.9 represents few of the analytical parameters of pollution in a young and stabilized landfill leachate.

Table 2.9: Pollution parameters in young and old leachate

Parameters	Young Landfill Leachate		Stabilized Landfill Leachate	
	Mean	Range	Mean	Range
BOD ₅ /COD	0.54	0.41 - 0.97	0.26	0.05 - 0.64
pH	6.20	4.88 - 6.7	7.90	7.30 - 8.80
SO ₄ ²⁻ /Cl ⁻	0.73	0.08 - 3.4	0.06	0.02 - 0.15
ORP (mV)	-22.60	-53 to -11	154.00	110 -218
VS/TS	0.48	0.21 to 0.66	0.28	0.22 - 0.37

Source: Tatsi and Zouboulis, 2002

The fresh leachate (from a young landfill) possesses high proportion of organic material, which can be removed by phytoremediation processes. Owing to phytoremediation reactions, fresh

leachate is expected to produce an acidic pH and an unpleasant smell. The decrease in VS/TS ratio from fresh to old leachate also suggests that stabilized leachate is less amenable to phytoremediation treatment as the landfill age increases. The redox potential and pH increases with the stabilization process. A color change from light yellow to dark brown or black is also observed due to iron oxidation from ferrous to ferric iron, resulting in an increase in turbidity. Figures 2.19 (a) and (b) show the variation of COD and $\text{NH}_4\text{-N}$ with the age of the landfills. There is a decreasing trend in emission of these two parameters as the landfill matures owing to the stabilization of the waste within.

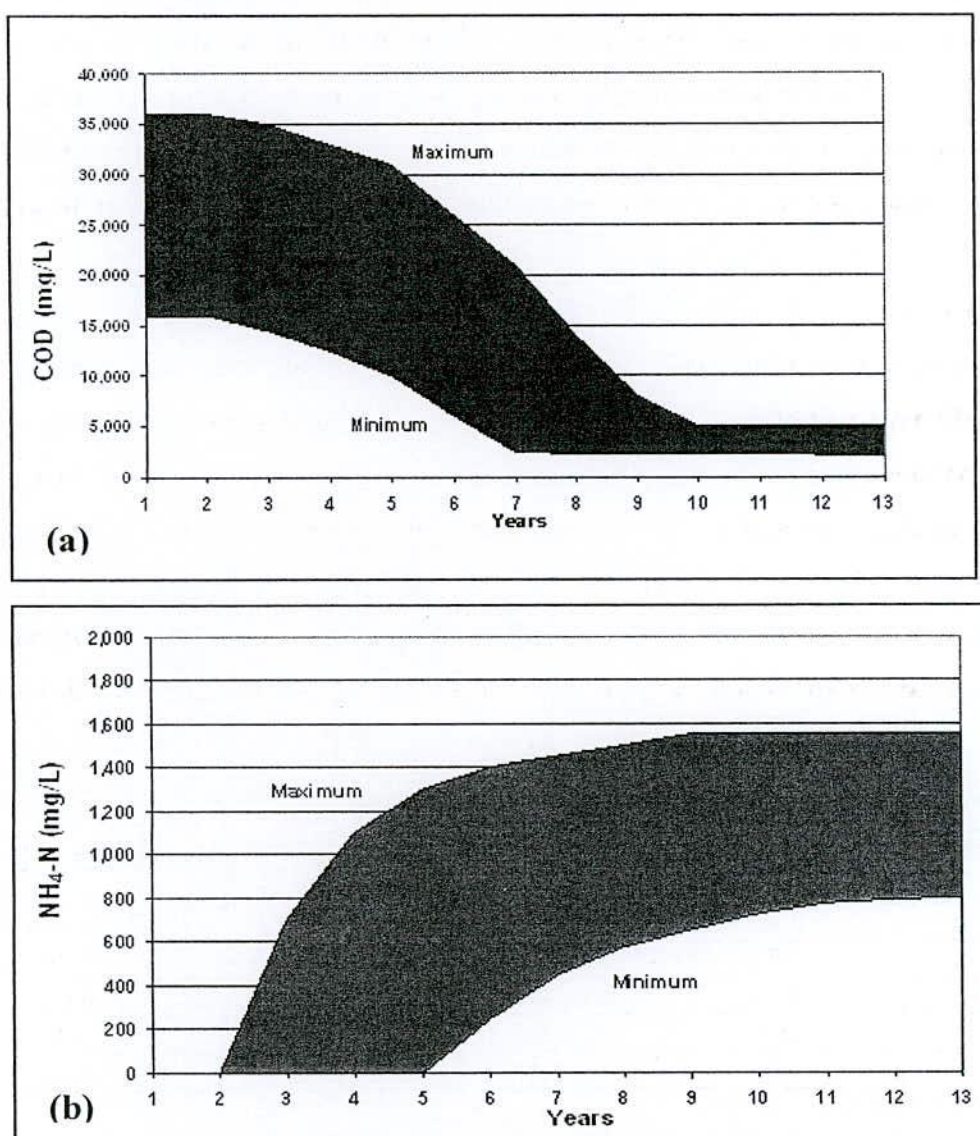


Figure 2.19: Variation of (a) COD and (b) $\text{NH}_4\text{-N}$ with landfill age (Source: Ehrig, 1983)

2.6.7.3 Composition of MSW

The leachate quality is significantly affected by the composition of refuse. Organic material present in the waste mainly comprise of kitchen waste while the inorganic constituents consist of plastic, glass, metal, ash, silt etc. The leachate composition depends upon the ratio of organic and inorganic components present in the waste disposed in the landfill. It is estimated that approximately one-half of the municipal solid waste is typically composed of cellulose and hemicellulose (Barlaz et al., 1989), which are considered readily degradable in the environment. The organic content leached is as a result of hydrolysis and degradation of higher molecular weight organic compounds by the microorganisms present in the waste. However, it has been shown that readily degradable refuse components can sometimes persist for surprisingly long periods in landfills owing to several environmental factors that limit the microbial growth (Suflita et al., 1992; Gurijala and Suflita, 1993). The composition of municipal solid waste in larger cities of China is different from the smaller cities. The organic components contribute about 31-36 % whereas inorganic components contribute to about 60% of the total solid waste. Comparison between different regions in China shows that there is more organic compound in South China than that in North China because the temperate region in the north uses coal as fuel and for domestic heating (Kylefors, 1997).

2.6.7.4 Filling Height

The surface to volume ratio of the waste in landfill has an impact over the infiltration, heat transfer and gas exchange occurring within the landfill (Noble and Arnold, 1991). It is expected that an increase in landfill height may limit the affect of seasonal variation in the leachate composition and can preserve the heat from the microbial action to enhance further degradation. However, aerobic conditions can be hindered due to limitations in gas transfer. Another important consideration is the rate at which the height of the landfill is reached. Kylefors, (1997) suggested that an increase in height of 4 m per year would increase the BOD₅ and COD concentrations to an extent in which the transition from acidogenic to methanogenic conditions would be delayed.

2.6.7.5 Density

Low-density waste has a larger volume of air infiltrating through the landfill that promotes aerobic degradation. This enhances decomposition of the easily degradable waste fractions and elevates temperature within the landfill, which in turn can improve the conversion of waste, thus

producing a better quality leachate. A prolonged aerobic phase can also lead to a drought condition within the landfill and reduce degradation rates. The reduction in degradation can also be attributed to the compaction achieved in the landfill. Pretreatment of the waste helps in compaction but the plastic content restricts the compaction to 400-500 kg/m³ as cited by Rnaweera and Tränkler (2001) for Phittsanulok landfill in Thailand. Chang (1993) observed that simple shredding of MSW assisted in increasing the density from 420-810 kg/m³.

2.6.7.6 Bottom liners and top covers

The bottom liners are selected to prevent seepage of leachate into the aquifers and water courses, whilst top covers aid in maintaining moisture within the fill as well as limit infiltration, thus slowing down the degradation process.

2.6.8 Factors Affecting Leachate Characteristics

Leachate quality is highly variable. The variation of leachate quality in MSW consignment landfill can be attributed to many interacting factors such as the composition and depth of MSW; decomposition and age of MSW; degree of compaction; landfill design and operation; liner (top and base) design and operation; MSW filling procedures; the availability of moisture content; available oxygen; rate of water movement (fluid addition) and temperature (Qasim and Chiang, 1994).

2.6.8.1 Decomposition of MSW

It is well recognized that there are three general phases of decomposition of MSW deposited in landfill (McBean et al., 1995; Qasim and Chiang, 1994). The aerobic phase immediately after waste placement is dominated by aerobic bacteria present in the waste at placement. During this phase the amount of leachate reaching the base of the landfill (i.e. reaching the collection system) is limited since the waste has not yet reached field capacity and much of the water infiltrating the waste, is taken up by the waste, which serves to increase the water content of the waste.

After oxygen has been depleted, facultative anaerobes tend to dominate the decomposition process (McBean et al., 1995; Qasim and Chiang, 1994). This phase that is marked by high concentrations of volatile fatty acids (VFA's) and high biochemical and chemical oxygen demand (BOD₅ and COD). The third phase of decomposition occurs when anaerobic methanogenic

bacteria becomes dominant (McBean et al., 1995). The consumption of VFA's, produced during the acid anaerobic phase, increases the pH to between pH 7 and 8 (Farquhar, 1989).

2.6.8.2 Age of MSW Deposited in Landfill

Leachate quality is greatly influenced by the length of time which has elapsed since deposition of MSW in landfill. Variations in leachate quality with age should be expected throughout most of the landfill life because organic matter will continue to undergo stabilization (Qasim and Chiang, 1994). The quantity of chemicals in the MSW is finite and, therefore, leachate quality reaches a peak after approximately two or three years followed by a gradual decline in ensuing years (McBean et al., 1995; Lu et al., 1985). Generally, leachate from new landfills will be high in BOD₅ and COD and will then steadily decline, leaving off after about 10 years (Akyurek, 1995). All contaminants do not peak at the same time. Due to their initially biodegradable nature, organic compounds decrease more rapidly than inorganic with increasing age of the landfill (Chain and DeWalle, 1976). Inorganic are only removed as a result of washout by infiltrating rainwater (Qasim and Chiang, 1994). Organic compounds, however, decrease in concentration through decomposition as well as washout.

2.6.8.3 Fluid Addition

The rate of fluid addition (infiltration) is dependent on several factors including but not limited to: rate of precipitation; presence of landfill cover; types of materials used in landfill cover; fluid losses due to runoff; evapotranspiration and storage (Qasim and Chiang, 1994). The rate of infiltration affects initial production of leachate, rate of leachate generated, and the rate of decomposition within the waste. Moreover, the rate of waste decomposition is partially dependent on the waste moisture content and infiltration rate (palmisano and Barlaz, 1995; Qasim and Chiang, 1994). A study by Blakey et al. (1992) reported that increasing the rate of fluid addition (infiltrating of precipitation) within the experimental landfill cells, decreased the time to initial leachate production and increased the rate at which organic material was consumed within the waste.

Moisture content is the most significant factor influencing waste stabilization and leachate quality (AL-Meshan et al., 2002). Moisture addition has been demonstrated repeatedly to have a stimulating effect on methanogenesis (Barlaz et al., 1989), although some researchers indicate that it is the movement of moisture through the waste as much as it is water addition that is

important (Klink and Ham, 1982). Moisture within the landfill serves as a reactant in the hydrolysis reactions, transports nutrients and enzymes, dissolves metabolites, provides pH buffering, dilutes inhibitory compounds, exposes surface area to microbial attack, and controls microbial cell swelling (Noble and Arnold, 1991). Lu et al. (1985) stated that high moisture flow rates can flush soluble organics and microbial cells out of the landfill and in such cases microbial activity plays a lesser role in determining leachate quality. Also, high moisture application rates can remove the majority of waste contaminants early in the life of the landfill. Under low flow rate of water conditions, anaerobic microbial activity is the significant factor governing leachate organic strength (McBean et al., 1995). The quantity of moisture is important because it directly affects stabilization rates within the landfill. Sulfita et al. (1992) and Miller et al. (1994) both noted the important role of moisture in supporting methanogenic fermentation of MSW when examining samples removed from operating landfills. Relatively dry landfills (i. e. 20 to 40 percent water) have very slow stabilization rates because there is only small quantity of moisture to support phytoremediation degradation. Recommended moisture content reported in the literature ranges from a minimum of 25 percent (wet basis) to optimum levels to 40 to 70 percent (Barlaz et al., 1989; Chen and Bowerman, 1974).

2.6.8.4 Materials used in Landfill Cover

Waste is landfilled over a period of time that may last as 20 years or more. Considering the decomposition processes with respect to time, it is expected that separate cells containing the same composition of deposited MSW will be at different stages of decomposition and the amount of generating contaminated leachate is vary (Armstrong and Rowe, 1999). Moreover, the leachate generating rate from the deposited MSW also depends on the types of materials used as a daily top cover because of infiltrating of rainwater (Palmisano and Barlaz, 1995; Qasim and Chiang, 1994)). Ham and Bookter (19982) studied the effect of placing of landfill cover after the deposition of waste. Two lysimeter cells (Cell 3 and Cell 4) were constructed for this portion of the study. Cell 3 had a soil cover over the waste lift, while Cell 4 was left uncovered. The initial lift of waste generated a peak COD of about 30,000 mg/L, in both the Cell 3 and 4, after approximately 4 to 5 months of operation, which corresponded to the regular production of significant amounts of leachate. After leachate COD had remained steady for a significant period of time. In addition, 12 months after the waste placement, COD rise sharply in Cell 4 (to approximately 15,000 mg/L) but Cell 3 did not, which suggests that the soil cover in Cell 3 played a role in leachate attenuation.

2.6.8.5 Sulfate to Chloride Ratio and pH

The value of pH is greatly influenced by the ratio of sulfate and chloride concentration. A decrease in the sulfate to chloride concentration ratio due to a rapid decrease in sulfate concentration while the chloride concentration declines more slowly. The rapid decrease in the concentration of sulfate is a result of predominately anaerobic conditions in the landfill under which sulfate is reduced to sulphide (Chain and DeWalle, 1976). Unlike the sulfate concentration, pH increases with time, which reflects the decrease in concentration of the partially ionized free volatile fatty acids (VFA's) (Chain and DeWalle, 1976).

2.7 Management of Leachate

The collected leachate is managed by the process of: (a) Recycling; (b) Evaporation; (c) Spray disposal; (d) Wetlands treatment and (e) Discharge to municipal wastewater collection systems.

2.8 Collection Facilities of Leachate

Leachate collection accomplished by a series of sloped terraces and a system of collection pipes. Perforated pipes are placed in each channel to convey the collected leachate to a central location to remove for treatment or reapplication. A typical view of leachate collection system is shown in Figure 2.20. The cross slope of terraces is usually 1 to 5 %, slope of the drainage channels is 0.5 to 1.0 %. The cross slope and flow length of the terraces determine the depth of leachate above the liner. The slope and maximum length of the drainage channel is selected based on the capacity of the drainage facilities. The detailed of the leachate collection pipe as shown in Figure 2.21.

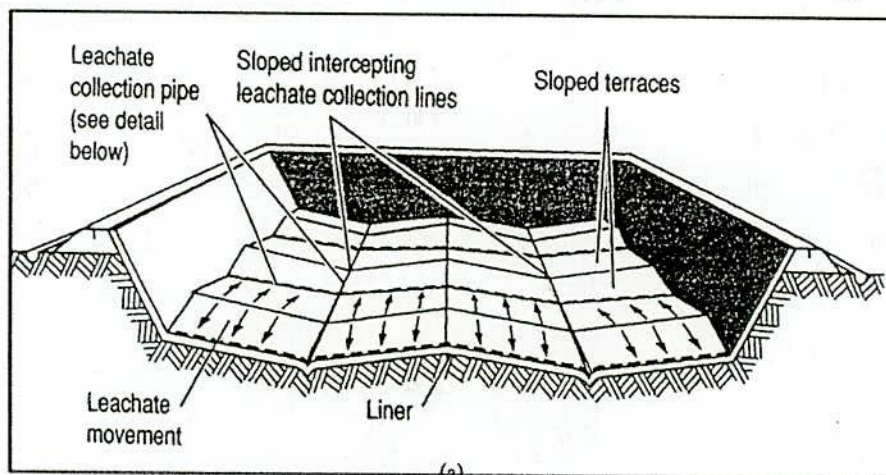


Figure 2.20: Leachate collection system with graded terrace

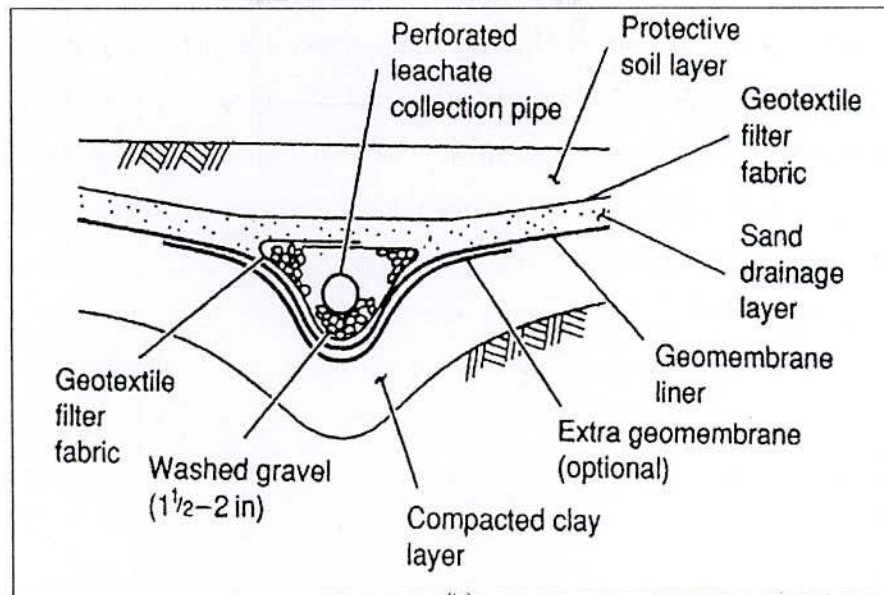


Figure 2.21: Detail of typical leachate collection pipe

2.9 Treatment Facilities of Landfill Leachate

Leachate treatment is dependent on the quality and quantity of the leachate input, discharge limits or removal efficiency requirements, quantity of residual products and their management, site location and economics. Generally, high organic and ammonia loads are the key factors in leachate treatment (Heavy, 2003). The feasibility of treating leachate to COD levels less than 1,000 mg/L is uncertain, since at these values COD is primarily composed of humic and fulvic acids. The effect of these substances on aquatic life of receiving waters is dependent extensively on specific cases. While developing a treatment sequence for leachate to be discharged into a river, Robinson et al. (2002) reported that COD levels of about 500 mg/L comprising humic and fulvic acids did not adversely affect aquatic life. High ammonia and phosphorus deficiency in leachate hamper the efficiency of phytoremediation treatment. A general consensus among researchers is that high nitrogen levels are also hazardous to receiving waters and need to be removed prior to discharge. This is generally carried out through phytoremediation nitrification-denitrification processes for young leachate and through physico-chemical processes in the stabilized leachate.

Leachate varies widely in quantity and in composition from one place to another (Kennedy et al., 1988). Such a variable nature along with other factors make the applicability of a treatment

method highly dependent on leachate characteristics and tolerance of the method against changes in leachate quality (Henry et al., 1982). The success of treatment depends also on the characteristics of the leachate and age of the landfill. Phytoremediation and physical/chemical treatment processes, land treatment systems and co-treatment with municipal wastewater can accomplish leachate treatment. Table 2.10 compares the performance of physical, chemical and phytoremediation treatment on different aged leachate.

Several wastewater treatment processes have generally been used to treat leachate (Amokrane et al., 1997). The major phytoremediation treatment processes comprise aerobic and anaerobic while physical and chemical treatment processes comprise oxidation, coagulation-flocculation, chemical precipitation, activated carbon absorption and membrane processes.

Table 2.10: Comparative performance of various treatment processes for leachate treatment

Treatment Process	Young <5years	Medium 5-10 years	Old >12 years	Metals	VOC	Nitrogen	Priority Pollutants	Solids
Physical								
Natural evaporation	A	A	A	A	A	A	A	A
Floatation	D	D	D	B	B	D	B	A
Air stripping	D	D	D	D	A	A	B	D
Filtration	D	D	D	A	D	D	D	A
Membrane processes	A	A	A	A	B	A	A	A
Chemical								
Coagulation/precipitation	C	B	C	A	D	C	D	A
Chemical Oxidation	C	B	B	D	D	D	A	D
Ion exchange	C	B	B	A	D	B	D	A
Carbon adsorption	C	B	A	D	A	D	A	D
Phytoremediation								
Aerobic suspended growth	A	B	C	A	A	B	B	B
Aerobic fixed film	A	B	C	A	A	B	B	B
Anaerobic suspended growth	A	B	C	A	A	B	B	B
Anaerobic fixed film	A	B	C	A	A	B	B	B

Source: Qasim and Chiang, 1994; VOC- Volatile Organic Compounds; A- Good; B- Fair; C- poor; D-Not applicable;

Leachate can be treated by three main methods: physical, chemical and phytoremediation treatments shown in Figure 2.22. Treatment can be a combination of two or three of the above methods. Air-stripping, adsorption are major physical leachate treatment methods (Amokrane et al., 1997; Bohdziewicz et al., 2001; Morawe et al., 1995; Trebouet et al., 2001), while the other methods such as coagulation, flocculation, chemical precipitation, chemical and electrochemical oxidation methods are the common chemical methods used for the landfill leachate treatment (Amokrane et al., 1997; Ahn et al., 2002; Chiang et al., 2001; Lin and Chang, 2000; Steensen, 1997; Marttinen et al., 2002). This combination method is most popularly used to achieve excellent leachate treatment efficiency (Figure 2.20) (Heyer and Stegmann, 2000).

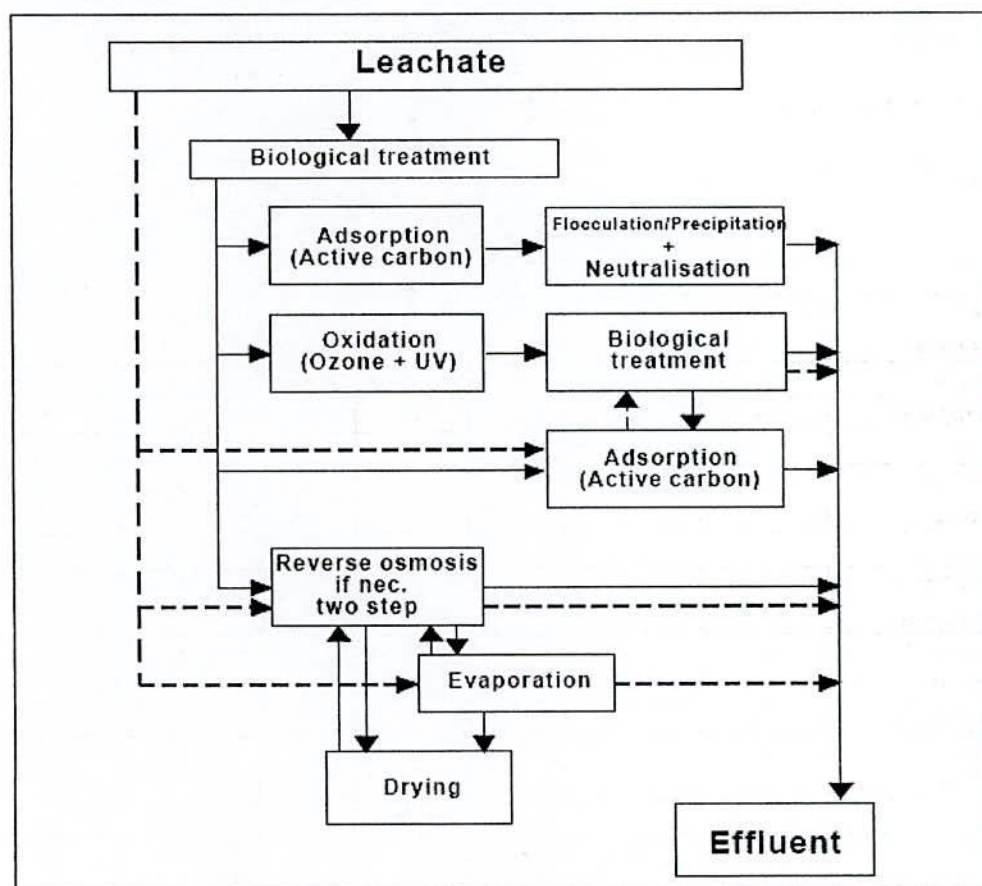


Figure 2.22: Scheme of often used methods and combinations for leachate treatment (source: Heyer and Stegmann, 2000)

The selection of the best treatment methods is controlled by several factors such as (Heyer and Stegmann, 2000): (a) Leachate characteristics- organic and inorganic contents; (b) Hazardous nature-concentration of organic, inorganic and toxic metals; (c) Degree of treatment-leachate

characteristics, legal requirements, and discharge alternatives; (d) Treat-ability studies, available experimental data and applicable technology and (e) Cost - availability of funds.

In this section, a review of the various treatments is mentioned in details. The leachate treatment processes have different effectiveness depending on the leachate from landfill of different ages. The phytoremediation treatment process has been found to be effective on leachate from young landfills (Loudidou and Zouboulis, 2000). Sometimes leachate can be treated by traditional package treatment plants on site, but this kind of treatment is expensive to build and operate (Liehr et al., 2000). An effective type of treatment is the phytoremediation process, especially for young leachate which has mainly volatile fatty acids, but it is not effective on old leachate because in many cases high COD value was found in leachate after phytoremediation treatment (Trebouet et al., 2001).

Table 2.11: Commonly used landfill leachate treatment processes

Treatment Process	Application	Comment
<i>Phytoremediation Process</i>		
Activated sludge	Removal of organics from leachate	Deforming additive may be necessary; separate clarifier needed
Sequencing batch reactors	Removal of organics	Similar to activated sludge, but no separate clarifier needed; only applicable to relatively low flow rates
Aerated stabilization basins	Removal of organics	Requires large land area
Fixed film processes (trickling filters, rotating phytoremediation contactors)	Removal of organics	Commonly used on industrial effluents similar to leachates, but untested on actual landfill leachate
Anaerobic lagoons and contactors	Removal of organics	Lower power requirements and sludge production than aerobic systems; required heating; greater potential for process instability; slower than aerobic systems
Nitrification/ denitrification	Removal of nitrogen	Nitrification/ denitrification can be accomplished simultaneously with the removal of organics
<i>Physical/Chemical</i>		
Sedimentation/flotation	Removal of suspended matter	Of limited applicability alone; used in conjunction with other treatment processes
Filtration	Removal of suspended matter	Useful only air polishing step
Air stripping	Removal of ammonia or volatile organics	May require air pollution control equipment
Steam stripping	Removal of volatile organics	High energy costs; condensate steam requires further treatment
Adsorption	Removal of organics	Proven technology; variable costs depending on leachate
Ion exchange	Removal of dissolved inorganic	Useful only as a polishing step
Ultra filtration	Removal of bacteria and high-molecular-weight organics	Subjected to fouling; of limited applicability to leachate
Reverse osmosis	Dilute solutions of inorganic	Costly; extensive pretreatment necessary
Neutralization	pH control	Of limited applicability to most leachates
Precipitation	Removal of metals and some anion	Produces a sludge, possibly requiring disposal as a hazardous waste
Oxidation	Removal of organics; detoxification of some inorganic species	Works best on dilute waste streams; use of chlorine can result in formation of chlorinated hydrocarbons
Evaporation	Where leachate discharge is not permissible	Resulting sludge may be hazardous; can be costly except in arid regions
Wet air oxidation	Removal of organics	Costly; works well on refractory organics

Source: Tchobanoglous et al., 2002

2.9.1 Phytoremediation Treatment

The most common practice for leachate treatment worldwide is phytoremediation treatment. Phytoremediation systems can be divided in anaerobic and aerobic treatment processes. Both can be realized by using different plant concepts. A combination of aerobic, anaerobic and anoxic processes is the main processes used for phytoremediation treatment (Im et al. 2001). Phytoremediation treatment of leachate usually results in low treatment efficiencies because of high COD, high ammonium-N content and also presence of toxic compounds such as heavy metals (Fikret et al., 2003). Most of organic materials in leachate from young landfill (<2yrs) is easily biodegradable by aerobic phytoremediation oxidation. However, some adjustment needs to be made to the pH by adding nutrient to optimize the process. The most common aerobic phytoremediation treatment methods are (Renou et al., 2008): (a) Aerated lagoons; (b) Activated sludge plants; (c) Rotating phytoremediation contactors (rbc); (c) Trickling filter; (d) Sequential batch plant; (e) Co-treatment with sewage; (f) Parts of the landfill body used as a reactor and (g) Anaerobic filter. Some of the phytoremediation treatment options are described as diagrammatically in the Figures 2.24 to 2.27 as stated in Table 2.11.

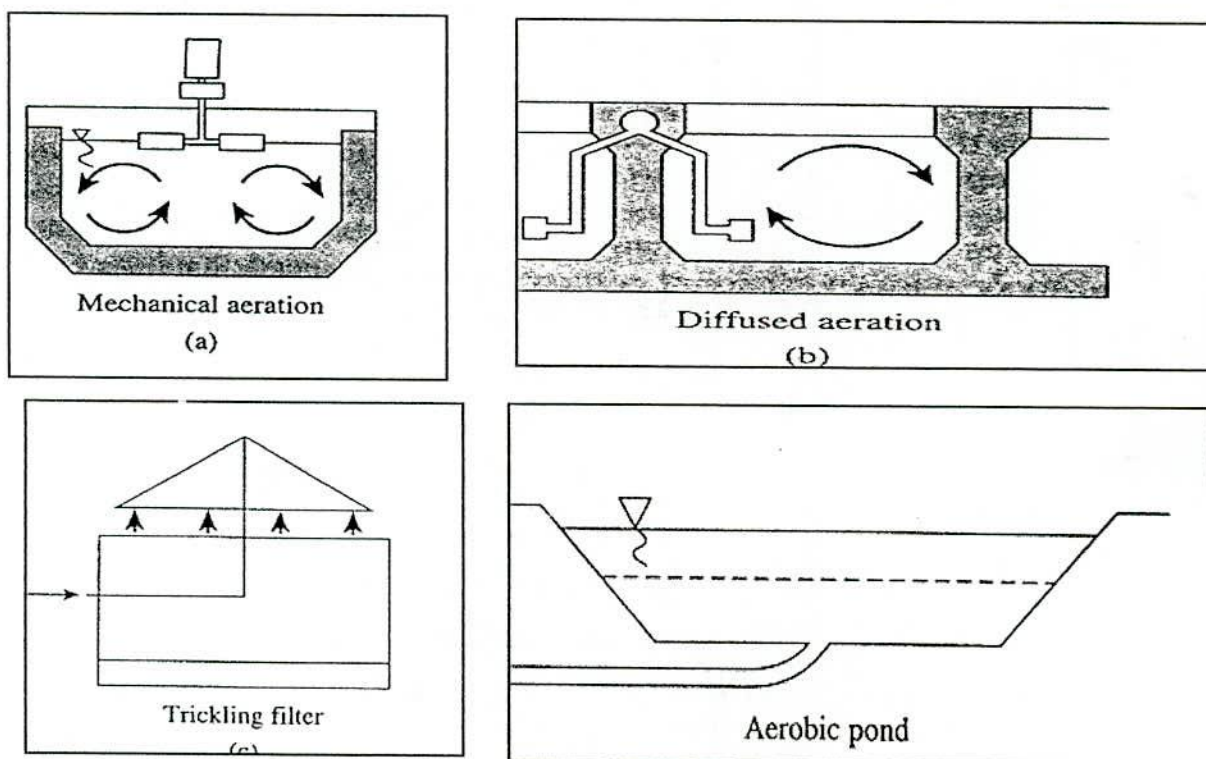


Figure 2.23: Aerobic systems

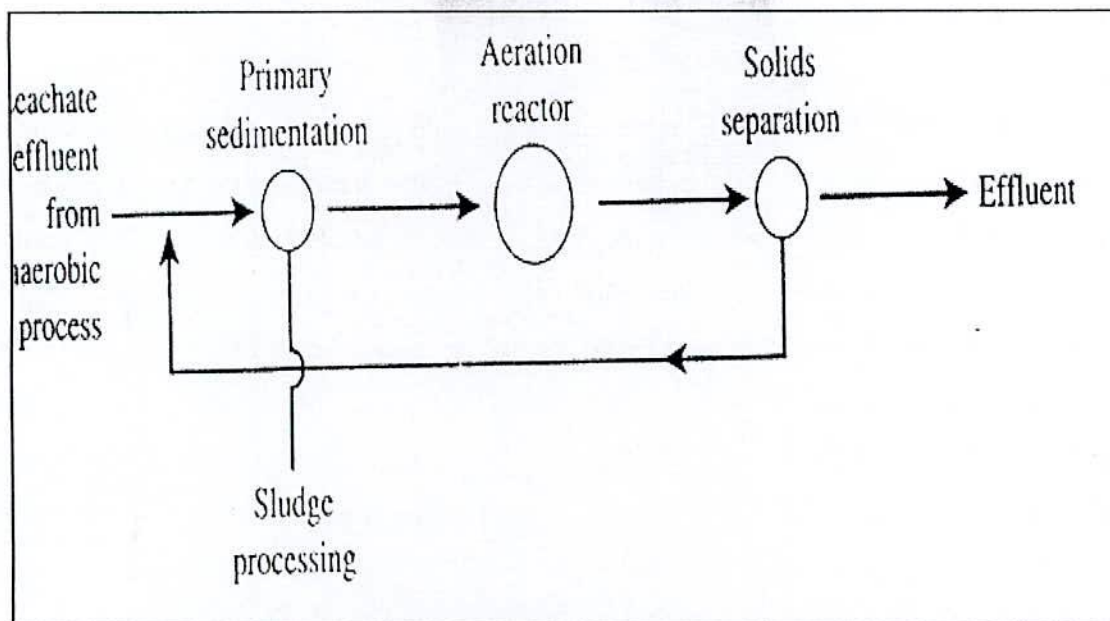


Figure 2.24: Treatment of anaerobic leachate by an aerobic process with sludge re-circulation

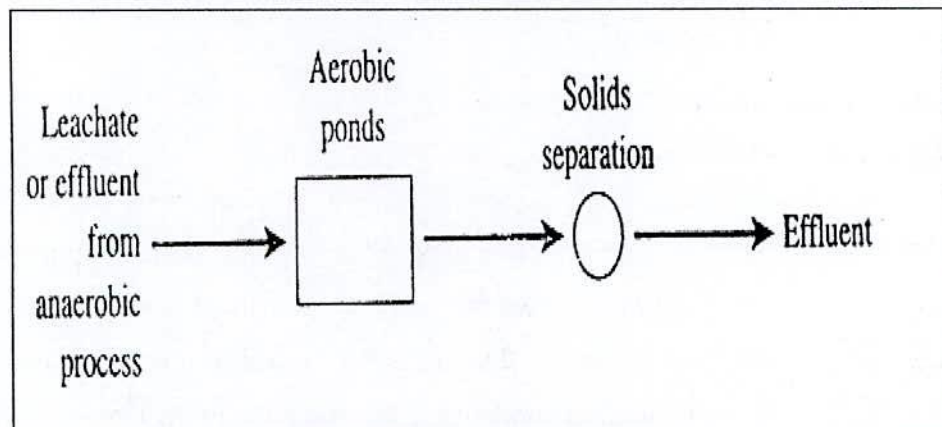


Figure 2.25: Aerated Lagoons

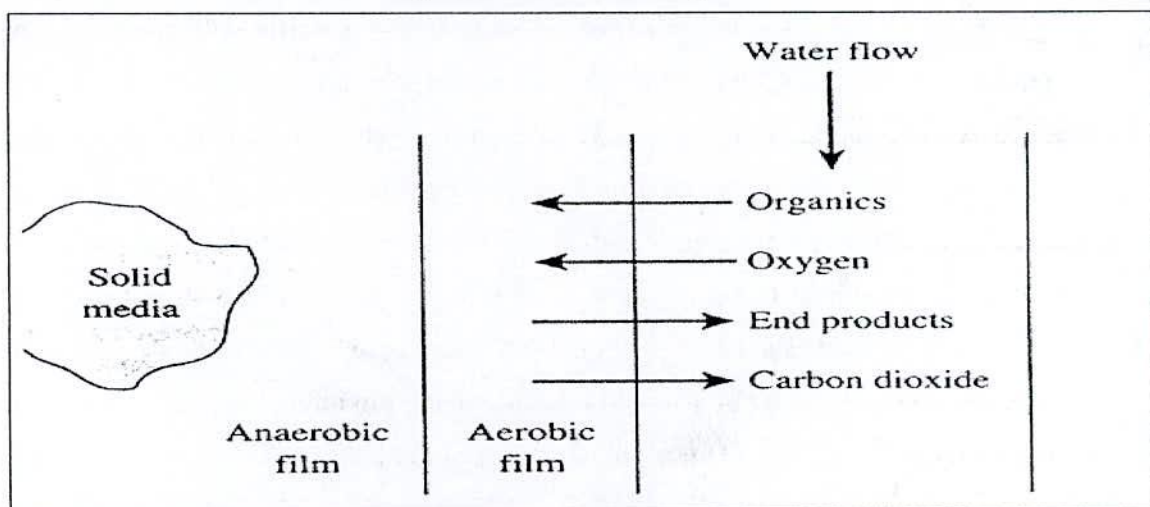


Figure 2.26: Trickling Filters

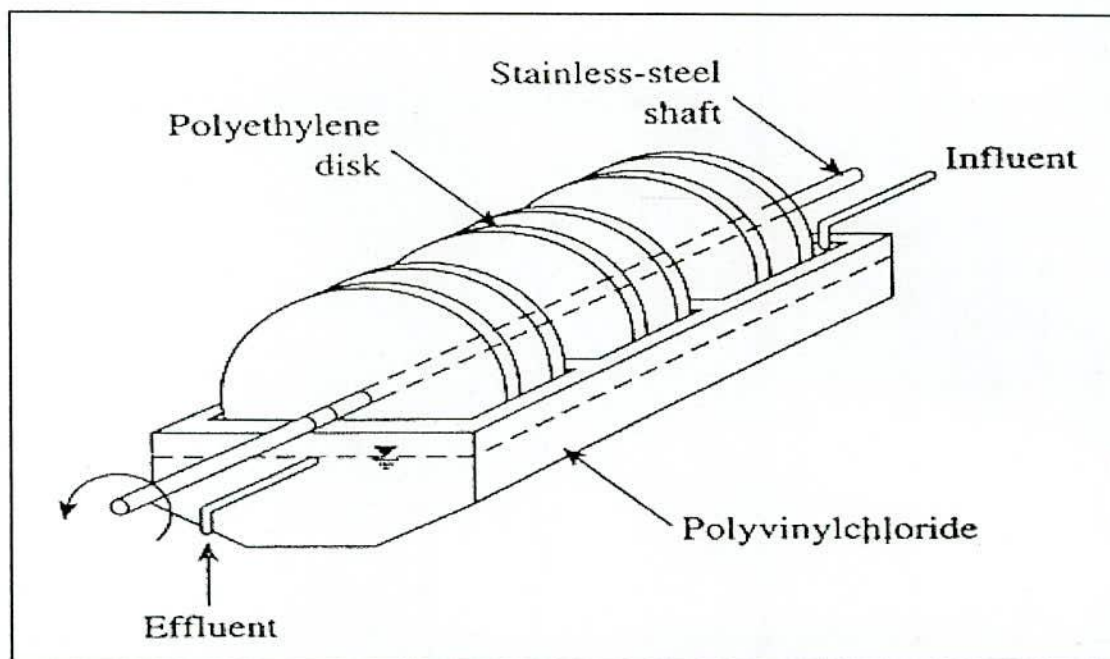


Figure 2.27: Rotating phytoremediation contactors

2.9.2 Physico-chemical Treatment

Physio-chemical treatments exist for not only removing refractory substances from the leachate, but also it is counted as a refining pre-step which is required before phytoremediation treatment of leachate (Rautenbach and Mellis, 1994). These methods are like those used to reduce COD, decrease suspended solids, colloids, particles, floating material, heavy metals, suspended soil and color (Tonni et al., 2005) by either, flotation, coagulation/flocculation, adsorption, chemical oxidation and air stripping. Physical/chemical treatments of landfill leachate are used in addition to the treatment line (pre-treatment or last purification) or to treat a specific pollutant (stripping for ammonia) (Renoua et al., 2008; Park et al., 2001). Sometimes a combination of physical, chemical and phytoremediation approaches is used for landfill leachate treatment, as it has been difficult to get efficiencies from the treatment using a single approach (Chiang et al., 2001; Ahn et al., 2002; Lin and Chang, 2000). On the other hand, within the chemical treatment methods which are used for the leachate treatment there are some main methods like coagulation, flocculation, chemical or electrochemical oxidation (Ahn et al., 2002; Chiang et al., 2001; Bohdziewicz et al., 2001; Marttinen et al., 2002; Trebouet et al., 2001). Before using phytoremediation treatment in order to improve COD removal, the Ozone pre-treatment should be used first (Kennedy and Lentz, 2000; Li and Zhao, 2001). Physical and chemical treatments of leachate were mainly done for removal of suspended matter volatile organics, high-molecular-weight organics, dissolved

inorganic and heavy metals. It was done by various process but the processes are costly. So the physical and chemical treatments of leachate are not economic for developing country like Bangladesh. Some of the physical and chemical treatments of leachate are described below.

2.9.2.1 Precipitation

Chemical precipitation of heavy metals in landfill leachate treatment involves the addition of chemicals to alter the physical state of dissolved and suspended solids and facilitate their removal by sedimentation.

2.9.2.2 Adsorption

Adsorption is a process in which the solid species is added to a solution containing other ions, called adsorbents are removed by adsorption onto the solid surface. In this system, solid state diffusion is the only mechanism by which a species can reach the interior of nonporous particles (Forstner et al., 1988). The use of Greek fly ash as a means of removal of heavy metal from wastewater has been examined. Nickel ion is selected as an example and removals of almost 100% are observed. The removal of an anionic toxic pollutant from solution such as arsenic makes several difficulties. Mainly due to the fact of precipitation process is not possible by the simple regulation of the solution pH. The application of iron sulphide or oxide minerals such as pyrite or red mud, as arsenic adsorbents might be a cheap and effective method for the treatment of arsenic bearing process solutions.

2.9.2.3 Coagulation and Flocculation

Coagulation and flocculation process is usually used for treating fresh leachate and it is applied as a pretreatment before phytoremediation treatment. Furthermore, the use of combined coagulation and flocculation with other processes such as reverse osmosis (Ozturk et al., 2003), photo-oxidation process and phytoremediation treatment (Kargi et al., 2003b; Hee-Chan et al., 2001; and Dae-Hee et al., 2002) have satisfactory results. Coagulation and flocculation is used to remove heavy metals and non-biodegradable organic compounds from landfill leachate (Tatsi et al., 2003; Kargi et al., 2003). Also, the coagulation and flocculation process can be used for the removal of non-biodegradable organic matters from hazardous landfill leachate. Coagulants have an opposite charge to those of suspended solids. The coagulants are used in the leachate in order to defuse the negative charges on dispersed solids which are not settled like color-producing organic substances and clay. When the charge is neutralized, the small particles which are

suspended stick together in order to increase the size of particles. Sometimes not all suspended particles are neutralized because the coagulant is not enough and needs more coagulant to be added (Ayoub et al., 2001). The next step after coagulation is flocculation which occurs in the moving particles that are not fixed into large flocs so that it can settle very fast. Coagulation further reduced suspended solids and neutralized pH. Coagulation and flocculation studies are carried out in usual jar test equipment. For more than 50 years, the jar test has been the typical technique used in wastewater and drinking water industry to improve the addition of coagulant and flocculants (Galvez et al., 2005). The coagulation process contains several stages but the three main stages are as follows (Ebeling et al., 2003):-

- a. Rapid Mixing step: coagulants are added to the flowing water and a high and fast intensity mixing is started. The main target is to get complete mixing of the coagulant with wastewater in order to increase the effectiveness of colloidal particles which are destabilized and then starts to coagulate (Nor Asikir and Agamuthu , 2007).
- b. Slow mixing step: the suspension of wastewater is slowly moved in order to enhance the coagulation of particles and to facilitate the growth of large flocs .
- c. Settling step: mixing is completed and the floc starts to settle.

The speed and duration of mixing are significant factors in both the first and second steps. The other important factor is the duration of settlement. To determine these significant factors, the literature on landfill leachate coagulation-flocculation was reviewed, and it revealed that the speed and duration of the fast and slow mixing steps and the period of settlement step used in jar test experiments were not exactly the same in all the studies. During the fast mixing step, the velocity varied between 100 and 200 rpm and the period between 2 to 5 minutes in most cases, although duration of 30 minutes also has been reported (Galvez et al., 2005). Through the slow mixing step, the speed varied between 20 to 60 rpm and the period between 5 to 55 minutes, while, in most studies the duration ranged between 15 to 30 minutes (Galvez et al., 2005). In the settling step, the duration of time differed from 15 to 60 minutes, whereas in most studies the period was 60 minutes. Finally, the flocs were shifted to a clarification basin. They settled at the bottom and were then removed, while the clarified effluent overflowed (Galvez et al., 2005).

2.9.2.4 Chemical Precipitation

Chemical precipitation process is used extensively as pre-treatment to reduce high concentration of ammonium nitrogen ($\text{NH}_4^+\text{-N}$) in leachate. As well, the COD reduce of 79 to 95. Then,

ammonium concentration reduced from 5600 to 110 mg/L in 15 minutes by the same method. Altinbas et al., (2002), studied the behavior of magnesium ammonium phosphate (MAP) precipitation (precipitated ammonium ions as magnesium ammonium phosphate) after anaerobic process pre-treatment of domestic wastewater and landfill leachate mixture. They found the maximum ammonia reduction was 66 % at a pH of 9.3.

2.9.2.5 Adsorption using Activated Carbon

The adsorption of pollutants using Activated Carbon either in columns or in powder form (Kargi et al., 2003, Kargi et al., 2004, Zamora et al., 2000) gives good reduction in COD levels than the chemical processes. The main disadvantage is the requirement for repeated renewal of columns or high utilization of powdered activated carbon (PAC). The color, inert COD and the Nonbiodegradable organics may be decreased to suitable levels for phytoremediation treatment landfill leachate. Rodriguez et al., (2004), studied PAC and many other resins to decrease the non-biodegradable organic matter from landfill leachate. Research reveals that Activated Carbon offered the highest adsorption capacity which was about 85% COD decrease (Kargi et al., 2003a; Kargi et al., 2004; Heavy et al., 2003). Almost 100 % elimination of both ammonia and BOD, and 69% of COD were achieved. Finally, limestone has been confirmed successful in removing metals from wastewaters. Aziz et al., (2004), indicated that 90 % of Fe could be removed from semi-aerobic landfill leachate by limestone filter.

2.9.2.6 Chemical Oxidation

The chemical oxidation method is used for the treatment of effluents consisting refractory compounds like landfill leachate. Currently, more interest has been focused on advanced oxidation processes (AOP). Nearly all of them with the exception of simple ozonation (O_3), use a combination of strong oxidants, e.g. H_2O_2 , irradiation, e.g. ultrasound (US), ultraviolet (UV), or electron beam (EB), and some catalysts, e.g. transition metal ions or photocatalysts. However, recent studies have confirmed that AOP is efficient for treating old or well - stabilized leachate in order to improve the biodegradability of refractory organic pollutants (Wang et al., 2003). On the other hand, this method (AOP) has some disadvantages such as using a lot of energy which is necessary for devices such as UV lamps, ozonizers and ultrasounds (Lopez et al., 2004). Also, Renoua et al., (2008) confirmed that AOP, adapted to well-stabilized or old leachate, are applied to develop the biodegradability of recalcitrant organic pollutants and oxidize organic substances.

2.9.2.7 Air Stripping

Recently, it has been found that the best method for removing a high concentration of $\text{NH}_4^+\text{-N}$ in wastewater treatment technologies is air stripping. The leachate usually contains high levels of ammonium and nitrogen, and both of them can be eliminated by using the air stripping method (Marttinen et al., 2002). This method is efficient at a high pH because Marttinen et al. (2002) confirmed that about 89% ammonia was reduced at pH 11 within 24 h retention time. However, this method has a disadvantage which is emission of NH_3 into air which can cause air pollution if ammonia cannot be properly absorbed with either H_2SO_4 or HCl (Zhou and Smith, 2001).

2.10 Gas Emissions from MSW Landfill

Landfill gas (LFG) (commonly termed “biogas” in some location) is one of the products generated as a consequence of the phytoremediation degradation of the organic fraction of the wastes placed in the landfill (Diaz et al., 1996; Popov, 2005). Landfill is the main source of emission of methane gas and that it is as much as 38% of the total anthropogenic source (Popov and Power 1999). A younger landfill emits lesser quantity of gas compared to an older one (Chan et al., 2002). LFG that are generated in a landfill are methane (55 %) and carbon dioxide (35 %) both of which are generated due to the disposal of organic waste into the landfills. These gases are released into the atmosphere (Fauziah and Agamuthu, 2003).

2.10.1 Factors Affecting Production of LFG

The rate and volume of landfill gas produced at a specific site depend on the characteristics of the waste (e.g., composition and age of the refuse) and a number of environmental factors (e.g., the presence of oxygen in the landfill, moisture content, and temperature).

2.10.1.1 Composition of Deposited MSW

The more organic waste present in a landfill, the more landfill gas is produced by bacterial decomposition. Some types of organic waste contain nutrients, such as sodium, potassium, calcium, and magnesium, that help bacteria thrive. When these nutrients are present, landfill gas production increases. Alternatively, some wastes contain compounds that harm bacteria, causing less gas to be produced.

2.10.1.2 Oxygen in the Landfill

Only when oxygen is used up will bacteria begin to produce methane. The more oxygen present in a landfill, the longer aerobic bacteria can decompose waste in Phase I. If waste is loosely buried or frequently disturbed, more oxygen is available, so that oxygen-dependent bacteria live longer and produce carbon dioxide and water for longer periods (Miroslav Nastev et al., 2001). If the waste is highly compacted, however, methane production will begin earlier as the aerobic bacteria are replaced by methane-producing anaerobic bacteria in Phase III. Methane gas starts to be produced by the anaerobic bacteria only when the oxygen in the landfill is used up by the aerobic bacteria; therefore, any oxygen remaining in the landfill will slow methane production. Barometric highs will tend to introduce atmospheric oxygen into surface soils in shallow portions of a landfill, possibly altering bacterial activity. In this scenario, waste in Phase IV, for example, might briefly revert to Phase I until all the oxygen is used up again.

2.10.1.3 Moisture Content

The presence of a certain amount of water in a landfill increases gas production because moisture encourages bacterial growth and transports nutrients and bacteria to all areas within a landfill (Klink and Ham, 1982). A moisture content of 40% or higher, based on wet weight of waste, promotes maximum gas production (e.g., in a capped landfill). Waste compaction slows gas production because it increases the density of the landfill contents, decreasing the rate at which water can infiltrate the waste. The rate of gas production is higher if heavy rainfall and/or permeable landfill covers introduce additional water into a landfill.

2.10.1.4 Temperature

Warm temperatures increase bacterial activity, which in turn increases the rate of landfill gas production. Colder temperatures inhibit bacterial activity. Typically, bacterial activity drops off dramatically below 50°F. Weather changes have a far greater effect on gas production in shallow landfills. This is because the bacteria are not as insulated against temperature changes as compared to deep landfills where a thick layer of soil covers the waste. A capped landfill usually maintains a stable temperature, maximizing gas production. Bacterial activity releases heat, stabilizing the temperature of a landfill between 77°F and 113°F, although temperatures up to 158°F have been noted. Temperature increases also promote volatilization and chemical reactions.

2.10.1.5 Age of Refuse

More recently buried waste will produce more gas than older waste. Landfills usually produce appreciable amounts of gas within 1 to 3 years. Peak gas production usually occurs 5 to 7 years after wastes are dumped. Almost all gas is produced within 20 years after waste is dumped; however, small quantities of gas may continue to be emitted from a landfill for 50 or more years. A low-methane yield scenario, however, estimates that slowly decomposing waste will produce methane after 5 years and continue emitting gas over a 40-year period (Harmsen, 1983). Different portions of the landfill might be in different phases of the decomposition process at the same time, depending on when the waste was originally placed in each area. The amount of organic material in the waste is an important factor in how long gas production lasts.

2.10.2 Duration of Phases of LFG

LFG is a mixture of gases. It contains 45-60 % of methane by volume, with the rest being mainly carbon dioxide and a trace amount of nitrogen, hydrogen, ammonia, sulfur dioxide and carbon monoxide. When MSW are deposited in a landfill, the wastes undergo a number of simultaneous phyto remediation, physical and chemical processes to give out landfill gas and other compounds. These processes include decomposition in which MSW are decomposed by bacteria under aerobic and anaerobic conditions, and volatilization in which wastes in liquid or solid form are vaporized into gaseous form (Gea et al., 2004). The decomposition of MSW in a landfill can be divided into 4 phases with different types of bacterial activities and various landfill gas compositions in each phase. Methane is produced in the third phase by methanogenic bacteria under anaerobic conditions (Figure 2.28).

Phase I (Initial Adjustment)

During the first phase of decomposition, aerobic bacteria—bacteria that live only in the presence of oxygen—consume oxygen while breaking down the long molecular chains of complex carbohydrates, proteins, and lipids that comprise organic waste. The primary byproduct of this process is carbon dioxide. Nitrogen content is high at the beginning of this phase, but declines as the landfill moves through the four phases. Phase I continues until available oxygen is depleted. Phase I decomposition can last for days or months, depending on how much oxygen is present

when the waste is disposed of in the landfill. Oxygen levels will vary according to factors such as how loose or compressed the waste was when it was buried.

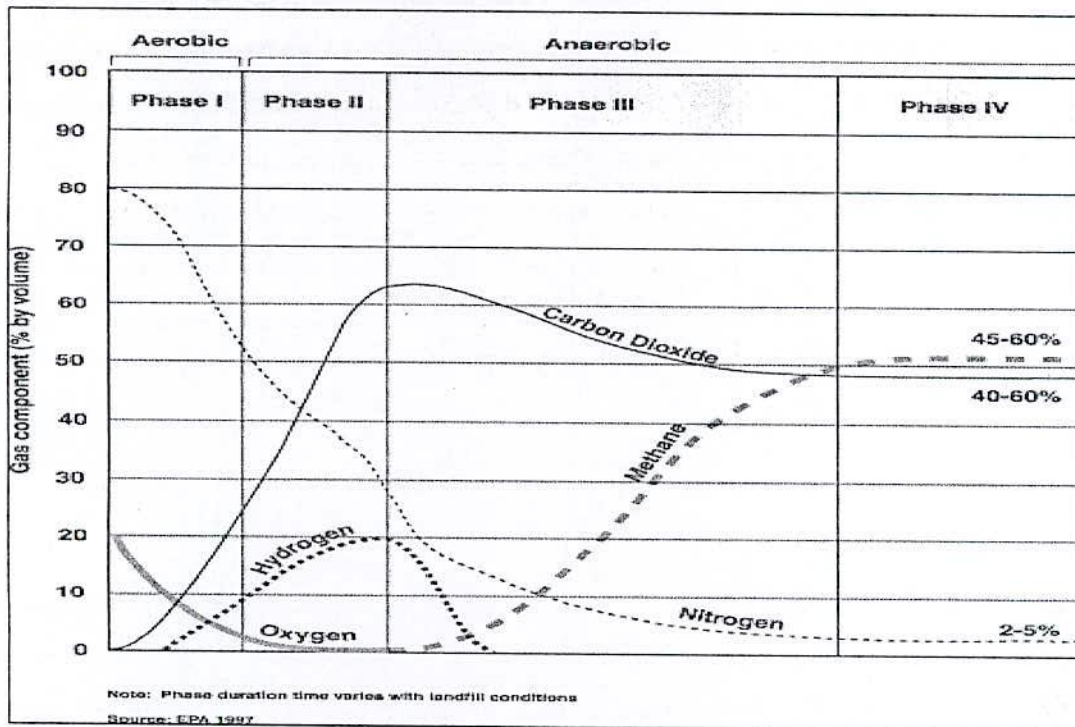


Figure 2.28: Phase of LFG generated from MSW in landfill

Phase II (Transition Phase)

Phase II decomposition starts after the oxygen in the landfill has been used up. Using an anaerobic process (a process that does not require oxygen), bacteria convert compounds created by aerobic bacteria into acetic, lactic, and formic acids and alcohols such as methanol and ethanol. The landfill becomes highly acidic. As the acids mix with the moisture present in the landfill, they cause certain nutrients to dissolve, making nitrogen and phosphorus available to the increasingly diverse species of bacteria in the landfill. The gaseous byproducts of these processes are carbon dioxide and hydrogen. If the landfill is disturbed or if oxygen is somehow introduced into the landfill, microbial processes will return to Phase I.

Phase III (Acid Phase)

Phase III decomposition starts when certain kinds of anaerobic bacteria consume the organic acids produced in Phase II and form acetate, an organic acid. This process causes the landfill to become a more neutral environment in which methane-producing bacteria begin to establish themselves. Methane- and acid-producing bacteria have a symbiotic, or mutually beneficial, relationship. Acid-

producing bacteria create compounds for the methanogenic bacteria to consume. Methanogenic bacteria consume CO₂ and acetate, too much of which would be toxic to acid-producing bacteria.

Phase IV (Methane Fermentation Phase and Maturation Phase)

Phase IV decomposition begins when both the composition and production rates of landfill gas remain relatively constant. Phase IV landfill gas usually contains approximately 45 to 60 % methane by volume, 40 to 60 % carbon dioxide, and 2 to 9 % other gases, such as sulfides. Gas is produced at a stable rate in Phase IV, typically for about 20 years; however, gas will continue to be emitted for 50 or more years after the waste is placed in the landfill. Gas production might last longer, for example, if greater amounts of organics are present in waste, such as at a landfill receiving higher than average amounts of domestic animal waste.

2.10.3 Gas Production Rates

Gas production rates of MSW vary with the composition and age of waste, waste volume, waste moisture content, and other factors. MSW landfill gas consists mainly of methane and carbon dioxide with lesser concentrations of nitrogen, oxygen, sulfides, ammonia and other constituents and trace concentrations of a variety of volatile organic compounds. Gas generation rates for MSW landfills can be estimated using simplified manual calculations (Tchobanoglous et al., 1993; McBean et al., 1995) or computer-based models such as the USEPA landfill air emissions estimation model (USEPA 1996). Estimates of Gas Production Rates as follows:

- Rapid degradation conditions: 3 to 7 years (4 to 10 L/kg/yr)
- Moderate degradation conditions: 10 to 20 years (1.5 to 3 L/kg/yr)
- Slow degradation conditions: 20 to 40 years (0.7 to 1.5 L/kg/yr)

2.10.4 Characteristics of LFG Generated from MSW in Landfill

The LFG is separated in good and bad gas according to the gas analysis. The landfill-gas of various gas wells is mixed in the gas control station, in order to achieve methane content higher than 45 per cent methane (minimum concentration of methane in power stations is 40 per cent, optimum concentration between 50 and 55 per cent). Landfill-gases are disposed by a high temperature flare if the concentration of methane is between 25 and 40 percent (Burdekin, 2003). The typical Landfill Gas Components are tabulated in Table 2.12.

Table 2.12: Typical landfill gas components

Component	Percent by Volume	Characteristics
Methane	45–60	Methane is a naturally occurring gas. It is colorless and odorless. Landfills are the single largest source of U.S. man-made methane emissions
Carbon dioxide	40–60	CO ₂ is found at small concentrations in atmosphere (0.03%). It's colorless, odorless and slightly acidic.
Nitrogen	2–5	Nitrogen comprises approximately 79% of the atmosphere. It is odorless, tasteless, and colorless.
Oxygen	0.1–1	Oxygen comprises approximately 21% of the atmosphere. It is odorless, tasteless, and colorless.
Ammonia	0.1–1	Ammonia is a colorless gas with a pungent odor.
NMOCS (non-methane organic compounds)	0.01–0.6	NMOCs are organic compounds (i.e., compounds that contain carbon). (Methane is an organic compound but is not considered an NMOC.) NMOCs may occur naturally or be formed by synthetic chemical processes. NMOCs most commonly found in landfills include acrylonitrile, benzene, 1,1-dichloroethane, 1,2-cis dichloroethylene, dichloromethane, carbonyl sulfide, ethyl-benzene, hexane, methyl ethyl ketone, tetrachloroethylene, toluene, trichloroethylene, vinyl chloride, and xylenes.
Sulfides	0–1	Sulfides (e.g., hydrogen sulfide, dimethyl sulfide, mercaptans) are naturally occurring gases that give the landfill gas mixture its rotten-egg smell. Sulfides can cause unpleasant odors even at very low concentrations.
Hydrogen	0–0.2	Hydrogen is an odorless, colorless gas.
Carbon monoxide	0–0.2	Carbon monoxide is an odorless, colorless gas.
Trace gases	Less than 0.6	

Source: Tchobanoglous et al., 1993; EPA 1995

2.11 Evaluation of Contamination Potential of Solid Waste Landfill using LPI

A number of incidences have been reported in the past, where leachate had contaminated the surrounding soil and polluted underlying ground water aquifer or nearby surface water (Chian and DeWalle, 1976; Kelley, 1976; Kumar et al., 2002; 2004; Alamgir et al., 2005). However, the principal concerns regarding leachate are related to the pollution potential of uncontrolled leachate migration into local surface water, groundwater or the sea (Lo 1996). A strong need has been felt to take appropriate remedial measures to avoid contamination of the underlying soils and groundwater aquifers from the leachate generated from the landfills (Leckie et al., 1979; Kouzeli-Katsiri et al., 1999; Alamgir et al., 2006). The state regulatory authorities in most of the countries around the world have framed regulations to safe guard against the contamination of groundwater sources from the leachate generated from the solid waste landfill. However, the remedial and preventive measures cannot be undertaken at all the existing closed and active landfill sites because of financial constraints. Remedial and preventive measures need to be taken up in a phased manner. Thus, a system needs to be developed to prioritize actions and to establish which landfills need immediate attention for remediation works. An index for easy comparison of leachate contamination potential of different landfills in a given geographical area would be a useful tool in this regard.

Kumar and Alappat (2003) have developed a technique to quantify the leachate contamination potential of different landfills on a comparative scale in terms of leachate pollution index (*LPI*). *LPI* has many potential applications including ranking of landfill sites, resource allocation, trend analysis, enforcement of standards, scientific research and public information. Due to the simplicity and similarity of composition of MSW, the developed tool of *LPI* was used in this study to evaluate the contamination potential of landfill lysimeter.

Table 2.13: Professional fields of panelists for *LPI* formulation (after Kumar and Alappat 2003)

SL No.	Professional status of the panelists	No. of panelists
01.	Regulatory authorities and scientists	15
02.	Consulting engineers	06
03.	Academicians	49
04.	Others including members of International Solid Waste Association (ISWA)	10
Total		80

2.11.1 Concept of Leachate Pollution Index

In an effort to develop a system for comparing the leachate pollution potential of various landfill sites in a given geographical area, 80 panelists consists of academicians in environmental science and engineering; environmental regulatory authority officials and scientists; consulting engineers; and members of International Solid Waste Association (ISWA) conducting the necessary survey around the world as presented in Table 2.13. The survey was conducted using multiple questionnaires to formulate *LPI* based on Rand Corporation's Delphi Technique (Dalkey, 1968).

Table 2.14: Significance and weights of the pollutant parameters (*after Kumar and Alappat 2003*)

Sl. No.	Pollutant	Significance	Pollutant weight
1	Total Chromium	4.057	0.064
2	Lead	4.019	0.063
3	COD	3.963	0.062
4	Mercury	3.923	0.062
5	BOD ₅	3.902	0.061
6	Arsenic	3.885	0.061
7	Cyanide	3.694	0.058
8	Phenol Compound	3.627	0.057
9	Zinc	3.585	0.056
10	pH	3.509	0.055
11	Total Kjeldahl Nitrogen	3.367	0.053
12	Nickel	3.321	0.052
13	Total Coliform Bacteria	3.289	0.052
14	Ammonia Nitrogen	3.250	0.051
15	Total Dissolved Solids	3.196	0.050
16	Copper	3.170	0.050
17	Chlorides	3.078	0.049
18	Total Iron	2.830	0.045
	TOTAL	63.165	1.000

2.11.2 Pollutant Variables Selection

From literature, *fifty (50)* commonly reported leachate parameters were selected for their possible inclusion in the *LPI*. In *questionnaire 1*, the panelists were introduced to the possibility of

preparing a tool in the form of *LPI*. Moreover, the panelists were also asked to consider *fifty (50)* leachate parameters for their possible inclusion in the proposed *LPI*. Panelists were also requested to add any variables to the list of *fifty (50)* parameters, which, they feel shall also be included in the *LPI*. They were also asked to designate all the parameters as follows: (a) Do not include; (b) Or undecided and (c) Or include. Panelists were also requested to rate each parameter marked 'include' according to the significance of its contribution to overall leachate pollution. The rating was to be done on a scale of '1' to '5'. The value '1' was to be used for the parameter that has lowest relative significance to the leachate contamination, while, the value '5' was to be used for the parameter that has highest relative significance. Based on response from panelists to *questionnaire 1*, and subsequent *questionnaire 2* which aimed at arriving at a better consensus, *eighteen (18)* leachate pollutants were selected. The *eighteen (18)* selected pollutants and the significance obtained for them are given in Table 2.14.

Table 2.15: Weight factors of leachate parameters for *sub-LPI* (after Kumar and Alappat, 2003)

Index	Parameters	Weight factor
LPI_{organic} (LPI_{or})	Chemical oxygen demand (COD)	0.267
	Phytoremediation oxygen demand (BOD_5)	0.263
	Phenol compound	0.246
	Total coliform bacteria (TCB)	0.224
	<i>Summation</i>	1.000
$LPI_{\text{inorganic}}$ (LPI_{in})	pH	0.214
	Total kjeldahl nitrogen (TKN)	0.2060
	Ammonia nitrogen (NH_4-N)	0.198
	Total dissolved solid (TDS)	0.195
	Chloride (Cl^-)	0.187
	<i>Summation</i>	1.000
$LPI_{\text{heavy metal}}$ (LPI_{hm})	Total chromium (Cr)	0.125
	Lead (Pb)	0.123
	Mercury (Hg)	0.121
	Arsenic	0.119
	Cyanide	0.114
	Zinc (Zn)	0.11
	Nickel (Ni)	0.102
	Copper (Cu)	0.098
	Total iron (Fe)	0.088
	<i>Summation</i>	1.000

2.11.3 Formulation of Sub-Pollution indices

To make LPI is more informative and useful among the scientific community and field professionals, the LPI may be subdivided into three sub-indices in terms of LPI in organic pollutant (LPI_{or}), LPI in inorganic pollutant (LPI_{in}) and LPI in heavy metal (LPI_{hm}) provided in Table 1. In the group of LPI_{or} , organic compounds are normally composed of a combination of carbon, hydrogen and oxygen, with nitrogen in some cases. In this group, pollutants selected for sub-LPI are BOD_5 , COD, phenol compounds and TCB. The weight factors for the pollutants in LPI_{or} have been recalculated on a scale of 1 (Table 2.15).

In contrary, chlorides, alkalinity, various forms of nitrogen, phosphorous, sulphur, pH, heavy metals, gases like hydrogen sulphide and methane, etc. constitute the inorganic component of leachate. The LPI inorganic component consists of Cl^- , pH, NH_4-N , TKN and TDS. The weight factors for the pollutants in LPI_{in} have been recalculated on a scale of 1 as if LPI_{in} is an absolute index. Moreover, many metals such as Cr, Pb, Zn, Ni, Cu, Fe and Hg are important constituents of leachate produced from landfills and considered in LPI_{hm} group. Two non-metal pollutants, arsenic and cyanide have also been included in this sub-group. The weight factors for the pollutants have been recalculated on a scale of 1. The leachate pollutants can be divided in to the subgroups as (i) LPI organic (LPI_{or}), (ii) LPI inorganic (LPI_{in}) and (iii) LPI heavy metals (LPI_{hm}) and also is evident in Figure 2.29.

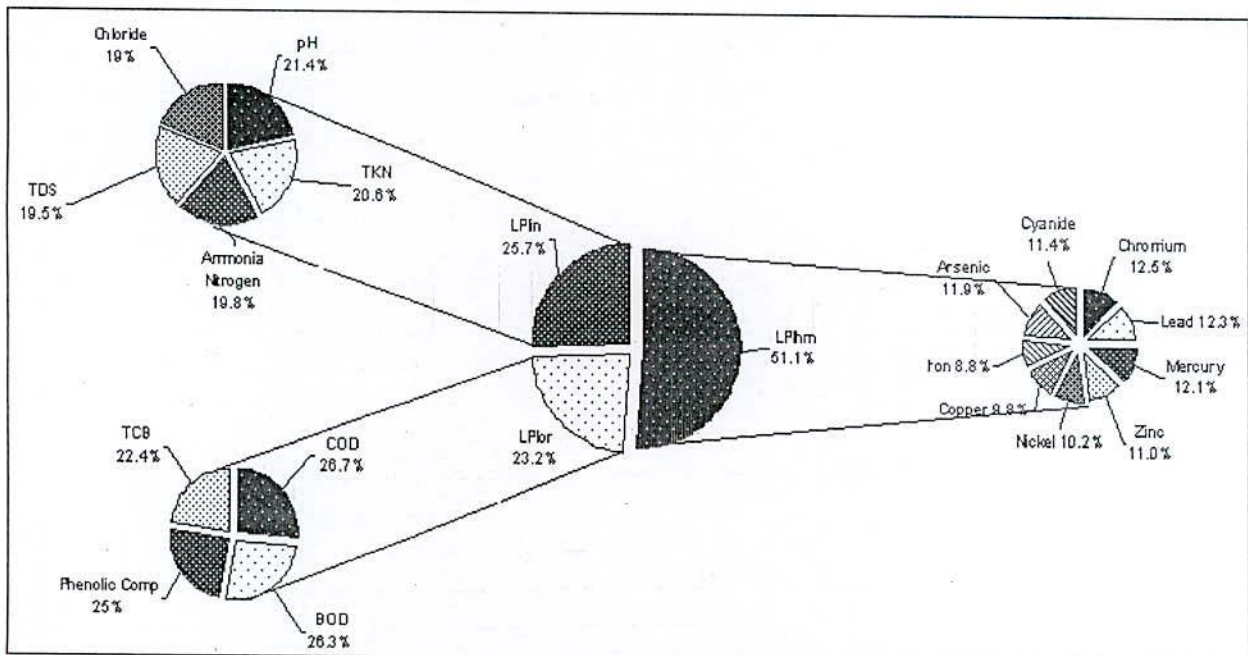


Figure 2.29: Three LPI subgroups and the pollutants in this subgroups with % weight factors (after Kumar and Alappat 2003)

2.11.4 Development of Pollutant Variable Rating Curves

In the third questionnaire, a selected group of panelists was requested to develop rating curves for all the *eighteen (18)* selected variables. This was done by providing graph sheets to the panelists. On the graph sheets, levels of leachate pollution (sub index score) from '0' to '100' were indicated on the ordinate of each graph, while, various level of concentrations of particular variable, up to the maximum limits reported in literature, were marked along the abscissa. The panelists were requested to draw a curve on each graph, which, in their judgment, represented the leachate pollution produced by the various concentrations of each pollutant variable. The panelists were requested to start the curves for each pollutant variable with a minimum value of '5' of leachate pollution even if there is no contamination from the pollutant to the overall leachate pollution. This was done to ensure that multiplicative aggregation function can be used at the later stage, if required, and the minimum value of '5' units of leachate pollution will ensure that the *LPI* value does not result in zero even if some of the pollutants do not show any pollution. Therefore, the theoretical range of *LPI* is from '0' to '100'. The responses received on the graph sheets have been used to produce a set of 'average curves', one for each pollutant variable (Robinson et al. 1985). The resulting curves are shown in Figure 2.30. As all the curves are obtained from the survey, they are implicit non-linear functions for which no mathematical equations can be given. In each figure, the bold line shows the arithmetic mean of all the panelists' curves, while, the x axis error bars indicate the 90% confidence limit. Approximately 75% of the panelists' curves fall within this area.

2.11.5 Variable Aggregation

The weighted sum linear aggregation function was used to sum up the behavior of all the leachate pollutant variables. The various possible aggregation functions were evaluated by Kumar and Alappat (2003) to select the best possible aggregation function. The sensitivity analysis of the six short-listed aggregation function was performed to arrive at the best possible aggregation function. The *LPI* can be calculated using the Equation (2.1):

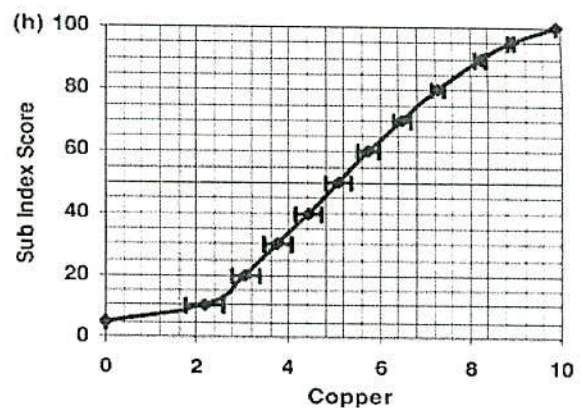
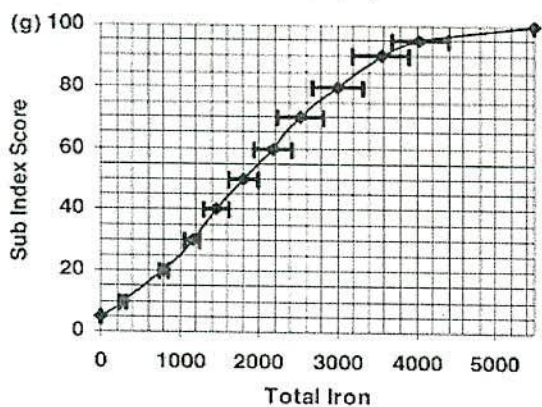
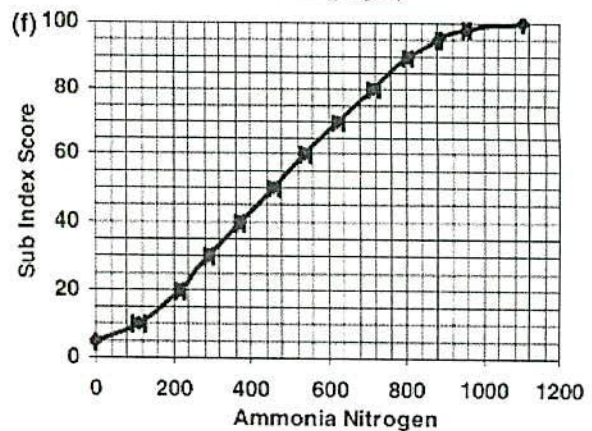
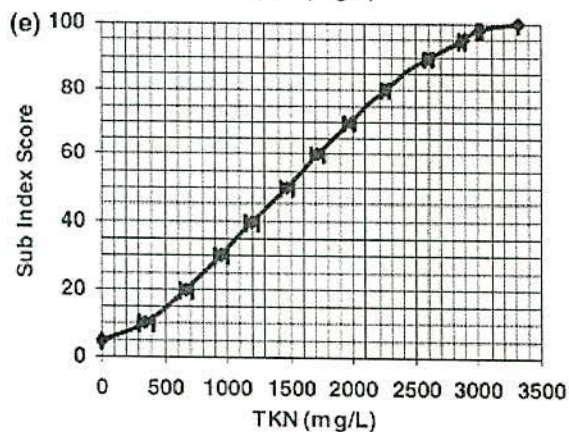
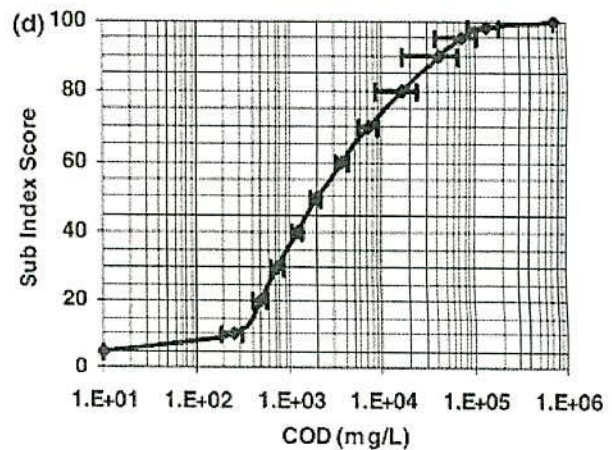
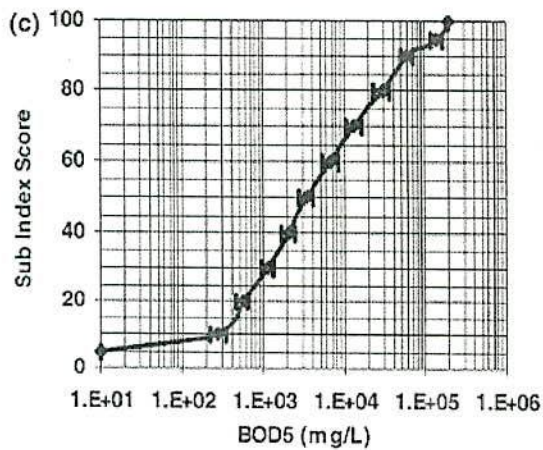
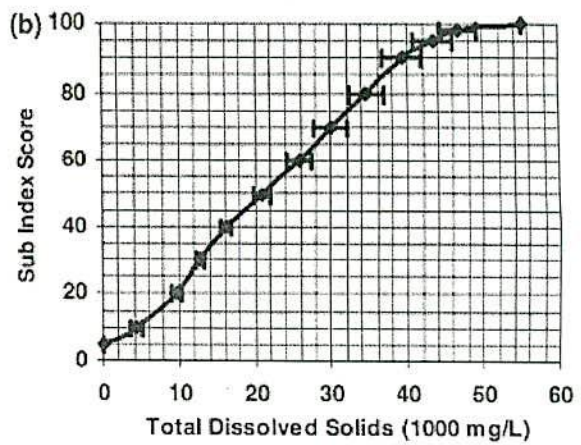
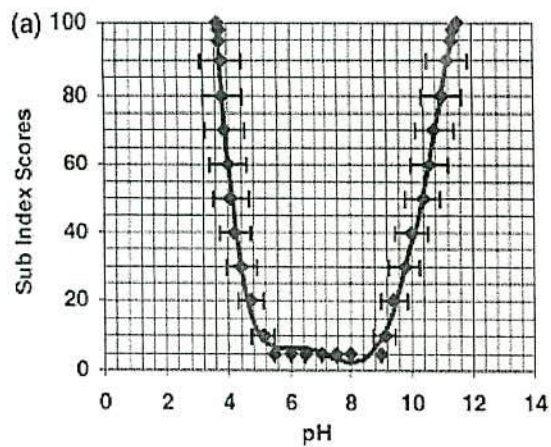
$$LPI = \sum_{i=1}^n w_i p_i \quad (2.1)$$

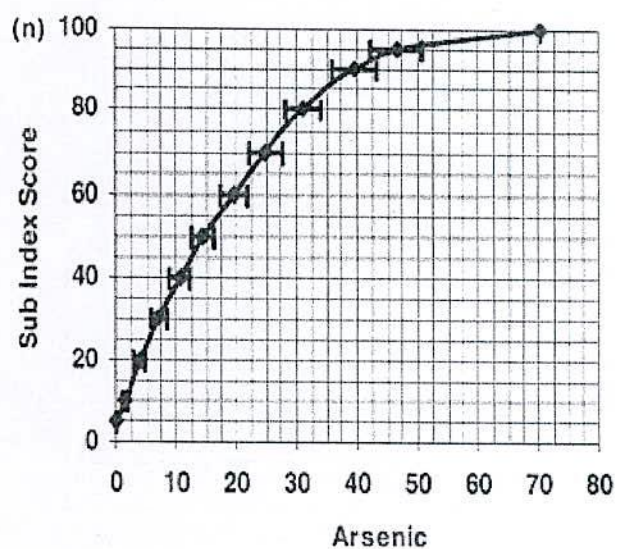
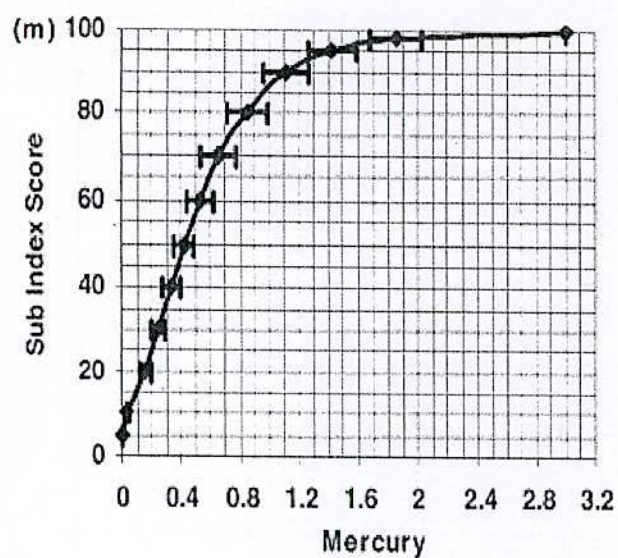
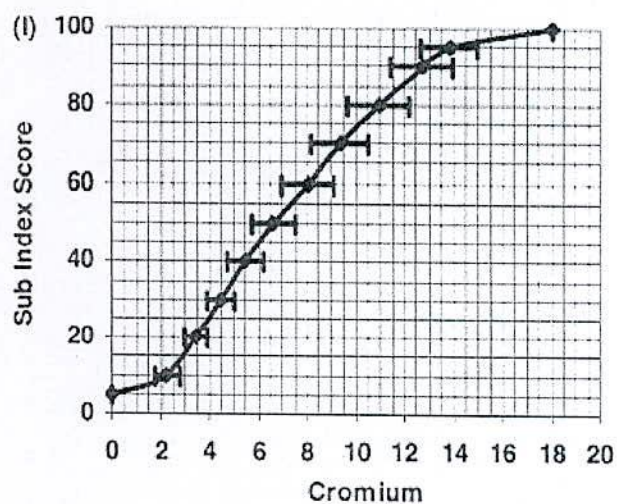
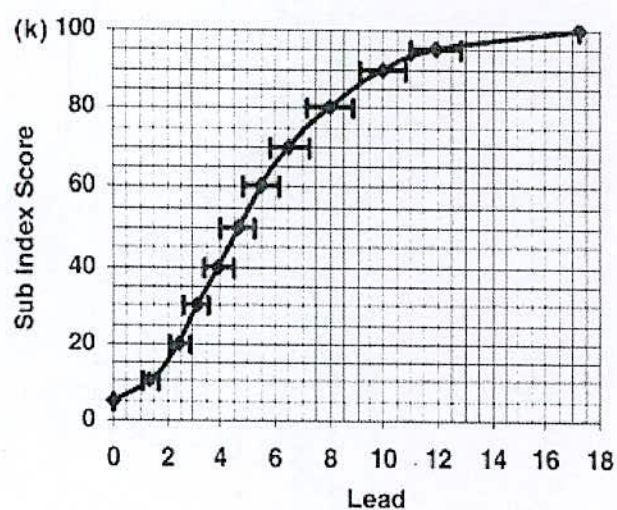
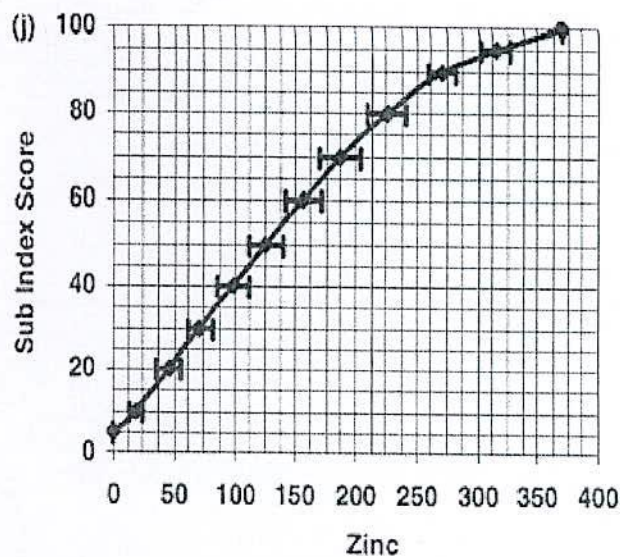
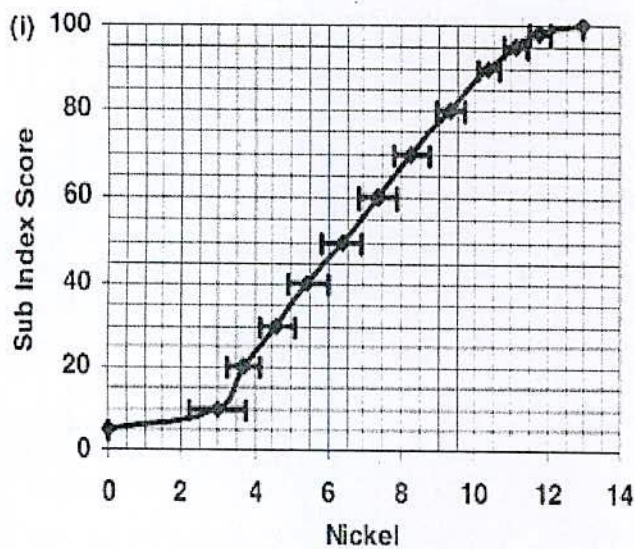
Where, where LPI is weighted additive leachate pollution index; w_i = the weight for the i^{th} pollutant variable; p_i = the sub-index value of the i^{th} leachate pollutant variable, number of leachate pollutant parameters; $n=18$ and $\sum w_i=1$.

However, when the data for all the leachate pollutant variables included in LPI are not available, the LPI can be calculated using the data set of the available leachate pollutants by the Equation (2.2):

$$LPI = \frac{\sum_{i=1}^m w_i p_i}{\sum_{i=1}^m w_i} \quad (2.2)$$

When, all the leachate parameters are unknown , $m < 18$ and $\sum_{i=1}^m w_i < 1$.





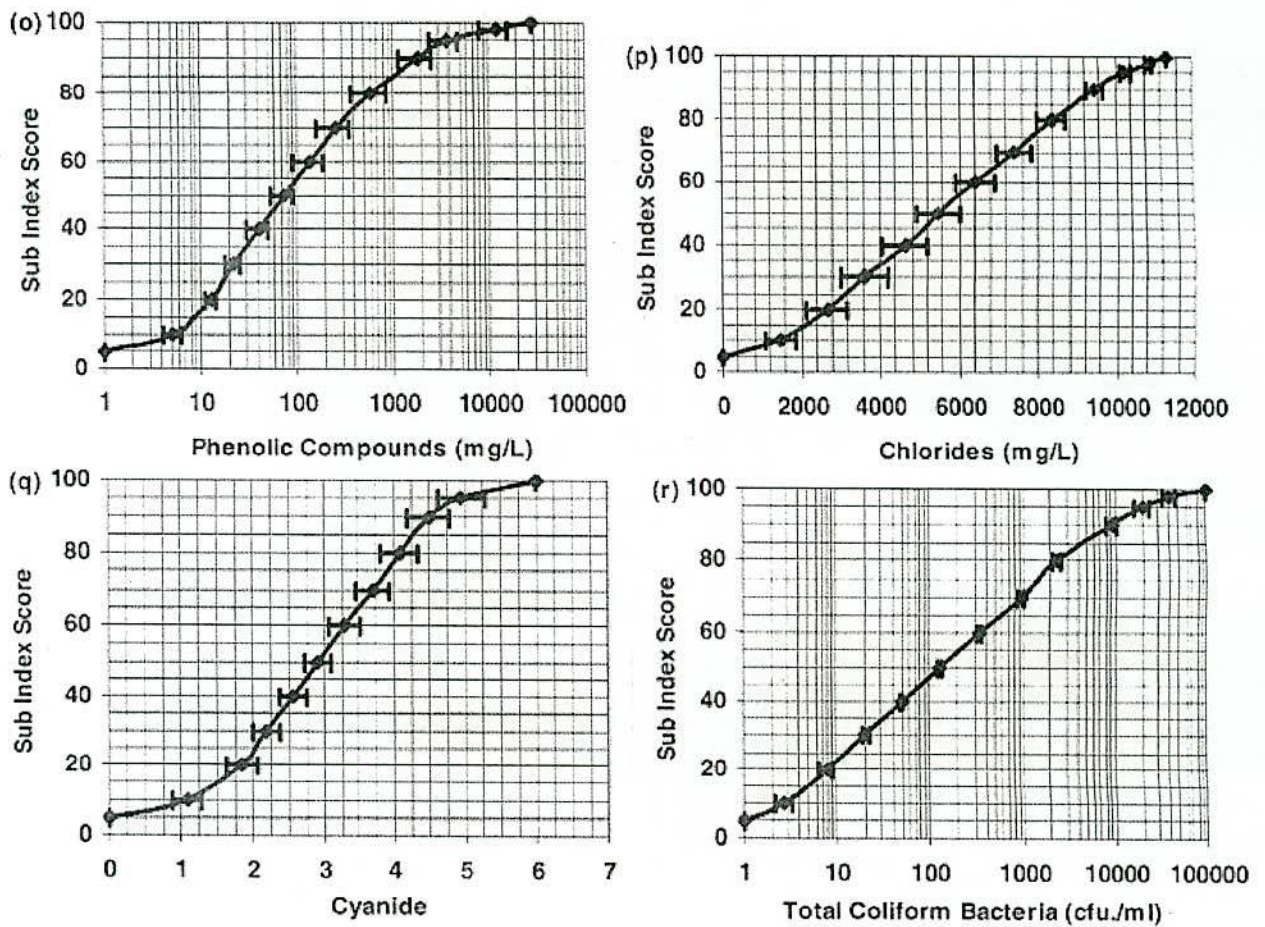


Figure 2.30: The averaged sub index curves of pollutant (a) pH (b) TDS (c) BOD₅ (d) COD (e) TKN (f) ammonia nitrogen (g) iron (h) copper (i) nickel (j) zinc (k) lead (l) chromium (m) mercury (n) arsenic (o) phenol (p) chlorides (q) cyanide (r) TCB (after Kumar and Alappat 2003)

Chapter Three

Materials and Methodology

3.1 General

In this study the volume and characteristics of leachate generated from municipal solid waste (MSW) deposited in lysimeter operated at varying landfill condition were monitored. One open dump lysimeter with two operating systems of leachate detection and collection system as well as two sanitary landfill lysimeter having two different cap liners were simulated. This research mainly focused on the performance of base liner in open dump lysimeter and cap liner in sanitary lysimeter. Moreover, the variation of leachate parameters with the increasing of elapsed period of MSW deposited in lysimeter operated at varying operational conditions as well as the tropical climatic variation also highlighted in this chapter. To reduce the pollutant concentration in leachate for meet the standard discharge condition, the performance of biological and chemical treatment were also investigated. In general, the methodology can be divided into major four tasks as such shown in Figure 3.1:

1. Task I: Design, construction, monitoring and investigation of landfill lysimeter:
 - a. This study has conducted to characterize clay sample used as compacted clay liners (CCLs) as well as MSW deposited in each lysimeter.
 - b. After the design of a reference cell shown in Figure 3.2, the construction of landfill lysimeter was started in January 2008 and completed in July 2008.
 - c. This study was also continuously monitored three lysimeters that had been operating since June 2008 to December 2010. These periods cover both the dry and rainy season provided in Figure 3.3.
2. Task II: Investigate the performance of base and cap liner as well as the tropical climatic influence on leachate characteristics:
 - a. This research was studied to measure the composition and flow rate of landfill gas (LFG) as well as quality and quantity of leachate.
 - b. This study has also conducted to investigate the effect of rainfall on leachate characteristics (inorganic, organic and nitrogen compounds as well as metal

and heavy metal concentrations). This phenomena directly affected by lysimeter construction configuration i.e.

3. Task III: Evaluate the contamination potential of landfill lysimeter:

- a. This study was investigated the contamination potential of landfill lysimeter using the quantifying index of leachate pollution index (LPI) and sub-pollution indices (sub-LPIs).
- b. This study was also conducted to estimate the errors involved in calculating the LPI due to the nonavailability of leachate data.

4. Task IV: Investigate the performance of biological and chemical treatment techniques:

- a. The research was conducted to examine the efficiency and performance/consequences of different adopted biological and chemical treatment for removing of pollutant in leachate.
- b. This part mainly emphasis to reduce the pollutant load of lysimeter leachate to meet the standard discharge condition with respect to the concentration of contaminants in leachate and the values of LPI of the treated leachate.

Table 3.1: Specifications, operational conditions of lysimeter used to simulate different landfill conditions

<i>lysimeter</i>	<i>Operating condition</i>	<i>Refuse placed (kg)</i>	<i>Liner specification</i>	<i>Simulation</i>
A	Open dump lysimeter with leachate detection (A_1) system	2860	400 mm thick CCL as a barrier between detection and collection system of lysimeter-A	present practice of open dumping
	Open dump lysimeter with leachate collection (A_2) system			
B	Sanitary landfill lysimeter with gas measurement and leachate recirculation system	2985	Cap liner-I (300 mm thick CCL)	applicability of designed top cover
C		2800	Cap liner-II (900 mm thick natural top soil)	

3.2 Construction of Landfill Lysimeter

The landfill lysimeter simulation was carried out in the geo-environmental research station at the backyard of Civil Engineering Building, KUET, Bangladesh. Refer to Figure 3.2, as the technical details for the construction of desired lysimeters. The catagory of lysimeter,

operational condition and the total weight of MSW deposited in each lysimeter were given in Table 3.1. The landfill lysimeters were constructed using the brick wall of 250 mm thick having outer and inner diameter of approximately 1.98 m and 1.48 m, respectively, with a total height of 3.35 m, resting on a 250 mm thick of reinforced cement concrete (RCC) mat foundation at a depth of 760 mm below the existing ground surface. The landfill lysimeter was plastered both the inner and outer sides with two coatings of waterproofing agent to avoid leakages and corrosion due to acidic environment. Further, the sanitary landfill lysimeters (B and C) consisted of LFG collection system above the MSW and leachate recirculation system below the MSW in landfill lysimeter. At the bottom of each landfill lysimeter, a cement concrete layer of 125 mm thick was provided then the landfill lysimeters were filled with stone chips (diameter 5-20 mm) and coarse sand (diameter 0.05-0.40 mm) to the height of 15 cm each to ensure proper leachate drainage. At the base of each landfill lysimeter after placing the perforated leachate collection pipe, a geo-textile blanket having 0.60 m wide and 1.65m length was placed to avoid rapid clogging by the sediments from landfill lysimeter. A leachate collection tank (3.68 x1.56 x1.64 m) accommodating four separate leachate discharge pipes in the temporary collection and storage containers, were constructed using 250 mm thick brick wall.

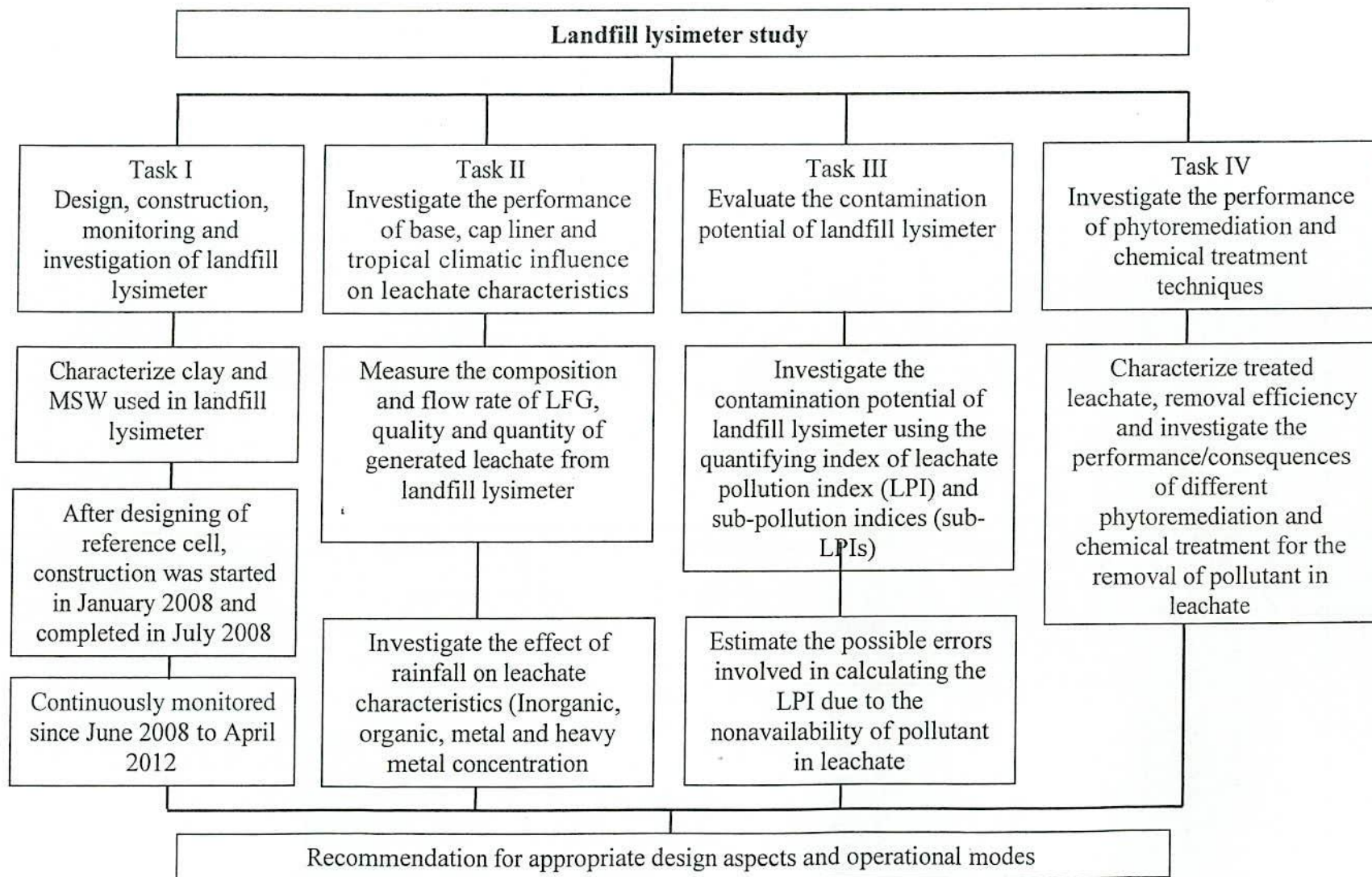


Figure 3.1: Flow chart of landfill lysimeter study at KUET campus

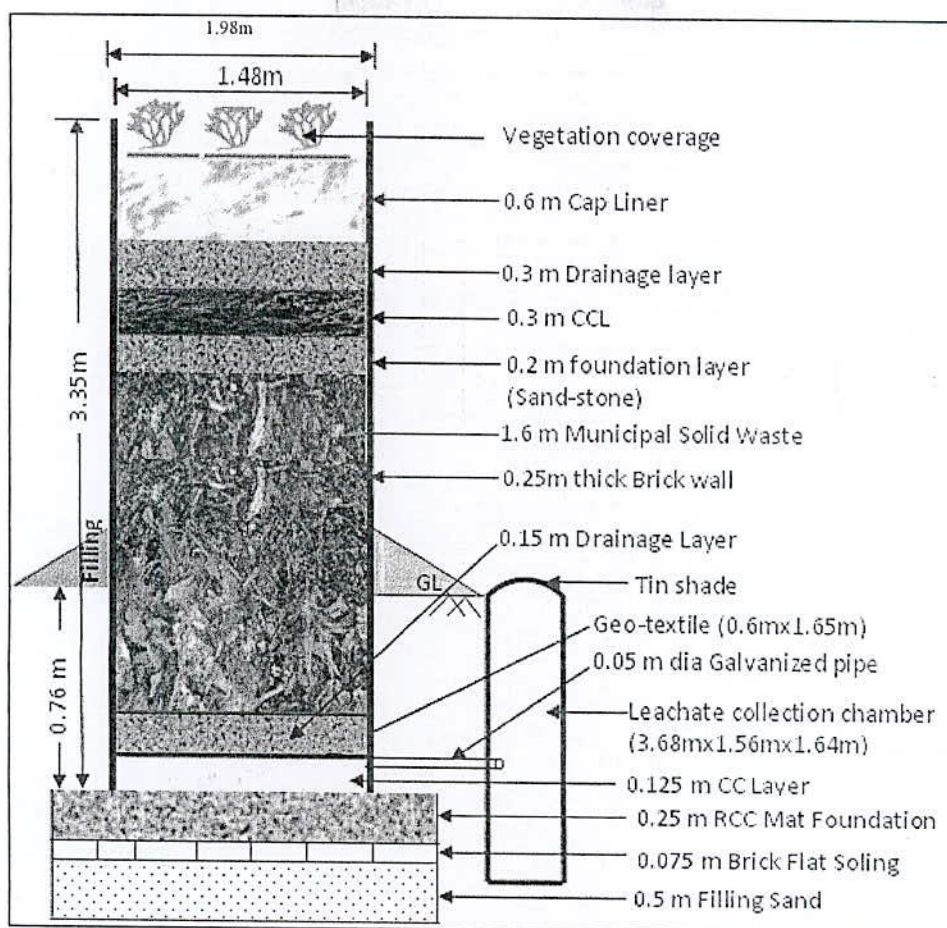


Figure 3.2: Schematic diagram of a reference cell for lysimeter construction

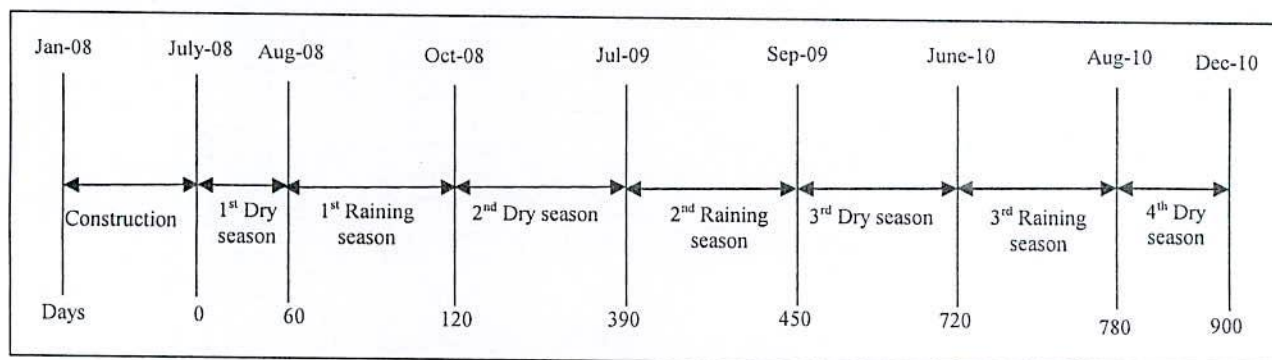


Figure 3.3: Period of construction of landfill lysimeter and monitoring

3.3 Construction, Monitoring and Investigation of Landfill Lysimeter

The construction, monitoring and the operation of landfill lysimeter is presented by a line diagram in Figure 3.3. Moreover, the flow chart of monitoring landfill lysimeter is provided in Figure 3.4. After design of reference cell, construction of three lysimeter was started in January 2008 and completed in July 2008. Following the construction of landfill lysimeter, the rate of leachate

generation and contamination potential of landfill leachate through LPI, settlement and LFG emission in terms of composition and flow rate have been monitored. The monitoring of quantity and flow rate of generated leachate was started in the 3rd week of June 2008 and still continued. Moreover, the monitoring of daily rainfall data was started in the first period of rainy season (August 2008 ~ October 2008). From the beginning to up the 150th day of entire landfill lysimeter operation (July 2008 ~ November 2008), the composition of LFG was measured, however, the monitoring of flow rate LFG was started after 50th day to up the 150th of landfill lysimeter operation (3rd week of August 2008~ November 2008).

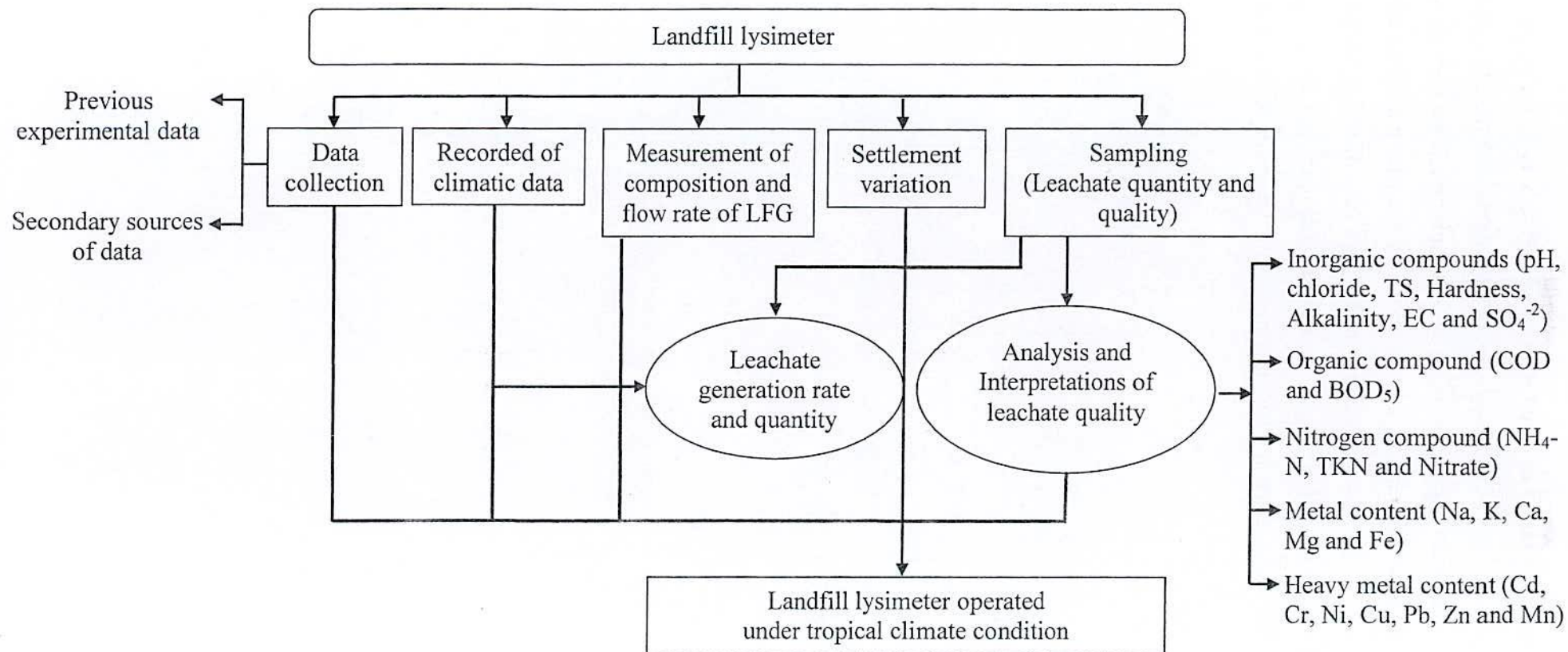


Figure 3.4: Flow chart of monitoring landfill lysimeter

3.4 Sampling and Analysis

The soil sample used as compacted clay liners (CCLs) was collected from pilot scale sanitary landfill (PSSL) situated at Rajbandh, Khulna, Bangladesh in the north side of Khulna-Satkhira Highway and 8 Km far from the Khulna city center. In addition, the MSW deposited in landfill lysimeter was collected from Khulna city area, similar to that of deposited in PSSL. Before used all the civil construction materials and MSW were analyzed in the laboratory and hence discussed in the following articles.

3.4.1 Analysis of Clay used as CCLs

The performance of all the geo-environmental facilities such as landfill liners, covers, vertical barrier depends mainly on the basic characteristics of the soils (Daniel et al., 1995). It is therefore important to know the physical and mechanical properties of the soils as thoroughly as possible before assessing their physico-chemical or hydro-mechanical behavior. Based on these concepts, in laboratory through standard ASTM (2004) methods, some relevant physical and mechanical properties of clay used as CCLs were determined provided in Table 3.2 and hence discussed in the following sections.

3.4.1.1 Soil Moisture Content

The moisture content of the collected soil sample was determined by using electric drying oven method in the laboratory and the testing standard is ASTM D2974. Soil sample was oven-dried for 24 hours at temperature 105°C.

3.4.1.2 Soil pH

Soil suspension with 1:1 (Soil: distilled water) was measured by pH meter in the laboratory.

3.4.1.3 Soil Atterberg Limits

The liquid limits and plastic limits as well as shrinkage limits of clay used as CCL were determined in the laboratory based on Atterberg limits test following the testing standard ASTM D4318 and ASTM D427, respectively.

3.4.1.4 Soil Compaction Properties

The maximum dry density and optimum moisture content of the soil were determined in the laboratory by standard proctor test following the testing standard ASTM D558. The optimum moisture content and maximum dry density were found 18% and 16 kN/m³, respectively.

3.4.1.5 Soil Hydraulic Properties

The coefficient of permeability of clay used as CCL was determined based on variable head test method following the testing standard ASTM D2434. This test was carried out on the test specimen, prepared by trimming a block sample. The coefficient of hydraulic conductivity was found 1.90×10^{-7} cm/sec.

Table 3.2: Measurement parameters of soil sample and analytical methods

Soil parameters	Unit	Value	Analytical method
Moisture content	%	22	ASTM D 2974
pH	-	6.7	
Liquid limit	%	43	ASTM D 4318
Plastic limit	%	22	
Plasticity index	%	21	--
Shrinkage limit	%	16	ASTM D427
Optimum moisture content	%	18	ASTM D558
Maximum dry density	kN/m ³	16	
Coefficient of permeability	cm/sec.	1.90×10^{-7}	ASTM D 2434
Sand: Silt: Clay	%	10: 56.6:33.4	ASTM D 422

3.4.1.6 Constituent of Soil Particles

The percentages of constituted soil particle of clay used as CCL was determined based on grain size analysis following the testing standard ASTM D422. Based on the combined analysis of soil used as CCL through sieve and hydrometer, the percentages of soil constituents was found as sand, silt and clay of 10, 56.6 and 33.4%, respectively.

3.4.1.7 Soil Mineralogical Composition

The mineralogical compositions of clay used as CCL is presented in Table 3.3 as measured in the laboratory of the Department of Applied Geology, Karlsruhe University, Germany (Roehl 2007).

Table 3.3: Mineralogical compositions of clay used as CCL in lysimeter (Roehl 2007)

Minerals (amount in weight-%)		Sample (0-7m)	Sample (13-23m)
Non-clay minerals	Quartz	19%	17%
	Feldspars	<1%	<1%
	Carbonates	<1%	<1%
Non-swelling clay minerals	Illite	~50%	~50%
	Kaolinite	~10%	~10%
	Chlorite	<1%	1-2%
Swelling clay minerals: Smectite		20%	19%

3.4.2 Analysis of MSW Deposited in Lysimeter

The degradation of the organic fraction from MSW in landfill produces a number of gases. The rate of gas production from MSW in landfill, especially CH₄ exhibits an upward trend as the moisture content of MSW increases and also the production rate depend on the deposition period, density and composition of MSW in landfill (Daniel et al., 1995). This information is enabled to formulate about the generation, accumulation and finally the collection scheme of generated gas from MSW in landfill. To this attempt, the following parameters of MSW are needed to be determined.

3.4.2.1 Physical Composition

The quality of leachate mainly depends on organic fraction (food and vegetable) and composition of MSW in landfill (Koener et al., 2007). The physical compositions of MSW sample were determined in the laboratory. Taken 3 Kg of MSW sample, then sorting all the composition mainly consisted of 93 (w/w) organic (food and vegetables), 3 (w/w) of plastic/polythene and 2 (w/w) of leather/rubber, 1 (w/w) of animal bone and rubber/leather as well as 1 (w/w) of rope/straw and egg pill. The obtained result reveals that food and vegetable fraction was the predominant component and about 93 (w/w) because of the higher fraction of organic substances being in MSW collected from Khulna city area.

3.4.2.2 Moisture Content and Organic Content

Moisture content plays an important role about the rate of decomposition of MSW and the rate of generation of leachate. The moisture content of MSW sample was measured in the laboratory by drying in the electric oven at 105°C for 24 hours. Moreover, for determining the organic content, MSW was incinerated in the muffle furnace at 550°C for 5 hours. The detailed procedure for measuring the moisture and organic content of MSW in lysimeter can be obtained in Austrian

Standard (S 2023). The moisture content of MSW was found of 65 % shown in Table 3.4 and these findings are agreed well with the moisture content values of 62- 66 % of MSW in Khulna city WasteSafe (2005).

Table 3.4: Physical characteristics of MSW sample deposited in landfill lysimeter

Physical characteristics	Unit	Value	Analytical method
Moisture content	%	65	Austrian Standard (S 2023)
Organic content	%	52	Austrian Standard (S 2023)
pH	--	7.79	pH meter
Volatile solids	%	58	Austrian Standard (S 2023)
Ash residue	%	46	Austrian Standard (S 2023)
Bulk density	kg/m ³	1000-1066	

3.4.2.3 Bulk Unit Weight

The unit weights were determined after the MSW deposited into each landfill lysimeter. The total weight of MSW deposited in landfill lysimeter A, B and C were 2860, 2985 and 2800 Kg, respectively, and total volume was 2.80 m³ (diameter 1.48 m; height 1.6 m). Then, the unit weights of the deposited MSW were determined of 1021, 1066 and 1000 Kg/m³ in lysimeter A, B and C, correspondingly provided in Table 3.4.

3.4.2.4 Particle Size Distribution

Before filling the landfill lysimeter with MSW, analysis of finer fraction was done. The constituents of particle size of MSW sample were determined with the use of a set of locally manufactured sieves of opening sizes are 400, 300, 200, 100, 76.2, 38.2, 19.1, 9.52, 4.76 and 2.38 mm considered as standard size (Diaz et al., 1996). Here, it is important to note that the percent finer of MSW was 100 % in 300 and 200 mm sieve openings, whereas the values were found as 76.25, 63.72, 45.22 and 24.34 % for the opening of 100, 76.2, 38.2 and 19.1 mm, respectively, as well as gradually decreases for smaller sieve openings. The findings are agreed well with the percent finer of MSW in six major cities, especially in Khulna city, Bangladesh WasteSafe (2005).

3.4.2.5 Chemical Composition of MSW

The chemical composition of MSW was measured in the laboratory through the required standard methods provided in Table 3.5.

Table 3.5: Chemical properties of MSW deposited in landfill lysimeter

Chemical characteristics	Unit	Value
Carbon, C	%	25.63
Nitrate, N	%	1.84
C/N ratio	--	15.39
Potassium, K	%	1.37
Phosphorous, P	%	0.41

Note: % P as $P_2O_5 = \% P \times 2.29$ and % K as $K_2O = \% K \times 1.20$

3.4.3 Leachate Characterization and Quality Analysis

Leachate sample was collected from leachate collection chamber at KUET lysimeter for quantitative and qualitative analysis once in two weeks during dry season and more frequents or event basis during rainy season. Around 500-800 ml leachate sample was taken and kept in the sampling bottle and placed in the refrigerator in the laboratory for measured and monitored the characteristics of lysimeter leachate after determining the total generation rate. The measuring parameters and analytical methods are shown in Table 3.6.

Table 3.6: Measurement parameters of leachate and analytical methods

Parameters	Unit	Analytical Equipment with Reference Model
pH	--	pH meter (HACH, Model No. Sens ion 156)
Chloride	mg/L	Potentiometric titration method using silver nitrate solution
TS	mg/L	Dried at 103-105°C in the laboratory
Hardness	mg/L	EDTA titrimetric
Alkalinity	mg/L	Titration
EC	mg/L	Conductivity meter (HACH, Model No. Sens ion 5).
COD	mg/L	Closed reflexive method as per the Standard Methods (APHA, 1998)
BOD ₅	mg/L	Dilution Method (Titration)
NH ₄ -N	mg/L	Nesslerization standard method as per the Standard Method (APHA 1998)
TKN	mg/L	Macro-kjeldahl method as per the Standard Method (APHA, 1998)
Ca	mg/L	Flame atomic absorption spectrophotometer (VARIAN; AA/2400)
K	mg/L	
Na	mg/L	
Mg	mg/L	
Fe	mg/L	
Cd	mg/L	Spectrophotometer (HACH; DR/2400) as per the Standard Method (APHA, 1998)
Ni	mg/L	
Zn	mg/L	
Cu	mg/L	
Cr	mg/L	
Mn	mg/L	
Pb	mg/L	

Notation: TS=total solid, EC=Electric conductivity, COD=chemical oxygen demand, BOD₅=biochemical oxygen demand, NH₄-N=ammonia nitrogen, TKN=total kjeldahl nitrogen, Ca=calcium, K=potassium, Na=sodium, Mg=magnissium, Fe=iron, Cd=cadmium, Ni=Nickel, Zn=Zinc, Cu=copper, Cr=chromium, Mn=manganese and Pb=lead.

3.5 Analysis of Contamination potential of Landfill Lysimeter

The formulation process and complete description on the development of leachate pollution index (*LPI*) has been discussed elsewhere (Kumar and Alappat 2003). The *LPI* represents the level of leachate contamination potential of a given solid waste landfill. It is a single number ranging from 5 to 100 (like a grade) that expresses the overall leachate contamination potential of a landfill based on several leachate pollution parameters at a given time.

3.5.1 Leachate Pollution Index

In the present study, after reviewed and analyzed the weighted sum linear aggregation function was found the most suitable aggregation method for calculating *LPI* by using the Equation (3.1).

$$LPI = \sum_{i=1}^n w_i p_i \quad (3.1)$$

Where, *LPI* is weighted additive leachate pollution index; w_i = the weight for the i^{th} pollutant variable; p_i = the sub-index value of the i^{th} leachate pollutant variable, number of leachate pollutant parameters; $n=18$ and $\sum w_i=1$.

However, when the data for all leachate pollutant variables included in *LPI* are not available, the *LPI* can be calculated using the data set of the available leachate pollutants by the Equation (3.2):

$$LPI = \frac{\sum_{i=1}^m w_i p_i}{\sum_{i=1}^m w_i} \quad (3.2)$$

When, all the leachate parameters are unknown, $m < 18$ and $\sum_{i=1}^m w_i < 1$.

3.5.2 Formulation of Sub-pollution Indices

Three sub-pollution indices (sub-*LPIs*) in terms of *LPI* in organic pollutant (LPI_{or}), *LPI* in inorganic pollutant (LPI_{in}) and *LPI* in heavy metal (LPI_{hm}) as well as overall *LPI* had been

developed in this study. After measuring leachate parameters, the sub-LPIs were calculated using the Equation 3.3. For calculating sub-LPIs and overall LPI, the following steps were followed:

1. The concentration of fifteen (15) leachate parameters for sub-LPI and overall LPI were measured in the laboratory at a regular interval of time up to the elapsed period 900 days.
2. Then evaluating sub-index scores (p_i) of all the pollutants included in sub-LPI and overall LPI based on developed variable rating curves with respect to their concentration.
3. The sub-pollution indices in terms of LPI_{or} , LPI_{in} and LPI_{hm} were calculated using the weight factors based on the aggregation function from Equation (3.2).
4. Finally, the aggregation of the three sub-LPIs gets the overall LPI. The three sub-LPI values are aggregated to calculate the overall LPI using following Equation (3.3).

$$LPI = (0.175LPI_{or} + 0.257LPI_{in} + 0.391LPI_{hm}) / 0.823 \quad (3.3)$$

It can be noted that Equation 3.3 has been derived based on the weight factors of pollutants included overall LPI and their contribution to each sub-LPI. However, the component of organic, inorganic and heavy metal is 17.5, 25.7 and 39.10 % for evaluating overall LPI and used to derive the Equation 3.3.

3.6 Treatment of Lysimeter Leachate

The concentration of contaminants in leachate was compared to the maximum discharge standard from some selected countries which were available in the literature. Result reveals most of the parameters exceed the permissible limit of maximum discharge standard indicates treatment was required for reducing the leachate concentration. Firstly, the leachate was treated in phytoremediation through aquatic reactors for removing pollutant load from leachate. The removal efficiency through the phytoremediation treatment process was not satisfactory. Then leachate was treated by coagulation process in various dosages and pH values. The treatment process were analyzed and hence discussed in the following articles.

3.6.1 Phytoremediation Treatment of Leachate

In the pilot scale treatment scheme, the adopted phytoremediation treatment through aquatic reactors by Duckweed (*Lemna minor*), Snail (*Pila globosa*), Helencha (*Enhydra fluctuans*) and Topapana (*Pistia stratiotes*) was carried out as shown in Figure 3.5. This study mainly focused

on the ability of some of the natural phytoremediation treatment systems available in Bangladesh, in removing nutrients in leachate and also dealt about the control system. The volume of the bucket that was used for phytoremediation treatment of leachate of 32 liter. During the treatment period, the bucket was placed in the laboratory in room temperature. For laboratory investigations, leachate samples at varying concentrated were prepared through the dilution of raw leachate with tap water. At such stage, the prepared 100 concentrations of leachate means 100 % of raw leachate was used and 50 concentration means 50 % of tap water was mixed with 50 % of raw leachate. Similarly 20 concentration of contaminants in leachate means 80 % of tap water was mixed with 20 % of raw leachate. In addition, the leachate samples subsequent to pre-treatment through different aquatic reactors were analyzed based on the elapsed period from the treatment, leachate concentration (conditioning system) and removal efficiency.

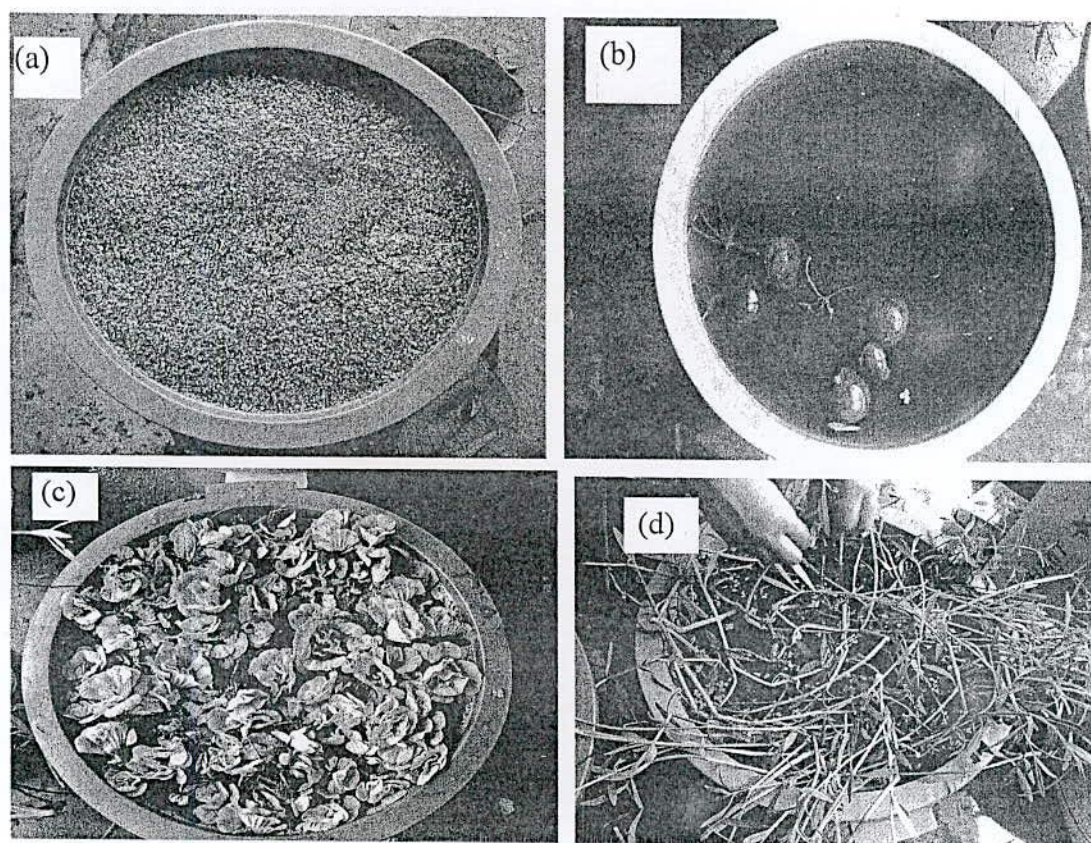


Figure 3.5: Different adopted phytoremediation treatment systems (a) Duckweed (*Lemna minor*), (b) Snail (*Pila globosa*), (c) Topapana (*Pistia stratiotes*) and (d) Helencha (*Enhydra fluctuans*)

3.6.2 Chemical Test of Leachate

Coagulation-flocculation experiments were performed in a conventional Jar-test Apparatus equipped with six backers shown in Figure 3.6 using the chemical coagulant of ferric chloride (FeCl_3) poly-aluminum chloride (PAC), ferrous sulphate (FeSO_4) and aluminum sulphate ($\text{Al}_2(\text{SO}_4)_3$). The experimental procedure consisted of three subsequent stages; the initial rapid mixing stage of 3 min at 100 rpm, the following slow mixing stage of 25 min at 40 rpm and the final settling step for 30 min. The pH values of leachate samples were adjusted to the desired levels by addition of the appropriate amounts of 6N sodium hydroxide or 6N sulfuric acid.

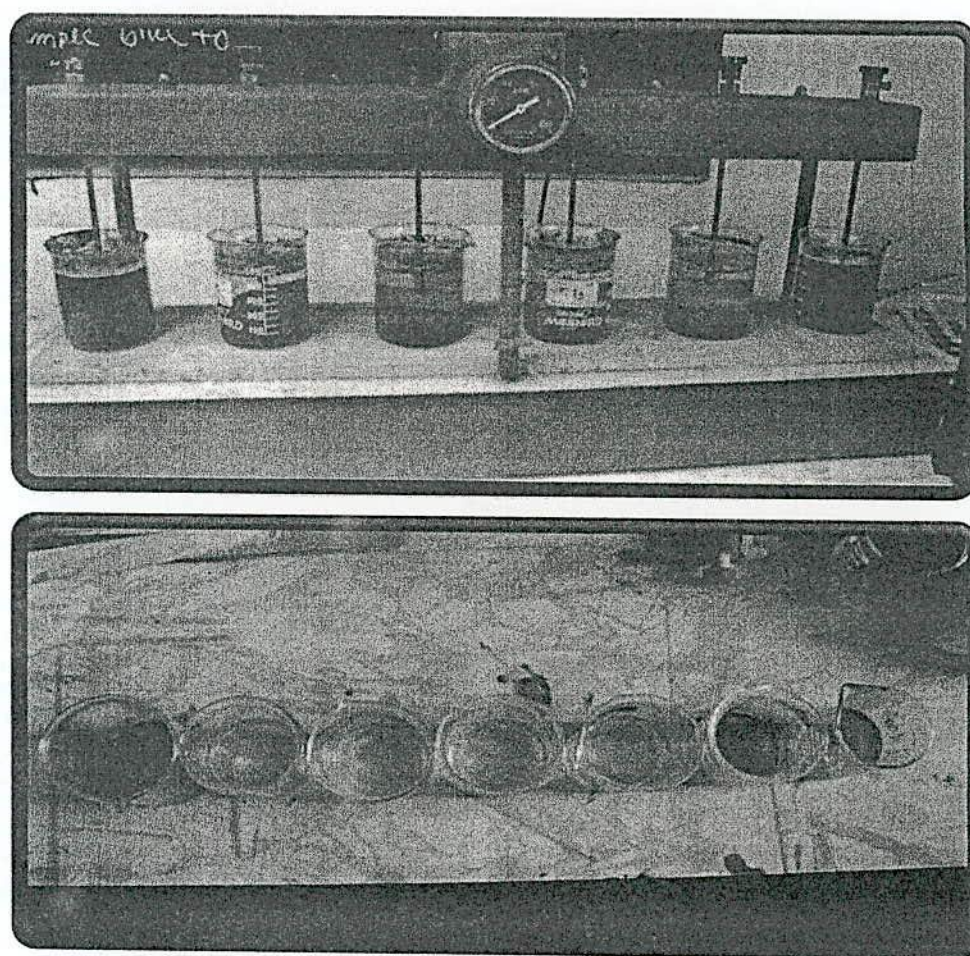


Figure 3.6: Conventional jar-test apparatus equipped with six backers

After the settling period, the supernatant was withdrawn from the beaker and was checked by chemical analysis. The withdrawal of sample was accomplished from a point about 2cm below the liquid level in the beaker by a pipette. The adding of coagulant in leachate, adjusted of pH to the desired levels, mixing speed for Jar Test Apparatus in the laboratory were trailed based on the procedure followed by Hamzeh et al. (2009) and Ebeling et al. (2003). The laboratory

investigation for chemical coagulation treatment of leachate was performed is represented in the flow diagram shown in Figure 3.7.

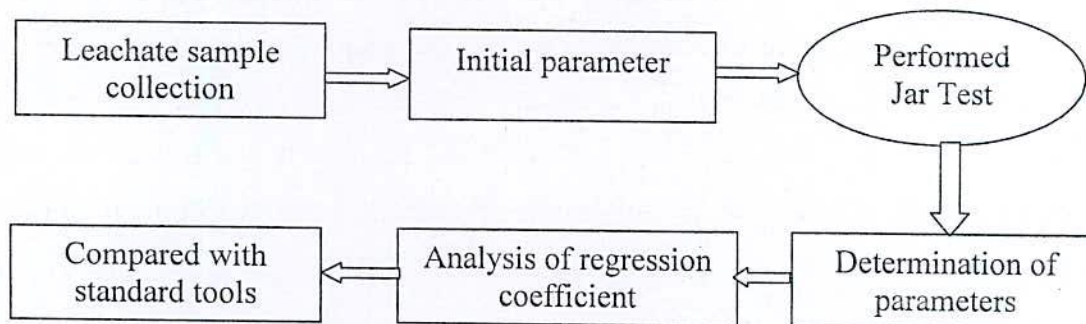


Figure 3.7: Flow diagram of chemical coagulation treatment of leachate

3.7 Analysis of Landfill Gas Emissions from MSW in Lysimeter

For the determination of composition in percentages of LFG mainly in comprising of CO_2 , CH_4 , O_2 , etc. generated from MSW deposited in sanitary lysimeter-B and C, Infra-red gas analyzer borrowed from Bauhaus University Weimer, Germany was used shown in Figure 3.8. In addition, the production rate of LFG in $\text{m}^3/\text{minutes}$ was measured by using the flow meter device (G2.5) purchased from Titas Gas Transmission and Distribution Company Limited, Bangladesh shown in Figure 3.9.

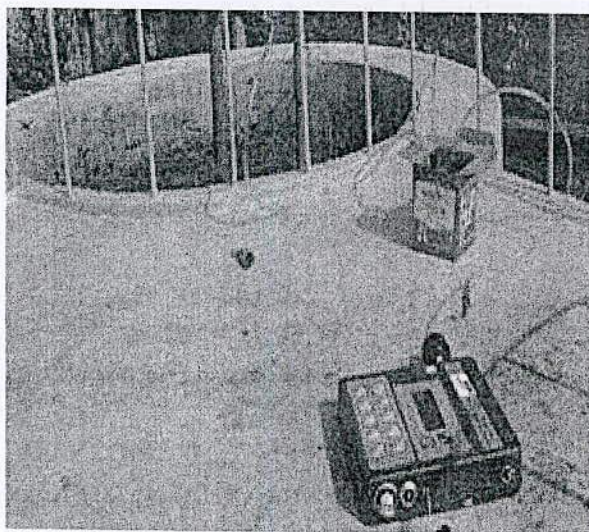


Figure 3.8: Infra-red gas analyzer

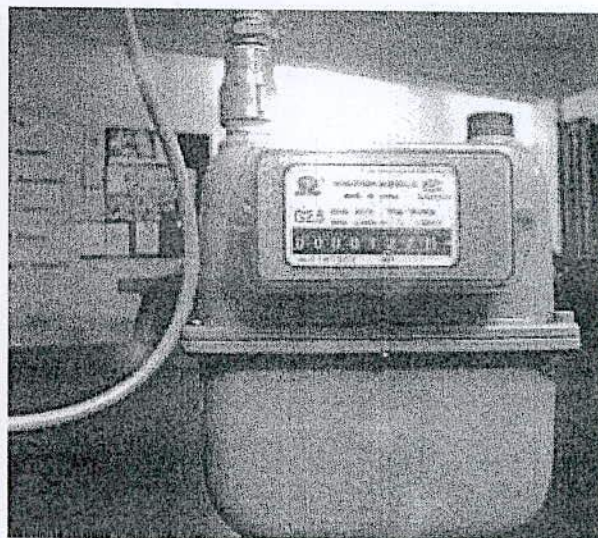


Figure 3.9: Flow meter device

Construction and Monitoring of Landfill Lysimeter

4.1 Background

The best appropriate ways of managing of municipal solid waste (MSW) generated from different sources are source reduction, reuse and recycling, but beyond this, the remaining MSW still have to be effectively managed with environmentally sound technologies (Alamgir et al., 2005). The key management tries of MSW are landfilling, composting, anaerobic digestion, combustion or incineration and gasification (Tchobanoglous et al., 1993). There are two options for dumping of MSW, one is open dumping and another one is sanitary landfill (Rafizul et al., 2011c). In South and Southeast Asia more than 90% of MSW is disposed in an open dumping landfill (Ashford et al., 2000). Considering this issue, it is necessary to develop an approach to design and operate the simple landfill, which are in-transition between the landfill in an open dumping and sanitary facilities (Visvanathan et al., 2002). To this endeavor, three landfill lysimeters test set-up were designed and hence constructed for performance analysis of pilot scale sanitary landfill (PSSL) situated at Rajbandh of Khulna city, Bangladesh.

Sanitary landfill is one of the secure and safe facilities for the disposal of MSW. Lysimeter is a simulate form of sanitary landfill in the sense of control device. The word lysimeter is a combination of two Greek words "*Lusis*" means *Solution* and "*Metron*" means *Measure* and the original aim is to measure soil leaching as stated by Rafizul et al. (2009a). To this attempt, three lysimeters were designed and hence constructed at KUET campus, to investigate the performance of both the base and cap liners. Moreover, for protection of leaching, both the cap and base liners made from compacted clay liners (CCLs) were used in landfill lysimeter. The base liner in lysimeter-A in terms of thickness and materials characteristics was the same as the PSSL situated at Rajbandh of Khulna city. However, two different types of cap liners were constructed in the experimental study; one in lysimeter-B was exactly the same as PSSL, another one in lysimeter-C was a simple and economic version. The MSW deposited in landfill lysimeter was collected from Khulna city area

shown in Figure 4.1, similar to that of deposited in PSSL, moreover, the average composition of MSW and moderate compaction density were maintained during the deposition of MSW in lysimeter. The locally made compaction hammer used for compact of clay and the compactness of CCL was checked by the Supervisor of Prof. Alamgir, shown in Figure 4.2. The functionality of locally available civil engineering materials used for lysimeter construction will be judged through its proper characterization. Moreover, the emission of LFG and leachate from MSW in lysimeter depends on the characteristics of clay used as CCLs and the deposited MSW in landfill lysimeter.



Figure 4.1: Collection of MSW from Khulna city area



Figure 4.2: Check of compactness of CCL

The relative negative impacts of MSW, dumping in a landfill of open condition are common practices and well known all over the world. So, it is necessary to save the environment and make it friendly against the mismanagement of MSW. It can only be control and achieved through the dumping of MSW in sanitary landfill. The sanitary landfill is a well-suited method for managing of solid waste and to investigate the performance of sanitary landfill the behavioral patterns namely; leachate generation, LFG emissions etc are required (Visvanathan et al., 2002). The state regulatory authorities in most of the countries around the world have framed regulations to safe guard against the contamination of groundwater sources from the leachate generated from landfills. A system needs to be developed to prioritize actions, and to establish which landfills needs immediate attention for remediation works. An index for easy comparison of leachate contamination potential of landfills would be a useful tool in this regard. To these endeavors, for evaluating contamination potential of landfill lysimeter, a quantifying tool known as leachate pollution index (*LPI*) as well as sub-pollution indices (*sub-LPIs*) were developed. The overall objectives of this study were formulated: (a) to examine the performance of base and cap liner in landfill lysimeter; (b) to evaluate the behavioral pattern of leachate and LFG emissions from MSW in lysimeter and (c) to evaluate the contaminate potential of landfill lysimeter through LPI.

This chapter concentrates the design, construction and monitoring of simulated landfill lysimeter at KUET campus, Bangladesh. Both the open dump and sanitary conditions having a base liner and two different types of cap liner were simulated. After the design of a reference cell, the construction of landfill lysimeter was started in January 2008 and completed in July 2008. In all construction process locally available civil construction materials were used. The MSW of 2800 to 2985 Kg having the total volume of 2.80 m³ (diameter 1.48 m; height 1.6 m) as well as moisture and organic content of 65, 52 %, respectively, was deposited in each lysimeter by applying required compaction energy. In contrast, both the composition in terms of methane (CH₄), carbon dioxide (CO₂) and oxygen (O₂) as well as the flow rate of landfill gas (LFG) generated from MSW deposited in sanitary lysimeter were measured. Result showed both the composition and flow rate varied significantly in relation to the variation of lysimeter operational condition. Moreover, sanitary landfill lysimeter-C showed higher composition of LFG in compared to sanitary lysimeter-B due to the providing of lower compaction of cap liner in sanitary lysimeter-C. It can be noted that in absence of CCLs and hence percolation of rainwater that facilitated rapid degradation of MSW in open dump lysimeter-A has resulted more settlement than that of sanitary

lysimeter-B and C. Moreover, in case of sanitary lysimeter-B and C, the leachate generation found lower than that of open dump lysimeter-A due to the providing of cap liner in sanitary lysimeter-B and C, played an important role to reduce the percolation of rainwater.

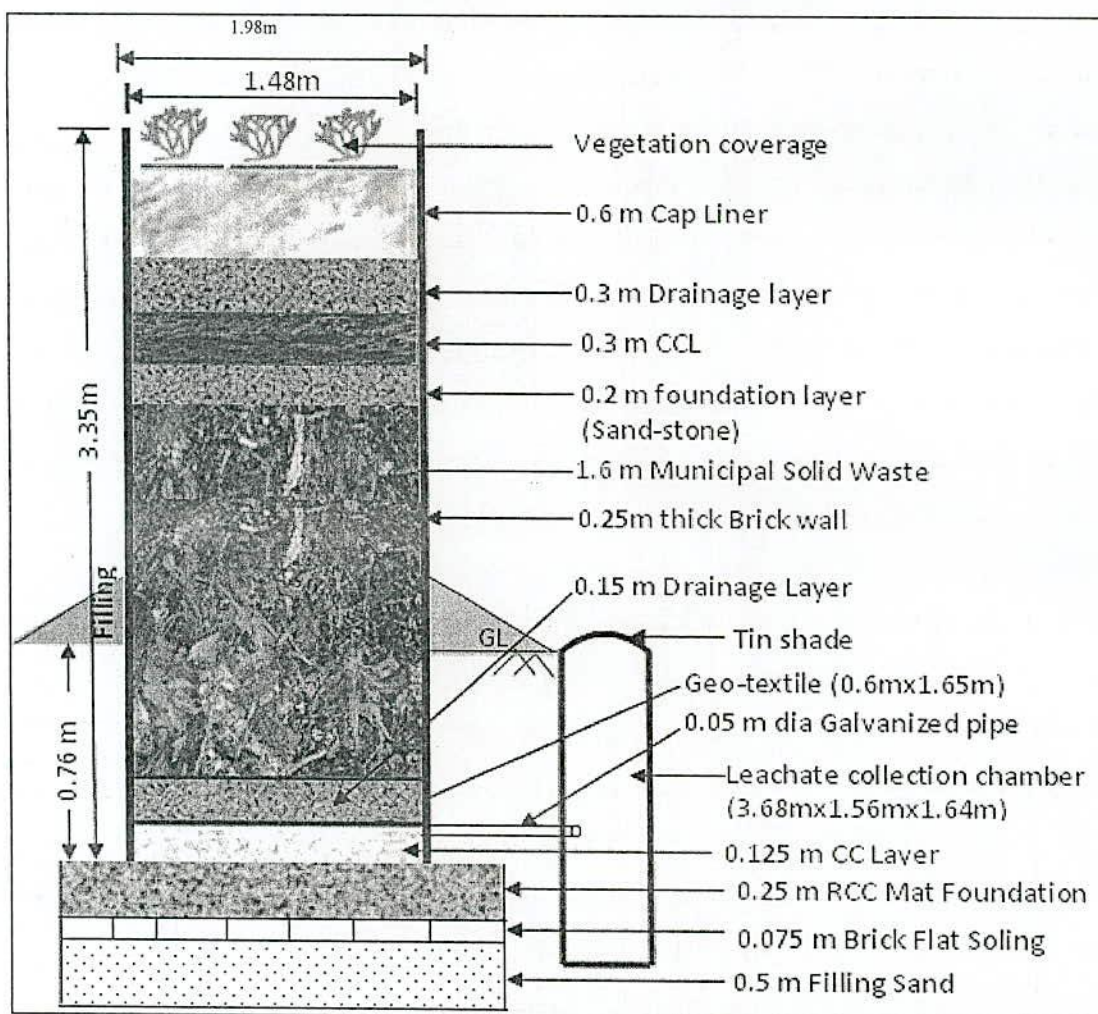


Figure 4.3: Schematic diagram of reference cell for landfill lysimeter design

4.2. Design and Construction of Landfill Lysimeter

The design of reference cell and construction of landfill lysimeter at KUET campus can be explained in detailed in the following articles.

4.2.1 Design of Reference Cell

A reference cell was designed prior to the construction of three lysimeters at KUET campus. After designing the reference cell as a model, the designated lysimeter at varying operational condition with different configuration were selected. Figure 4.3 presents a schematic diagram

of landfill lysimeter showing all the design components in detailed. In reference cell, the deposited MSW mainly consisted of 93 (w/w) organic (food and vegetables), 3 (w/w) of plastic/polythene and 2 (w/w) of leather/rubber, 1 (w/w) of animal bone and rubber/leather as well as 1 (w/w) of rope/straw and egg pill. The organic content and moisture content of the deposited MSW were found 52 % and 65 %, respectively, and the total volume was 2.80 m³ (diameter 1.48 m; height 1.6 m) with a manual compaction to achieve the unit weight of 1,064 kg/m³. At the bottom of reference cell, a cement concrete layer of 125 mm thick was provided then the lysimeters were filled with stone chips (diameter 5-20 mm) and coarse sand (diameter 0.05-0.40 mm) to the height of 15 cm of each to ensure uniform and uninterrupted drainage. The clay used as CCL having the percentages of constituents of sand, silt and clay of 10, 56.6 and 33.4 %, respectively, while, the value of optimum moisture content and maximum dry density of 18% and 16 kN/m³, respectively, and the coefficient of hydraulic conductivity of 1.90x10⁻⁷ cm/sec (Rafizul et al., 2009a).

Table 4.1: Specifications, operational conditions of lysimeter used to simulate different landfill conditions

<i>lysimeter</i>	<i>Operating condition</i>	<i>Refuse placed (kg)</i>	<i>Liner specification</i>	<i>Simulation</i>
A	Open dump lysimeter with leachate detection (A ₁) system	2860	400 mm thick CCL as a barrier between leachate detection and collection system of lysimeter-A	present practice of open dumping
	Open dump lysimeter with leachate collection (A ₂) system			
B	Sanitary landfill lysimeter with gas collection and leachate recirculation system	2985	Cap liner-I (300 mm thick CCL)	applicability of designed top cover
C		2800	Cap liner-II (900 mm thick natural top soil)	

4.2.2 Construction of Landfill Lysimeter

The landfill lysimeter test facilities were set-up in the geo-environmental research station at the backyard of Civil Engineering Building, KUET, Bangladesh shown in Figure 4.4. Refer to Figure 4.3, as the technical detailed for the construction of three lysimeters. Lysimeter was used to simulate the different landfill concept, operational condition and the total weight of MSW was deposited in each lysimeter as presented in Table 4.1. The three landfill lysimeter were constructed using the brick wall of 250 mm thick having outer and inner diameter of

approximately 1.98 m and 1.48 m, respectively, with a total height of 3.35 m, resting on a 250 mm thick of reinforced cement concrete (RCC) mat foundation at a depth of 760 mm below the existing ground surface. A pictorial view of reinforcement used for the construction of RCC mat as shown in Figure 4.5. The landfill lysimeter was plastered both the inner and outer sides with two coatings of waterproofing agent to avoid leakages and corrosion due to acidic environment. Further, the sanitary landfill lysimeters (B and C) consisted of LFG collection system above the MSW and leachate recirculation system below the MSW in landfill lysimeter. Although the recirculation system was provided in sanitary lysimeter-B and C, but the leachate/water was not recirculated in the lysimeter due to some difficulties.

At the bottom of each landfill lysimeter, a cement concrete layer of 125 mm thick was provided then the landfill lysimeters were filled with stone chips (diameter 5-20 mm) and coarse sand (diameter 0.05-0.40 mm) to the height of 15 cm each to ensure proper leachate drainage. At the base of each landfill lysimeter after placing the perforated leachate collection pipe, a geo-textile blanket having 0.60 m wide and 1.65m length was placed to avoid rapid clogging by the sediments from landfill lysimeter. A leachate collection tank (3.68 x1.56 x1.64 m) accommodating four separate leachate discharge pipes in the temporary collection and storage containers, were constructed using 250 mm thick brick wall shown in Figure 4.6. Brief descriptions of the constructed landfill lysimeter having three different conditions were given in followings.

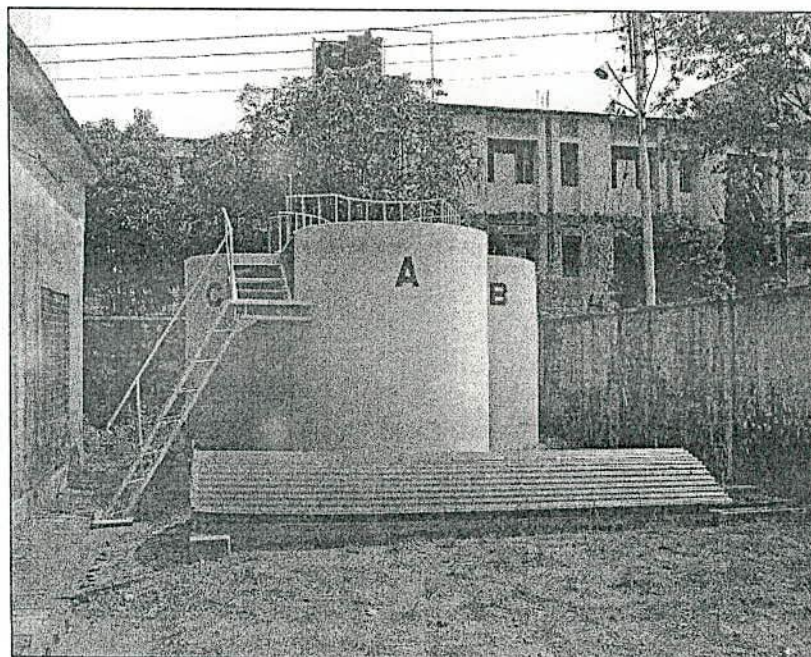


Figure 4.4: Pictorial view of lysimeter at KUET campus

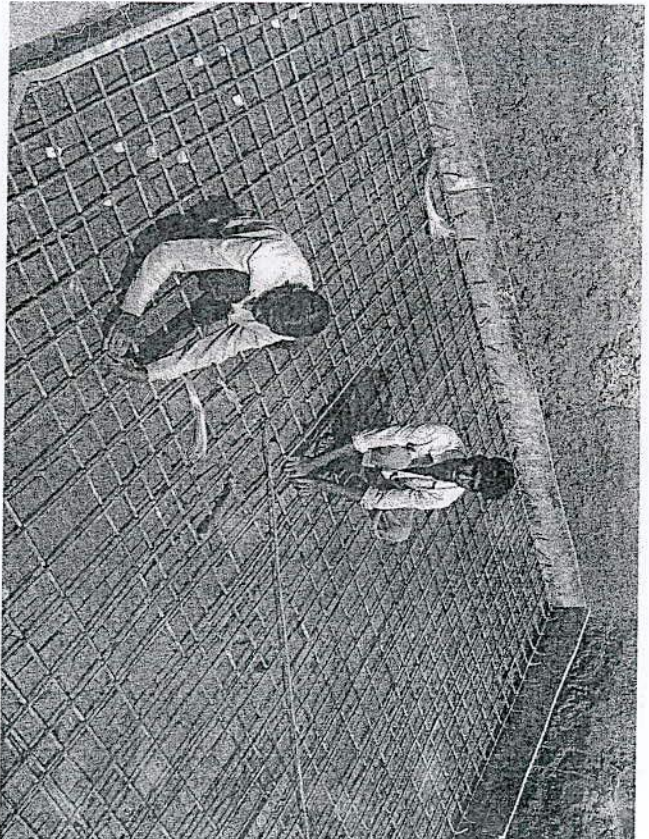


Figure 4.5: Pictorial view of reinforcement in RCC mat

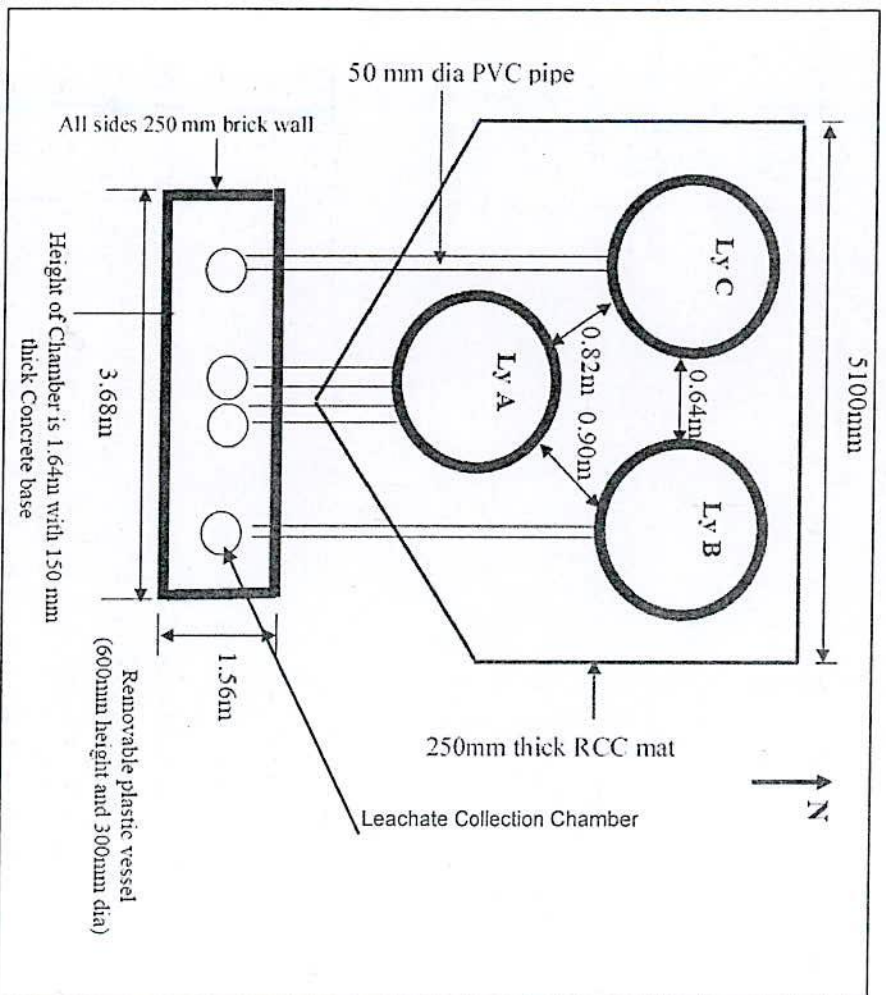


Figure 4.6: Layout of leachate collection chamber

4.2.2.1 Landfill Lysimeter-A (Open Dump)

The type and volume of MSW deposited in open dump lysimeter-A was exactly the same as deposited in the reference cell. In open dump lysimeter-A, a CCL of 400 mm thick was placed as the base liner and a layer of compost of 150 mm thick was used as the top cover to simulate the behaviour of present practice of open dumping in Bangladesh as depicted in Figure 4.7. In this lysimeter the MSW was not covered by a top cover system to pervert the movement of air, water and generated LFG. Moreover, the thickness of the deposited MSW in lysimeter-A was such that it is expected the atmospheric air can move in the entire MSW deposited in this cell with negligible inference. Due to the mentioned practical situations, lysimeter-A, represented the aerobic condition (open dump) comparing the counterparts i.e anaerobic (sanitary landfill) lysimeter-B and lysimeter-C.

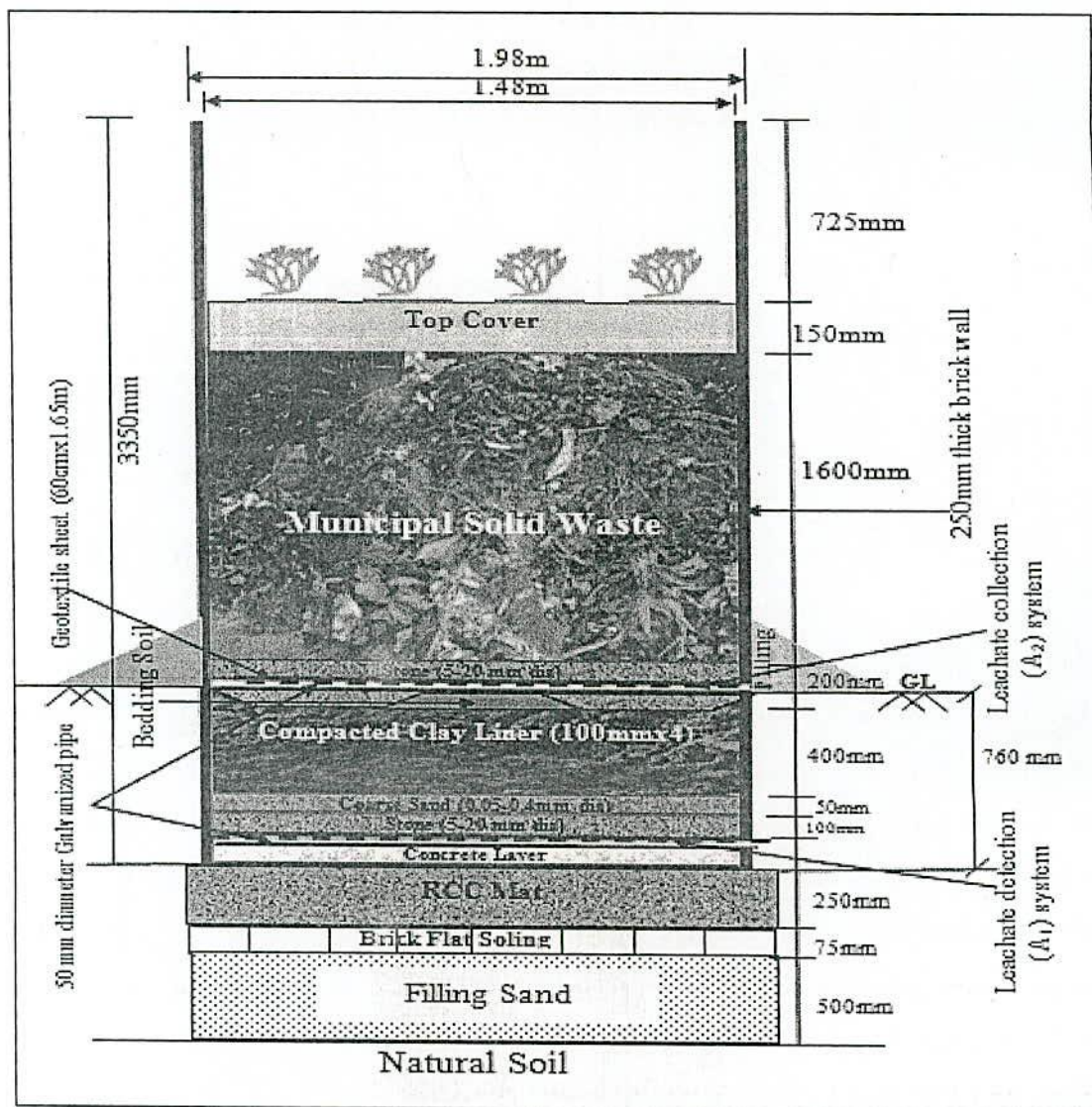


Figure 4.7: Schematic diagram of open dump lysimeter-A

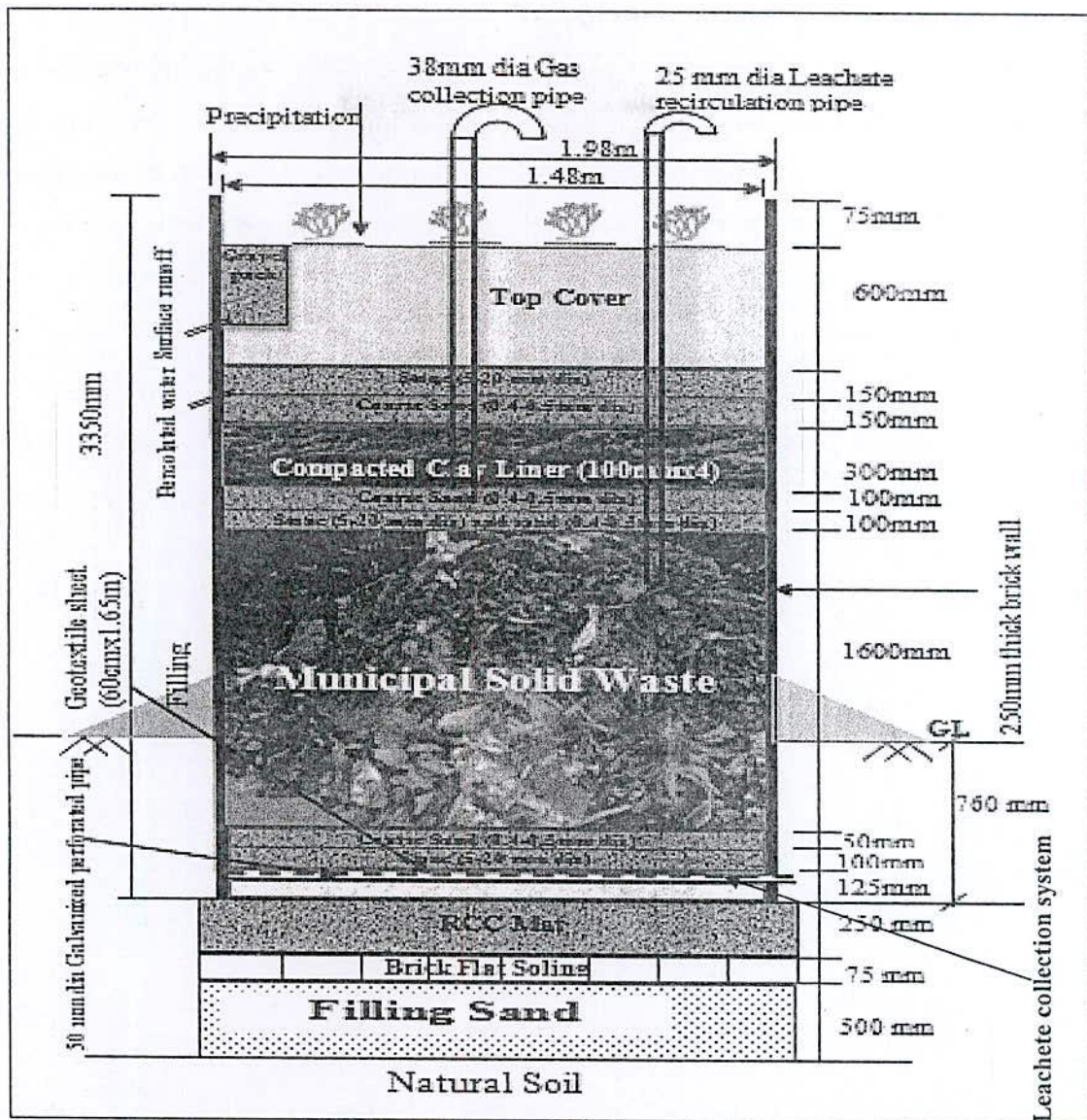


Figure 4.8: Schematic diagram of sanitary landfill lysimeter-B

4.2.2.2 Sanitary Landfill Lysimeter-B (Cap liner I)

In sanitary landfill lysimeter-B as detailed in Figure 4.8, the characteristics and volume of the deposited MSW was similar to that of the open dump lysimeter-A. However, it was differed with open dump lysimeter-A, by a top cover similar to that of PSSSL situated at Rajbandh in Khulna, without having a base liner, because this cell aimed to examine the applicability of the designed top cover. The top cover consisted of stone chips (diameter 5-20 mm) and coarse sand (diameter 0.05-0.40 mm) layer each of 100 mm thickness, then a 300 mm thick CCL was provided. On the CCL, there were 150 mm thick coarse sand (diameter 0.05-0.40 mm) and 150 mm thick stone chips (diameter 5-20 mm), which was followed by 600 mm thick top soil. In sanitary landfill lysimeter-B, 38 mm diameter of gas collection and 25 mm diameter of leachate recirculation pipe were installed. During the installation of these pipes

and penetration through the top cover, special arrangements i.e. disc shaped rubber gasket having 3mm thickness and 300 mm diameter was used for the protection of any possible leakage between the pipe and surrounding soil media as illustrates in Figure 4.9.

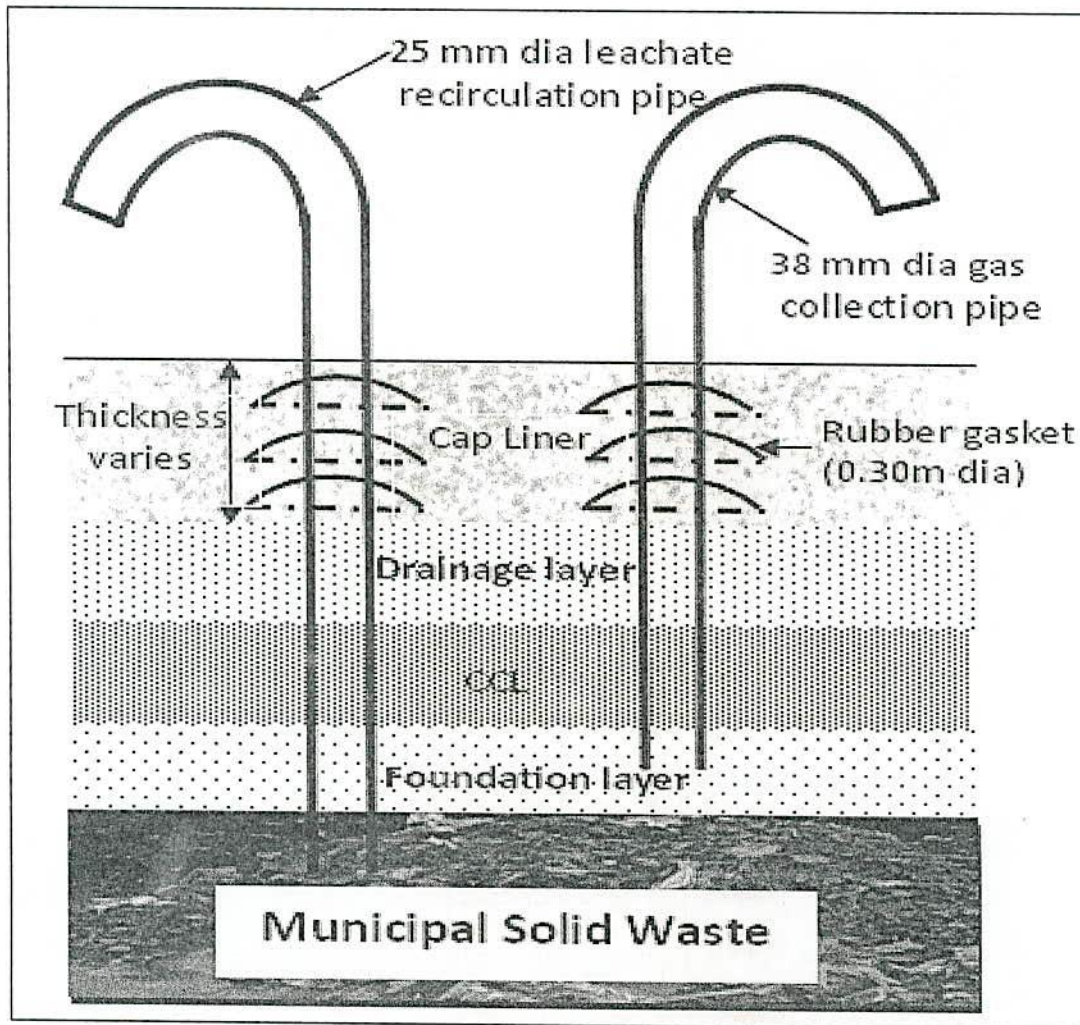


Figure 4.9: Gas collection and leachate recirculation system in lysimeter-B and C

4.2.2.3 Sanitary Landfill Lysimeter-C (Cap liner II)

In sanitary landfill lysimeter-C, there was also no base liner and the provided top cover was different than that of the sanitary landfill lysimeter-B. In this case no CCL was used; however, 900 mm thick natural top soil was used instead of 300 mm CCL and 600 mm thick top soil as depicted in Figure 4.10. Moreover, the drainage and gas collection layers were remained same as the sanitary landfill lysimeter-B. In sanitary landfill lysimeter-C, 38 mm diameter of LFG collection and 25 mm diameter of leachate recirculation pipe was set-up, similar to that of sanitary landfill lysimeter-B. Designated compaction of the CCL in the lysimeter means the degree of compaction which was provided in the PSSSL. To achieve the

designated compaction at the CCL of lysimeter, locally manufactured hammer similar to that used in the PSSL was employed.

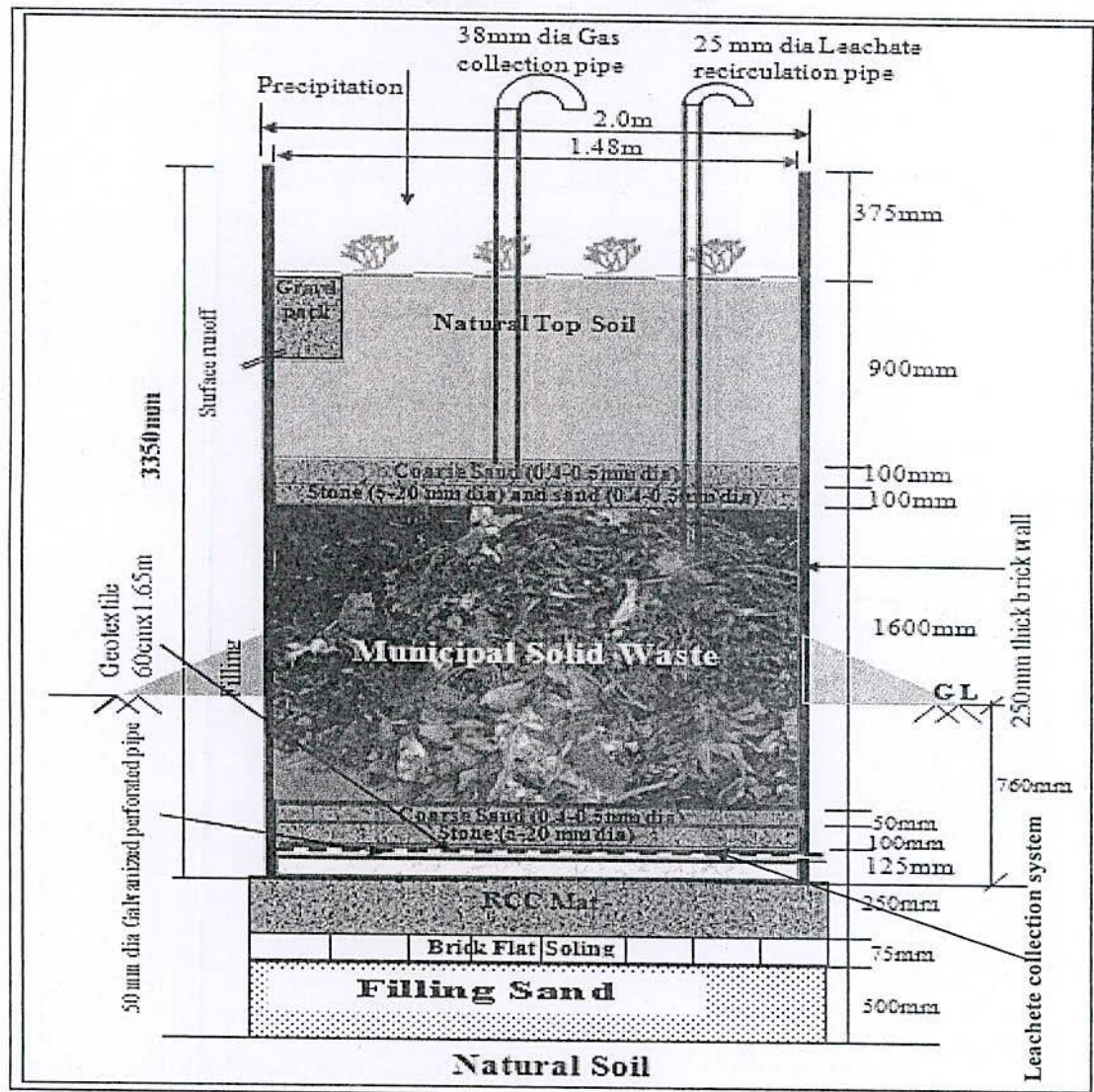


Figure 4.10: Schematic diagram of landfill lysimeter-C

4.2.3 Characteristics of MSW Deposited in Landfill Lysimeter

The quality of generated contaminants leachate and the emissions of LFG from solid waste landfill depends on the type of MSW, degradation of organic fraction from MSW, degree of compaction, depth of fill and the age of MSW in landfill (Alamgir et al., 2006). In addition, the rate of leachate generation and LFG from solid waste landfill depends mainly on the precipitation and the type of top cover. This is only achieved to formulate the information about the composition, organic content and constituents of particle size of solid waste in

landfill (Rafizul et al., 2009c). To this attempt, the following parameters of the deposited MSW in landfill lysimeter were determined.

4.2.3.1 Physical Properties

The quality of leachate mainly depends on organic fraction (food and vegetable) and composition of MSW in landfill (Koener et al., 2007). The physical properties of MSW were determined in the laboratory shown in Table 4.2. Taken 3 Kg of MSW, then sorting all the composition mainly consisted of 93 (w/w) organic (food and vegetables), 3 (w/w) of plastic/polythene and 2 (w/w) of leather/rubber, 1 (w/w) of animal bone and rubber/leather as well as 1 (w/w) of rope/straw and egg pill. The obtained result reveals that food and vegetable fraction was the predominant component and about 93 (w/w) because of the higher fraction of organic substances being in MSW collected from Khulna city area.

Table 4.2: Parameters of MSW sample deposited in landfill lysimeter

<i>Waste characteristics</i>	<i>Value</i>
Fraction of Food/Vegetable waste (w/w)	93
Moisture content, w (%)	65
Organic content, OC (%)	52
Unit weight (kg/m ³)	1000-1066

4.2.3.2 Moisture and Organic Content

Moisture content plays an important role about the rate of decomposition of MSW and the rate of generation of leachate. The moisture content of MSW was measured in the laboratory by drying in the electric oven at 105°C for 24 hours. Moreover, for determining the organic content MSW was incinerated in the muffle furnace at 550°C for 5 hr. The detailed procedure for measuring the moisture and organic content of MSW samples in lysimeter can be obtained in Austrian Standard (S 2023). The moisture content of MSW was found of 65 % and these findings were agreed well with the moisture content values of 62- 66 % of MSW in Khulna city (WasteSafe, 2005).

4.2.3.3 Particle Size Distribution

Before filling the landfill lysimeter with MSW, analysis of finer fraction was done and is shown in Table 4.3 and also in Figure 4.11. The constituents of particle size of MSW were determined with the use of a set of locally manufactured sieves of opening sizes are 400, 300,

200, 100, 76.2, 38.2, 19.1, 9.52, 4.76 and 2.38 mm considered as standard size (Diaz et al. 1996). Here, it is important to note that the percent finer of MSW was 100 % in 300 and 200 mm sieve openings, whereas the values were found as 76.25, 63.72, 45.22 and 24.34 % for the opening of 100, 76.2, 38.2 and 19.1 mm, respectively, as well as gradually decreases for smaller sieve openings. The findings were agreed well with the percent finer of MSW in six major cities, especially in Khulna city (WasteSafe, 2005).

Table 4.3: Sieve analysis of MSW sample deposited in landfill lysimeter

<i>Finer fraction (%)</i>				
300-200 mm	100 mm	76.2 mm	38.2 mm	19.1 mm
100 (%)	76.25 (%)	63.72 (%)	45.22 (%)	24.34 (%)

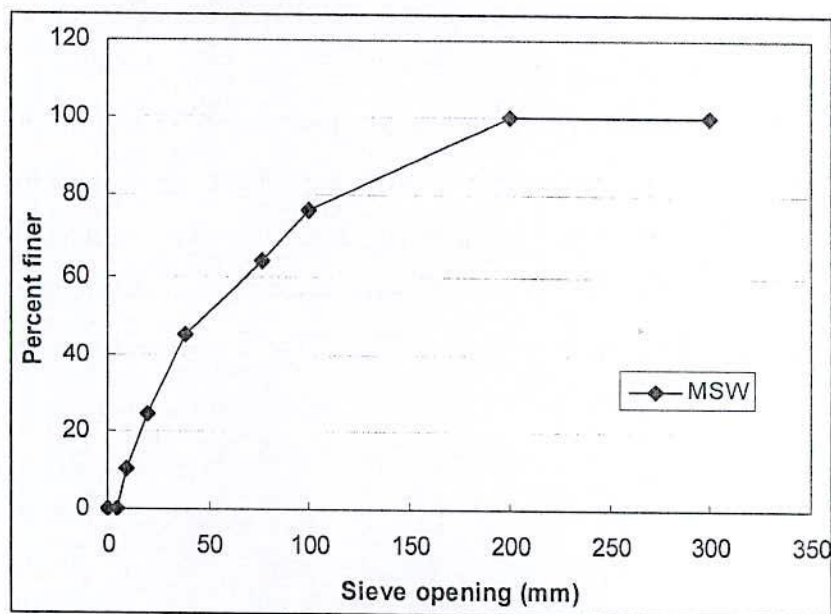


Figure 4.11: Particle size distribution of MSW sample deposited in lysimeter

4.2.3.4 Unit Weight

The unit weights were determined after the MSW deposited into each landfill lysimeter. The total weight of MSW deposited in landfill lysimeter A, B and C were 2860, 2985 and 2800 Kg, respectively, and total volume was 2.80 m³ (diameter 1.48 m; height 1.6 m). Then, the unit weights of the deposited MSW were determined of 1021, 1066 and 1000 Kg/m³ in lysimeter A, B and C, correspondingly provided in Table 4.2.

Table 4.4: Mineralogical compositions of clay sample used as CCL in landfill lysimeter (Roehl, 2007)

<i>Minerals (amount in weight-%)</i>		<i>Sample (0-7 m)</i>	<i>Sample (13-23 m)</i>
Non-clay minerals	Quartz	19%	17%
	Feldspars	<1%	<1%
	Carbonates	<1%	<1%
Non-swelling clay minerals	Illite	~50%	~50%
	Kaolinite	~10%	~10%
	Chlorite	<1%	1-2%
Swelling clay minerals: Smectite		20%	19%

4.2.4 Characteristics of Clay Used as Liner in Landfill Lysimeter

The performance of all the geo-environmental facilities such as landfill liners, covers, vertical barrier depends mainly on the basic characteristics of the soils (Daniel et al., 1995). It is therefore important to know the physical and mechanical properties of the soils as thoroughly as possible before assessing their physico-chemical or hydro-mechanical behavior (Rafizul et al., 2011a). Moreover, Daniel (1995) a researcher stated that using clay as the CLL in solid waste landfill the following fundamental criteria to be satisfied such as coefficient of permeability ($k \leq 1 \times 10^{-7}$ cm/s), plasticity index ($PI < 7$), water content ($w\%$) > plastic limit (PL %) as well as at least 30 % fines and 15 % clay. In the laboratory through standard ASTM (2004) methods, some physical and mechanical properties of clay used as CCL were determined. Based on the evaluated results, the average value of moisture content, plastic limit, liquid limit, plasticity index, and shrinkage limit were found as 22, 22, 43, 21 and 16 %, respectively. In addition, the percentages of soil constituents were found as sand, silt and clay of 10, 56.6 and 33.4 %, respectively, while, the value of optimum moisture content and maximum dry density of 18 % and 16 kN/m³, respectively, and the coefficient of hydraulic conductivity of 1.90×10^{-7} cm/sec. The mineralogical compositions of clay used as CCL is presented in Table 4.4 as measured in the laboratory of the Department of Applied Geology, Karlsruhe University, Germany (Roehl, 2007).

4.3 Monitoring of Landfill Lysimeter

After the completion of lysimeter construction, it was continuously monitored for measuring leachate quantity and concentration, settlement of deposited MSW in lysimeter, LFG flow rate and composition. The monitoring phase is discussed in the following articles.

4.3.1 Tropical Condition during Study Period

The construction, monitoring and the operation of landfill lysimeter is presented by a line diagram in Figure 4.12. After design of reference cell, construction of three lysimeter was started in January 2008 and completed in July 2008. Following the construction of landfill lysimeter, the rate of leachate generation and contamination potential of lysimeter through LPI, settlement and LFG emission in terms of composition and flow rate have been monitored.

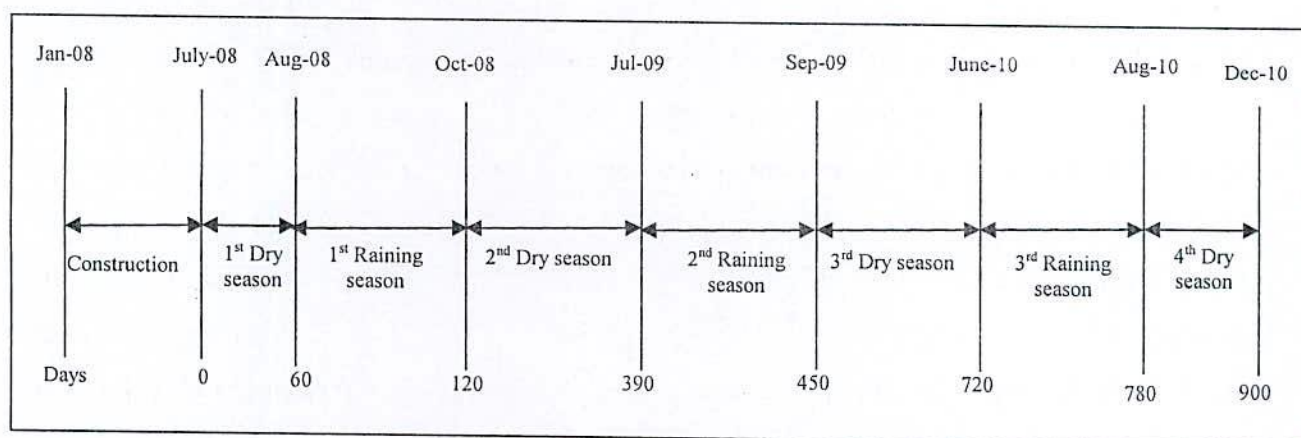


Figure 4.12: Period of construction of landfill lysimeter and monitoring

The monitoring of quantity and flow rate of generated leachate was started in the 3rd week of June 2008 and still continued. Moreover, the monitoring of daily rainfall data was started in the first period of rainy season (August 2008 ~ October 2008). From the beginning to up the 150th day of entire landfill lysimeter operation (July 2008 ~ November 2008), the composition of LFG was measured, however, the monitoring of flow rate LFG was started after 50th day to up the 150th of landfill lysimeter operation (3rd week of August 2008 ~ November 2008).

4.3. 2 Settlement of MSW in Landfill Lysimeter

Figure 4.13 summarizes the settlement rate of MSW deposited in landfill lysimeter during the experimental period. The Figure 4.13 depicts that after 50th day of entire lysimeter operation, the settlement amount was 3.5, 2.1 and 2.5 % (% of waste thickness), for lysimeter-A, B and C, respectively. Moreover, after 50th day, starting the 1st rainy season to up the 135th of operation, the settlement was increased rapidly and ranging from 3.5 to 19.0, 2.1 to 6.7 and 2.5 to 10.2 % in relation to the increasing of elapsed period from waste deposition, in landfill

lysimeter-A, B and C, respectively. It can be noted that sanitary landfill lysimeter-B, with more compaction density of an extra CCL showed lower settlement than open dump lysimeter-A and sanitary lysimeter-C. Moreover, the lower compaction used as 900 mm natural topsoil in sanitary landfill lysimeter-C against lysimeter-B has resulted more primary settlement than that of landfill lysimeter-B. This indicated the importance of the operational mode of landfill and the stability of the landfill cells. A study conducted by Trankler et al. (2005) and Visvanathan et al. (2002) observed the settlement rate in lysimeter during the experimental study period. It noted that a cell, with highest compaction density had, the lowest settlement, indicating the importance of pre-treatment of MSW prior to landfilling. Whereas, lower compaction in another cell has resulted in more primary settlement. So, it can be concluded that settlement pattern in this study were in agreement with the statement given by Trankler et al. (2005) and Visvanathan et al. (2002).

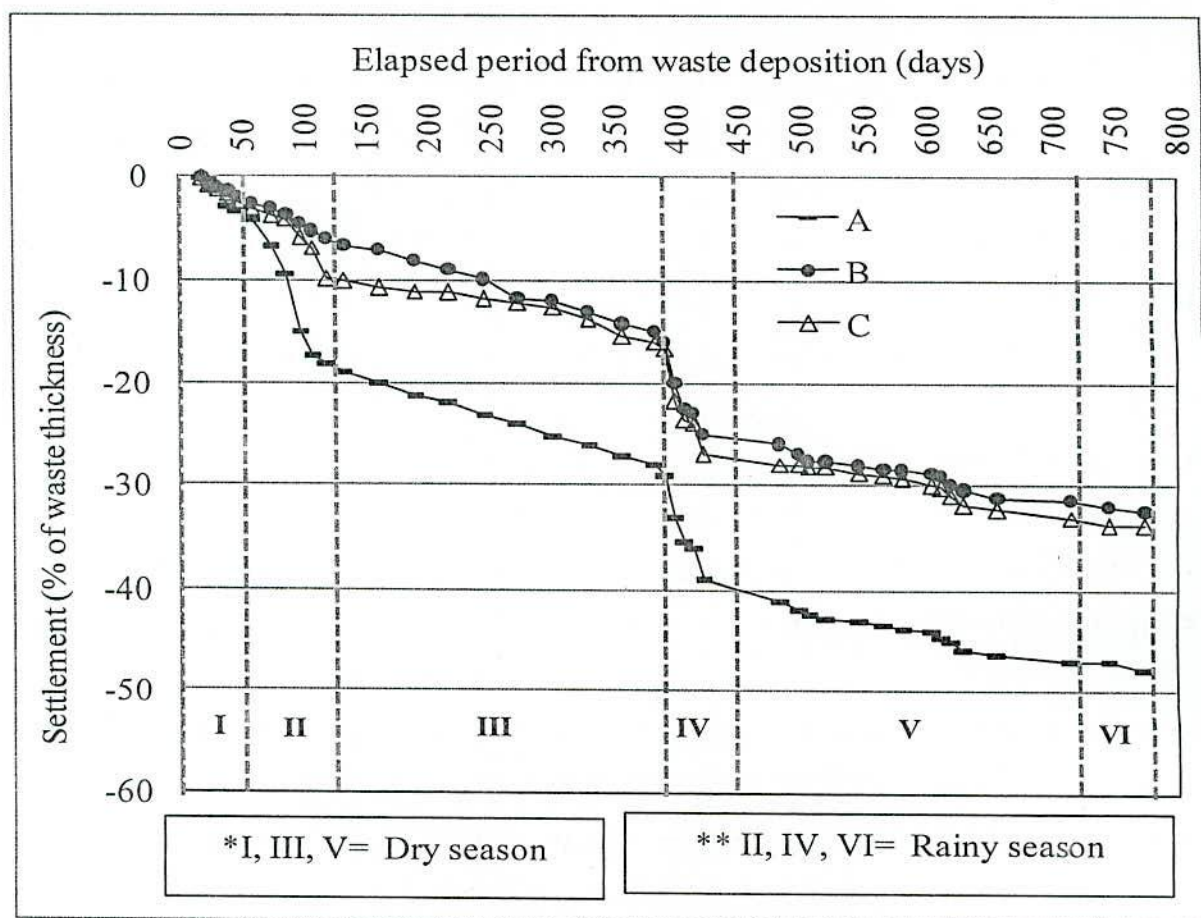


Figure 4.13: Variation of settlement of MSW in entire landfill lysimeter operation

In addition, in absence of compaction effort or CCL and hence due to percolation of rainwater that facilitated rapid degradation of MSW in open dump lysimeter-A has resulted in

the more settlement and remained stable until the completion of this study than that of sanitary landfill lysimeter-B and C. However, El-Fadel et al. (1998) stated that rate of settlement of MSW in landfill depends primarily on the composition of refuse, moisture content response for biodegradation of MSW in landfill, percolation of rainwater in refuse and the operational practices of landfill. So, the observed maximum settlement in open dump lysimeter-A, are agreed well with the statement given by Visvanathan et al. (2002) and El-Fadel et al. (1998).

Here, it is interesting to note that after 390th day, starting the 2nd rainy season to 425th day of operation, the settlement observed in the range of 29.0 to 39.0, 16.0 to 25.0 and 16.5 to 27.0 %, for landfill lysimeter-A, B and C, respectively. Moreover, the settlement during 2nd rainy season found higher than the 1st rainy season and the settlement was steady increased during the dry season. In addition, at the 775th day of operation, the ultimate settlement was observed of 47.9, 32.4 and 33.8 %, for landfill lysimeter-A, B and C, respectively. Based on results, it can be concluded that the settlement for open dump lysimeter-A found higher than that of sanitary landfill lysimeter-B and C. A study conducted by Trankler et al. (2005) and Visvanathan et al. (2007) and observed that the settlement of open cell is more than that of closed cell, because the compaction density of the waste in closed cell is higher than that of open cell. So, finally, it can be concluded the findings in this study was agreed well with the statement given by Trankler et al. (2005) and Visvanathan et al. (2007).

4.3.3 Quantification of Leachate in Landfill Lysimeter

A study conducted by Alamgir et al. (2006) reported that leachate is formed from solid waste landfill when the refuse moisture content exceeds its field capacity (rainfall, initial moisture content, etc) and those that affect leachate or moisture distribution within the landfill. While increased moisture content is the major contribution to leachate formation, it is also commonly associated with enhancing biodegradation processes in landfills. Moreover, it is not environmentally acceptable a solid waste landfill cover which infiltrating the rainwater and hence contaminate the surrounding soil and ground water (Rafizul et al., 2011b). The leachate production varies in a wide range but is not directly related to the total amount of precipitation. Moreover, the high evaporation capacity throughout the dry season has to be carefully assessed (Alamgir et al., 2006).

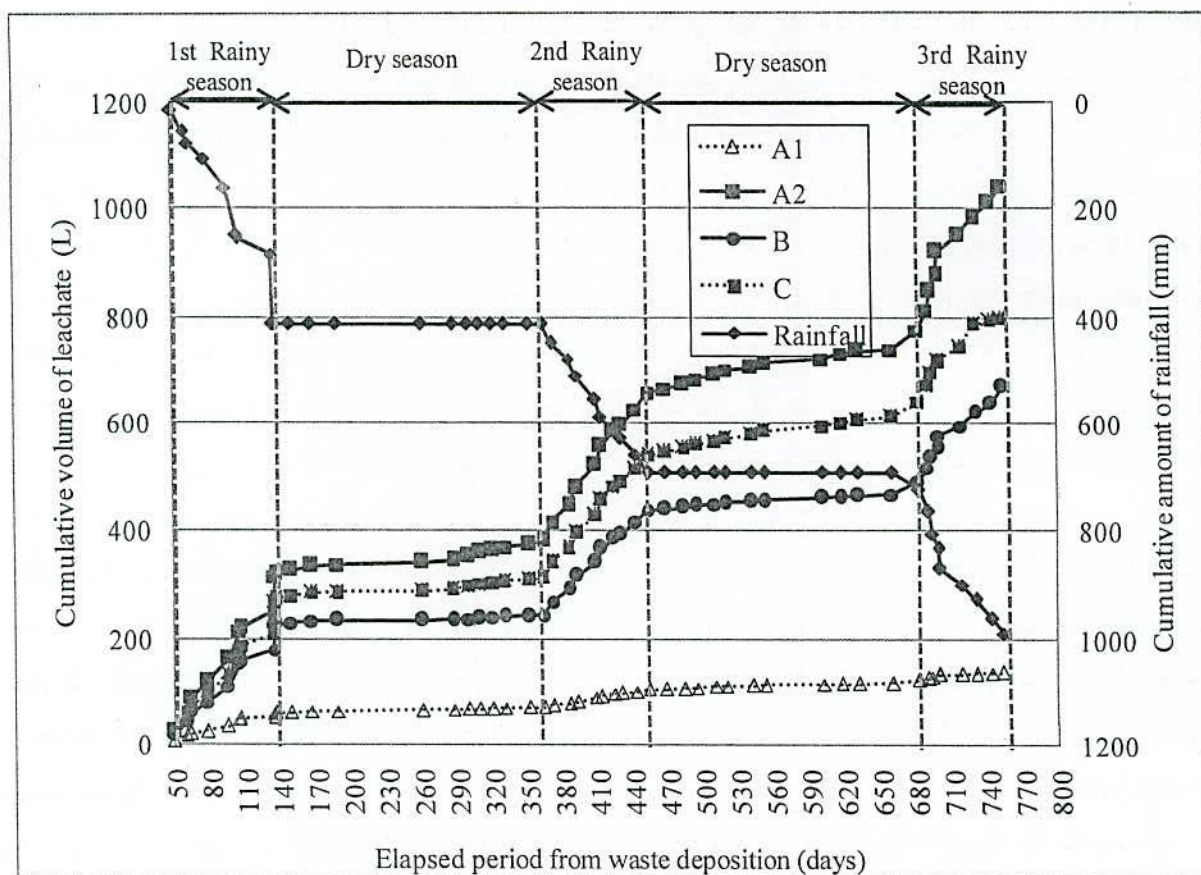


Figure 4.14: Cumulative rainfall and leachate generation in entire landfill lysimeter operating system

The cumulative amount of rainfall and generated leachate from the leachate detection (A_1) and collection (A_2) system of open dump lysimeter-A as well as the collection systems of sanitary landfill lysimeter-B and C is evident in Figure 4.14, for the period of July 2008 to August 2010. During the first rainy season (July to August 2008), highest amount of leachate was generated from the collection system (A_2) of open dump lysimeter-A. Here, it can be noted that after 135 day of lysimeter operation, cumulative leachate generation rate was recorded 315, 224 and 265 liter for the collection system (A_2) of open dump lysimeter-A as well as collection system of sanitary lysimeter-B and C, respectively. It also implied the cumulative leachate generation rate from collection system (A_2) of open dump lysimeter-A was about 41.0 and 19.0 % more than that of the collection system of sanitary landfill lysimeter-B and C, respectively. Moreover, the leachate generation was found as lower in the detection system (A_1) than the other system. Here, it can be established that the variation of leachate generation in case of detection and collection system of open dump lysimeter-A may be occurred due to the providing of 400 mm thick CCL as a barrier between the detection

and collection system of open dump lysimeter-A. As the collection system (A_2) of lysimeter-A was provided just below the MSW deposited in open dump lysimeter-A and the followed detection system (A_1) was separated with the 400 mm thick CCL and this operational mode may be considered for the variation of leachate quantity between these two systems. Moreover, the variation of leachate quantity for the collection system of lysimeter-A and B may be occurred due to the simulation behaviour of open dumping and providing the base liner in open dump lysimeter-A as well as sanitary landfill and providing the cap liner in sanitary landfill lysimeter-B. In contrast, the quantity of leachate in case of collection system of sanitary landfill lysimeter-B and C may be occurred due to the difference of landfill lysimeter-B and C in terms of thickness and compaction conditions of cap liner.

Here it can be noted that sanitary landfill lysimeter-B and C showed lower leachate generation than that of open dump lysimeter-A, although the amount of rainfall was same. That was occurred because of the providing of cap liner in sanitary landfill lysimeter-B and C, played an important role to reduce the percolating of rainwater in sanitary landfill lysimeter-B and C. Same lysimeter investigational concern was demonstrated by Visvanathan et al. (2002), where the top cover soil design selection played an important role. It was observed for open cell, without a CCL, rain water was percolated rapidly into the lysimeter and hence produces relatively higher quantity of leachate, whereas, due to the providing a CLL having high compaction density expected to produce relatively low leachate, especially during the dry season. Moreover, a study conducted by Alamgir et al. (2006) and stated that leachate generation from MSW landfill was influenced by the percolating of rainwater. It was also reported that water holding capacity (field capacity) decreases in relation to the increasing of age of MSW in landfill. The result was further supported from Ehrig (1983).

However, considering about 65 % of moisture content and 52 % of organic waste composition in MSW sample deposited in lysimeter, the amount of leachate generation was strongly related to rainfall and cover system (Rafizul et al., 2011c). During the second rainy season (July to September 2009), higher amount of leachate again generated at the lysimeter operational about 455 day from the collection system (A_2) of open dump lysimeter-A and it was about 51.0 and 22.0 % more than that of sanitary landfill lysimeter-B and lysimeter-C, respectively. However, it was observed that after 450 day of entire lysimeter operation, the leachate generation was also increased steady than the successively rainy season.

4.3.4 Assessment of Lysimeter Leachate

The leachate samples were collected at a regular interval of time from leachate collection chamber at KUET lysimeter and then analyzed in the laboratory. In the laboratory, pH was determined by pH meter (HACH, Model No. Sens ion 156) and conductivity by conductivity meter (HACH, Model No. Sens ion 5). Chloride was determined by potentiometric titration method using silver nitrate solution, Total solid (TS) dried at 103-105⁰C, Alkalinity by titration method and Hardness by EDTA titrimetric method as per the Standard Methods (APHA, 1998). COD by closed reflexive method, Ammonia nitrogen (NH₄-N) by nesslerization standard method and total kjeldahl nitrogen (TKN) by macro-kjeldahl method as per the Standard Methods (APHA, 1998) were determined in the laboratory. Sulfate (SO₄⁻²) by Sulfa Ver 4 method and nitrate (NO₃⁻-N) by Cadmium reduction method using spectrophotometer (HACH, DR/2500) were determined. The concentration of Calcium (Ca), Potassium (K), Sodium (Na), Magnesium (Mg) and Iron (Fe) were measured by using flame atomic absorption spectrophotometer (VARIAN, AA/2400). Heavy metals viz., Cadmium (Cd), Chromium (Cr), Copper (Cu), Lead (Pb), Nickel (Ni), Zinc (Zn) and Manganese (Mn) were analyzed using spectrophotometer (HACH, DR/2400) Standard Methods (APHA, 1998). After measured all the relevant parameters then it was analyzed in relation to the variation of elapsed period of MSW deposited in lysimeter at varying operational landfill condition as well as tropical seasonal variation in the concern section. Moreover, the contamination potential of landfill lysimeter was evaluated by using a quantifying tool knows as leachate pollution index (LPI).

4.3.5 Composition of LFG in Sanitary Lysimeter-B and C

The composition of LFG emissions from MSW in sanitary landfill lysimeter-B was measured using the Infra-red gas analyzer. The Table 4.5 and Figure 4.15 illustrated the composition of LFG over a certain period of decomposition of organic fraction of MSW placed in sanitary landfill lysimeter-B. This figure depicted that the value of CH₄ changes in the range of 45.7 to 59.0 %, from the deposition period of 3 to 60 days and then reduced 58.3 to 21.8 % from the deposition period of 60 to 150 days. In addition, the value of CO₂ varies from 25.7 to 36.0 % from the deposition period of 3 to 60 days and then reduced 33.3 to 15.0 % from the

deposition period of 60 to 150 days. The value of O₂ varies in the range of 0 to 16.3 % from the deposition period of 3 to 150 days.

Table 4.5: Composition of LFG emissions from MSW in sanitary landfill lysimeter-B

Elapsed period from waste deposition (days)	Gas composition (%)		
	Methane (CH ₄)	Carbon dioxide (CO ₂)	Oxygen (O ₂)
3	45.7	25.7	0
10	49.8	25.9	3.6
20	51.8	32.1	5.8
30	53.9	33.8	5.9
40	55.2	34.8	6.1
60	59.1	35.9	6.4
75	56.1	33.1	9.2
90	52.6	32.5	13.6
100	50.9	32.3	14.3
140	30.2	23.4	14.1
150	21.8	15.1	16.3

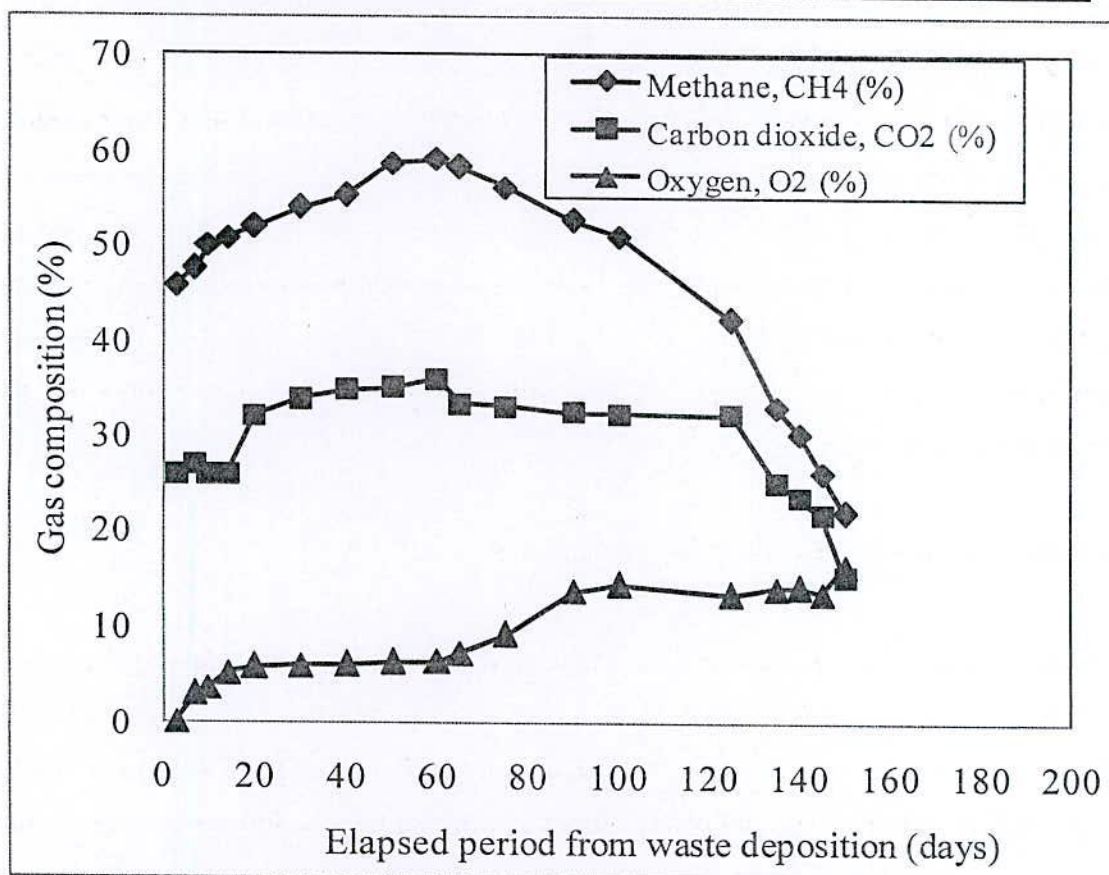


Figure 4.15: Composition of LFG in sanitary landfill landfill lysimeter-B

In contrast, the variation of composition of LFG with the variation of deposition period of sanitary landfill lysimeter-C is shown in Table 4.6 and also in Figure 4.16. This figure revealed that the values of CH₄ vary in the range of 52.2 to 60.3 %, from the deposition period of 3 to 30 days and then reduced 57.2 to 31.8 % from the deposition period of 40 to 150 days. However, the values of CO₂ vary from 28.6 to 33.8 % from the deposition period of 3 to 40 days and then reduced 31.2 to 17.1 % from the deposition period of 50 to 150 days. The values of O₂ change in the range of 1.4 to 19.3 % from the deposition period of 3 to 150 days. Based on the observed results, it can be depicted that sanitary landfill lysimeter-B showed higher composition of LFG than that of sanitary landfill lysimeter-C. From the Figures 4.15 and 4.16 it can be recognized that there was a clear increasing trends of LFG composition as a liner variation with the increase of elapsed period up to a certain stage and then decreased. Typically, the composition of LFG ranges of 40 to 60 % of CH₄, 40 to 50 % of CO₂ and 1 % of O₂ (Tchobanoglous and Vigil, 1993). The findings of this study are in agreed well with the postulation given by Tchobanoglous and Vigil (1993) for the same cases.

Table 4.6: Composition of LFG emissions from MSW in sanitary landfill lysimeter-C

Elapsed period from waste deposition (days)	Gas Composition (%)		
	Methane (CH ₄)	Carbon dioxide (CO ₂)	Oxygen (O ₂)
3	52.2	28.6	1.4
6	53.1	29.2	3.2
10	54.6	29.7	3.4
14	55.1	30.3	3.6
20	56.8	32.1	3.8
30	60.3	32.6	3.9
40	57.2	33.8	4
50	56.2	31.2	4.5
60	56.5	32.1	5.4
65	57.2	33.1	7.2
75	56.1	32.1	9.2
90	55.6	31.3	13.6
100	51.9	30.1	14.3
125	50.2	29.2	13.3
135	43.1	25.1	14
140	40.2	23.4	14.1
145	36.1	22.6	13.4
150	31.8	17.1	9.3

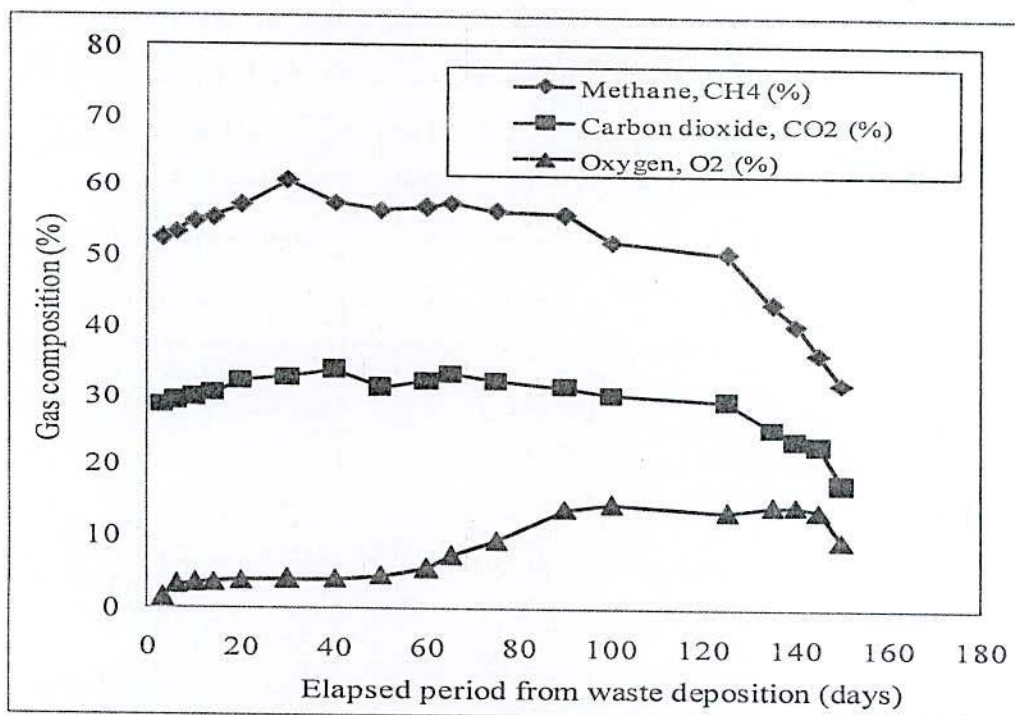


Figure 4.16: Composition of LFG in sanitary landfill lysimeter-C

4.3.6 Production Rate of LFG in Sanitary Landfill Lysimeter-B

The rate of LFG production over a certain elapsed period from the decomposition of organic fraction of MSW placed in sanitary landfill lysimeter-B was measured depicted in Table 4.7 and also in Figure 4.17. The Figure 4.17 depicted the ranges of LFG production vary from 114.2 to 504 L/day from the deposition period of 52 to 70 days and then reduced to 454.8 to 201.6 L/day from the deposition period from 80 to 150 days. From the figure it can be perceived that there was a definite increasing trend of LFG production up to the elapsed deposition period of 70 days and then decreased. The rate of decomposition of MSW, as measured by LFG production, reached a peak within the first two years and then slowly tapers off, up to the period of more than 25 years (Tchobanoglous and Vigil, 1993). The production rate of LFG was found rapidly (5 years or less- some highly biodegradation wastes within days of being placed in landfill) and slowly (5 to 50 years) for the decomposition of organic fraction of MSW in landfill. Tchobanoglous et al. (1993) suggested that the rate of LFG production reaches to the peak at 1 and 5 years for rapidly and slowly decomposable material in MSW, respectively. This statement proved that rate of LFG production is increased up to a certain elapsed period of waste placed in a landfill and then decreased, which agrees well with the findings of this study. Moreover, the time difference,

Tchobanoglous et al. (1993) are referring to real scale landfills and this study is on pilot scale landfills as well as the amount of wastes are considerably different are directed affected the results of this study and reported by Tchobanoglous et al. (1993).

Table 4.7: Gas production rate from MSW in sanitary landfill lysimeter-B

Elapsed period from waste deposition (days)	Gas production rate (m ³ /minutes)	Gas production rate (L/days)
52	7.93E-05	114.2
59	9.59E-05	138.1
62	1.84E-04	264.4
68	2.38E-04	342.0
70	3.50E-04	504.0
80	3.16E-04	454.8
93	2.75E-04	396.0
94	2.61E-04	375.9
97	2.37E-04	341.6
98	2.23E-04	320.7
99	2.02E-04	291.4
100	1.96E-04	282.1
101	2.00E-04	288.0
111	1.80E-04	259.2
120	1.60E-04	230.4
130	1.70E-04	244.8
140	1.50E-04	216.0
150	1.40E-04	201.6

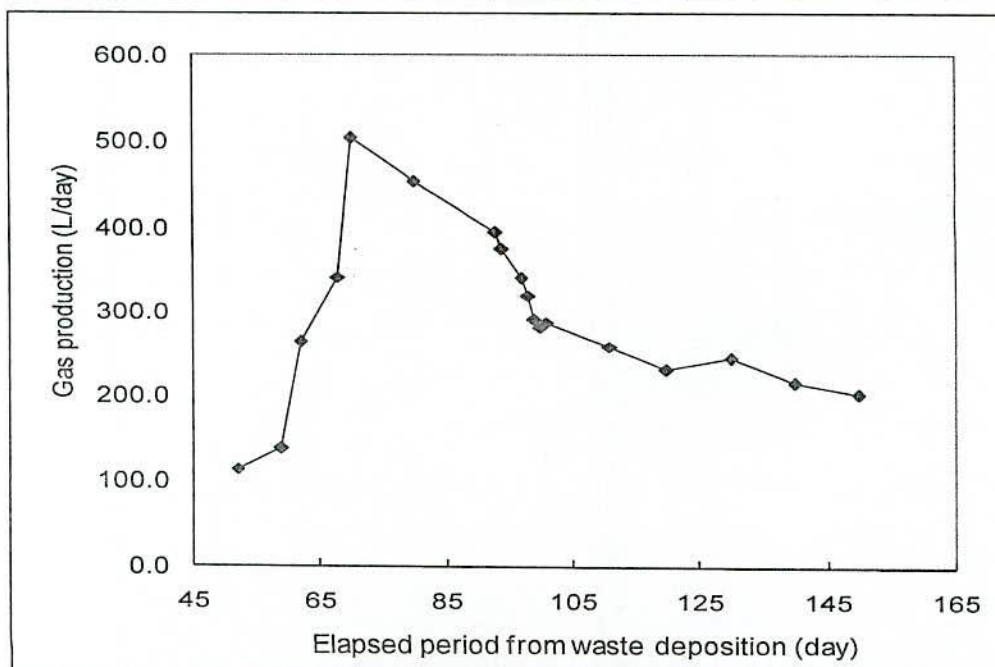


Figure 4.17: Production rate of LFG in sanitary landfill lysimeter-B

4.4 Summary of the Findings

The functionality of locally available construction materials used for solid waste landfill was judged in this study through the proper investigation and evaluation of generated LFG and leachate in three lysimeters from similar nature of MSW. The study revealed rapid leachate production was occurred in an open dump lysimeter-A than that of the other two sanitary landfill lysimeter-B and C which indicated the importance of providing the barrier layer of CCL and the cover materials selection in landfill design. It can be noted that sanitary landfill lysimeter-C showed higher composition of LFG in compared to the sanitary lysimeter-B due to the providing of lower compaction of cap liner in sanitary landfill lysimeter-C. In absence of CCL and hence percolation of rainwater in an open dump lysimeter-A showed higher rate of leachate generation and settlement than that of sanitary landfill lysimeter-B and C. It can be noted that sanitary landfill lysimeter-B with an extra CCL showed lower settlement than that of sanitary landfill lysimeter-C and indicated the importance of providing of the compaction density as well as the cap and base liners in solid waste landfill. Here it can be concluded that to minimize the volume of leachate with high pollutant concentration and then contaminant the surrounding ground and underlying ground water, sanitary landfill with CCL was the best option for MSW disposal.

Characterization and Seasonal Variation of Lysimeter Leachate

5.1 Background

The term 'landfill' can be treated as synonymous to 'sanitary landfill' of municipal solid waste (MSW), only if the latter is designed on the principle of waste containment and is characterized by the presence of a liner and leachate collection system to prevent ground water contamination (Visvanathan et al., 2002). Most of the landfill in developing countries does not have any liners at the base or proper top covers, which results in the potential problems of ground water/surface water contamination due to the leachate generated from solid waste landfill (Horing et al., 1999; McBean et al., 1995). Chemically contaminated leachate is one of the byproducts in landfill degradation reactions (Alamgir et al., 2006). One of the severe problems associated with the open dumping of MSW is percolation of leachate into the surrounding environment, subsequent contamination of the land and water bodies (Walker, 1969; Chian and DeWalle, 1976; Kelly, 1976; Masters, 1998 and Kumar et al., 2002). El-Fadel et al. (2002) reported that composition of landfill leachate can exhibit considerable spatial and temporal variations depending upon the site, management practices, refuse characteristics (i.e. composition and age), and internal landfill processes (hydrolysis, adsorption, speciation, dissolution, ion exchange, re-dox reactions, precipitation etc.). The variation of leachate quality in MSW landfill can be attributed to many interacting factors such as the composition and depth of MSW; decomposition and age of MSW; degree of compaction; landfill design and operation; liner (top and base) design and operation; MSW filling procedures; the availability of moisture content; available oxygen; rate of water movement (fluid addition) and temperature (Qasim and Chiang, 1994). Therefore, it is difficult to generalize the chemical composition of leachate that possesses at a particular time of sampling. In addition, leachate quality may vary from time to time and site to site due to the variables such as waste composition, temperature, moisture content, climatic changes etc. (Alkalay et al., 1998).

This study aimed to characterize the leachate and to investigate the tropical climatic influence on leachate characteristics of lysimeter studies under different seasonal

variations at KUET campus, Bangladesh. Three different situations of landfill were considered here as well as both the open dump lysimeter-A having a base liner and sanitary lysimeter-B and C at two different types of cap liner were simulated. The leachate characteristics, leachate generation and climatic influence parameter had been continually monitored since June 2008 to December 2010. These periods cover both the dry and rainy season. The leachate generation had followed the rainfall pattern. The open dump lysimeter-A without top cover showed higher leachate generation than that of sanitary lysimeter-B and C. Moreover, the open dump lysimeter-A showed lower concentration of TKN and $\text{NH}_4\text{-N}$ as well as TKN load, while both the concentration and load of COD higher in compared with sanitary lysimeter-B and C. In addition, sanitary lysimeter-B, not only depicted lower leachate generation, but also produced reasonable lower concentration and load of COD in compared with open dump lysimeter-A. Result revealed that lysimeter operational mode had direct effect on leachate quality. Finally, it can be concluded that the knowledge of leachate quality will be useful in planning and providing remedial measures of proper liner system in sanitary landfill design and leachate treatment.

5.2 Analytical Methods for the Assessment of Leachate

The leachate samples were collected at a regular interval of time from leachate collection chamber at KUET lysimeter and then analyzed in the laboratory. In the laboratory, pH was determined by pH meter (HACH, Model No. Sens ion 156) and Electric Conductivity by conductivity meter (HACH, Model No. Sens ion 5). Chloride was determined by potentiometric titration method using silver nitrate solution, Total solid (TS) dried at $103\text{--}105^\circ\text{C}$, Alkalinity by titration method and Hardness by EDTA titrimetric method as per the Standard Methods (APHA, 1998). COD by closed reflexive method, Ammonia nitrogen ($\text{NH}_4\text{-N}$) by nesslerization standard method and total kjeldahl nitrogen (TKN) by macro-kjeldahl method as per the Standard Methods (APHA, 1998) were determined in the laboratory. Sulfate (SO_4^{2-}) by Sulfa Ver 4 method and nitrate ($\text{NO}_3^-\text{-N}$) by Cadmium reduction method using spectrophotometer (HACH, DR/2500) were determined. The concentration of Calcium (Ca), Potassium (K), Sodium (Na), Magnesium (Mg) and Iron (Fe) were measured by using flame atomic absorption spectrophotometer (VARIAN, AA/2400). Heavy metals viz., Cadmium (Cd), Chromium (Cr), Copper (Cu), Lead (Pb), Nickel (Ni), Zinc (Zn) and Manganese (Mn) were analyzed using spectrophotometer (HACH, DR/2400) Standard Methods (APHA, 1998).

Table 5.1: Measured concentration of parameters in leachate of landfill lysimeter

Parameter	Operating condition of landfill lysimeter			
	A ₁	A ₂	B	C
<i>Inorganic, organic and nitrogen and compound</i>				
pH	5.98-8.17 (6.77)	6.14-8.02 (7.25)	6.40-8.61 (7.42)	6.30-8.38 (7.48)
Chloride	970-3097 (2238)	1155-3572 (2395)	510-1870 (1086)	110-1810 (1181)
TS	280-10400 (6026)	5019-36690(13244)	2920-14770(10919)	500-27280 (14047)
TDS	210-9930 (5720)	140-35810 (12507)	1800-29980(9786)	420-26000 (13132)
TSS	70-1080 (306)	17-1380 (736)	90-2540 (1133)	47-2340 (915)
Hardness	129.8-3241(2083)	1000-10000 (2371)	1210-14000 (2962)	1096-10000 (2449)
Alkalinity	400-5550 (1100)	980-10000 (2930)	1000-8770 (4805)	900-9435 (4642)
EC	5.3-17.7 (7.30)	3.1-24.7 (9.38)	5.2-16.5 (7.70)	3.7-21.7 (11.26)
Sulfate	-	100-1180 (607.50)	110-1110 (543)	-
COD	160-20800 (2498)	800-60000 (8425)	320-60000 (5654)	300-60000 (11137)
TKN	195-1120 (594.52)	251-1430 (785.61)	480-2187 (1307.07)	312-1860 (1014.31)
NH ₄ -N	187-705 (428.50)	127.9-901 (547.57)	190-997 (653.26)	187-965.7 (598.34)
Nitrate	-	6-22 (14.43)	2-24 (12.2)	-
<i>Metal concentrations</i>				
Ca	254-790 (414.63)	218- 664 (388.99)	153-578 (355.78)	140-664 (406.53)
K	856-1967 (1429.91)	1102-2589 (2067.79)	1009-1764 (1447.45)	567-1957 (1247.28)
Na	1268-2425 (2052.93)	1252-2370 (2046.57)	1256-2764 (2214.91)	1012-2409 (1657.34)
Mg	147-590 (381.17)	127-564 (349.85)	228-606 (412.57)	156-594 (359.44)
Fe	1.8-70 (19.53)	3.4-83 (24.22)	3.6-91 (27.94)	1.4-72 (6.30)
<i>Heavy metal concentrations</i>				
Cd	0.04-0.265 (0.104)	0.04-0.168 (0.078)	0.04-0.178 (0.073)	0.04-0.105 (0.058)
Ni	0.04-0.075 (0.054)	0.04-0.055 (0.045)	0.045-0.09 (0.066)	0.04-0.07 (0.050)
Zn	0.25-1.27 (0.757)	0.15-0.97 (0.537)	0.10-0.55 (0.312)	0.10-0.576 (0.212)
Cu	0.04-0.98 (0.437)	0.04-0.97 (0.344)	0.04-0.76 (0.196)	0.04-0.60 (0.177)
Cr	0.01-0.07 (0.045)	0.01-0.056 (0.038)	0.023-0.03 (0.060)	0.01-0.025 (0.044)
Mn	0.80-6.0 (3.922)	2.5-21.2 (7.422)	0.50-19.3 (6.833)	0.80-8.0 (4.283)
Pb	0.12-0.32 (0.205)	0.179-0.40 (0.271)	0.25-0.78 (0.448)	0.10-0.476 (0.292)

Notation: TS=total solid, TDS=total dissolve solid, TSS=total suspended solid, EC=Electric conductivity, COD=chemical oxygen demand, TKN=total kjeldahl nitrogen, NH₄-N=ammonia nitrogen, Ca=calcium, K=potassium, Na=sodium, Mg=magnissium, Fe=iron, Cd=cadmium, Ni=Nickel, Zn=Zinc, Cu=copper, Cr=chromium, Mn=manganese and Pb=lead.

All values in mg/L, except pH and conductivity (mS/cm). Range is given for the minimum and maximum values, while the value of parenthesis indicates the mean values of the maximum numbers of leachate samples were forty one.

5.3 Characterization of Lysimeter Leachate

The variation of inorganic compounds (pH, chloride, TS, TDS, TSS, Hardness, Alkalinity, EC and Sulfate), organic compounds (COD) and nitrogen compound (TKN, $\text{NH}_4\text{-N}$ and Nitrate), metal concentration (Ca, K, Na, Mg and Fe) as well as heavy metal concentration (Cd, Cr, Cu, Pb, Ni, Zn and Mn) in relation to the variation of elapsed period of MSW deposited in lysimeter at varying operational landfill condition as well as tropical seasonal variation were analyzed and hence discussed in the following articles.

5.3.1 Inorganic, Organic and Nitrogen Compounds in Leachate

In the laboratory, inorganic compounds (pH, chloride, TS, TDS, TSS, Hardness, Alkalinity, Electric Conductivity and Sulfate), organic compounds (COD) and nitrogen compound (TKN, $\text{NH}_4\text{-N}$ and Nitrate) of leachate were monitored and measured as presented in Table 5.1. However, the variation of inorganic and organic compounds in relation to the increasing of elapsed period, changes of climatic condition as well as the open and sanitary lysimeter operational condition were highlighted and hence discussed in followings.

5.3.1.1 pH in Leachate

The pH in leachate is considered to be the most significant parameter affecting leachate concentration in MSW landfill (Bilgili et al., 2007). Metal dissolution is enhanced at low pH which is one of the characteristics of young landfill leachate. MSW contains soil and organic matter that have significant sorptive capacity especially at high pH (Kjeldsen et al., 2002; Bozkurt et al., 1999). The pH curves in case of detection (A_1) and collection (A_2) system of open dump lysimeter-A as well as the collection system of sanitary lysimeter-B and C is evident in Figure 5.1. The Figure 5.1 depicted that pH was ranging from 6.33 to 7.75 and 7.38 to 8.61 for the collection system (A_2) of open dump lysimeter-A and sanitary lysimeter-B, respectively, in the first 100 day of entire lysimeter operation. After 100 day, pH began to increase and it was reached to 8 for the collection system (A_2) of open dump lysimeter-A, while, it was dropped to 6.4 for the collection system of sanitary lysimeter-B. It can be noted that after 100 day of operation, pH for the collection system of sanitary lysimeter-C found comparatively higher than that of other operating system of lysimeter. Moreover, after 160 day of entire lysimeter operation, pH for the detection system (A_1) of open dump lysimeter-A found lower than the collection system- A_2 of lysimeter-A. Here, it can be established that the

variation of pH in case of detection and collection system of open dump lysimeter-A may be occurred due to the providing of 400 mm thick CCL as a barrier between the detection and collection system of lysimeter-A. As the collection system (A_2) of open dump lysimeter-A was provided just below the MSW deposited in lysimeter-A and the followed detection system (A_1) was separated with the 400 mm thick CCL and this operational mode may be considered for the variation of pH between these two systems.

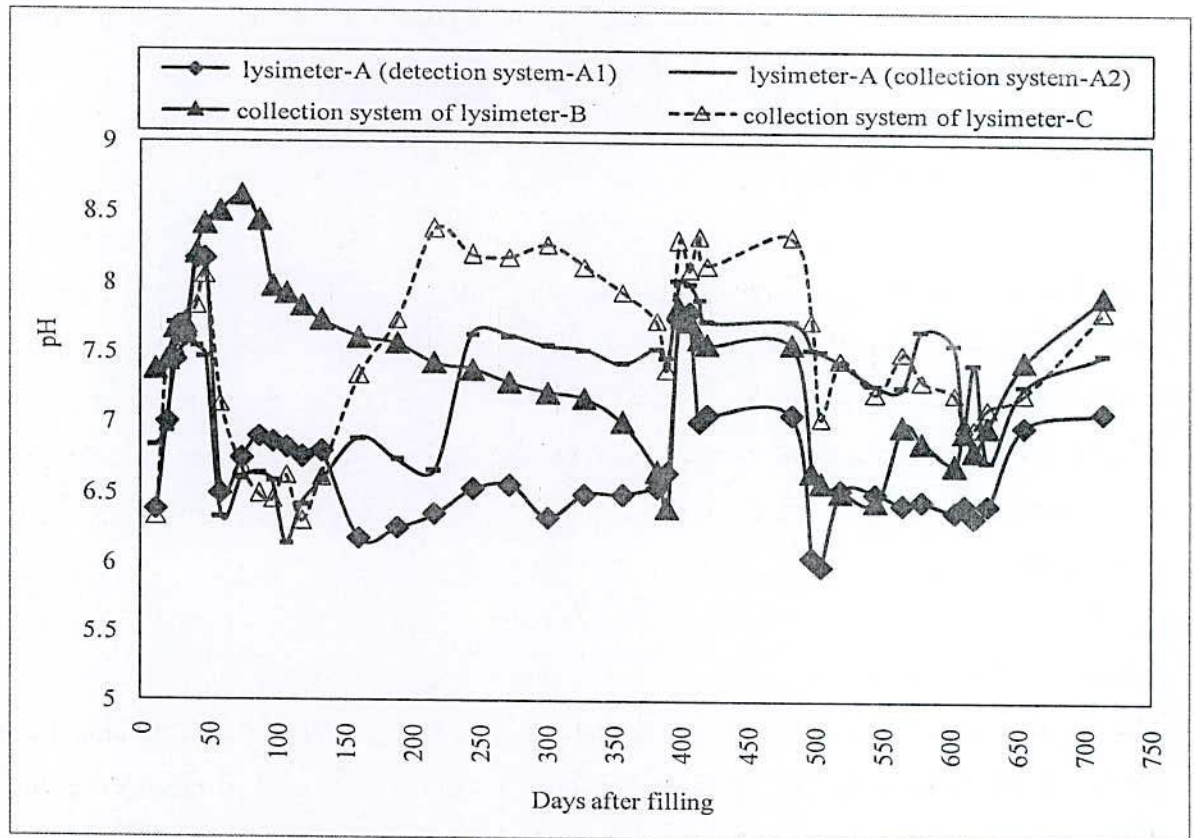


Figure 5.1: The change of pH in leachate of open and sanitary lysimeter

Moreover, the variation of pH for the collection system of lysimeter-A and B may be occurred due to the simulation behaviour of open dumping and providing the base liner in open dump lysimeter-A as well as sanitary landfill and providing the cap liner in lysimeter-B. In contrast, pH for the collection system of sanitary lysimeter-B and C may be occurred due to the difference of landfill lysimeter-B and C in terms of thickness and compaction conditions of cap liner. The consumption of volatile fatty acids (VFA's) in MSW, produced during the acid anaerobic phase, increases pH in between 7 and 8 (Farquhar, 1989). So, the increase of pH for the collection system of open dump lysimeter-A are agreed well with the postulation stated by Farquhar (1989). After that, no considerable changes were observed of pH in leachate and it was measured between 6 and 8.

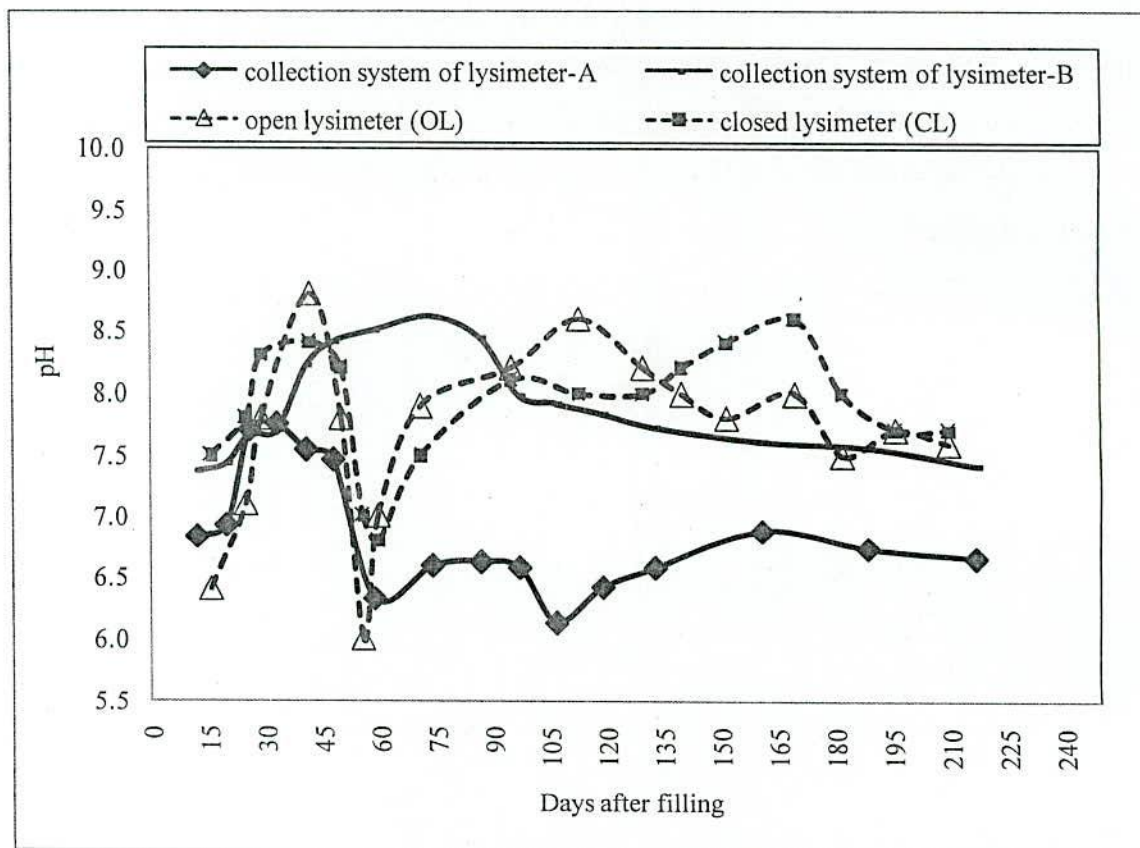


Figure 5.2: Comparison of predicted pH in the present study with the other researcher

These results are in accordance with the data stated by Cossu et al. (2003); Ishigaki et al. (2003) and Nakasaki et al. (1993). However, to depict the validity of the findings in this study then also compared with those results in case of open lysimeter (OL) and closed lysimeter (CL) postulated by Trankler et al. (2005) and Visvanathan et al. (2007) shown in Figure 5.2. The Figure 5.2 reveals that pH for the collection system of sanitary lysimeter-B was higher than that of the collection system of open dump lysimeter-A and it was continued as well as similar trend was also observed for the same cases of lysimeter studied by Trankler et al. (2005) and Visvanathan et al. (2007).

5.3.1.2 Chloride

Chloride in leachate is considered to be a very conservative anion that is only attenuated during dilution. Ehrig (1983) suggested that there is no observable difference of chloride between acidogenic and methanogenic phases of solid waste landfill. The changes of Cl^- in relation to the increasing of elapsed period from MSW deposited in entire lysimeter are evident in Figure 5.3. It is important to note that for the detection (A_1) and collection (A_2)

system of open dump lysimeter-A as well as the collection system of sanitary lysimeter-B and C, Cl^- varied from 970 to 3037, 1155 to 3572, 510 to 1870 and 110 to 1810 mg/L, respectively. At the beginning to up the 100 day of operation, Cl^- dropped and ranging from 3037 to 970, 3572 to 1155, 1350 to 550 and 760 to 130 mg/L, for the detection and collection system of open dump lysimeter-A, as well as the collection system of sanitary lysimeter-B and C, respectively.

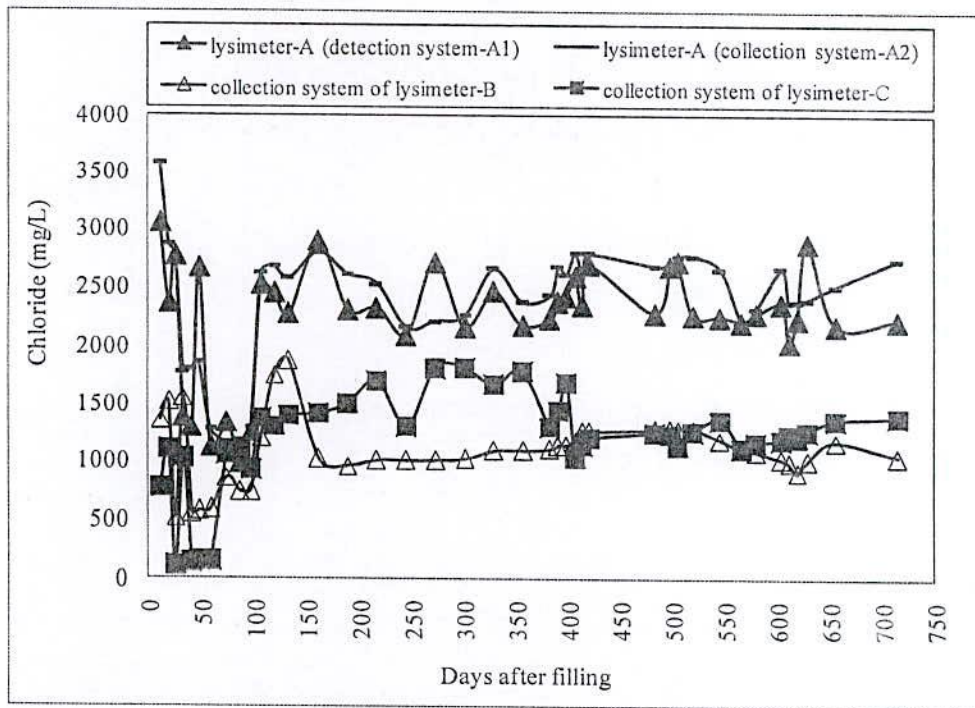


Figure 5.3: The change of Cl^- of open and sanitary lysimeter

It can be perceived that Cl^- decreases up to 100 day of entire lysimeter operation (Figure 5.3) due to comparatively the higher rate of leachate production during this operational period because the concentration of chloride may be diluted. Result revealed that after 100 day of entire lysimeter operation, Cl^- began to rise rapidly and it reached of 2507.5, 2607.5, 1190 and 1370 mg/L, for the detection and collection system of open dump lysimeter-A as well as the collection system of sanitary lysimeter-B and C, respectively. After this rapid increase, no considerable changes were observed for all the cases and it was continued. Here, it can be noted that chloride release from MSW in open dump lysimeter-A (both the detection and collection system) found higher than from MSW in both the sanitary lysimeter- B and C (Figure 5.3). Chu et al. (1994) reported that chloride increases with the increasing of age of waste in landfill. It was noticed that pH (Figure 5.1) and Cl^- began to increase simultaneously in all the cases of lysimeter operation and it was continued. This situation also followed by

Manning and Robinson (1999) and stated that as a result of the increase of pH in leachate, the dissolution of chloride increases and thus the chloride in leachate also increases.

5.3.1.3 Relation of Solid Particles

The variation of solid particles in terms of total solid (TS), total dissolved solid (TDS) and total suspended solid (TSS) in leachate in relation to the increasing of elapsed period for the collection system of open dump lysimeter-A and sanitary lysimeter-B shown in Figure 5.4. This figure revealed the concentration of TS decreases rapidly from 36,690 to 16,360 mg/L up to the 74 day, in case of open dump lysimeter-A, while, decreases rapidly from 30,739 to 5,960 mg/L by 110 day for sanitary lysimeter-B. Here, it is interesting to note that after day about 75, the concentration of TS also began to decrease and it dropped to 860 mg/L for open dump lysimeter-A, while, 3800 for sanitary lysimeter-B. Yuen et al. (2001) reported that TS concentration is expected to decrease as the leachate moves from acidogenic to methanogenic but the dissolved solids concentrations do not change in large quantities as total solid.

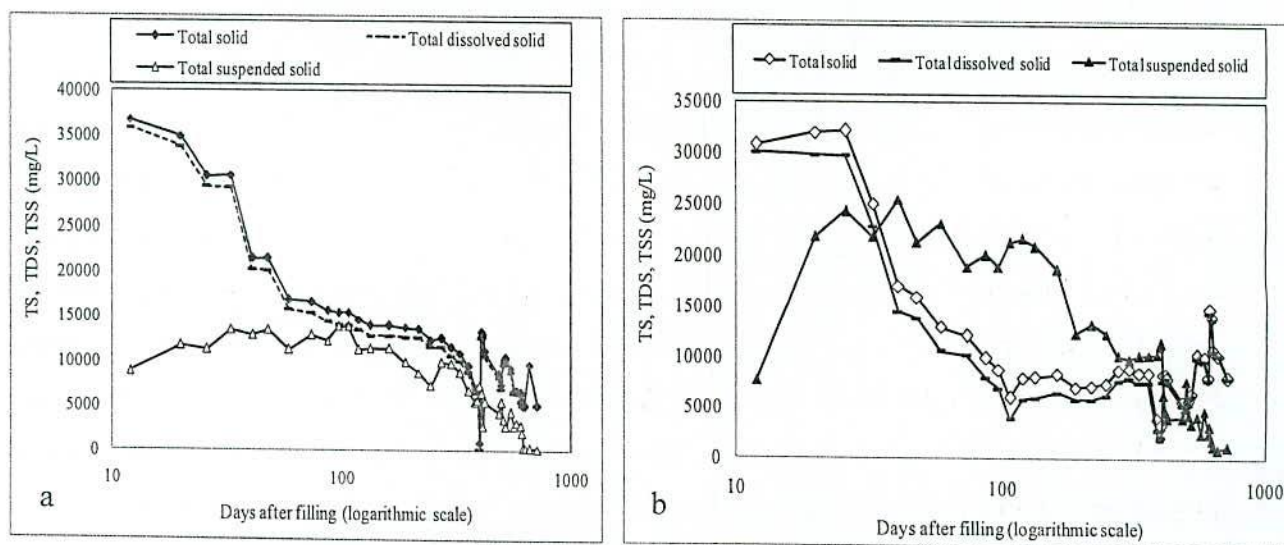


Figure 5.4: Variation of TS, TDS and $TSS \cdot 10^{-1}$ with waste age in the collection system of (a) open dump lysimeter-A and (b) sanitary lysimeter-B

Based on the Figure 5.4, it was also observed that in case of open dump lysimeter-A, the concentration of TS has changed significantly in the range of 860 to 36,690 mg/L and for sanitary lysimeter-B of 3800 to 30,739 mg/L. The Figure 5.4 depicts that the concentration of TS in case of open dump lysimeter-A was found as (36,690 mg/L) higher than that of sanitary lysimeter-B (30,739 mg/L). A study by Kouzeli-Katsiri et al. (1999) reported that leachate samples from MSW landfill has high TS indicating the abundant presence of loose materials that easily get dissolved with the percolating water. But, with the increase in age of deposited

waste, the availability of loose materials has reduced considerably due to the compaction of waste. The solids joining the leachate at the later stage are the products of chemical and biological degradation of waste (Rafizul et al., 2009a). The concentration of TS in leachate depends not only on elapsed period from the waste deposition but also the types, applicability and compactness of base and cap liner (Mollekopf et al., 2002; Diaz et al., 1996). Due to the influence of the above factors, the magnitudes of TS in open dump lysimeter-A, was higher than that of sanitary lysimeter-B, although the trend was similar. Moreover, this variation may be occurred due to the simulation behaviour of open dumping and providing the base liner in lysimeter-A as well as sanitary landfill and providing the cap liner in lysimeter-B.

5.3.1.4 Relation of Hardness, Alkalinity, Chloride and COD concentration

The variation of total Hardness, Alkalinity and COD concentration in leachate in relation to the increasing of elapsed period from waste deposition in open dump lysimeter-A is shown in Figure 5.5. Here, it can be noted that at the initial stage of open dump lysimeter-A, Hardness as CaCO_3 (10, 000 mg/L), Alkalinity as CaCO_3 (10,000 mg/L) and COD concentration (60,000 mg/L) was found the highest concentration. Christensen et al. (2001) stated that Ca concentration has a tendency of complex formation with HCO_3^- , dissolved organic compounds and dissolution reactions involving calcite (CaCO_3). It also observed that thus the dissolution process is closely linked to the dissolved carbonate compounds and as a result of the rapidly dissolution process, leachate generated from MSW deposited in landfill that has high Alkalinity values ($\sim 10,000$ mg/L as CaCO_3). However, after day 50, the values dropped rapidly from 10000 to 2222, 10000 to 3100 and 60000 to 2240 mg/L, for Hardness, Alkalinity and COD, respectively for the dilution of deposited MSW for percolating of rainfall into the lysimeter. It can be concluded that Hardness, Alkalinity and COD seems to be proportional to one another in a scatter manner (i. e. when COD decreases Hardness and Alkalinity also decreases and it was continued (Figure 5.5). The reason for the decrease in COD level may be the quick degradation of the solid wastes in the lab scale MSW in anaerobic reactor (Sponza and Agdag, 2004; Rafizul et al., 2009a). It is difficult to generalize the concentration of a particular parameter (i. e. pH, COD, Hardness, Alkalinity, etc) in leachate at a specific time, and in most of the cases, concentration increases during a relatively short initial phase then, decrease with time (Rowe, 1995; Ham and Bookter, 1982).

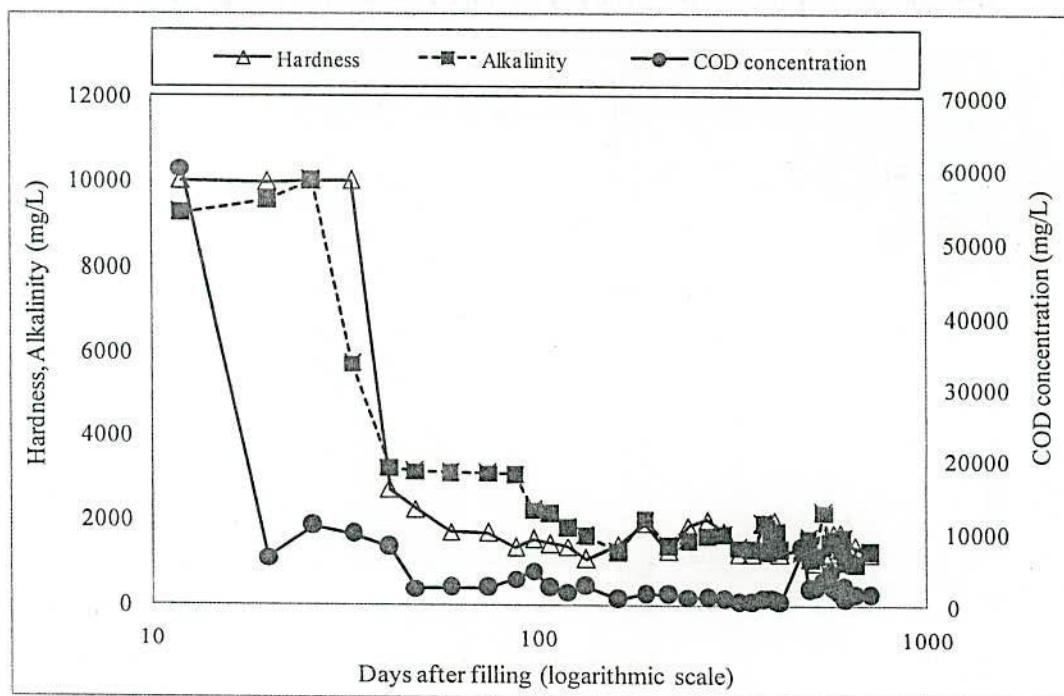


Figure 5.5: Variation of hardness, alkalinity and COD in open dump lysimeter-A

5.3.1.5 COD Concentration

The variation of COD in relation to the increasing of elapsed period is evident in Figure 5.7. The concentration of COD decreases rapidly with the range of 60,000 to 7640, 60,000 to 3640 and 60,000 to 7960 mg/L, up to the elapsed period 48 day, for collection system of open dump lysimeter-A as well as sanitary lysimeter-B and C, respectively. Here, it is interesting to note that COD decreases sharply from 50 to 100 day for entire lysimeter operation due to comparatively the higher rate of leachate production for the dilution of deposited MSW for percolating of rainfall into the lysimeter. Moreover, the LFG concentrations from sanitary lysimeter-B was measured shown in Figure 5.8. Result revealed that methane concentration decreases sharply from 60 to 150 day due to the higher rate of leachate production for the dilution of deposited MSW for percolating of rainfall into the lysimeter. After day 100, COD also decreases steadily and it was continued. Moreover, due to their initially biodegradable nature, organic compound decreases more rapidly than that of inorganic compound with increasing the age of landfill (Chain and DeWalle, 1976). A decrease of COD occurs over the elapsed period of landfill and it can be attributed to a combination of reduction in organic contaminants and the increased biodegradation of organic compounds (Krug and Ham, 1995). A constant decrease in COD is also expected as

degradation of organic matter continues (Ehrig, 1989). It can be noted that initially higher concentration of COD (60,000 mg/L) and after day 100, the steady decreasing trend are also supported by Chain and DeWalle (1976); Krug and Ham (1995) and Ehrig (1989).

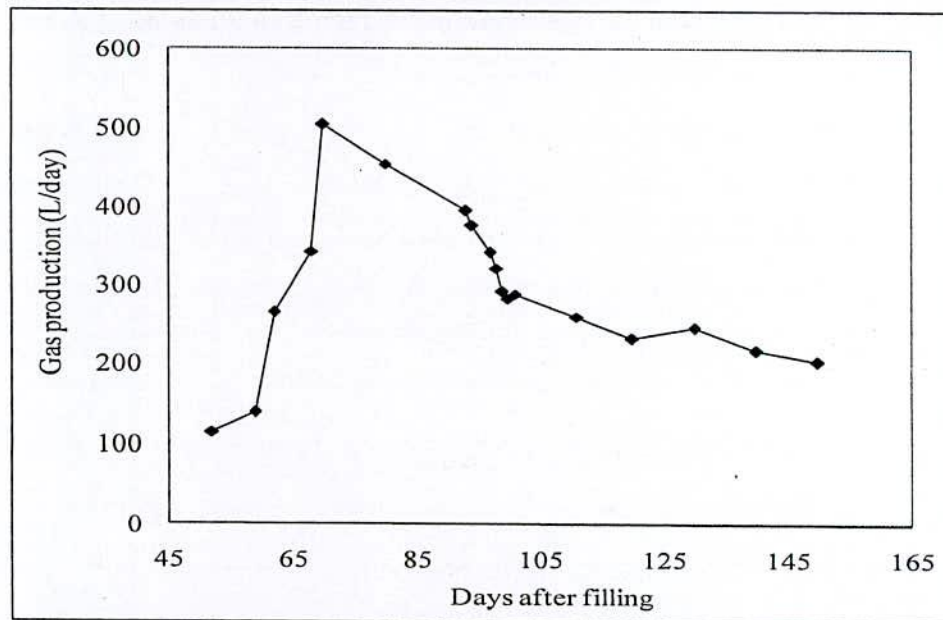


Figure 5.6: Production rate of LFG in sanitary landfill lysimeter-B

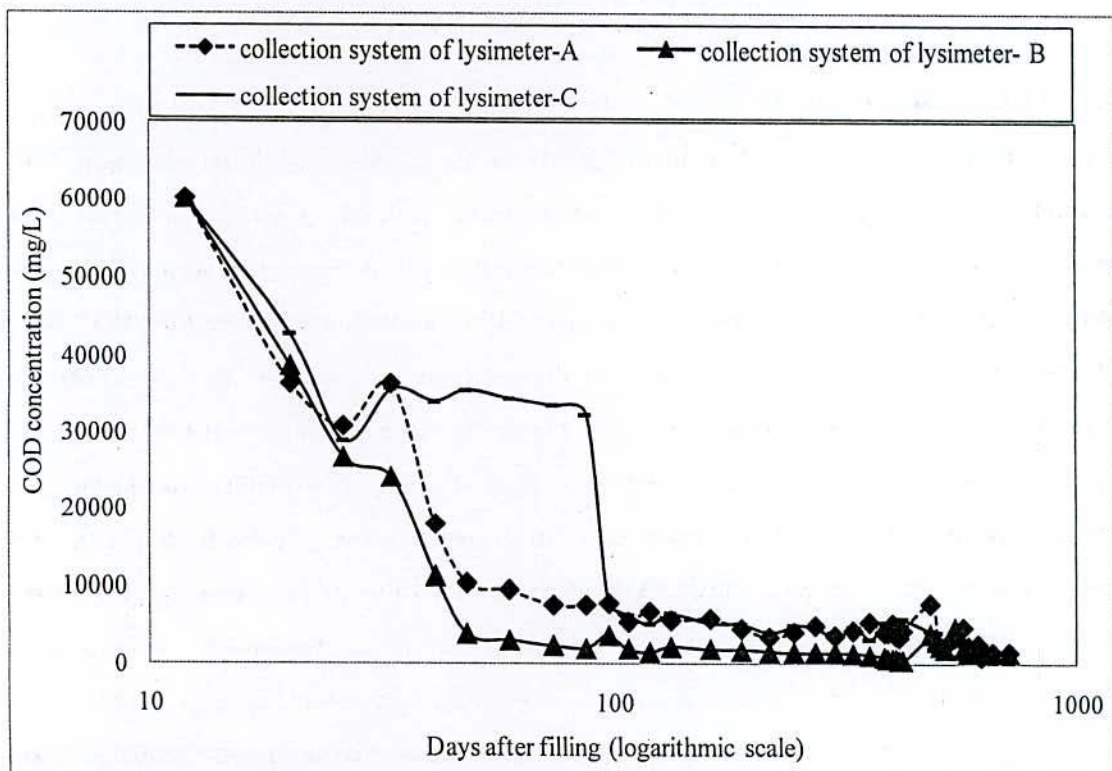


Figure 5.7: COD concentration in leachate of open and sanitary landfill lysimeter

Figure 5.7 revealed COD found higher for open dump lysimeter-A than that of sanitary lysimeter-B and it continued until the completion of this study. A study conducted by Ham

and Bookter (1982) and observed the effect of placing of landfill cover after the deposition of waste in lysimeter. Two lysimeter cells (Cell 3 and Cell 4) were constructed and cell 3 had a soil cover over the waste lift, while Cell 4 was left uncovered. The initial lift of waste generated a peak COD of about 30,000 mg/L, in both the Cell 3 and 4, after approximately 4 to 5 months of operation, which corresponded to the regular production of significant amounts of leachate. After this operational period, COD had remained steady for a significant period of time. In addition, 12 months after the waste placement, COD rise sharply in Cell 4 (to approximately 15,000 mg/L) but Cell 3 did not, which suggests that the soil cover in Cell 3 played a role in leachate attenuation. The findings in case of present study were found as similar to that of stated by Ham and Bookter (1982).

5.3.1.6 Variation of COD Concentration with Landfill Gas

The highest concentration of methane gas occurs after 50 day of sanitary lysimeter-B operation shown in Figure 5.6 and the COD concentration decrease rapidly up to the 95 day (Figure 5.7). Robinson (2000) stated that rapid decrease in COD concentration after certain period in leachate demonstrates the effectiveness of the methanogenic micro-organisms in the removal of the residual organic compounds. Here, it is demonstrated that biological activity may occur in sanitary lysimeter-B and it is revealed by the rapid production of LFG up to 70 day of operation (Figure 5.6). Due to the above mentioned biological situations in sanitary lysimeter-B, COD concentration decrease rapidly up to the 95 day (Figure 5.7). However, the rapid increase of methane concentration at the initial stage suggests that a significant portion of the leachate was organic and that biodegradation contributes to produce the high level of COD concentration (Robinson, 1989). As the methane gas production rate increases, carbon dioxide, hydrogen, VFA, chloride and organic loading decreases (Murphy et al., 1995). Moreover, based on Figure 5.7, it can be concluded that at the initial stage i.e. after 3 day of sanitary lysimeter-B, methane concentration found comparatively higher (45.7%) which led the higher concentration of COD at the initial stage of lysimeter operation at varying landfill condition.

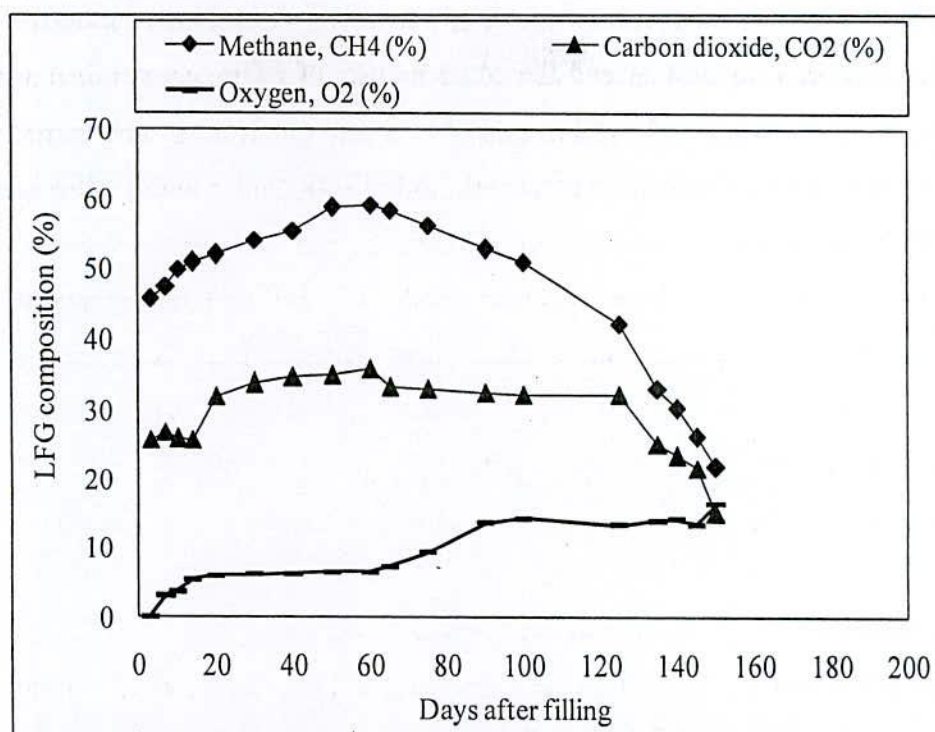


Figure 5.8: Biogas concentrations in sanitary landfill lysimeter-B

The drop in biogas concentrations after the 60 day of sanitary lysimeter-B operation and it was continued (Figure 5.8) indicated a decrease in biological activity. However, Figure 5.7 depicted that COD levels remain steady at approximately 900 mg/L, this indicated that a significant proportion of degradable organics were still present in leachate of sanitary lysimeter-B. The COD concentration, did not further reach high levels after the onset of methanogenesis as in other investigations (Novella et al., 2001; Robinson et al., 2005). Furthermore, there was a negligible acidic inhibition evident in the early stages of the degradation process, as was found in other studies (Cossu et al., 2003). This may be attributed in the present study due to the large proportion of slowly degradable material present in the lysimeter.

5.3.1.7 Relation of COD Concentration, Chloride and pH

The COD, chloride and pH profile in leachate of sanitary lysimeter-B is provided in Figure 5.9. The experimental data showed considerable scatter because it was the characteristics of landfill contaminated leachate data (Rowe, 1995; Ham and Bookter, 1982). Moreover, the conversion of VFA's increases the pH within the solid waste cell. The methane fermentation occurs; subsequently the pH level rises in the range of 7 to 8 (Murphy et al., 1995). Here, it can be noted that COD and chloride concentration seems to be the proportional to one another (i. e. when COD decreases chloride also decreases) (Figure 5.9). This trend was

correlated to the change of pH in leachate with the elapsed period, especially during 50 day when the pH at peak about 8.31 and the concentration of COD and chloride was dropped to 3840 and 570 mg/L, respectively (Figure 5.9). At this time, the leachate characteristic was found as similar to that expected in leachate of older solid waste landfill (Farquhar, 1989 and Mollekopf et al., 2002).

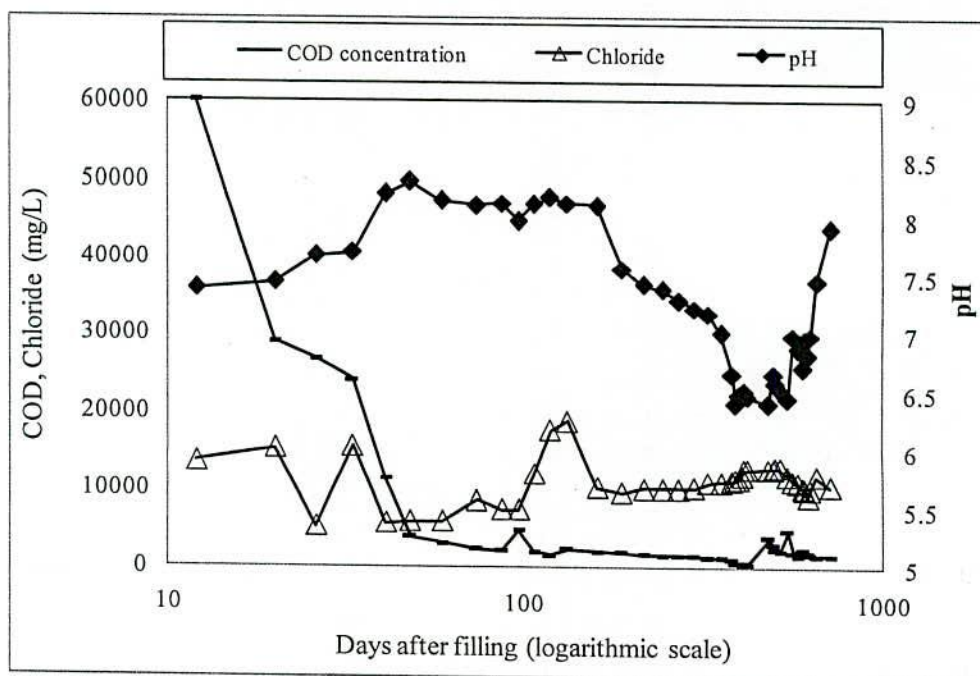


Figure 5.9: Evaluation of COD, chloride*10⁻¹ and pH in leachate of sanitary lysimeter-B

The decrease in COD and chloride concentration, and rise in pH in 50 day, suggested that leachate from lysimeter being collected, treated and disposal. Here, it is interesting to note that the decreasing of COD and chloride may be due to the biological activity in sanitary lysimeter-B and it was revealed by the rapid production of LFG up to 70 day of operation (Figure 5.13). Moreover, the experimental result reveals that COD concentration varies but not in manner that can be easily correlated with chloride concentration. For example, at the operational day of 20 and 50 days, the values of pH, COD and Cl⁻ were found 7.44, 28800 mg/L and 1510 mg/L as well as 8.31, 3840 mg/L and 570 mg/L, respectively. Among three parameters (COD, chloride and pH), both the COD and chloride concentrations were found as high but pH was low in 20 day after waste deposition, however, in 50 day, pH was found at peak while COD and chloride concentrations were found as low.

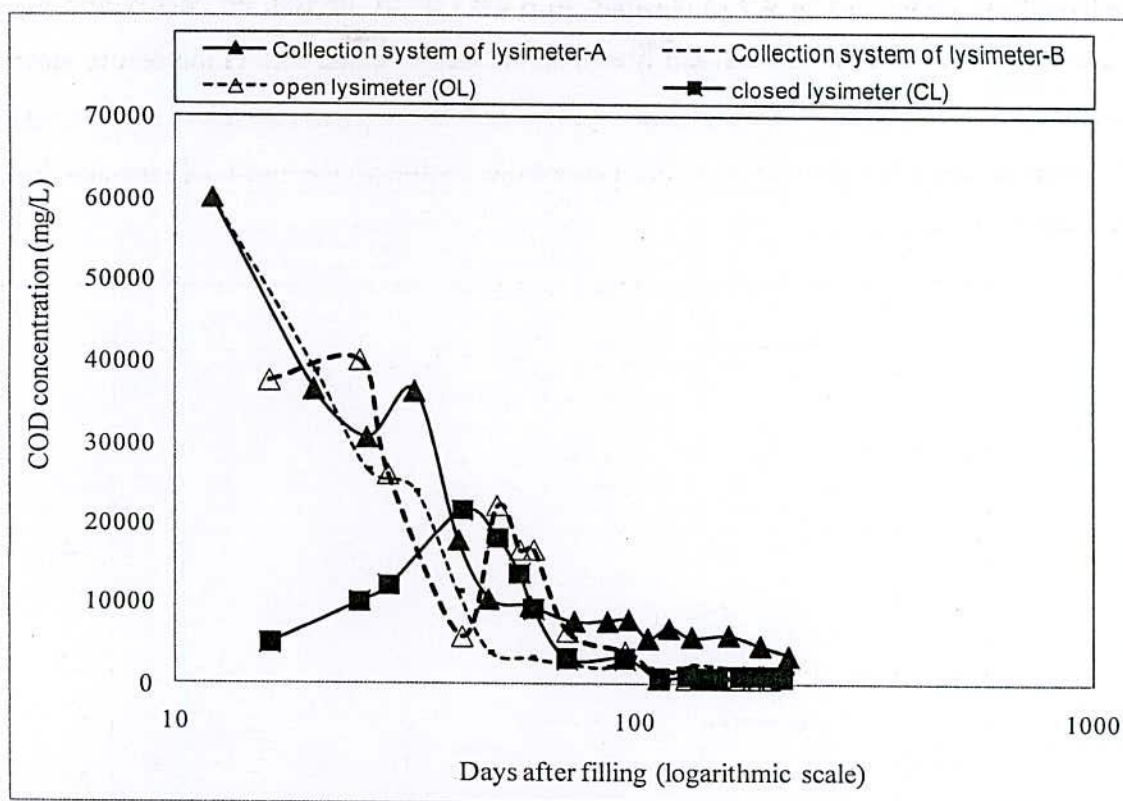


Figure 5.10: Comparison of predicted COD in the present with the other researcher

However, to depict the validity of the findings in this study then also compared with those results in case of open lysimeter (OL) and closed lysimeter (CL) postulated by Trankler et al. (2005) and Visvanathan et al. (2007) shown in Figure 5.10. The Figure 5.10 reveals that the in case of open dump lysimeter-A, the concentration of COD was higher than that of sanitary lysimeter-B and it was continued and similar trend was also studied by Trankler et al. (2005) and Visvanathan et al. (2007).

5.3.1.8 Relation of pH and Conductivity

The variation of pH and electric conductivity (EC) profile over the elapsed period for the collection system of open dump lysimeter-A is provided in Figure 5.11. The Figure 5.11 revealed that pH was ranging from 6.6 to 6.8 in the first 100 day of open dump lysimeter-A operation. After day 100, pH began to increase and it reached to 8. Qasim and Chiang (1994) suggested that increase in pH of leachate with time as a result of the decrease in the concentration of VFA. Moreover, the increase in pH is due to onset of methanogenic activity as a result increase in methane gas production and decrease in hydrogen, carbon dioxide and VFA (Kim, 2005). Murphy et al. (1995) reported that pH in leachate <7.0, was in the acidic side of pH scale, but after in the scale of >7.0, waste leachate had alkaline pH. Here, it is

interesting to note that based on the observed results up to the elapsed period of 100 day for the collection system of open dump lysimeter-A, the leachate was in the acidic side of pH, afterwards, waste leachate had alkaline pH.

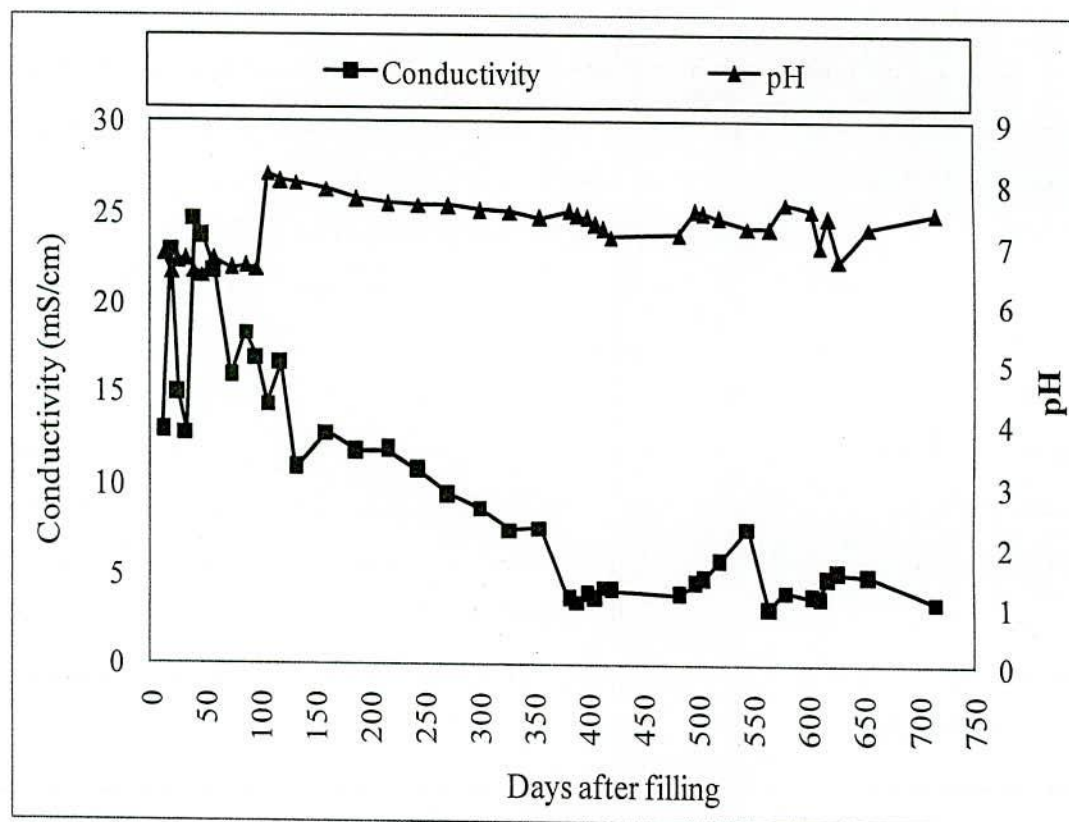


Figure 5.11: Variation of conductivity and pH of open dump lysimeter-A

Figure 5.11 reveals that EC decreases with the increase of elapsed period for the collection system of open dump lysimeter-A. The values of EC varied from 3.1 and 24.7ms/cm. At day 40, the collection system of open dump lysimeter-A showed the highest EC (24.7ms/cm) and lowest pH of 6.54 and it was clear that pH decreases, while, EC increases in relation to the increasing of elapsed period. The maximum value of EC was found 24.7 ms/cm in 40 day and then started to decrease and at 566 day the minimum value 3.1 ms/cm was recorded. This was also supported by Rich et al. (2008) and advocated that metals tend to form hydroxides or undergo sulfidation in the anaerobic phase and the majority of these compounds are not readily soluble. The salts content in leachate is harmony to the EC values and it reflects its total concentration of ionic solutes and is a measure of the solution's ability to convey an electric current.

5.3.1.9 Nitrogen in Leachate

The variation in leachate nitrogenous compounds in terms of TKN and $\text{NH}_4\text{-N}$ of entire lysimeter operation is provided in Figures 5.12 and 5.13, respectively. The TKN is the sum of organic nitrogen (Organic-N) and $\text{NH}_4\text{-N}$ (APHA, 1998). The $\text{NH}_4\text{-N}$ is representative of inorganic matter. The landfill lysimeter leachate contained low concentration of organic nitrogen and very high concentration of $\text{NH}_4\text{-N}$ (60-90 % of TKN (Johansen et al., 1976; Lema et al., 1988)). Nitrogen which has potential to pollute water and soil is another major constituent in the leachate. Figure 5.12 showed that TKN in leachate varied from 1430 to 251, 2187 to 480 and 1860 to 312 mg/L, for the collection system of open dump lysimeter-A as well as the sanitary lysimeter-B and C, respectively. Here, the higher value of TKN was recorded for sanitary lysimeter-B against the other counterparts i.e. sanitary lysimeter-C and open dump lysimeter-A. The open dump lysimeter-A produced low TKN concentrations by reason of dilution of pollutant due to its top cover design enhance rainfall percolation and similar trend was also observed by Tubtimthai (2003). In case of sanitary lysimeter-C, TKN increases upto 1860mg/L by the 90th day and then started to decrease whereas for the collection system of open dump lysimeter-A and sanitary lysimeter-B, TKN decrease and then remain almost constant throughout the experiment (Figure 5.12).

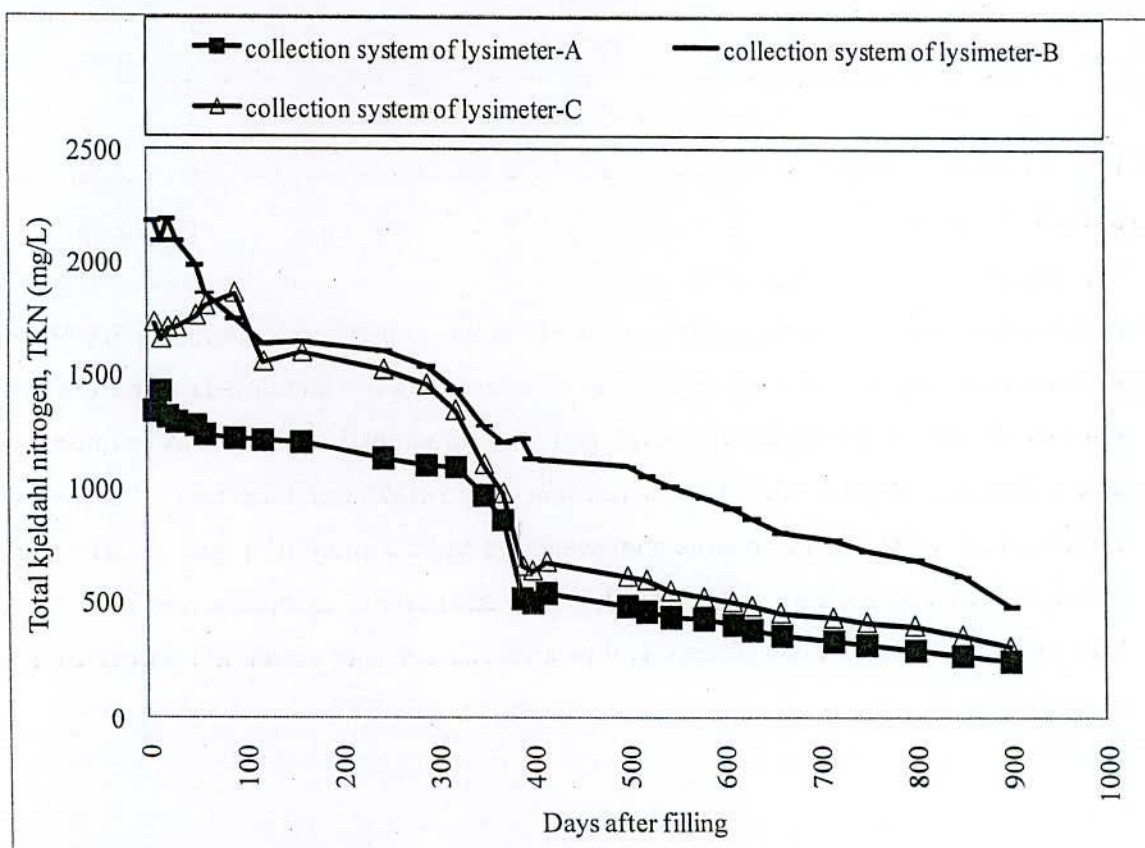


Figure 5.12: Variation of TKN in leachate of open and sanitary landfill lysimeter

Moreover, the $\text{NH}_4\text{-N}$ reduced from the initial values and ranging from 901.3 to 127.9, 997 to 190 and 965.7 to 187 mg/L for the collection system of open dump lysimeter-A as well as sanitary lysimeter-B and C, respectively, and maintained throughout the study period shown in Figure 5.13. Here, the higher $\text{NH}_4\text{-N}$ was recorded for sanitary lysimeter-B and C than that of open dump lysimeter-A. It is known that acetate utilizing methanogens are more sensitive than hydrogen utilizers, particularly at high $\text{NH}_4\text{-N}$ concentrations (Calli et al., 2005).

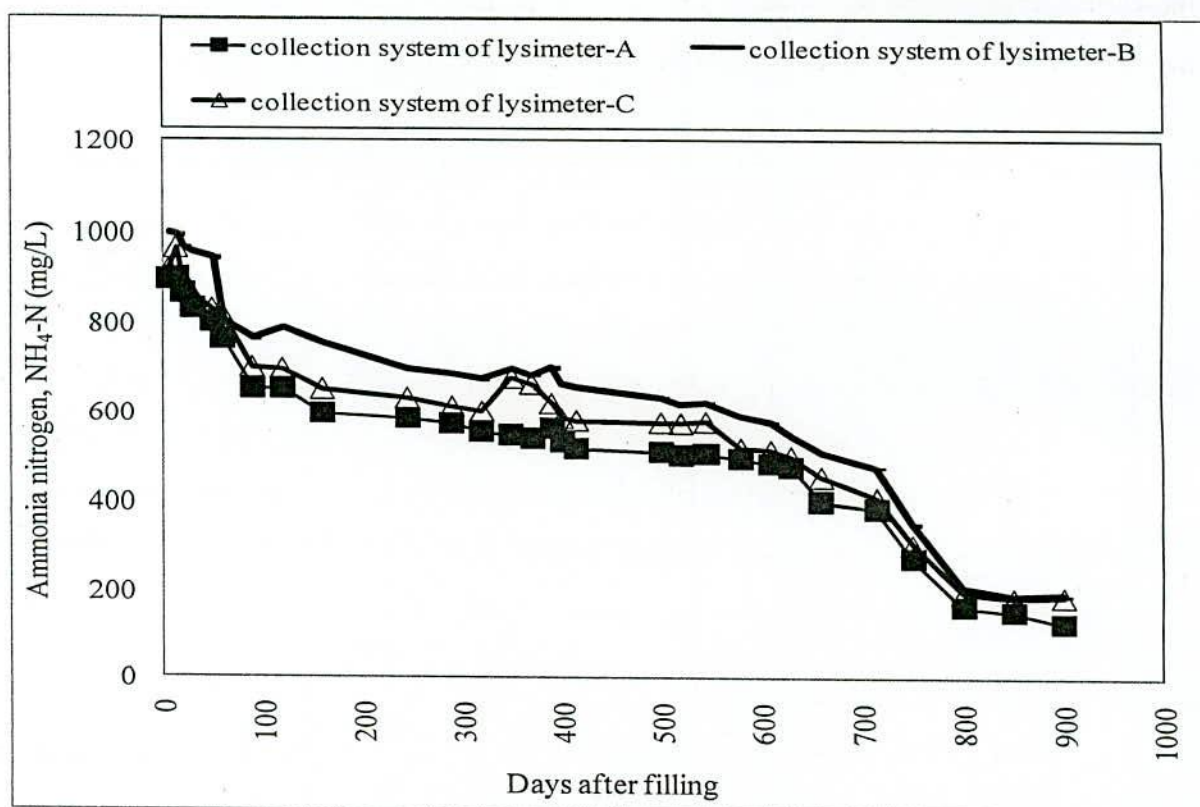


Figure 5.13: Variation of $\text{NH}_4\text{-N}$ in leachate of open and sanitary lysimeter

Van Velsen (1979) has reported that acclimation to high concentration of $\text{NH}_4\text{-N}$ was possible in anaerobic reactors. According to Speece (1996) and Jokela et al. (2002) such a decrease of $\text{NH}_4\text{-N}$ could be attributed to the ammonium bicarbonate Alkalinity, which in turn maintains a pH close to neutral in the anaerobic solid waste bioreactors. At the end of the study period, both the nitrogenous compounds reached a minimum level of TKN (251, 480 and 312 mg/L) as well as $\text{NH}_4\text{-N}$ (127.9, 190 and 187 mg/L) during the 900th day for the collection system of open dump lysimeter-A as well as sanitary lysimeter-B and C, respectively. However, the maximum concentrations of TKN (1430, 2187 and 1860 mg/L) and $\text{NH}_4\text{-N}$ (901.3, 997 and 965.7 mg/L) were recorded within the 90th day of lysimeter operation of collection system of open dump lysimeter-A as well as sanitary lysimeter-B and C, respectively. Chu et al. (1994) too have reported that the $\text{NH}_4\text{-N}$ of landfill leachate ranged

between 500 and 1500 mg/L after a period of 3-8 years and will remain at this level at least for the next 50 years. According to Kulikowska et al. (2008) ammonium represents the major proportion of total nitrogen. In comparison to soluble organics, the release of soluble nitrogen from waste into leachate continues over longer period. As a result the concentration of $\text{NH}_4\text{-N}$ decreases with the increase in age of the landfill which is due to hydrolysis and fermentation of nitrogenous fractions of biodegradable refuses substances (Abbas et al. 2009). Nitrification is a process of nitrogen compound oxidation (effectively, loss of electrons from the nitrogen atom to the oxygen atoms):

1. $2 \text{NH}_4^+ + 3 \text{O}_2 \rightarrow 2 \text{NO}_2^- + 2 \text{H}_2\text{O} + 4 \text{H}^+$ (Nitrosomonas)
2. $2 \text{NO}_2^- + 1 \text{O}_2 \rightarrow 2 \text{NO}_3^-$ (Nitrobacter, Nitrospina)
3. $\text{NH}_3 + \text{O}_2 \rightarrow \text{NO}_2^- + 3\text{H}^+ + 2\text{e}^-$
4. $\text{NO}_2^- + \text{H}_2\text{O} \rightarrow \text{NO}_3^- + 2\text{H}^+ + 2\text{e}^-$

Moreover, $\text{NH}_4\text{-N}$, the great majority of TKN (Lema et al., 1988), did not decreasing trend in concentration with time. The ammonia concentration released from waste by the decomposition of proteins and there is no mechanism for its degradation under Methanogenic condition. So, only leaching can decrease the $\text{NH}_4\text{-N}$ concentration (Kjeldsen et al., 2002).

5.3.1.10 Relation of Sulfate-chloride Ratio and pH

The Figure 5.14 represents the relationship of $\text{SO}_4^{2-}/\text{Cl}^-$ and pH in leachate with the increasing of elapsed period from MSW deposited in open dump lysimeter-A and sanitary lysimeter-B. Here, it can be noted that the value of $\text{SO}_4^{2-}/\text{Cl}^-$ decreases with the increase of elapsed period for sanitary lysimeter-B, while, it increases up to the 80th day of lysimeter operation and then decreases and continues for the collection system of open dump lysimeter-A. However, the predicted value of $\text{SO}_4^{2-}/\text{Cl}^-$ found higher for sanitary lysimeter-B than that of open dump lysimeter-A. Based on Figure 5.14, it can be concluded that for both the lysimeters, pH increases with increasing the $\text{SO}_4^{2-}/\text{Cl}^-$ in leachate. The value of pH is greatly influenced by the $\text{SO}_4^{2-}/\text{Cl}^-$ (Bilgili et al., 2007). A decrease in the $\text{SO}_4^{2-}/\text{Cl}^-$ due to rapid decreases in sulfates, while, the chloride declines more slowly. Here, it is interesting to note that for sanitary lysimeter-B, the reduction of $\text{SO}_4^{2-}/\text{Cl}^-$ is only a biological process and the reduction of SO_4^{2-} has a higher energy benefit for organism than methane production. There the SO_4^{2-} degradation is the first phase before intensive methane production (Chain and DeWalle, 1976). The biological process may be occurred in sanitary lysimeter-B and it is

revealed by the rapid production of LFG up to 70 day of lysimeter operation shown in Figure 5.13. Moreover, the rapid decreases of sulfate are a result of predominately anaerobic condition in solid waste landfill under which sulfate is reduced to sulfide (Chain and DeWalle, 1976). Sulfide then precipitates with various metals. Unlike decrease of sulfate, pH increases with time, which reflects the decrease in concentration of the partially ionized free volatile fatty acids (VFA's) (Chain and DeWalle, 1976).

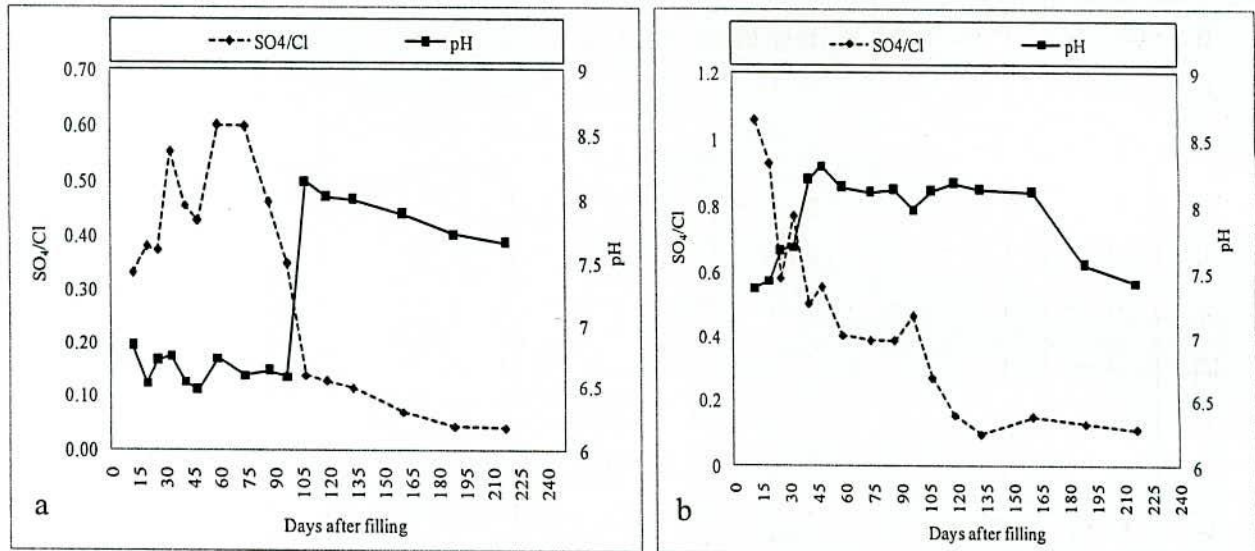


Figure 5.14: Variation of SO_4/Cl^- and pH with increasing the elapsed period in (a) open dump lysimeter-A and (b) sanitary lysimeter-B

Table 5.2 Concentrations of metal and heavy metal in leachate of landfill lysimeter and leachate data from literature

Parameters (mg/L)	Jensen et al. (1999)	Kjeldsen et al. (2001)	Kalyuzhnyi et al. (2004)	Sinan et al. (2006)	WasteSafe (2010)	Diaz et al. (1996)	Results in the present study			
							A ₁	A ₂	B	C
<i>Metal concentrations</i>										
Ca	-	-	-	120-980	-	5-4080	254-790	218- 664	153-578	140-664
K	-	-	-	1600-5000	-	2.8-3770	856-1967	1102-2589	1009-1764	567-1957
Na	-	-	-	800-5100	-	0-7700	1268-2425	1252-2370	1256-2764	1012-2409
Mg	--		-	-	-	0.06-1400	147-590	127-564	228-606	156-594
Fe	-	-	4.08–170.4	40-100	-	0.2- 5500	1.8-70	3.4-83	3.6-91	1.4-72
<i>Heavy metal concentrations</i>										
Cd	0.0002-0.0036	0.0068	0.0008–0.024	0.04-3.0	0.006-0.009	-	0.04-0.265	0.04-0.168	0.04-0.178	0.04-0.105
Ni	0.028-0.084	0.13	-	0.1-4.8	0.03-0.11	-	0.04-0.075	0.04-0.055	0.045-0.09	0.04-0.07
Zn	0.085-5.31	0.67	0.86–28.8	0.1-21	0.04-0.75	0-1000	0.25-1.27	0.15-0.97	0.10-0.55	0.10-0.576
Cu	0.002-0.0034	0.07	0.04–0.24	0.1-3.3	0.04-1.1	0-9.9	0.04-0.98	0.04-0.97	0.04-0.76	0.04-0.60
Cr	0-0.019	0.076	-	0.01-7.8	0.027-0.038	-	0.01-0.07	0.01-0.056	0.023-0.03	0.01-0.025
Mn	-	-	-	-	0.4-3.9	16.5-15000	0.80-6.0	2.5-21.2	0.50-19.3	0.80-8.0
Pb	0-0.016	0.07	0.038–0.1	0.01-0.11	0.03-0.086	-	0.12-0.32	0.179-0.40	0.25-0.78	0.10-0.476

Notation: Ca=Calcium; K=Potassium; Na=Sodium; Mg=Magnesium; Fe=Iron; Cd=Cadmium; Ni=Nickel; Zn=Zinc; Cu=Copper; Cr=Chromium; Mn=Manganese and Pb=Lead. All values in mg/L. Range is given for the minimum and maximum values, while the value of parenthesis indicates the mean values.

5.3.2 Metal and Heavy Metal Concentrations

Landfill leachate might contain heavy metals in considerable concentrations among many other constituents (Andreottola et al., 1990; Reinhart et al., 1998). Heavy metals may constitute an environmental problem, if the leachate migrates into surface water or groundwater, or a treatment issue where the leachate is collected and treated prior to discharge (Christensen et al., 2001; Bozkurt et al., 1999; Martensson et al., 1999). The metal concentrations in leachate of calcium (Ca), potassium (K), sodium (Na), magnesium (Mg) and iron (Fe) as well as heavy metal concentration viz., cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), nickel (Ni), zinc (Zn) and manganese (Mn) were measured in the laboratory provided in Table 5.2. According to a statistical evaluation by Kylefors and Lagerkvist (1997), the concentrations of metal are expected to reduce as the leachate changes from acidogenic to methanogenic, concurrent with a decrease in redox potential and an increase in pH. The rate of Fe oxidation at pH level below 6.0 is increased by the presence of certain inorganic catalysts of the action of micro-organisms. The Fe concentration also imparts a test to water, which is detectable at very low concentration (Flayhammar et al., 1999; Revans et al., 1999; Kjeldsen et al., 2002). Heavy metal leachability from the fresh waste is mainly depending on complexation and sorption within the lysimeter.

Based on evaluated results, it can be depicted that metal concentrations which were comparatively found higher in leachate of open dump lysimeter were Ca and K, however, the heavy metal concentrations of Cd, Cu, Zn and Mn, and those apparently lower were metals of Na, Mg and Fe as well as heavy metals of Cr, Pb and Ni. To these attempts, although there has a large number of studies in literature, the following are considered of Jensen et al. (1999); Kjeldsen et al. (2001); Kalyuzhnyi et al. (2004); annual report of WasteSafe (2010); Sinan et al. (2006) and Diaz et al. (1996).

5.3.2.1 Calcium Concentration

Calcium and Magnesium concentrations are the two important ions in the evaluation of buffering capacity of leachate during the waste degradation in landfill (Karthikeyan et al., 2004). The Ca concentration has a tendency of complex formation with HCO_3^- and dissolved organic compounds and dissolution reactions involving calcite (CaCO_3) and may be siderite (FeCO_3) (Christensen et al., 2001). Thus, the dissolution process is closely linked to the dissolved carbonate compounds.

The variation of Ca concentration in leachate in relation to the increasing of elapsed period from MSW deposition in open dump lysimeter-A and sanitary lysimeter-B and C is evident in Figure 5.15. The Figure 5.15 revealed that the Ca ranging from 253.5 to 790 mg/L, 218 to 664 mg/L, 153 to 578 mg/L and 140 to 664.4 mg/L, for leachate detection (A_1) and collection system (A_2) of open dump lysimeter-A and sanitary lysimeter-B and C, respectively. Here, it is interesting to note that the highest concentration of Ca was measured in leachate detection (A_1) system of open dump lysimeter-A with 790 mg/L, whereas, the lowest of 140 mg/L for sanitary lysimeter-B. It may be established that the variation of Ca regarding to entire lysimeter operation systems may be occurred due to the providing of 400 mm thick CCL as a barrier between leachate detection (A_1) and collection system (A_2) of open dump lysimeter-A, simulation behaviour of open dumping and base liner as well as sanitary landfill and cap liner of open dump lysimeter-A and an open dump lysimeter-B as well as the difference of sanitary lysimeter-B and C in terms of thickness and compaction conditions of cap liner.

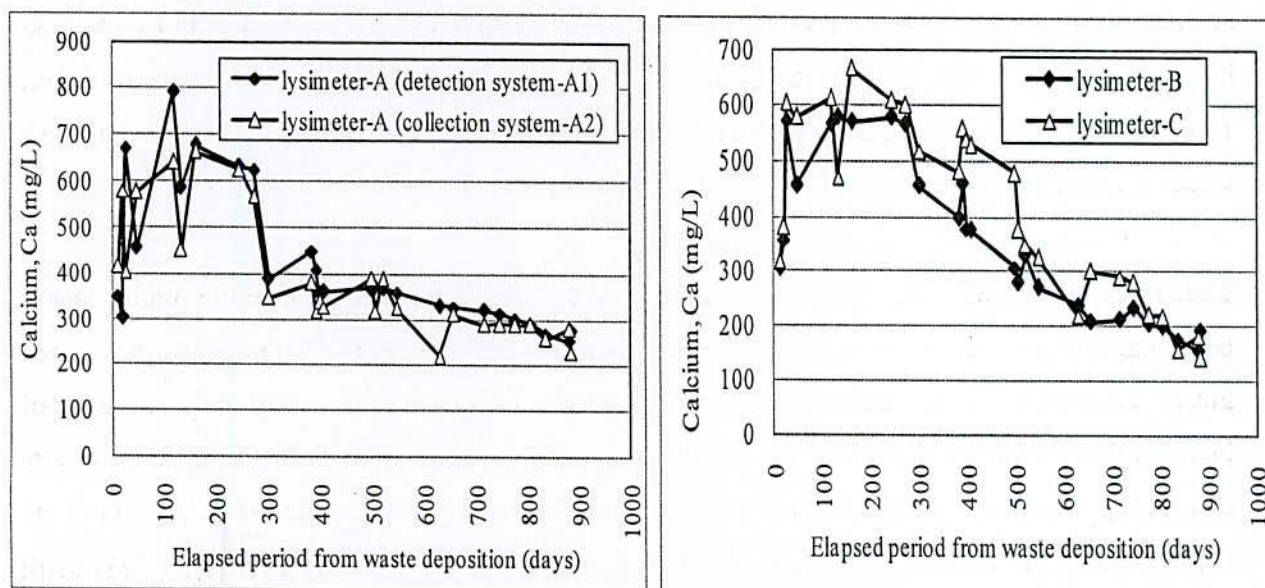


Figure 5.15: The changes of Ca concentration in leachate of landfill lysimeter

On the other side, Ca concentration decreases rapidly below 400 mg/L after day 300 in both the cases of leachate detection (A_1) and collection system (A_2) of open dump lysimeter-A, while, it markedly decreases around 200 mg/L after day 650, for both the cases of sanitary lysimeter-B and C. Christensen et al. (2001) reported that as a result of the rapidly dissolution process, leachate generated from MSW deposited in landfill that has high Alkalinity values ($\sim 10,000$ mg/L as CaCO_3) and the Ca concentration was decreased. However, the slow increase of pH and the slowly generation of the dissolution process due to the sanitary

condition, cause a slow decrease in Ca concentration. Moreover, a study conducted by Sinan et al. (2006) reported that in case of both the open dump reactors (A_1 and A_2), the Ca concentration was decreased below 100 mg/L after day 100 of operation and markedly slow decrease was observed for both the sanitary reactors AN_1 and AN_2 , with 100 mg/L after 600 days of landfilling in reactors.

So, here, it is to a great extent to state that the findings in this study were in agreement with the postulation given by Christensen et al. (2001) and Sinan et al. (2006), because the Alkalinity was found as round ($\sim 10,000$ mg/L as $CaCO_3$), markedly increasing trend of pH occurred at the operating day 100 as well as resemblance to present lysimeter practices with the simulated by Sinan et al. (2006), for both the leachate detection (A_1) collection system (A_2) of open dump lysimeter-A and providentially, in this case, the Ca concentration was decreased markedly. Finally, it can be concluded that the Ca concentration in terms of minimum and maximum with respect to entire landfill lysimeter operation systems as shown in Table 5.2, the maximum value exists within the range given by Sinan et al. (2006) and also Diaz et al. (1996), however, the minimum concentration exceeds the minimum limit as they were stated.

5.3.2.2 Potassium and Sodium Concentrations

The concentration of potassium is immobilized in the easily degradable organic matter, but it becomes soluble due to the decomposition processes within the MSW landfill (Burton et al., 2001). Potassium ion has the least complex forming ability and gets associated to the other ions that can be leached at first from the MSW bed (Brady and Weil, 1999).

The Figure 5.16 showed the variation of K concentration in relation to the increasing of elapsed period in case of leachate detection (A_1) and collection system (A_2) of open dump lysimeter-A and sanitary lysimeter-B and C. The Figure 5.16 depicted that concentration of K ranging from 856 to 1967 mg/L, 1102 to 2589 mg/L, 1009 to 1764 mg/L and 567 to 1957 mg/L, for leachate detection (A_1) and collection system (A_2) of open dump lysimeter-A and sanitary lysimeter-B and C, respectively. At the beginning of open dump lysimeter operation, K concentration was determined as 1651 and 1816 mg/L and after 50 day, it was dropped markedly to 856 and 1577 mg/L, and at 500 day, it reached as maximum values of 1370 and 2590 mg/L, for leachate detection (A_1) and collection system (A_2) of open dump lysimeter-A, respectively. However, at the beginning of the sanitary lysimeter operation, K concentration

was measured as 1606 and 1510 mg/L for an open dump lysimeter-B and C, respectively. There was no considerable change of K concentration for both the leachate detection (A_1) and collection system (A_2) of open dump lysimeter-A after 600 day of operation.

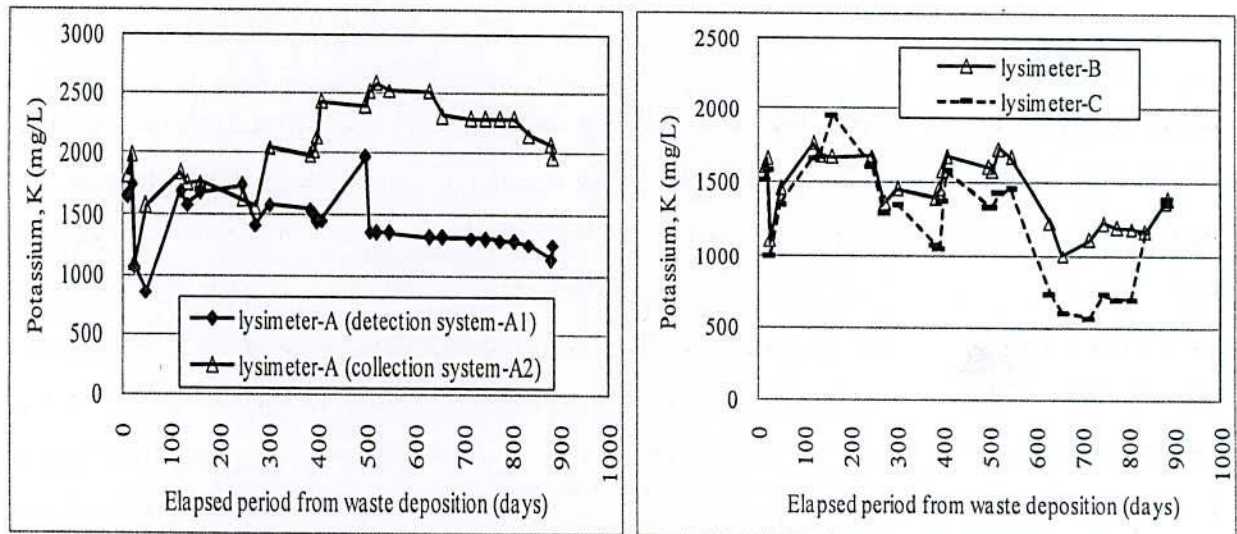


Figure 5.16: The changes of K concentration in leachate of landfill lysimeter

Here, it is interesting to note that the highest concentration of K was measured in the leachate collection (A_2) system with 2589.0 mg/L, whereas, the lowest of 567.2 mg/L in sanitary lysimeter-C. Here, it can be established that the variation of K concentration may be occurred regarding to entire lysimeter operation system due to the providing of 400 mm thick CCL as a barrier between leachate detection (A_1) and collection system (A_2) of open dump lysimeter-A, simulation behaviour of open dumping and base liner as well as sanitary landfill and cap liner in case of open dump lysimeter-A and an open dump lysimeter-B as well as the difference of sanitary lysimeter-B and C in terms of thickness and compaction conditions of cap liner.

The variation of Na concentration in relation to the increasing of elapsed period in case of leachate detection (A_1) and collection system (A_2) of open dump lysimeter-A and sanitary lysimeter-B and C is evident in Figure 5.17. Based on Figure 5.17 it can be depicted that Na concentration ranging from 1268 to 2424 mg/L, 1252 to 2370 mg/L, 1256 to 2764 mg/L and 1012 to 2409 mg/L, for leachate detection (A_1) and collection system (A_2) of open dump lysimeter-A and sanitary lysimeter-B and C, respectively. Here, it is important to note that the highest concentration of Na was measured in case of an open dump lysimeter-B with 2764

mg/L, whereas, the lowest of 1012 mg/L in sanitary lysimeter-C and the concentration of K was differed regarding to entire lysimeter operation systems.

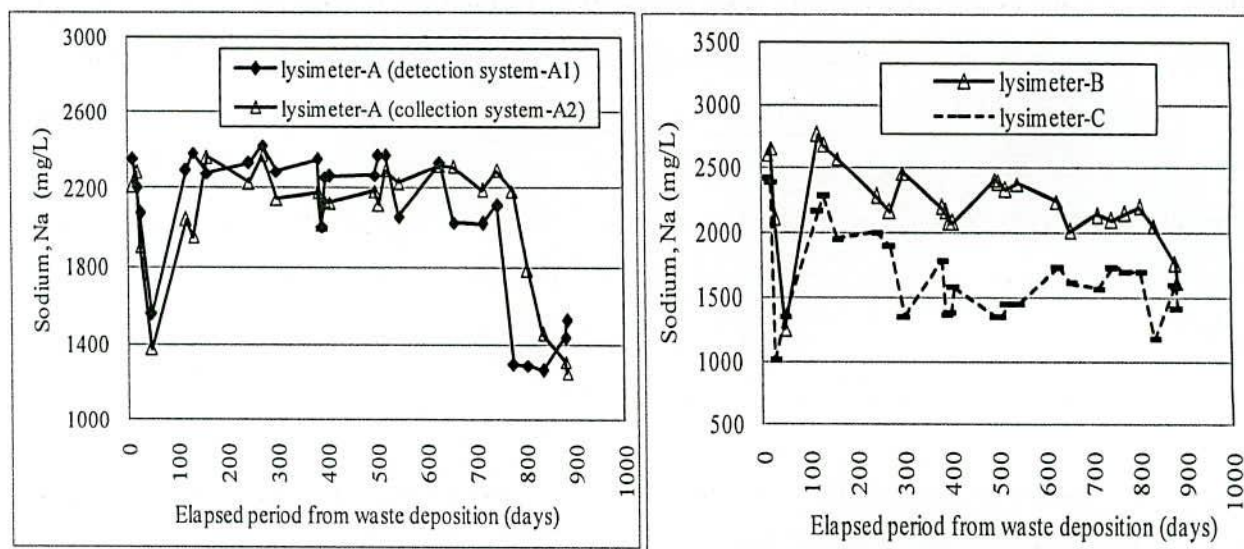


Figure 5.17: The changes of Na concentration in leachate of landfill lysimeter

Here, it is interesting to note that the trend for both the concentrations of K and Na were found as almost similar. A study conducted by Bilgili et al. (2006) stated that the Na and K concentrations of leachate were in the same trend with chloride Cl^- concentration. This situation was confirmed by Kimmel and Braids (1980) and also Sinan et al. (2006) who showed a linear relationship between Na and Cl^- concentrations in water samples obtained from a leachate plume at different distances from a landfill. So, it can be concluded that the findings in terms of Cl^- , K and Na concentrations in the present study were agreed well with the postulation given by Kimmel and Braids (1980) and Sinan et al. (2006). The results of K and Na in terms of minimum and maximum concentrations with respect to entire lysimeter operation systems are in agreement with the results obtained by Sinan et al. (2006) and also Diaz et al. (1996). In contrast, the minimum concentrations of both the K and Na exceed the minimum limit stated by Diaz et al. (1996).

5.3.2.3 Magnesium Concentration

The Figure 5.18 reveals the variation of Mg concentration in relation to the increasing of elapsed period in case of leachate detection (A_1) and collection system (A_2) of open dump lysimeter-A and sanitary lysimeter-B and C. The Figure 5.18 depicts that Mg concentration ranging from 147 to 590 mg/L, 127 to 564 mg/L, 228 to 606 mg/L and 156 to 594 mg/L, for leachate detection (A_1) and collection system (A_2) of open dump lysimeter-A and sanitary

lysimeter-B and C, respectively. At the beginning of the open dump lysimeter operation, Mg concentration was determined as 456 and 406 mg/L and at 120 day operation, it reached as maximum values of 590 and 541 mg/L for leachate detection (A_1) and collection system (A_2) of open dump lysimeter-A, respectively. However, at the beginning of the sanitary lysimeter operation, Mg concentration in leachate was measured as 606 and 416 mg/L for sanitary lysimeter-B and C, respectively. Here it can be concluded that the concentration of Mg was decreased markedly until the end of this study, there was no considerable change in both the leachate detection (A_1) and collection system (A_2) of open dump lysimeter-A after 650 day of operation.

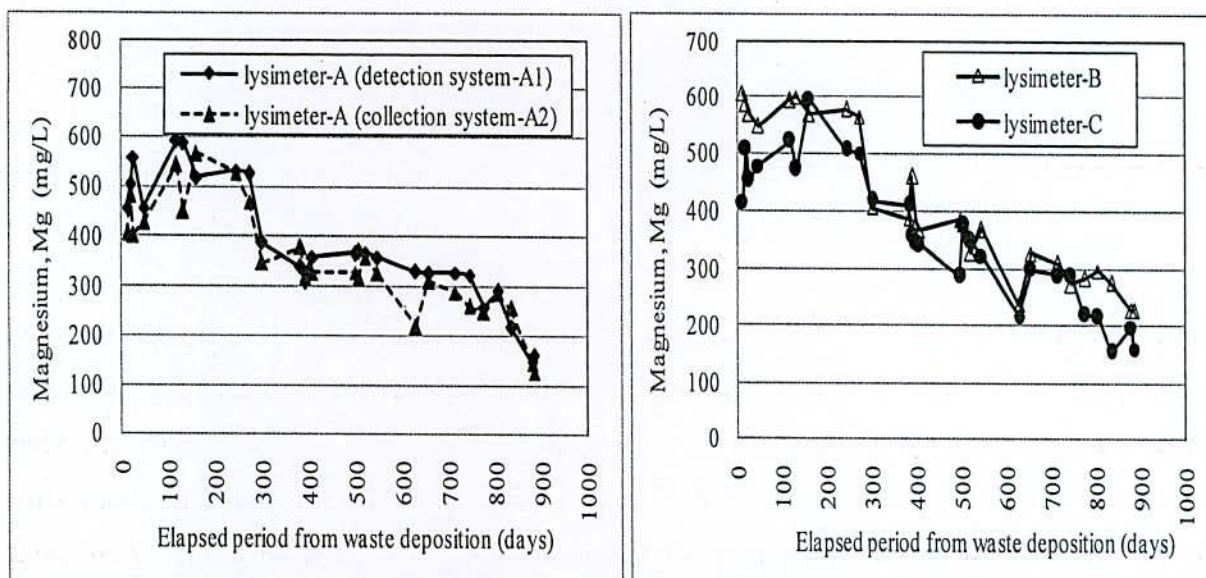


Figure 5.18: The changes of Mg concentration in leachate of landfill lysimeter

Here, it is important to note that the highest concentration of Mg was measured in sanitary lysimeter-B with 606 mg/L, whereas, the lowest of 127 mg/L was in the collection system open dump lysimeter-A. Here, it can be established that the variation of K concentration may be occurred with regarding to entire landfill lysimeter operation system due to the providing of 400 mm thick CCL as a barrier between leachate detection (A_1) and collection system (A_2) of open dump lysimeter-A, simulation behaviour of open dumping and base liner as well as sanitary landfill and cap liner in case of open dump lysimeter-A and sanitary lysimeter-B as well as the difference of sanitary lysimeter-B and C in terms of thickness and compaction conditions of cap liner.

5.3.2.4 Iron Concentration

The concentration of Fe varied from 1.8 to 70 mg/L, 3.4 to 83 mg/L, 3.6 to 91 mg/L and 1.4 to 72 mg/L in relation to the increasing of elapsed period from MSW deposition, for leachate detection (A₁) and collection system (A₂) of open dump lysimeter-A and sanitary lysimeter-B and C, respectively, is evident in Figure 5.19. Here, it may be noted that the highest concentration of Fe was measured in the sanitary lysimeter-B with 91 mg/L, whereas, the lowest of 1.40 mg/L for sanitary lysimeter-C. Here, it may be established that the variation of Fe concentrations regarding to entire lysimeter operation systems may be occurred due to the providing of 400 mm thick CCL as a barrier between leachate detection (A₁) and collection system (A₂) of open dump lysimeter-A, simulation behaviour of open dumping and base liner as well as sanitary landfill and cap liner of open dump lysimeter-A and sanitary lysimeter-B as well as the difference of sanitary lysimeter-B and C in terms of thickness and compaction conditions of cap liner.

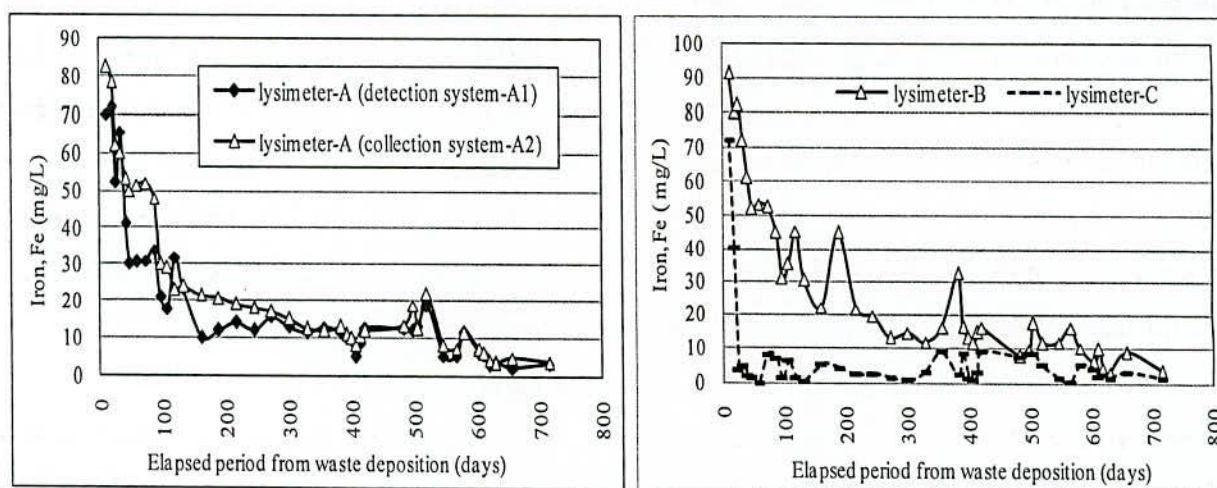


Figure 5.19: The changes of Fe concentration in leachate of landfill lysimeter

From the beginning to 100 days of landfill lysimeter operation, Fe concentrations were dropped drastically in the range of 70 to 21 mg/L, 83 to 30 mg/L, 91 to 31 mg/L and 72 to 1.2 mg/L, for leachate detection (A₁) and collection system (A₂) of open dump lysimeter-A and sanitary lysimeter-B and C, respectively. After day of 100, the Fe concentration also began descending steadily and reached the values of 1.8 mg/L, 3.4 mg/L, 3.6 mg/L and 1.4 mg/L until the end of this study, for leachate detection (A₁) and collection system (A₂) of open dump lysimeter-A and sanitary lysimeter-B and C, respectively.

However, a study conducted by Sinan et al. (2006) reported that the Fe concentrations were decreased rapidly from 100 to 40 and 50 mg/L after 30 days for open dump reactors A₁ and A₂, respectively, while it was decreased to 50 and 60 mg/L in sanitary landfill reactors of AN₁ and AN₂ after day 250, respectively. Subsequently, here it may be concluded that the almost similar trend was observed and also agreed well for both the cases of aerobic and anaerobic reactors stated by Sinan et al. (2006). The results of Fe in terms of minimum and maximum concentrations with respect to entire lysimeter operation systems are in agreement with the results obtained by Kalyuzhnyi et al. (2004) and Diaz et al. (1996). In contrast, the minimum concentrations of Fe exceed the minimum limit stated by Diaz et al. (1996).

5.3.2.5 Cadmium and Copper Concentrations

Cd concentration was measured in the range of 0.04 to 0.265, 0.04 to 0.168, 0.04 to 0.178 and 0.04 to 0.105, while, Cu ranging from 0.04 to 0.98, 0.04 to 0.97, 0.04 to 0.76 and 0.04 to 0.60 in relation to the changing of elapsed period from waste deposition, for leachate detection (A₁), leachate collection system (A₂) of open dump lysimeter-A and sanitary lysimeter-B and C, respectively are evident in Figure 5.20. At the beginning of open dump lysimeter operation, the Cd concentration was found 0.265 and 0.168 mg/L, and after 120 day, it decreased markedly 0.078 and 0.097 mg/L, for leachate detection (A₁), leachate collection system (A₂), respectively. From the day of 660 to until the end of this study, there was no significance change for both the cases of open dump lysimeter.

Moreover, at the beginning of open dump lysimeter operation, the Cu concentration was found 0.04 and 0.04 mg/L, and after 100 day operation, it was increased rapidly up the day of operation 500, 0.98 and 0.97 mg/L, for the leachate detection (A₁), leachate collection system (A₂), respectively. From the day of 630 and 775 to until the end of this trial, it was decreased rapidly for both the cases of open dump lysimeter system. In the other side, both the Cd and Cu concentrations in case of sanitary lysimeter-B and C were found the almost similar trend of open dump lysimeter operation, although the values of Cd and Cu in case of open dump lysimeter operation were found as higher than the case of sanitary lysimeter operation. Finally, it can be concluded that the findings in the present study in case of Cd and Cu concentration exceed the lower limit reported by Jensen et al. (1999); Kjeldsen et al. (2001); Kalyuzhnyi et al. (2004); Sinan et al. (2006); WasteSafe 2010 and Diaz et al. (1996).

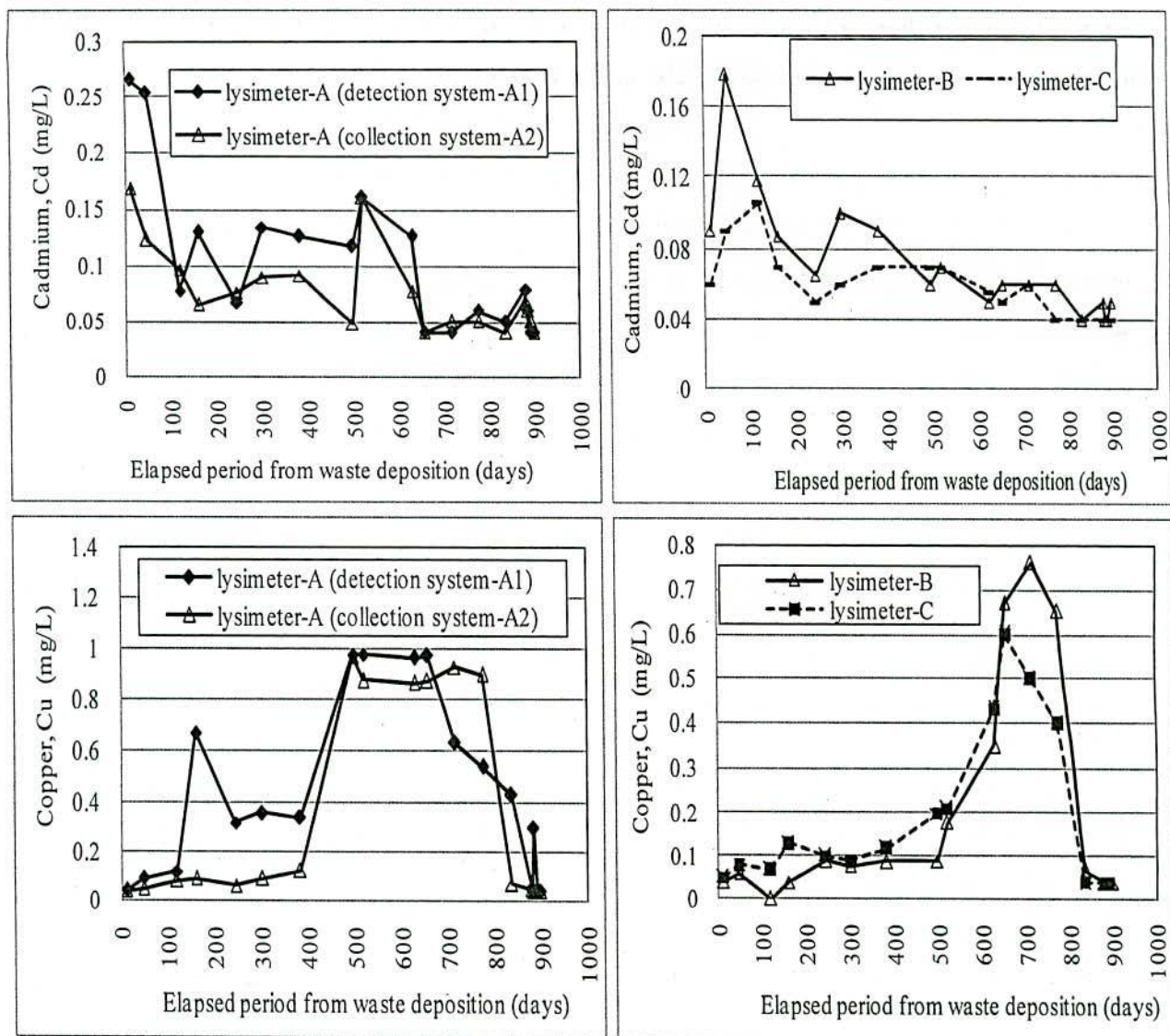


Figure 5.20: The changes of Cd and Cu concentrations in leachate of lysimeter

5.3.2.6 Nickel and Zinc Concentrations

The Figure 5.21 illustrates the variation of Ni and Zn concentration in relation to the increasing of elapsed period for both the operation of open dump and sanitary lysimeter. The Ni concentration ranging from 0.04 to 0.075, 0.04 to 0.055, 0.04 to 0.09 and 0.04 to 0.07, while, Zn ranging from 0.25 to 1.267, 0.15 to 0.97, 0.10 to 0.55 and 0.10 to 0.576, in relation to the changing of elapsed period, for leachate detection (A_1), leachate collection system (A_2) of open dump lysimeter-A and sanitary lysimeter-B and C, respectively. From the beginning of sanitary lysimeter operation to up the day of 520, the Ni concentration was increased markedly and reached to the values of 0.09 and 0.07 mg/L, and after 520 day operation, it was dropped, for landfill lysimeter-B and C, respectively. Moreover, from the beginning of

sanitary lysimeter operation to up the day of 380, the Zn concentration increased rapidly with 0.55 and 0.576 mg/L, for lysimeter-B and C, respectively.

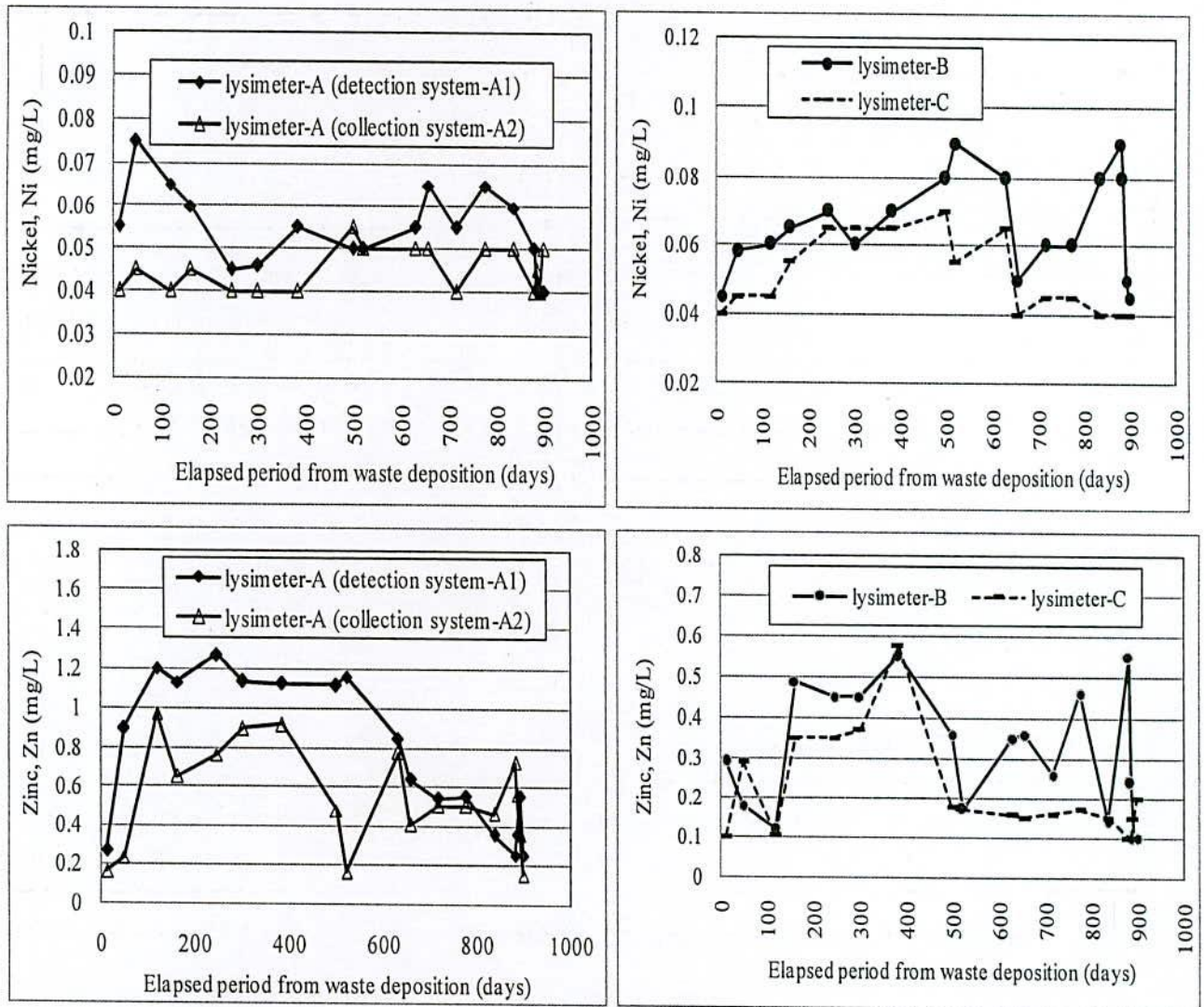


Figure 5.21: The changes of Ni and Zn concentrations in leachate of landfill lysimeter

In the other side, both the Ni and Zn concentrations in case of sanitary lysimeter-B and C were found as almost similar to the trend of open dump lysimeter operation, although the values of Ni and Zn in case of sanitary lysimeter operation were found as higher than that of open dump lysimeter operation. However, a study conducted by Sinan et al. (2006) reported that the Ni and Zn were found as higher for sanitary landfill reactors than that of open dump reactors. So, it can be concluded that findings in terms of Ni and Zn in the present study were agreed well with the statement stated by Sinan et al. (2006).

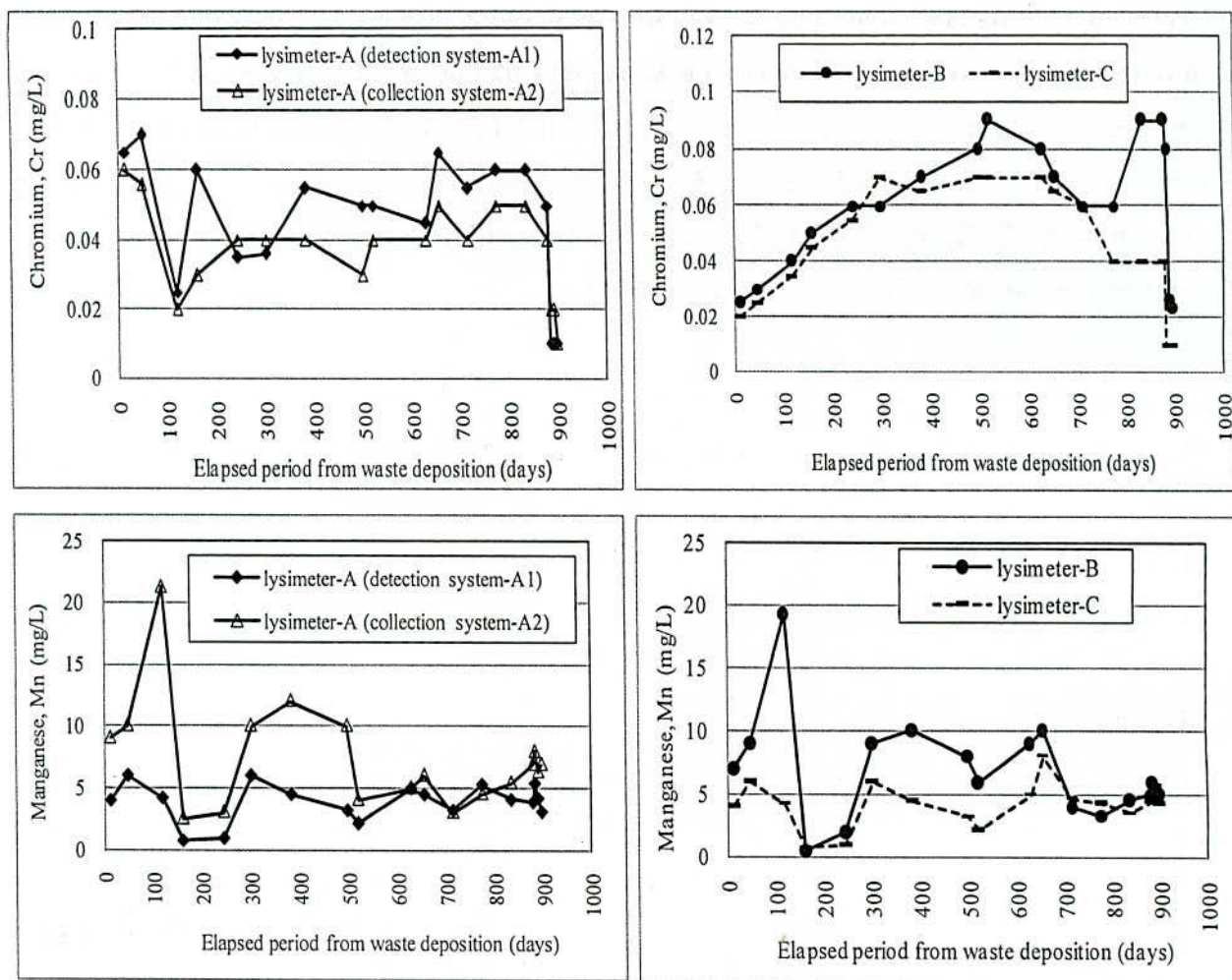


Figure 5.22: The changes of Cr and Mn concentrations in leachate of landfill lysimeter

5.3.2.7 Chromium and Manganese Concentrations

The variation of Cr and Mn concentrations with in relation to the increasing of elapsed period are shown in Figure 5.22. At the beginning of open dump lysimeter operation, Cr concentration found 0.065 and 0.06 mg/L, for leachate detection (A_1) and leachate collection system (A_2), respectively. At the day of 120, Cr concentration decreased as 0.02 and 0.02 mg/L for both the cases, and after 120 day to end of this study, the leachate detection system shows the higher than the leachate collection system. Here, it can also be noted that the Cr concentration for sanitary lysimeter operation were found as higher than that of open dump lysimeter system, however, the concentration of Cr was found as higher in case of sanitary lysimeter-B, with 0.09 mg/L. Moreover, a study conducted by Sinan et al. (2006) reported that the concentration of Cr was found as higher in case of sanitary reactors than that of open dump reactors.

In addition, the Mn concentration ranging from 0.80 to 6.0, 2.5 to 21.2, 0.50 to 19.3 and 0.80 to 8.0 mg/L, in relation to the changing of elapsed period, for the leachate detection (A_1), leachate collection system (A_2) of open dump lysimeter-A and sanitary lysimeter-B and C, respectively. However, the highest concentration of Mn was found for the collection system of open dump lysimeter-A with 21.2 mg/L and both the open dump and sanitary lysimeter operation showing almost the same concentration of Mn.

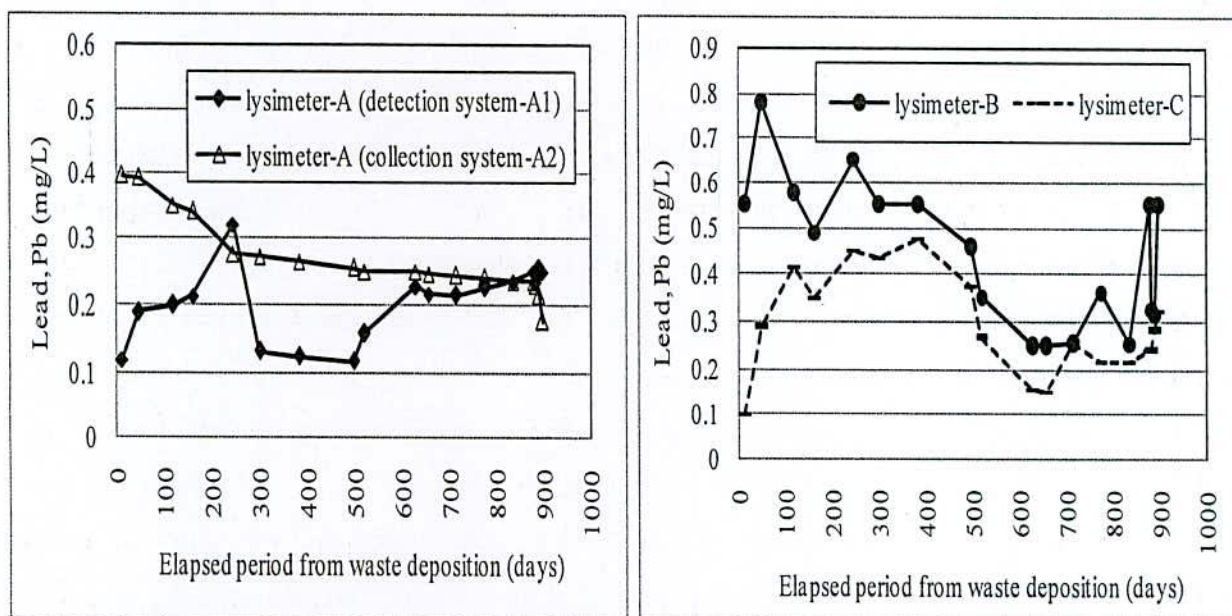


Figure 5.23: The changes of Pb concentration in leachate of landfill lysimeter

5.3.2.8 Lead Concentration

The Figure 5.23 illustrates the variation of Pb concentration in relation to the increasing of elapsed period for both the operation of open dump and sanitary lysimeter. The Pb concentration ranging of 0.12 to 0.32, 0.12 to 0.397, 0.25 to 0.78 and 0.10 to 0.476 mg/L, in relation to the changing of elapsed period, for the leachate detection (A_1), leachate collection system (A_2) of open dump lysimeter-A and sanitary lysimeter-B and C, respectively. Here, it is interesting to note that the highest concentration of Pb was measured in sanitary lysimeter-B with 0.78 mg/L, whereas, the lowest of 0.12 mg/L in both the cases of leachate detection system of open dump lysimeter-A and the sanitary landfill lysimeter-C and the concentration of Pb was differed regarding to entire landfill lysimeter operation system.

Here, it can be established that the variation of Pb concentration may be occurred regarding to entire landfill lysimeter operation system due to the providing of 400 mm thick CCL as a barrier between leachate detection (A_1) and collection system (A_2) of open dump lysimeter-

A, simulation behaviour of open dumping and base liner as well as sanitary landfill and cap liner in case of open dump lysimeter-A and sanitary lysimeter-B as well as the difference of sanitary lysimeter-B and C in terms of thickness and compaction conditions of cap liner.

5.3.3 Influence of Tropical Seasonal Variations on Landfill Lysimeter Operation

To investigate the variation of leachate quality in terms of pH, chloride, TS, EC, COD and TKN (concentration and load) in relation to the changes of tropical condition, periodic monitoring of leachate quality was carried out in the laboratory. However, the entire lysimeter observation consisted of dry and wet climatic condition as well as the age of MSW in lysimeter and it reveals that lysimeter operational mode played a significant role for the variation of leachate quality and hence discussed in followings.

5.3.3.1 Variation of Leachate Generation

In a MSW landfill the leachate generation is not constant flow depending on the initial moisture content, composition of solid waste, and the influence of climate: rainfall, evaporation, in which the landfill is situated. In humid climate, the potential for leachate generation high as a result of the difference between net water input and water stored will available form more leachate (Blight, 1996). Moreover, it is not environmentally acceptable a solid waste landfill cover which percolating the rainwater and hence contaminate the surrounding soil and ground water. The leachate production varies in a wide range but is not directly related to the total amount of precipitation. Moreover, the high evaporation capacity throughout the dry season has to be carefully assessed (Alamgir et al., 2006).

The amount of rainfall and cumulative leachate generation from the detection (A_1) and collection (A_2) system of open dump lysimeter-A as well as the collection system of sanitary lysimeter-B and C was recorded and provided in Figure 5.24, for the period of July 2008 to August 2010. During the first rainy season (July to August 2008), highest amount of leachate was generated from the collection system (A_2) of open dump lysimeter-A. Here, it can be noted that after 135 day of lysimeter operation, cumulative leachate generation rate was recorded 315, 224 and 265 liter for the collection system (A_2) of open dump lysimeter-A as well as collection system of sanitary lysimeter-B and C, respectively. It also implied the cumulative leachate generation rate from collection system (A_2) of open dump lysimeter-A was about 41.0 and 19.0 % more than that of the collection system of sanitary lysimeter-B

and C, respectively. Moreover, the leachate generation was found as lower in the detection system (A_1) than the other system. Here, it can be established that the variation of leachate generation in case of detection and collection system of open dump lysimeter-A may be occurred due to the providing of 400 mm thick CCL as a barrier between the detection and collection system of lysimeter-A. As the collection system (A_2) of lysimeter-A was provided just below the MSW deposited in lysimeter-A and the followed detection system (A_1) was separated with the 400mm thick CCL and this operational mode may be considered for the variation of leachate quantity between these two systems. Moreover, the variation of leachate quantity for the collection system of lysimeter-A and B may be occurred due to the simulation behaviour of open dumping and providing the base liner in lysimeter-A as well as sanitary landfill and providing the cap liner in lysimeter-B. In contrast, the quantity of leachate in case of collection system of sanitary lysimeter-B and C may be occurred due to the difference of lysimeter-B and C in terms of thickness and compaction conditions of cap liner.

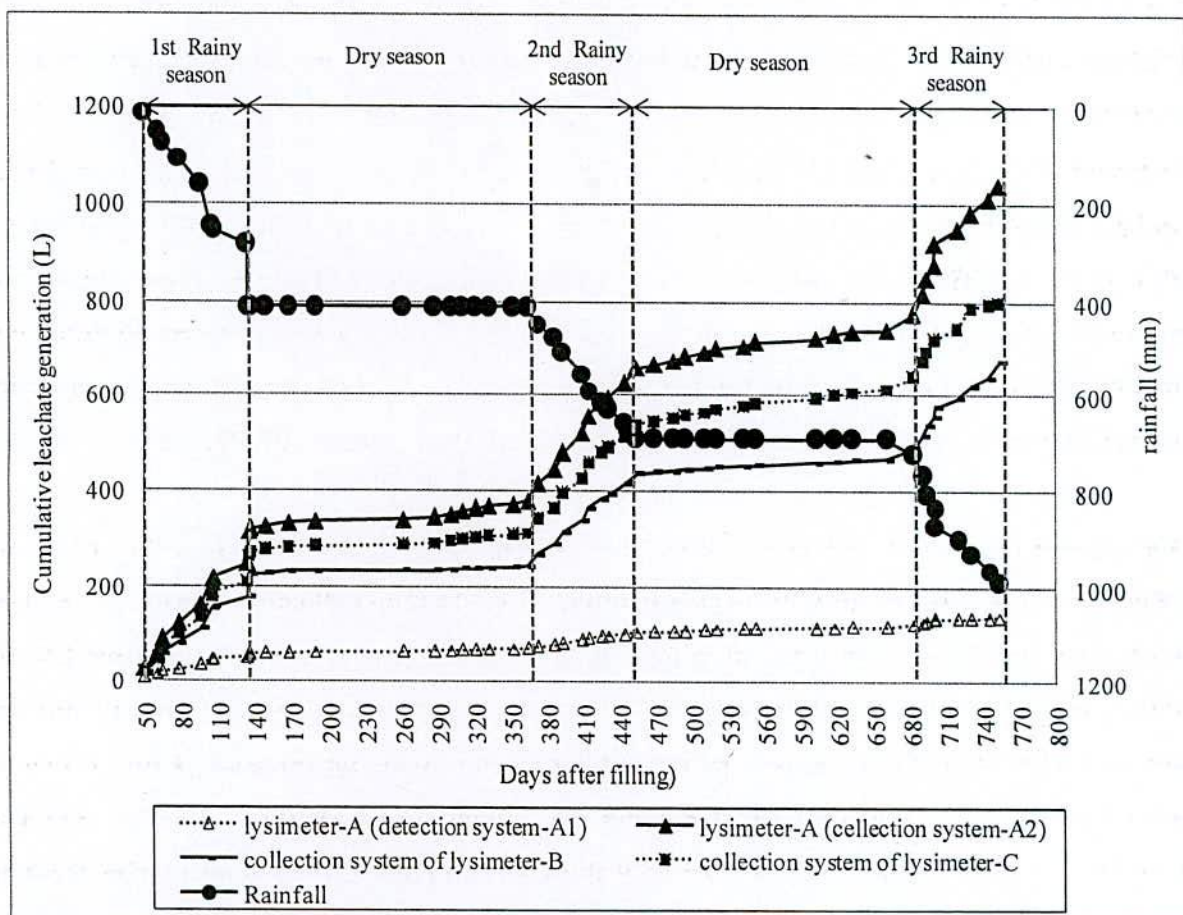


Figure 5.24: Relationship between rainfall and cumulative leachate production from landfill lysimeter

Here it can be noted that in sanitary lysimeter-B and C, the leachate generation found lower than that of open dump lysimeter-A, although the amount of rainfall was same because the provided cap liner in sanitary lysimeter-B and C, played an important role to reduce the percolating of rainwater in sanitary lysimeter-B and C and similar trend was followed by Visvanathan et al. (2002). It was advocated that for open cell, without a CCL, rain water was percolated rapidly into the lysimeter and hence produces relatively higher quantity of leachate, whereas, due to the providing a CCL having high compaction density expected to produce relatively low leachate, especially during the dry season. The result was further supported from Ehrig (1983). However, considering about 65 % of the moisture content and 52 % of organic waste composition in the deposited MSW in lysimeter, the amount of leachate generation was found to be strongly related to rainfall and cover system (Rafizul et al. 2009b). During the second rainy season (July to September 2009), high amount of leachate was again generated at the lysimeter operational about 455 day from the collection system (A₂) of open dump lysimeter-A and it was about 51.0 and 22.0 % more than that of sanitary lysimeter-B and lysimeter-C, respectively. However, it was observed that after 450 day of entire lysimeter operation, the leachate generation was also increased steady than the successively rainy season.

5.3.3.2 Variation of pH

The variation of pH in leachate against the changes of climatic condition regarding to the entire lysimeter operation is evident in Figure 5.25. The pH in leachate varied widely within the range of 6.17 to 8.17, 6.14 to 8.0, 6.4 to 8.61 and 6.3 to 8.73 in relation to the increasing of elapsed period for the detection (A₁) and collection (A₂) system of open dump lysimeter-A as well as the collection system of sanitary lysimeter-B and C, respectively. Figure 5.25 depicted that for the operated system A₁ and A₂ of open dump lysimeter-A as well as sanitary lysimeter-C, the leachate was acidic (pH below 7.0) at the initial stage during the dry season and it was remained stable until 20 day of operating period. It was shifted to alkaline (pH above 7.0) for the entire lysimeter within the operating period of 50 day during the dry season. Moreover, after 50 day during the rainy season, due to the percolating of rain water into the open dump lysimeter-A and sanitary lysimeter-C for their looser conditions of cap liner as well as the higher rate of leachate production (Figure 5.24) than that of sanitary lysimeter-B, pH was shifted to acidic (pH below 7.0). Here, it is considering that the rainfall in this site is acidic and this change may indicate the decomposition of organic fraction of MSW deposited in lysimeter. The researchers Trankler et al. (2005) and Visvanathan et al.

(2007) operating two cells for MSW in sense of open lysimeter (OL) and closed lysimeter (CL) and observed that pH in leachate for both the cases was initially acidic (pH below 7.0), then it was increased and shifted to alkaline (pH above 7.0). It can be concluded that the findings in case of open dump lysimeter-A and sanitary lysimeter-C, were agreed well with the postulation stated by Trankler et al. (2005) and Visvanathan et al. (2007).

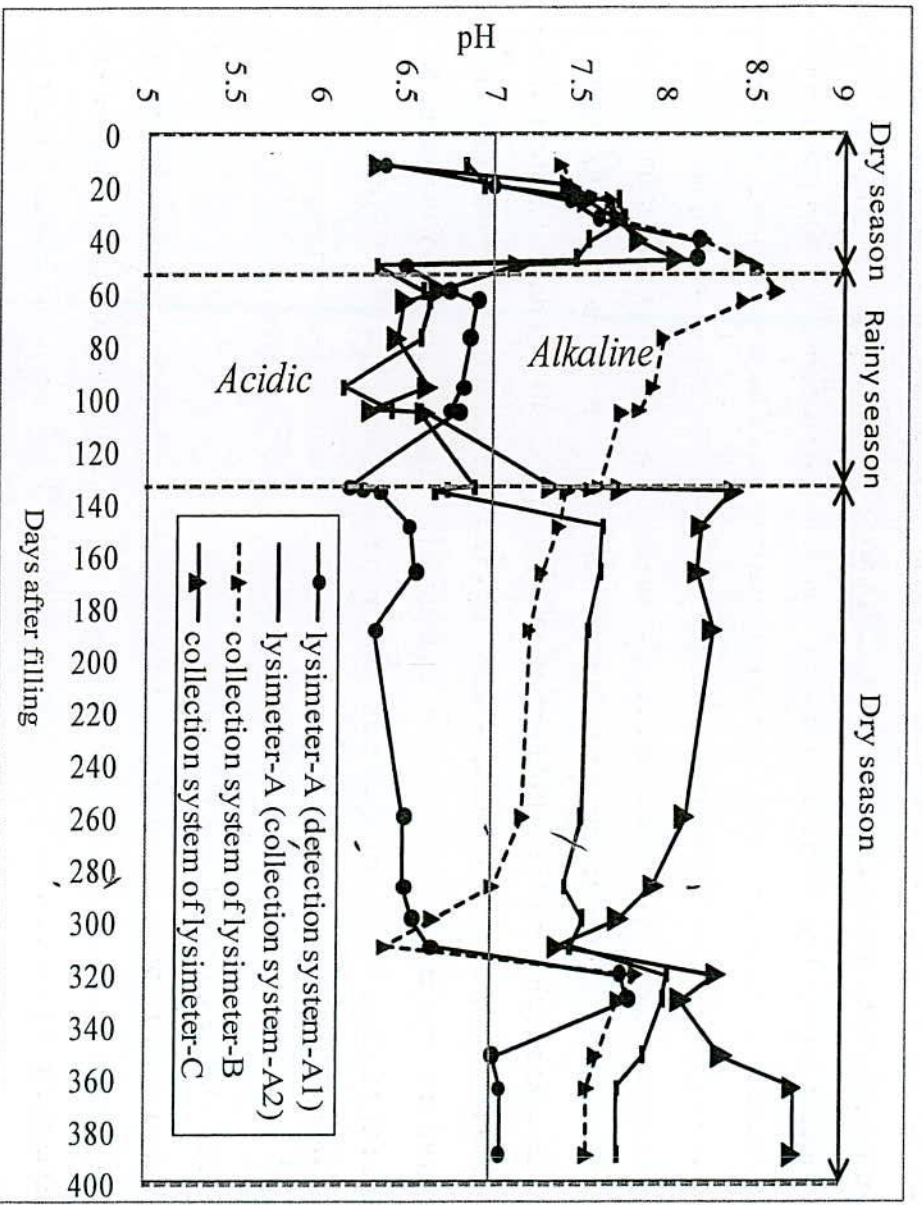


Figure 5.25: Temporal variation of pH in leachate of open and sanitary landfill lysimeter

Here, it is interesting to note that during the rainy season, pH reduces markedly and showing the boundary of acidic phase until the end of rainy season except sanitary lysimeter-B. Chiemchaisri and Srisukphun (2003) observed a similar decrease in pH during continuous rainfall and attributed it to accumulation of carbon dioxide. The determination of chemical characteristics of leachate at different rainwater application rates suggested that pH was ranged from 4.4 to 6.2 with an average of 5.3 (Chiemchaisri and Srisukphun, 2003). In contrast, after the end of rainy season i.e. 135 day of operation, pH of A₁ system was remained stable in acidic phases until 320 day and then shifted to alkaline during the dry

season, while, pH of A₂ system of open dump lysimeter-A and sanitary lysimeter-B, was also reached in alkaline and remained stable .

Very low pH (~6.14) was recorded at 95 day of A₂ system of open dump lysimeter-A during the rainy season, indicating that open dump lysimeter-A is in active acid forming phase. In open dump lysimeter-A, initially leachate pH was acidic indicating the accumulation of VFA in the early stage of bioreactor operations. Chian and Dewalle (1976) have reported that pH in leachate increases with time due to the decrease in the concentration of VFA in the system. The increase in pH suggests that a steady state has been reached between acid-producing and consuming processes within the reactors.

On the other side, leachate of sanitary lysimeter-B was alkaline initially (~7.38). A drop in pH was observed after 50 day, followed by also a decrease until 310 day for entire lysimeter operating system. Although the MSW in sanitary lysimeter-B, produced leachate of alkaline nature, after rainfall and at 290 day of operation, neutral activity occurs reducing the pH equal to 7.0, then, stimulated acidogenic activity reducing the pH below 7.0. The near neutral pH of leachate is also reasonably consistent with the literature (Tatsi et al., 2002) which suggested that pH is naturally buffered. Chian and DeWalle (1976) reported that pH of leachate increased with time due to decrease of concentration of the partially ionized free VFA. The increase in pH suggested that a steady state has been reached between acid-producing processes (e.g., cellulose and lignin degradation) and acid consuming processes (e.g., methane formation) at the landfill (Chu et al., 1994).

5.3.3.3 Variation of Chloride Concentration

In the present study, at the beginning of lysimeter operation to the starting of rainy season, the chloride was ranging of 3,572 to 1,850, 1,350 to 570 and 760 to 145 mg/L, for open dump lysimeter-A and sanitary lysimeter-B and C, respectively, as shown in Figure 5.26. However, after 50 day of lysimeter operation, during the rainy season, the chloride rapidly increases and ranging from 1,850 to 2,600, 570 to 1,150 and 145 to 1,700 mg/L, for open dump lysimeter-A and sanitary lysimeter-B and C, respectively. After 135 day of lysimeter operation, starting of the dry season, the chloride was found as lower than that of rainy season. A study conducted by Yuen et al. (2001) and reported that during monsoon season, rainwater percolated through the refuse beds and solubilized the constituents, producing a

larger volume of dilute leachate, while during the dry summer months, the concentration of certain pollutants (ammonia, sodium, potassium and chloride) were lower.

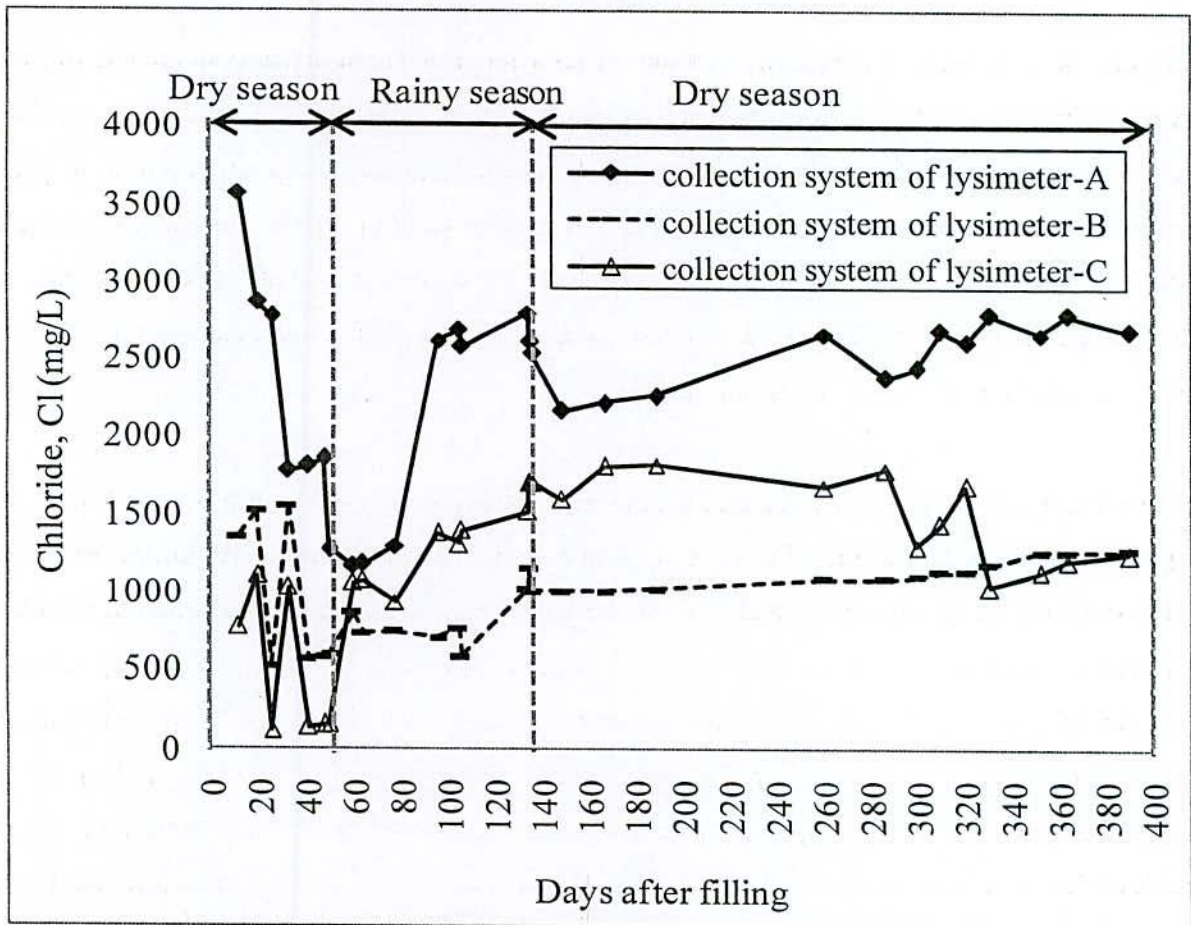


Figure 5.26: Temporal variation of chloride in leachate of open and sanitary landfill lysimeter

5.3.3.4 Variation of Total Solid

The temporal variation of total solid (TS) in relation to the increasing of elapsed period for the collection system of open dump lysimeter-A as well as sanitary lysimeter-B and C shown in Figure 5.27. The Figure 5.27 reveals that TS was initially high, but it decreases during the rainy season. Moreover, starting to ending of rainy season (50 to 135 days), the concentration of TS dropped within the range of 16,870 to 13,510, 12,920 to 7,120 and 15,290 to 10,400 mg/L, for the collection system of open dump lysimeter-A as well as sanitary lysimeter-B and C, respectively. A study conducted by Kouzeli-Katsiri et al. (1999) and reported that leachate from MSW landfill having high TS indicating the abundant presence of loose materials that easily get dissolved with the percolating of water. But, with the increase in age of deposited waste, the availability of loose materials has reduced considerably due to the compaction of waste in landfill.

Moreover, Qasim and Chiang (1994) stated that the concentration of TS was only removed as a result of washout by infiltrating rainwater. However, the TS was found as higher in open dum lysimeter-A than that of sanitary lysimeter-B and C. A study conducted by Yuen et al. (2001) reported that the TS in open dump of aerobic reactors were higher than sanitary landfill of anaerobic reactors. So, the finding in case of present study was agreed well with the statement given by Kouzeli-Katsiri et al. (1999); Qasim and Chiang (1994) and Yuen et al. (2001). The concentration of TS in leachate depends not only on elapsed period from the waste deposition but also the types, applicability and compactness of base and cap liner (Rafizul et al., 2009a). Due to the influence of the above factors, the magnitudes of TS in case of open dump lysimeter-A, was higher than that of sanitary lysimeter-B, although the trend was similar. However, this variation may be occurred due to the variation between this two lysimeter interms of aerobic and anaerobic, base liner and cap liner performance.

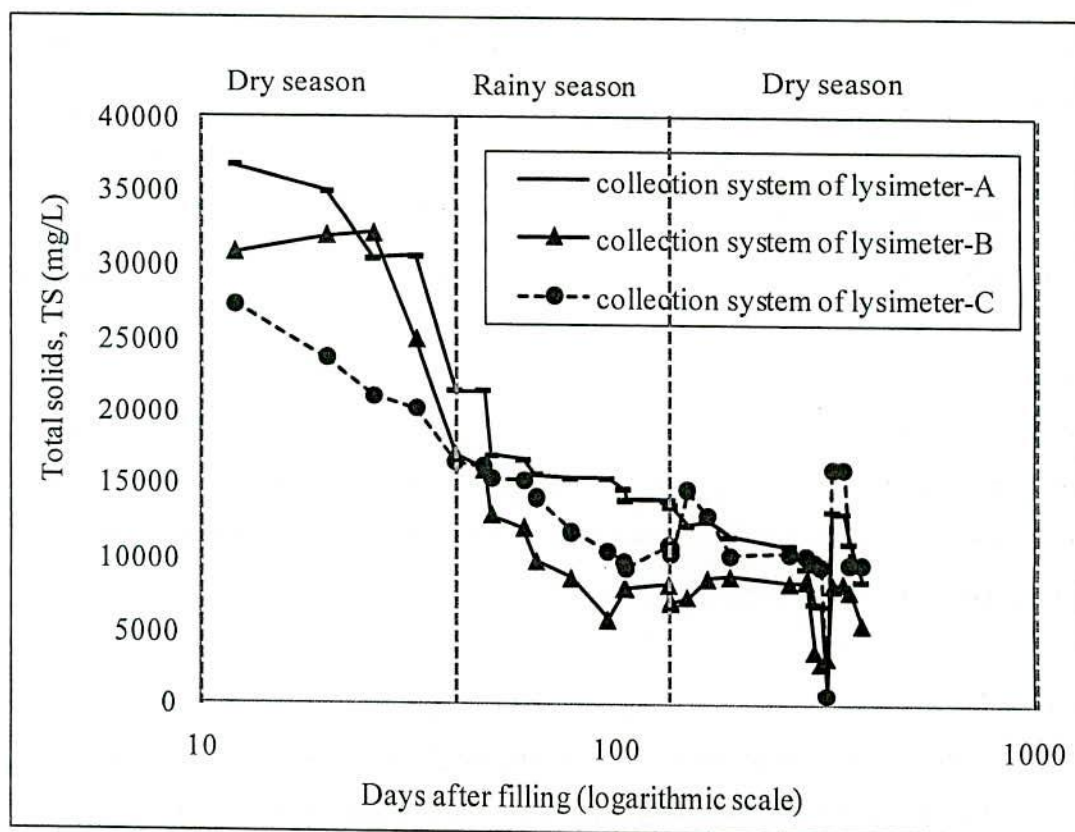


Figure 5.27: Temporal variations of TS of open dump and sanitary lysimeter

The experimental result reveals that the variation of TS in leachate throughout the rainy seasons was not as much of as obvious. Most of this variation is due to intensive rainfalls in

alternation with some dry periods even during rainy season. According to an observations by Qasim and Chiang (1994), the dry season causes a standstill of decomposition due to lack of moisture and with begin of the rainy season biological activity restart. If it is intended to maintain steady state conditions for a landfill to accelerate the degradation that such kind of landfill pattern is for sure detrimental and less efficient. Moreover, the producing of solid particles in tremendous dry season is as similar to rainy season. Here, it can be concluded that considering the above factors, the producing rate of TS in dry season was found as almost same as preceding rainy season.

5.3.3.5 Variation of COD Concentration

Figure 5.28 shows the temporal variation of COD concentration in leachate in relation to the increasing of elapsed period for the collection system of entire lysimeter. The COD found initially about 60,000 mg/L for both the open dump and sanitary lysimeter, but it was dropped steady with the range of 60,000 to 10,240, 60,000 to 3,840 and 60,000 to 35,550 mg/L until the end of dry season for open dump lysimeter-A as well as sanitary lysimeter-B and C, respectively. The Figure 5.28 depicts that at the beginning of rainy season, i. e. after 50 day of operation, COD dropped rapidly and remained stable until the end of rainy season. A study conducted by Chain and DeWalle (1976) and stated that due to the initially biodegradable nature as well as washout of MSW due to rainfall, COD decreases with increasing the age of landfill. Moreover, the COD was seemed to be diluted due to the rainfall events and then decreases (Trankler et al., 2005; Monteiro et al., 2002). Variations in leachate quality with age should be expected throughout most of the landfill life because organic matter will continue to undergo stabilization (Qasim and Chiang, 1994). Here, it can be noted that comparatively COD decreases during rainy season for sanitary lysimeter-B due to the higher rate of leachate production (Figure 5.28) and the biological activity for rapid production of LFG up to 70 day of operation (Figure 5.8).

El-Fadel et al. (2002) stated that the COD found higher during summer and gets diluted during monsoon. This may be due to the enhanced leaching of pollutants from the wastes dumped at the top layer during the initial precipitation followed by the dilution effects of rainfall. It can be noted that COD for both the cases of open dump lysimeter-A and sanitary lysimeter-C, were found higher until the completion of study period, because the infiltration rate of rainfall in open dump lysimeter-A and sanitary lysimeter-C was comparatively higher than that of sanitary lysimeter-B due to the simplicity and looser conditions which implied

more dilution of MSW deposited in lysimeter. Moreover, a study by Chiemchaisri and Srisukphun (2003) suggested that the COD in leachate was significantly influenced by water infiltration through the waste layer. A study conducted by Aluko et al. (2003) reported that higher concentration of COD in leachate in wet season rather than during dry season.

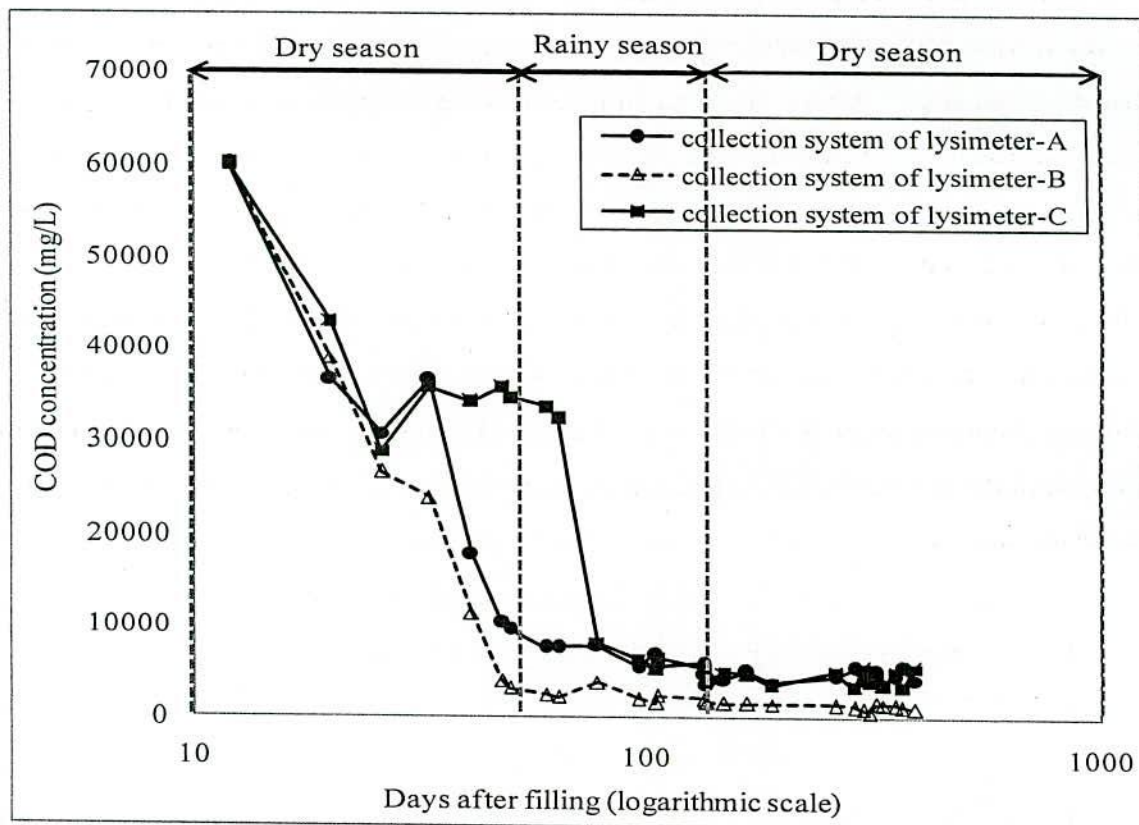


Figure 5.28: Temporal variation of COD in leachate of open and sanitary landfill lysimeter

5.3.3.6 Variation of Conductivity

The Figure 5.29 shows the temporal variation of electric conductivity (EC) in leachate for the collection system of open dump and sanitary lysimeter. Based on Figure 5.29, it can be concluded that EC was ranging from 10.4 to 25.8, 5.3 to 19.3 and 8.9 to 21.2 mS/cm in relation to the increasing of operational period for open dump lysimeter-A as well as sanitary lysimeter-B and C, respectively. It can be observed that the highest EC was found for open dump lysimeter-A, with 25.8 mS/cm, whereas, the lowest of sanitary lysimeter-B with 5.3 mS/cm. However, this situation was also observed by Trankler et al. (2005) and Visvanathan et al. (2007) and reported that for two cells in sense of open lysimeter (OL) and closed lysimeter (CL), the EC was initially low, but it was increased at the beginning of the rainy season. However, the EC in the open cell was higher than that of closed cell.

On the other hand, in the present study, starting to ending of rainy season (50 to 135 days), EC dropped rapidly within the range of 24.7 to 12.7, 8.9 to 6.9 and 19.1 to 10.7 mS/cm, for open dump lysimeter-A as well as sanitary lysimeter-B and C, respectively, then after 135 day during dry season, it increases rapidly for all the cases of lysimeter operating system. Moreover, a study conducted by Qasim and Chiang (1994) and reported that inorganic compounds (i.e. solids, conductivity etc.) of leachate in MSW landfill are only removed as a result of washout by percolating of rainwater. However, a study conducted by Yuen et al. (2001) and reported that the highest EC was recorded at the beginning stage of monsoon period in leachate from deposited MSW in lysimeter. It also advocated that it may be mainly due to the percolation and flushing effect of rain water that washed out all the inorganic compounds from the MSW in landfill. Moreover, the seasons are affecting the EC values especially during rainy season it is fluctuated as a result of the dilution. The EC values got drastically reduced due to dilution towards the end of monsoon period and it was found to be the higher at the dry season and similar trend was followed by Qasim and Chiang (1994) and Yuen et al. (2001).

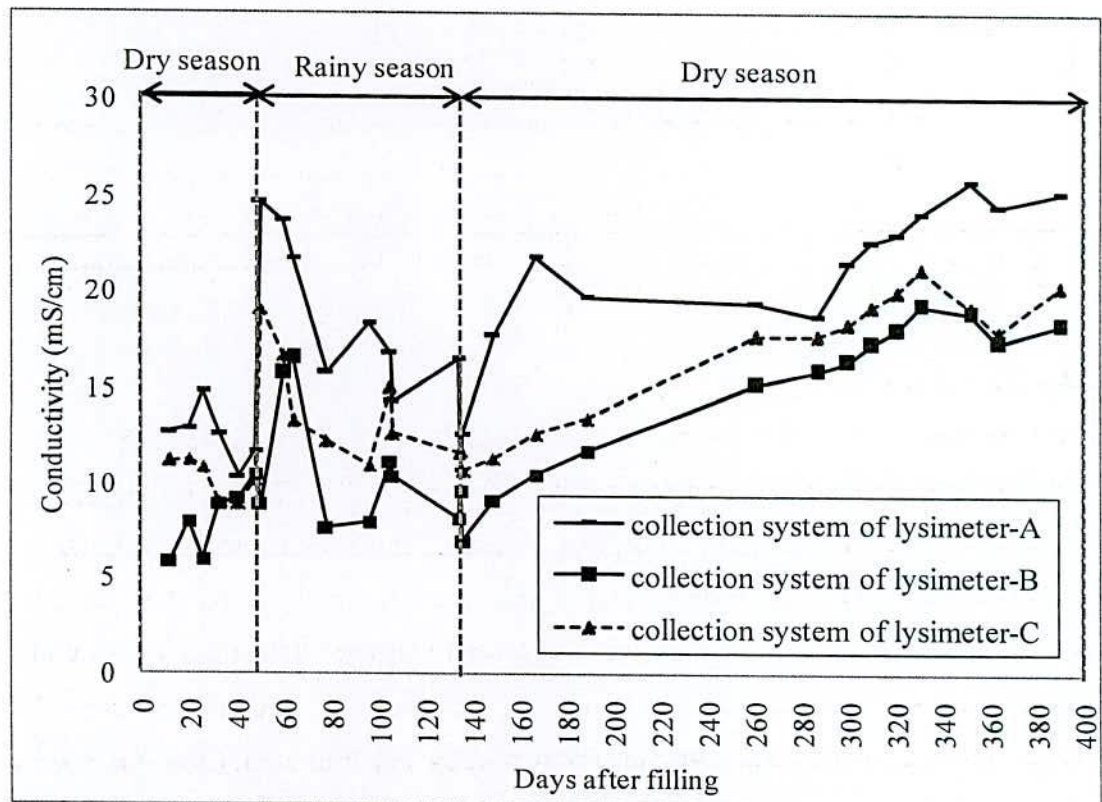


Figure 5.29: Temporal variation of conductivity in leachate of open and sanitary lysimeter

5.3.3.7 Carbon and Nitrogen Load in Landfill Lysimeter

The cumulative load of COD and TKN for the collection system of open dump lysimeter-A as well as sanitary lysimeter-B and C was calculated from the COD and TKN concentration and leachate generation. Figures 5.30 and 5.31, the distribution of cumulative COD and TKN load, respectively, shown a clear seasonal pattern characterized by low load in dry season and high load in rainy season. Result revealed that, at the 50 day to up the 135 day of lysimeter operation, during the rainy season, the COD load increases rapidly with the ranging from 147 to 3202, 4.7 to 1035 and 11 to 1291 mg/ kg solid waste in relation to the increasing of elapsed period from waste deposition, for the collection system of lysimeter-A, B and C, respectively. But, after 135 day of lysimeter operation, during the dry season, the COD load was stable because few leachate flows was produced and similar trend was followed by Trankler et al. (2005) and Visvanathan et al. (2007) and advocated that COD load of open cell was higher than those of closed cell. However, the loading gradually increases during the rainy season, but did not change during the dry season due to low degradation and leachate generation.

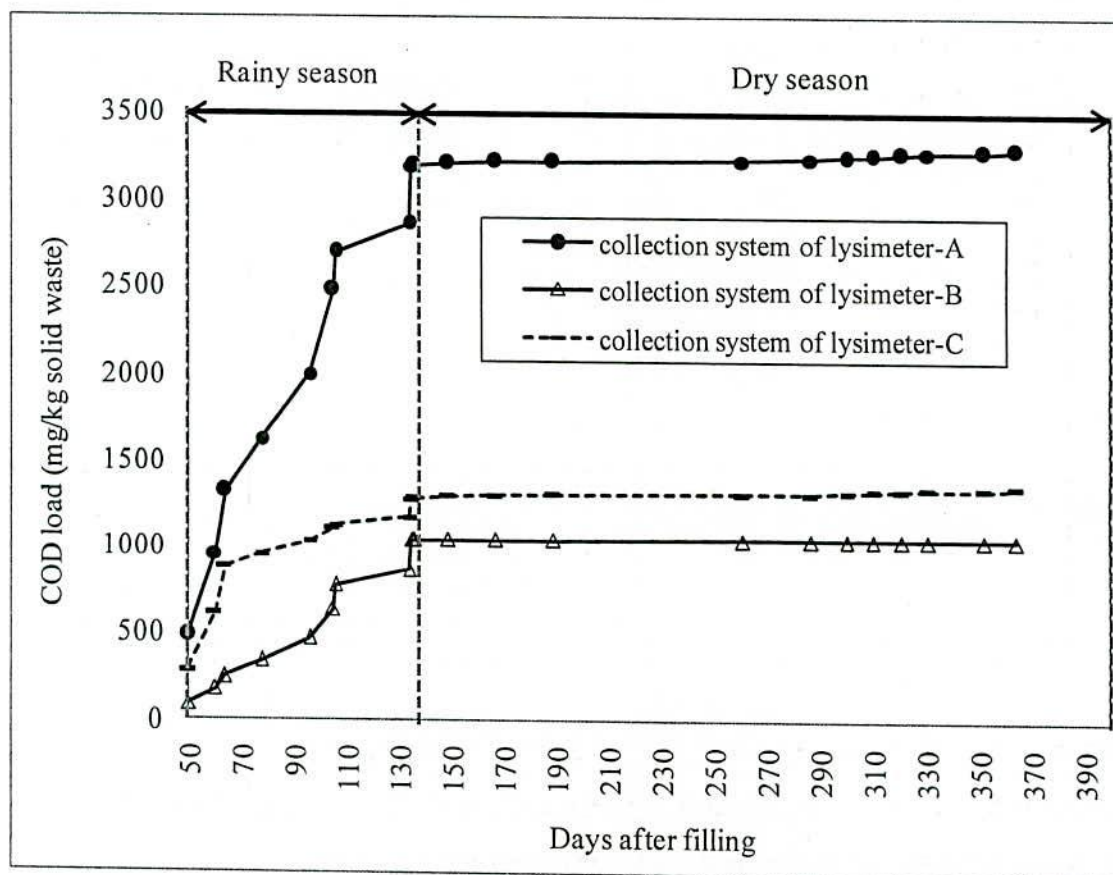


Figure 5.30: The cumulative COD load of open and sanitary landfill lysimeter

In contrast, during rainy season, the cumulative COD of three landfill lysimeter has risen sharply. The open dump lysimeter-A showed the highest COD load owing to the high moisture content (65 %) in deposited MSW and due to the percolating of rainfall and it stimulated the activity of microorganism. Although, the COD concentration of open dump lysimeter-A found considerable lower but the top cover design of open dump promoted rainfall percolation to the landfill; so, it achieved the higher COD load compared with sanitary lysimeter-B and C. Here, it can be noted that COD load was found higher for open dump lysimeter-A than that of sanitary lysimeter-B and similar trend was also observed by Ham and Bookter (1982) and advocated that cumulative COD load for open reactors was higher than that of closed reactors.

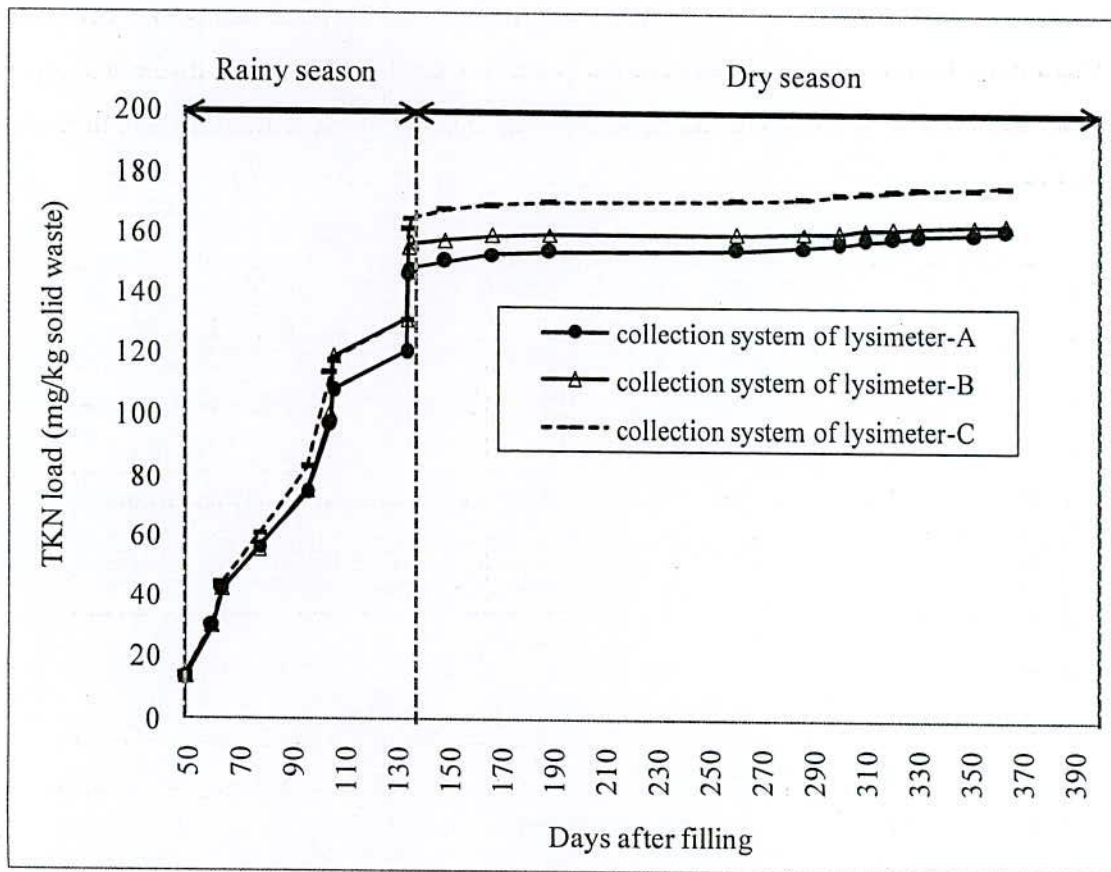


Figure 5.31: The cumulative TKN load of open and sanitary landfill lysimeter

Figure 5.31 illustrates the cumulative load of TKN for the collection system of open dump lysimeter-A as well as sanitary lysimeter-B and C was calculated from the TKN concentration and leachate generation. Result revealed that during the rainy season (50-135 day of lysimeter operation), TKN load increases rapidly with the ranging from 0.50 to 146, 1 to 155 and 1 to 161 mg/ kg solid waste in relation to the increasing of elapsed period from

waste deposition, for the collection system of lysimeter-A, B and C, respectively. The cumulative TKN of landfill lysimeter leachate has somewhat increased from initial until end of dry season. During rainy season, the cumulative TKN of three landfill lysimeter has quickly increased from initial until end of rainy season. Although the leachate generations for open dump lysimeter-A is comparatively higher than that of sanitary lysimeter-B and C, but due to the lower TKN concentration, the cumulative TKN load of open dump lysimeter-A was lower compared with other counterparts i.e. sanitary lysimeter-B and C.

5.4 Summary of the Findings

The field level landfill simulation with various top cover design and operational condition of lysimeter greatly influences the leachate quality. Moreover, the open dump lysimeter showed lower concentration of TKN and $\text{NH}_4\text{-N}$ as well as TKN load, while both the concentration and load of COD higher in compared to sanitary lysimeter. It can be noted that chloride increased, while pH, COD concentration, EC and TS in leachate regarding to entire lysimeter operational system decreased during the rainy season. The COD was found initially the highest in concentration, but rapidly decreased with the rainfall events. Based on evaluated results, it can be depicted that metal concentrations which were comparatively higher in leachate of open dump lysimeter were Ca and K, however, the heavy metal concentrations of Cd, Cu, Zn and Mn, and those apparently lower were metals of Na, Mg and Fe as well as heavy metals of Cr, Pb and Ni. The seasonal variation of leachate generation pattern indicated that the highest degradation of MSW occurred during the rainy season and lowest occurred during the dry season due to lack of moisture in lysimeter. Hence, there is a need for change in operational conditions during the dry season to enhance the biodegradation of MSW by recirculation of leachate stored during the monsoon period. Result reveals that low leaching actions during dry season resulted in a smaller volume but high-strength leachate quality. The knowledge of leachate quality will be useful in planning and providing remedial measures of proper liner system in sanitary landfill design and leachate treatment. Here it can be concluded that to minimize the volume of leachate with high pollutant concentration and then contaminant the surrounding ground and underlying ground water, sanitary landfill with standard design configuration was the best option for MSW disposal.

Chapter Six

Contamination Potential of Landfill Lysimeter

6.1 Background

Leachate generated from a solid waste landfill may enter the underlying groundwater or the adjoining surface water bodies and can seriously degrade the water quality (Chian and DeWalle, 1976; Lo, 1996; Masters, 1998). In an effort to quantify the leachate pollution potential of the landfill sites, an index known as the leachate pollution index (LPI) was developed using Delphi technique (Kumar and Allapat, 2003a). The formulation of an environmental index involves four basic steps: (1) selection of variables; (2) derivation of weights; (3) formulation of their subindice equation and (4) aggregation of the subindices (Kumar and Allapat, 2005c). In the present study, firstly various possible aggregation methods were reviewed and applied in an effort to select the most appropriate one for calculating LPI. Secondly, the LPI was calculated using the proposed equation by Kumar and Alappat (2004) for overall LPI and sub-pollution indices (sub-LPIs). Thirdly, the possible errors for calculating LPI due to non-availability of leachate parameters were also analyzed.

The aggregation function is one of the most important steps in calculating any pollution potential. If aggregation function is ambiguous, the result will raise an unnecessary alarm, indicating a comparatively less polluted environmental situation as mere contaminated. Similarly, if the aggregation function is eclipsed a false sense of security may be created, indicating a highly polluted environmental situation as less polluted. Result reveals that the weighted linear sum aggregation method is the best possible aggregation function for calculating LPI. In this study, finally the weighted linear sum aggregation function was used for evaluating the LPI.

6.2 Selecting Suitable Aggregation Function for LPI

To select the most appropriate aggregation for LPI, various possible aggregation functions were applied in this study. For the present study, the leachate characteristics of lysimeter at

KUET campus have been considered. The selecting criteria for the most possible appropriate aggregation function were analyzed and hence discussed in the following articles.

6.2.1 Concept of Leachate Pollution Index

In an effort to develop a system for comparing the leachate pollution potential of various landfill sites in a given geographical area, 80 panelists consists of academicians in environmental science and engineering; environmental regulatory authority officials and scientists; consulting engineers; and members of International Solid Waste Association (ISWA) conducting the necessary survey around the world as presented in Table 6.1. The survey was conducted using multiple questionnaires to formulate *LPI* based on Rand Corporation's Delphi Technique (Dalkey 1968).

Table 6.1: Professional fields of panelists for *LPI* formulation (after Kumar and Alappat 2003a)

SL No.	Professional status of the panelists	No. of panelists
01.	Regulatory authorities and scientists	15
02.	Consulting engineers	06
03.	Academicians	49
04.	Others including members of International Solid Waste Association (ISWA)	10
Total		80

6.2.2 Pollutant Variables Selection

Panelists were requested to rate each parameter marked 'include' according to the significance of its contribution to overall leachate pollution. The rating was to be done on a scale of '1' to '5'. The value '1' was to be used for the parameter that has lowest relative significance to the leachate contamination, while, the value '5' was to be used for the parameter that has highest relative significance. The 18 leachate pollution parameters selected for inclusion in the *LPI*, based on the survey of panelists, were chromium (Cr), lead (Pb), chemical oxygen demand (COD), mercury (Hg), 5 day biochemical oxygen demand (BOD₅), arsenic (As), cyanide (CN), phenolic compounds, zinc (Zn), pH, total Kjeldahl nitrogen (TKN), nickel (Ni), total coliform bacteria (TCB), ammonical nitrogen (NH₄), total dissolved

solids (TDS), copper (Cu), chlorides (Cl⁻), and total iron (Fe) (Kumar and Alappat 2003a). The weights for these parameters were calculated based on the significance levels given by the panelists for these parameters on a scale of 1 to 5 and are shown in Table 6.2.

Table 6.2: Significance and weights of the pollutant parameters (after Kumar and Alappat 2003a)

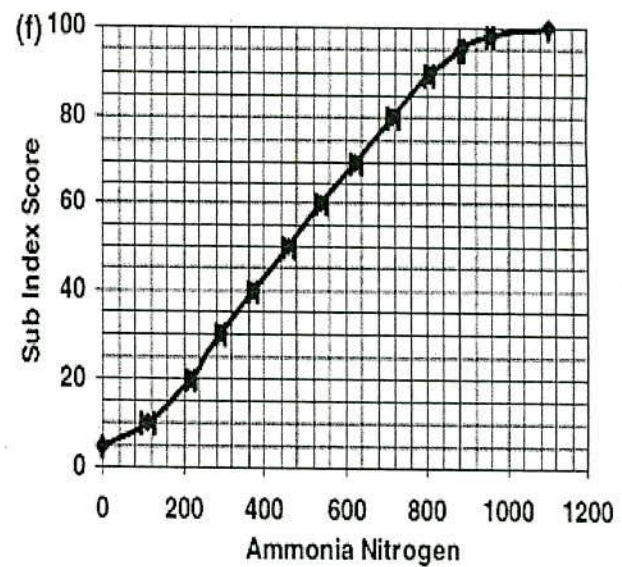
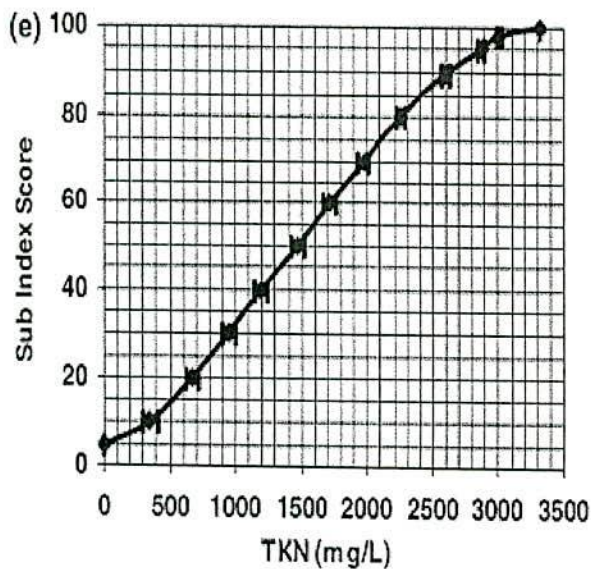
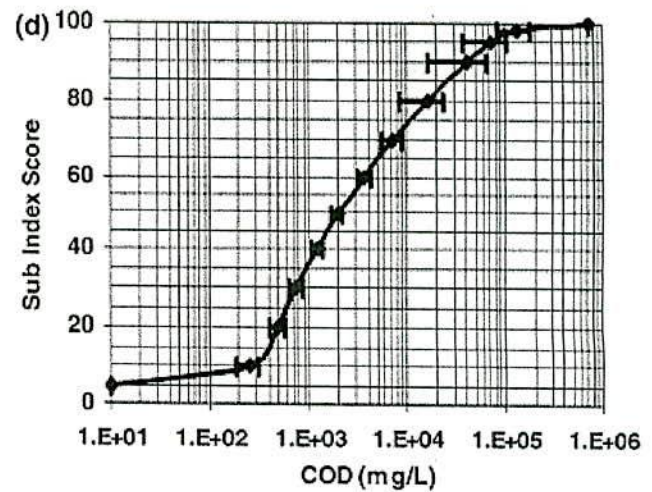
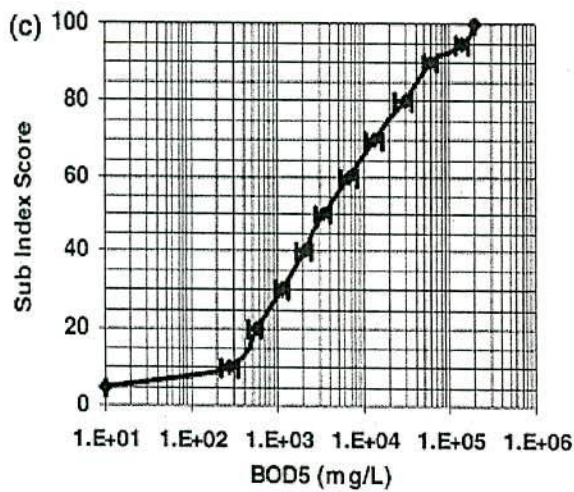
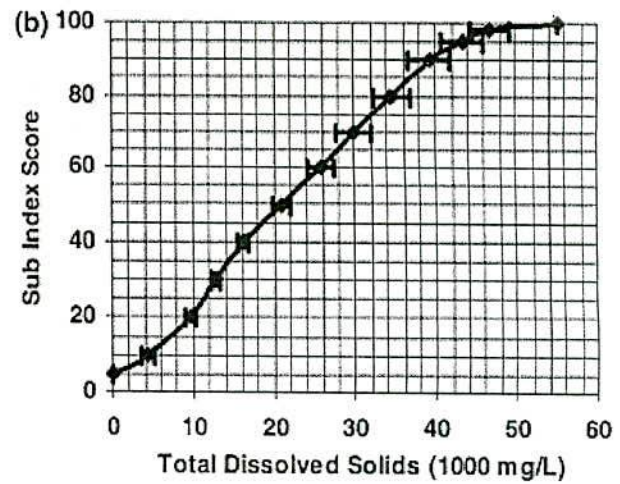
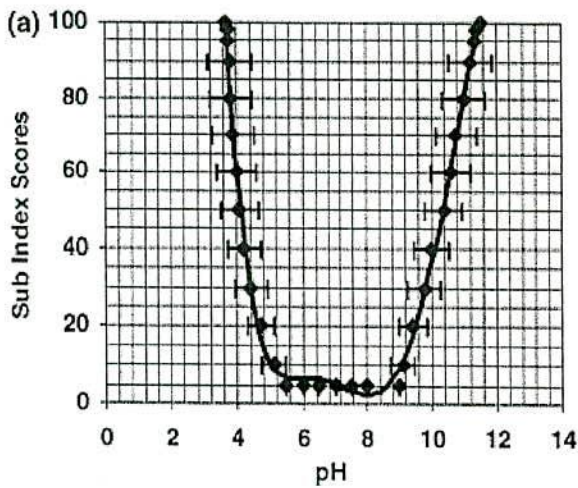
Sl. No.	Pollutant	Significance	Pollutant weight, w_i	*Concentration of lysimeter leachate, c_i
1	Total Chromium	4.057	0.064	1.75
2	Lead	4.019	0.063	0.68
3	COD	3.963	0.062	8425
4	Mercury	3.923	0.062	0.4
5	BOD ₅	3.902	0.061	1398
6	Arsenic	3.885	0.061	0.01
7	Cyanide	3.694	0.058	1.3
8	Phenol Compound	3.627	0.057	4
9	Zinc	3.585	0.056	1.3
10	pH	3.509	0.055	7.3
11	Total Kjeldahl Nitrogen	3.367	0.053	3000
12	Nickel	3.321	0.052	0.23
13	Total Coliform Bacteria	3.289	0.052	8000
14	Ammonia Nitrogen	3.250	0.051	1300
15	Total Dissolved Solids	3.196	0.050	12540
16	Copper	3.170	0.050	0.98
17	Chlorides	3.078	0.049	3597
18	Total Iron	2.830	0.045	82
	TOTAL	63.165	1.000	

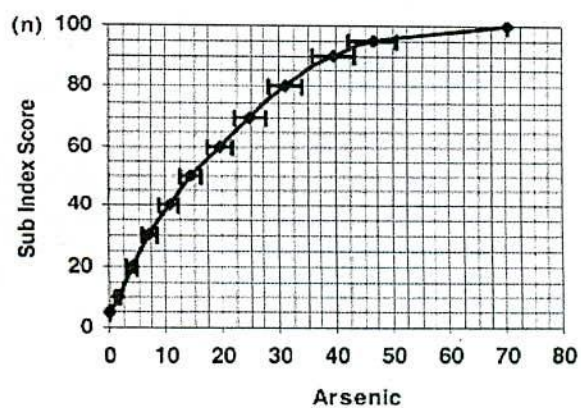
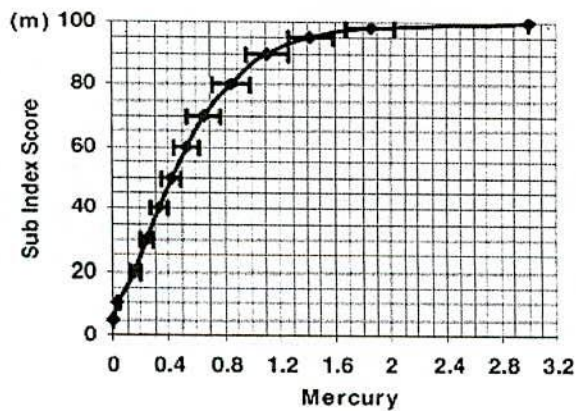
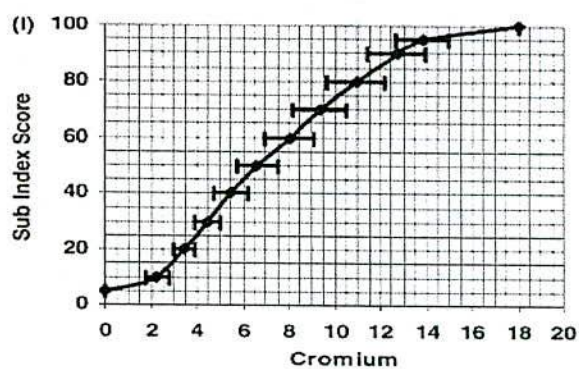
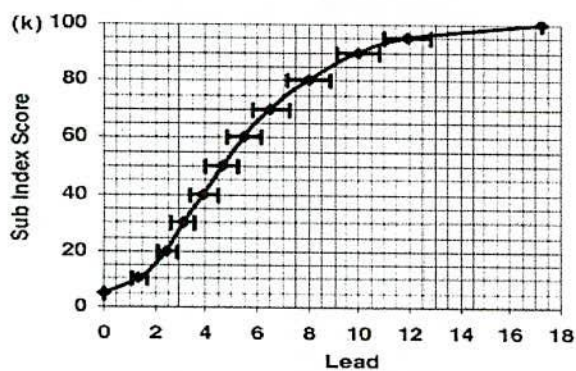
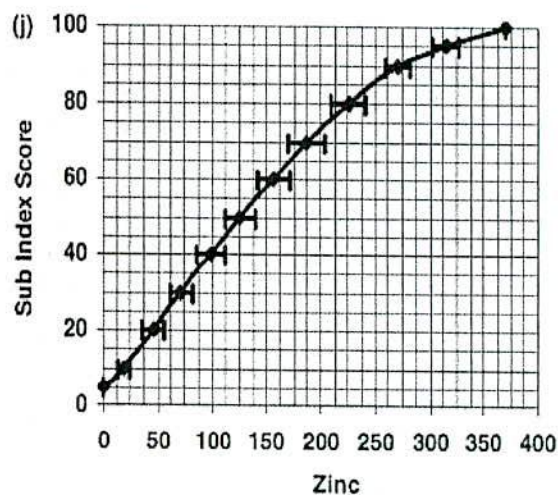
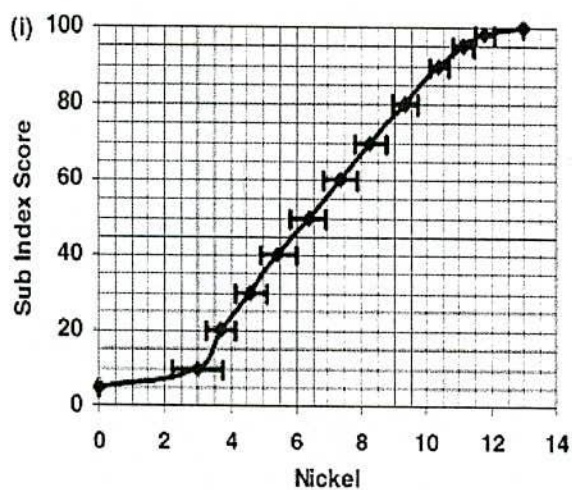
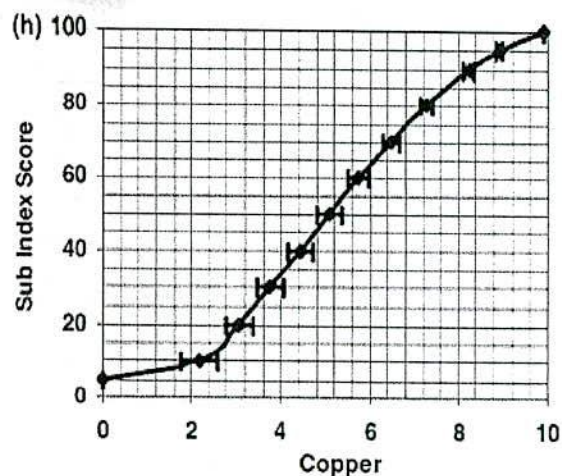
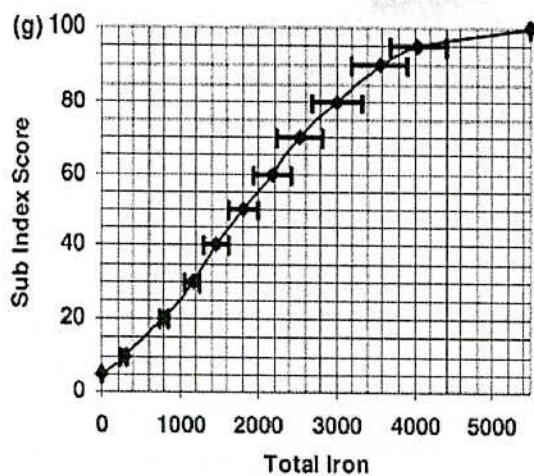
* the values of leachate parameters measured in the laboratory in the present study

6.2.3 Development of Pollutant Variable Rating Curves

A selected group of panelists were asked to draw curves for the pollutant variables included in LPI with respect to leachate pollution ranging from 5 (best) to 100 (worst). Levels of leachate pollution from 0 to 100 were indicated on the ordinate of each graph, while various levels of concentration of particular variable, up to maximum limits reported in literature, were indicated on abscissa. The curves drawn by the panelists were averaged to obtain "average subindex" curves for each parameter shown in Fig. 6.1. In this study, the sub-index

score (w_i) was evaluated corresponding to the concentration of leachate parameters by using this developed curves for calculating LPI.





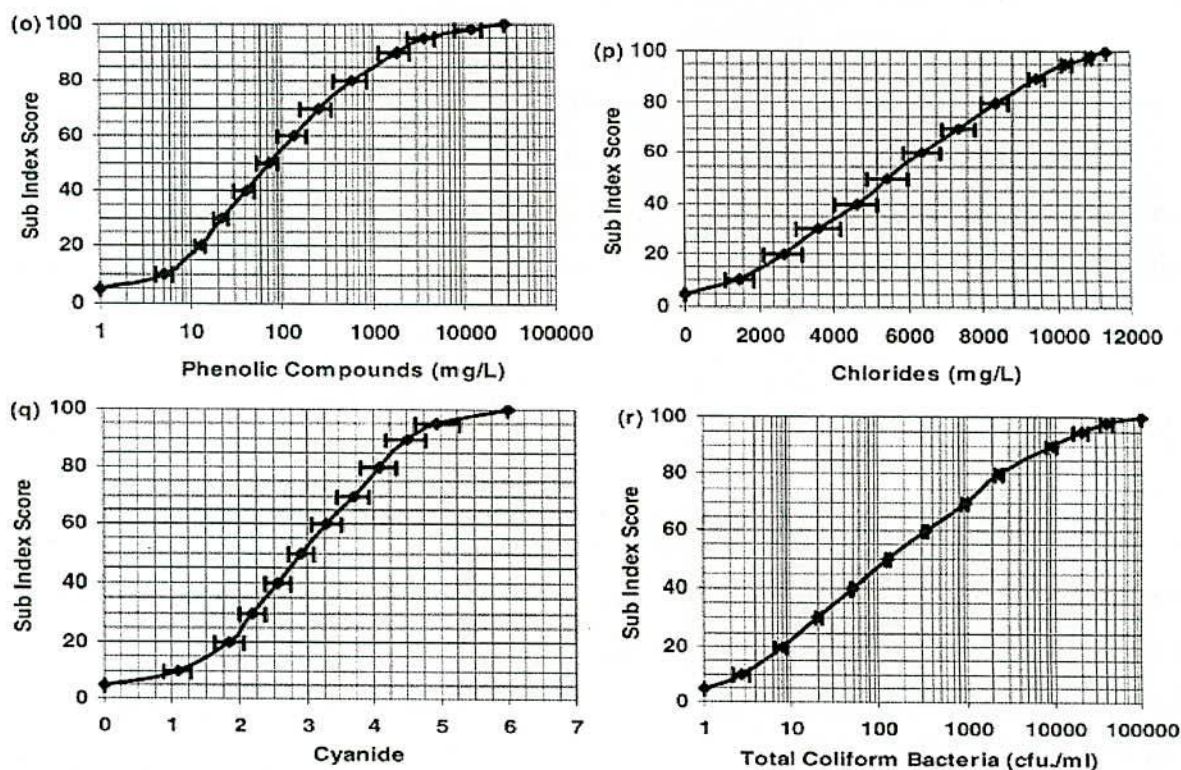


Figure 6.1: The averaged sub index curves (a) pH (b) TDS (c) BOD₅ (d) COD (e) TKN (f) ammonia nitrogen (g) iron (h) copper (i) nickel (j) zinc (k) lead (l) chromium (m) mercury (n) arsenic (o) phenol (p) chlorides (q) cyanide (r) TCB (after Kumar and Alappat 2003a)

6.2.4 Aggregation Function

Aggregation has been defined as “the process of adding variables or units with similar properties to come up with a single number that represents the approximate overall value of its individual component.” Aggregation function consists of the following three forms:

- I. Additive form (summation function), in which individual variables are added together;
- II. Multiplicative form (multiplication function) in which a product is formed of some or all of the variables and
- III. Maximum or minimum operator form, in which just the maximum or the minimum subindex value of the variable directly accepted.

6.2.5 Selecting of Suitable Aggregation Function

To select the most appropriate aggregation for LPI, the various possible aggregation functions are applied to landfill lysimeter leachate characteristics at KUET campus. For the present study, the leachate characteristics of lysimeter at KUET campus have been considered. The LPI values for the treated leachate of India have also been calculated using all the aggregation functions to demonstrate the behavior of various aggregation functions. The concentrations of the various leachate pollutant variables were shown in Table 6.2, Column 4. The different aggregation functions were used for selecting suitable aggregation function of unweighted additive form (LPI_{ua}), weighted linear additive form (LPI_{wa}), root sum power additive form (LPI_2), root sum power additive form ($r=4$) (LPI_4), root sum power additive form ($r=10$) (LPI_{10}), weighted root sum power additive form ($r=4$) (LPI_{w4}), weighted root sum power additive form ($r=10$) (LPI_{w10}), root mean square additive form (LPI_{rm}), weighted root sum square aggregation function (LPI_{mr}), maximum operator function (LPI_{max}), ambiguity and eclipsity free aggregation function ($LPI_{2.5}$), weighted ambiguity and eclipsity free aggregation function ($LPI_{w2.5}$), multiplicative aggregation function (LPI_{wm}) and unweighted multiplicative aggregation function (LPI_{um}). The calculation of LPI based on these aggregation methods provided in Table C.1 in the Appendix-C. The LPI values for the treated leachate were also calculated using all these aggregation functions. In fact, the data set considered is not for the treated leachate of any municipal landfill site, but it is for the maximum permissible discharge limits for the various pollutant variables according to Indian regulations (Government of India, 2000), assuming these to be the characteristics of the treated leachate. The LPI for treated leachate using all the aggregation functions were computed and shown in Table C.2 in the Appendix-C.

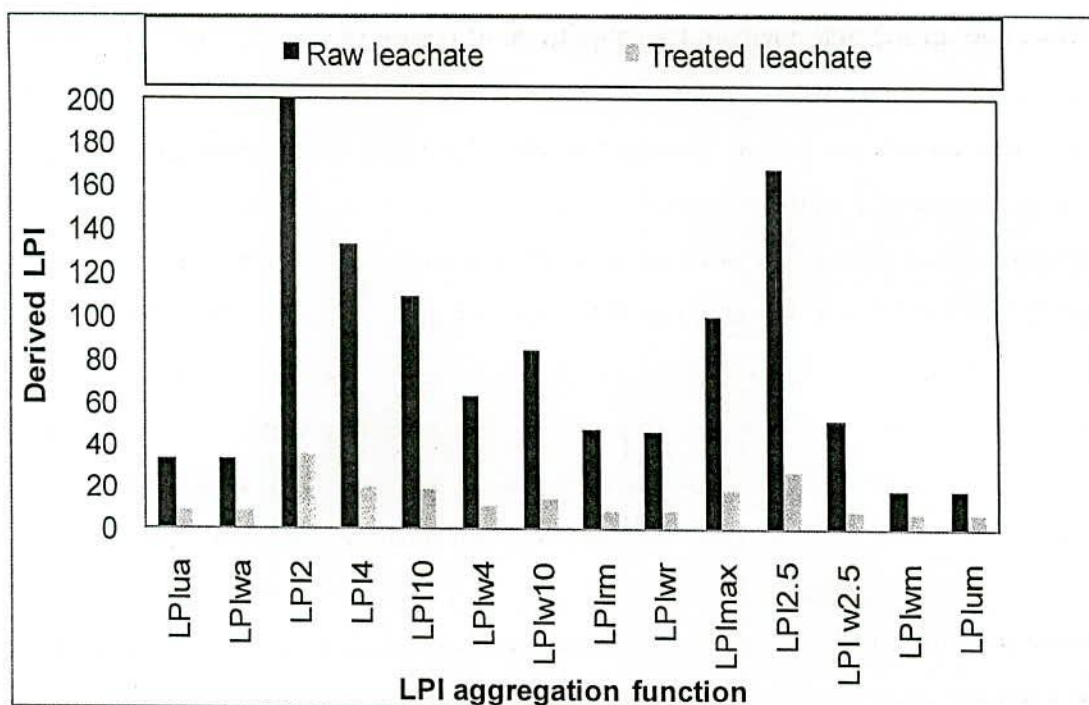


Figure 6.2: LPI values of raw leachate from lysimeter and treated leachate

The LPI values for the landfill lysimeter at KUET campus, calculated using all the aggregation methods stated earlier. The values of LPI of landfill lysimeter by using these aggregation functions provided in Figure 6.2. The LPI values of the treated leachate are also plotted in Figure 6.2. The LPI values calculated using various aggregation methods indicate that root sum power, 4th root power, 10th root power and the calculated LPI values exceed the maximum reported individual pollutant subindex value. All these values also exceed the theoretical range of LPI, i.e., 5-100. However, the 10th root power aggregation function results in the least ambiguous results, followed by the 4th root, the ambiguity and eclipsity free (2.5th root), and the root sum square aggregation functions. The maximum operator aggregation function does not show ambiguity of results, but it cannot be used for calculating LPI values, as its results cannot be used to compare the fine gradations of leachate pollution.

The results of the two multiplicative aggregation functions, the weighted multiplicative aggregation function and the unweighted multiplicative aggregation function, indicate high eclipsing of the data. The values are very low as compared to the other additive form aggregation functions. The unweighted additive form and root mean square additive form aggregation functions suffer from the drawback that the weight of the variables are not

considered, and all the variables are assumed to be of the same weight. Though the weighted linear sum aggregation function also suffers from the eclipsity problem, the eclipsity produced is small, as the number of the variables included in the aggregation function is large. The eclipsity problem is associated with this aggregation function when the dichotomous state of the index is to be reported, which is not the case here. The weighted sum aggregation, weighted root mean square, weighted 2.5th root, weighted 4th root, weighted 10th root, and weighted multiplicative aggregation functions, however, fulfill other criteria, such as weights of all the pollutant the variables being considered, and are easy to ascertain. The sensitivity of these six aggregation function to the changes of the individual pollutants is further conducted to select the best possible aggregation function.

The sensitivity analysis of the six aggregation functions, which takes into consideration the weights attached to the pollutants, with respect to change in concentration of two pollutants is performed independently. The six aggregations selected for sensitivity analysis are:

1. Weighted sum additive aggregation function, LPIwa
2. Wighted root sum square aggregation function, LPIwr
3. Weighted 2.5throot (ambiguity and eclipsity free) aggregation function, LPIw2.5
4. Weighted 4th root sum aggregation function, LPIw4
5. Weighted 10th root sum aggregation function, LPIw10
6. Weighted multiplicative aggregation function, LPIwm

The two pollutants selected were Cr, which was the most significant variable and thus has the highest “weight” value, and Fe which was least significant pollutant with the lowest “weight” value. It will be hypothetical to assume that all the leachate pollutant variables included in LPI for a particular landfill will take on the highest possible subindex value of 100. Therefore, it is felt more practical to study the sensitivity analysis on actual landfill leachate data. For performing the sensitivity analysis, the subindex value of Cr is varied from 5 to 100 in the same data set of landfill lysimeter at KUET campus, and the LPI values using these six aggregation functions were calculated. The variations in the LPI values of this six aggregation functions with respect to the change in the subindex value of Cr as shown in Figure 6.3. The variations of the LPI values for all six aggregation functions with respect to the change in the subindex value of Fe from 5 to 100 for the same data set are shown in

Figure 6.4. The calculated percentage variation of the LPI values over the minimum value for the subindex variation of Cr and Fe are shown in Table 6.3.

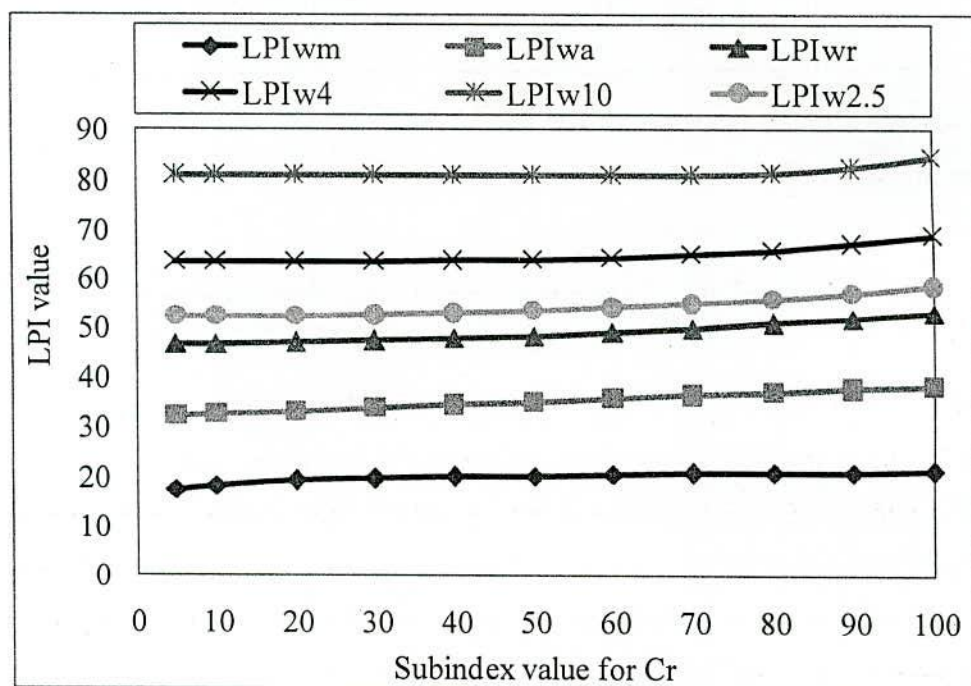


Figure 6.3: Sensitivity of weighted additive, weighted square root, weighted ambiguity eclipsity free, weighted fourth root, weighted tenth root, and weighted ultiplicative aggregation function with respect to changes in subindex of Cr

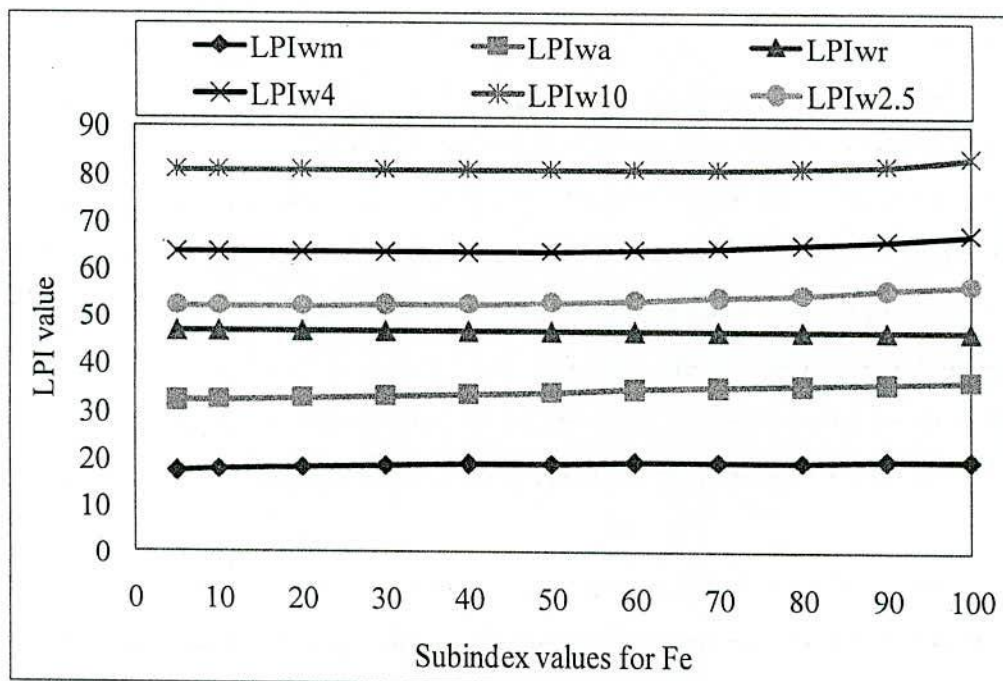


Figure 6.4: Sensitivity of weighted additive, weighted square root, weighted ambiguity eclipsity free, weighted fourth root, weighted tenth root, and weighted multiplicative aggregation function with respect to changes in subindex values of Fe

Table 6.3: Sensitivity analysis results of selected aggregation functions for change in subindex values of chromium and total iron from 5 to 100

No.	Aggregation function	Changes in LPI (%) for	
		Cr	Fe
1	Weighted sum additive aggregation function, LPI _{wa}	18.89	13.31
2	Weighted multiplicative aggregation function, LPI _{wm}	21.18	14.48
3	Weighted root sum square aggregation function, LPI _{wr}	13.76	0.09
4	Weighted 2.5 th root (ambiguity and eclipsity free) aggregation function, LPI _{w2.5}	11.99	8.63
5	Weighted 4 th root sum aggregation function, LPI _{w4}	8.73	6.35
6	Weighted 10 th root sum aggregation function, LPI _{w10}	4.42	3.25

From Table 6.3, it can be concluded that weighted multiplicative aggregation function is the most sensitive one in comparison to other aggregation functions, showing change in LPI values of 21.18 and 14.48 % for Cr and Fe, respectively. The next most sensitive aggregation function is the weighted linear sum aggregation function, which shows 18.89 and 13.31% variation in LPI for the two pollutants, followed by the weighted root square, weighted 4th root, and weighted 10th root aggregation function. The weighted 10th root aggregation function is least sensitive to the subindex changes of chromium and total iron.

Further, the behavior of LPI_{w10}, LPI_{w4}, LPI_{w2.5}, and LPI_{wr} values with respect to the changes in subindex values of Cr and Fe, shown in Figures 6.3 and 6.4, clearly indicates that these aggregation function are least sensitive to changes in the subindex values, particularly for the lower values of the subindex. The LPI_{w10} value remains almost constant for a change in the subindex value of Cr from 5 to 70, while the LPI_{w4} value remains almost constant for a change in the subindex value of Cr from 5 to 60. Similarly, the LPI_{w2.5} and LPI_{wr} are also insensitive for the changes in the subindex value of chromium from 5 to 40. The behavior of these aggregation functions with respect to the changes in the subindex values of Fe is similar. Therefore, these aggregation functions may not be useful when the fine gradation in leachate pollution of different landfill sites spread over a given area is to be compared.

Though the sensitivity analysis shows that the variation of LPI_{wm} values for the change in subindex values of Cr and Fe was the highest, it suffers from the drawback that the function was nonlinear. Figure 6.3 and 6.4 indicate that the LPI_{wm} values hardly change when the subindex values of Cr and Fe vary from 50 to 100, but the changes in LPI_{wm} values is more

rapid when the subindex value changes from 5 to 50. Thus the LPI_{wm} curve does not represent the change in subindex values as effectively as LPI_{wa}. Moreover, the weighted multiplication aggregation function shows far higher eclipsity as compared to the weighted sum linear aggregation function and thus may not be the most appropriate aggregation function for calculating LPI. The variation in LPI_{wa} values is comparatively sensitive and linear to changes in the subindex value of Cr and Fe throughout their range.

Finally, it can be concluded that weighted sum linear aggregation method was the most suitable aggregation function for estimating the values of LPI. In this study for evaluating the contamination potential of lysimeter, weighted sum linear aggregation was used.

6.3 Evaluation of Contamination potential of Landfill Lysimeter using LPI

In this chapter, the concept of *LPI* was described in brief and stepwise procedure to calculate the *LPI* using the actual concentrations of leachate generated from MSW deposited in landfill lysimeter. However, the stepwise detailed of formulation of *LPI* is presented and hence discussed in the following articles.

6.3.1 Variable Aggregation

The weighted sum linear aggregation function was used to sum up the behavior of all the leachate pollutant variables. The various possible aggregation functions were established stated in the earlier for selecting the best possible aggregation function. The sensitivity analysis of the six short-listed aggregation function was performed to arrive at the best possible aggregation function. Moreover, a study conducted by Kumar and Alappat (2004) and also proved weighted sum linear aggregation function was found to be the most suitable one for the calculation of LPI. So, for calculating LPI, following Equation 6.1 is used:

$$LPI = \sum_{i=1}^n w_i p_i \quad (6.1)$$

Where, where LPI is weighted additive leachate pollution index; w_i = the weight for the i^{th} pollutant variable; p_i = the sub-index value of the i^{th} leachate pollutant variable, number of leachate pollutant parameters; $n=18$ and $\sum w_i=1$.

However, when the data for all the leachate pollutant variables are not available, PI can be calculated using the data set of the available leachate pollutants by the Equation 6.2:

$$LPI = \frac{\sum_{i=1}^m w_i p_i}{\sum_{i=1}^m w_i} \quad (6.2)$$

When, all the leachate parameters are unknown, $m < 18$ and $\sum_{i=1}^m w_i < 1$.

6.3.2 Laboratory Investigations

Leachate samples were collected at a regular interval of times from leachate collection chamber accomplished of four distinct collecting system such as detection (A_1) and collection (A_2) system of open dump lysimeter-A as well as collection system of sanitary lysimeter-B and C. In the laboratory, pH was determined by pH meter (HACH, Model No. Sens ion 156), chloride by potentiometric titration method using silver nitrate solution, BOD₅ by BOD meter (HACH, HQ-40d), TCB by filter membrane system, Arsenic using sulfamic acid and zinc powder as well as COD by closed reflexive method as per the standard methods (APHA, 1998). Total dissolved solid (TDS) dried at 103-105°C, ammonia nitrogen (NH₄-N) by nesslerization standard method and total kjeldahl nitrogen (TKN) by macro-kjeldahl method as per the standard methods (APHA, 1998) were determined in the laboratory. The concentration of Fe, Cu, Zn, Cr, Ni and Pb were analyzed using spectrophotometer (HACH; DR/2400) in accordance with the standard method (APHA, 1998). After measuring laboratory parameters, the LPI was calculated using the Equations 6.1 and 6.2 stated earlier.

6.3.3 Significance and Assessment of Parameters Involved in LPI

The leachate parameters involved in LPI for the detection (A_1) and collection (A_2) system of open dump lysimeter-A as well as the collection system of sanitary lysimeter-B and C are presented in Table 6.4. The ranges were given for the minimum and maximum values, while the value of parenthesis indicates the mean values. Moreover, the significance, assessment and comparison of the evaluated leachate parameters involved in LPI were analyzed and discussed in followings.

Table 6.4: Concentration of relevant leachate parameters for evaluating LPI

Parameter	Operating condition of landfill lysimeter			
	A_1	A_2	B	C
pH	5.98-8.17 (6.77)	6.14-8.02 (7.25)	6.40-8.61 (7.42)	6.30-8.38 (7.48)
Chloride	970-3097 (2238)	1155-3572 (2395)	510-1870 (1086)	110-1810 (1181)
TDS	210-9930 (5720)	140-35810 (12507)	1800-29980 (9786)	420-26000 (13132)
TKN	195-1120 (594.52)	251-1430 (785.61)	480-2187 (1307.07)	312-1860 (1014.31)
NH ₄ -N	187-705 (428.50)	127.9-901.3 (547.57)	190-997 (653.26)	187-965.7 (598.34)
BOD ₅	83-6750 (2310.43)	143-20420 (5176.5)	437-12358 (3308.7)	490-16733 (4428.3)
COD	160-20800 (2498)	800-60000 (8425)	320-60000 (5654)	300-60000 (11137)
TCB	98-6540 (2468.70)	145-8398 (3101.33)	152-8200 (3065.52)	85-8230 (2895.89)
Fe	1.8-70 (19.5)	3.4-82.6 (24.2)	3.6-91 (27.9)	1.4-72 (6.3)
As	0.01-0.02 (0.01)	0.01-0.05 (0.03)	0.01-0.03 (0.01)	0.01-0.02 (0.01)
Zn	0.25-1.267 (0.76)	0.15-0.97 (0.54)	0.10-0.55 (0.31)	0.10-0.576 (0.2)
Cu	0.04-0.98 (0.44)	0.04-0.97 (0.34)	0.04-0.76 (0.20)	0.04-0.60 (0.18)
Cr	0.01-0.07 (0.05)	0.01-0.056 (0.04)	0.023-0.03 (0.06)	0.01-0.025 (0.04)
Pb	0.12-0.32 (0.20)	0.179-0.397 (0.3)	0.25-0.78 (0.44)	0.10-0.476 (0.3)
Ni	0.04-0.075 (0.05)	0.04-0.055 (0.05)	0.045-0.09 (0.07)	0.04-0.07 (0.05)

Note: TDS=total dissolve solid, TKN=total kjeldahl nitrogen, NH₄-N=ammonia nitrogen, BOD₅= biological oxygen demand, COD=chemical oxygen demand, TCB= total coliform bacteria, Fe=iron, As=arsenic, Zn=zinc, Cu=copper, Pb=lead and Ni=nickel. All values in mg/L, except pH and TCB ((cfu/100ml)). Range is given for the minimum and maximum values, while the value of parenthesis indicates the mean values.

6.3.3.1 pH

The pH in leachate is considered to be the most significant parameter affecting leachate concentration in MSW landfill (Bilgili et al., 2007). Qasim and Chiang (1994) suggested that increase of pH in leachate with time as a result of the decrease in the concentration of volatile fatty acids (VFA). Moreover, the increase in pH is due to onset of methanogenic activity as a result increase in methane gas production and decrease in hydrogen, carbon dioxide and VFA (Kim, 2005). Murphy et al. (1995) reported that pH in leachate <7.0, was in the acidic side of pH scale, but after in the scale of >7.0, waste leachate had alkaline pH. Moreover, a study conducted by Christensen et al. (2001) and observed that leachate is generally found to have pH between 4.5 and 9. Initial low pH is due to high concentration of VFAs (Bohdziewicz et al., 2008). Stabilized leachate shows fairly constant pH with little variations and it may range between 7.5 and 9. Kulikowska and Klimiuk (2008) and Tatsi et al. (2002) reported similar range of pH from old landfill sites, that is, 7.46–8.61 and 7.3–8.8, respectively.

The values of pH in leachate from lysimeter at varying operational condition were provided in Table 6.4. Result reveals that pH was ranging from 6.33 to 7.75 and 7.38 to 8.61 for the collection system (A_2) of open dump lysimeter-A and sanitary lysimeter-B, respectively, in

the first 100 day of entire lysimeter operation. After 100 day, pH began to increase and it was reached to 8 for the collection system (A₂) of open dump lysimeter-A. A study conducted by Abbas et al. (2009) and advocated that pH of young leachate is less than 6.5, while old landfill leachate has pH higher than 7.5. Moreover, consumption of volatile fatty acids (VFA's) in MSW, produced during the acid anaerobic phase, increases pH in between 7 and 8 Farquhar (1989). So, the range and increase of pH for the collection system of open dump lysimeter-A were agreed well with the postulation stated by Abbas et al. (2009) as well as Farquhar (1989). After that, no considerable changes were observed of pH in leachate and it was measured between 6 and 8. These results were also in accordance with the data stated by Cossu et al. (2003); Ishigaki et al. (2003) and Nakasaki et al. (1993). However, to depict the validity of the findings in this study then also compared with those results in case of open lysimeter (OL) and closed lysimeter (CL) postulated by Trankler et al. (2005) and Visvanathan et al. (2007). The values of pH for the collection system of sanitary lysimeter-B was higher than that of the collection system of open dump lysimeter-A and it was continued as well as similar trend was also observed for the same cases of lysimeter studied by Trankler et al. (2005) and Visvanathan et al. (2007).

6.3.3.2 Chlorides

Chloride in leachate is considered to be a very conservative anion that is only attenuated during dilution. Ehrig (1983) suggested that there is no observable difference of chloride between acidogenic and methanogenic phases of solid waste landfill. According to Deng and Englehardt (2007), the concentration of chlorides may range between 200 to 3000 mg/L for a 1-2 year old landfill and the concentration decreases to 100 to 400 for a landfill greater than 5-10 years old. The values of chloride in leachate from lysimeter at varying operational condition were provided in Table 6.4. Result reveals that collection system of lysimeter-A had the highest concentration of chloride than that of other lysimeter operational condition. Chu et al. (1994) reported that chloride concentration increases with the increasing age of waste fill. Its release is not controlled by factors such as pH (Komilis et al., 1999; Rafizul et al., 2009).

It can be noted that pH and Cl⁻ concentrations began to increase simultaneously in all the cases of sanitary lysimeter operation. This situation can be explained by the findings of

Manning and Robinson (1999). As a result of the increase in pH, the dissolution of chloride increases and thus the chloride concentration in the leachate increases. The values of pH and Cl^- concentrations increase at the same operation days of 100, and the findings are agreed well with the statement stated by Manning and Robinson (1999). Bowman et al. (2002) found chlorides as high as 8000 mg/L in Newington landfill leachate in Sydney. Because chlorides are usually not attenuated by soil and are extremely mobile under all conditions, they have a special significance as the tracer element of leachate plume linking the groundwater (Kumar and Alappat, 2005b).

6.3.3.3 TDS

TDS comprises mainly of inorganic salts and dissolved organics. TDS is one of the parameters taken into consideration for licensing discharge of landfill leachate in many countries such as the Koshy et al. (2008). The amount of TDS reflects the extent of mineralization and a higher TDS concentration can change the physical and chemical characteristics of the receiving water. The increase in salinity due to increase in TDS concentration also increases toxicity by changing the ionic composition of water. The values of TDS in leachate from lysimeter at varying operational condition were provided in Table 6.4. Based on observed results it can be depicted that the highest values of TDS of 9930, 33801, 29980 and 26000 mg/L were recorded for the detection and collection system of open dump lysimeter-A as well as the collection system of sanitary lysimeter-B and C and then it was dropped with the increasing of elapsed period. A study conducted by Yuen et al. (2001) and reported that TS concentration is expected to decrease as the leachate moves from acidogenic to methanogenic but the TDS concentrations do not change in large quantities as total solid. So, the decreasing trend of TDS in this study were agreed well with the statement given by Yuen et al. (2001). The solids joining with leachate at the later stage are the products of chemical and biological degradation. The concentration of TDS in leachate depends not only on elapsed period from the waste deposition but also the types, applicability and compactness of base and cap liner (Mollekopf et al., 2002; Diaz et al., 1996).

6.3.3.4 Nitrogen

The TKN is the sum of organic nitrogen (Organic-N) and $\text{NH}_4\text{-N}$ (APHA 1998). The $\text{NH}_4\text{-N}$ is representative of inorganic matter (Rafizul et al., 2012). The landfill lysimeter leachate

contains low concentration of organic nitrogen and very high concentration of $\text{NH}_4\text{-N}$ (60-90 % of TKN (Johansen and Carison, 1976; Lema et al., 1988). Moreover, according to Kulikowska and Klimiuk (2008) ammonium represents the major proportion of total nitrogen. Moreover, $\text{NH}_4\text{-N}$, the great majority of TKN (Lema et al., 1988), did not decreasing trend in concentration with time. The ammonia concentration released from waste by the decomposition of proteins and there is no mechanism for its degradation under Methanogenic condition. So, only leaching can decrease the $\text{NH}_4\text{-N}$ concentration (Kjeldsen et al., 2002).

In contrary, the concentration of TKN and $\text{NH}_4\text{-N}$ in leachate from lysimeter at varying operational condition were provided in Table 6.4. Result reveals that both the concentration of TKN and $\text{NH}_4\text{-N}$ in leachate of lysimeter at varying operational condition was decreased in relation to the increase of elapsed period of MSW deposition in lysimeter. A study conducted by Abbas et al. (2009) and reported that in comparison to soluble organics, the release of soluble nitrogen from waste into leachate continues over longer period. As a result the concentration of $\text{NH}_4\text{-N}$ decreases with the increase in age of the landfill which is due to hydrolysis and fermentation of nitrogenous fractions of biodegradable refuses substances. So, the findings are agreed well with the postulation given by Abbas et al. (2009).

According to Speece (1996) and Jokela et al. (2002) such a decrease of $\text{NH}_4\text{-N}$ could be attributed to the ammonium bicarbonate alkalinity, which in turn maintains a pH close to neutral in the anaerobic solid waste bioreactors. Moreover, the higher values of TKN and $\text{NH}_4\text{-N}$ were recorded for the collection system of sanitary lysimeter-B against the other counterparts i.e. sanitary lysimeter-C and open dump lysimeter-A (Table 6.4). The open dump lysimeter-A produces low TKN concentrations by reason of dilution of pollutant due to its top cover design enhance rainfall percolation and similar trend was also observed by Tubtimthai (2003). These findings were also supported by Van Velsen (1979) and he has reported that acclimation to high concentration of $\text{NH}_4\text{-N}$ was possible in sanitary (anaerobic) reactors. However, the maximum concentrations of TKN (1120, 1430, 2187 and 1860 mg/L) and $\text{NH}_4\text{-N}$ (705, 901.3, 997 and 965.7 mg/L) were recorded within the 90th day of lysimeter operation of detection and collection system of open dump lysimeter-A as well as the collection system of sanitary lysimeter-B and C, respectively. Chu et al. (1994) too have

reported that the $\text{NH}_4\text{-N}$ of landfill leachate ranged between 500 and 1500mg/L after a period of 3-8 years and will remain at this level at least for the next 50 years.

6.3.3.5 *BOD₅ and COD*

Jones et al. (2006) reported that in the initial acidogenic biodegradation stage, the leachate is characterized by high BOD_5 and COD. Young landfill leachate is characterized by high BOD_5 (4000–13,000 mg/L) and COD (30,000–60,000 mg/L) (Foo et al., 2009). According to Tatsi et al. (2002), young leachate may have BOD_5 as high as 81,000 mg/L. A much higher value of COD (70,900 mg/L) is reported in leachate obtained from the Thessaloniki Greater Area (Greece) by Tatsi et al. (2002). A decrease in BOD_5 and COD is often reported with the increase in age of the landfill. For stabilized leachates, COD generally ranges between 5000–20,000 mg/L (Li et al., 2002). The BOD_5/COD ratio provides a good estimate of the state of the leachate and this ration for young leachate is generally between 0.4-0.5 (Kurniawan et al., 2006). During the methanogenic phase, the organic strength of the leachate is reduced by methanogenic bacteria such as *methanogenic archaea* and the VFAs also declines which results in a ratio of BOD_5/COD less than 0.1 (Kurniawan et al., 2006; Rivas et al., 2004).

In contrary, the concentration of BOD_5 and COD in leachate from lysimeter at varying operational condition were provided in Table 6.4. The concentrations of BOD_5 and COD were initially about 20000 mg/L and 60000 mg/L, respectively, for the collection system of open dump lysimeter-A and it were dropped with the increase of elapsed period. Similay trend were also observed for other operational condition of landfill lysimeter-B (BOD_5 (12000 mg/L) and COD (60000 mg/L)) and C (BOD_5 (17000 mg/L) and COD (60000mg/L)). This high readings indicate that there are organic materials in the open dump lysimeter-A which are highly biodegradable (Mizanur et al., 1999). It was further supported by Chian and DeWalle (1976) and advocated that due to the initially biodegradable nature, organic compound decreases more rapidly than that of inorganic compound with increasing the age of landfill. A young landfill generates a leachate which has high BOD_5 and COD, but this strength decreases rapidly after a short period of time (i.e. around one year). For example, the concentration of BOD_5 and COD in the leachate at the age of 6 and 9 months is 10,000-20,000 mg/L and 20,000-40,000 mg/L, respectively while, the concentration of BOD_5 and COD in the leachate at the age of one and 1.5 years is 1,560-1,800 mg/L and 5370-7040

mg/L, respectively (Agamuthu, 2001; Curi et al., 1999). Moreover, the variation in leachate quality with age should be expected throughout most of the landfill life because organic matter will continue to undergo stabilization (Qasim and Chiang, 1994). A decrease of COD occurs over elapsed period of landfill and it can be attributed to a combination of reduction in organic contaminants and the increased biodegradation of organic compounds (Krug and Ham, 1995). A constant decrease in COD is also expected as degradation of organic matter continues (Ehrig, 1989).

6.3.3.6 Heavy Metals

The leachate from MSW landfills are highly contaminated and have higher concentration of organic and inorganic pollutants as well as toxic substances of metals (Kettunen et al., 1998). The main processes for the low metal concentrations in leachate are sorption and precipitation. The solubility of metals with sulfides and carbonates is low and sulfide precipitation is often cited as an explanation for low concentrations of heavy metal in leachate (Bozkurt et al., 1999). In general, the concentration of heavy metals in landfill leachate is fairly low (Christensen et al., 2001). The concentration of heavy metal viz Fe, As, Zn, Cu, Cr, Pb and Ni in leachate from lysimeter at varying operational condition were provided in Table 6.4. Result reveals that initially the concentration of heavy metal was high, but, it was started to decrease with the increasing of elapsed period.

Heavy metal in landfill lysimeter is generally higher at earlier stages because of higher metal solubility as a result of low pH caused by production of organic acids Kulikowska and Klimiuk (2008). 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 (Harmsen, 1983). A lower concentration of Ni (0.13mg/L), Zn (0.61 mg/L), Cu (0.07mg/L), Pb (0.07 mg/L), and Cr (0.08 mg/L) were found in 106 Danish landfills by Christensen et al. (2001) and Kjeldsen and Christophersen (2001). The high dissolved organic carbon (DOC) in leachate renders the metals nontoxic because only the free metals are known to exhibit toxicity (Vigneault et al., 2005; Koukal et al., 2003). However, the solubility and mobility of metals may increase in the presence of natural and synthetic complexing ligands such as EDTA and humic substances (Jones et al., 2006). Further, colloids have great affinity for heavy metals and a

significant but highly variable fraction of heavy metals is associated with colloidal matter (Christensen et al., 2001; Jensen and Christensen, 1999). According to Baun and Christensen (2004), 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. Jensen and Christensen (1999) found that 10–60% of Ni, 30–100% Cu and 0–95% Zn were constituted in colloidal fractions.

6.3.4 Interpretation of Parameters Involved in LPI

The leachate characteristics as well as the individual and overall LPI obtained for elapsed period of 14-900 day from MSW deposited in landfill lysimeter at different operational condition of leachate detection (A_1) and collection (A_2) system of open dump lysimeter-A as well as the collection system of sanitary lysimeter-B and C were evaluated. Calculation of LPI of some elapsed period was provided in Table C. 4-28 and also in Figure C.1 in the Appendix-C. Since the data for all the parameters required for LPI was not accessible, the LPI has been calculated on the basis of the available data. Results for 7 days provided in Table 6.5 depicts that concentration of Cr, BOD₅, As, Zn, TKN, Ni, TCB, TDS, Cu, chloride and Fe was higher for the collection system of lysimeter-A, while the collection system of sanitary lysimeter-B contains higher Pb, pH and NH₄-N. A significant difference between the individual and overall pollution ratings for both the collection system of open dump lysimeter-A and sanitary lysimeter-B was observed due to the distinct difference to their leachate concentrations. Here, it can be noted that concentration of leachate parameters involved in LPI for the detection (A_1) and collection (A_2) system of open dump lysimeter-A, differs and it implies the significance difference of individual and cumulative pollution ratings between these two lysimeter operating system. Moreover, the concentrations of As, Ni and Cu were fairly similar for both the collection system of sanitary lysimeter-B and C. Although these two lysimeter exhibited notable differences for Cr, BOD₅, Zn, TDS, chloride and Fe, but the influence of individual and cumulative polluting rating is insignificant.

The concentrations of Cr, COD, BOD₅, As, Zinc, TKN, Ni, TDS, Cu and chloride in leachate for the collection system of open dump lysimeter-A were higher than that of the collection system of sanitary lysimeter-C which resulted in significantly higher cumulative pollution

rating. However, comparatively the higher Cr, BOD₅, As, Zn, TKN, Ni, TCB, TDS, Cu, chloride and Fe significantly influenced the cumulative pollution ratings of collection (A₂) system of open dump lysimeter-A. Result reveals that difference of Cr, As, Zn, pH, Ni, Cu and Fe concentration was found to be significant but, their individual pollutant rating was insignificant for entire lysimeter operating system. As the individual pollution ratings of COD, TKN, NH₄-N, TDS and chloride were found to be lower for the detection (A₁) system of open dump lysimeter-A, the cumulative pollution rating of lysimeter-A was consequently lower. It can also be concluded that Cr, COD, BOD₅, TKN, TDS and Fe for the collection (A₂) system of sanitary lysimeter-A in case of 7 days elapsed period was more than 2.76, 2.65, 1.38, 2.16, 3.61 and 1.76 times higher than detection (A₁) system of lysimeter-A, and consequently the cumulative pollution rating for collection system was 1.35 times higher than detection system of lysimeter-A. Here, it can be noted that all the concentration except Zn, Cu and chloride in case of the detection (A₁) system of open dump lysimeter-A were found to be the lowest than that of the collection system of lysimeter-A, B and C and had the lowest individual and cumulative pollution rating as well as consequently the lower LPI (Table 6.5).

In contrary, reveals that concentration of leachate for 120 days elapsed period (Table C.10) in case of the collection (A₂) system of open dump lysimeter-A was found to be the highest and it implies the highest overall LPI than that of other operating system. All the concentrations in leachate except Cr, Zn, Ni, NH₄-N, Cu and Fe in case of the detection (A₁) system of open dump lysimeter-A has the lowest and it implies the lower individual, cumulative and overall LPI than that of other lysimeter operating system. It is important to note that Cr, Pb, Zn, pH, Cu and Fe differs significantly with each of lysimeter operating system, however, the difference of their individual pollutant rating was negligible. The Fe is varied widely to each other, but, their individual pollutant rating difference was fairly insignificant (Table C.10).

In contrast, the Table 6.10 reveals that concentration of leachate, individual and cumulative pollutant rating as well as the overall LPI was fairly same for the operating condition of landfill lysimeter. Here, it is important to note that concentration of pollutant parameter in leachate decreases with the increase of days after filling of MSW in lysimeter. Moreover, Table 6.10 depicts that leachate concentration at elapsed period 900 days was comparatively lower and which implies the lower LPI than the previous elapsed period.

Table 6.5 Calculation of LPI at 7 day after filling of MSW in landfill lysimeter

Pollutant variable	Variable weight, w_i	Pollutant concentration, c_i				Individual pollutant rating, p_i				Overall pollutant rating, $w_i p_i$			
		A ₁	A ₂	B	C	A ₁	A ₂	B	C	A ₁	A ₂	B	C
Chromium	0.064	0.076	0.21	0.17	0.09	5	5	5	5	0.32	0.32	0.32	0.32
Lead	0.063	0.41	0.55	0.92	0.65	7	7	9	8	0.441	0.441	0.567	0.504
COD	0.062	22650	60000	60000	56490	84	94	94	93	5.208	5.828	5.828	5.766
Mercury	-	-	-	-	-	-	-	-	-	-	-	-	-
BOD ₅	0.061	2080	2860	2790	2286	41	46	45	42	2.501	2.806	2.745	2.562
Arsenic	0.061	0.01	0.04	0.03	0.02	5	5	5	5	0.305	0.305	0.305	0.305
Cyanide	-	-	-	-	-	-	-	-	-	-	-	-	-
Phenol	-	-	-	-	-	-	-	-	-	-	-	-	-
Zinc	0.056	1.4	1.5	0.98	0.65	5.5	5	5	5	0.308	0.28	0.28	0.28
pH	0.055	6.87	7.87	7.92	7.38	6	5	5	6	0.33	0.275	0.275	0.33
TKN	0.053	1010	2180	1430	1340	33	78	50	45	1.749	4.134	2.65	2.385
Nickel	0.052	0.1	0.19	0.13	0.12	5	5	5	5	0.26	0.26	0.26	0.26
TCB	0.052	6540	8280	8200	8230	85	89	90	90	4.42	4.628	4.68	4.68
NH ₄ -N	0.051	705	897	997	920	77	95	99	97	3.927	4.845	5.049	4.947
TDS	0.05	9876	35670	29120	26580	21	83	69	63	1.05	4.15	3.45	3.15
Copper	0.05	1.3	1.6	1.1	1.2	7	7	7	7	0.35	0.35	0.35	0.35
Chlorides	0.049	3037.00	3572.00	1350.00	760.00	23	31	12	8	1.127	1.519	0.588	0.392
Total Iron	0.045	25.9	45.7	43.5	38.7	5.5	6	6	6	0.2475	0.27	0.27	0.27
Summation	0.824									22.54	30.41	27.62	26.50
Derived LPI										27.36	36.91	33.52	32.16

Note: COD=chemical oxygen demand, BOD₅= biological oxygen demand, TKN=total kjeldahl nitrogen, NH₄-N=ammonia nitrogen, TCB= total coliform bacteria and TDS=total dissolve solid. All concentrations are in mg/L, except pH and total coliform bacteria unit (cfu/100ml) and NA= Leachate concentration not available.

Table 6.6 Overall LPI in landfill lysimeter at varying operational condition

<i>Days after filling</i>	<i>Operating condition of landfill lysimeter</i>			
	A ₁	A ₂	B	C
7	27.36	36.91	33.52	32.16
14	26.48	36.13	34.04	32.37
21	26.31	35.72	33.96	30.71
30	28.78	32.13	32.12	32.85
40	25.29	30.30	29.20	29.19
50	17.26	31.23	32.99	31.22
60	19.70	30.75	27.87	30.06
70	25.05	30.61	28.75	29.25
90	21.69	28.55	24.63	30.07
120	17.03	29.02	24.36	26.08
140	24.23	30.22	28.18	28.54
160	22.40	27.34	24.00	24.47
190	24.67	29.72	28.17	28.30
220	24.23	29.27	28.05	28.36
245	18.33	25.70	22.31	24.83
280	24.04	28.71	26.78	27.60
300	17.89	24.07	22.61	25.41
320	23.29	28.40	26.60	27.48
380	16.80	23.20	20.39	24.52
390	14.74	20.63	17.75	18.79
400	14.69	20.53	17.43	18.54
415	14.15	20.53	17.31	18.17
500	15.41	22.25	22.64	22.61
520	14.81	22.02	18.72	21.00
545	17.19	24.10	21.30	18.54
580	17.25	20.59	18.51	19.99
610	14.33	20.73	19.22	20.36
630	18.47	19.48	19.61	17.87
660	13.86	20.06	17.48	19.48
715	17.18	18.24	18.18	14.54
750	16.72	17.64	17.15	12.94
800	13.36	17.39	14.66	16.32
850	16.37	15.27	16.03	12.61
900	14.52	13.82	13.79	12.07
Mean	19.53	25.33	23.48	23.74

6.3.5 Derived Leachate Pollution Index

The predicted values of *LPI* in relation to the variation of lysimeter operating system such as detection (A_1) and collection (A_2) system of open dump lysimeter-A as well as the collection system of sanitary lysimeter-B and C, at the elapsed period 7- 900 days after filling of MSW in lysimeter is provided in Table 6.6 and also in Figures 6.5 to 6.8. Figure depicted that derived *LPI* deduces from 27.36-14.52 , 36.91-13.82, 33.52-13.79 and 32.16-12.07, for the detection (A_1) and collection (A_2) system of open dump lysimeter-A as well as the collection system of sanitary lysimeter-B and C, at the elapsed period 7- 900 day after filling of MSW in lysimeter, correspondingly. At the elapsed period 7, collection (A_2) system of open dump lysimeter-A showed higher *LPI* (36.91) than the other counterparts that means detection (A_1) system of open dump lysimeter-A as well as the collection system of sanitary lysimeter-B and C (Figure 6.6). The highest *LPI* for the collection system of open dump lysimeter-A further indicates that MSW deposited in open dump lysimeter-A has not yet stabilized. This is also evident from the high BOD_5 and COD values. The standard concentration for the disposal of treated leachate to inland surface water as per the Management and Handling Rules (The Gazette of Government of India 2000) should not exceed 2.0, 0.1, 250, 0.01, 30, 0.20, 0.20, 1.0, 5.0, 5.5-9.0, 100, 3.0, 50.0, 2100, 3.0 and 1000 mg/L for Cr, Pb, COD, Hg, BOD_5 , As, CN, Phenol, Zn, pH, TKN, Ni, NH_3 -N, TDS, Cu and Cl^- , respectively and their corresponding overall *LPI* of 7.38. Moreover, the concentration of all the parameters of leachate in lysimeter-A, B and C, except Cr, Ni, Cu, pH and Zn exceed the permissible limits of treated leachate discharging into inland surface water (Table 6.2, Column 5). Here, it can be concluded that comparison of leachate characteristics with the standards set for the disposal of treated leachate verifies the fact that leachate generated from landfill lysimeter is highly contaminated and will have to be treated before discharge (so that the *LPI* comes below 7.38).

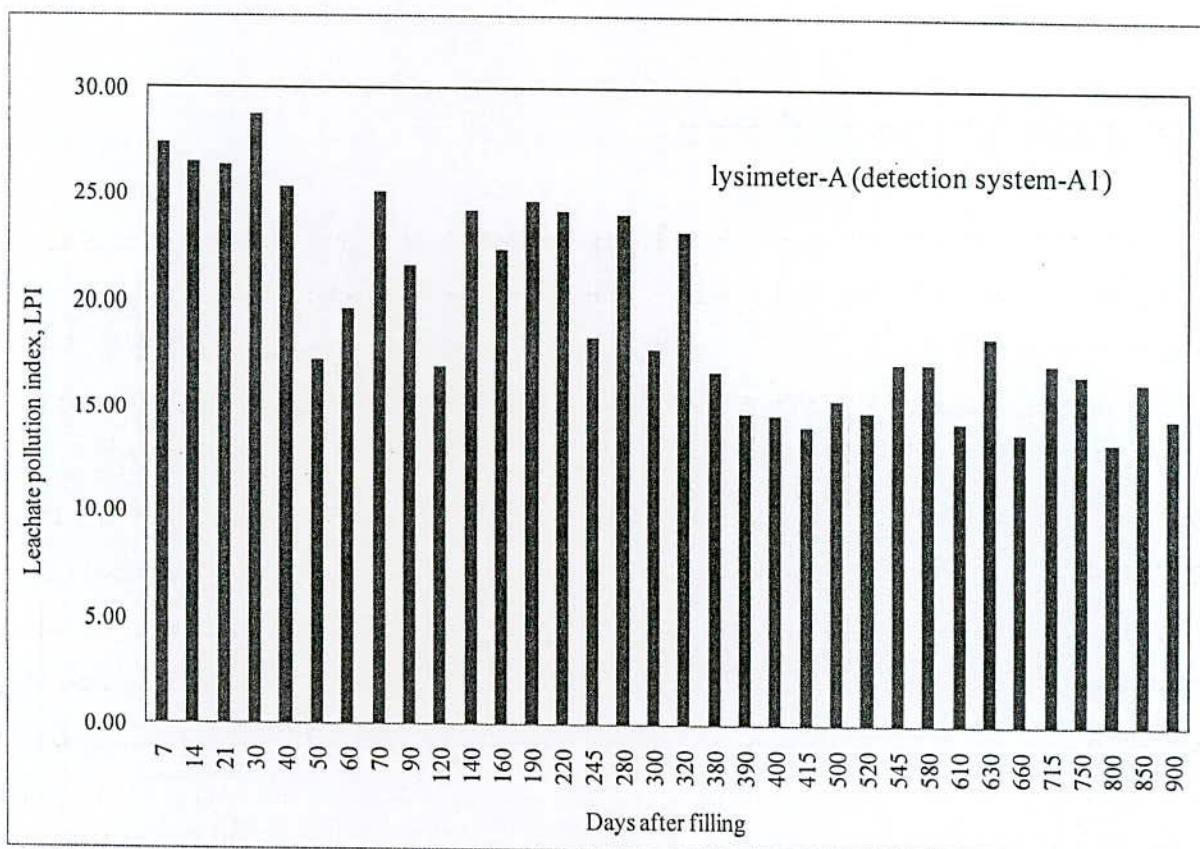


Figure 6.5: Overall LPI in detection system of open dump lysimeter-A

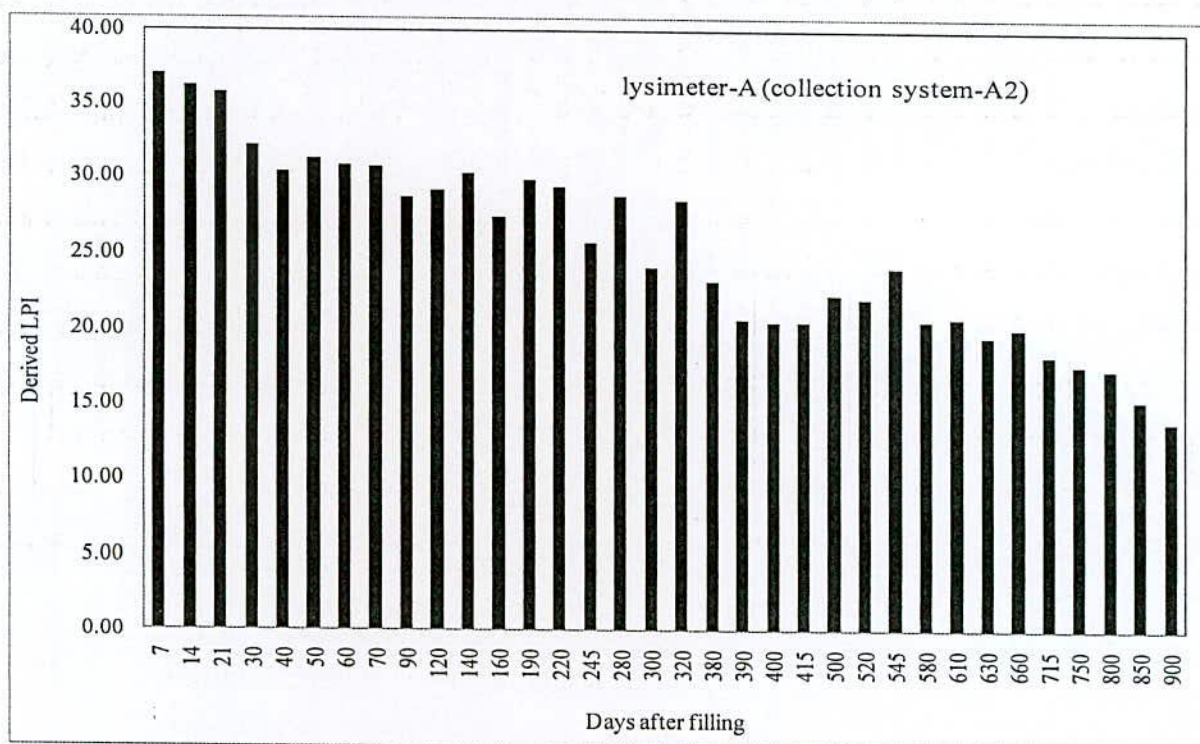


Figure 6.6: Overall LPI in collection system of open dump lysimeter-A

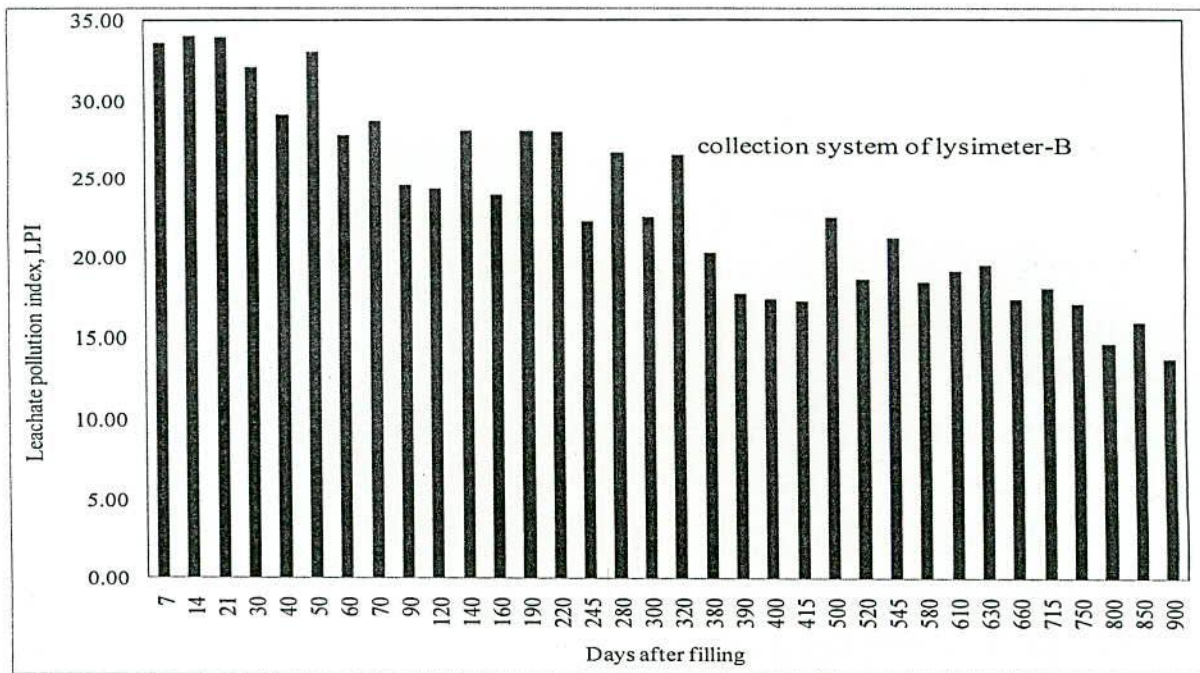


Figure 6.7: Overall LPI in collection system of sanitary lysimeter-B

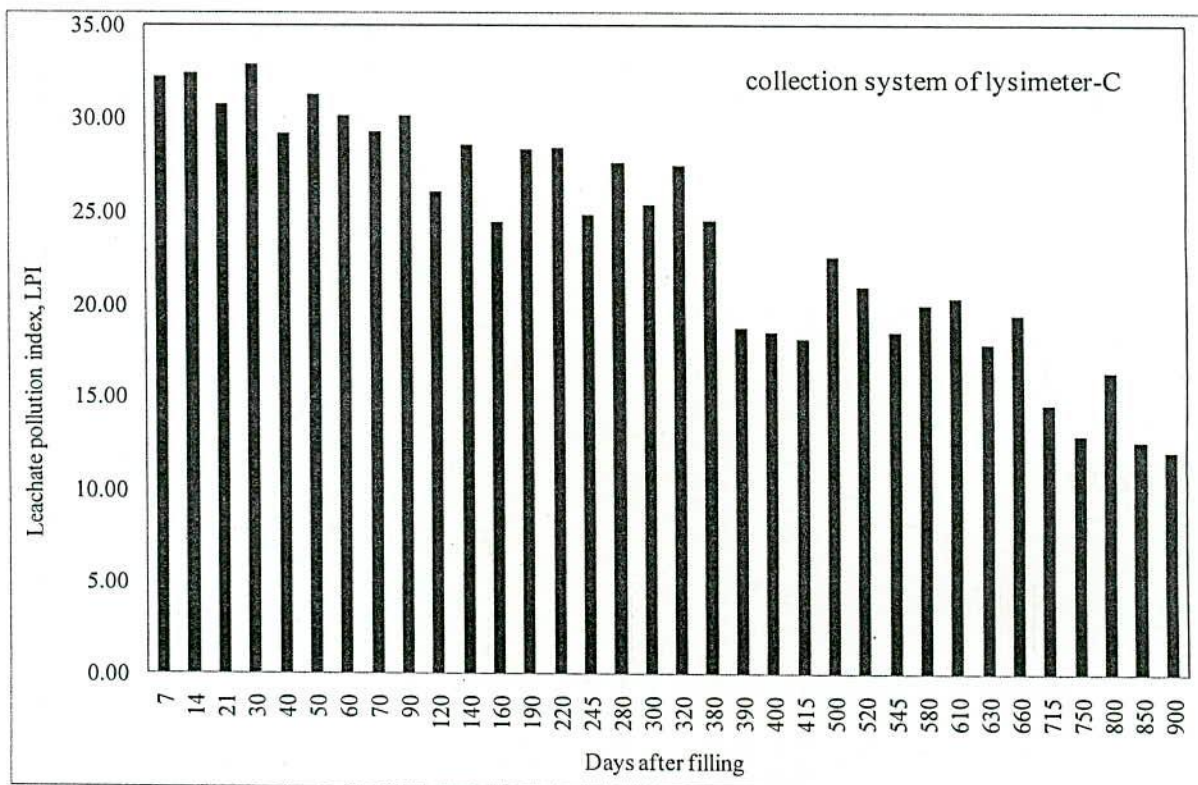


Figure 6.8: Overall LPI in collection system of sanitary lysimeter-C

Result revealed that leachate generated from entire landfill lysimeter is highly contaminated and *LPI* for all the operational condition of landfill lysimeter exceed the *LPI* (7.38) of treated leachate. The high *LPI* demands that leachate generated from the landfill lysimeter should be treated. Here, it is important to note that the decreasing of all the concentration of pollutant in leachate involved in *LPI* against the elapsed period implied the decreasing pattern of *LPI* at varying elapsed period for entire lysimeter operating system. The lowest *LPI* (13.36) at elapsed period 800 day, for the detection (A_1) system of open dump lysimeter-A indicates the relatively lower contamination potential. However, the individual contaminants shall meet the state discharge standards before discharge of leachate into any surface water body. Moreover, it can be depicted that comparatively the lowest *LPI* for the landfill lysimeter sites are attributable to low concentrations of heavy metals in the leachate. Landfill age also plays an important role in the leachate characteristics and hence, influences the *LPI* value (Lo, 1996).

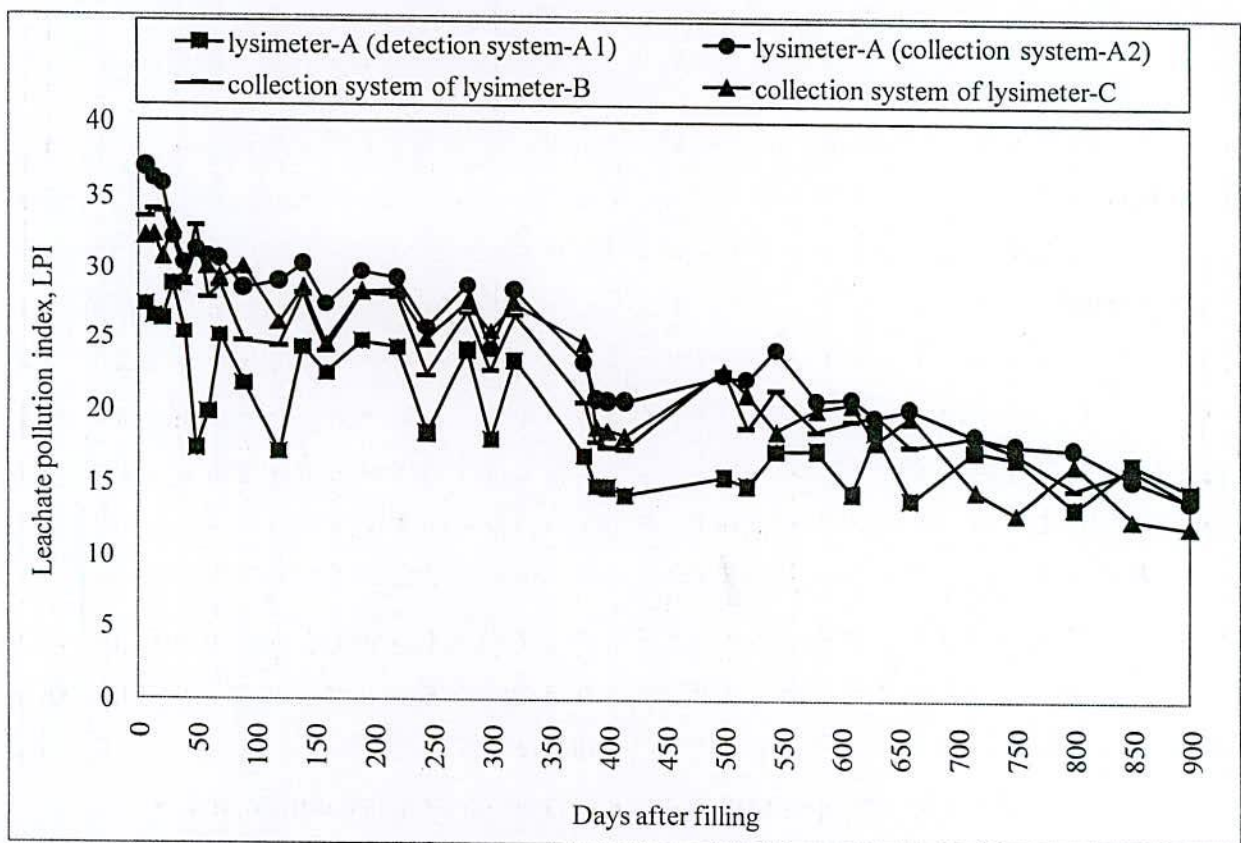


Figure 6.9: Variation of *LPI* with elapsed period of landfill lysimeter at varying operational condition

The decreasing trend of *LPI* at different operational condition of landfill lysimeter in relation to the increasing of days after filling of MSW is evident in Figure 6.9. It depicts that collection (A_2) system of open dump lysimeter-A had the highest *LPI*, while, lowest for the detection (A_1) system of lysimeter-A until the completion of this study and provided in Figure 6.9. Moreover, collection system of open dump lysimeter-A shows the highest individual and cumulative pollution rating and consequently the higher overall *LPI* because of the higher concentration of parameters in leachate (Figure 6.9). A researcher Truett (1975) advocated *LPI* is a planning index, specifically for decision-making, as one used by United States Environmental Protection Agency (USEPA) for planning MSW treatment project.

Moreover, Figure 6.9 also depicted that collection (A_2) system of lysimeter-A had the highest *LPI* because of the highest concentration of pollutant parameters in leachate which implied the highest individual and cumulative pollution rating and consequently the highest values of overall *LPI*. Here, it can be established that the variation of concentration of pollutant parameter in leachate in case of detection and collection system of open dump lysimeter-A may be occurred due to the providing of 400 mm thick CCL as a barrier between the detection and collection system of lysimeter-A. As the collection system (A_2) of open dump lysimeter-A was provided just below the MSW deposited in lysimeter-A and the followed detection system (A_1) was separated with the 400 mm thick CCL and this operational mode may be considered for the variation of pH between these two systems. So, it can be concluded that these distinct variation of concentration of pollutant parameter in leachate finally implies the varied *LPI* between these two system.

In contrary, the collection (A_2) system of open dump lysimeter-A showed higher *LPI* and it continued until the completion of this study against the counterpart i.e. the collection system of sanitary lysimeter-B and C provided in Figure 6.9. It is important to note that the decreasing of *LPI* with the increases of elapsed period happens due to the reduction of concentration of pollutant parameters involved in *LPI*. Moreover, Qasim and Chiang (1994) stated that variation of concentration of pollutant in MSW landfill leachate can be attributed to many interacting factors such as the composition and depth of MSW; decomposition and

age of MSW; degree of compaction; landfill design and operation; liner (top and base) design and operation; MSW filling procedures; the availability of moisture content; available oxygen; rate of water movement (fluid addition) and temperature. However, it can be established that the variation of leachate concentration for the collection system of lysimeter-A and B may be occurred due to the simulation behavior of open dumping and providing the base liner in open dump lysimeter-A as well as sanitary landfill and providing the cap liner in lysimeter-B. In contrast, the variation of leachate concentration for the collection system of sanitary lysimeter-B and C may be occurred due to the difference of landfill lysimeter-B and C in terms of thickness and compaction conditions of cap liner. So, it can be concluded that these distinct variation of concentration of pollutant parameter in leachate finally implies the varied individual, cumulative pollutant rating and the overall LPI.

Table 6.7 Weight factors of leachate parameters based on *sub-LPI* (after Kumar and Alappat, 2004)

Index	Parameters	Weight factor
LPI _{organic} (LPI _{or})	Chemical oxygen demand (COD)	0.267
	Biological oxygen demand (BOD ₅)	0.263
	Phenol compound	0.246
	Total coliform bacteria (TCB)	0.224
	<i>Summation</i>	1.000
LPI _{inorganic} (LPI _{in})	pH	0.214
	Total kjeldahl nitrogen (TKN)	0.2060
	Ammonia nitrogen (NH ₄ -N)	0.198
	Total dissolved solid (TDS)	0.195
	Chloride (Cl ⁻)	0.187
	<i>Summation</i>	1.000
LPI _{heavy metal} (LPI _{hm})	Total chromium (Cr)	0.125
	Lead (Pb)	0.123
	Mercury (Hg)	0.121
	Arsenic	0.119
	Cyanide	0.114
	Zinc (Zn)	0.11
	Nickel (Ni)	0.102
	Copper (Cu)	0.098
	Total iron (Fe)	0.088
	<i>Summation</i>	1.000

6.4 Formulation of Sub-Pollution Indices

The principal concern of this article is to formulate the sub-pollution indices (sub-LPIs) and evaluate the individual and overall leachate pollutant index (LPI) of landfill lysimeter at KUET campus, Bangladesh. To these endeavors, leachate samples from collection chamber of landfill lysimeter were sampling and the relevant parameters required for evaluating sub-LPIs and overall LPI were measured and monitored in the laboratory. Three sub-LPIs in terms of LPI in organic pollutant (LPI_{or}), LPI in inorganic pollutant (LPI_{in}) and LPI in heavy metal (LPI_{hm}) as well as overall LPI had been developed. After measuring the laboratory parameters, the sub-LPI was calculated using the Equation 3. For calculating sub-pollution indices (sub-LPI) and overall LPI, the following steps were followed:

1. The concentration of fifteen (15) leachate parameters were measured at a regular interval of time up to the elapsed period 900 days. Moreover, the concentration of leachate at elapsed period 7 days is provided in *Table 6.8, column 4*. Moreover, the sub-LPI for all the study period was stated in the Tables C. 29-47 in the Appendix-C.
2. Then evaluating sub-index scores (pi) of all the pollutants based on variables rating curves with respect to their concentration (*Table 6.8, column 5*).
3. The sub-pollution indices in terms of LPI_{or} , LPI_{in} and LPI_{hm} were calculated using the weight factors given in *Table 6.7* based on the aggregation function from Equation (6.2) (*Table 6.8, column 6*). The calculated values of LPI_{or} , LPI_{in} and LPI_{hm} for entire lysimeter operational period provided in in the Appendix-C.
4. Finally, the aggregation of the three sub-LPIs gets the overall LPI. The three sub-LPI values are aggregated to calculate the overall LPI using following Equation (6.3) provided in in the Appendix-C

$$LPI = (0.175LPI_{or} + 0.257LPI_{in} + 0.391LPI_{hm}) / 0.823 \quad (6.3)$$

It can be noted that Equation 3 has been derived based on the weight factors of pollutants included overall LPI and their contribution to each sub-LPI. However, the component of organic, inorganic and heavy metal is 17.5, 25.7 and 39.10 % for evaluating overall LPI and used to derive the Equation 6.3.

Table 6.8 illustrates the calculation of sub-LPI and overall LPI for a particular elapsed period of 7 days of leachate sampling. The detection (A_1) and collection (A_2) system of open dump lysimeter-A as well as the collection system of sanitary lysimeter-B and C had the highest component of organic fraction against the other counter fraction i.e. inorganic and heavy metal fraction (Table 6.7). Consequently, all the lysimeter operating system shows the highest LPI_{or} than that of LPI_{in} and LPI_{hm} provided in Figure 6.10. Moreover, Table 6.8 reveals that organic fraction for A_2 system of lysimeter-A was highest and consequently the highest LPI_{or} than the other operating system provided in Figure 6.11.

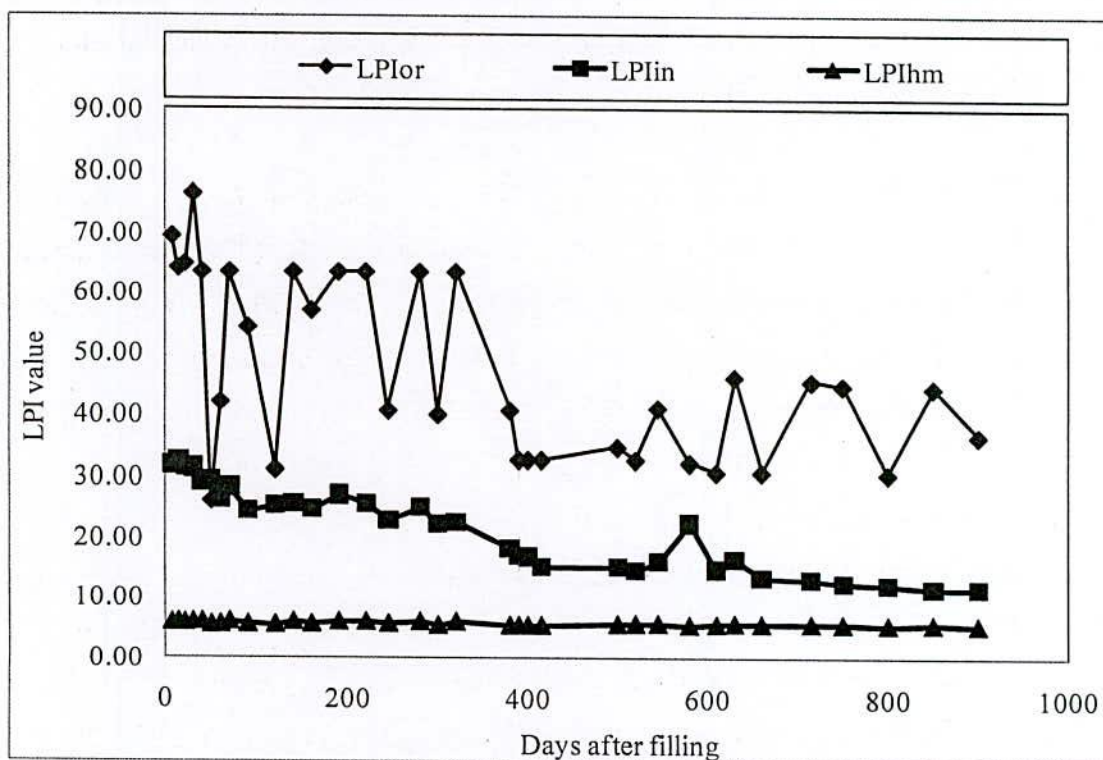


Figure 6.10: Sub-pollution indices of landfill lysimeter

Table 6.8 shows that values of BOD_5 , TKN, TCB, TDS, chloride, Cr, As, Zn, Ni, Cu and Fe was highest and consequently the highest individual and overall LPI for collection (A_2) system of lysimeter-A. A significant difference between individual and cumulative pollution ratings for both the collection system of open dump lysimeter-A and sanitary lysimeter-C was observed due to the distinct difference in their concentrations (Table 6.8).

Table 6.8 Characteristics of leachate, sub-*LPI* and overall *LPI* lysimeter at period 7 day

Index (1)	Parameter (2)	Weight factor, w_i (3)	Pollutant concentration, c_i (4)				Individual pollutant rating, p_i (5)				Overall pollutant rating, $w_i p_i$ (6)			
			A_1	A_2	B	C	A_1	A_2	B	C	A_1	A_2	B	C
<i>LPI_{or}</i>	COD	0.267	22650	60000	60000	56490	84	94	94	93	22.43	25.10	25.10	24.83
	BOD ₅	0.263	2080	2860	2790	2286	41	46	45	42	10.78	12.10	11.84	11.05
	Phenol	-	-	-	-	-	-	-	-	-	-	-	-	-
	TCB	0.224	6540	8280	8200	8230	85	89	90	90	19.04	19.94	20.16	20.16
	Total	0.754									52.25	57.13	57.09	56.04
<i>LPI</i>											69.30	75.77	75.72	74.32
<i>LPI_{in}</i>	pH	0.214	6.87	7.87	7.92	7.38	6.0	5.0	5.0	6.0	1.28	1.07	1.07	1.28
	TKN	0.206	1010	2180	1430	1340	33	78	50	45	6.80	16.07	10.30	9.27
	NH ₄ -N	0.198	705	897	997	920	77	95	99	97	15.25	18.81	19.60	19.21
	TDS	0.195	9876	35670	29120	26580	21	83	69	63	4.10	16.19	13.46	12.29
	Cl ⁻	0.187	3037	3572	1350	760	23	31	12	8	4.30	5.80	2.24	1.50
	Total	1.000									31.72	57.93	46.67	43.54
<i>LPI</i>											31.72	57.93	46.67	43.54
<i>LPI_{hm}</i>	Cr	0.125	0.08	0.21	0.17	0.09	5.0	5.0	5.0	5.0	0.63	0.63	0.63	0.63
	Pb	0.123	0.41	0.55	0.92	0.65	7.0	7.0	9.0	8.0	0.86	0.86	1.11	0.98
	Hg	-	-	-	-	-	-	-	-	-	-	-	-	-
	As	0.119	0.01	0.04	0.03	0.02	5.0	5.0	5.0	5.0	0.60	0.60	0.60	0.60
	Cn	-	-	-	-	-	-	-	-	-	-	-	-	-
	Zn	0.11	1.40	1.50	0.98	0.65	5.5	5.0	5.0	5.0	0.61	0.55	0.55	0.55
	Ni	0.102	0.10	0.19	0.13	0.12	5.0	5.0	5.0	5.0	0.51	0.51	0.51	0.51
	Cu	0.098	1.30	1.60	1.10	1.20	7.0	7.0	7.0	7.0	0.69	0.69	0.69	0.69
	Fe	0.088	25.90	45.70	43.50	38.70	5.5	6.0	6.0	6.0	0.48	0.53	0.53	0.53
	Total	0.765									4.37	4.36	4.60	4
<i>LPI</i>											5.71	5.69	6.01	5.85
<i>LPI</i>			$(0.175LPI_{or} + 0.257LPI_{in} + 0.391LPI_{hm}) / 0.823$								27.35	36.91	33.53	32.18

All the concentrations except Cl^- , Zn and Cu were lower for the A_1 system of lysimeter-A than that of collection system of lysimeter-A, B and C and has lowest individual and cumulative pollution rating and consequently lower LPI shown in Figure 6.12. Here, it can be established that variation of leachate concentration for A_1 and A_2 system may be occurred due to the providing of 400 mm thick CCL as a barrier between the detection and collection system of lysimeter-A. As the A_2 system of lysimeter-A was provided just below the MSW deposited in lysimeter-A and the followed A_1 was separated with the 400 mm thick CCL and this operational mode may be considered for the variation of leachate concentration. Moreover, the variation for the collection system of lysimeter-A and B may be occurred due to the simulation behaviour of open dumping and providing the base liner in open dump lysimeter-A as well as sanitary landfill and providing the cap liner in lysimeter-B. In contrary, the variation of leachate concentration (Table 6.8) for collection system of sanitary lysimeter-B and C may be occurred due to difference of lysimeter-B and C in terms of thickness and compaction conditions of cap liner.

The LPI of A_2 system of lysimeter-A is slightly higher than the collection system of lysimeter-C but both these lysimeters have higher LPI than the collection system of lysimeter-B (Figure 6.13). This can be ascribed to the lower individual pollution ratings of A_1 system of lysimeter-A due to the relatively lower concentrations of all the pollutants except Cl^- , Zn and Cu. Here, it of interested to note that *LPI* has decreased in relation to the increasing of elapsed period provided in Figure 6.12. The overall LPI was higher for A_2 system of lysimeter-A because of the higher concentration of pollutant has the highest individual and cumulative pollution rating and consequently the higher LPI than the other operational system. Here, it is important to note that standards for the disposal of treated leachate to water as per the Management and Handling Rules (The Gazette of India 2000) should not exceed 2.0, 0.1, 250, 0.01, 30, 0.20, 0.20, 1.0, 5.0, 5.5-9.0, 100, 3.0, 50.0, 2100, 3.0 and 1000 for Cr, Pb, COD, Hg, BOD_5 , As, Cn, Phenol, Zn, pH, TKN, Ni, $\text{NH}_3\text{-N}$, TDS, Cu and Cl^- concentration and their corresponding overall *LPI* of 7.38. The comparison of leachate characteristics with the standards for the disposal of treated leachate verifies the fact that the leachate generated from A_2 system of lysimeter-A is highly contaminated and *LPI* for entire lysimeter operating system exceed the *LPI* of treated leachate of 7.38. The high *LPI* demands that leachate generated from landfill lysimeter should be treated.

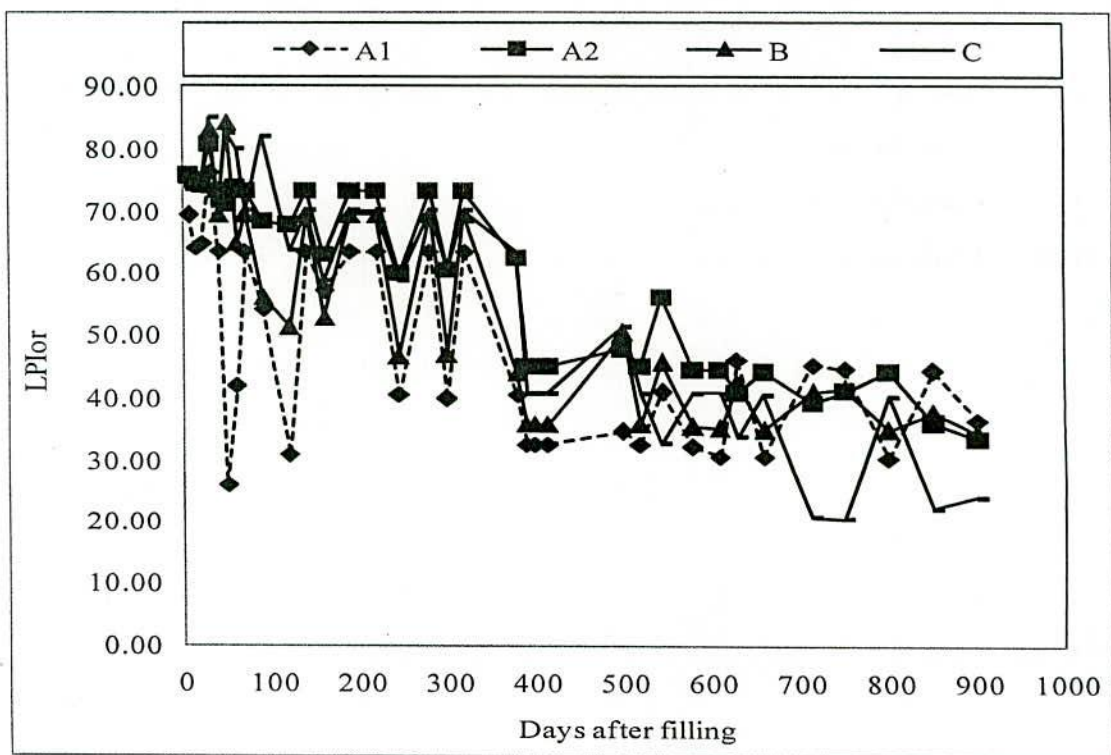


Figure 6.11: LPI in organic pollutant of open dump and sanitary lysimeter

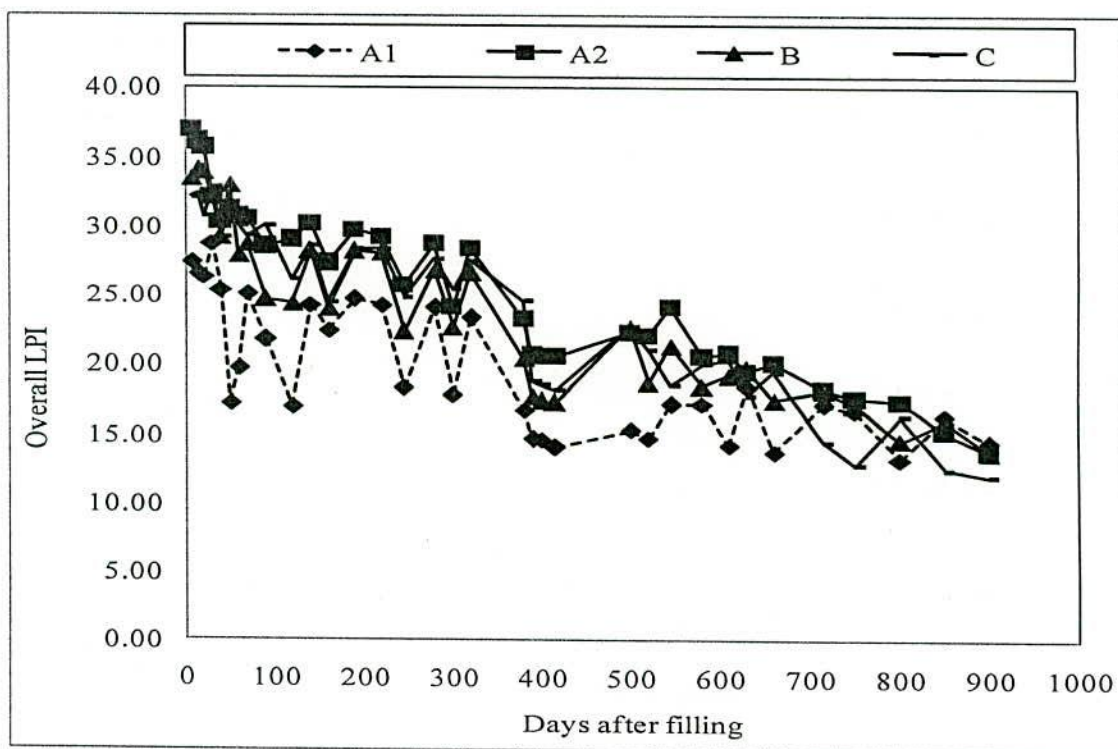


Figure 6.12: Overall LPI of open dump and sanitary lysimeter.

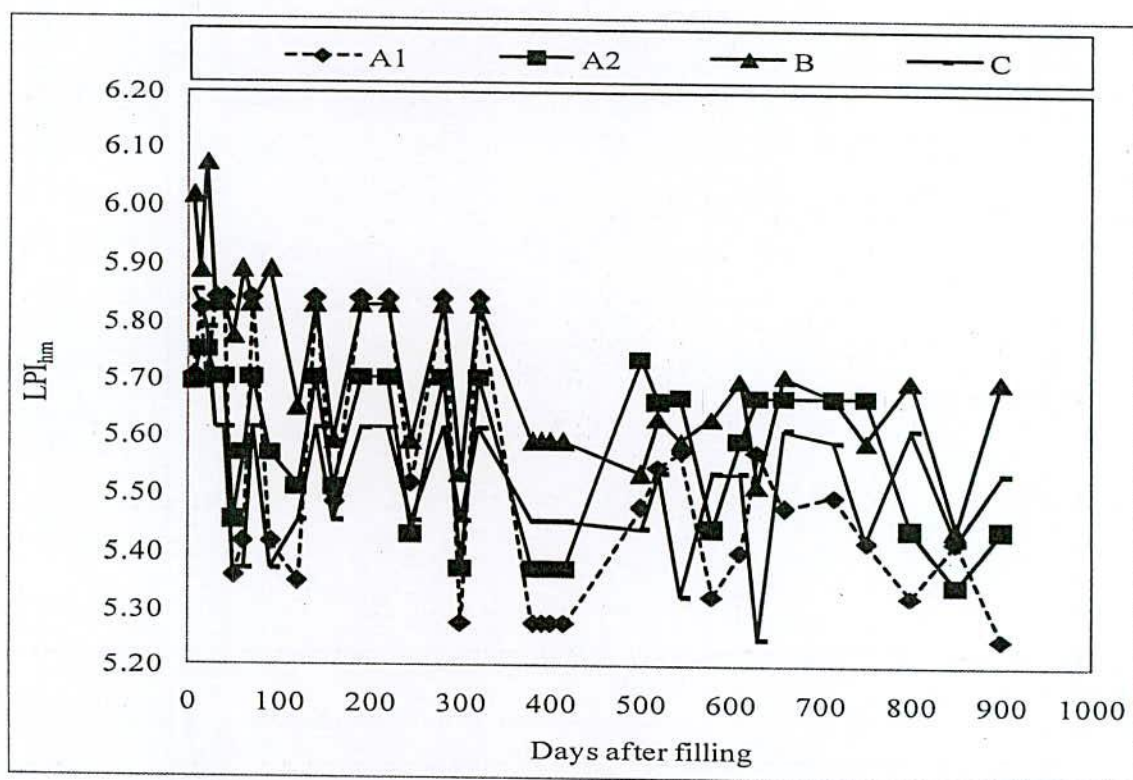


Figure 6.13: LPI in heavy metal of open dump and sanitary lysimeter

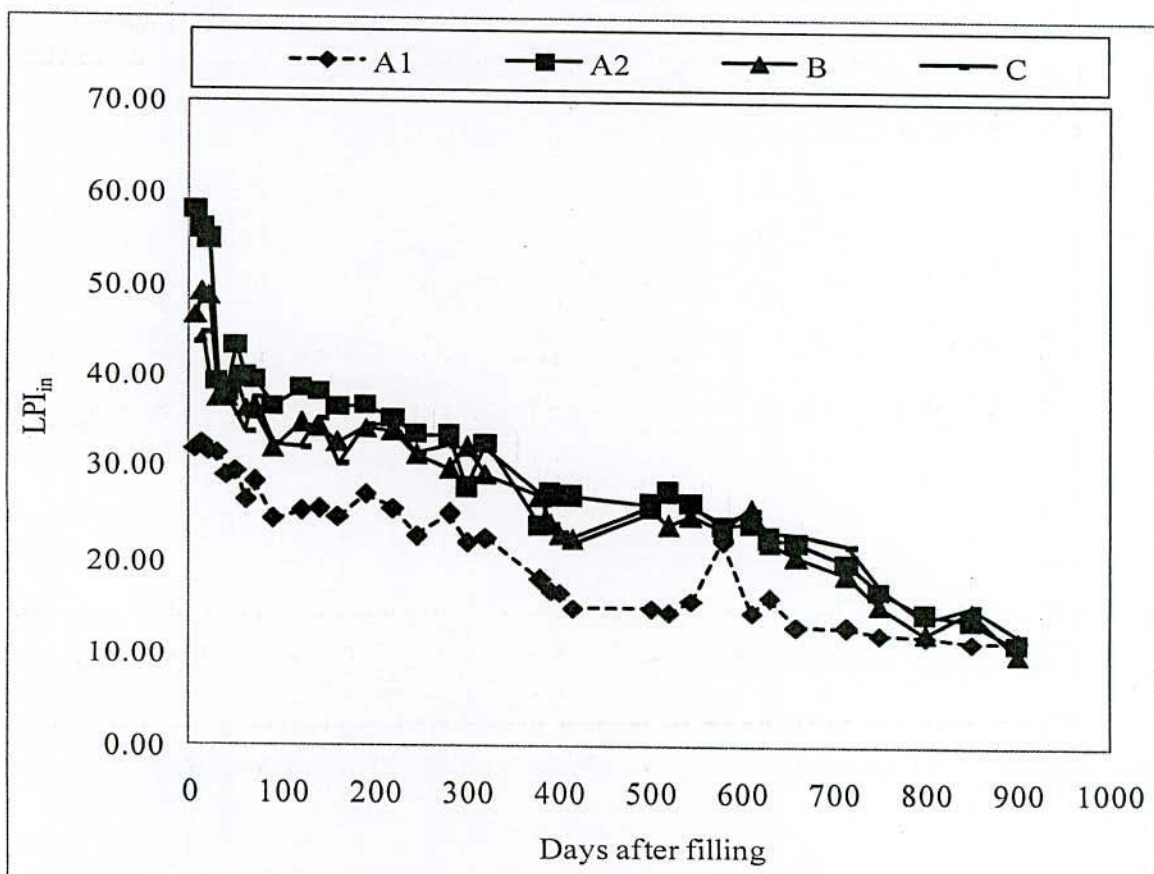


Figure 6.14: LPI in inorganic pollutant of open dump and sanitary lysimeter

Moreover, it can be depicted that the comparatively lower LPI_{hm} for entire lysimeter operating system (Figure 6.10) are attributable to low concentrations of heavy metals in leachate (Table 6.13). Moreover, due to the lower concentration of heavy metal for the A_1 system of lysimeter-A, consequently shows the lowest LPI_{in} provided in Figure 6.13. In contrary, comparatively the higher inorganic compound than heavy metal implies the highest LPI_{in} than that of LPI_{hm} (Table 6.13). Moreover, comparatively the higher inorganic compound implies the highest LPI_{in} for the A_2 system of lysimeter-A shown in Figure 6.14.

6.5 Comparison of Derived LPI of Landfill Lysimeter with Published Results

The comparison of mean LPI values of lysimeter at four distinct operational condition of detection (A_1) and collection (A_2) system of open dump lysimeter-A as well as the collection system of sanitary lysimeter-B and C with the published results available in the literature for the same cases is provided in Figure 6.15. In the present study the evaluated mean LPI values were found 19.53, 25.33, 23.48 and 23.74 for the detection (A_1) and collection (A_2) system of open dump lysimeter-A as well as the collection system of sanitary lysimeter-B and C, respectively. Moreover, a study conducted by Umar et al. (2010) for calculating LPI on four selected solid waste disposal sites in Malaysia named Pulau Burung landfills (PBLs) (sanitary landfill level III through leachate recirculation and controlled tipping), Ampang Jajar Landfill Site (AJLS) (semiaerobic closed landfill having no base liner), Kuala Sepetang Landfill Site (KSLS) (improved anaerobic landfill, natural marine clay and local soil are used as cover material for dumped waste with leachate collection pond) and Kulim Landfill Site (KLS). The derived LPI was found 23.45, 16.44, 21.77 and 19.50 for PBLs, AJLS, KSLS and KLS disposal sites, respectively. On the other hand, Kumar and Alappat (2003b) selected Okhla Sanitary landfill (OSL), New Delhi (no base liner or leachate collection and treatment systems) solid waste disposal site as a case study for calculating LPI and it was found 42.18. In addition, a study conducted by Kumar and Alappat (2005a) and selected four landfill named Ma Tso Lung (MTL) and Nagu Chi Wan (NCW) closed landfill sites as well as Pillar Point (PP) and Shuen Wan (SW) active landfill sites in Hong Kong for calculating LPI and it was found 45.01, 15.97, 36.48 and 39.04, respectively. Figure 6.15 depicts that the collection (A_2) system of open dump lysimeter-A showed higher LPI value than that of other lysimeter

operational condition. Here, it can be concluded that among the selected disposal sites, four landfill of OSL, MLT, PP and SW having more LPI due to their operational configuration than that of present lysimeter studies. Because the present study is a pilot scale laboratory experiment.

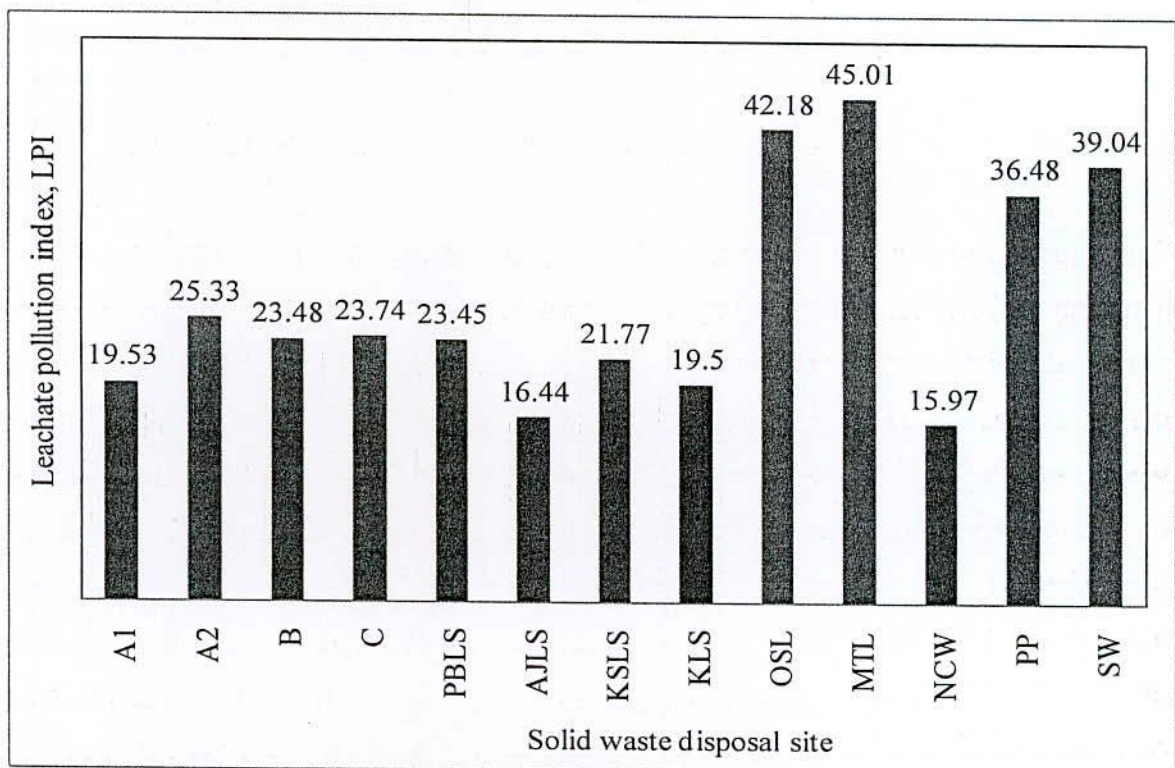


Figure 6.15: Comparison of the leachate contamination potential of Landfill lysimeter with the other researchers

6.6 Errors Involved in the Estimation of LPI Due to Nonavailability of Parameter

LPI is an environmental index and it is based on the concentration of 18 pollutants of the leachate and their corresponding significance. That means, for calculating the LPI of a landfill, concentration of these 18 parameters are to be known. However, sometimes the data for all the 18 pollutants included in the LPI may not be available to calculate the LPI. In this study, the possible errors involved in calculating the LPI due to the nonavailability of data were analyzed and described. To assess the errors involved in calculating LPI due to nonavailability of leachate data, a case study is taken up. Leachate samples from landfill

lysimeter at KUET campus, Bangladesh were collected and analyzed in the laboratory and the concentration of pollutant parameters in leachate is provided in Table 6.9, to evaluate the error involved in calculation of LPI due to nonavailability of data. Based on this study, it can be concluded that the errors may be high if the data for the pollutants having significantly high or low concentration are not available. However, LPI can be reported with a marginal error if the concentrations of the nonavailable pollutants are not completely biased.

Table 6.9 Concentration of pollutant parameters in leachate of landfill lysimeter

SL ⁽¹⁾	Leachate pollutant ⁽²⁾	Concentration* ⁽³⁾	Sub-index value (p _i) ⁽⁴⁾
1	Total chromium (Cr)	1.75	6.5
2	Lead (Pb)	0.68	9
3	Chemical oxygen demand (COD)	8425	70
4	Mercury (Hg)	0.4	59
5	Biochemical oxygen demand (BOD ₅)	1398	35
6	Arsenic (As)	0.01	5.5
7	Cyanide (Cn)	1.3	10
8	Phenol compounds	4	8.5
9	Zinc (Zn)	1.3	5
10	pH	7.3	6
11	Total kjeldhal nitrogen (TKN)	3000	98
12	Nickel (Ni)	0.23	8
13	Total coliform bacteria (TCB)	8000	92
14	Ammonia nitrogen (NH ₄ -N)	1300	100
15	Total dissolved solid (TDS)	12540	28
16	Copper (Cu)	0.98	7
17	Chlorides (Cl ⁻)	3597	30
18	Total Iron (Fe)	82	9.5

*All values in mg/L except pH and total coliform unit (cfu/100ml). * Average of 4 samples were taken between 1st September to 1st November 2011.*

To estimate the possible errors involved in calculating LPI, due to the nonavailability of leachate data, two approaches have been made as (1) Ignoring pollutant data based on weight factor and (2) Ignoring pollutant data based on sub-index value. The sub-index values of all the parameters in leachate based on their concentrations were evaluated reported in Table 6.9. The subindexes have been derived from the subindex curves for all the parameters reported by Kumar and Alappat (2003a). LPI based on these sub-index values has been calculated using Equation (6.1) and provided in the fifth column, Table 6.10. The LPI calculated based on these 18 parameters is considered to be the true LPI value.

6.6.1 Errors Introduced by Ignoring Pollutant Data Based on Weight Factor

In this approach, two options were discussed. In the first option, the data of the pollutants having low weight factors was ignored and in the second option, the data of the pollutants with high weight factors were assumed to be not available.

6.6.1.1 Removing Pollutants with Low Weight Factors

1. In the first step, the concentration of the total iron, the parameter having lowest weight, is presumed to be unknown. Hence, by deleting the subindex value of total iron, the LPI value is derived by using Eq. (6.2). The derived LPI value is reported in the sixth column, Table 6.10.
2. In the next step, the concentration of chlorides, the parameter having second lowest weight, is also presumed to be unknown in addition to the concentration of total iron. Again using Eq. (6.2), the LPI of the data set with 16 parameters is calculated and reported in the seventh column, Table 6.10.
3. In a similar fashion, it is presumed that the copper, total dissolved solids, ammonia nitrogen, total coliform bacteria, nickel, total kjeldhal nitrogen, pH, and zinc are also not known one by one in addition to the earlier unknown concentrations of parameters. The derived LPI considering concentration of 15, 14, 13, 12, 11, 10, 9, 8, 7, 6, 5 and 4 parameters are calculated and reported in columns 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18 and 19 of Table 6.9, respectively.
4. The percentage error introduced calculating LPI with respect to the LPI when data are available for all 18 leachate pollutants, is also reported in the last row of respective columns of Table 6.10.
5. The variation in LPI values with respect to the number of parameters considered in calculating LPI is provided in Figure 6.16. It also gives the percentage error introduced in calculating LPI values with respect to the number of parameters considered.

Table 6.10 Estimating errors involved in calculating LPI values due to nonavailability of data (Parameters with low weight factors ignored)

Pollutant	Pollutant weight, w_i	Pollutant concentration, C_i	Subindex value, P_i	LPI with selected parameters ($w_i P_i$)														
				18	17	16	15	14	13	12	11	10	9	8	7	6	5	4
Cr	0.064	1.75	6.5	0.416	0.416	0.416	0.416	0.416	0.416	0.416	0.416	0.416	0.416	0.416	0.416	0.416	0.416	0.416
Pb	0.063	0.68	9	0.567	0.567	0.567	0.567	0.567	0.567	0.567	0.567	0.567	0.567	0.567	0.567	0.567	0.567	0.567
COD	0.062	8425	70	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34
Hg	0.062	0.4	59	3.658	3.658	3.658	3.658	3.658	3.658	3.658	3.658	3.658	3.658	3.658	3.658	3.658	3.658	3.658
BOD ₅	0.061	1398	35	2.135	2.135	2.135	2.135	2.135	2.135	2.135	2.135	2.135	2.135	2.135	2.135	2.135	2.135	-
As	0.061	0.01	5.5	0.3355	0.3355	0.3355	0.3355	0.3355	0.3355	0.3355	0.3355	0.3355	0.3355	0.3355	0.3355	0.3355	-	-
Cu	0.058	1.3	10	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	-	-	-
Phenol	0.057	4	8.5	0.4845	0.4845	0.4845	0.4845	0.4845	0.4845	0.4845	0.4845	0.4845	0.4845	0.4845	-	-	-	-
Zn	0.056	1.3	5	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	-	-	-	-	-
pH	0.055	7.3	6	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	-	-	-	-	-	-
TKN	0.053	3000	98	5.194	5.194	5.194	5.194	5.194	5.194	5.194	5.194	-	-	-	-	-	-	-
Ni	0.052	0.23	8	0.416	0.416	0.416	0.416	0.416	0.416	0.416	-	-	-	-	-	-	-	-
TCB	0.052	8000	92	4.784	4.784	4.784	4.784	4.784	4.784	-	-	-	-	-	-	-	-	-
NH ₄ N	0.051	1300	100	5.1	5.1	5.1	5.1	5.1	-	-	-	-	-	-	-	-	-	-
TDS	0.05	12540	28	1.4	1.4	1.4	1.4	-	-	-	-	-	-	-	-	-	-	-
Cu	0.05	0.98	7	0.35	0.35	0.35	-	-	-	-	-	-	-	-	-	-	-	-
Chloride	0.048	3597	30	1.44	1.44	-	-	-	-	-	-	-	-	-	-	-	-	-
Iron	0.045	82	9.5	0.4275	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Summation	1.000			32.238	31.810	30.370	30.020	28.620	23.520	18.736	18.320	13.126	12.796	12.516	12.032	11.452	11.116	8.981
Total weight				1.000	0.955	0.907	0.857	0.807	0.756	0.704	0.652	0.599	0.544	0.488	0.431	0.373	0.312	0.251
Derived LPI				32.238	33.309	33.484	35.029	35.465	31.111	26.614	28.098	21.913	23.522	25.648	27.915	30.701	35.628	35.78
Percent error				0.000	3.323	3.867	8.660	10.011	3.494	17.445	12.840	32.026	27.035	20.442	13.407	4.766	10.518	10.99

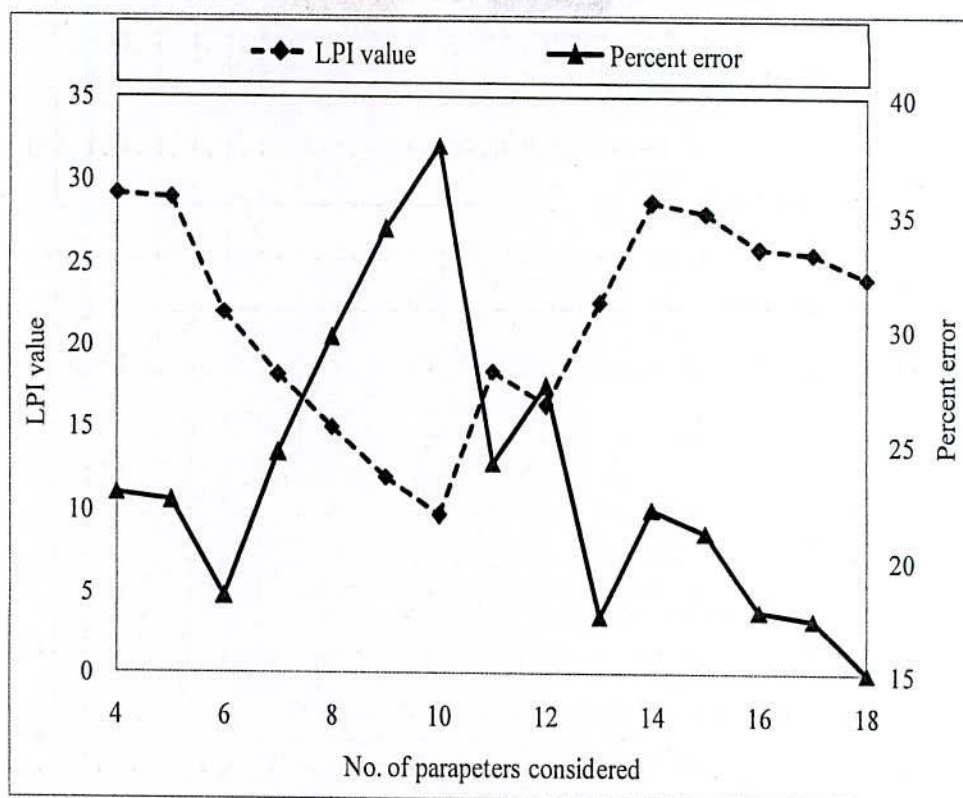


Figure 6.16 Variation of LPI and percent error when low weight parameters are ignored

6.6.1.2 Removing Pollutants with High Weight Factors

A similar procedure was followed here starting with the parameter having the highest weight factor. The results considering this fashion provided in Table C. 52 in the Appendix-C.

1. In the first step, the concentration of the chromium, which has the highest weight factor, is presumed to be unknown. The LPI value, ignoring the subindex value of chromium, is calculated and reported in column 6, Table C.52.
2. Then, step by step it is presumed that the concentrations of the pollutants lead, COD, mercury, BOD₅, arsenic, cyanide, phenol, zinc, and pH are not known in addition to the earlier presumed unknown parameters. The LPI values so calculated are reported in Table C.52.
3. The percentage error in calculating LPI values, with respect to the LPI value when data for all 18 parameter are considered, is also reported in the last row of respective columns of Table C.52.
4. Figure 6.17 shows the variation in LPI values with respect to the number of pollutants considered in calculating LPI. It also gives the percentage error introduced in calculating LPI values with respect to the number of parameters considered.

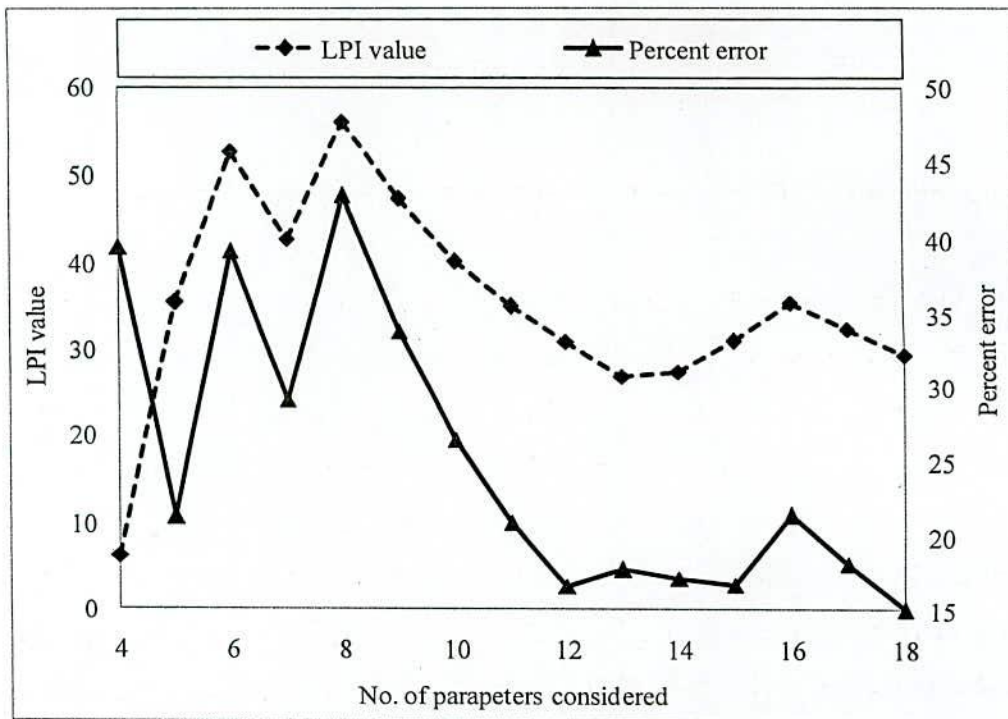


Figure 6.17 Variation of LPI and percent error when high weight parameters are ignored

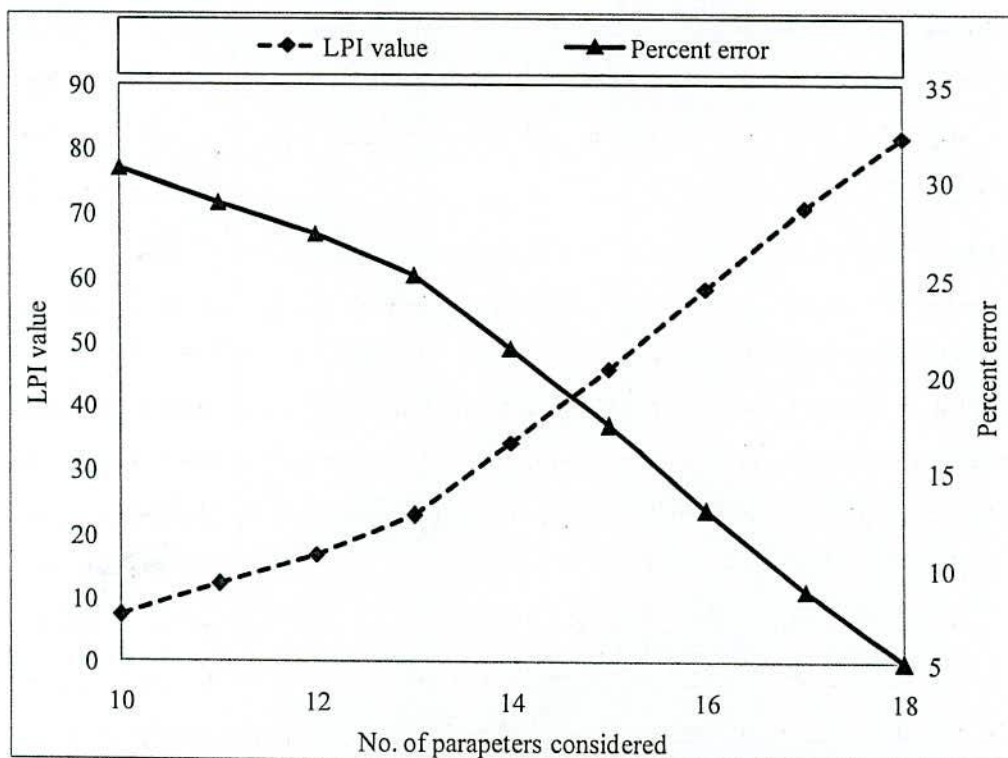


Figure 6.18 Variation of LPI and percent error when parameters with highest sub-index values ignored

6.6.2 Errors Introduced by Ignoring Pollutant Data Based on Sub-index Value

In this approach, three scenarios were considered as reveals:

1. Firstly, it was presumed that data for one parameter having the highest sub-index value are not available and then calculate LPI. Next it is presumed that the data for two sub-indices having the highest sub-index values are not available and so on for three, four, fifth to eight parameters. From Table 6.9, column 4, it was observed that the pollutants having the highest sub-index values are $\text{NH}_4\text{-N}$, TKN, TCB, COD, Hg, BOD_5 chloride and TDS with sub-index values of 100, 98, 92, 70, 59, 35, 30 and 28 respectively. To start with, it is presumed that data for $\text{NH}_4\text{-N}$ are not available. Based on this assumption, the LPI value was calculated using Eq. (6.2), and reported in column 6, Table C.53 in the Appendix. In the next step it is presumed that data for TKN are also not available in addition to $\text{NH}_4\text{-N}$. The LPI value based on this assumption is calculated using Eq. (6.2) and reported in column 7, Table C.53. Similarly, it is presumed that data for three and then four pollutants are not available, and the corresponding LPI values are calculated and reported in columns 8 and 9 of Table C.53. Moreover, in the similar fashion, it is presumed that data for fifth to eight pollutants are not available, and the corresponding LPI values are calculated and reported in columns 10 to 13 in Table C.53. The percentage error introduced in calculating these fourteen LPI was also calculated and reported in the last row of respective columns in Table C.53 and shown in Figure 6.18.
2. Then it is presumed that the data for one parameter having the least sub-index value are unknown and then LPI calculated. Subsequently it is presumed that, data for two, three, four and eight parameters having the lowest sub-index values are not available. From column 4 of Table 6.8, it is observed that the parameters having the lowest sub-index values are Zn, As, pH, Cr, Cu, Ni, phenolic compound and Pb with sub-index values of 5, 5.5, 6, 6.5, 7, 8, 8.5 and 9 respectively. The above procedure is repeated for calculating LPI values. The percentage error introduced in calculating LPI for each presumption is also calculated and reported in respective columns of Table C.54 in the Appendix and the results are shown in Figure 6.19.

3. After that it is presume that the data for two parameters, having the highest and lowest sub-index value are unknown simultaneously. The parameter having the highest sub-index value is $\text{NH}_4\text{-N}$ and the one having the lowest sub-index value is Zn. The LPI for this is calculated and reported in column4, Table 6.9. Subsequently it is presume that data for four parameters: two parameters with highest sub-index values ($\text{NH}_4\text{-N}$ and TKN) and two parameters with lowest sub-index values (Zn and As) are not available. The LPI for this presumption is calculated and reported in column 7, Table C.55. Moreover, it is presume that data for six parameters: three parameters with highest sub index values ($\text{NH}_4\text{-N}$, TKN and COD) and three parameters with lowest sub-index values (Zn, As and pH) are not available. The LPI for this presumption is calculated and reported in column 8, Table 6.19. Subsequently, it is presume that data for eight parameters: four parameters with highest and four with lowest sub index values are not available. The LPI for this presumption is calculated and reported in column 9, Table C.55. The percent error introduced in calculating LPI values is reported in the last row of respective columns in Table C.55 in the Appendix and the results are shown in Figure 6.20.

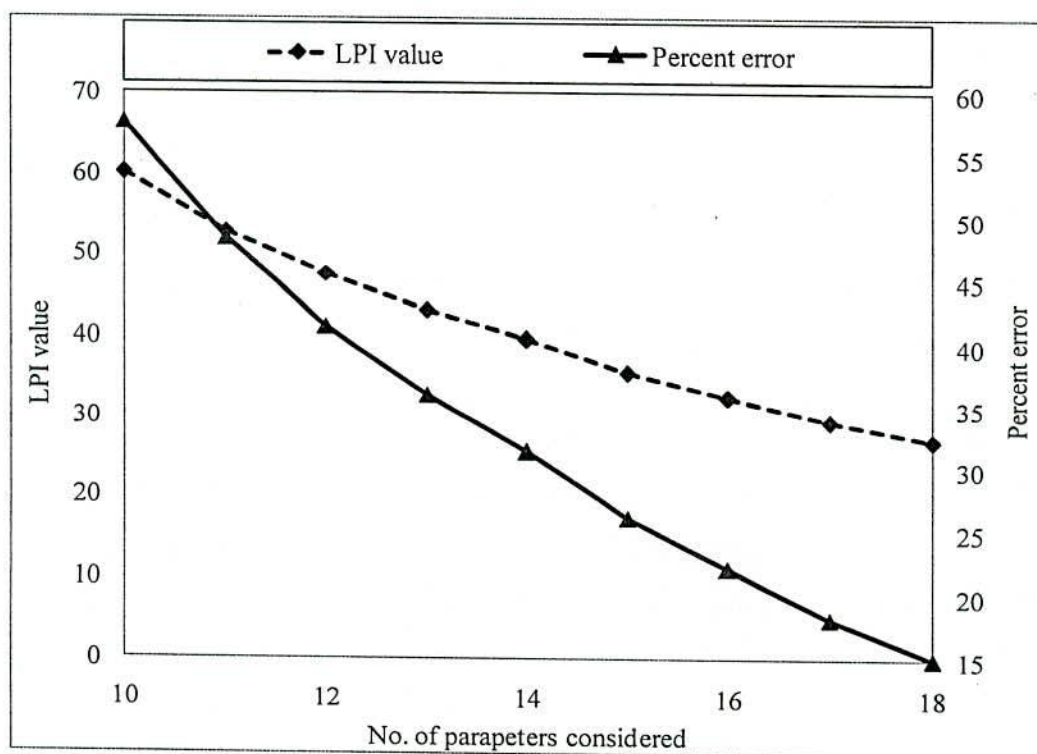


Figure 6.19 Variation of LPI and percent error when parameters with lowest sub-index values ignored

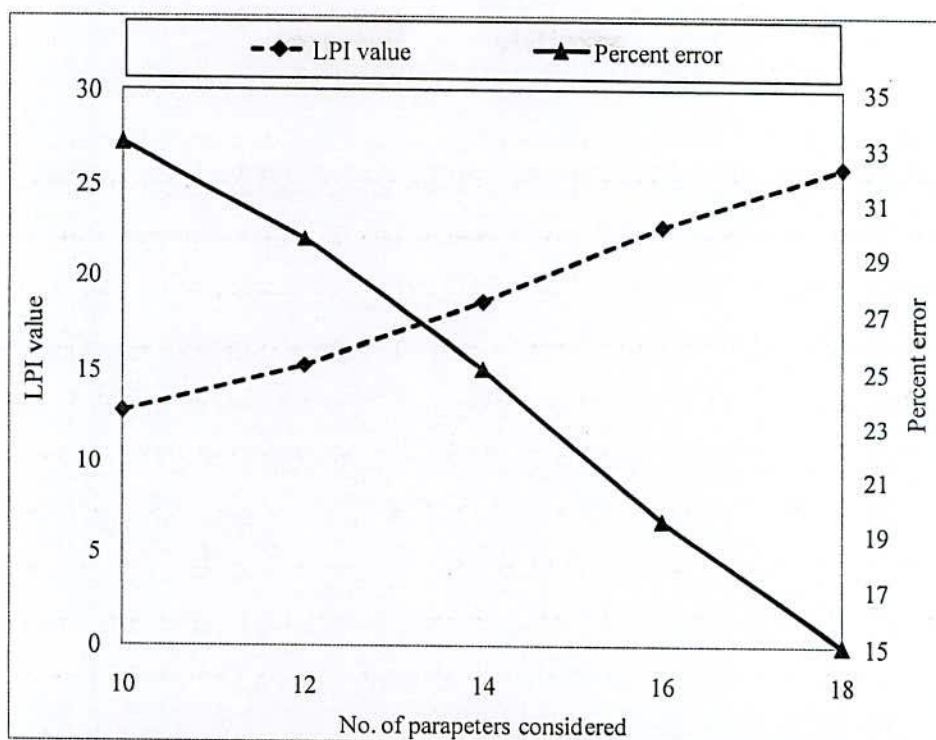


Figure 6.20 Variation in LPI due to nonavailability of data parameters with highest and lowest sub-index values ignored simultaneously

It can be depicted that the error introduced in calculating LPI is 3.32%, when concentration of one parameter, i.e., total iron (pollutant with lowest weight factor) is not considered (Figure 6.16). It also depicts that error increases to 3.87% when concentration of two parameters, total iron and chlorides, is unknown. Then the error also increases to 8.66% when data for three parameters, total iron, chlorides, and copper, is not known. The error introduced in LPI is the highest, i.e., 32.03%, when data of eight parameters is not considered. After this, the error decreases with the increase in the number of missing parameters. The error is just 4.77% when only six parameters are considered (that is when data for twelve parameters are not considered).

Similarly from Figure 6.17, it is observed that the error is 5.46%, when data for one parameter that is chromium (pollutant with highest weight factor) is not considered in calculating LPI. The error increases to 11.06% when data for two pollutants, chromium and lead, are ignored in calculating LPI. The error is highest, i.e., 47.84%, when data for the ten pollutants are ignored. But the percent error dips to 24.06% when eleven parameters are not considered in calculating the LPI value. This leads to the conclusion that the error involved in calculating LPI does not vary with the number of parameters considered and the variation is erratic. The erratic behavior in the error introduced in the LPI is due to the fact that the

parameters ignored while calculating LPI had significantly different subindex values with respect to the overall LPI of landfill lysimeter.

6.6.3 Errors Introduced by Ignoring Pollutant Data Based on Subindex Value

The error introduced is highest, i.e., 76.85%, when data for the eight parameters having the highest subindex values are not considered (Figure 6.18) and it was found 71.64 % when data for the seven parameters having the highest subindex values are not considered. However, it may reduce to 24.03% and 11.30 when data for the two and one parameters having the highest subindex values, respectively are not considered. Moreover, the errors introduced due to nonconsideration of data of one parameters having the lowest subindex values are 5.01 % and it rises gradually to 66.31 % (Figure 6.19) when data for the eight parameters are not considered.

Here, it is important to note that derived LPI are lower than the true LPI value in the case when pollutants with high sub-index values are ignored. On the contrary, the derived LPI are higher than the true LPI when data for the pollutants with low sub-index values are ignored. Hence, the results obtained by ignoring data for the pollutants with high subindex values produce falsified results, leading to a false sense of security, indicating a relatively more polluted environment as less polluted. But in the case when data for the pollutants with low subindex values are ignored, distended results are obtained and the results will raise an unnecessary alarm by indicating a comparatively less polluted environmental situation to be more contaminated. Based on this discussion, it is possible to conclude that the errors involved in LPI values are high and dangerous when the data for the pollutants having high subindex values are not available as compared to the scenario when data for the parameters having low subindex values are not available. The error involved in LPI values is low when data for the pollutants having highest and lowest subindex values are not considered simultaneously.

6.7 Summary of the Findings

Aggregation function is one of the most important steps in calculating any pollution potential. Result revealed that weighted linear sum aggregation function was the best possible aggregation function for calculating LPI. LPI is a good tool and it provides an evocative method of evaluating the contamination potential of different solid waste disposal sites. The LPI can be a useful tool to monitor the leachate trends over the lifetime of landfill site, and thus can help to take necessary decisions as deem fit. Result reveals that among four lysimeter operating system, collection system of open dump lysimeter had the highest LPI value, while detection system had the lowest LPI. The component of organic fraction in leachate for entire lysimeter operating system showed higher against the other counter fraction i.e. inorganic and heavy metal fraction and consequently showed the higher LPI_{or} than that of LPI_{in} and LPI_{hm} . Result reveals that maximum error (32.03 %) was introduced in calculating LPI when the data for the eight low weight parameters were not considered, but the error was as low as 3.32 % when data for one parameter were not considered. Similarly the error involved in calculating LPI was maximum (47.84 %) when data for ten high weight parameters were ignored, but the error involved was low (2.95 %) when data for three high weight factors were ignored. Finally, it can be concluded that comparison of leachate characteristics with the standards set for the disposal of treated leachate verifies the fact that leachate generated from lysimeter was highly contaminated and LPI exceed the LPI of treated leachate and proper treatment to be ensured before discharging the leachate. To these attempts, then the leachate samples were treated in the laboratory by using biological reactors and chemical coagulant to remove the concentration in leachate to meet the standard discharge conditions.

Treatment Techniques of Lysimeter Leachate

7.1 Background

This chapter illustrates the leachate treatment options that can be effectively adopted for safe discharge of leachate into the natural streams. Leachate treatment is an integral part of the sustainable solid waste management practices (Kargi and Pamukoglu, 2003; Jannatul, 2013). However, the design, construction and operation of leachate treatment facilities have not been standardized due to uncertainties in leachate characteristics and quantity (Alkalay et al., 1998). The characteristics of the landfill leachate can usually be represented by the basic parameters COD, BOD₅, the ratio BOD₅/COD, pH, TSS, NH₄-N, TKN and heavy metals (Davis and Cornwell, 1998). The concentration of lysimeter leachate were treated in the laboratory through the required standards methods. Then, the concentration were compared to the maximum discharge standard from some selected countries which were available in the literature provided in Table 7.1. Table 7.1 reveals most of the parameters exceed the permissible limit of maximum discharge standard. Then it is required to treat for reducing the leachate concentration before discharging into natural streams. Leachate samples having the ratio of BOD₅ and COD is less than 0.30, should be treated by chemical treatment process; 0.30-0.60 by combined process of phytoremediation and chemical treatment process; greater than 0.60 which indicates for removing leachate concentration, it should be treated by phytoremediation process (Mahmud et al., 2012).

To investigate the performance of different treatment systems, leachate samples from Landfill Lysimeter at KUET campus were collected and relevant parameters were measured and monitor in the laboratory provided in Table 7.1. Firstly, the leachate was treated in phytoremediation through aquatic reactors by Duckweed (*Lemna minor*), Snail (*Pila globosa*), Helenchia (*Enhydra fluctuans*) and Topapana (*Pistia stratiotes*) for removing pollutant load from leachate. However, through the phytoremediation treatment process, the removal efficiency was not satisfactory. Then leachate was treated by coagulation process using chemical of Ferric Chloride (FeCl₃), Poly aluminum Chloride (PAC), Ferrous Sulphate (FeSO₄) and Aluminum Sulphate (Al₂(SO₄)₃) in various dosages and pH values. At the initial

stage, optimum dosage of coagulants for removal of pollutant in leachate was determined and these optimum dosage was further used for treating leachate at varying pH values from 4-9.

Table 7.1: Comparison of lysimeter raw leachate concentration, maximum discharge standard for landfill and regulatory standards for standards set by DoE on ECR, 97 for Effluent (Wastewater) as well as industrial wastewater as specified in the Environmental Quality (Sewage and Industrial Effluents) Regulation, 1979; EQA, 1974)

Parameter	Standard set by DoE (Bangladesh) ⁽¹⁾			India ⁽²⁾	German ⁽³⁾	Hong Kong ⁽⁴⁾	Standard A ⁽⁵⁾	Standard B ⁽⁵⁾	*Initial quality of lysimeter leachate
	Inland Surface Water	Public Sewerage System	Irrigated Land						
Cr	0.5	1	1	2.0	0.5	0.1	0.2	1.0	--
Pb	0.1	1	0.1	0.1	0.5	0.1	0.01	0.5	0.67
COD	200	400	400	250	200	200	50	100	3040
Hg	0.01	0.01	0.01	0.01	0.01	0.02	0.005	0.05	--
BOD ₅	50	250	100	30	20	800	20	50	2754
As	0.2	0.05	0.2	0.2	--	--	0.05	0.1	--
CN	0.1	2	0.2	0.2	--	--	0.05	0.1	--
Phenol	1	5	1	1.0	--	--	0.001	1.0	--
Zinc	5	10	10	5.0	2.0	0.6	1.0	1.0	1.38
pH	6-9	6-9	6-9	5.5-9.0	5.5-8.5	5-7.5	6.0-9.0	5.5-9.0	9.33
TKN	100	100	100	100	70	100	--	--	--
Ni	1	2	1	3.0	1.0	0.6	0.2	1.0	0.09
NH ₄ -N	50	75	75	50	30	5.0	--	--	--
TDS	2100	2100	2100	2100	600	500	--	--	5580
Cu	0.5	3	3	3.0	0.5	1.0	0.2	1.0	0.98
Cl ⁻	600	600	600	1000	800	850	1.0	2.0	650
Fe	2	2	2	--	--	--	--	--	27.70
Alkalinity	--	--	--	--	--	--	--	--	1600
Hardness	--	--	--	--	--	--	--	--	926
Ca	--	--	--	--	--	--	--	--	247
Na	--	--	--	--	--	--	--	--	2435

All units are in mg/L. * Average of 4 samples taken between from 1st August to 30th September 2009.

Note: ¹Jannatul Ferdous 2013 (Standards Set by DoE on ECR, 97 for Effluent (Wastewater, inland surface water); ²Kumar and Alappat 2003a; ³Meier et al., 2002 and ⁴Environmental Protection Department (EPD) (Maximum discharge standard for landfill leachate from selected countries) and ⁵Standard A: Upstream of water supply intake and ⁵Standard B: Downstream of water supply intake (Regulatory Standards for industrial wastewater as specified in the Environmental Quality (Sewage and Industrial Effluents) Regulation, 1979; EQA, 1974)

7.2 Phytoremediation Treatment of Lysimeter Leachate

Table 7.1 shows the leachate characteristics resulting from four samplings at two weeks interval for about 2 months from 1st August to 30th September 2009. In the laboratory, leachate samples at varying concentrated were prepared through the dilution of raw leachate with tap water. At such stage, the prepared 100 concentrations of leachate means 100% of raw leachate was used and 50 concentration means 50 % of tap water was mixed with 50 % of raw leachate. Similarly 20 concentration of contaminants in leachate means 80 % of tap water was mixed with 20 % of raw leachate. Lachate samples subsequent to pre-treatment through different aquatic reactors were analyzed based on the elapsed period from the treatment, leachate concentration (conditioning system) and removal efficiency. In the laboratory, leachate samples were analyzed for pH by pH meter (HACH, Model No. Sens ion 156), Alkalinity by titration method, Hrdness by EDTA titrimetric method as well as COD by closed reflexive method as per the Standard Methods (APHA, 1998). The Ca Na, K and Mg ions were determined using flame atomic absorption spectrophotometer (VARIAN; AA/2400). Heavy metals viz., Cu, Cr, Cd, Ni, Pb, Mn, Fe and Zn were analyzed using spectrophotometer (HACH; DR/2400) as per the Standard Methods (APHA, 1998).

7.2.1 Effect on Leachate Concentration

In the laboratory, leachate samples at varying concentrated of 100, 50 and 20 were prepared through the dilution of raw leachate with tap water as well as the effect and the consequences of different phytoremediation treatment were analyzed and hence discussed in followings.

Table 7.2: pH in 100 concentration of contaminants in leachate at varying elapsed period

Elapsed period from treatment (weeks)	Concentration in control and treated leachate				
	Control	Topapana	Helencha	Duckweed	Snail
0	9.33				
7	9.24	9.22	8.97	9.1	8.27
14	9.20	9.12	8.93	9.06	8.33
21	9.23	9.1	8.9	8.93	8.43
28	9.22	9.11	8.85	8.88	8.31
35	9.28	9.07	8.79	8.72	8.28
42	9.18	9.0	8.45	8.59	8.2
49	8.92	8.69	8.37	8.7	8.27
56	8.85	8.51	8.28	8.69	8
63	8.72	8.42	8	8.45	7.87
70	8.44	8.14	7.87	8	7.65

7.2.1.1 Inorganic and Organic Compounds

The concentrations of inorganic and organic compounds in terms of pH, Cl^- , Alkalinity, Hardness, TDS and COD in leachate in relation to the increasing to elapsed period after treating with aquatic reactors were investigated and hence discussed in followings.

The values of pH in leachate is considered to be the most significant parameter affecting leachate concentration in MSW landfill (Bilgili et al., 2007). Metal dissolution is enhanced at low pH which is one of the characteristics of young landfill leachate. MSW contains soil and organic matter that have significant sorptive capacity especially at high pH (Kjeldsen et al., 2002; Bozkurt et al., 1999). The values of pH in leachate after treated phytoremediation ly at varying elapsed period provided in Table 7.2 and also in Figure 7. 1.

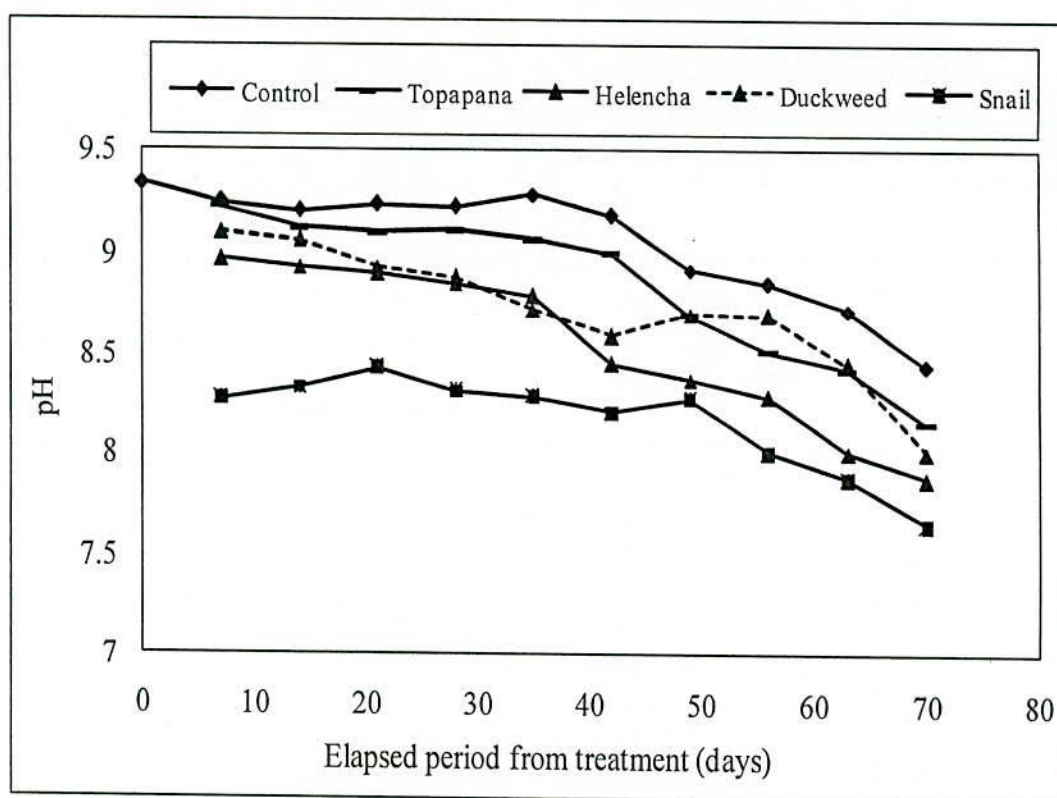


Figure 7.1: Variation of pH against different treatment on leachate of 100 concentration

The Figure 7.1 illustrates the variation of pH with the increase of elapsed period from the treatment; to investigate the consequence of the different phytoremediation treatment systems by topapana, helencha, duckweed and snail. Based on Table 7.2 and Figure 7.1, it can be noted that pH decreases with the increases of elapsed period from the treatment for all the treatment systems until the completion of this study. The Figure 7.1 also depicts that all the treatment systems provides the lower values of pH against of control system and the

removal efficiency was found as positive for all the cases. Moreover, the removal efficiency of snail was higher than that of other treatment systems. However, the variation of pH at different phytoremediation treatment system for 100, 50 and 20 concentration of contaminants in leachate at elapsed period 21 days provided in Figure 7.2. Here, it is important to note that pollutant load (pH) decreases with the decreasing of leachate concentration. From Figure 7.2 it is observed that pH falls down with the decreases of concentration of raw leachate by applying conditioning system. Moreover, the trend of 100 concentration of contaminants in leachate sample having more values of pH than that of other two concentrated leachate samples. Diaz (1996) stated that preparation of leachate samples or prerequisite, such as dilution becomes effective to enhance the further treatment to some extent. It is evident from that more dilution condition of leachate, more enhance to the treatment capability for phytoremediation components and having low pH concentrations. However, Diaz (1996) also postulated that pH is the logarithmic hydrogen concentration of any liquid. Generally pH depends on temperature, amount of hydrogen ion etc. and it increases with the increase of hydrogen ion and the liquid becomes acidic.

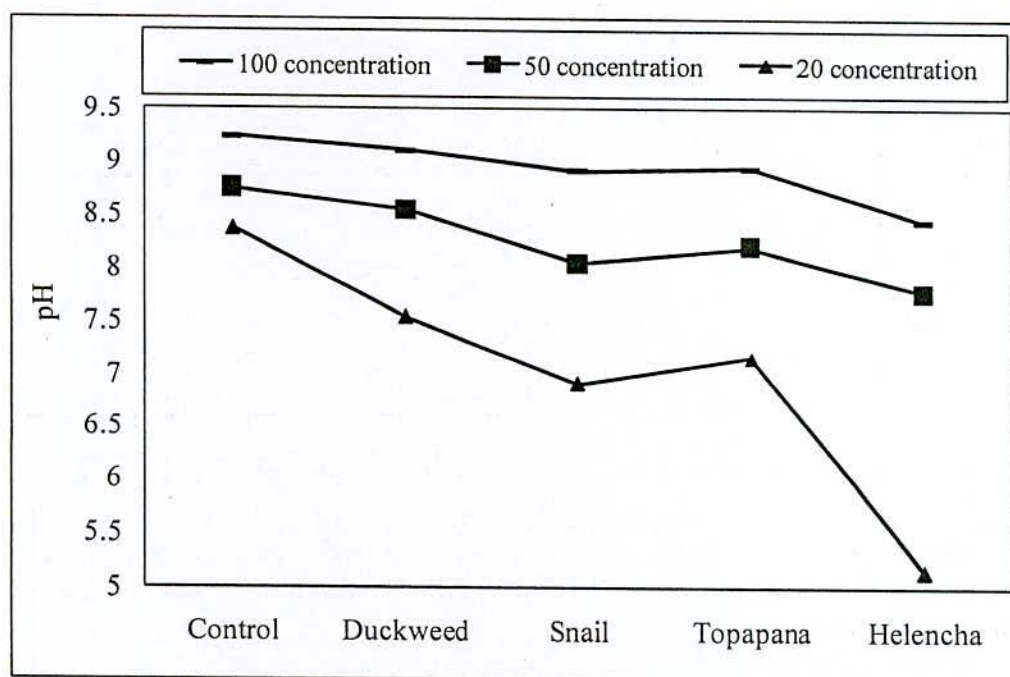


Figure 7.2: Comparison of pH among different treatment system after 21 days

A decrease of COD occurs over the elapsed period of landfill and it can be attributed to a combination of reduction in organic contaminants and the increased biodegradation of organic compounds (Krug and Ham, 1995). A constant decrease in COD is also expected as degradation of organic matter continues (Ehrig, 1989). The values of COD in 100

concentration of contaminants in leachate varies in relation to the increasing of elapsed period from the treatment systems by topapana, helencha, duckweed and snail until the end of this study provided in Figure 7.3. This figure reveals that decreased with the increase of elapsed period and showing almost similar decreasing trend for all the treatment systems. In addition, the concentration of COD in case of control system was found as higher than that of the subjected treatment systems. It can be noted that all the treatment systems showing positive and very efficient performance for the removal of COD concentration.

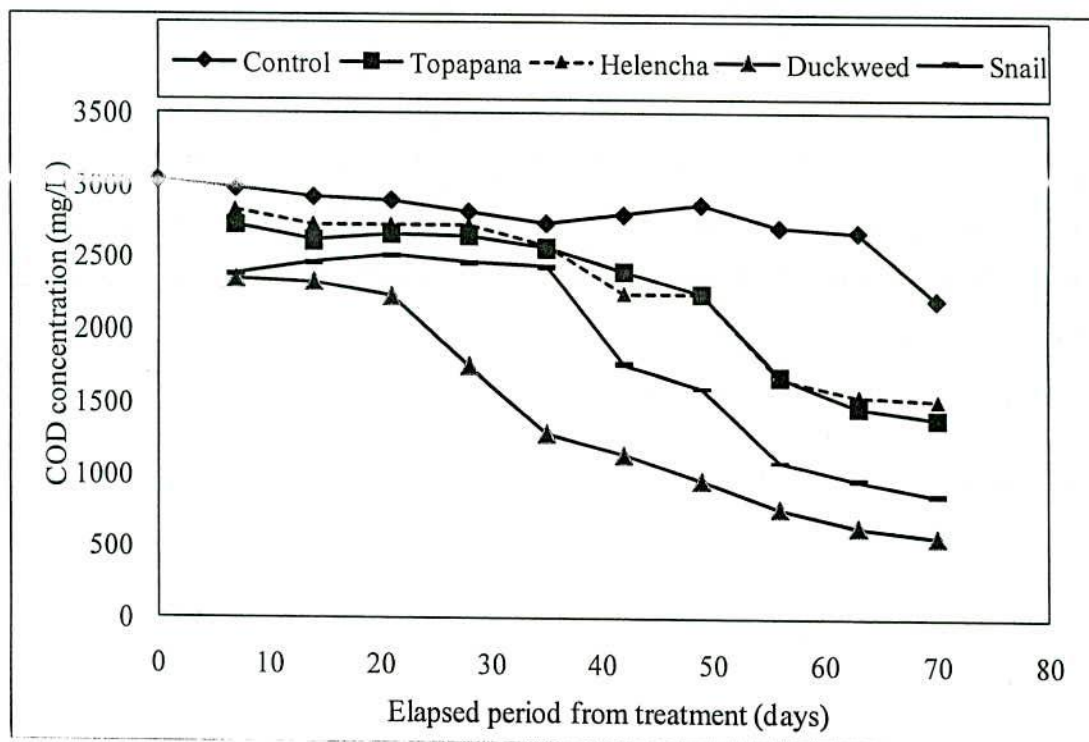


Figure 7.3: Variation of COD against of different treatment on leachate of 100 concentration

Here, it important to note that COD decreases with the decreasing of leachate concentration. Result shows that COD fall down with the decreases of concentration of raw leachate by applying conditioning system. The trend of 100 concentration of contaminants in leachate sample having more COD than that of other two concentrated leachate samples. COD is the measure of oxygen consumed during the oxidation of the oxidizable organic matter by a strong oxidizing agent. The determinations of COD are of great importance where BOD values cannot be determined accurately due to the presence of toxins and unfavorable conditions for growth of microorganism. The COD test remains a very important parameter in management and design of treatment plants because of its rapidity in determination.

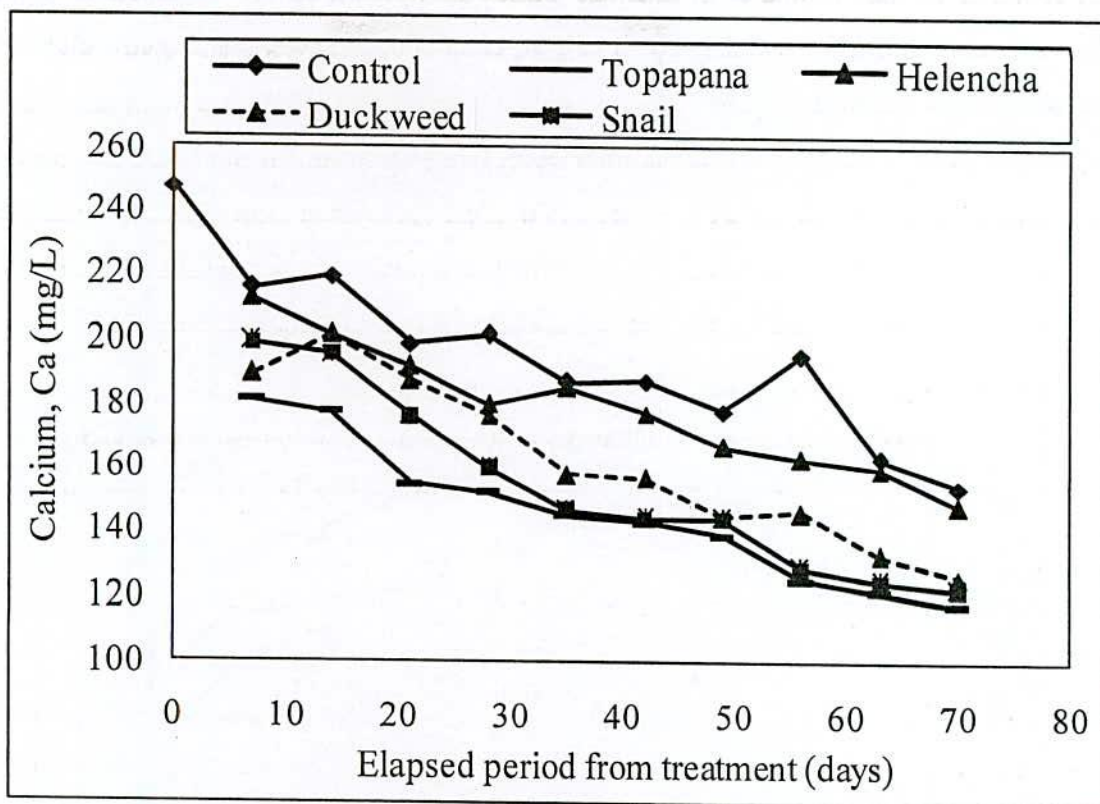


Figure 7.4: Variation of Ca against of different treatment on leachate of 100 concentration

7.2.1.2 Metals Concentration

The concentrations of metals in terms of Ca, Na, K, Mg, Cu, Zn, Pb and Ni in leachate in relation to the increasing to elapsed period after treating phytoremediation ly were investigated in this study. The decreasing trend of Ca in leachate of 100 concentration in relation to the increasing of elapsed period after treating leachate phytoremediation ly with locally available aquatic reactors of topapana, helencha, duckweed and snail provided in Figure 7.4. The Ca and Mg are two important ions in the evaluation of buffering capacity of leachate during the waste degradation in landfill (Karthikeyan et al., 2004). The Ca concentration has a tendency of complex formation with HCO_3^- and dissolved organic compounds and dissolution reactions involving calcite (CaCO_3) and may be siderite (FeCO_3) (Christensen et al. 2001). Thus, the dissolution process is closely linked to the dissolved carbonate compounds. Here, it is interesting to note that adopted phytoremediation treatment system deduced the values of Ca against the control system (without treatment) at varying elapsed period (Figure 7.4). Figure 7.4 reveals that Ca drops from 181-117, 212-147, 189-125.5 and 198.3-122 mg/L from the elapsed period 7-70 days, for topapana, helencha, duckweed and snail, respectively. For a particular elapsed period say 49 days, Ca reduces at

138, 166, 143.7 and 143 mg/L against the initial quality of leachate for topapana, helencha, duckweed and snail, respectively. So, it can be concluded that topapara is more effective to remove Ca from leachate.

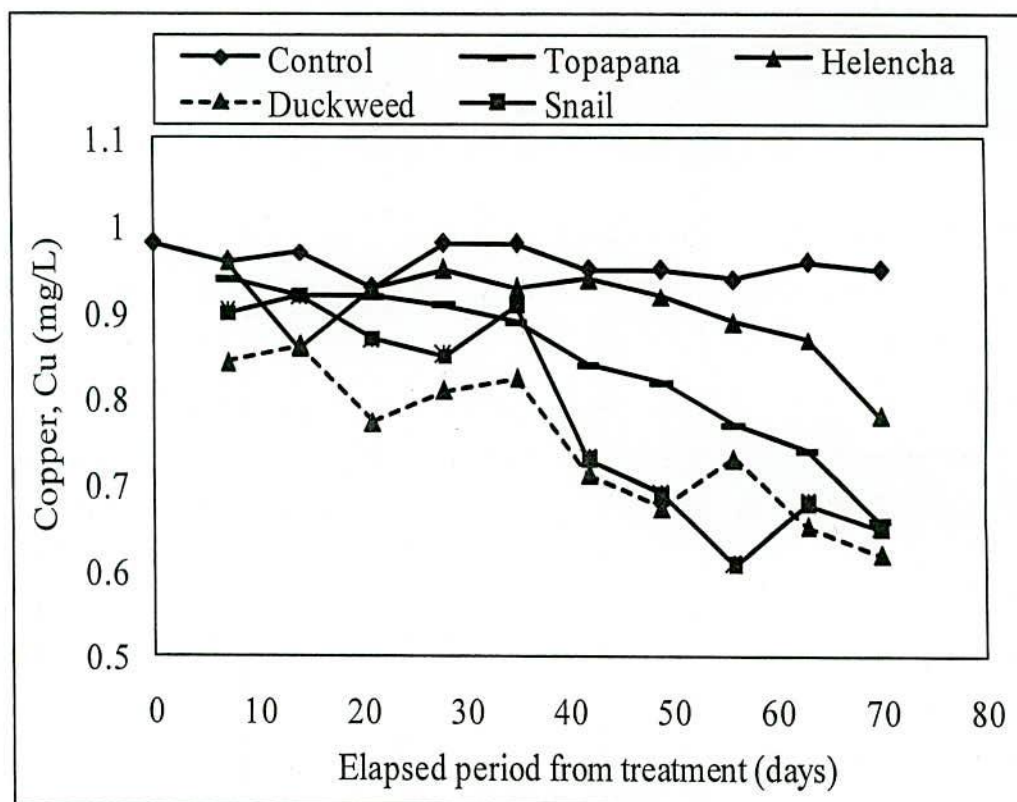


Figure 7.5: Variation of Cu against of different treatment on leachate of 100 concentration

The variation of heavy metal of Cu in control system and leachate of 100 concentration against of elapsed period after treating with topapana, helencha, duckweed and snail provided in Figure 7.5. The main processes for the low metal concentrations in leachate are sorption and precipitation. Solid wastes contain soils and organic matter, which have a significant sorptive capacity, especially at neutral to high pH prevailing in methanogenic leachate (Bozkurt et al., 1999). However, the solubility of the metals with sulfides and carbonates is low and sulfide precipitation is often cited as an explanation for low concentrations of heavy metal in leachate. Sulfides and carbonates are capable of forming precipitates with heavy metals of Cd, Ni, Zn, Cu and Pb. In general, sulfide precipitation is expected to dominate heavy metal attenuation as compared to complexation agents (Bozkurt et al., 1999). Result reveals that Cu drops from 0.94-0.66, 0.96-0.78, 0.84-0.62 and 0.90-0.65 mg/L from the elapsed period 7-70 days, for topapana, helencha, duckweed and snail, respectively. For a particular elapsed period say 21 days, the values of Cu reduces at 0.92, 0.93, 0.77 and 0.87

mg/L against the initial quality of leachate for topapana, helencha, duckweed and snail, respectively. it can be concluded that duckweed was more effective to remove Cu in leachate.

7.2.2 Removal Efficiency of Pollutant in Leachate

The percentage of removal of different phytoremediation treatment systems based on the elapsed period from the treatment was analyzed and hence discussed in the following sections.

7.2.2.1 Inorganic and Organic Compounds

The removal efficiency of inorganic and organic compounds in terms of pH, Cl^- , alkalinity, hardness, TDS and COD in leachate in relation to the increasing to elapsed period after treating with aquatic reactors were investigated and hence discussed in followings.

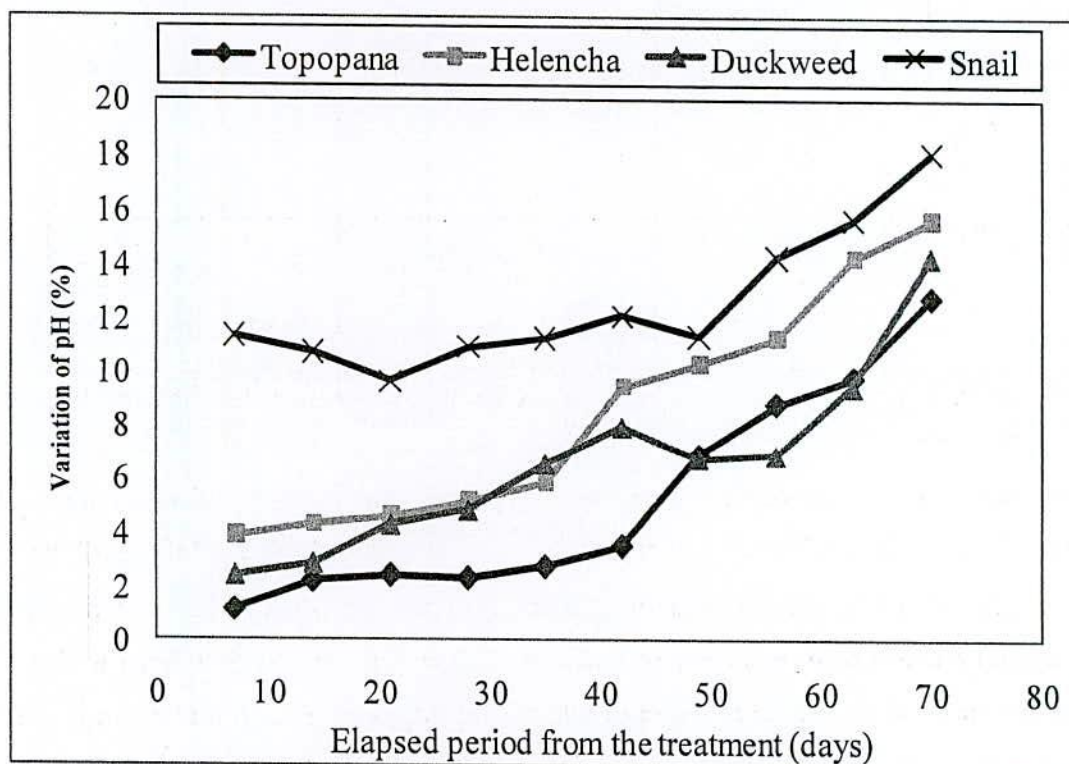


Figure 7.6: Percentage reduction of pH in leachate of 100 concentration at varying elapsed period

The removal efficiency of pH ranging from 13-18% for different adopted phytoremediation treatment after the elapsed period of 70 days from the treatment for 100 concentration of contaminants in leachate illustrates in Figure 7.6. The Figure 7.6 depicts that at 70 days of treatment, effective removal were achieved for topapana, helencha, duckweed and snail of 13, 16, 14 and 18%, respectively. Based on the findings it can be concluded that snail shows the

highest performance of pH removal, which was obtained as 18 %. Here, it can be noted that some of the treatment systems was very effective to remove some particular parameter like snail was more effective for the removal of pH in leachate. Experimental result reveals that for leachate of 100 concentration, the percent removal of pH ranging from 1-11; 2-11, 2-10, 2-11, 3-11, 4-12, 7-11, 9-14, 10-16 and 13-18 % at the elapsed period 7, 14, 21, 28, 35, 42, 49, 56, 63 and 70 days for topapana, helencha, duckweed and snail, respectively. Here, it can be concluded that removal efficiency of pH increases with the increasing of elapsed period from the treatment shown in Figure 7.7. Figure 7.7 reveals that snail shows the highest removal of pH, while topopana having the lowest removal efficiency until the completion of this study.

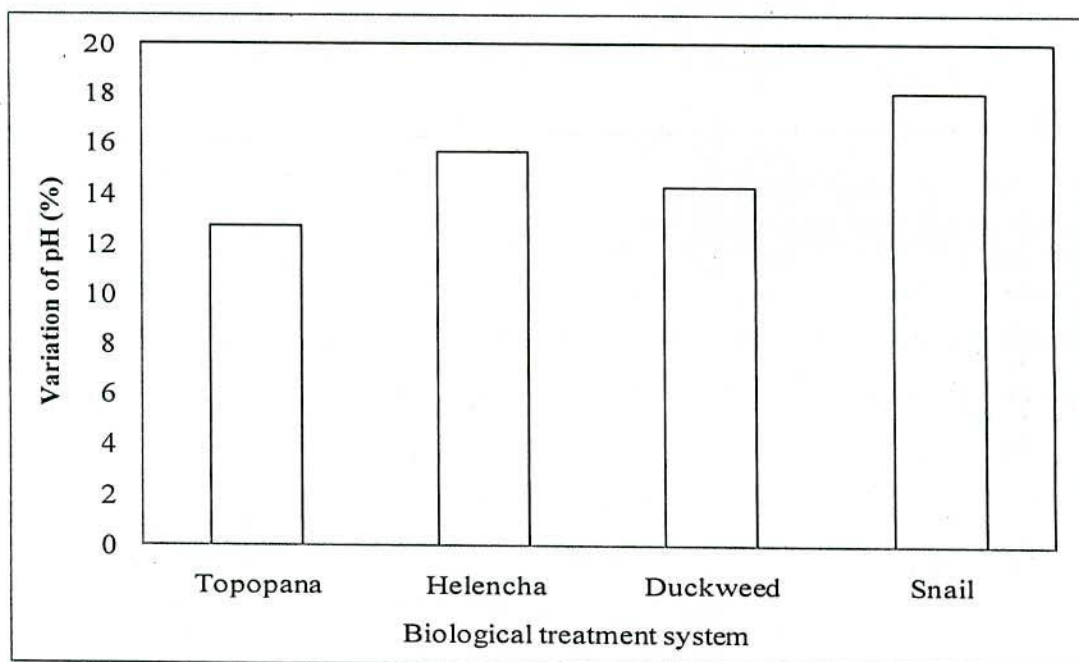


Figure 7.7: Reduction of pH in leachate of 100 concentration after 70 days from treatment

7.2.2.2 Metals Concentration

The percent removal of metals in terms of Ca, Na, K, Mg, Cu, Zn, Pb and Ni in leachate in relation to the increasing to elapsed period after treating phytoremediation ly was investigated in this study. The increasing trend of percent removal of Ca with the increasing of elapsed period provided in Figures 7.8. Figure 7.8 reveals that topopana was achieved to remove Ca at the highest of 53 % while, helencha having the lowest of 40 % at the elapsed period of 70 days. In contrary, the removal efficiency for topopana of Ca at varying concentration were performed and it reveals that topopana achieved the highest reduction of Ca when the concentration of contaminants in leachate is 100, while it was the lowest when concentration of contaminants in leachate is 20.

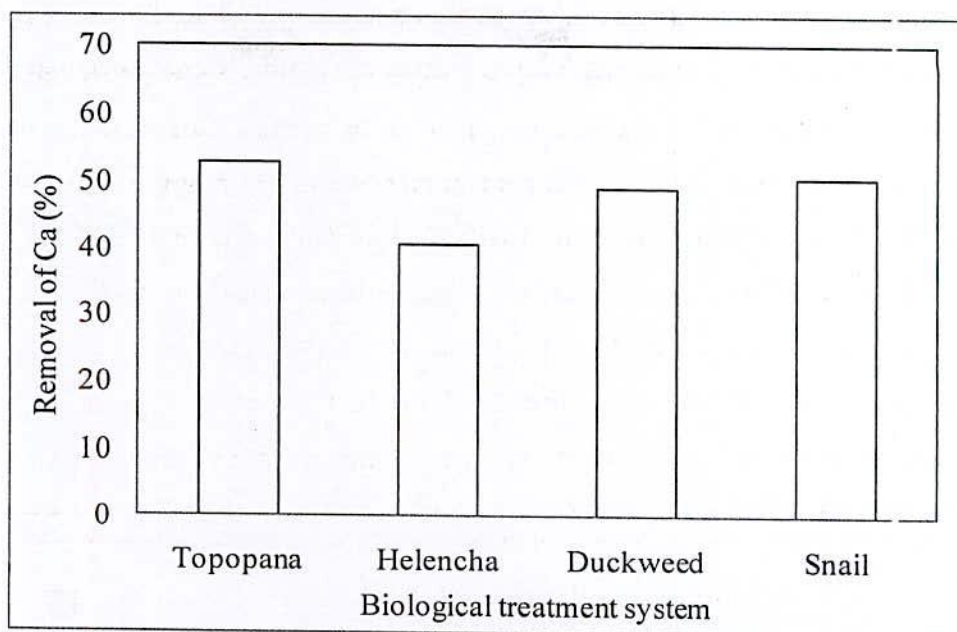


Figure 7.8: Percentage reduction of Ca in leachate of 100 concentration after 70 days from treatment

The percent reduction of Zn in leachate of 50 concentration with topopana, helencha, duckweed and snail at the elapsed period of 28 days is provided in Figure 7.9. Figure 7.9 reveals that duckweed was achieved to remove Zn at the highest of 56 % while, topopana having the lowest of 35% at the elapsed period of 28 days. Moreover, the removal efficiency of Zn was ranging from 35.0 to 56.0% for the different adopted phytoremediation treatment after the elapsed period of 28 days from the treatment for 50 concentration of contaminants in leachate.

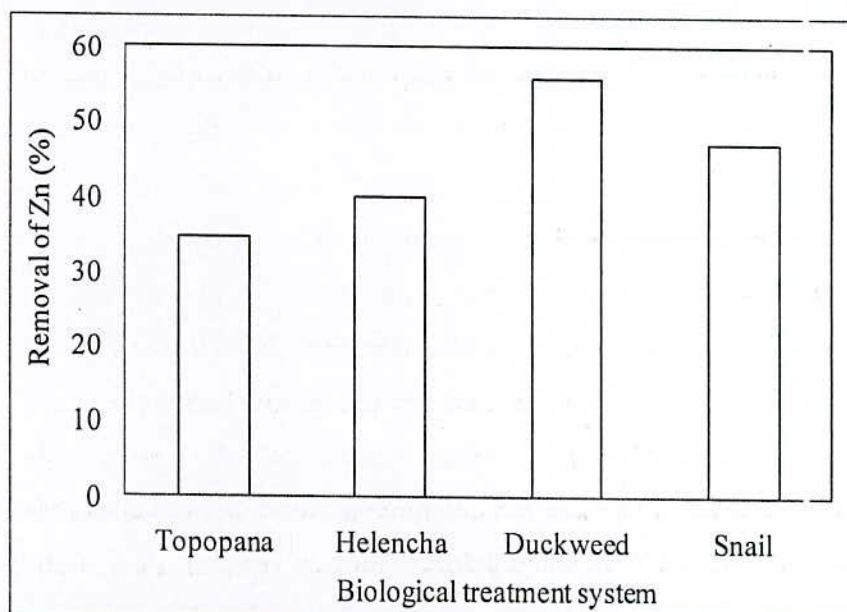


Figure 7.9: Percentage reduction of Zn in leachate of 50 concentration after 28 days from treatment

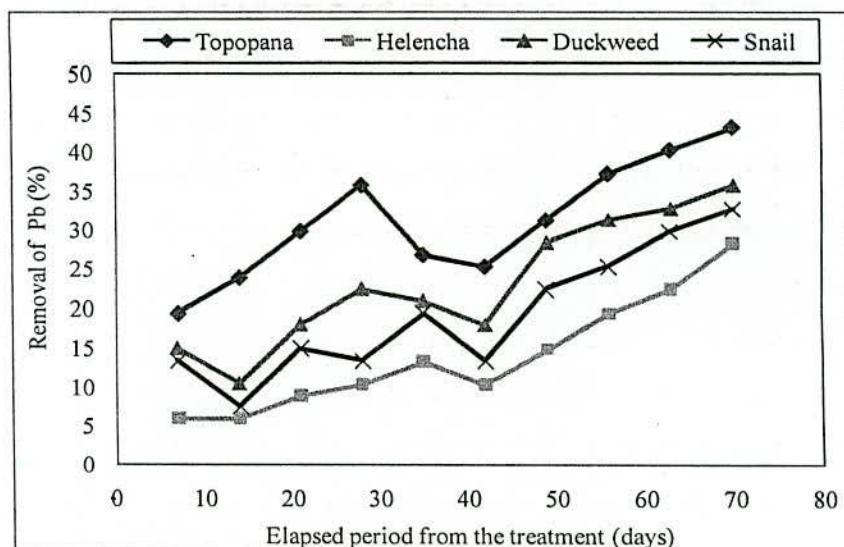


Figure 7.10: Percentage reduction of Pb in leachate of 100 concentration at varying elapsed period

In contrary, the increasing trend of removal efficiency of Pb in leachate of 100 concentration with the increasing of elapsed period from the treatment shown in Figure 7.10. Figure 7.10 reveals that topopana shows the highest removal of Pb, while helencha having the lowest removal efficiency until the completion of this study. The corresponding Figures for removal efficiency of parameters explained in this section as well as other parameters were provided in the Appendix-D.

The phytoremediation treatment systems were more effective when the concentration was low and no single treatment system showing commonly the better performance for all the pollutant in leachate. In addition to meet the standard discharges condition; the lysimeter leachate was further sampling from the leachate collection chamber and tested in the laboratory shown in Table 7.3. Furthermore, after tested in the laboratory, for removing leachate concentration then treated through the chemical process and discussed in following articles.

7.3 Chemical Coagulation Treatment of Lysimeter Leachate

Coagulation-flocculation experiments were performed in a conventional Jar-test apparatus equipped with six backers using Ferric Chloride (FeCl_3), Poly aluminum Chloride (PAC), Ferrous Sulphate (FeSO_4) and Aluminum Sulphate ($\text{Al}_2(\text{SO}_4)_3$). For the jar-test experiment, leachate samples were removed from the cold room and were conditioned for about 1 hour under ambient temperature. Sample container was thoroughly shaken for re-suspension of

settled solids. 500 mL of raw leachate was transferred into the 1-litre beakers with the height of 15 cm and internal diameter of 10 cm. Leachate samples were subjected to jar-test after pH adjustment and pre-selected chemical coagulant addition. The experimental procedure consisted of three subsequent stages; initial rapid mixing stage of 3 min at 110 rpm, following slow mixing stage of 25 min at 40 rpm and final settling step for 30 min.

The pH of leachate was adjusted to the desired levels by addition of the appropriate amounts of 6N sodium hydroxide or 6N sulfuric acid. After the settling period, the supernatant was withdrawn from the beaker and was checked by chemical analysis. The withdrawal of sample was accomplished from a point about 2 cm below the liquid level in the beaker by a pipette. A study established by Ebeling et al. (2003) stated that the combined of coagulation-flocculation studies are carried out in usual jar test equipment. The mixing of coagulant in leachate, adjusted of pH to the desired levels, mixing speed of Jar-test apparatus in the laboratory were trailed based on the procedure followed by Ebeling et al. (2003).

Table 7.3: Characteristics of raw leachate from landfill lysimeter

Characteristics	unit	Range	Mean*
<i>Inorganic and organic compound</i>			
pH	--	6.14-8.0	7.31
Turbidity	NTU	55-201	106
Leachate colour	Pt-Co	1450-2340	2190
Total kjeldahl nitrogen (TKN)	mg/L	145-689	402
Ammonia nitrogen (NH ₄ -N)	mg/L	121-604.6	389.5
Chloride	mg/L	1150-3580	2395
Total suspended solid (TSS)	mg/L	18-1390	750
Hardness	mg/L	1000-10000	2372
Alkalinity	mg/L	980-10000	2930
Chemical oxygen demand (COD)	mg/L	160-800	510
Phytoremediation oxygen demand (BOD ₅)	mg/L	122-679	487
Conductivity	mS/cm	3.10-24.70	9.38
<i>Metal concentrations</i>			
Calcium (Ca)	mg/L	153-256	214
Potassium (K)	mg/L	856-1764	1444
Sodium (Na)	mg/L	1012-2212	1489
Magnesium (Mg)	mg/L	127-540	227
Iron (Fe)	mg/L	1.80-82.6	25.0
<i>Heavy metal concentrations</i>			
Cadmium (Cd)	mg/L	0.04-0.105	0.043
Nickel (Ni)	mg/L	0.045-0.09	0.058
Zinc (Zn)	mg/L	0.10-1.27	0.595
Copper (Cu)	mg/L	0.04-0.97	0.213
Chromium (Cr)	mg/L	0.01-0.08	0.06
Manganese (Mn)	mg/L	0.80-8.50	4.40
Lead (Pb)	mg/L	0.12-0.476	0.235

* Average of 4 samples taken between 1st July and 30th August 2010

7.3.1 Chemical Coagulant at Varying Concentration

Experiments were conducted using FeCl_3 , PAC, FeSO_4 and $\text{Al}_2(\text{SO}_4)_3$ at optimum dosage for the removal of inorganic compounds of turbidity, colour, COD, TSS, BOD_5 and $\text{NH}_4\text{-N}$ as well as metal concentrations of Ca, K, Na and Mg and heavy metal of Cu, Zn, Cd, Ni and Pb. The ratio of BOD_5/COD (0.95) shows a readily biodegradability of the organic content in MSW of landfill lysimeter. The TKN is the sum of organic nitrogen (Organic-N) and $\text{NH}_4\text{-N}$ (APHA, 1998). The $\text{NH}_4\text{-N}$ is representative of inorganic matter. It can be noted that FeCl_3 was achieved for optimum reduction of pollutant in leachate at optimum dosage of 3000 mg/L, while PAC, FeSO_4 and $\text{Al}_2(\text{SO}_4)_3$ of 4000, 3000 and 2000 mg/L, respectively.

7.3.1.1 Treatment with FeCl_3 at Different Concentration

After treating leachate with FeCl_3 at varying dosages, the concentration of inorganic compounds, metal and heavy metal was recorded and shown in Table 7.4. The concentration of pollutant in treated leachate by using PAC, FeSO_4 and $\text{Al}_2(\text{SO}_4)_3$ at different dosages as well as at varying pH values was recorded in the Appendix-D. However, percentage reduction of pollutant in relation to the increasing of FeCl_3 dosages was studied and presented in Figure 7.17. Figure 7.17 reveals that increasing trend of reduction in relation to the increasing of FeCl_3 dosages continued approached the optimum dosage after which the reduction rate was started to reduce gradually. The similar trend was also observed by Hamidi et al. (2007).

Figure 7.11 revealed that reduction of TSS was 81% using FeCl_3 at optimum dosage of 3000mg/L. However, a study conducted by Jayabala (2005) and observed that FeCl_3 was able to achieve 97% removal of TSS when wastewater was treated with 3000mg/L. In this study, the reduction of turbidity was 95%, while for colour COD, BOD_5 and $\text{NH}_4\text{-N}$ were found 86, 50, 41 and 75 %, respectively. The minimum removal of turbidity, BOD_5 and $\text{NH}_4\text{-N}$ were 51, 28 and 56 % at a dosage of 0.50g/mL while for colour 76 % for both the dosages of 0.50 g/mL and 4.50 g/mL. Hamidi et al. (2007) observed that removal of colour, turbidity and SS (at 200 mg/L of FeCl_3) is 66 %, 57% and 72%, respectively. Moreover, maximum reduction of Ca, K and Na using FeCl_3 was 100%, while Mg was reduced by 80% as shown in Figure 7.17. The reduction of Cu, Zn, Cd, Ni and Pb was also observed (Figure 7.11). Figure 7.11 reveals that efficiency of removal enhanced approached optimum dosage after which it rate was started to reduce gradually. Results showed that maximum reduction of Cu, Cd, Ni and Pb was 100%, while Zn was reduced by 93 % (Figure 7.11).

Table 7.4: Results of concentration dosage for treating leachate using FeCl_3

Parameter	EQA A	EQA B	Raw leachate	Concentration (mg/L) of treated leachate at varying chemical dosage (500mL)						
				0.5	1	1.5	2	3	4	4.5
Turbidity			106	52.3	7.58	5.29	6.83	7.82	20.6	21.5
Colour			2190	520.0	456.0	297.0	355.0	420.0	401.0	520.0
COD			510	345.0	272.0	255.0	268.0	282.0	310.0	380.0
BOD ₅			487	350	312	286	298	301	313	335
NH ₄ -N			402	176	126	101	154	163	165	160
TSS			750	190.0	170.0	140.0	310.0	410.0	420.0	520.0
Ca			214	103.0	12.0	0.0	10.0	14.0	28.0	35.0
K			1444	469.0	367.0	0.0	256.0	356.0	567.0	798.0
Na			1489	986.0	567.0	0.0	235.0	543.0	976.0	987.0
Mg			226.58	165.0	89.0	45.0	56.0	76.0	98.0	156.0
Cu	0.2	1.0	0.213	0.128	0.09	0.0	0.07	0.092	0.112	0.097
Zn	1.0	1.0	0.595	0.265	0.30	0.04	0.20	0.267	0.223	0.437
Cd	0.01	0.02	0.043	0.023	0.0013	0.0	0.012	0.027	0.029	0.034
Ni			0.058	0.026	0.03	0.0	0.004	0.027	0.022	0.044
Pb	0.01	0.5	0.235	0.126	0.11	0.0	0.12	0.127	0.122	0.147

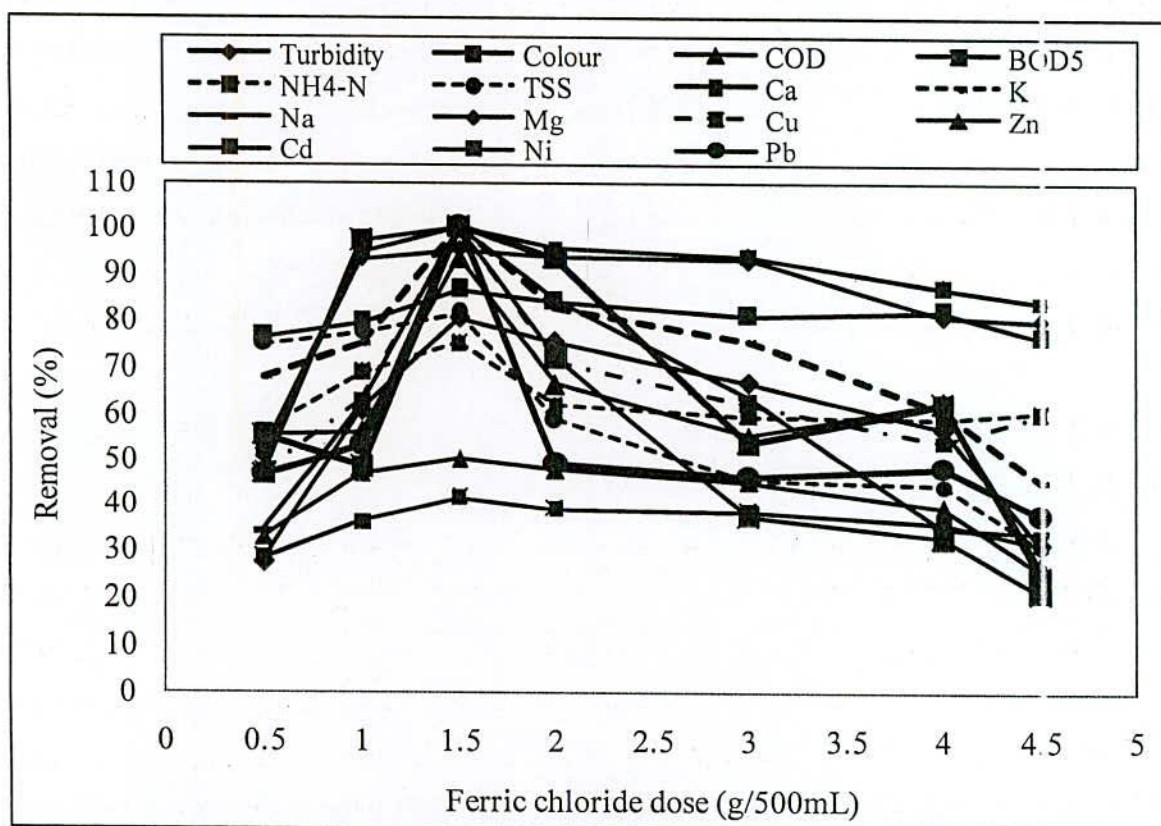


Figure 7.11: Reduction of inorganic, organic, metal and heavy metal concentrations in leachate using FeCl_3 dose

7.3.1.2 Treatment with PAC at Different Concentration

The efficiency of PAC for the removing of inorganic and organic compounds, metal and heavy metal concentrations in leachate is shown in Figure 7.12. The experimental results reveal that reduction of turbidity by PAC at optimum dosage of 4000mg/L was 89 %, while, for colour, COD, BOD₅, NH₄-N and TSS it was found 86, 41, 39, 69 and 79 %, respectively (Figure 7.12). Moreover, the reduction of Ca using PAC was 93 %, while, for K, Na, and Mg it was 83, 82 and 86 %, respectively (Figure 7.12). The efficiency in removing Zn was 85%, while for Cu, Cd, Ni and Pb it was 77, 72, 78 and 53 %, respectively (Figure 7.12).

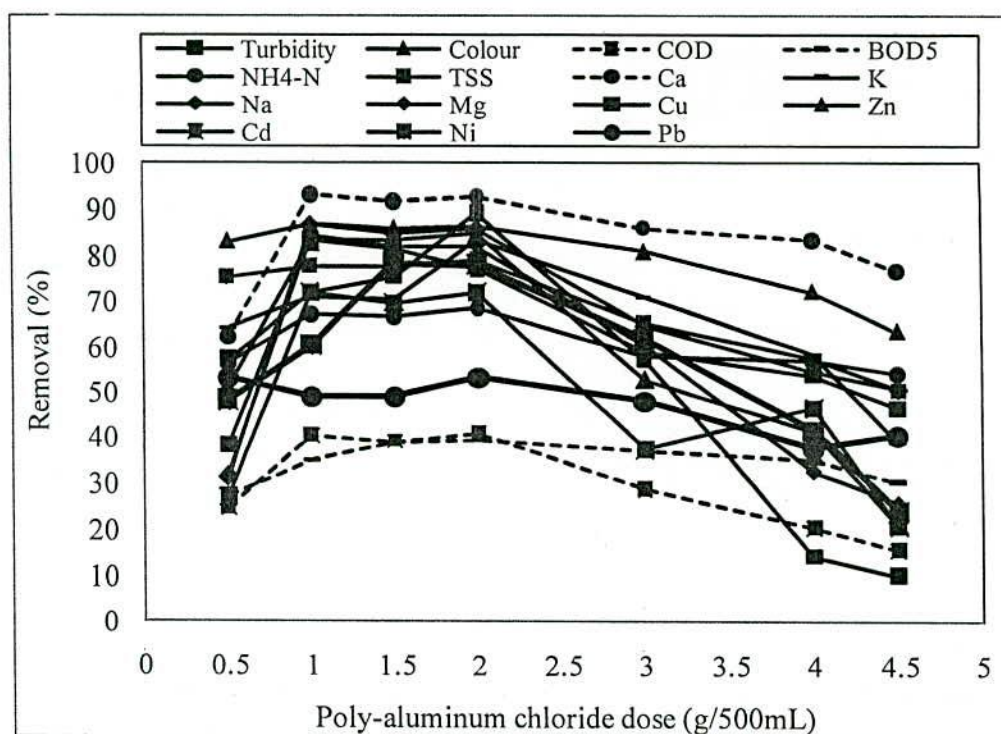


Figure 7.12: Reduction of inorganic, organic, metal and heavy metal concentrations in leachate using PAC dose

7.3.1.3 Treatment with FeSO₄ at Different Concentration

The efficiency of using FeSO₄ at varying dosages in removing of inorganic and organic compound as well as metal and heavy metal concentration in leachate is shown in Figure 7.13. Based on Figure 7.13, it was found the turbidity reduced by 93 %, while for colour, COD, BOD₅, NH₄-N and TSS it was found 87, 32, 38, 67 and 79 %, respectively. In contrast,

the efficiency in removing metal concentration of Ca, K, Na and Mg was found 92, 83, 82 and 83 %, respectively and heavy metals of Cu, Zn, Cd, Ni and Pb was 83, 82, 74, 60 and 94 %, correspondingly (Figure 7.13).

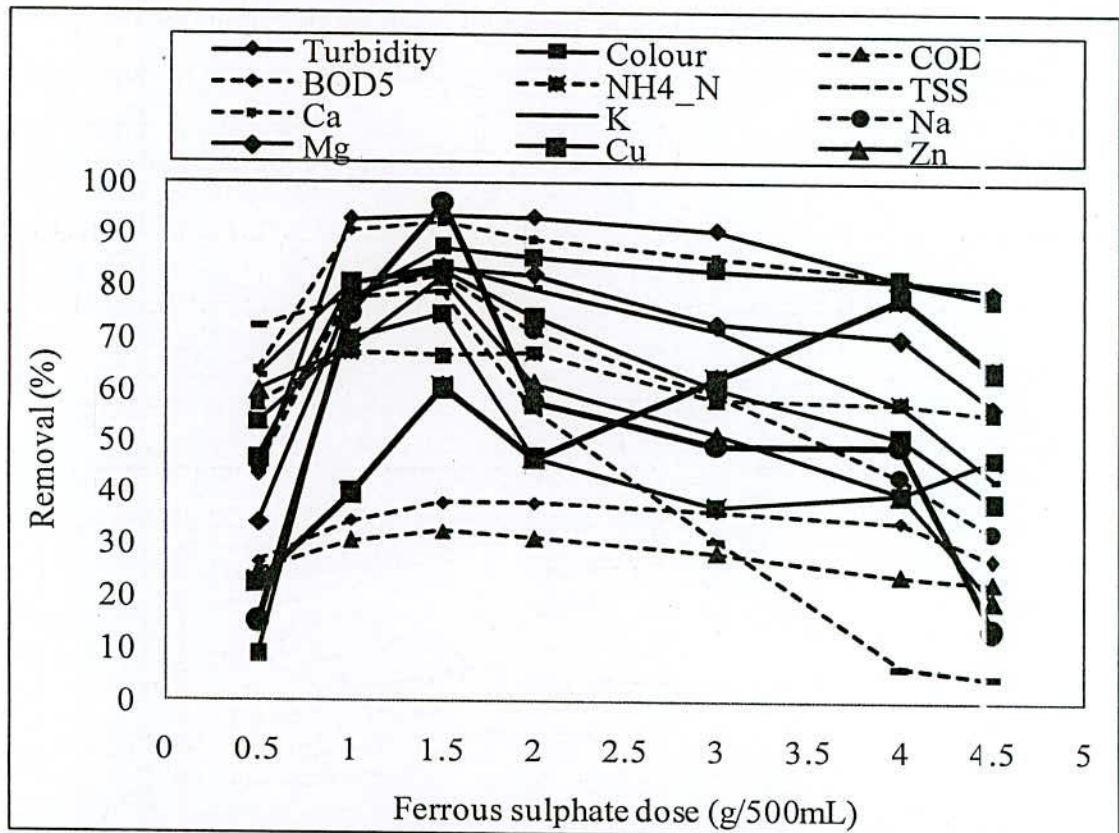


Figure 7.13: Reduction of inorganic, organic, metal and heavy metal concentrations in leachate using FeSO_4 dose

7.3.1.4 Treatment with $\text{Al}_2(\text{SO}_4)_3$ at Different Concentration

The reduction of turbidity using $\text{Al}_2(\text{SO}_4)_3$ was 92 %, while for leachate colour, COD and TSS was 88, 40 and 79 %, respectively at optimum dosage of 2000 mg/L as shown in Figure 7.14. Figure 7.14 gives a good view on the effect of the increased addition of $\text{Al}_2(\text{SO}_4)_3$ at the optimum dosage of 2000 mg/L, for the removal of metals concentrations of Ca, K, Na and Mg as well as the heavy metals of Cu, Zn, Cd, Ni and Pb in leachate and the curve increased towards the optimum and then it decreased. The reduction of Ca, K, Na and Mg using $\text{Al}_2(\text{SO}_4)_3$ was reduced by 94, 85, 84 and 89 %, correspondingly. However, the maximum efficiency in removing the Cu using $\text{Al}_2(\text{SO}_4)_3$ was 84 %, while for Zn, Cd, Ni and Pb was found 83, 77, 57 and 74 %, respectively at optimum dosage of 2000 mg/L (Figure 7.14).

Here, it of interested to note that COD was reduced 30-50 % only using the all chemical coagulants stated earlier. As seen from results using FeCl_3 , PAC, FeSO_4 and $\text{Al}_2(\text{SO}_4)_3$ the percentage reduction of all the pollutant parameters was increased up to an optimum dosage and beyond which decreased slowly. Similar findings are in agreed well with those obtained by Tatsi et al. (2003). This result is mainly due to the fact that the optimum dosage produced flocs a good structure and consistency, but in the lower dosage than the optimum dosage produced flocs small and the influence on settling velocity of sludge. In the higher dosage than optimum dosage, in addition to small size of flocs, restability of floc can be happened (Mahmud et al., 2012).

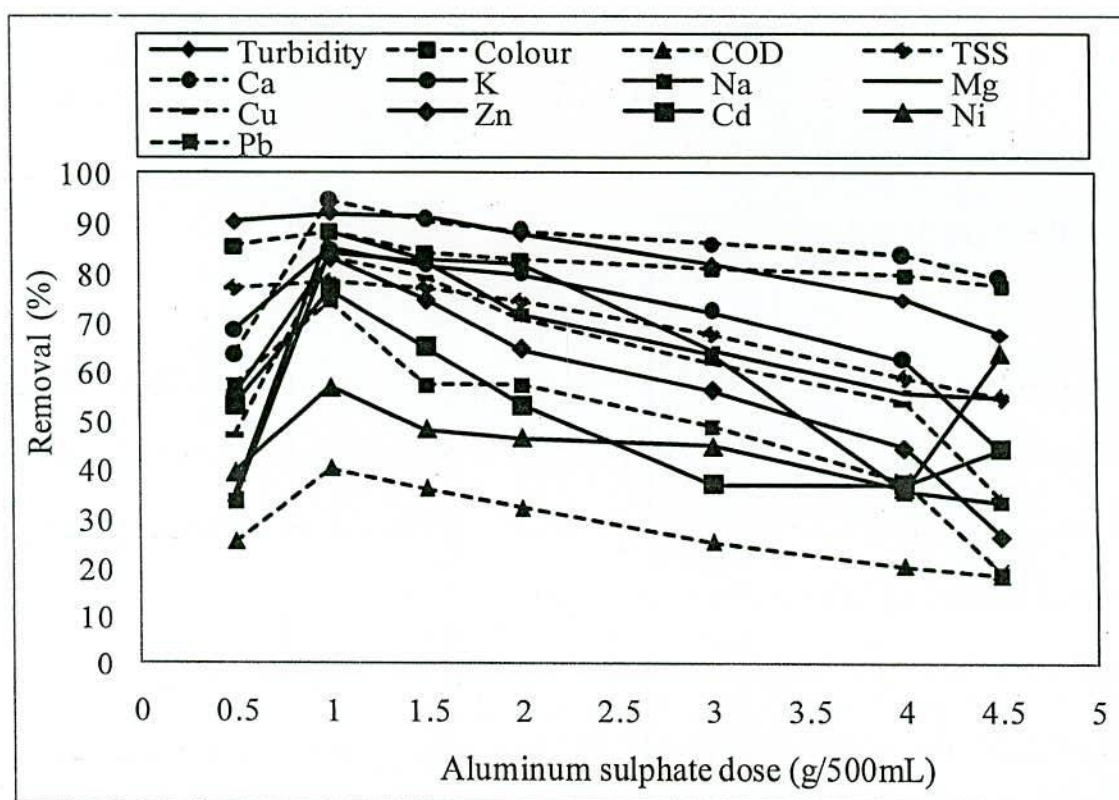


Figure 7.14: Reduction of inorganic, organic, metal and heavy metal concentrations in leachate using $\text{Al}_2(\text{SO}_4)_3$ dose

7.3.2 Regression Coefficient for Optimum Coagulant Dosage

To depict the accuracy of mixing amount of coagulation dosages for removing of pollutant in leachate may be represented by the regression coefficient (R^2) (Imran et al., 2011). In this study, the regression coefficient was analyzed to investigate the accuracy and efficiency of removing pollutant and hence evident in Figures 7.15-7.16. Figure 7.15 shows the effect of

concentration of FeCl_3 on the removal of colour and cadmium. The curve increased up to the optimum coagulant dosage (OpCD) and then it was decreased. Here, by separating the curve into two lines (Figures 7.15 a & b), regression analysis was performed to investigate the correlation of concentration of FeCl_3 on the removal of pollutant. It was showed that they are linearly significant and R^2 were ranged between 0.943 to 0.812 and 0.792 to 0.901 for colour and Cd, respectively. For example the regression coefficient for removing colour was $R^2 = 0.943$ approached the optimum dosage (Figure 7.15a), and $R^2 = 0.812$ after the optimum dosage (Figure 7.15b). However, the curve (Figure 7.15) was then split into two parts for analysis of Cd shown in Figures 7.15a & b. The regression coefficient for removing of Cd was 0.792 approached the optimum dosage (Figure 7.15a), and after the optimum dosage $R^2=0.901$ (Figure 7.15b).

Figure 7.16 shows the effect of PAC on the removal of turbidity and K and it was separated into two lines (Figures 7.16 a & b) as well as they are linearly significant and R^2 were ranged between 0.957 to 0.979 and 0.832 to 0.932, for turbidity and K, respectively. For example the regression coefficient for removing turbidity and K was $R^2 = 0.957$ and 0.832 approached the optimum dosage (Figure 7.16a), and $R^2 = 0.979$ and 0.932 after the optimum dosage (Figure 7.16b), respectively. The regression analysis of the other parameters was provided in the Appendix-D.

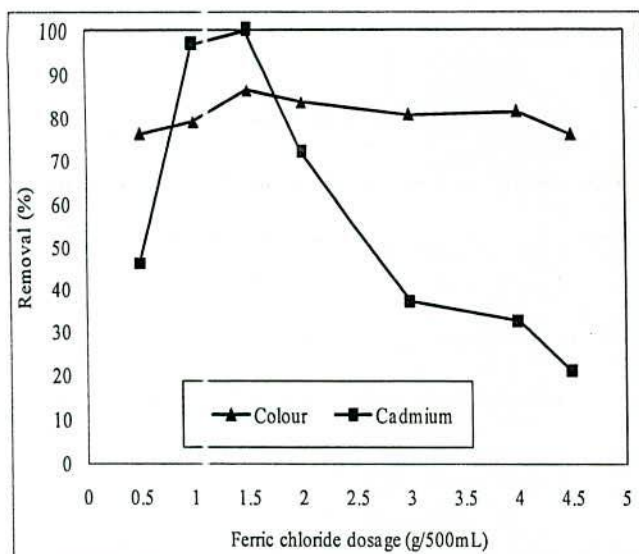


Figure 7.15: Effect of concentration of FeCl_3 for removal of colour and Cd in leachate

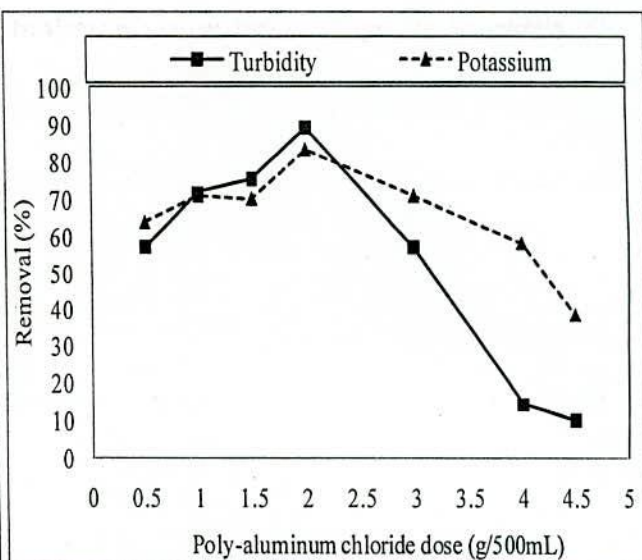


Figure 7.16: Effect of concentration of PAC for removal of turbidity and K in leachate

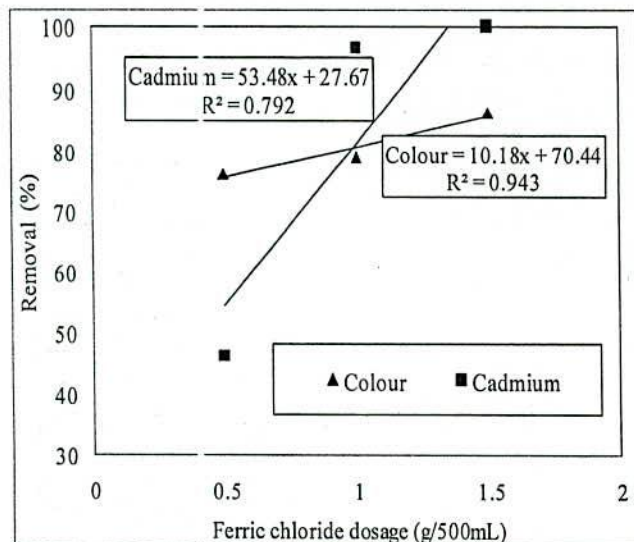


Figure 7.15a: Regression for removing colour and Cd using FeCl_3 approached the OpCD

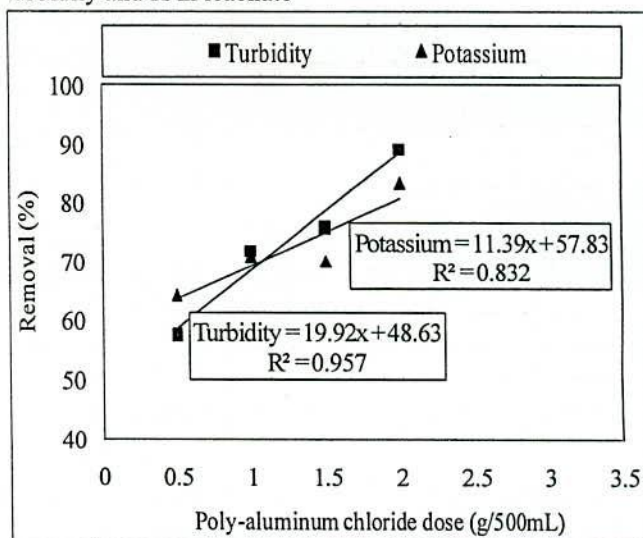


Figure 7.16a: Regression for removing turbidity and K using PAC approached the OpCD

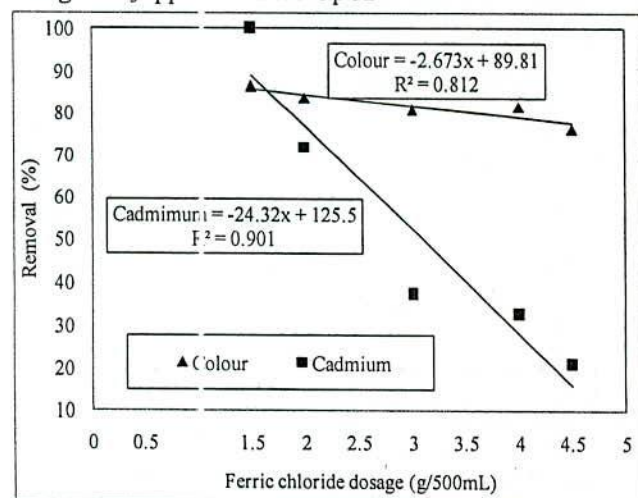


Figure 7.15b: Regression for colour and Cd using FeCl_3 after the OpCD

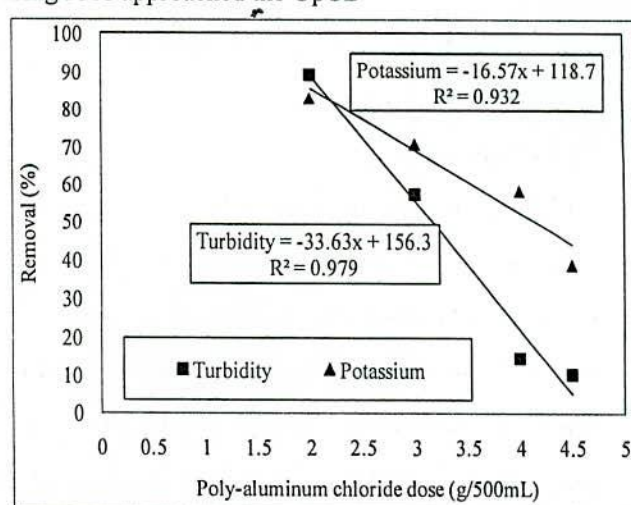


Figure 7.16b: Regression for turbidity and K using PAC after the OpCD

7.4 Effect of pH on the Optimum Coagulant Dosage

The range of pH was examined from 4 to 9 using FeCl_3 , PAC, FeSO_4 and $\text{Al}_2(\text{SO}_4)_3$ is shown in Figures 17-20, while the original pH value of raw leachate was 7.31. From Figures 17-20, efficiency of coagulation-flocculation was obtained in the pH of 6.5 to 7.5 for all the coagulant (approximately near the original pH) and the optimum pH was 7.0. However, in order to evaluate the effect of pH on the reduction of inorganic compound, metal and heavy metal, experiments were conducted by different chemical coagulants at varying pH of 4 to 9 and hence discussed in followings.

Table 7.5: Results of treatment at varying pH with optimum concentration using FeCl_3

Parameters	EQA A	EQA B	Untreated leachate	Treated of leachate with various pH at optimum concentration of FeCl_3					
				pH 4	pH 5	pH 6	pH 7	pH 8	pH 9
Turbidity			106	28.72	21.54	11.42	6.36	8.48	13.6
Colour			2190	540.0	358.40	306.60	262.80	306.0	350.40
COD			510	301.0	285.0	264.0	255.0	268.0	295.0
BOD ₅			487	357	317	309	295	300	310
NH ₄ -N			402	178	149	143	134	137	141
TSS			750	200.0	180.0	165.0	157.50	172.50	187.50
Ca			214.10	34.0	28.0	12.0	9.0	12.0	14.0
K			1444.20	364.0	256.0	245.0	201.0	236.0	268.0
Na			1488.70	317.0	259.0	227.0	201.0	256.0	236.0
Mg			226.58	83.0	48.0	44.0	32.0	90.0	96.0
Cu	0.2	1.0	0.213	0.40	0.40	0.40	0.30	0.50	0.50
Zn	1.0	1.0	0.595	0.160	0.115	0.105	0.100	0.120	0.127
Cd	0.01	0.02	0.040	0.021	0.012	0.011	0.0	0.002	0.015
Ni			0.060	0.031	0.022	0.011	0.0	0.012	0.015
Pb	0.01	0.5	0.24	0.120	0.100	0.021	0.0	0.022	0.017

7.4.1 Effect of pH on Coagulation with FeCl_3 and PAC

The effect of pH on the reduction of inorganic compound as well as metal and heavy metal, maintaining the concentration of FeCl_3 at optimum coagulant dosage of 3000mg/L is presented in Table 7.5 and also in Figure 7.17. The Figure 7.17 reveals that maximum removal of pollutant using FeCl_3 at optimum dosage of 3000mg/L at pH 7, while, minimum removal was found for most of the pollutants at pH 4. At pH 7, FeCl_3 was effective in removing turbidity, colour, COD, BOD₅, NH₄-N and TSS by 94, 88, 39, 67, 50 and 79%, respectively, while, minimum reduction of 73% for turbidity, 75% for colour, 41% for COD and 73% for TSS at pH 4. In contrast, Figure 7.17 reveals that the maximum reduction of Ca,

K, Na and Mg was found 96, 86, 86 and 86 % as well as Cd, Ni and Pb was 100 % except for Cu and Zn, it was 81 and 83 %, respectively. Moreover, the minimum reduction was found 81, 73, 51, 47, 49 % for Cu, Zn, Cd, Ni and Pb at pH 4. According to Jayabala (2005) treatment of leachate to remove As and Cd with FeCl_3 at optimum concentration (40mg/L) achieved 99.8 % reduction of As and 94 % of Cd at pH 6.

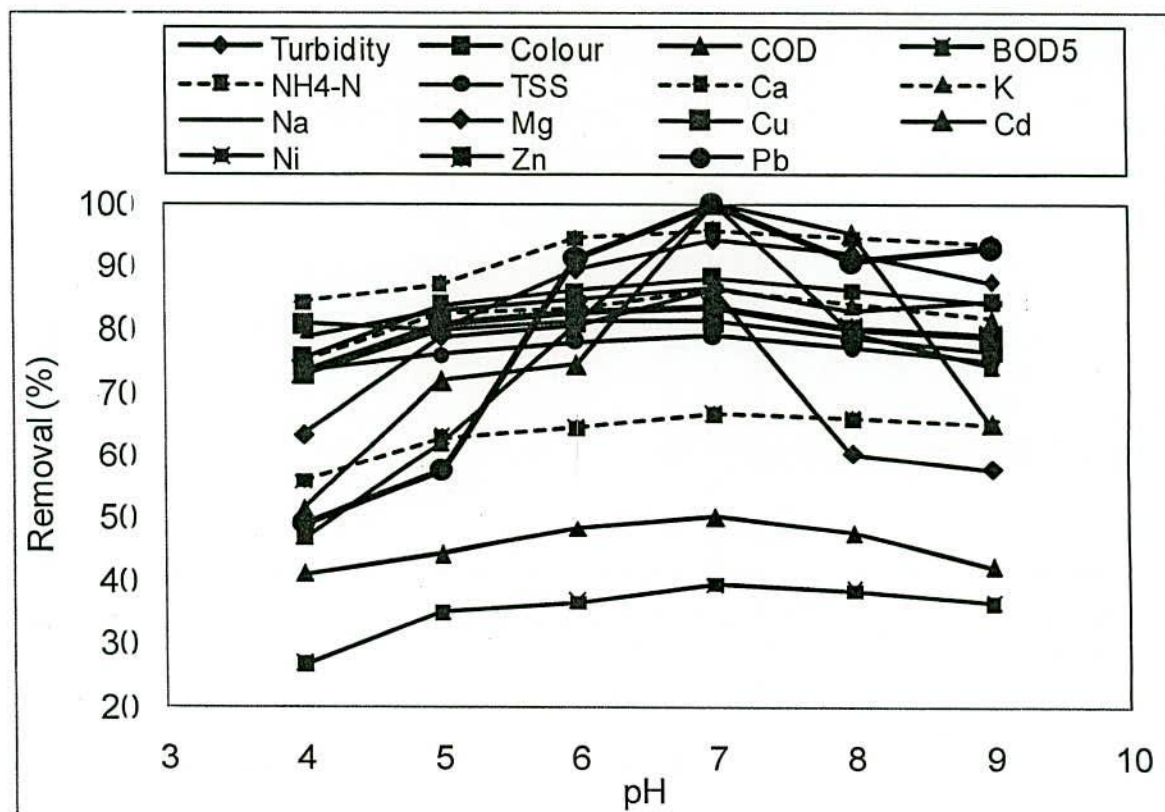


Figure 7.17: Reduction of inorganic, organic, metal and heavy metal concentrations at varying pH using FeCl_3 at optimum coagulation dosage

In contrary, the reduction of inorganic compounds as well as metal and heavy metal concentration in leachate using PAC at Optimum dosage of 4000 mg/L is shown in Figure 7.18. Here, it is interesting to note that the removal efficiency was increased in relation to the increasing of pH up to the optimum pH at 7, and then it was decreased. Based on Figure 7.18, it can be concluded that maximum removal efficiency of turbidity with of 91%, while, the minimum was found for COD with 45 %. Based on Figure 7.18, it can be seen that maximum reduction of metal occurred for Ca of 94 %, while minimum was found for Na of 84 %. Moreover, the reduction for PAC at pH 7 for Cu, Zn, Cd, Ni and Pb was 85, 82, 93, 86 and 96 %, respectively. The minimum reduction of heavy metals occurred at pH 4 and it was 75 % for Cu, 55 % for Zn, 72 % for Cd, 53 % for Ni and 53 % for Pb.

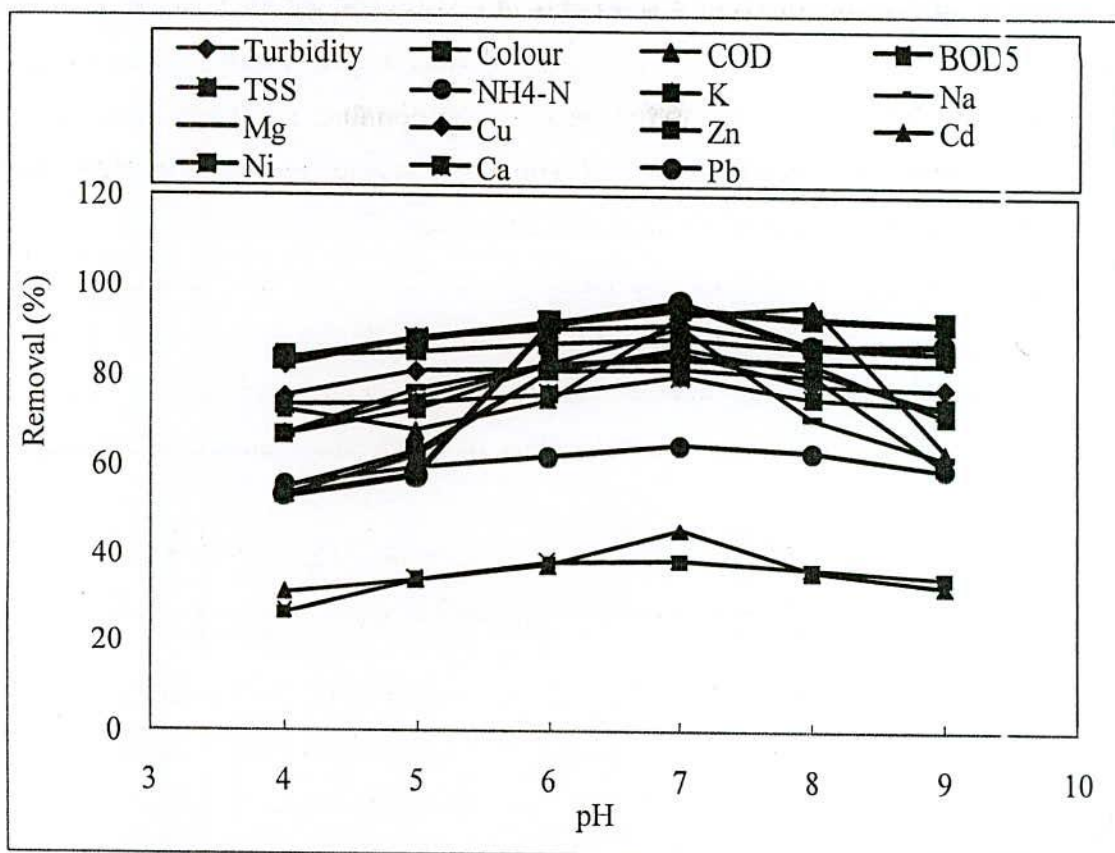


Figure 7.18: Reduction of inorganic, organic, metal and heavy metal concentrations at varying pH using PAC at optimum coagulation dosage

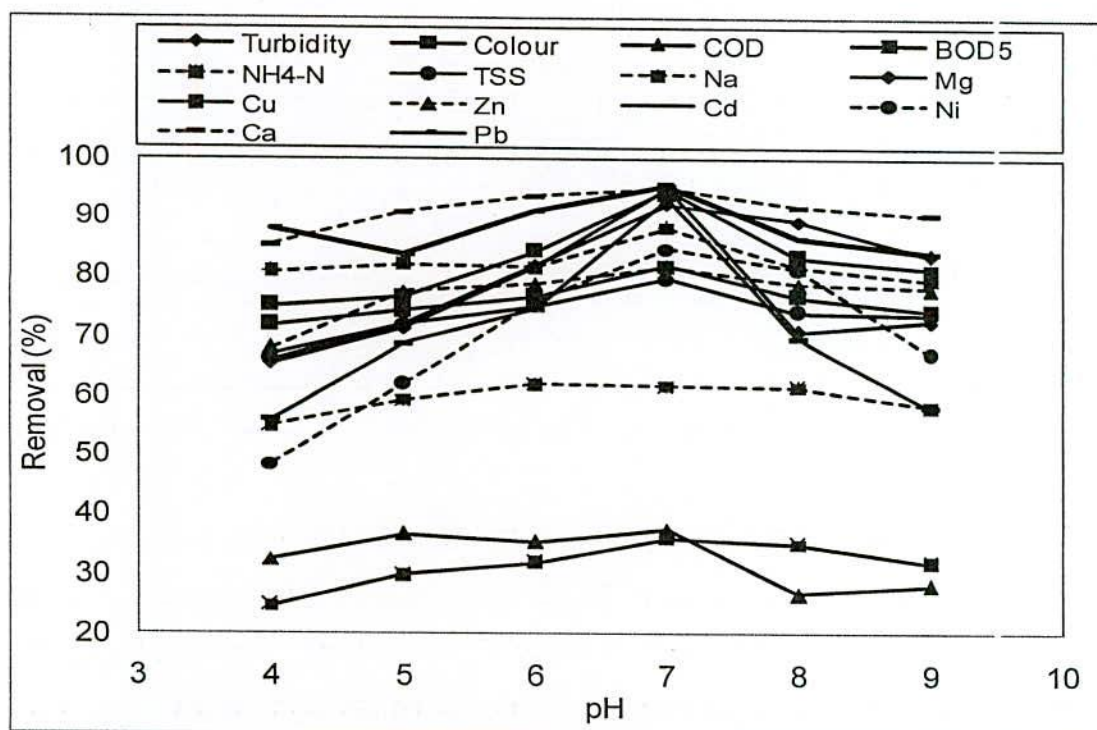


Figure 7.19: Reduction of inorganic, organic, metal and heavy metal concentrations at varying pH using FeSO₄ at optimum coagulation dosage

7.4.2 Effect of pH on Coagulation with FeSO_4 and $\text{Al}_2(\text{SO}_4)_3$

The maximum reduction was occurred using FeSO_4 at optimum pH 7 for colour was 95 % while minimum was found for COD of 37 % (Figure 7.19). However, for Ca, K, Na and Mg was reduced by 95, 88, 88 and 95 %, correspondingly, as well as 82, 82, 93, 84 and 95 % was found for Cu, Zn, Cd, Ni and Pb, respectively (Figure 7.19). The reduction of pollutants in leachate using the optimum dosage of 2000 mg/L, for $\text{Al}_2(\text{SO}_4)_3$ is evident in Figure 7.20. Here, it is interesting to note that the removal efficiency was increased with in relation to the increasing of pH values up to the optimum values of pH 7, and then it was decreased. The similar trend was observed by Steensen (1997) using $\text{Al}_2(\text{SO}_4)_3$ at pH 7. Here, it can be noted that minimum was found for COD with 39 % for alum at pH 7 (Figure 7.20) while, maximum was found of calcium with the values of 94 % (Figure 7.20).

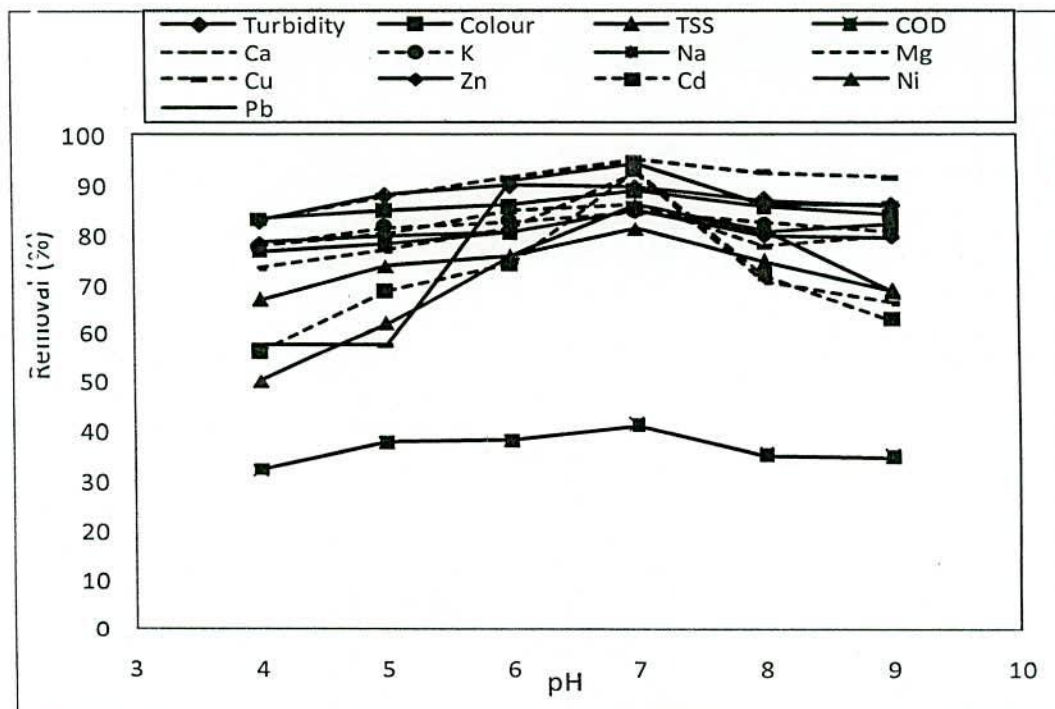


Figure 7.20: Reduction of inorganic, organic, metal and heavy metal concentrations at varying pH using $\text{Al}_2(\text{SO}_4)_3$ at optimum coagulation dosage

7.5 Results of Leachate Treatment through Optimum Coagulation Dosage

The optimum results were achieved using different coagulants of FeCl_3 , PAC, FeSO_4 and $\text{Al}_2(\text{SO}_4)_3$ at optimum dosage of 3000, 4000, 3000 and 2000 mg/L, respectively, at optimum pH 7 and mixing speed 110 rpm for the removal of pollutants in leachate are evident in Table

7.6 and also in Figure 7.21. At optimum dosage with varying pH, four chemical coagulants show varying percentage reduction in concentration of parameters. FeCl_3 was able to achieve complete removal of Ca, K, Na, Cu, Cd, Ni and Pb at optimum dosage, while at optimum pH it was able to achieve complete removal of Cd, Ni and Pb. Results showed that optimum reduction of turbidity was found 95, 89 and 93 %; 93, 85 and 82 % for the reduction of Zn, for FeCl_3 , PAC and FeSO_4 at optimum dosage, respectively. The removal efficiency for most of the pollutants, FeCl_3 was more effective than the other coagulants at optimum pH 7.

Table 7.6: Comparative reduction of pollutant using coagulant at optimum condition

Coagulant	Optimum Condition	Removal efficiency (%)														
		Turbidity	Color	COD	TSS	BOD ₅	NH ₄ -N	Calcium	Potassium	Sodium	Manganese	Copper	Zinc	Cadmium	Nickel	Lead
FeCl_3	3000mg/L pH 7	95	86	50	81	41	75	100	100	100	80	100	93	100	100	100
		94	88	50	79	39	67	96	86	86	86	81	83	100	100	100
PAC	4000mg/L pH 7	89	86	41	79	39	69	93	83	82	86	77	85	72	78	53
		91	88	45	80	38	64	94	84	84	91	85	82	93	86	96
FeSO_4	3000mg/L pH 7	93	87	32	79	38	67	92	83	82	83	83	82	74	60	96
		92	95	37	79	36	62	95	88	88	95	82	82	93	84	95
$\text{Al}_2(\text{SO}_4)_3$	2000mg/L pH 7	92	88	40	79	37	66	94	85	84	89	84	83	77	57	74
		90	89	41	81	35	63	95	85	85	92	86	85	93	86	94

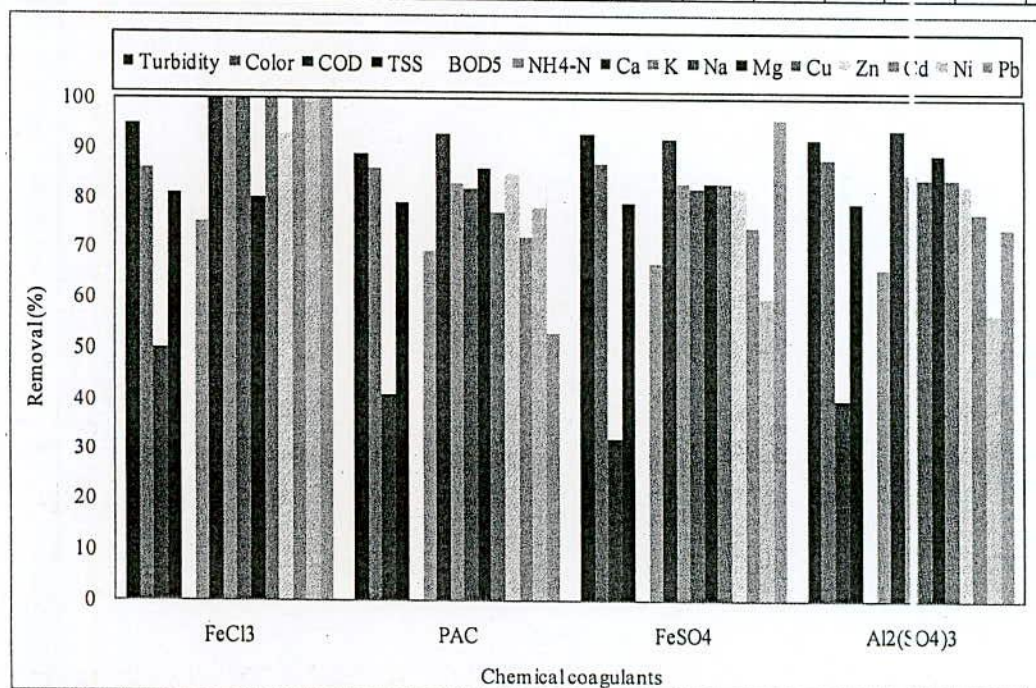


Figure 7.21: Results of leachate treatment with various coagulants at optimum coagulation dosage

Results indicate that leachate treatment with FeCl_3 at optimum dosage of 3000 mg/L at pH 7 with mixing speed 110 rpm was able to reduce Cd, Ni and Pb by 100%, to 0 mg/L which is below the Environmental Quality requirements (Sewage and Industrial Effluent) as well as the maximum discharging standard for landfill leachate from selected countries (USA, Germany, Hong Kong and Malaysia) (Figure 7.22a). Moreover, treatment with FeCl_3 at optimum dosage of 3000 mg/L at pH 7 with mixing speed 110 rpm was only able to reduce COD by 50 %, to 255mg/L, which is still above Environmental Quality requirements (Sewage and Industrial Effluent), Bangladesh standards for discharging treated leachate into Inland surface water and maximum discharging standard for landfill leachate from selected countries (USA, Germany, France, Hong Kong, South Korea and Malaysia) (Figure 7.22b).

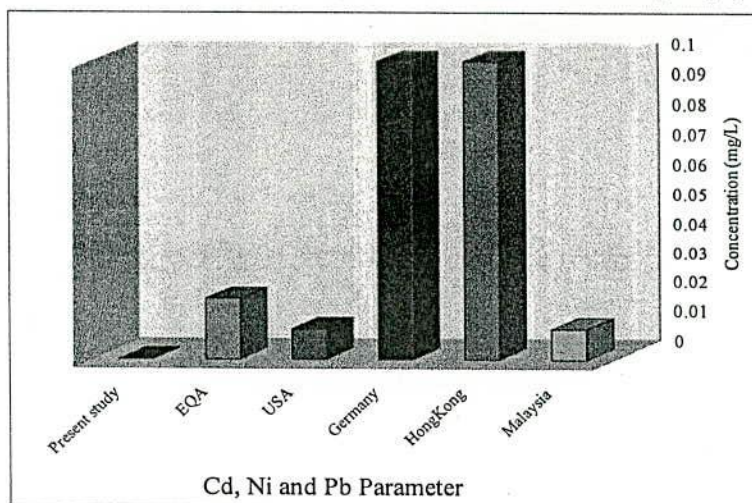


Figure 7.22a: Compared the efficiency of FeCl_3 removal of Cd, Ni and Pb with standard tools

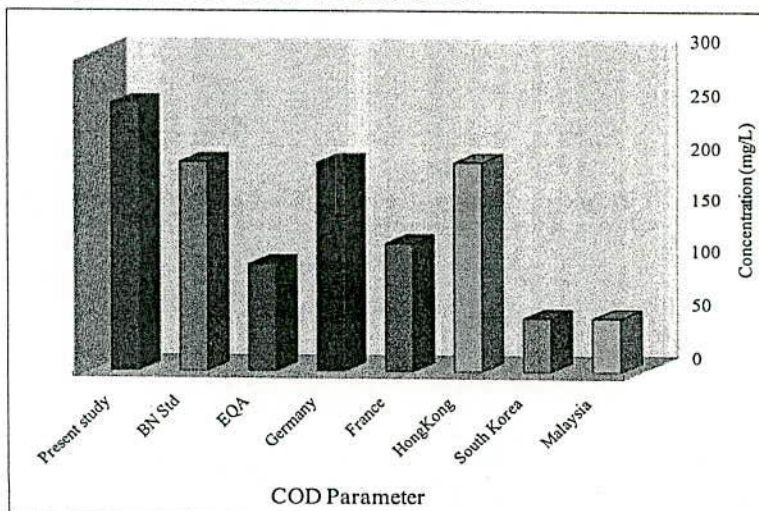


Figure 7.22b: Compared the efficiency of FeCl_3 removal of COD with standard tool

In contrast, PAC at 4000 mg/L, pH7 and mixing speed 110 rpm has an ability to remove the Zn (Figure 7.23a) by 82 %, to 0.11 mg/L, Ni (Figure 7.23b) by 86, to 0.008 mg/L which is below the environmental quality requirements as well as maximum discharging standard for leachate from selected countries (USA, Germany, Hong Kong and Malaysia). The finding of this study using FeCl_3 and PAC for the removal of heavy metals is quite similar to the finding observed by Jayabala (2005) and stated that FeCl_3 at 40 mg/L and pH 6 was able to reduce As and Cd to 0.0015 mg/L which is below the EQA requirements, moreover, using PAC at 4 mg/L was able to reduce As to 0.409 mg/L at pH 8, which was still above EQA requirements.

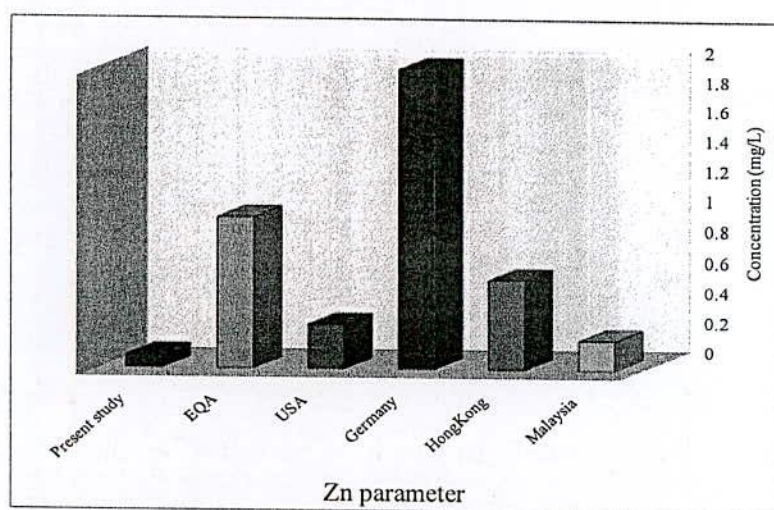


Figure 7.23a: Compared the efficiency of PAC on removal of Zn with standard tools

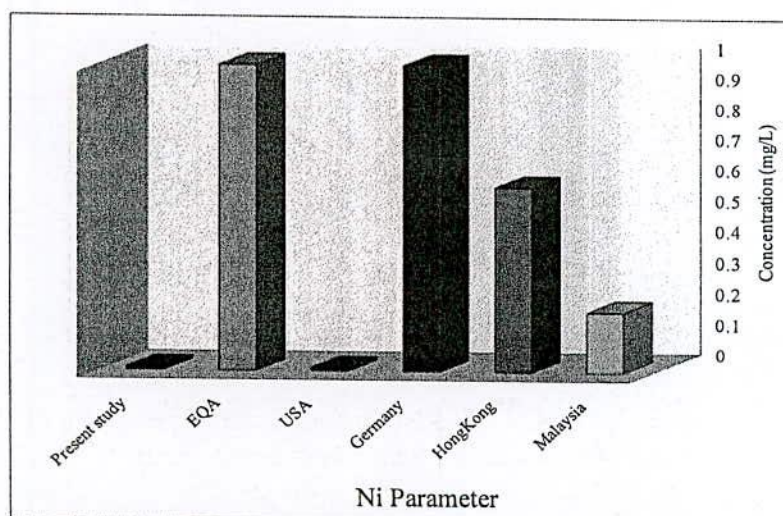


Figure 7.23b: Compared the efficiency of PAC on removal of Ni with standard tools

Experimental results showed that FeCl_3 was the effective chemical compared to PAC, FeSO_4 and $\text{Al}_2(\text{SO}_4)_3$ because this chemical was able to give more reduction. Result reveals that maximum reduction using FeCl_3 at optimum dosage of 3000 mg/L of Ca, K, Na, Cu, Cd, Ni and Pb was 100 %, while for Mg and Zn was 80 and 93 %, correspondingly. The reduction using PAC at optimum dosage of 4000 mg/L for Ca, K, Na, Mg, Zn, Cu, Cd, Ni and Pb was 93, 83, 82, 86, 85, 77, 72, 78 and 53 %, respectively. Moreover, using the FeSO_4 at optimum dosage of 3000 mg/L, the efficiency for removing of turbidity was 93 %, while for colour, COD and TSS it was found 87, 32 and 79 %, respectively, as well as the metal concentrations of Ca, K, Na and Mg was found 92, 83, 82 and 83 % and heavy metal of Cu, Zn, Cd, Ni and Pb was 83, 82, 74, 60 and 94 %, correspondingly. In contrary, the reduction using $\text{Al}_2(\text{SO}_4)_3$ at optimum dosage of 2000 mg/L for Ca, K, Na, Mg, Zn, Cu, Cd, Ni and Pb was 94, 85, 84, 89, 84, 83, 77, 57 and 74 %, respectively. Experimental results showed that FeCl_3 was the effective chemical compared to PAC, FeSO_4 and $\text{Al}_2(\text{SO}_4)_3$ because it was able to give more reduction of pollutant.

Here it can be noted that to reduce the pollutant potential in lysimeter leachate by using FeCl_3 at optimum condition, the leachate samples collected from four distinct operational conditions such as detection (A_1), collection (A_2) system of open dump lysimeter-A, collection system of sanitary lysimeter-B and C were tested in the laboratory and the concentration of treated leachate shown in Table 7.7.

Table 7.7: Comparison of treated lysimeter leachate concentration, maximum discharge standard for landfill and regulatory standards for standards set by DoE on ECR, 97 for Effluent (Wastewater) as well as industrial wastewater as specified in the Environmental Quality (Sewage and Industrial Effluents) Regulation, 1979; EQA, 1974)

Parameter	Standard set by DoE (Bangladesh) ⁽¹⁾			India ⁽²⁾	German ⁽³⁾	Hong Kong ⁽⁴⁾	Standard A ⁽⁵⁾	Standard B ⁽⁵⁾	Concentration of treated leachate of lysimeter			
	Inland Surface Water	Public Sewerage System	Irrigated Land						A ₁	A ₂	B	C
Cr	0.5	1	1	2.0	0.5	0.1	0.2	1.0	0.045	0.04	0.08	0.07
Pb	0.1	1	0.1	0.1	0.5	0.1	0.01	0.5	0	0	0	0
COD	200	400	400	250	200	200	50	100	55	85	60	57
Hg	0.01	0.01	0.01	0.01	0.01	0.02	0.005	0.05				
BOD ₅	50	250	100	30	20	800	20	50	85	102	88	80
As	0.2	0.05	0.2	0.2			0.05	0.1	0.01	0.04	0.03	0.02
CN	0.1	2	0.2	0.2			0.05	0.1				
Phenol	1	5	1	1.0			0.001	1.0				
Zinc	5	10	10	5.0	2.0	0.6	1.0	1.0	1.13	0.92	0.55	0.576
pH	6-9	6-9	6-9	5.5-9.0	5.5-8.5	5-7.5	6.0-9.0	5.5-9.0	6.1	6.27	6.45	6.21
TKN	100	100	100	100	70	100			95	180	112	51
Ni	1	2	1	3.0	1.0	0.6	0.2	1.0	0	0	0	0
NH ₄ -N	50	75	75	50	30	5.0						
TCB									27	45	25	33
TDS	2100	2100	2100	2100	600	500			980	1100	1002	780
Cu	0.5	3	3	3.0	0.5	1.0	0.2	1.0	0.04	0.04	0.04	0.04
Cl ⁻	600	600	600	1000	800	850	1.0	2.0	540	900	602	511
Fe	2	2	2						5.1	3.2	3.3	2.1

Notation: ¹Jannatul Ferdous 2013 (Standards Set by DoE on ECR, 97 for Effluent (Wastewater, inland surface water); ²Kumar and Alappat 2003a; ³Meier et al., 2002 and ⁴Environmental Protection Department (EPD) (Maximum discharge standard for landfill leachate from selected countries) and

⁵Standard A: Upstream of water supply intake and ⁵Standard B: Downstream of water supply intake (Regulatory Standards for industrial wastewater as specified in the Environmental Quality (Sewage and Industrial Effluents) Regulation, 1979; EQA, 1974)

All units are in mg/L, except pH and TCB.

7.6 Comparison of LPI of Treated Leachate with Maximum Discharge Standards

The accepted limit for the disposal of leachate into water bodies and their corresponding *LPI* as per the standards set by DoE (Bangladesh) on ECR, 97 for Effluent (Wastewater) reported by (Jannatul, 2013), the management and handling rules (The Gazette of Government of India 2000), in Germany reported by Meier et al. (2002) as well as in Hong Kong stated by Environmental Protection Department, EPD (2005) provided in Table 7.8. Result reveals that concentration of all the parameters of leachate in lysimeter-A, B and C, exceed the permissible limits of treated leachate. Here, it can be concluded that comparison of leachate characteristics with the standards set for the disposal of treated leachate verifies the fact that

leachate generated from lysimeter is highly contaminated and will have to be treated before discharging into the natural streams. To these attempts, for reducing pollutant potential in lysimeter leachate by using FeCl_3 at optimum condition, the leachate samples collected from four distinct operational conditions such as detection (A_1), collection (A_2) system of open dump lysimeter-A, collection system of sanitary lysimeter-B and C were tested in the laboratory and the concentration of treated leachate shown in Table 7.8. Then the LPI of the treated lysimeter leachate as well as all the maximum discharge standards were evaluated provided in the Table D.17 in the Appendix-D. Here, it is interesting to note that the derived LPI of treated leachate of landfill lysimeter was found within the limit of maximum leachate discharge standards (Figure 7.24). Finally, it can be concluded that generated leachate from lysimeter at KUET campus may be discharge without further treatment into the natural streams.

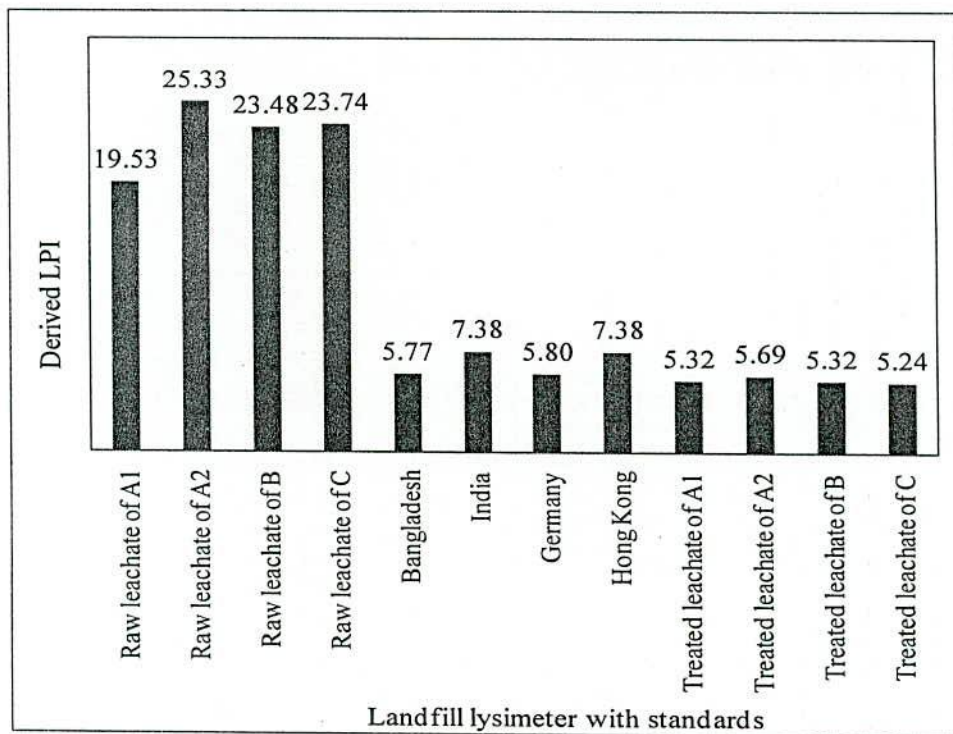


Figure 7.24: Comparison of derived LPI of raw and treated leachate with disposal standards

Table 7.8: Treated leachate concentration of landfill lysimeter and maximum leachate discharge standards

Serial No.	Leachate pollutant	Leachate disposal standards, c_t				Treated leachate concentration of landfill lysimeter			
		Bangladesh	India	Germany	Hong Kong	A ₁	A ₂	B	C
1	Chromium	0.5	2	0.5	0.1	0.045	0.04	0.08	0.07
2	Lead	0.1	0.1	0.5	0.1	0	0	0	0
3	COD	200	250	200	200	55	85	60	57
4	Mercury	0.01	0.01	0.01	0.02	No standard	No standard	No standard	No standard
5	BOD ₅	50	30	20	800	85	102	88	80
6	Arsenic	0.2	0.2	No standard	No standard	0.01	0.04	0.03	0.02
7	Cyanide	0.1	0.2	No standard	No standard	No standard	No standard	No standard	No standard
8	Phenol	1	1	No standard	No standard	No standard	No standard	No standard	No standard
9	Zinc	5	5	2	0.6	1.126	0.92	0.55	0.576
10	pH	6-9	5.5-9.0	5.5-8.5	5-7.5	6.1	6.27	6.45	6.21
11	TKN	100	100	70	100	95	180	112	51
12	Nickel	1	3	1	0.6	0	0	0	0
13	TCB	No standard	No standard	No standard	No standard	No standard	No standard	No standard	No standard
14	NH ₄ -N	50	50	30	5	27	45	25	33
15	TDS	2100	2100	600	500	980	1100	1002	780
16	Copper	0.5	3	0.5	1	0.04	0.04	0.04	0.04
17	Chlorides	600	1000	800	850	540	900	602	511
18	Total Iron	2	No standard	No standard	No standard	5.1	3.2	3.3	2.1
Corresponding LPI		5.77	7.38	5.80	7.38	5.32	5.69	5.32	5.24

All units are in mg/L, except pH

7.7 Summary of the Findings

The phytoremediation treatment systems using aquatic reactors were more effective when the concentration was low and no single treatment system showing commonly the better performance for all the pollutant in leachate. Moreover, through the phytoremediation treatment process the removal efficiency was not satisfactory with respect to the permissible limit of leachate discharge standards. In addition to meet the standard discharges condition then the leachate was treated through the chemical coagulation process by using FeCl_3 , PAC, FeSO_4 and $\text{Al}_2(\text{SO}_4)_3$ in various dosages and pH. Result revealed that FeCl_3 more effective for removing pollutant. In the laboratory, leachate was further treated by using FeCl_3 at optimum dosage and the concentration and consequently the values of LPI of treated leachate were found within the limit of maximum discharge standards. It can be concluded that leachate generated from lysimeter may be discharge after required level of chemical treatment into the natural streams to maintain the limit of maximum discharge standards..

Chapter Eight

Conclusions and Recommendations

8.1 Conclusions

Based on the observed results, the following conclusions have been drawn:

1. The rapid leachate production in an open dump lysimeter-A than that of the other two sanitary lysimeter-B and C indicated the importance of the barrier layer of CCL and the cover materials selection in landfill design.
2. The field level landfill simulation with various top cover designs and operational condition of lysimeter greatly influences the leachate quality.
3. The sanitary lysimeter-B with an extra CCL showed the lowest settlement than that of sanitary lysimeter-C and indicated the importance of the compaction density as well as the cap and base liners in solid waste landfill.
4. During rainy season, COD load in leachate increased rapidly in relation to the increasing of elapsed period of MSW deposition for the collection system of lysimeter-A, B and C, while, during dry season, it was stable because of the decrease of leachate production.
5. Both the composition in terms of CH_4 , CO_2 and O_2 as well as the flow rate of LFG generated from MSW in landfill lysimeter varied significantly in relation to the variation of lysimeter operational condition.
6. Sanitary lysimeter-C showed higher composition of LFG in compare to the lysimeter-B due to the providing of lower compaction of cap liner in sanitary lysimeter-C.
7. In absence of CCL and hence percolation of rainwater facilitated rapid degradation of MSW in open dump lysimeter-A and resulted in the higher settlement than that of sanitary lysimeter-B and C.
8. In case of sanitary lysimeter-B and C, the leachate generation lower than that of open dump lysimeter-A due to the providing of cap liner in sanitary lysimeter-B and C, played an important role to reduce the percolation of rainwater.
9. Chloride increased, while pH, TS, EC and COD concentration decreased in leachate regarding to entire lysimeter operational system during the rainy season. The COD was initially high concentration, but rapidly decreased with the rainfall events.

10. The open dump lysimeter-A had lower TKN, $\text{NH}_4\text{-N}$ and TKN load, while both the COD concentration and load was higher compared with sanitary lysimeter-B and C.
11. Sanitary lysimeter-B, not only had the lowest leachate generation, but also produced reasonable low COD concentration and load compared with open dump lysimeter-A.
12. Metal concentrations of Ca and K as well as heavy metal concentrations of Cd, Cu, Zn and Mn was comparatively higher, while, metal concentrations of Mg and Fe as well as heavy metals of Cr, Pb and Ni lower in leachate of open dump lysimeter.
13. The knowledge of leachate quality will be useful in planning and providing remedial measures of proper liner system in sanitary landfill design and leachate treatment.
14. Result showed that the component of organic fraction in leachate for entire lysimeter operating system higher against the other counter fraction i.e. inorganic and heavy metal fraction and consequently showed the higher LPI_{or} than that of LPI_{in} and LPI_{hm} .
15. Result reveals that among four lysimeter operating system, collection system of open dump lysimeter-A had the highest sub-LPIs and overall LPI , while, detection system of open dump lysimeter-A lowest.
16. LPI can be used as a tool to assess the leachate pollution potential from landfill lysimeter particularly at places where there is a high risk of leachate migration and pollution of groundwater.
17. The possible errors involved in calculating LPI due to the nonavailability of data were analyzed. Result revealed that errors in the estimating of LPI may be high if the data for the pollutants having significantly high or low concentration are not available.
18. The comparison of the leachate characteristics with the standards set for the disposal of treated leachate verified the fact that the leachate generated from lysimeter was highly contaminated and the LPI exceed the LPI value of treated leachate and proper treatment will have to be ensured before discharging the lysimeter leachate.
19. The phytoremediation treatment systems were more effective when the concentration was low and no single treatment system showing commonly the better performance for all the pollutant in leachate.
20. Results showed that maximum reduction using FeCl_3 at OpCD of 3000mg/mL of Ca, K, Na, Cu, Cd, Ni and Pb was 100%, while for Mg and Zn was 80 and 93%, correspondingly.
21. The reduction using PAC at OpCD of 4000mg/L for Ca, K, Na, Mg, Zn, Cu, Cd, Ni and Pb was 93, 83, 82, 86, 85, 77, 72, 78 and 53%, respectively.

22. Moreover, using the FeSO_4 at OpCD of 3000mg/L, the efficiency for removing of turbidity was 93%, while for colour, COD and TSS it was found 87, 32 and 79%, respectively, as well as the metal concentrations of Ca, K, Na and Mg was found 92, 83, 82 and 83% and heavy metal of Cu, Zn, Cd, Ni and Pb in leachate was 83, 82, 74, 60 and 94%, correspondingly.
23. In contrary, the reduction using $\text{Al}_2(\text{SO}_4)_3$ at OpCD of 2000mg/L for Ca, K, Na, Mg, Zn, Cu, Cd, Ni and Pb was 94, 85, 84, 89, 84, 83, 77, 57 and 74 %, respectively.
24. Experimental results showed that FeCl_3 was the effective chemical compared to PAC, FeSO_4 and $\text{Al}_2(\text{SO}_4)_3$ because this chemical was able to give more reduction of pollutant in leachate.
25. Using FeCl_3 at optimum dosage, the concentration of contaminants in leachate and consequently the vales of LPI of treated leachate of landfill lysimeter was found within the limit of maximum leachate discharge standards. Finally, it can be concluded that leachate generated from lysimeter may be discharge after required level of chemical treatment into the natural streams to maintain the limit of maximum discharge standards.

8.2 Recommendations

Based on the result of landfill lysimeter studies the following recommendations could be further implied for future studies.

1. Experimental study on leachate storage during rainy season and recirculation during dry season for the evaluation of better leachate management technique and biodegradation of MSW.
2. Study on pretreatment, natural/passive aeration and leachate circulation combination under the tropical influence for improved degradation and sustainable landfilling.
3. Determination of long term effect of methane oxidation in top covers soil and changes in its properties.
4. Effective methane oxidation properties in combination with leachate recirculation system. Leachate recirculation would provide enough moisture and nutrients for the microorganisms and thus increase the biodegradation of MSW.

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Appendix-A

Rainfall Intensity, Leachate Volume and Settlement Data

Table A.1 Variation of Rainfall Intensity during the Experimental Period

Season	Date	Time (Day)	Rainfall (mm)
Rainy Season	8/1/08	48	0.0
	8/11/08	50	13.0
	8/15/08	60	41.0
	8/29/08	64	23.0
	9/17/08	78	29.0
	9/26/08	96	57.0
	9/27/08	105	85.0
	10/25/08	106	6.0
	10/26/08	134	30.0
	10/27/08	135	128.0
Dry Season	11/10/08	136	0.0
	11/28/08	149	0.0
	12/20/08	167	0.0
	2/2/09	189	0.0
	2/24/09	261	0.0
	3/7/09	287	0.0
	4/17/09	300	0.0
	4/28/09	310	0.0
	5/8/09	321	0.0
	5/29/09	331	0.0
	6/3/09	352	0.0
	6/27/09	364	0.0
	7/5/09	372	35.0
Rainy Season	7/19/09	386	30.0
	7/26/09	393	32.0
	8/12/09	409	45.0
	8/17/09	414	36.0
	8/28/09	425	26.0
	9/4/09	431	14.0
	9/17/09	444	29.0
	9/27/09	454	34.0
	10/12/09	469	0.0
Dry Season	10/28/09	485	0.0
	11/8/09	495	0.0
	11/24/09	511	0.0
	1/3/10	520	0.0
	1/27/10	543	0.0

	2/7/10	553	0.0
	3/27/10	603	0.0
	4/12/10	618	0.0
	4/27/10	633	0.0
	5/25/10	661	0.0
Rainy Season	6/17/10	683	32.0
	6/25/10	691	41.0
	6/28/10	694	40.0
	7/4/10	700	28.0
	7/5/10	701	35.0
	7/23/10	719	30.0
	8/5/10	731	27.0
	8/19/10	745	36.0
	8/28/10	754	26.0

Table A.2 Variation of Leachate Volume during the Experimental Period

Season	Date	Time (Day)	Cumulative amount of rainfall (mm)	Cumulative amount of leachate volume (L) at varying operational condition of landfill lysimeter			
				A ₁	A ₂	B	C
Rainy Season	8/1/08	48	0	2	1	1	1
	8/11/08	50	13	7	25	19	23
	8/15/08	60	54	16	61	41	50
	8/29/08	64	77	20	89	59	73
	9/17/08	78	106	25	121	79	99
	9/26/08	96	163	35	163	111	134
	9/27/08	105	248	47	215	153	179
	10/25/08	106	254	48	220	157	187
	10/26/08	134	284	51	250	179	210
	10/27/08	135	412	58	315	224	266
Dry Season	11/10/08	136	412	59	321	227	273
	11/28/08	149	412	60	327	229	279
	12/20/08	167	412	61	334	233	284
	2/2/09	189	412	62	337	234	286
	2/24/09	261	412	64	341	235	289
	3/7/09	287	412	65	346	236	292
	4/17/09	300	412	66	352	237	298
	4/28/09	310	412	67	359	239	301
	5/8/09	321	412	68	364	240	304
	5/29/09	331	412	69	369	241	307
	6/3/09	352	412	70	374	243	310
	6/27/09	364	412	71	381	244	313

Rainy Season	7/5/09	372	447	75	415	269	343
	7/19/09	386	477	78	445	291	366
	7/26/09	393	509	81	479	317	396
	8/12/09	409	554	90	521	342	427
	8/17/09	414	590	93	556	367	457
	8/28/09	425	616	97	584	385	480
	9/4/09	431	630	98	596	393	490
	9/17/09	444	659	101	626	415	513
	9/27/09	454	693	105	659	437	538
Dry Season	10/12/09	469	693	106	666	439	545
	10/28/09	485	693	107	675	441	552
	11/8/09	495	693	108	683	445	559
	11/24/09	511	693	111	692	447	564
	1/3/10	520	693	112	701	450	571
	1/27/10	543	693	113	706	452	578
	2/7/10	553	693	114	715	454	585
	3/27/10	603	693	115	723	459	594
	4/12/10	618	693	116	733	461	601
	4/27/10	633	693	117	739	464	607
	5/25/10	661	693	118	741	466	614
	6/17/10	683	725	123	776	490	641
Rainy Season	6/25/10	691	766	127	816	515	673
	6/28/10	694	806	130	850	536	696
	7/4/10	700	834	134	878	554	719
	7/5/10	701	869	134.5	921	576	722
	7/23/10	719	899	135	949	594	745
	8/5/10	731	926	135.5	983	620	789
	8/19/10	745	962	136.5	1011	638	795
	8/28/10	754	988	137.5	1039	672	799

Table A.3 Variation of Settlement of MSW Deposited in Landfill Lysimeter

Season	Date	Time (Day)	Variation of settlement (% of waste thickness) at varying operational condition of landfill lysimeter		
			A	B	C
Dry season	7/1/08	20	-0.3	-0.15	-0.25
	7/28/08	26	-0.5	-0.98	-0.9
Rainy Season	8/2/08	33	-1.5	-1.2	-1.3
	8/12/08	41	-3	-1.6	-1.8
	8/28/08	48	-3.5	-2.1	-2.5
	9/7/08	59	-4.2	-2.7	-3.1
	9/16/08	74	-6.8	-3.1	-3.8
	9/26/08	87	-9.5	-3.8	-4.2
	10/20/08	97	-14.9	-4.7	-5.9

	10/28/08	107	-17.2	-5.4	-6.9
Dry season	11/8/08	119	-18.2	-6.1	-10
	11/28/08	133	-19	-6.7	-10.2
	12/25/08	161	-20	-7.1	-10.8
	1/5/09	189	-21.2	-8.2	-11.1
	1/25/09	217	-22	-9	-11.2
	2/17/09	245	-23.3	-10	-11.8
	3/7/09	273	-24	-11.8	-12.2
	3/27/09	301	-25.2	-12	-12.6
	4/8/09	329	-26.2	-13	-13.8
	4/27/09	357	-27.2	-14.2	-15.4
	5/5/09	383	-28.1	-15	-16
	5/28/09	391	-29	-16	-16.6
Rainy Season	7/6/09	399	-33	-20	-21.8
	7/15/09	407	-35.4	-22.5	-23.7
	7/28/09	414	-36	-23	-24
	8/5/09	421	-39	-25	-27
	8/25/09	483	-41	-26	-28
	8/25/09	497.98	-42	-27	-28
	9/5/09	505	-42.4	-27.7	-28.2
	9/27/09	520	-42.8	-27.7	-28.2
Dry season	1/27/10	546	-43	-28.1	-28.8
	2/25/10	566	-43.3	-28.4	-29
	3/29/10	580	-43.8	-28.5	-29.4
	4/25/10	604	-44.1	-28.8	-30
	5/30/10	611	-44.6	-29	-30.2
Rainy Season	6/5/10	619	-45	-29.9	-30.9
	6/25/10	629	-45.9	-30.4	-31.8
	7/13/10	656	-46.3	-31.2	-32.3
	7/25/10	715	-47	-31.4	-33
	8/5/10	745	-47	-32	-33.7
	8/28/10	775	-47.9	-32.4	-33.8

Appendix-B

Measured Concentration of Parameters in Leachate of Landfill Lysimeter

Table B.1 Variation of pH in the lysimeters

Date	Time (day)	Variation of pH at varying operational condition of landfill lysimeter			
		A ₁	A ₂	B	C
24/06/08	12	6.38	6.83	7.38	6.33
02/07/08	20	6.99	6.93	7.44	7.43
08/07/08	26	7.44	7.71	7.67	7.53
15/07/08	33	7.6	7.75	7.7	7.71
23/07/08	41	8.17	7.54	8.21	7.83
30/07/08	48	8.16	7.47	8.41	8.05
10/08/08	59	6.49	6.33	8.5	7.12
25/08/08	74	6.73	6.59	8.61	6.68
08/09/08	87	6.89	6.63	8.43	6.49
18/10/08	97	6.85	6.58	7.98	6.45
28/10/08	107	6.81	6.14	7.92	6.62
10/11/08	119	6.75	6.42	7.84	6.3
24/11/08	133	6.79	6.58	7.73	6.61
22/12/08	161	6.17	6.88	7.61	7.33
20/01/09	189	6.25	6.73	7.56	7.73
18/02/09	217	6.35	6.66	7.42	8.38
16/03/09	245	6.53	7.63	7.38	8.2
14/04/09	273	6.56	7.62	7.28	8.18
12/05/09	301	6.33	7.55	7.21	8.27
10/06/09	329	6.5	7.52	7.17	8.12
08/07/09	357	6.5	7.42	7	7.94
04/08/09	383	6.55	7.53	6.66	7.73
11/08/09	391	6.65	7.46	6.4	7.38
18/08/09	399	7.75	8.02	7.84	8.3
26/8/09	407	7.79	8	7.73	8.1
02/09/09	414	7	7.88	7.61	8.33
09/09/09	421	7.05	7.73	7.56	8.13
11/11/09	483	7.05	7.73	7.56	8.33
26/11/09	497.98	6.05	7.53	6.66	7.73
03/12/09	505	5.98	7.51	6.58	7.03
18/12/09	520	6.53	7.43	6.52	7.45
14/01/10	546	6.51	7.27	6.45	7.21
04/02/10	566	6.43	7.26	6.98	7.5

18/02/10	580	6.45	7.67	6.87	7.3
12/03/10	604	6.38	7.56	6.71	7.21
19/03/10	611	6.43	6.98	6.94	7
27/03/10	619	6.34	7.43	6.81	6.97
07/04/10	629	6.43	6.73	6.98	7.11
04/05/10	656	6.98	7.27	7.45	7.21
04/07/10	715	7.08	7.5	7.92	7.81
03/08/10	745				
02/09/10	775				
01/10/10	805				
30/10/10	835				
15/11/10	880				
19/11/10	884				
26/11/10	891				
03/12/10	898				

Table B.2 Seasonal Variation of pH in the lysimeters

Season	Date	Time (Day)	Seasonal variation of pH at varying operational condition of landfill lysimeter			
			A1	A2	B	C
Dry season	24/06/08	12	6.38	6.83	7.38	6.33
	02/07/08	20	6.99	6.93	7.44	7.43
	08/07/08	26	7.44	7.71	7.67	7.53
	15/07/08	33	7.6	7.75	7.7	7.71
	23/07/08	41	8.17	7.54	8.21	7.83
	30/07/08	48	8.16	7.47	8.41	8.05
Raining season	8/1/08	50	6.49	6.33	8.5	7.12
	8/11/08	60	6.73	6.59	8.61	6.68
	8/15/08	64	6.89	6.63	8.43	6.49
	8/29/08	78	6.85	6.58	7.98	6.45
	9/17/08	96	6.81	6.14	7.92	6.62
	9/26/08	105	6.75	6.42	7.84	6.3
	9/27/08	106	6.79	6.58	7.73	6.61
	10/25/08	134	6.17	6.88	7.61	7.33
	10/26/08	135	6.25	6.73	7.56	7.73
	10/27/08	136	6.35	6.66	7.42	8.38
Dry season	11/10/08	149	6.53	7.63	7.38	8.2
	11/28/08	167	6.56	7.62	7.28	8.18
	12/20/08	189	6.33	7.55	7.21	8.27

	2/2/09	261	6.5	7.52	7.17	8.12
	2/24/09	287	6.5	7.42	7	7.94
	3/7/09	300	6.55	7.53	6.66	7.73
	4/17/09	310	6.65	7.46	6.4	7.38
	4/28/09	321	7.75	8.02	7.84	8.3
	5/8/09	331	7.79	8	7.73	8.1
	5/29/09	352	7	7.88	7.61	8.33
	6/3/09	364	7.05	7.73	7.56	8.73
	6/27/09	390	7.05	7.73	7.56	8.73

Table B.3 Variation of Chloride in the lysimeters

Date	Time (day)	Variation of Chloride (mg/L) at varying operational condition of landfill lysimeter			
		A ₁	A ₂	B	C
24/06/08	12	3037	3572	1350	760
02/07/08	20	2357	2857	1510	1100
08/07/08	26	2762	2762	510	110
15/07/08	33	1370	1770	1550	1020
23/07/08	41	1280	1800	550	130
30/07/08	48	2650	1850	570	145
10/08/08	59	1120	1270	580	150
25/08/08	74	1325	1155	850	1050
08/09/08	87	970	1170	725	1070
18/10/08	97	1240	1290	730	920
28/10/08	107	2508	2608	1190	1370
10/11/08	119	2440	2670	1750	1300
24/11/08	133	2270	2570	1870	1390
22/12/08	161	2880	2790	1010	1410
20/01/09	189	2300	2600	950	1500
18/02/09	217	2320	2520	1000	1700
16/03/09	245	2090	2150	1000	1290
14/04/09	273	2705	2205	1000	1800
12/05/09	301	2150	2250	1010	1810
10/06/09	329	2450	2650	1080	1670
08/07/09	357	2170	2370	1085	1780
04/08/09	383	2225	2425	1100	1290
11/08/09	391	2370	2670	1125	1432
18/08/09	399	2420	2600	1125	1679
26/8/09	407	2580	2780	1175	1025
02/09/09	414	2342	2650	1255	1129
09/09/09	421	2680	2780	1255	1200

11/11/09	483	2275	2675	1265	1240
26/11/09	497.98	2672	2678	1265	1225
03/12/09	505	2710	2750	1275	1125
18/12/09	520	2262	2762	1275	1250
14/01/10	546	2249	2649	1175	1350
04/02/10	566	2205	2205	1100	1105
18/02/10	580	2265	2308	1075	1155
12/03/10	604	2350	2650	1010	1175
19/03/10	611	2025	2365	985	1215
27/03/10	619	2225	2375	900	1200
07/04/10	629	2875	2387	1000	1250
04/05/10	656	2175	2500	1160	1350
04/07/10	715	2215	2730	1030	1378
03/08/10	745				
02/09/10	775				
01/10/10	805				
30/10/10	835				
15/11/10	880				
19/11/10	884				
26/11/10	891				
03/12/10	898				

Table B.4 Seasonal Variation of Chloride in the lysimeters

Season	Date	Time (Day)	Seasonal variation of Chloride (mg/L) at varying operational condition of landfill lysimeter			
			A1	A2	B	C
Dry season	24/06/08	12		3572	1350	760
	02/07/08	20		2857	1510	1100
	08/07/08	26		2762	510	110
	15/07/08	33		1770	1550	1020
	23/07/08	41		1800	550	130
	30/07/08	48		1850	570	145
Raining season	8/1/08	50		1270	580	150
	8/11/08	60		1155	850	1050
	8/15/08	64		1170	725	1070
	8/29/08	78		1290	730	920
	9/17/08	96		2608	690	1370
	9/26/08	105		2670	750	1300
	9/27/08	106		2570	570	1390
	10/25/08	134		2790	1010	1510

Dry season	10/26/08	135		2600	1150	1700
	10/27/08	136		2520	1000	1700
	11/10/08	149		2150	1000	1590
	11/28/08	167		2205	1000	1800
	12/20/08	189		2250	1010	1810
	2/2/09	261		2650	1080	1670
	2/24/09	287		2370	1085	1780
	3/7/09	300		2425	1100	1290
	4/17/09	310		2670	1125	1432
	4/28/09	321		2600	1125	1679
	5/8/09	331		2780	1175	1025
	5/29/09	352		2650	1255	1129
	6/3/09	364		2780	1255	1200
	6/27/09	390		2675	1265	1240

Table B.5 Variation of Solid Particles in the lysimeters

Date	Time (day)	Variation of Solid Particles (mg/L) at varying operational condition of landfill lysimeter					
		A ₂			B		
		TS	TDS	TSS	TS	TDS	TSS
24/06/08	12	36690	35810	8800	30739	29980	7590
02/07/08	20	34880	33710	11700	31900	29720	21800
08/07/08	26	30430	29300	11300	32060	29630	24300
15/07/08	33	30540	29200	13400	25019	22840	21790
23/07/08	41	21480	20200	12800	16990	14450	25400
30/07/08	48	21490	20150	13400	15920	13790	21300
10/08/08	59	16870	15740	11300	12920	10610	23100
25/08/08	74	16630	15350	12800	12050	10160	18900
08/09/08	87	15600	14380	12200	9890	7880	20100
18/10/08	97	15380	14000	13800	8770	6880	18900
28/10/08	107	15380	14000	13800	5960	3830	21300
10/11/08	119	14570	13440	11300	7980	5810	21700
24/11/08	133	13920	12780	11400	8041	5950	20910
22/12/08	161	13920	12780	11400	8310	6440	18700
20/01/09	189	13630	12640	9900	7000	5770	12300
18/02/09	217	13510	12640	8700	7120	5800	13200
16/03/09	245	12292	11572	7200	7400	6170	12300
14/04/09	273	12557	11570	9870	8717	7700	10170
12/05/09	301	11547	10572	9750	8892	7910	9820
10/06/09	329	10919	10040	8790	8476	7456	10200
08/07/09	357	9457	8790	6670	8519	7493	10260

04/08/09	383	6980	6440	5400	3800	2770	10300
11/08/09	391	6940	6380	5600	2920	1800	11200
18/08/09	399	860	140	7200	3310	2170	11400
26/8/09	407	13280	12640	6400	8330	7700	6300
02/09/09	414	13049	12780	2690	8370	7910	4600
09/09/09	421	11115	10572	5430	7888	7493	3950
11/11/09	483	8642	8222	4200	5600	5200	4000
26/11/09	498	7340	6800	5400	5400	4630	7700
03/12/09	505	9963	9620	3430	5750	5320	4300
18/12/09	520	10450	10180	2700	6470	6130	3400
14/01/10	546	9217	8790	4270	10400	9980	4200
04/02/10	566	6710	6440	2700	9960	9720	2400
18/02/10	580	6690	6380	3100	10100	9630	4700
12/03/10	604	6500	6220	2800	8080	7840	2400
19/03/10	611	5570	5380	1900	14770	14450	3200
27/03/10	619	5030	5000	300	13970	13790	1800
07/04/10	629	5019	4990	290	10730	10610	1200
04/05/10	656	9670	9650	200	10250	10160	900
04/07/10	715	5017	5000	170	7990	7880	1100
03/08/10	745						
02/09/10	775						
01/10/10	805						
30/10/10	835						
15/11/10	880						
19/11/10	884						
26/11/10	891						
03/12/10	898						

Table B.6 Seasonal Variation of Solid Particles in the lysimeters

Season	Date	Time (Day)	Seasonal variation of Solid Particles (mg/L) at varying operational condition of landfill lysimeter								
			A ₂			B			C		
			TS	TDS	TSS	TS	TDS	TSS	TS	TDS	TSS
Dry season	24/06/08	12	36690	35810	880	30739	29980	759	27280	26000	1280
	02/07/08	20	34880	33710	1170	31900	29720	2180	23720	21940	1780
	08/07/08	26	30430	29300	1130	32060	29630	2430	21150	19020	2130
	15/07/08	33	30540	29200	1340	25019	22840	2179	20190	17850	2340
	23/07/08	41	21480	20200	1280	16990	14450	2540	16420	14140	2280
	30/07/08	48	21490	20150	1340	15920	13790	2130	16130	14590	1540

Raining season	8/1/08	50	16870	15740	1130	12920	10610	2310	15290	13160	2130
	8/11/08	60	16630	15350	1280	12050	10160	1890	15240	13460	1780
	8/15/08	64	15600	14380	1220	9890	7880	2010	14070	12150	1920
	8/29/08	78	15380	14000	1380	8770	6880	1890	11840	10170	1670
	9/17/08	96	15380	14000	1380	5960	3830	2130	10580	8800	1780
	9/26/08	105	14570	13440	1130	7980	5810	2170	9830	8300	1530
	9/27/08	106	13920	12780	1140	8041	5950	2091	9450	8210	1240
	10/25/08	134	13920	12780	1140	8310	6440	1870	10930	9390	1540
	10/26/08	135	13630	12640	990	7000	5770	1230	10760	9670	1090
	10/27/08	136	13510	12640	870	7120	5800	1320	10400	9280	1120
Dry season	11/10/08	149	12292	11572	720	7400	6170	1230	14550	13420	1130
	11/28/08	167	12557	11570	987	8717	7700	1017	12917	11930	987
	12/20/08	189	11547	10572	975	8892	7910	982	10315	9340	975
	2/2/09	261	10919	10040	879	8476	7456	1020	10472	9593	879
	2/24/09	287	9457	8790	667	8519	7493	1026	10260	9593	667
	3/7/09	300	6980	6440	540	3800	2770	1030	9860	9670	190
	4/17/09	310	6940	6380	560	2920	1800	1120	9520	9280	240
	4/28/09	321	860	140	720	3310	2170	1140	700	420	280
	5/8/09	331	13280	12640	640	8330	7700	630	16020	15930	90
	5/29/09	352	13049	12780	269	8370	7910	460	16040	15340	700
	6/3/09	364	11115	10572	543	7888	7493	395	9685	9593	92
	6/27/09	390	8642	8222	420	5600	5200	400	9650	9500	150

Table B.7 Variation of Hardness in the lysimeters

Date	Time (day)	Variation of Hardness (mg/L) at varying operational condition of landfill lysimeter			
		A ₁	A ₂	B	C
24/06/08	12	129.8	10000	14000	10000
02/07/08	20	283.5	9963.6	13026	8902.5
08/07/08	26	370.4	10000	10000	8736.8
15/07/08	33	527.9	10000	2778	4861.5
23/07/08	41	749.4	2700	2870.6	3055.8
30/07/08	48	900	2222.4	2407.6	2315
10/08/08	59	900	1704	2519	2444
25/08/08	74	972.3	1685.32	2106.65	2347.4
08/09/08	87	1083.42	1342.7	2037.2	1898.3
18/10/08	97	1092.68	1527.9	2037.2	1620.5
28/10/08	107	1092.68	1426	1713.1	1481.6
10/11/08	119	1092.68	1363	1344	1324.1
24/11/08	133	1157.5	1064.9	1805.7	1435.3

22/12/08	161	1259	1389	1759.4	1574.2
20/01/09	189	1435.3	1900	1240	1560
18/02/09	217	1620.5	1259	1611	1704
16/03/09	245	2222.4	1852	2593	2778
14/04/09	273	2315	2000	2204	2112
12/05/09	301	2315	1741	2870	2232
10/06/09	329	2537.24	1204	1440	1296
08/07/09	357	2537.24	1204	1300	1196
04/08/09	383	2796.52	1900	1250	1260
11/08/09	391	2796.52	1259	1611	1700
18/08/09	399	2963.2	1852	2593	1778
26/8/09	407	3083.58	2000	2204	2122
02/09/09	414	3241	1741	2870	2230
09/09/09	421	3241	1204	3200	1096
11/11/09	483	3162.3	1320.3	3320	1320
26/11/09	497.98	3120.3	1375	2570	1580
03/12/09	505	2522.3	1222.3	2232	2010.3
18/12/09	520	3170.4	1000	2407.6	1196
14/01/10	546	3227.9	1200	2519	1260
04/02/10	566	2749.4	1222.4	2106.65	2230
18/02/10	580	2900	1704	2037.2	1324.1
12/03/10	604	3021	1685.32	2300	1435.3
19/03/10	611	2972.3	1342.7	2250	2444
27/03/10	619	3083.42	1320.3	1911	2347.4
07/04/10	629	3092.68	1375	2467	2224
04/05/10	656	2740.8	1370.48	2407.6	2222.4
04/07/10	715	2837.2	1203.8	2574	1296
03/08/10	745				
02/09/10	775				
01/10/10	805				
30/10/10	835				
15/11/10	880				
19/11/10	884				
26/11/10	891				
03/12/10	898				

Table B.8 Variation of Alkalinity in the lysimeters

Date	Time (day)	Variation of Alkalinity (mg/L) at varying operational condition of landfill lysimeter			
		A ₁	A ₂	B	C
24/06/08	12	1150	9250	8000	9000
02/07/08	20	1000	9550	8250	7250
08/07/08	26	5550	10000	8770	9435
15/07/08	33	1150	5700	5500	7350
23/07/08	41	550	3200	4250	4300
30/07/08	48	950	3100	4500	5000
10/08/08	59	400	3080	4200	6400
25/08/08	74	560	3060	5070	4745
08/09/08	87	900	3050	5300	4400
18/10/08	97	1250	2200	6150	5750
28/10/08	107	550	2150	4050	3200
10/11/08	119	400	1800	3600	2550
24/11/08	133	750	1600	3000	2300
22/12/08	161	463	1237	3111.2	2778
20/01/09	189	900	2000	5240	4560
18/02/09	217	1220	1380	5300	4200
16/03/09	245	1300	1507	5500	5000
14/04/09	273	1200	1600	6000	5990
12/05/09	301	1297	1641	2870	2232
10/06/09	329	1180	1330	4720	4000
08/07/09	357	1170	1320	4720	4000
04/08/09	383	900	1900	5240	4560
11/08/09	391	1020	1280	2300	4200
18/08/09	399	1000	1500	5500	5000
26/8/09	407	900	1600	1000	900
02/09/09	414	797	1741	2870	2232
09/09/09	421	1180	1320	4720	4000
11/11/09	483		1250		
26/11/09	497.98		1560		
03/12/09	505		1090		
18/12/09	520		1176		
14/01/10	546		2160		
04/02/10	566		1458		
18/02/10	580		1560		
12/03/10	604		1320		
19/03/10	611		1570		
27/03/10	619		1020		

07/04/10	629		1070		
04/05/10	656		980		
04/07/10	715		1280		
03/08/10	745				
02/09/10	775				
01/10/10	805				
30/10/10	835				
15/11/10	880				
19/11/10	884				
26/11/10	891				
03/12/10	898				

Table B.9 Variation of Conductivity in the lysimeters

Date	Time (day)	Variation of Conductivity (mS/cm) at varying operational condition of landfill lysimeter			
		A ₁	A ₂	B	C
24/06/08	12		12.8	5.9	10.9
02/07/08	20		23	8.9	9.0
08/07/08	26		14.8	9.2	8.9
15/07/08	33		12.7	10.5	10.2
23/07/08	41		24.7	8.9	19.1
30/07/08	48		23.7	15.7	16.7
10/08/08	59		21.7	16.5	13.3
25/08/08	74		15.8	7.6	12.3
08/09/08	87		18.3	7.9	11.0
18/10/08	97		16.8	11.2	15.0
28/10/08	107		14.3	10.4	12.7
10/11/08	119		16.5	8.1	11.7
24/11/08	133		10.8	9.6	11.8
22/12/08	161		12.7	6.9	10.7
20/01/09	189		11.7	9.1	9.4
18/02/09	217		11.8	7.5	8.7
16/03/09	245		10.7	6.8	7.5
14/04/09	273		9.4	5.2	7.7
12/05/09	301		8.7	5.9	3.7
10/06/09	329		7.5	6.4	21.7
08/07/09	357		7.6	5.3	13.2
04/08/09	383		3.7	6.3	10.2
11/08/09	391		3.5	6.6	12.7
18/08/09	399		3.9	6.4	13.4

26/8/09	407		3.7	6.5	14.0
02/09/09	414		4.3	6.6	18.1
09/09/09	421		4.1	5.9	13.7
11/11/09	483		3.9	5.8	13.3
26/11/09	497.98		4.5	7.7	12.3
03/12/09	505		4.8	6.3	12.0
18/12/09	520		5.7	5.3	11.0
14/01/10	546		7.6	5.3	19.7
04/02/10	566		3.1	6.8	10.1
18/02/10	580		4.1	7.6	9
12/03/10	604		3.8	7.4	7.7
19/03/10	611		3.7	6.5	4.7
27/03/10	619		4.8	6.6	5.7
07/04/10	629		5.1	6.9	5.7
04/05/10	656		4.9	6.8	5.8
04/07/10	715		3.5	7.2	6.2
03/08/10	745				
02/09/10	775				
01/10/10	805				
30/10/10	835				
15/11/10	880				
19/11/10	884				
26/11/10	891				
03/12/10	898				

Table B.10 Seasonal Variation of Conductivity in the lysimeters

Season	Date	Time (Day)	Seasonal variation of Conductivity (mS/cm) at varying operational condition of landfill lysimeter			
			A1	A2	B	C
Dry season	24/06/08	12		12.8	5.8	11.2
	02/07/08	20		13	7.9	11.3
	08/07/08	26		14.8	5.9	10.9
	15/07/08	33		12.7	8.9	9.0
	23/07/08	41		10.4	9.2	8.9
	30/07/08	48		11.8	10.5	10.2
Raining season	8/1/08	50		24.7	8.9	19.1
	8/11/08	60		23.7	15.7	16.7
	8/15/08	64		21.7	16.5	13.3
	8/29/08	78		15.8	7.6	12.3
	9/17/08	96		18.3	7.9	11.0

	9/26/08	105		16.8	11.2	15.0
	9/27/08	106		14.3	10.4	12.7
	10/25/08	134		16.5	8.1	11.7
	10/26/08	135		10.8	9.6	11.8
	10/27/08	136		12.7	6.9	10.7
Dry season	11/10/08	149		17.7	9.1	11.4
	11/28/08	167		21.8	10.5	12.7
	12/20/08	189		19.7	11.8	13.5
	2/2/09	261		19.4	15.2	17.7
	2/24/09	287		18.7	15.9	17.7
	3/7/09	300		21.5	16.4	18.3
	4/17/09	310		22.6	17.3	19.2
	4/28/09	321		23	18	20
	5/8/09	331		24.1	19.3	21.2
	5/29/09	352		25.8	18.9	19.2
	6/3/09	364		24.5	17.4	17.9
	6/27/09	390		25.2	18.3	20.3

Table B.11 Variation of Sulfate in the lysimeters

Date	Time (day)	Variation of Sulfate (mg/L) at varying operational condition of landfill lysimeter			
		A ₁	A ₂	B	C
24/06/08	12		1180	1110	
02/07/08	20		1086	940	
08/07/08	26		1030	880	
15/07/08	33		980	810	
23/07/08	41		820	780	
30/07/08	48		790	650	
10/08/08	59		760	640	
25/08/08	74		690	720	
08/09/08	87		540	670	
18/10/08	97		450	340	
28/10/08	107		360	320	
10/11/08	119		340	270	
24/11/08	133		290	180	
22/12/08	161		194	150	
20/01/09	189		110	120	
18/02/09	217		100	110	
16/03/09	245				
14/04/09	273				
12/05/09	301				

10/06/09	329				
08/07/09	357				
04/08/09	383				
11/08/09	391				
18/08/09	399				
26/8/09	407				
02/09/09	414				
09/09/09	421				
11/11/09	483				
26/11/09	497.98				
03/12/09	505				
18/12/09	520				
14/01/10	546				
04/02/10	566				
18/02/10	580				
12/03/10	604				
19/03/10	611				
27/03/10	619				
07/04/10	629				
04/05/10	656				
04/07/10	715				
03/08/10	745				
02/09/10	775				
01/10/10	805				
30/10/10	835				
15/11/10	880				
19/11/10	884				
26/11/10	891				
03/12/10	898				

Table B.12 Variation of COD in the lysimeters

Date	Time (day)	Variation of COD (mg/L) at varying operational condition of landfill lysimeter			
		A ₁	A ₂	B	C
24/06/08	12	240	60000	60000	60000
02/07/08	20	6400	36400	38800	42800
08/07/08	26	8880	30656	26640	28744
15/07/08	33	20800	36300	24000	35600
23/07/08	41	10500	17800	11200	34000
30/07/08	48	320	10240	3840	35550

10/08/08	59	896	9360	3042	34480
25/08/08	74	3536	7457	2288	33536
08/09/08	87	2880	7520	2000	32360
18/10/08	97	1600	7640	3640	7960
28/10/08	107	1440	5400	1920	6240
10/11/08	119	160	6760	1440	5120
24/11/08	133	2720	5560	2240	6400
22/12/08	161	2880	5800	1920	5280
20/01/09	189	800	4520	1820	5120
18/02/09	217	640	3420	1560	3990
16/03/09	245	960	4120	1490	4860
14/04/09	273	800	4940	1460	4650
12/05/09	301	800	3726	1400	3400
10/06/09	329	240	4400	1320	4800
08/07/09	357	240	5346	1120	3200
04/08/09	383	800	4087	900	5300
11/08/09	391	640	4120	560	3880
18/08/09	399	960	5120	590	4760
26/8/09	407	800	3640	560	4750
02/09/09	414	800	3530	400	4640
09/09/09	421	240	4400	320	5800
11/11/09	483	320	7800	3840	4240
26/11/09	497.98	896	2240	3042	4120
03/12/09	505	3536	2360	2288	2400
18/12/09	520	2880	2288	2000	1280
14/01/10	546	1600	3520	4640	1120
04/02/10	566	1440	4640	1920	990
18/02/10	580	160	2400	1440	860
12/03/10	604	2720	1760	2240	650
19/03/10	611	2880	2560	1920	400
27/03/10	619	2880	800	1820	800
07/04/10	629	2880	1520	1560	800
04/05/10	656	2880	1420	1490	300
04/07/10	715	2880	1420	1490	300
03/08/10	745				
02/09/10	775				
01/10/10	805				
30/10/10	835				
15/11/10	880				
19/11/10	884				
26/11/10	891				

03/12/10	898				
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Table B.13 Total COD Leaching

Season	Date	Time (Day)	Total COD leachate (mg/kg of solid waste) at varying operational condition of landfill lysimeter			
			A1	A2	B	C
Rainy Season	8/1/08	48		146.94	4.64	10.92
	8/11/08	50		477.23	83.31	282.03
	8/15/08	60		948.72	173.90	605.64
	8/29/08	64		1316.05	246.29	871.64
	9/17/08	78		1625.30	337.71	945.61
	9/26/08	96		1998.31	465.54	1023.67
	9/27/08	105		2466.68	626.56	1106.01
	10/25/08	106		2690.10	766.02	1124.31
	10/26/08	134		2855.84	853.90	1167.71
	10/27/08	135		3185.84	1032.16	1270.19
Dry Season	11/10/08	136		3193.01	1033.72	1280.17
	11/28/08	149		3201.65	1034.72	1290.59
	12/20/08	167		3213.75	1036.68	1298.90
	2/2/09	189		3217.65	1037.15	1301.33
	2/24/09	261		3223.81	1037.59	1306.48
	3/7/09	287		3233.15	1037.97	1309.91
	4/17/09	300		3241.73	1038.27	1321.27
	4/28/09	310		3251.81	1038.64	1325.43
	5/8/09	321		3260.76	1038.84	1330.54
	5/29/09	331		3267.13	1039.03	1335.63
	6/3/09	352		3273.30	1039.30	1340.60
	6/27/09	364		3284.07	1039.40	1346.82

Table B.14 Seasonal Variation of COD in the lysimeters

Season	Date	Time (Day)	Seasonal variation of COD (mg/L) at varying operational condition of landfill lysimeter			
			A1	A2	B	C
Dry season	24/06/08	12		60000	60000	60000
	02/07/08	20		36400	38800	42800
	08/07/08	26		30656	26640	28744
	15/07/08	33		36300	24000	35600
	23/07/08	41		17800	11200	34000
	30/07/08	48		10240	3840	35550

Raining season	8/1/08	50		9360	3042	34480
	8/11/08	60		7457	2288	33536
	8/15/08	64		7520	2000	32360
	8/29/08	78		7640	3640	7960
	9/17/08	96		5400	1920	6240
	9/26/08	105		6760	1440	5120
	9/27/08	106		5560	2240	6400
	10/25/08	134		5800	1920	5280
	10/26/08	135		4520	1820	5120
	10/27/08	136		3420	1560	3990
Dry season	11/10/08	149		4120	1490	4860
	11/28/08	167		4940	1460	4650
	12/20/08	189		3726	1400	3400
	2/2/09	261		4400	1320	4800
	2/24/09	287		5346	1120	3200
	3/7/09	300		4087	900	5300
	4/17/09	310		4120	560	3880
	4/28/09	321		4940	1460	4650
	5/8/09	331		3726	1400	3400
	5/29/09	352		4400	1320	4800
	6/3/09	364		5346	1120	3200
	6/27/09	390		4087	900	5300

Table B.15 Variation of TKN in the lysimeters

Date	Time (day)	Variation of TKN (mg/L) at varying operational condition of landfill lysimeter			
		A ₁	A ₂	B	C
19/06/08	7	1010	1340	2180	1730
26/06/08	14	1120	1430	2090	1658
03/07/08	21	1010	1320.8	2187	1706
12/07/08	30	1001	1297	2090	1709
01/08/08	50	997	1280	1980	1760
11/08/08	60	980	1244	1860	1806
11/09/08	90	956	1225	1743.9	1860
11/11/08	120	945	1218	1637	1556
21/12/08	160	937	1210	1645	1598
16/03/09	245	845	1137	1603	1521
01/05/09	290	820	1109	1534	1456
01/06/09	320	800	1101	1432	1345
01/07/09	350	764	976	1278	1109
21/07/09	370	540	865	1201	980

10/08/09	390	378	520	1220	657
19/08/09	400	378	504	1130	637
03/09/09	415	365	538	1122	676
28/11/09	500	356	485	1098	612
08/09/09	520	345	467	1056	597
13/01/10	545	337	443	1008	550
18/02/10	580	325	431	956	521
18/03/10	610	305	407	915	503
08/04/10	630	290	381	867	486
08/05/10	660	278	364	806	456
04/07/10	715	263	340	770	435
08/08/10	750	247	321	720	417
28/09/10	800	233	300	686	402
18/11/10	850	221	278	610	360
05/12/10	900	195	251	480	312

Table B.16 TKN Leaching

Season	Date	Time (Day)	TKN leaching (mg/kg of solid waste) at varying operational condition of landfill lysimeter			
			A ₁	A ₂	B	C
Rainy Season	8/1/08	48		0.47	0.73	0.62
	8/11/08	50		12.47	13.34	13.65
	8/15/08	60		29.09	29.46	30.12
	8/29/08	64		41.79	42.07	44.17
	9/17/08	78		56.11	55.34	60.52
	9/26/08	96		74.38	75.29	83.11
	9/27/08	105		96.65	99.83	113.03
	10/25/08	106		107.30	118.48	117.47
	10/26/08	134		119.99	130.61	130.61
	10/27/08	135		145.83	154.79	161.05
Dry Season	11/10/08	136		148.16	156.33	164.69
	11/28/08	149		150.47	157.29	167.58
	12/20/08	167		152.86	159.00	169.56
	2/2/09	189		153.77	159.40	170.26
	2/24/09	261		154.49	159.81	170.97

3/7/09	287		155.38	160.19	171.65
4/17/09	300		156.50	160.57	173.10
4/28/09	310		157.69	161.30	173.75
5/8/09	321		158.51	161.66	174.39
5/29/09	331		159.28	161.99	174.98
6/3/09	352		160.04	162.64	175.54
6/27/09	364		161.03	162.94	176.08

Table B.17 Variation of $\text{NH}_4\text{-N}$ in the lysimeters

Date	Time (day)	Variation of $\text{NH}_4\text{-N}$ (mg/L) at varying operational condition of landfill lysimeter			
		A ₁	A ₂	B	C
19/06/08	7	705	897	997	920
26/06/08	14	700	901.3	992.7	965.7
03/07/08	21	702.3	865.3	967.2	898.7
12/07/08	30	687.4	832	955.5	865
01/08/08	50	682	802	943.7	831.2
11/08/08	60	675	765	803	820
11/09/08	90	634.2	654.9	765	702
11/11/08	120	610	654	787	698
21/12/08	160	543	597	754	653
16/03/09	245	504.9	586.7	697.5	632.8
01/05/09	290	487.7	576	686	614
01/06/09	320	468.7	555.8	673.5	602.7
01/07/09	350	435	549	698	678
21/07/09	370	420	540	684	665
10/08/09	390	412	563.2	702	621
19/08/09	400	410	531.9	665	587
03/09/09	415	320	520	655	582
28/11/09	500	315	510	634	578
08/09/09	520	307	501.7	620	576
13/01/10	545	316.2	507.8	623.8	579.7
18/02/10	580	297.4	497	590	520
18/03/10	610	287	486	576	515
08/04/10	630	265	475	545	501
08/05/10	660	245	402	509	455
04/07/10	715	222	386	476	409
08/08/10	750	201.7	276	354	307
28/09/10	800	196	165	208	198
18/11/10	850	187	154	190	187
05/12/10	900	190	127.9	192.7	190

Table B.18 Variation of Nitrate in the lysimeters

Date	Time (day)	Variation of Nitrate (mg/L) at varying operational condition of landfill lysimeter			
		A ₁	A ₂	B	C
24/06/08	12		1180	1110	
02/07/08	20		1086	940	
08/07/08	26		1030	880	
15/07/08	33		980	810	
23/07/08	41		820	780	
30/07/08	48		790	650	
10/08/08	59		760	640	
25/08/08	74		690	720	
08/09/08	87		540	670	
18/10/08	97		450	340	
28/10/08	107		360	320	
10/11/08	119		340	270	
24/11/08	133		290	180	
22/12/08	161		194	150	
20/01/09	189		110	120	
18/02/09	217		100	110	
16/03/09	245				
14/04/09	273				
12/05/09	301				
10/06/09	329				
08/07/09	357				
04/08/09	383				
11/08/09	391				
18/08/09	399				
26/8/09	407				
02/09/09	414				
09/09/09	421				
11/11/09	483				
26/11/09	497.98				
03/12/09	505				
18/12/09	520				
14/01/10	546				
04/02/10	566				
18/02/10	580				
12/03/10	604				
19/03/10	611				
27/03/10	619				

07/04/10	629				
04/05/10	656				
04/07/10	715				
03/08/10	745				
02/09/10	775				
01/10/10	805				
30/10/10	835				
15/11/10	880				
19/11/10	884				
26/11/10	891				
03/12/10	898				

Table B.20 Variation of Ca in the lysimeters

Date	Time (day)	Variation of Ca (mg/L) at varying operational condition of landfill lysimeter			
		A ₁	A ₂	B	C
24/06/08	12	350.5	415.8	305.9	315.8
02/07/08	20	301.2	580.8	356.8	380.8
08/07/08	26	670.7	402.1	567.9	602.1
30/07/08	48	455.9	576.8	456.3	576.8
10/11/08	119	789.9	640.6	564.3	610.6
24/11/08	133	586.4	450.4	578	470.4
22/12/08	161	677.8	664.2	568	664.2
16/03/09	245	630.9	625.8	578	605.8
14/04/09	273	624.9	569.6	564.8	599.6
12/05/09	301	387	347	456.3	517
04/08/09	383	448.7	379.6	398	479.6
11/08/09	391	409	317	459	557
18/08/09	399	357	338	377.6	538
26/8/09	407	360	327.9	376.1	527.9
26/11/09	498	367	388	306.3	478
03/12/09	505	370	317	278.4	377
18/12/09	520	368	389	328.7	349
14/01/10	546	358.8	325.7	269.8	325
07/04/10	629	330.7	217.9	238.3	217.9
04/05/10	656	327.8	310.6	208.6	300.6
04/07/10	715	320.7	289.3	211.2	289.3
03/08/10	745	314.2	289.7	234.4	279.7
02/09/10	775	298.8	287.6	204.3	220.6
01/10/10	805	291.3	287.5	198.3	217.5

30/10/10	835	267.9	256	176.4	156
15/11/10	880	253.5	280.5	153	180
19/11/10	884	276.5	228.5	191.5	140
26/11/10	891				
03/12/10	898				

Table B.21 Variation of K in the lysimeters

Date	Time (day)	Variation of K (mg/L) at varying operational condition of landfill lysimeter			
		A ₁	A ₂	B	C
24/06/08	12	1650.5	1815.8	1605.9	1509.9
02/07/08	20	1741.2	1980.8	1656.8	1576.8
08/07/08	26	1070.7	1102.1	1117.9	1011.9
30/07/08	48	855.9	1576.8	1456.3	1356.3
10/11/08	119	1689.9	1840.6	1764.3	1664.3
24/11/08	133	1586.4	1750.4	1678	1676
22/12/08	161	1677.8	1764.2	1668	1956.7
16/03/09	245	1730.9	1625.8	1678	1601.2
14/04/09	273	1424.9	1569.6	1364.8	1298.7
12/05/09	301	1587	2047	1456.3	1356.3
04/08/09	383	1548.7	1979.6	1398	1091
11/08/09	391	1509	2017	1459	1059
18/08/09	399	1457	2138	1577.6	1377.6
26/8/09	407	1460	2427.9	1676.1	1576.1
26/11/09	498	1967	2388	1606.3	1346
03/12/09	505	1370	2517	1578.4	1342
18/12/09	520	1368	2589	1728.7	1432.8
14/01/10	546	1358.8	2525.7	1669.8	1456.9
07/04/10	629	1330.7	2517.9	1238.3	738.3
04/05/10	656	1327.8	2310.6	1008.6	608.6
04/07/10	715	1320.7	2289.3	1121.2	567.2
03/08/10	745	1314.2	2289.7	1234.4	734.4
02/09/10	775	1298.8	2287.6	1204.3	704.3
01/10/10	805	1291.3	2287.5	1198.3	698.3
30/10/10	835	1267.9	2156	1176.4	1176.4
15/11/10	880	1138.05	2069.95	1370.05	1370.05
19/11/10	884	1264.4	1966.5	1389.5	1389.5
26/11/10	891				
03/12/10	898				

Table B.22 Variation of Na in the lysimeters

Date	Time (day)	Variation of Na (mg/L) at varying operational condition of landfill lysimeter			
		A ₁	A ₂	B	C
24/06/08	12	2350.3	2215.2	2605	2409.1
02/07/08	20	2201.2	2280.8	2656.4	2376.8
08/07/08	26	2070.7	1902.1	2117.9	1011.9
30/07/08	48	1555.9	1376.8	1256.3	1356.4
10/11/08	119	2289.9	2040.6	2764.3	2164.3
24/11/08	133	2386.4	1950.4	2678	2276
22/12/08	161	2277.8	2364.2	2568	1956.7
16/03/09	245	2330.9	2225.8	2278	2002.1
14/04/09	273	2424.9	2369.6	2164.8	1898.8
12/05/09	301	2287	2147	2456.3	1356.3
04/08/09	383	2348.7	2179.6	2198	1791
11/08/09	391	2009	2017	2159	1359
18/08/09	399	2257	2138	2077.6	1377.6
26/8/09	407	2260	2127.9	2076.1	1576.1
26/11/09	498	2267	2188	2406.3	1346
03/12/09	505	2370	2117	2378.4	1342
18/12/09	520	2368	2289	2328.7	1443.2
14/01/10	546	2058.8	2225.7	2369.8	1452.9
07/04/10	629	2330.7	2317.9	2238.3	1738.3
04/05/10	656	2027.8	2310.6	2008.6	1608.6
04/07/10	715	2020.7	2189.3	2134	1567.2
03/08/10	745	2114.2	2289.7	2098	1734.4
02/09/10	775	1298.8	2187.6	2143	1704.3
01/10/10	805	1291.3	1787.5	2198.3	1698.3
30/10/10	835	1267.9	1456	2054.4	1176.4
15/11/10	880	1438.75	1312.35	1765.3	1603.65
19/11/10	884	1525.5	1251.6	1623.76	1420.7
26/11/10	891				
03/12/10	898				

Table B.23 Variation of Mg in the lysimeters

Date	Time (day)	Variation of Mg (mg/L) at varying operational condition of landfill lysimeter			
		A ₁	A ₂	B	C
24/06/08	12	455.7	405.5	605.9	415.8
02/07/08	20	501.9	480.8	586.8	506.9
08/07/08	26	556.9	402.1	567.9	452.1
30/07/08	48	455.9	426.8	546.3	476.8
10/11/08	119	589.9	540.6	594.3	520.6
24/11/08	133	586.4	450.4	598.9	470.4
22/12/08	161	517.3	564.2	568	594.2
16/03/09	245	530.9	525.8	578	505.6
14/04/09	273	524.9	469.6	564.8	499.6
12/05/09	301	387	347	406.3	417
04/08/09	383	338.4	379.6	388	409.6
11/08/09	391	309	317	459	357
18/08/09	399	327	338	377.6	345.9
26/8/09	407	360	327.9	366.1	342.7
26/11/09	498	367	328	386.3	288
03/12/09	505	370	317	378.4	377
18/12/09	520	368	359	328.7	349
14/01/10	546	358.8	325.7	369.8	325
07/04/10	629	330.7	217.9	238.3	217.9
04/05/10	656	327.8	310.6	328.6	300.6
04/07/10	715	328.7	289.3	311.2	289.3
03/08/10	745	324.2	259.7	274.4	289.7
02/09/10	775	258.8	247.6	284.3	220.1
01/10/10	805	291.3	287.5	298.3	217.5
30/10/10	835	217.9	256	276.4	156
15/11/10	880	147.25	145.2	228.35	199.35
19/11/10	884	159.95	127.15	228.4	161.25
26/11/10	891				
03/12/10	898				

Table B.24 Variation of Fe in the lysimeters

Date	Time (day)	Variation of Fe (mg/L) at varying operational condition of landfill lysimeter			
		A ₁	A ₂	B	C
24/06/08	12	70.13	82.60	91.20	72.00
02/07/08	20	72.06	78.42	80.04	40.20
08/07/08	26	52.20	62.10	82.22	3.33
15/07/08	33	65.60	60.12	71.70	4.60
23/07/08	41	41.10	53.40	61.10	2.00
30/07/08	48	30.20	50.00	52.00	1.60
10/08/08	59	30.80	51.60	53.20	0.00
25/08/08	74	30.97	52.10	52.40	8.00
08/09/08	87	34.00	48.00	44.80	6.80
18/10/08	97	21.10	30.30	30.80	1.20
28/10/08	107	17.70	29.00	35.20	6.00
10/11/08	119	32.00	23.00	45.10	1.50
24/11/08	133	23.30	24.10	30.50	0.30
22/12/08	161	10.20	21.70	22.00	5.10
20/01/09	189	12.00	20.70	45.00	4.20
18/02/09	217	14	19.00	21.5	2.2
16/03/09	245	12	18.1	19.4	2.6
14/04/09	273	15.42	17	13.06	1.42
12/05/09	301	13.02	15.14	14.52	0.75
10/06/09	329	11.6	12.6	11.7	3.2
08/07/09	357	12.8	11.9	16.1	8.9
04/08/09	383	11.4	13	32.5	2.2
11/08/09	391	10	11.1	16.4	8.6
18/08/09	399	9.42	10	13.06	1.42
26/8/09	407	5.02	8	11.52	0.75
02/09/09	414	8.6	10.6	14.7	3.2
09/09/09	421	12.8	11.9	16.1	8.9
11/11/09	483	12.45	13.3	7.56	7.3
26/11/09	497.98	12.2	18.9	9.65	8.6
03/12/09	505	13	12.5	17.3	8.52
18/12/09	520	18.7	22.2	11.6	5
14/01/10	546	5.20	8.04	11.7	1.50
04/02/10	566	5.20	7.22	16.1	0.30
18/02/10	580	11.4	11.70	10.14	5.10
12/03/10	604	6	7.10	6	4.20
19/03/10	611	5.42	6.00	10	2.00
27/03/10	619	3.10	4.20	4	2.5

07/04/10	629	3.70	3.40	3.2	1.4
04/05/10	656	2.20	4.80	8.9	3.06
04/07/10	715	3.2	3.80	3.6	1.52
03/08/10	745				
02/09/10	775				
01/10/10	805				
30/10/10	835				
15/11/10	880				
19/11/10	884				
26/11/10	891				
03/12/10	898				

Table B.25 Variation of Cd in the lysimeters

Date	Time (day)	Variation of Cd (mg/L) at varying operational condition of landfill lysimeter			
		A ₁	A ₂	B	C
24/06/08	12	0.265	0.168	0.09	0.06
30/07/08	48	0.253	0.123	0.178	0.09
10/11/08	119	0.078	0.097	0.1176	0.105
22/12/08	161	0.13	0.065	0.087	0.07
16/03/09	245	0.067	0.0765	0.065	0.05
12/05/09	301	0.134	0.09	0.1	0.06
04/08/09	383	0.126	0.092	0.09	0.07
26/11/09	498	0.1176	0.0476	0.06	0.07
18/12/09	520	0.16	0.16	0.07	0.07
07/04/10	629	0.126	0.078	0.05	0.056
04/05/10	656	0.04	0.04	0.06	0.05
04/07/10	715	0.04	0.05	0.06	0.06
02/09/10	775	0.06	0.05	0.06	0.04
30/10/10	835	0.05	0.04	0.04	0.04
15/11/10	880	0.08	0.07	0.05	0.04
19/11/10	884	0.06	0.06	0.04	0.04
26/11/10	891	0.04	0.05	0.04	0.04
03/12/10	898	0.04	0.04	0.05	0.04

Table B.26 Variation of Ni in the lysimeters

Date	Time (day)	Variation of Ni (mg/L) at varying operational condition of landfill lysimeter			
		A ₁	A ₂	B	C
24/06/08	12	0.055	0.04	0.045	0.04
30/07/08	48	0.075	0.045	0.058	0.045
10/11/08	119	0.065	0.04	0.06	0.045
22/12/08	161	0.06	0.045	0.065	0.055
16/03/09	245	0.045	0.04	0.07	0.065
12/05/09	301	0.046	0.04	0.06	0.065
04/08/09	383	0.055	0.04	0.07	0.065
26/11/09	498	0.05	0.055	0.08	0.07
18/12/09	520	0.05	0.05	0.09	0.055
07/04/10	629	0.055	0.05	0.08	0.065
04/05/10	656	0.065	0.05	0.05	0.04
04/07/10	715	0.055	0.04	0.06	0.045
02/09/10	775	0.065	0.05	0.06	0.045
30/10/10	835	0.06	0.05	0.08	0.04
15/11/10	880	0.05	0.04	0.09	0.04
19/11/10	884	0.04	0.045	0.08	0.04
26/11/10	891	0.04	0.04	0.05	0.04
03/12/10	898	0.04	0.05	0.045	0.04

Table B.27 Variation of Zn in the lysimeters

Date	Time (day)	Variation of Zn (mg/L) at varying operational condition of landfill lysimeter			
		A ₁	A ₂	B	C
24/06/08	12	0.265	0.16	0.29	0.1
30/07/08	48	0.9	0.23	0.178	0.29
10/11/08	119	1.2	0.97	0.1176	0.105
22/12/08	161	1.13	0.65	0.487	0.35
16/03/09	245	1.267	0.765	0.45	0.35
12/05/09	301	1.134	0.9	0.45	0.37
04/08/09	383	1.126	0.92	0.55	0.576
26/11/09	498	1.1176	0.476	0.36	0.176
18/12/09	520	1.16	0.16	0.17	0.17
07/04/10	629	0.85	0.78	0.35	0.156
04/05/10	656	0.64	0.4	0.36	0.15
04/07/10	715	0.54	0.5	0.26	0.16
02/09/10	775	0.55	0.5	0.46	0.17
30/10/10	835	0.35	0.46	0.14	0.15

15/11/10	880	0.25	0.73	0.55	0.1
19/11/10	884	0.35	0.56	0.24	0.1
26/11/10	891	0.55	0.35	0.1	0.15
03/12/10	898	0.25	0.15	0.1	0.2

Table B.28 Variation of Cu in the lysimeters

Date	Time (day)	Variation of Cu (mg/L) at varying operational condition of landfill lysimeter			
		A ₁	A ₂	B	C
24/06/08	12	0.04	0.04	0.04	0.04
30/07/08	48	0.09	0.05	0.06	0.05
10/11/08	119	0.12	0.08	0.05	0.08
22/12/08	161	0.67	0.09	0.04	0.07
16/03/09	245	0.32	0.06	0.09	0.13
12/05/09	301	0.36	0.09	0.078	0.1
04/08/09	383	0.342	0.123	0.089	0.09
26/11/09	498	0.98	0.97	0.09	0.12
18/12/09	520	0.98	0.876	0.18	0.2
07/04/10	629	0.966	0.866	0.35	0.21
04/05/10	656	0.975	0.875	0.67	0.43
04/07/10	715	0.63	0.93	0.76	0.6
02/09/10	775	0.54	0.9	0.65	0.5
30/10/10	835	0.43	0.07	0.07	0.4
15/11/10	880	0.05	0.05	0.04	0.04
19/11/10	884	0.3	0.04	0.04	0.04
26/11/10	891	0.04	0.05	0.04	0.04
03/12/10	898	0.04	0.04	0.04	0.04

Table B.29 Variation of Cr in the lysimeters

Date	Time (day)	Variation of Cr (mg/L) at varying operational condition of landfill lysimeter			
		A ₁	A ₂	B	C
24/06/08	12	0.065	0.06	0.025	0.02
30/07/08	48	0.07	0.056	0.03	0.025
10/11/08	119	0.025	0.02	0.04	0.035
22/12/08	161	0.06	0.03	0.05	0.045
16/03/09	245	0.035	0.04	0.06	0.055
12/05/09	301	0.036	0.04	0.06	0.07
04/08/09	383	0.055	0.04	0.07	0.065
26/11/09	498	0.05	0.03	0.08	0.07

18/12/09	520	0.05	0.04	0.09	0.07
07/04/10	629	0.045	0.04	0.08	0.07
04/05/10	656	0.065	0.05	0.07	0.065
04/07/10	715	0.055	0.04	0.06	0.06
02/09/10	775	0.06	0.05	0.06	0.04
30/10/10	835	0.06	0.05	0.09	0.04
15/11/10	880	0.05	0.04	0.09	0.04
19/11/10	884	0.01	0.02	0.08	0.01
26/11/10	891	0.01	0.02	0.026	0.01
03/12/10	898	0.01	0.01	0.023	0.01

Table B.30 Variation of Mn in the lysimeters

Date	Time (day)	Variation of Mn (mg/L) at varying operational condition of landfill lysimeter			
		A ₁	A ₂	B	C
24/06/08	12	4	9	7	4
30/07/08	48	6	10	9	6
10/11/08	119	4.2	21.2	19.3	4.2
22/12/08	161	0.8	2.5	0.5	0.8
16/03/09	245	1	3	2	1
12/05/09	301	6	10	9	6
04/08/09	383	4.5	12	10	4.5
26/11/09	498	3.2	10	8	3.2
18/12/09	520	2.2	4	6	2.2
07/04/10	629	5	5	9	5
04/05/10	656	4.5	6	10	8
04/07/10	715	3.2	3	4	4.7
02/09/10	775	5.3	4.5	3.3	4.3
30/10/10	835	4.1	5.4	4.6	3.5
15/11/10	880	3.9	6.9	5	4.5
19/11/10	884	5.4	7.9	6	5.2
26/11/10	891	4.2	6.3	5.2	5.7
03/12/10	898	3.1	6.9	5.1	4.3

Table B.31 Variation of Pb in the lysimeters

Date	Time (day)	Variation of Pb (mg/L) at varying operational condition of landfill lysimeter			
		A ₁	A ₂	B	C
24/06/08	12	0.120	0.397	0.550	0.100
30/07/08	48	0.190	0.392	0.780	0.290
10/11/08	119	0.200	0.350	0.576	0.415
22/12/08	161	0.213	0.340	0.487	0.350
16/03/09	245	0.321	0.276	0.650	0.450
12/05/09	301	0.134	0.273	0.550	0.437
04/08/09	383	0.126	0.265	0.550	0.476
26/11/09	498	0.118	0.256	0.460	0.376
18/12/09	520	0.160	0.250	0.350	0.270
07/04/10	629	0.229	0.250	0.250	0.156
04/05/10	656	0.216	0.246	0.250	0.150
04/07/10	715	0.215	0.245	0.257	0.260
02/09/10	775	0.226	0.240	0.360	0.217
30/10/10	835	0.235	0.235	0.254	0.215
15/11/10	880	0.250	0.235	0.550	0.241
19/11/10	884	0.235	0.230	0.324	0.245
26/11/10	891	0.255	0.215	0.315	0.285
03/12/10	898	0.250	0.178	0.550	0.325

Appendix-C

Data for Aggregation Function, LPI and Sub-LPIs of Landfill Lysimeter

Table C.1: Aggregation functions used by different researchers for pollution indices

Equ. No.	Aggregation function	Function expression	Users	Specific remarks	Reported Table/column
1	Unweighted Additive Form	$LPI_{ua} = \frac{1}{n} \sum_{i=1}^n p_i$	Brown et al. (1970); Prati et al. (1971); McDuffie and Haney (1973)	Ambiguous function; shows eclipsing region; simple but little flexibility; unsuitable for dichotomous subindices.	Table C.2, Column 5.
2	Weighted Linear Additive Form	$LPI_{wa} = \sum_{i=1}^n w_i p_i$	Horton (1965); Brown et al. (1970); Prati et al. (1971); Dinius(1972); Dee et al. (1973); Inhaber(1974); Ott (1978); Ball and Church (1980); Egborge and Coker (1986); Mohan et al. (1996); Giljanovic (1999); Prasad and Bose (2001); Bardalo et al. (2001); Kumar and Alappat(2004)	Ambiguity free function; shows small eclipsing with large number of variables; not suitable for dichotomous subindices; widely used aggregation function.	Table C.2, Column 6.
3	Root Sum Power Additive form	$LPI_r = \left(\sum_{i=1}^n p_i^r \right)^{1/r}$	Swamee and Tyagi(1999); Kumar and Alappat (2004)	Shows reduced eclipsing but exhibit ambiguity problem; with increase in r , ambiguity decreases. If $r \rightarrow \infty$, it becomes ambiguity and eclipsity free function; use of aggregation function for $r > 2$ is not practiced for aggregation of water pollution indices.	
3(a)	Root Sum Power Additive form ($r=2$)	$LPI_2 = \left(\sum_{i=1}^n p_i^2 \right)^{1/2}$			Table C.2, Column 7.
3(b)	Root Sum Power Additive form ($r=4$)	$LPI_4 = \left(\sum_{i=1}^n p_i^4 \right)^{1/4}$			Table C.2, Column 8.

3(c)	Root Sum Power Additive form(r=10)	$LPI_{10} = \left(\sum_{i=1}^n p_i^{10} \right)^{1/10}$			Table C.2, Column 9.
Equ. No.	Aggregation function	Function expression	Users	Specific remarks	Reported Table/column
4	Weighted Root Sum Power Additive Form	$LPI_{wr} = \left(\sum_{i=1}^n w_i p_i^r \right)^{1/r}$	Kumar and Alappat (2004)	Exhibits slightly reduced ambiguity, unwidely used aggregation function.	
4(a)	Weighted Root Sum Power Additive Form (r=4)	$LPI_{w4} = \left(\sum_{i=1}^n w_i p_i^4 \right)^{1/4}$			Table C.2, Column 10.
4(b)	Weighted Root Sum Power Additive Form (r=10)	$LPI_{w10} = \left(\sum_{i=1}^n w_i p_i^{10} \right)^{1/10}$			Table C.2, Column 11.
5	Root Mean Square Additive Form	$LPI_{rm} = \left(\sum_{i=1}^n \frac{1}{n} p_i^2 \right)^{1/2}$	Inhaber (1974); Kumar and Alappat (2004)	Exhibits small ambiguity problems.	Table C.2, Column 12.
6	Weighted Root Sum Square Aggregation Function	$LPI_{wr} = \frac{(\sum_{i=1}^n w_i p_i^2)^{0.5}}{\sum_{i=1}^n w_i}$	Inhaber (1975); Kumar and Alappat (2004)	Exhibits small eclipsing problems.	Table C.2, Column 13.
7	Maximum Operator Function	$LPI_{max} = \max. \{p_1, p_2, \dots, p_n\}$	Smith 91990); Swamee and Tyagi (2000); Kumar and Alappat (2004)	No eclipsing problem but exhibit ambiguity for large number of variables; suitable for aggregation of air pollution subindices; limited application for water quality indices.	Table C.2, Column 14.
8	Ambiguity And Eclipsity Free Aggregation Function	$LPI_{aef} = \sum_{i=1}^n (p_i^{1/r})^r$	Swamee and Tyagi (1999); Kumar and Alappat (2004)	Eclipsity and ambiguity free function, limited application for air pollution indices; minimal ambiguity for $r=0.4$.	
8(a)	LPI _{2.5} Ambiguity and Eclipsity Free Aggregation	$LPI_{2.5} = \sum_{i=1}^n (p_i^{2.5})^{0.4}$			Table C.2, Column 15.

	Function				
Equ. No.	Aggregation function	Function expression	Users	Specific remarks	Reported Table/column
9	Weighted Ambiguity and Eclipsity Free Aggregation Function	$LPI_{w2.5} = \left(\sum_{i=1}^n w_i p_i^{2.5} \right)^{0.4}$	Kumar and Alappat (2004)	Eclipsity&Embiguity free function; limited application for leachate pollution indices.	Table C.2, Column 16.
10	Multiplicative Aggregation Function	$LPI_{wm} = \prod_{i=1}^n p_i^{w_i}$	Walski and Parker (1974); Ball and Church (1980); Bhargava(1983, 1985); Dinius(1987); Swamee and Tyagi(2000); Kumar and Alappat (2004)	Nonlinear; ambiguity free but exhibits eclipsing at low weights and increasing scale indices; insensitive when applied to large number of variables.	Table C.2, Column 17.
11	Unweighted Multiplicative Aggregation Function	$LPI_{um} = \left(\prod_{i=1}^n p_i \right)^{1/n}$	Landwehr and Deininger (1976); Bhargava (1985); Kumar and Alappat (2004)	Exhibits small eclipsity problem, applied for comparison purposes only.	Table C.2, Column 18.
12	Geometric Aggregation Function	$LPI_{gm} = \left(\prod_{i=1}^n p_i^{g_i} \right)^{1/\gamma}$	Walski and Parker (1974)	Nonlinear; ambiguity free but exhibits eclipsing at low weights and increasing scale indices; insensitive when applied to large number of variables.	

Table C.2: LPI values for leachate characteristics of landfill lysimeter leachate at KUET campus, using different aggregation functions

Pollutant (1)	w_i (2)	Conc. (3)	p_i (4)	LPI_{ua} (5)	LPI_{wa} (6)	LPI_2 (7)	LPI_4 (8)	LPI_{10} (9)	LPI_{w4} (10)	LPI_{w10} (11)	LPI_{rm} (12)	LPI_{wr} (13)	LPI_{max} (14)	$LPI_{2.5}$ (15)	$LPI_{w2.5}$ (16)	LPI_{wm} (17)	LPI_{um} (18)
Cr	0.064	1.75	6.5	6.5	0.416	42.25	1.79E+03	1.35E+08	1.14E+02	8.62E+06	42.25	2.704	6.5	1.08E+02	6.89E+00	1.13	6.5
Pb	0.063	0.68	9	9	0.567	81	6.56E+03	3.49E+09	4.13E+02	2.20E+08	81	5.103	9	2.43E+02	1.53E+01	1.15	9
COD	0.062	8425	70	70	4.34	4900	2.40E+07	2.82E+18	1.49E+06	1.75E+17	4900	303.8	70	4.10E+04	2.54E+03	1.30	70
Hg	0.062	0.4	59	59	3.658	3481	1.21E+07	5.11E+17	7.51E+05	3.17E+16	3481	215.8	59	2.67E+04	1.66E+03	1.29	59
BOD ₅	0.061	1398	35	35	2.135	1225	1.50E+06	2.76E+15	9.15E+04	1.68E+14	1225	74.7	35	7.25E+03	4.42E+02	1.24	35
As	0.061	0.01	5.5	5.5	0.3355	30.25	9.15E+02	2.53E+07	5.58E+01	1.55E+06	30.25	1.84	5.5	7.09E+01	4.33E+00	1.11	5.5
CN	0.058	1.3	10	10	0.58	100	1.00E+04	1.00E+10	5.80E+02	5.80E+08	100	5.8	10	3.16E+02	1.83E+01	1.14	10
Phenol	0.057	4	8.5	8.5	0.4845	72.25	5.22E+03	1.97E+09	2.98E+02	1.12E+08	72.25	4.11	8.5	2.11E+02	1.20E+01	1.13	8.5
Zn	0.056	1.3	5	5	0.28	25	6.25E+02	9.77E+06	3.50E+01	5.47E+05	25	1.4	5	5.59E+01	3.13E+00	1.09	5
pH	0.055	7.3	6	6	0.33	36	1.30E+03	6.05E+07	7.13E+01	3.33E+06	36	1.98	6	8.82E+01	4.85E+00	1.10	6
TKN	0.053	3000	98	98	5.194	9604	9.22E+07	8.17E+19	4.89E+06	4.33E+18	9604	509	98	9.51E+04	5.04E+03	1.28	98
Ni	0.052	0.23	8	8	0.416	64	4.10E+03	1.07E+09	2.13E+02	5.58E+07	64	3.33	8	1.81E+02	9.41E+00	1.11	8
TCB	0.052	8000	92	92	4.784	8464	7.16E+07	4.34E+19	3.73E+06	2.26E+18	8464	440	92	8.12E+04	4.22E+03	1.27	92
NH ₃	0.051	1300	100	100	5.1	10000	1.00E+08	1.00E+20	5.10E+06	5.10E+18	10000	510	100	1.00E+05	5.10E+03	1.26	100
TDS	0.05	12540	28	28	1.4	784	6.15E+05	2.96E+14	3.07E+04	1.48E+13	784	39.2	28	4.15E+03	2.07E+02	1.18	28
Cu	0.05	0.98	7	7	0.35	49	2.40E+03	2.82E+08	1.20E+02	1.41E+07	49	2.45	7	1.30E+02	6.48E+00	1.10	7
C ⁺	0.049	3597	30	30	1.47	900	8.10E+05	5.90E+14	3.97E+04	2.89E+13	900	44.1	30	4.93E+03	2.42E+02	1.18	30
Fe	0.045	82	9.5	9.5	0.4275	90.25	8.15E+03	5.99E+09	3.67E+02	2.69E+08	90.25	4.	9.5	2.78E+02	1.25E+01	1.11	9.5
Total	1.001			587	32.2675	39948	3.03E+08	2.28E+20	1.61E+07	1.19E+19	39948	2170	100	3.62E+05	1.95E+04	18.04	4.79E+22
LPI value				32.61	32.27	199.87	131.93	108.61	63.36	80.82	47.11	46.53	100.00	167.30	52.05	18.04	18.20

Note: TCB= total Coliform bacteria; TKN= total Kjeldhal nitrogen; and TDS total dissolved solids. All the values are in mg/L except for pH and TCB.

Table C.3: Leachate Pollution Index (LPI) values for treated leachate using different aggregation functions

Pollutant	w_i	Conc ^b	p_i	LPI_{ua}	LPI_{wa}	LPI_2	LPI_4	LPI_{10}	LPI_{w4}	LPI_{w10}	LPI_{rm}	LPI_{wr}	LPI_{max}	$LPI_{2.5}$	$LPI_{w2.5}$	LPI_{wm}	LPI_{um}
Cr	0.06	2	9	9	0.58	81	6.56E+03	3.49E+09	4.20E+02	2.23E+08	81	5.18	9	243.00	15.55	1.15	9
Pb	0.06	0.1	5	5	0.32	25	6.25E+02	9.77E+06	3.94E+01	6.15E+05	25	1.58	5	55.90	3.52	1.11	5
COD	0.06	250	10	10	0.62	100	1.00E+04	1.00E+10	6.20E+02	6.20E+08	100	6.20	10	316.23	19.61	1.15	10
Hg	0.06	0.01	6	6	0.37	36	1.30E+03	6.05E+07	8.04E+01	3.75E+06	36	2.23	6	88.18	5.47	1.12	6
BOD ₅	0.06	30	6	6	0.37	36	1.30E+03	6.05E+07	7.91E+01	3.69E+06	36	2.20	6	88.18	5.38	1.12	6
As	0.06	0.2	5	5	0.31	25	6.25E+02	9.77E+06	3.81E+01	5.96E+05	25	1.53	5	55.90	3.41	1.10	5
CN	0.06	0.2	6	6	0.35	36	1.30E+03	6.05E+07	7.52E+01	3.51E+06	36	2.09	6	88.18	5.11	1.11	6
Phenol	0.06	1	5	5	0.29	25	6.25E+02	9.77E+06	3.56E+01	5.57E+05	25	1.43	5	55.90	3.19	1.10	5
Zinc	0.06	5	6	6	0.34	36	1.30E+03	6.05E+07	7.26E+01	3.39E+06	36	2.02	6	88.18	4.94	1.11	6
pH	0.06	5.5-9	5	5	0.28	25	6.25E+02	9.77E+06	3.44E+01	5.37E+05	25	1.38	5	55.90	3.07	1.09	5
TKN	0.05	100	6	6	0.32	36	1.30E+03	6.05E+07	6.87E+01	3.20E+06	36	1.91	6	88.18	4.67	1.10	6
Ni	0.05	3	10	10	0.52	100	1.00E+04	1.00E+10	5.20E+02	5.20E+08	100	5.20	10	316.23	16.44	1.13	10
TCB	0.05	3 ^a	10	10	0.52	100	1.00E+04	1.00E+10	5.20E+02	5.20E+08	100	5.20	10	316.23	16.44	1.13	10
NH ₃	0.05	50	7	7	0.36	49	2.40E+03	2.82E+08	1.22E+02	1.44E+07	49	2.50	7	129.64	6.61	1.10	7
TDS	0.05	2100	7	7	0.35	49	2.40E+03	2.82E+08	1.20E+02	1.41E+07	49	2.45	7	129.64	6.48	1.10	7
Cu	0.05	3	18	18	0.90	324	1.05E+05	3.57E+12	5.25E+03	1.79E+11	324	16.20	18	1374.62	68.73	1.16	18
Cl ⁻	0.05	1000	8	8	0.39	64	4.10E+03	1.07E+09	2.01E+02	5.26E+07	64	3.14	8	181.02	8.87	1.11	8
Fe	0.05	100 ^a	7	7	0.32	49	2.40E+03	2.82E+08	1.08E+02	1.27E+07	49	2.21	7	129.64	5.83	1.09	7
Total	1.00			136	7.47	1196	1.62E+05	3.61E+12	8.40E+03	1.81E+11	1196	64.61	18	3800.76	203.34	7.05	2.16E+15
LPI value				7.56	7.47	34.58	2.01E+01	1.80E+01	9.57E+00	1.34E+01	8.15	8.03	18	27.04	8.38	7.05	7.11

Table C.4: Calculation of LPI at 14 day after filling of MSW in landfill lysimeter

Pollutant variable	Variable weight, w_i	Pollutant concentration, c_i				Individual pollutant rating, p_i				Overall pollutant rating, $w_i p_i$			
		A ₁	A ₂	B	C	A ₁	A ₂	B	C	A ₁	A ₂	B	C
Chromium	0.064	0.1	0.23	0.21	0.11	5	5	5	5	0.32	0.32	0.32	0.32
Lead	0.063	0.39	0.6	0.85	0.7	7	7	7.5	7.5	0.441	0.441	0.4725	0.4725
COD	0.062	9754	48400	43280	42560	69	91.5	91	91	4.278	5.673	5.642	5.642
Mercury	0	-	-	-	-	-	-	-	-	-	-	-	-
BOD ₅	0.061	2210	2980	2670	2310	41	46	45	42	2.501	2.806	2.745	2.562
Arsenic	0.061	0.02	0.05	0.02	0.02	5	5	5	5	0.305	0.305	0.305	0.305
Cyanide	0	-	-	-	-	-	-	-	-	-	-	-	-
Phenol	0	-	-	-	-	-	-	-	-	-	-	-	-
Zinc	0.056	1.3	1.2	0.91	0.63	5.5	5	5	5	0.308	0.28	0.28	0.28
pH	0.055	7.12	8.56	8.5	7.67	6	5	5	5	0.33	0.275	0.275	0.275
TKN	0.053	1120	2090	1658	1430	38	74	58	49	2.014	3.922	3.074	2.597
Nickel	0.052	0.13	0.18	0.15	0.14	5	5	5	5	0.26	0.26	0.26	0.26
TCB	0.052	6540	8398	7768	7340	85	89	90	90	4.42	4.628	4.68	4.68
NH ₄ -N	0.051	700	901.3	992.7	965.7	75	96	98	97	3.825	4.896	4.998	4.947
TDS	0.05	8765	32589	30823	28790	17	76	71	66	0.85	3.8	3.55	3.3
Copper	0.05	1.23	1.46	1.13	1.24	7	7	7	7	0.35	0.35	0.35	0.35
Chlorides	0.049	3320.00	3750.00	2210.00	820.00	27	31	16	8	1.323	1.519	0.784	0.392
Total Iron	0.045	70.13	82.60	91.20	72.00	6.5	6.5	7	6.5	0.2925	0.2925	0.315	0.2925
Summation	0.824									21.82	29.77	28.05	26.68
Derived LPI										26.48	36.13	34.04	32.37

Table C.5: Calculation of LPI at 21 day after filling of MSW in landfill lysimeter

Pollutant variable	Variable weight, w_i	Pollutant concentration, c_i				Individual pollutant rating, p_i				Overall pollutant rating, $w_i p_i$			
		A ₁	A ₂	B	C	A ₁	A ₂	B	C	A ₁	A ₂	B	C
Chromium	0.064	0.086	0.19	0.17	0.098	5	5	5	5	0.32	0.32	0.32	0.32
Lead	0.063	0.32	0.55	0.75	0.62	7	7	9	8	0.441	0.441	0.567	0.504
COD	0.062	10276	47100	42310	45320	71	91.5	91	91	4.402	5.673	5.642	5.642
Mercury	0	-	-	-	-	-	-	-	-	-	-	-	-
BOD ₅	0.061	2180	2754	2520	2209	41	45	44.5	41	2.501	2.745	2.7145	2.501
Arsenic	0.061	0.02	0.04	0.02	0.02	5	5	5	5	0.305	0.305	0.305	0.305
Cyanide	0	-	-	-	-	-	-	-	-	-	-	-	-
Phenol	0	-	-	-	-	-	-	-	-	-	-	-	-
Zinc	0.056	1.1	1.3	0.86	0.68	5.5	5	5	5	0.308	0.28	0.28	0.28
pH	0.055	6.99	6.93	7.44	7.43	6	6	5	5	0.33	0.33	0.275	0.275
TKN	0.053	1010	1875	1659	1320.8	33	66	57	45	1.749	3.498	3.021	2.385
Nickel	0.052	0.042	0.078	0.064	0.053	5	5	5	5	0.26	0.26	0.26	0.26
TCB	0.052	6439	8125	7929	7550	85	89	90	90	4.42	4.628	4.68	4.68
NH ₄ -N	0.051	702.3	865.3	967.2	898.7	80	94	97	95	4.08	4.794	4.947	4.845
TDS	0.05	6380	33710	29687	22487.9	14	78	69	46	0.7	3.9	3.45	2.3
Copper	0.05	0.77	1.36	1.1	0.97	6	7	7	6.5	0.3	0.35	0.35	0.325
Chlorides	0.049	3560.60	3890.00	2412.00	1010.0	26	33	18	8.5	1.274	1.617	0.882	0.4165
Total Iron	0.045	72.06	78.42	80.04	40.20	6.5	6.5	6.5	6	0.2925	0.2925	0.2925	0.27
Summation	0.824									21.68	29.43	27.99	25.31
Derived LPI										26.31	35.72	33.96	30.71

Table C.6: Calculation of LPI at 30 day after filling of MSW in landfill lysimeter

Pollutant variable	Variable weight, w_i	Pollutant concentration, c_i				Individual pollutant rating, p_i				Overall pollutant rating, $w_i p_i$			
		A ₁	A ₂	B	C	A ₁	A ₂	B	C	A ₁	A ₂	B	C
Chromium	0.064	0.07	0.06	0.09	0.07	5	5	5	5	0.32	0.32	0.32	0.32
Lead	0.063	0.32	0.4	0.78	0.5	7	7	9	8	0.441	0.441	0.567	0.504
COD	0.062	20800	36400	38800	42800	83	88	90	92	5.146	5.456	5.58	5.704
Mercury		-	-	-	-	-	-	-	-	-	-	-	-
BOD ₅	0.061	6750	12358	16733	20420	62	68	73	77	3.782	4.148	4.453	4.697
Arsenic	0.061	0.02	0.3	0.02	0.02	5	5	5	5	0.305	0.305	0.305	0.305
Cyanide		-	-	-	-	-	-	-	-	-	-	-	-
Phenol		-	-	-	-	-	-	-	-	-	-	-	-
Zinc	0.056	1.3	0.97	0.55	0.58	5.5	5	5	5	0.308	0.28	0.28	0.28
pH	0.055	6.43	7.5	7.92	7.21	7	5	5	6	0.385	0.275	0.275	0.33
TKN	0.053	1001	1735	1620	1297	30	62	55	45	1.59	3.286	2.915	2.385
Nickel	0.052	0.075	0.045	0.058	0.045	6	5.5	5.5	5.5	0.312	0.286	0.286	0.286
TCB	0.052	6320	8005	7900	7510	85	87	87	86	4.42	4.524	4.524	4.472
NH ₄ -N	0.051	687.4	832	955.5	865	80	87	98	93	4.08	4.437	4.998	4.743
TDS	0.05	7490	5000	7880	17700	16	12	17	43	0.8	0.6	0.85	2.15
Copper	0.05	0.98	0.97	0.09	0.12	7	7	5.5	5.5	0.35	0.35	0.275	0.275
Chlorides	0.049	3037	3572	1350	660	25	31	12	8	1.225	1.519	0.588	0.392
Total Iron	0.045	3.2	3.8	3.6	1.5	5.5	5.5	5.5	5	0.2475	0.2475	0.2475	0.225
Summation	0.824									23.711	26.4745	26.4635	27.068
Derived LPI										28.78	32.13	32.12	32.85

Table C.7: Calculation of LPI at 50 day after filling of MSW in landfill lysimeter

Pollutant variable	Variable weight, w_i	Pollutant concentration, c_i				Individual pollutant rating, p_i				Overall pollutant rating, $w_i p_i$			
		A ₁	A ₂	B	C	A ₁	A ₂	B	C	A ₁	A ₂	B	C
Chromium	0.064	0.07	0.056	0.03	0.025	5	5	5	5	0.32	0.32	0.32	0.32
Lead	0.063	0.19	0.39	0.78	0.29	6	7	9	6.5	0.378	0.441	0.567	0.4095
COD	0.062	320	10240	38040	35550	12	74	89	88	0.744	4.588	5.518	5.456
Mercury		-	-	-	-	-	-	-	-	-	-	-	-
BOD ₅	0.061	124	3420	22403	19573	8	55	78	76	0.488	3.355	4.758	4.636
Arsenic	0.061	0.02	0.03	0.02	0.02	5	5	5	5	0.305	0.305	0.305	0.305
Cyanide		-	-	-	-	-	-	-	-	-	-	-	-
Phenol		-	-	-	-	-	-	-	-	-	-	-	-
Zinc	0.056	0.9	0.23	0.18	0.29	5	5	5	5	0.28	0.28	0.28	0.28
pH	0.055	8.16	7.47	8.41	8.05	5	5	5	5	0.275	0.275	0.275	0.275
TKN	0.053	997	1704	1605	1280	30	60	55	44	1.59	3.18	2.915	2.332
Nickel	0.052	0.075	0.045	0.058	0.045	6	5.5	5.5	5.5	0.312	0.286	0.286	0.286
TCB	0.052	6295	7960	7890	7486	64	87	86	84	3.328	4.524	4.472	4.368
NH ₄ -N	0.051	682	802	943.7	831.2	75	90	97	86	3.825	4.59	4.947	4.386
TDS	0.05	5590	20150	13790	14590	13	49	34	38	0.65	2.45	1.7	1.9
Copper	0.05	0.09	0.05	0.06	0.05	5.5	5.5	5.5	5.5	0.275	0.275	0.275	0.275
Chlorides	0.049	2650	1850	570	145	25	13	7	5.5	1.225	0.637	0.343	0.2695
Total Iron	0.045	0.2	0.2	2	1.6	5	5	5	5	0.225	0.225	0.225	0.225
Summation	0.824									14.22	25.731	27.186	25.723
Derived LPI										17.26	31.23	32.99	31.22

Table C.8: Calculation of LPI at 60 day after filling of MSW in landfill lysimeter

Pollutant variable	Variable weight, w_i	Pollutant concentration, c_i				Individual pollutant rating, p_i				Overall pollutant rating, $w_i p_i$			
		A ₁	A ₂	B	C	A ₁	A ₂	B	C	A ₁	A ₂	B	C
Chromium	0.064	0.07	0.056	0.03	0.025	5	5	5	5	0.32	0.32	0.32	0.32
Lead	0.063	0.18	0.392	0.78	0.29	6	7	9	6.5	0.378	0.441	0.567	0.4095
COD	0.062	896	9360	3042	34480	36	78	62	87	2.232	4.836	3.844	5.394
Mercury		-	-	-	-	-	-	-	-	-	-	-	-
BOD ₅	0.061	384	5520	2856	12554	12	58	47	68	0.732	3.538	2.867	4.148
Arsenic	0.061	0.02	0.03	0.02	0.02	5	5	5	5	0.305	0.305	0.305	0.305
Cyanide		-	-	-	-	-	-	-	-	-	-	-	-
Phenol		-	-	-	-	-	-	-	-	-	-	-	-
Zinc	0.056	0.88	0.23	0.17	0.29	5	5	5	5	0.28	0.28	0.28	0.28
pH	0.055	6.49	6.33	8.5	7.12	6	6.5	5	5	0.33	0.3575	0.275	0.275
TKN	0.053	980	1680	1595	1244	30	60	55	40	1.59	3.18	2.915	2.12
Nickel	0.052	0.075	0.045	0.058	0.045	6	5.5	5.5	5.5	0.312	0.286	0.286	0.286
TCB	0.052	6229	7945	7878	7452	84	87	89	86	4.368	4.524	4.628	4.472
NH ₄ -N	0.051	675	765	803	820	75	85	90	91	3.825	4.335	4.59	4.641
TDS	0.05	4490	15740	10610	13160	12	38	24	27	0.6	1.9	1.2	1.35
Copper	0.05	0.09	0.05	0.06	0.05	5.5	5.5	5.5	5.5	0.275	0.275	0.275	0.275
Chlorides	0.049	1120.00	1270.00	580.00	150.00	9	10	7	5.5	0.441	0.49	0.343	0.2695
Total Iron	0.045	30.80	51.60	53.20	8.67	5.5	6	6	5	0.2475	0.27	0.27	0.225
Summation	0.824									16.235	25.3375	22.965	24.77
Derived LPI										19.70	30.75	27.87	30.06

Table C.9: Calculation of LPI at 90 day after filling of MSW in landfill lysimeter

Pollutant variable	Variable weight, w_i	Pollutant concentration, c_i				Individual pollutant rating, p_i				Overall pollutant rating, $w_i p_i$			
		A ₁	A ₂	B	C	A ₁	A ₂	B	C	A ₁	A ₂	B	C
Chromium	0.064	0.07	0.054	0.03	0.026	5	5	5	5	0.32	0.32	0.32	0.32
Lead	0.063	0.19	0.41	0.77	0.30	6	7	9	6.5	0.378	0.441	0.567	0.4095
COD	0.062	2880	7520	2000	32360	54	72	50	86	3.348	4.464	3.1	5.332
Mercury		-	-	-	-	-	-	-	-	-	-	-	-
BOD ₅	0.061	1024	3235	1576	18526	28	49	35	75	1.708	2.989	2.135	4.575
Arsenic	0.061	0.02	0.03	0.02	0.02	5	5	5	5	0.305	0.305	0.305	0.305
Cyanide		-	-	-	-	-	-	-	-	-	-	-	-
Phenol		-	-	-	-	-	-	-	-	-	-	-	-
Zinc	0.056	0.9	0.23	0.178	0.29	5	5	5	5	0.28	0.28	0.28	0.28
pH	0.055	6.89	6.63	8.43	6.49	6	7	5	7	0.33	0.385	0.275	0.385
TKN	0.053	956	1652	1575	1225	30	57	55	40	1.59	3.021	2.915	2.12
Nickel	0.052	0.075	0.045	0.058	0.045	6	5.5	5.5	5.5	0.312	0.286	0.286	0.286
TCB	0.052	6260	7900	7897	7445	85	87	88	86	4.42	4.524	4.576	4.472
NH ₄ -N	0.051	634.2	654.9	765	702	70	72	74	78	3.57	3.672	3.774	3.978
TDS	0.05	3670	14380	7880	12150	8	37	17	28	0.4	1.85	0.85	1.4
Copper	0.05	0.09	0.05	0.06	0.05	5.5	5.5	5.5	5.5	0.275	0.275	0.275	0.275
Chlorides	0.049	970.00	1170.00	725.00	1070.0	8	9	7.5	8.5	0.392	0.441	0.3675	0.4165
Total Iron	0.045	34.00	48.00	44.80	6.80	5.5	6	6	5	0.2475	0.27	0.27	0.225
Summation	0.824									17.875	23.523	20.2955	24.779
Derived LPI										21.69	28.55	24.63	30.07

Table C.10: Calculation of LPI at 120 day after filling of MSW in landfill lysimeter

Pollutant variable	Variable weight, w_i	Pollutant concentration, c_i				Individual pollutant rating, p_i				Overall pollutant rating, $w_i p_i$			
		A ₁	A ₂	B	C	A ₁	A ₂	B	C	A ₁	A ₂	B	C
Chromium	0.064	0.03	0.02	0.04	0.04	5.00	5.00	5.00	5.00	0.32	0.32	0.32	0.32
Lead	0.063	0.20	0.35	0.58	0.42	6.00	7.00	7.50	7.00	0.38	0.44	0.47	0.44
COD	0.062	160	6760	1440	5120	8.50	68.00	44.00	67.00	0.53	4.22	2.73	4.15
Mercury	-	NA	NA	NA	NA	-	-	-	-	-	-	-	-
BOD ₅	0.061	83	3575	980	2179	8.00	51.00	27.00	41.00	0.49	3.11	1.65	2.50
Arsenic	0.061	0.02	0.04	0.02	0.02	5.00	5.00	5.00	5.00	0.31	0.31	0.31	0.31
Cyanide	-	NA	NA	NA	NA	-	-	-	-	-	-	-	-
Phenol	-	NA	NA	NA	NA	-	-	-	-	-	-	-	-
Zinc	0.056	1.20	0.97	0.12	0.11	5.00	5.00	5.00	5.00	0.28	0.28	0.28	0.28
pH	0.055	6.75	6.42	7.84	6.30	6.00	7.00	5.00	7.00	0.33	0.39	0.28	0.39
TKN	0.053	945	1637	1556	1218	27.00	58.00	54.00	40.00	1.43	3.07	2.86	2.12
Nickel	0.052	0.07	0.04	0.06	0.05	5.50	5.50	5.50	5.50	0.29	0.29	0.29	0.29
TCB	0.052	6212	7945	7898	7460	85.00	87.00	88.00	86.00	4.42	4.52	4.58	4.47
NH ₄ -N	0.051	610	654	787	698	66.00	73.00	88.00	85.00	3.37	3.72	4.49	4.34
TDS	0.05	4440	13440	5810	8300	9.00	34.00	13.00	18.00	0.45	1.70	0.65	0.90
Copper	0.05	0.12	0.08	0.05	0.08	5.50	5.50	5.50	5.50	0.28	0.28	0.28	0.28
Chlorides	0.049	2440	2670	1750	1300	19.00	21.00	13.00	10.00	0.93	1.03	0.64	0.49
Total Iron	0.045	32	23	45.10	1.50	5.50	5.50	6.00	5.00	0.25	0.25	0.27	0.23
Summation	0.824									14.03	23.92	20.07	21.49
Derived LPI										17.03	29.02	24.36	26.08

Table C.11: Calculation of LPI at 160 day after filling of MSW in landfill lysimeter

Pollutant variable	Variable weight, w_i	Pollutant concentration, c_i				Individual pollutant rating, p_i				Overall pollutant rating, $w_i p_i$			
		A ₁	A ₂	B	C	A ₁	A ₂	B	C	A ₁	A ₂	B	C
Chromium	0.064	0.06	0.03	0.05	0.045	5	5	5	5	0.32	0.32	0.32	0.32
Lead	0.063	0.213	0.34	0.487	0.35	6	7	7.5	7	0.378	0.441	0.4725	0.441
COD	0.062	2876	5800	1920	5280	55	67	49	66	3.41	4.154	3.038	4.092
Mercury		-	-	-	-	-	-	-	-	-	-	-	-
BOD ₅	0.061	1550	1760	805	965	35	37	26.5	28	2.135	2.257	1.6165	1.708
Arsenic	0.061	0.02	0.03	0.02	0.02	5	5	5	5	0.305	0.305	0.305	0.305
Cyanide		-	-	-	-	-	-	-	-	-	-	-	-
Phenol		-	-	-	-	-	-	-	-	-	-	-	-
Zinc	0.056	1.13	0.65	0.487	0.35	5	5	5	5	0.28	0.28	0.28	0.28
pH	0.055	6.17	6.88	7.61	7.33	7	5	5	5	0.385	0.275	0.275	0.275
TKN	0.053	937	1625	1560	1210	26	57	55	40	1.378	3.021	2.915	2.12
Nickel	0.052	0.06	0.045	0.065	0.055	5.5	5.5	5.5	5.5	0.286	0.286	0.286	0.286
TCB	0.052	6187	7855	7802	7356	85	88	88	86	4.42	4.576	4.576	4.472
NH ₄ -N	0.051	543	597	754	653	58	66	78	74	2.958	3.366	3.978	3.774
TDS	0.05	4310	12780	6440	9390	10	32	15	21	0.5	1.6	0.75	1.05
Copper	0.05	0.67	0.09	0.04	0.07	7	5.5	5.5	5.5	0.35	0.275	0.275	0.275
Chlorides	0.049	2880.00	2790.00	1010.00	1410.0	23	23	9	11	1.127	1.127	0.441	0.539
Total Iron	0.045	10.20	21.70	22.00	5.10	5	5.5	5.5	5	0.225	0.2475	0.2475	0.225
Summation	0.824									18.457	22.5305	19.7755	20.162
Derived LPI										22.40	27.34	24.00	24.47

Table C.12: Calculation of LPI at 190 day after filling of MSW in landfill lysimeter

Pollutant variable	Variable weight, w_i	Pollutant concentration, c_i				Individual pollutant rating, p_i				Overall pollutant rating, $w_i p_i$			
		A ₁	A ₂	B	C	A ₁	A ₂	B	C	A ₁	A ₂	B	C
Chromium	0.064	0.07	0.06	0.09	0.07	5	5	5	5	0.32	0.32	0.32	0.32
Lead	0.063	0.32	0.4	0.78	0.5	7	7	9	8	0.441	0.441	0.567	0.504
COD	0.062	20800	36400	38800	42800	80	88	90	88	4.96	5.456	5.58	5.456
Mercury	-	-	-	-	-	-	-	-	-	-	-	-	-
BOD ₅	0.061	1050	1640	1433	2020	28	45	31	35	1.708	2.745	1.891	2.135
Arsenic	0.061	0.02	0.03	0.02	0.02	5	5	5	5	0.305	0.305	0.305	0.305
Cyanide	-	-	-	-	-	-	-	-	-	-	-	-	-
Phenol	-	-	-	-	-	-	-	-	-	-	-	-	-
Zinc	0.056	1.3	0.97	0.55	0.58	5.5	5	5	5	0.308	0.28	0.28	0.28
pH	0.055	6.43	7.5	7.92	7.21	6	5	5	6	0.33	0.275	0.275	0.33
TKN	0.053	853.3	1505	1348	1065	27	50	42	31	1.431	2.65	2.226	1.643
Nickel	0.052	0.075	0.045	0.058	0.045	6	5.5	5.5	5.5	0.312	0.286	0.286	0.286
TCB	0.052	6200	7965	8200	8150	85	89	90	90	4.42	4.628	4.68	4.68
NH ₄ -N	0.051	572	783	876	786	66	86	95	85	3.366	4.386	4.845	4.335
TDS	0.05	7490	5000	7880	17700	14	12	17	43	0.7	0.6	0.85	2.15
Copper	0.05	0.98	0.97	0.09	0.12	7	7	5.5	5.5	0.35	0.35	0.275	0.275
Chlorides	0.049	3037	3572	1350	660	23	31	12	8	1.127	1.519	0.588	0.392
Total Iron	0.045	3.2	3.8	3.6	1.5	5.5	5.5	5.5	5	0.2475	0.2475	0.2475	0.225
Summation	0.824									20.325	24.4885	23.2155	23.316
Derived LPI										24.67	29.72	28.17	28.30

Table C.13: Calculation of LPI at 245 day after filling of MSW in landfill lysimeter

Pollutant variable	Variable weight, w_i	Pollutant concentration, c_i				Individual pollutant rating, p_i				Overall pollutant rating, $w_i p_i$			
		A ₁	A ₂	B	C	A ₁	A ₂	B	C	A ₁	A ₂	B	C
Chromium	0.064	0.035	0.04	0.06	0.055	5	5	5	5	0.32	0.32	0.32	0.32
Lead	0.063	0.321	0.276	0.65	0.45	7	6.5	7.5	7	0.441	0.4095	0.4725	0.441
COD	0.062	960	4120	1490	4860	36	63	44	64	2.232	3.906	2.728	3.968
Mercury		-	-	-	-	-	-	-	-	-	-	-	-
BOD ₅	0.061	218	1520	465	1765	9	35	16	31	0.549	2.135	0.976	1.891
Arsenic	0.061	0.02	0.03	0.01	0.01	5	5	5	5	0.305	0.305	0.305	0.305
Cyanide		-	-	-	-	-	-	-	-	-	-	-	-
Phenol		-	-	-	-	-	-	-	-	-	-	-	-
Zinc	0.056	1.267	0.765	0.45	0.35	5	5	5	5	0.28	0.28	0.28	0.28
pH	0.055	6.53	7.63	7.38	8.2	7	5	5	5	0.385	0.275	0.275	0.275
TKN	0.053	845	1603	1521	1137	26	55	52	38	1.378	2.915	2.756	2.014
Nickel	0.052	0.045	0.04	0.07	0.065	5.5	5.5	5.5	5.5	0.286	0.286	0.286	0.286
TCB	0.052	5621	6190	6420	6220	83	85	86	85	4.316	4.42	4.472	4.42
NH ₄ -N	0.051	504.9	586.7	697.5	632.8	56	66	76	71	2.856	3.366	3.876	3.621
TDS	0.05	2110	11572	6170	13420	10	26	14	33	0.5	1.3	0.7	1.65
Copper	0.05	0.32	0.06	0.09	0.13	6	5.5	5.5	5.5	0.3	0.275	0.275	0.275
Chlorides	0.049	2090.00	2150.00	1000.00	1290.0	15	15	8.5	10	0.735	0.735	0.4165	0.49
Total Iron	0.045	12	18.1	19.4	2.6	5	5.5	5.5	5	0.225	0.2475	0.2475	0.225
Summation	0.824									15.108	21.175	18.3855	20.461
Derived LPI										18.33	25.70	22.31	24.83

Table C.14: Calculation of LPI at 300 day after filling of MSW in landfill lysimeter

Pollutant variable	Variable weight, w_i	Pollutant concentration, c_i				Individual pollutant rating, p_i				Overall pollutant rating, $w_i p_i$			
		A ₁	A ₂	B	C	A ₁	A ₂	B	C	A ₁	A ₂	B	C
Chromium	0.064	0.036	0.04	0.06	0.07	5	5	5	5	0.32	0.32	0.32	0.32
Lead	0.063	0.134	0.273	0.55	0.437	5.5	6.5	7.5	7	0.3465	0.4095	0.4725	0.441
COD	0.062	800	3726	1400	3400	32	61	39	60	1.984	3.782	2.418	3.72
Mercury		-	-	-	-	-	-	-	-	-	-	-	-
BOD ₅	0.061	321	1917	652	2165	12	39	23.5	42	0.732	2.379	1.4335	2.562
Arsenic	0.061	0.02	0.03	0.01	0.01	5	5	5	5	0.305	0.305	0.305	0.305
Cyanide		-	-	-	-	-	-	-	-	-	-	-	-
Phenol		-	-	-	-	-	-	-	-	-	-	-	-
Zinc	0.056	1.134	0.9	0.45	0.37	5	5	5	5	0.28	0.28	0.28	0.28
pH	0.055	6.33	7.55	7.21	8.27	7	5	5	5	0.385	0.275	0.275	0.275
TKN	0.053	820	1109	1534	1456	25	36	51	50	1.325	1.908	2.703	2.65
Nickel	0.052	0.046	0.04	0.06	0.065	5.5	5.5	5.5	5.5	0.286	0.286	0.286	0.286
TCB	0.052	4870	5438	5100	4987	82	85	84	83	4.264	4.42	4.368	4.316
NH ₄ -N	0.051	487.7	576	686	614	54	60	78	70	2.754	3.06	3.978	3.57
TDS	0.05	3890	10572	7910	9340	9	22	17	21	0.45	1.1	0.85	1.05
Copper	0.05	0.36	0.09	0.078	0.1	6	5.5	5.5	5.5	0.3	0.275	0.275	0.275
Chlorides	0.049	2150.00	2250.00	1010.00	1810.0	16	16.5	9	13.5	0.784	0.8085	0.441	0.6615
Total Iron	0.045	13.02	15.14	14.52	0.75	5	5	5	5	0.225	0.225	0.225	0.225
Summation	0.824									14.74	19.83	18.63	20.94
Derived LPI										17.89	24.07	22.61	25.41

Table C.15: Calculation of LPI at 380 day after filling of MSW in landfill lysimeter

Pollutant variable	Variable weight, w_i	Pollutant concentration, c_i				Individual pollutant rating, p_i				Overall pollutant rating, $w_i p_i$			
		A ₁	A ₂	B	C	A ₁	A ₂	B	C	A ₁	A ₂	B	C
Chromium	0.064	0.055	0.04	0.07	0.065	5	5	5	5	0.32	0.32	0.32	0.32
Lead	0.063	0.126	0.265	0.55	0.476	5.5	6.5	7.5	7	0.3465	0.4095	0.4725	0.441
COD	0.062	852	4087	900	5300	33	63	36	66	2.046	3.906	2.232	4.092
Mercury		-	-	-	-	-	-	-	-	-	-	-	-
BOD ₅	0.061	465	2361	565	2453	15.5	43	19	45	0.9455	2.623	1.159	2.745
Arsenic	0.061	0.02	0.03	0.01	0.01	5	5	5	5	0.305	0.305	0.305	0.305
Cyanide		-	-	-	-	-	-	-	-	-	-	-	-
Phenol		-	-	-	-	-	-	-	-	-	-	-	-
Zinc	0.056	1.126	0.92	0.55	0.576	5	5	5	5	0.28	0.28	0.28	0.28
pH	0.055	6.51	7.27	6.45	7.21	7	5	7	5	0.385	0.275	0.385	0.275
TKN	0.053	540	865	1201	980	15	27	36	30	0.795	1.431	1.908	1.59
Nickel	0.052	0.055	0.04	0.07	0.065	5.5	5.5	5.5	5.5	0.286	0.286	0.286	0.286
TCB	0.052	2130	2987	2730	2650	79	84	83	82	4.108	4.368	4.316	4.264
NH ₄ -N	0.051	420	540	684	665	44	55	75	70	2.244	2.805	3.825	3.57
TDS	0.05	4190	6440	2770	9670	10	14	7	21	0.5	0.7	0.35	1.05
Copper	0.05	0.342	0.123	0.089	0.09	6	5.5	5.5	5.5	0.3	0.275	0.275	0.275
Chlorides	0.049	2225.00	2425.00	1100.00	1290.0	15.5	18.5	9	10	0.7595	0.9065	0.441	0.49
Total Iron	0.045	11.4	13	32.5	2.2	5	5	5.5	5	0.225	0.225	0.2475	0.225
Summation	0.824									13.845	19.115	16.802	20.208
Derived LPI										16.80	23.20	20.39	24.52

Table C.16: Calculation of LPI at 390 day after filling of MSW in landfill lysimeter

Pollutant variable	Variable weight, w_i	Pollutant concentration, c_i				Individual pollutant rating, p_i				Overall pollutant rating, $w_i p_i$			
		A ₁	A ₂	B	C	A ₁	A ₂	B	C	A ₁	A ₂	B	C
Chromium	0.064	0.06	0.05	0.08	0.06	5	5	5	5	0.32	0.32	0.32	0.32
Lead	0.063	0.21	0.25	0.55	0.476	5.5	6.5	7.5	7	0.3465	0.4095	0.4725	0.441
COD	0.062	800	3830	845	5120	33	63	36	55	2.046	3.906	2.232	3.41
Mercury		-	-	-	-	-	-	-	-	-	-	-	-
BOD ₅	0.061	345	437	490	510	12	15	16	19	0.732	0.915	0.976	1.159
Arsenic	0.061	0.01	0.02	0.01	0.01	5	5	5	5	0.305	0.305	0.305	0.305
Cyanide		-	-	-	-	-	-	-	-	-	-	-	-
Phenol		-	-	-	-	-	-	-	-	-	-	-	-
Zinc	0.056	1.126	0.92	0.55	0.576	5	5	5	5	0.28	0.28	0.28	0.28
pH	0.055	6.55	7.53	6.66	7.73	7	5	7	5	0.385	0.275	0.385	0.275
TKN	0.053	365	1122	676	538	10	40	20	15	0.53	2.12	1.06	0.795
Nickel	0.052	0.055	0.04	0.07	0.065	5.5	5.5	5.5	5.5	0.286	0.286	0.286	0.286
TCB	0.052	271	343	325	255	56.5	59	59	50	2.938	3.068	3.068	2.6
NH ₄ -N	0.051	412	563.2	702	621	43	59	77	70	2.193	3.009	3.927	3.57
TDS	0.05	4023	6240	2700	9238	10	14	7	21	0.5	0.7	0.35	1.05
Copper	0.05	0.36	0.09	0.078	0.1	6	5.5	5.5	5.5	0.3	0.275	0.275	0.275
Chlorides	0.049	2370.00	2670.00	1125.00	1432.0	15.5	18.5	9	10	0.7595	0.9065	0.441	0.49
Total Iron	0.045	10	11.1	16.4	8.6	5	5	5.5	5	0.225	0.225	0.2475	0.225
Summation	0.824									12.146	17	14.625	15.481
Derived LPI										14.74	20.63	17.75	18.79

Table C.17: Calculation of LPI at 400 day after filling of MSW in landfill lysimeter

Pollutant variable	Variable weight, w_i	Pollutant concentration, c_i				Individual pollutant rating, p_i				Overall pollutant rating, $w_i p_i$			
		A ₁	A ₂	B	C	A ₁	A ₂	B	C	A ₁	A ₂	B	C
Chromium	0.064	0.05	0.04	0.06	0.065	5	5	5	5	0.32	0.32	0.32	0.32
Lead	0.063	0.121	0.251	0.52	0.43	5.5	6.5	7.5	7	0.3465	0.4095	0.4725	0.441
COD	0.062	960	5120	590	4760	33	63	36	55	2.046	3.906	2.232	3.41
Mercury		-	-	-	-	-	-	-	-	-	-	-	-
BOD ₅	0.061	340	465	510	576	12	15	16	19	0.732	0.915	0.976	1.159
Arsenic	0.061	0.01	0.02	0.01	0.01	5	5	5	5	0.305	0.305	0.305	0.305
Cyanide		-	-	-	-	-	-	-	-	-	-	-	-
Phenol		-	-	-	-	-	-	-	-	-	-	-	-
Zinc	0.056	1.2	0.852	0.52	0.58	5	5	5	5	0.28	0.28	0.28	0.28
pH	0.055	7.75	8.02	7.84	8.3	5	5	5	5	0.275	0.275	0.275	0.275
TKN	0.053	378	1220	657	520	10	40	20	15	0.53	2.12	1.06	0.795
Nickel	0.052	0.055	0.04	0.07	0.065	5.5	5.5	5.5	5.5	0.286	0.286	0.286	0.286
TCB	0.052	258	320	310	240	56.5	59	59	50	2.938	3.068	3.068	2.6
NH ₄ -N	0.051	410	531.9	665	587	42	56	74	66	2.142	2.856	3.774	3.366
TDS	0.05	4020	6260	2678	9530	10	14	7	21	0.5	0.7	0.35	1.05
Copper	0.05	0.342	0.123	0.089	0.09	6	5.5	5.5	5.5	0.3	0.275	0.275	0.275
Chlorides	0.049	2420.00	2600.00	1125.00	1679.0	18	20	9	10	0.882	0.98	0.441	0.49
Total Iron	0.045	9.42	10	13.06	1.42	5	5	5.5	5	0.225	0.225	0.2475	0.225
Summation	0.824									12.107	16.9205	14.362	15.277
Derived LPI										14.69	20.53	17.43	18.54

Table C.18: Calculation of LPI at 415 day after filling of MSW in landfill lysimeter

Pollutant variable	Variable weight, w_i	Pollutant concentration, c_i				Individual pollutant rating, p_i				Overall pollutant rating, $w_i p_i$			
		A ₁	A ₂	B	C	A ₁	A ₂	B	C	A ₁	A ₂	B	C
Chromium	0.064	0.055	0.04	0.07	0.065	5	5	5	5	0.32	0.32	0.32	0.32
Lead	0.063	0.124	0.265	0.55	0.476	5.5	6.5	7.5	7	0.3465	0.4095	0.4725	0.441
COD	0.062	852	4087	900	3300	33	63	36	55	2.046	3.906	2.232	3.41
Mercury		-	-	-	-	-	-	-	-	-	-	-	-
BOD ₅	0.061	345	437	490	510	12	15	16	19	0.732	0.915	0.976	1.159
Arsenic	0.061	0.01	0.01	0.01	0.01	5	5	5	5	0.305	0.305	0.305	0.305
Cyanide		-	-	-	-	-	-	-	-	-	-	-	-
Phenol		-	-	-	-	-	-	-	-	-	-	-	-
Zinc	0.056	1.126	0.92	0.55	0.576	5	5	5	5	0.28	0.28	0.28	0.28
pH	0.055	6.51	7.27	6.45	7.21	7	5	7	5	0.385	0.275	0.385	0.275
TKN	0.053	378	1130	637	504	10	40	20	15	0.53	2.12	1.06	0.795
Nickel	0.052	0.055	0.04	0.07	0.065	5.5	5.5	5.5	5.5	0.286	0.286	0.286	0.286
TCB	0.052	245	304	300	229	56.5	59	59	50	2.938	3.068	3.068	2.6
NH ₄ -N	0.051	320	520	655	582	31	56	69	60	1.581	2.856	3.519	3.06
TDS	0.05	3928	6387	2710	9230	10	14	7	21	0.5	0.7	0.35	1.05
Copper	0.05	0.342	0.123	0.089	0.09	6	5.5	5.5	5.5	0.3	0.275	0.275	0.275
Chlorides	0.049	2342.00	2650.00	1255.00	1290.0	18	20	10	10	0.882	0.98	0.49	0.49
Total Iron	0.045	8.6	10.6	14.7	3.2	5	5	5.5	5	0.225	0.225	0.2475	0.225
Summation	0.824									11.656	16.9205	14.266	14.971
Derived LPI										14.15	20.53	17.31	18.17

Table C.19: Calculation of LPI at 500 day after filling of MSW in landfill lysimeter

Pollutant variable	Variable weight, w_i	Pollutant concentration, c_i				Individual pollutant rating, p_i				Overall pollutant rating, $w_i p_i$			
		A ₁	A ₂	B	C	A ₁	A ₂	B	C	A ₁	A ₂	B	C
Chromium	0.064	0.05	0.03	0.08	0.07	5	5	5	5	0.32	0.32	0.32	0.32
Lead	0.063	0.1176	0.256	0.46	0.376	5.5	6.5	7	6.5	0.3465	0.4095	0.441	0.4095
COD	0.062	896	2240	3042	4120	33	52	57	63	2.046	3.224	3.534	3.906
Mercury		-	-	-	-	-	-	-	-	-	-	-	-
BOD ₅	0.061	535	1452	1890	1985	20	34	37	39	1.22	2.074	2.257	2.379
Arsenic						-	-	-	-	-	-	-	-
Cyanide		-	-	-	-	-	-	-	-	-	-	-	-
Phenol		-	-	-	-	-	-	-	-	-	-	-	-
Zinc	0.056	1.1176	0.476	0.36	0.176	5	5	5	5	0.28	0.28	0.28	0.28
pH	0.055	6.05	7.53	6.66	7.73	7	5	6	5	0.385	0.275	0.33	0.275
TKN	0.053	356	1098	612	485	10	35	20	16	0.53	1.855	1.06	0.848
Nickel	0.052	0.05	0.055	0.08	0.07	5.5	5.5	5.5	5.5	0.286	0.286	0.286	0.286
TCB	0.052	234	296	291	217	54	59	58	52	2.808	3.068	3.016	2.704
NH ₄ -N	0.051	315	510	634	578	30	56	72	65	1.53	2.856	3.672	3.315
TDS	0.05	3620	6800	5400	9720	9	15	13	22	0.45	0.75	0.65	1.1
Copper	0.05	0.98	0.97	0.09	0.12	7	7	5.5	5.5	0.35	0.35	0.275	0.275
Chlorides	0.049	2672.00	2678.00	1265.00	1225.0	20	20	19	19	0.98	0.98	0.931	0.931
Total Iron	0.045	12.2	18.9	9.65	8.6	5	5.5	5	5	0.225	0.2475	0.225	0.225
Summation	0.763									11.756	16.975	17.277	17.2535
Derived LPI										15.41	22.25	22.64	22.61

Table C.20: Calculation of LPI at 520 day after filling of MSW in landfill lysimeter

Pollutant variable	Variable weight, w_i	Pollutant concentration, c_i				Individual pollutant rating, p_i				Overall pollutant rating, $w_i p_i$			
		A ₁	A ₂	B	C	A ₁	A ₂	B	C	A ₁	A ₂	B	C
Chromium	0.064	0.055	0.04	0.07	0.065	5	5	5	5	0.32	0.32	0.32	0.32
Lead	0.063	0.120	0.265	0.55	0.476	5.5	6.5	7.5	7	0.3465	0.4095	0.4725	0.441
COD	0.062	849	4087	900	3300	33	63	36	55	2.046	3.906	2.232	3.41
Mercury		-	-	-	-	-	-	-	-	-	-	-	-
BOD ₅	0.061	345	437	490	510	12	15	16	19	0.732	0.915	0.976	1.159
Arsenic													
Cyanide		-	-	-	-	-	-	-	-	-	-	-	-
Phenol		-	-	-	-	-	-	-	-	-	-	-	-
Zinc	0.056	1.126	0.92	0.55	0.576	5	5	5	5	0.28	0.28	0.28	0.28
pH	0.055	6.51	7.27	6.45	7.21	7	5	7	5	0.385	0.275	0.385	0.275
TKN	0.053	345	1056	597	467	10	35	18	15	0.53	1.855	0.954	0.795
Nickel	0.052	0.05	0.05	0.09	0.055	5.5	5.5	5.5	5.5	0.286	0.286	0.286	0.286
TCB	0.052	217	281	282	201	56.5	59	59	50	2.938	3.068	3.068	2.6
NH ₄ -N	0.051	307	501.7	620	576	31	56	71	65	1.581	2.856	3.621	3.315
TDS	0.05	3950	10180	6130	16990	10	21	14	43	0.5	1.05	0.7	2.15
Copper	0.05	0.98	0.876	0.18	0.2	7	6.5	5.5	5.5	0.35	0.325	0.275	0.275
Chlorides	0.049	2262.00	2762.00	1275.00	1250.0	15.5	20.5	10	10	0.7595	1.0045	0.49	0.49
Total Iron	0.045	18.7	22.2	11.6	5	5.5	5.5	5	5	0.2475	0.2475	0.225	0.225
Summation	0.763									11.30	16.80	14.28	16.02
Derived LPI										14.81	22.02	18.72	21.00

Table C.21: Calculation of LPI at 545 day after filling of MSW in landfill lysimeter

Pollutant variable	Variable weight, w_i	Pollutant concentration, c_i				Individual pollutant rating, p_i				Overall pollutant rating, $w_i p_i$			
		A ₁	A ₂	B	C	A ₁	A ₂	B	C	A ₁	A ₂	B	C
Chromium	0.064	0.065	0.05	0.07	0.065	5	5	5	5	0.32	0.32	0.32	0.32
Lead	0.063	0.2164	0.246	0.25	0.15	6	6.5	6.5	5.5	0.378	0.4095	0.4095	0.3465
COD	0.062	1440	4640	1920	990	44	65	49	37	2.728	4.03	3.038	2.294
Mercury		-	-	-	-	-	-	-	-	-	-	-	-
BOD ₅	0.061	865	2526	1150	385	26	45	30	12	1.586	2.745	1.83	0.732
Arsenic						-	-	-	-	-	-	-	-
Cyanide		-	-	-	-	-	-	-	-	-	-	-	-
Phenol		-	-	-	-	-	-	-	-	-	-	-	-
Zinc	0.056	0.64	0.4	0.36	0.15	5	5	5	5	0.28	0.28	0.28	0.28
pH	0.055	6.43	7.26	6.98	7.5	7	5.5	6	5	0.385	0.3025	0.33	0.275
TKN	0.053	337	1008	550	443	10	31	16	11	0.53	1.643	0.848	0.583
Nickel	0.052	0.065	0.05	0.05	0.04	5.5	5.5	5.5	5.5	0.286	0.286	0.286	0.286
TCB	0.052	205	267	274	191	55	58	60	52	2.86	3.016	3.12	2.704
NH ₄ -N	0.051	316.2	507.8	623.8	579.7	32	55	72	62	1.632	2.805	3.672	3.162
TDS	0.05	7800	8790	9980	16880	16	20	22	43	0.8	1	1.1	2.15
Copper	0.05	0.975	0.875	0.67	0.43	7	7	6.5	6	0.35	0.35	0.325	0.3
Chlorides	0.049	2249.00	2649.00	1175.00	1350.0	15.5	20	9.5	10	0.7595	0.98	0.4655	0.49
Total Iron	0.045	5.20	8.04	11.7	1.50	5	5	5	5	0.225	0.225	0.225	0.225
Summation	0.763									13.119	18.392	16.249	14.1475
Derived LPI										17.19	24.10	21.30	18.54

Table C.22: Calculation of LPI at 580 day after filling of MSW in landfill lysimeter

Pollutant variable	Variable weight, w_i	Pollutant concentration, c_i				Individual pollutant rating, p_i				Overall pollutant rating, $w_i p_i$			
		A ₁	A ₂	B	C	A ₁	A ₂	B	C	A ₁	A ₂	B	C
Chromium	0.064	0.057	0.04	0.07	0.065	5	5	5	5	0.32	0.32	0.32	0.32
Lead	0.063	0.126	0.265	0.55	0.476	5.5	6.5	7.5	7	0.3465	0.4095	0.4725	0.441
COD	0.062	850	4087	900	3300	33	63	36	55	2.046	3.906	2.232	3.41
Mercury		-	-	-	-	-	-	-	-	-	-	-	-
BOD ₅	0.061	345	437	490	510	12	15	16	19	0.732	0.915	0.976	1.159
Arsenic													
Cyanide		-	-	-	-	-	-	-	-	-	-	-	-
Phenol		-	-	-	-	-	-	-	-	-	-	-	-
Zinc	0.056	1.126	0.92	0.55	0.576	5	5	5	5	0.28	0.28	0.28	0.28
pH	0.055	6.51	7.27	6.45	7.21	7	5	7	5	0.385	0.275	0.385	0.275
TKN	0.053	325	956	521	431	10	30	15	13	0.53	1.59	0.795	0.689
Nickel	0.052	0.055	0.04	0.07	0.065	5.5	5.5	5.5	5.5	0.286	0.286	0.286	0.286
TCB	0.052	198	241	261	183	55	57	58	50	2.86	2.964	3.016	2.6
NH ₄ -N	0.051	297.4	497	590	520	64	55	66	56	3.264	2.805	3.366	2.856
TDS	0.05	7700	6380	9630	15810	16.5	14	21	39	0.825	0.7	1.05	1.95
Copper	0.05	0.31	0.11	0.09	0.08	6	5.5	5.5	5.5	0.3	0.275	0.275	0.275
Chlorides	0.049	2265.00	2307.50	1075.00	1155.0	15.5	15.5	9	10	0.7595	0.7595	0.441	0.49
Total Iron	0.045	11.4	11.70	10.14	5.10	5	5	5	5	0.225	0.225	0.225	0.225
Summation	0.763									13.159	15.71	14.1195	15.256
Derived LPI										17.25	20.59	18.51	19.99

Table C.23: Calculation of LPI at 630 day after filling of MSW in landfill lysimeter

Pollutant variable	Variable weight, w_i	Pollutant concentration, c_i				Individual pollutant rating, p_i				Overall pollutant rating, $w_i p_i$			
		A ₁	A ₂	B	C	A ₁	A ₂	B	C	A ₁	A ₂	B	C
Chromium	0.064	0.045	0.04	0.08	0.07	5	5	5	5	0.32	0.32	0.32	0.32
Lead	0.063	0.2285	0.25	0.25	0.156	6	6.5	6.5	5.5	0.378	0.4095	0.4095	0.3465
COD	0.062	2880	1520	1560	800	55	45	45	33	3.41	2.79	2.79	2.046
Mercury		-	-	-	-	-	-	-	-	-	-	-	-
BOD ₅	0.061	1265	690	845	560	31	24	26.5	21	1.891	1.464	1.6165	1.281
Arsenic													
Cyanide		-	-	-	-	-	-	-	-	-	-	-	-
Phenol		-	-	-	-	-	-	-	-	-	-	-	-
Zinc	0.056	0.85	0.78	0.35	0.156	5	5	5	5	0.28	0.28	0.28	0.28
pH	0.055	6.43	6.73	6.98	7.11	7	6.5	5	5	0.385	0.3575	0.275	0.275
TKN	0.053	290	867	486	381	10	29	14	10	0.53	1.537	0.742	0.53
Nickel	0.052	0.055	0.05	0.08	0.065	5.5	5.5	5.5	5.5	0.286	0.286	0.286	0.286
TCB	0.052	171	217	234	152	53	56	58	50	2.756	2.912	3.016	2.6
NH ₄ -N	0.051	265	475	545	501	26	49	59	54	1.326	2.499	3.009	2.754
TDS	0.05	7910	4990	10610	15800	17	12	25	39	0.85	0.6	1.25	1.95
Copper	0.05	0.966	0.866	0.35	0.21	7	7	6	5.5	0.35	0.35	0.3	0.275
Chlorides	0.049	2875.00	2387.00	1000.00	1250.0	22.5	17	9	9.5	1.1025	0.833	0.441	0.4655
Total Iron	0.045	3.70	3.40	3.2	1.4	5	5	5	5	0.225	0.225	0.225	0.225
Summation	0.763									14.089	14.863	14.96	13.634
Derived LPI										18.47	19.48	19.61	17.87

Table C.24: Calculation of LPI at 715 day after filling of MSW in landfill lysimeter

Pollutant variable	Variable weight, w_i	Pollutant concentration, c_i				Individual pollutant rating, p_i				Overall pollutant rating, $w_i p_i$			
		A ₁	A ₂	B	C	A ₁	A ₂	B	C	A ₁	A ₂	B	C
Chromium	0.064	0.055	0.04	0.06	0.06	5	5	5	5	0.32	0.32	0.32	0.32
Lead	0.063	0.2154	0.245	0.257	0.26	6	6.5	6.5	6.5	0.378	0.4095	0.4095	0.4095
COD	0.062	2880	1420	1490	300	55	44	44	11	3.41	2.728	2.728	0.682
Mercury		-	-	-	-	-	-	-	-	-	-	-	-
BOD ₅	0.061	1660	605	845	143	35	22	26	8	2.135	1.342	1.586	0.488
Arsenic						-	-	-	-	-	-	-	-
Cyanide		-	-	-	-	-	-	-	-	-	-	-	-
Phenol		-	-	-	-	-	-	-	-	-	-	-	-
Zinc	0.056	0.54	0.5	0.26	0.16	5	5	5	5	0.28	0.28	0.28	0.28
pH	0.055	7.08	7.5	7.92	7.81	6	5	5	5	0.33	0.275	0.275	0.275
TKN	0.053	263	770	435	340	8	24	11	9	0.424	1.272	0.583	0.477
Nickel	0.052	0.055	0.04	0.06	0.045	5.5	5.5	5.5	5.5	0.286	0.286	0.286	0.286
TCB	0.052	145	197	214	127	46	54	55	47	2.392	2.808	2.86	2.444
NH ₄ -N	0.051	222	386	476	409	21	39	54	44	1.071	1.989	2.754	2.244
TDS	0.05	7493	5000	7880	17700	16	12	16	43	0.8	0.6	0.8	2.15
Copper	0.05	0.63	0.93	0.76	0.6	6.5	7	7	6.5	0.325	0.35	0.35	0.325
Chlorides	0.049	2215.00	2730.00	1030.00	1378.0	15	21	8.5	10	0.735	1.029	0.4165	0.49
Total Iron	0.045	3.2	3.80	3.6	1.52	5	5	5	5	0.225	0.225	0.225	0.225
Summation	0.763									13.111	13.9135	13.873	11.0955
Derived LPI										17.18	18.24	18.18	14.54

Table C.25: Calculation of LPI at 750 day after filling of MSW in landfill lysimeter

Pollutant variable	Variable weight, w_i	Pollutant concentration, c_i				Individual pollutant rating, p_i				Overall pollutant rating, $w_i p_i$			
		A ₁	A ₂	B	C	A ₁	A ₂	B	C	A ₁	A ₂	B	C
Chromium	0.064	0.06	0.05	0.06	0.04	5	5	5	5	0.32	0.32	0.32	0.32
Lead	0.063	0.2255	0.24	0.36	0.217	6	6.5	6.5	6	0.378	0.4095	0.4095	0.378
COD	0.062	2580	1350	1410	340	54	42	44	12	3.348	2.604	2.728	0.744
Mercury		-	-	-	-	-	-	-	-	-	-	-	-
BOD ₅	0.061	1432	943	865	176	34	27.5	26	9	2.074	1.6775	1.586	0.549
Arsenic						-	-	-	-	-	-	-	-
Cyanide		-	-	-	-	-	-	-	-	-	-	-	-
Phenol		-	-	-	-	-	-	-	-	-	-	-	-
Zinc	0.056	0.55	0.5	0.46	0.17	5	5	5	5	0.28	0.28	0.28	0.28
pH	0.055	7	7.6	7.8	7.7	6	5	5	5	0.33	0.275	0.275	0.275
TKN	0.053	247	720	417	321	8	20	11	9	0.424	1.06	0.583	0.477
Nickel	0.052	0.065	0.05	0.06	0.045	5.5	5.5	5.5	5.5	0.286	0.286	0.286	0.286
TCB	0.052	137	186	200	118	46	56	57	44	2.392	2.912	2.964	2.288
NH ₄ -N	0.051	201.7	276	354	307	18	29	38	32	0.918	1.479	1.938	1.632
TDS	0.05	6590	4670	6790	13470	15	12	15	33	0.75	0.6	0.75	1.65
Copper	0.05	0.54	0.9	0.65	0.5	6	7	6.5	6	0.3	0.35	0.325	0.3
Chlorides	0.049	2102.00	2610.00	1020.00	1248.0	15	20	8.5	9.5	0.735	0.98	0.4165	0.4655
Total Iron	0.045	4.3	4.10	3.6	1.2	5	5	5	5	0.225	0.225	0.225	0.225
Summation	0.763									12.76	13.46	13.09	9.87
Derived LPI										16.72	17.64	17.15	12.94

Table C.26: Calculation of LPI at 800 day after filling of MSW in landfill lysimeter

Pollutant variable	Variable weight, w_i	Pollutant concentration, c_i				Individual pollutant rating, p_i				Overall pollutant rating, $w_i p_i$			
		A ₁	A ₂	B	C	A ₁	A ₂	B	C	A ₁	A ₂	B	C
Chromium	0.064	0.050	0.04	0.07	0.065	5	5	5	5	0.32	0.32	0.32	0.32
Lead	0.063	0.110	0.263	0.55	0.476	5.5	6.5	7.5	7	0.3465	0.4095	0.4725	0.441
COD	0.062	796	4086	900	3300	33	63	36	55	2.046	3.906	2.232	3.41
Mercury		-	-	-	-	-	-	-	-	-	-	-	-
BOD ₅	0.061	345	437	490	510	12	15	16	19	0.732	0.915	0.976	1.159
Arsenic													
Cyanide		-	-	-	-	-	-	-	-	-	-	-	-
Phenol		-	-	-	-	-	-	-	-	-	-	-	-
Zinc	0.056	1.126	0.92	0.55	0.576	5	5	5	5	0.28	0.28	0.28	0.28
pH	0.055	6.51	7.27	6.45	7.21	7	5	7	5	0.385	0.275	0.385	0.275
TKN	0.053	233	686	402	300	8	22	12	8.5	0.424	1.166	0.636	0.4505
Nickel	0.052	0.055	0.04	0.07	0.065	5.5	5.5	5.5	5.5	0.286	0.286	0.286	0.286
TCB	0.052	122	178	181	104	49	56	56	48	2.548	2.912	2.912	2.496
NH ₄ -N	0.051	196	165	208	198	19	17	20	20	0.969	0.867	1.02	1.02
TDS	0.05	5469	5437	6382	13879	12	12	14	26	0.6	0.6	0.7	1.3
Copper	0.05	0.43	0.07	0.07	0.4	6	5.5	5.5	6	0.3	0.275	0.275	0.3
Chlorides	0.049	2120.00	2376.00	1092.00	1187.0	15	17	9	10	0.735	0.833	0.441	0.49
Total Iron	0.045	5.9	3.2	4.5	2.6	5	5	5.5	5	0.225	0.225	0.2475	0.225
Summation	0.763									10.196	13.2695	11.183	12.4525
Derived LPI										13.36	17.39	14.66	16.32

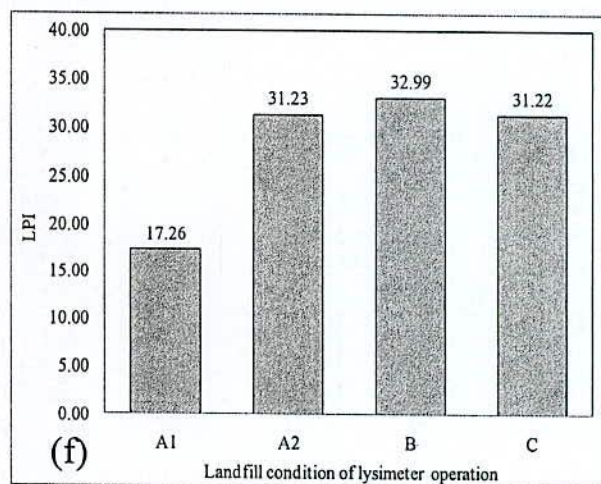
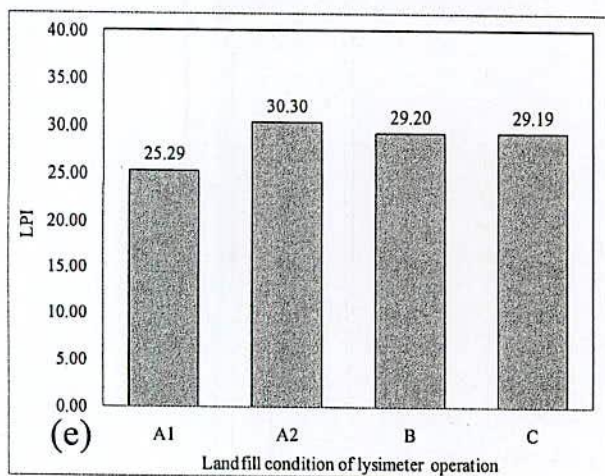
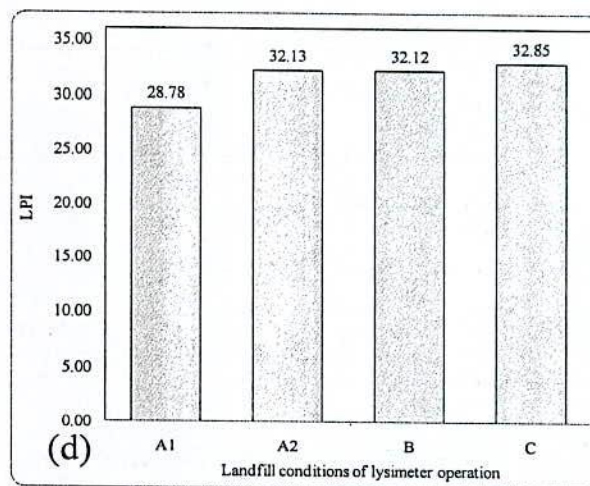
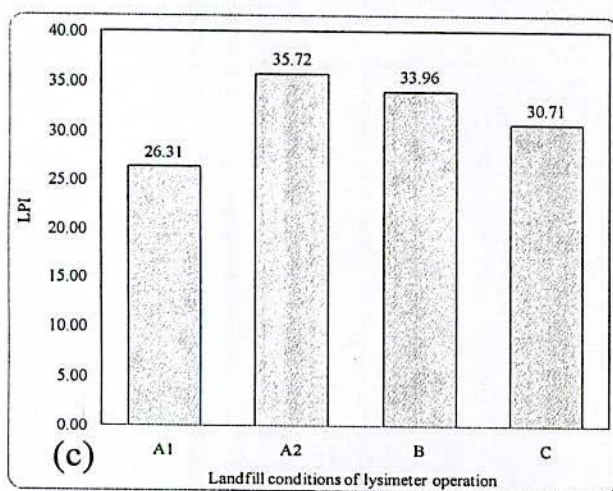
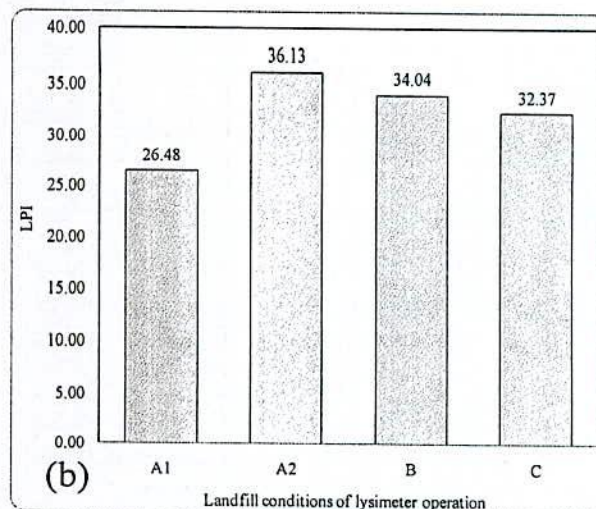
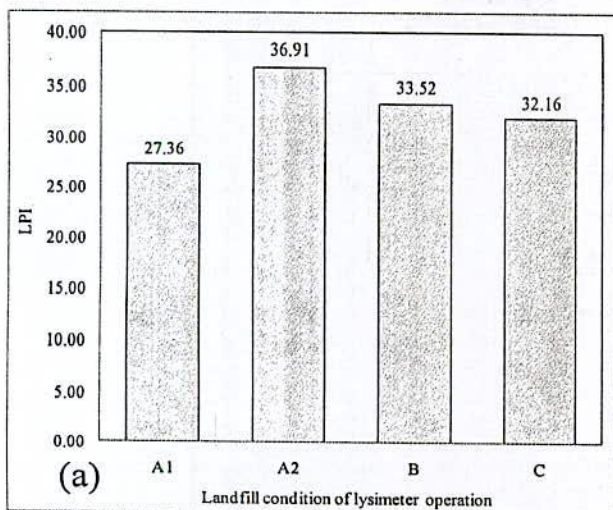
Table C.27: Calculation of LPI at 850 day after filling of MSW in landfill lysimeter

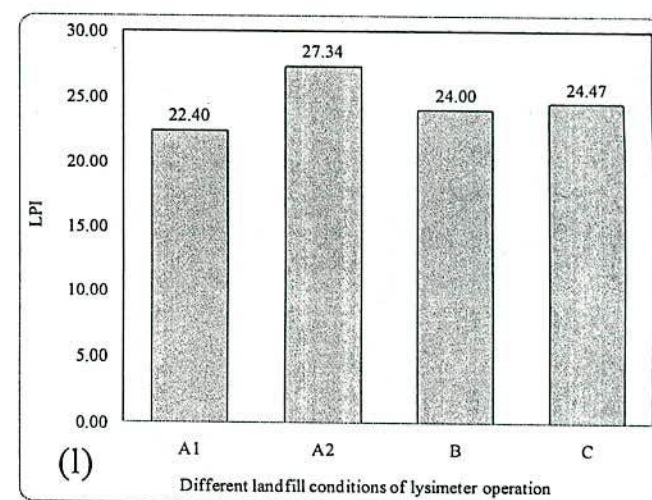
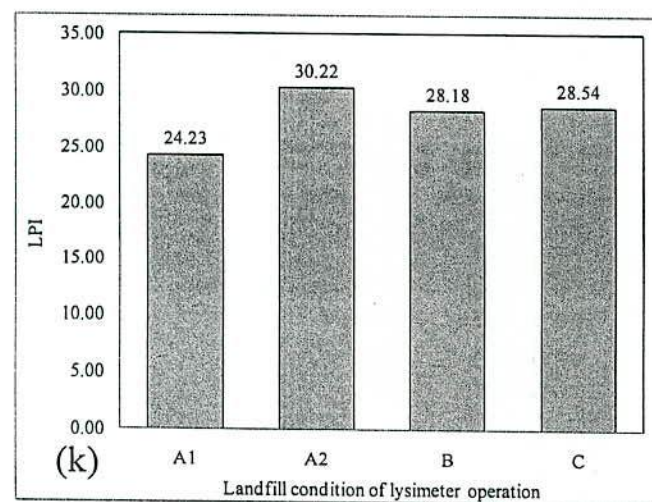
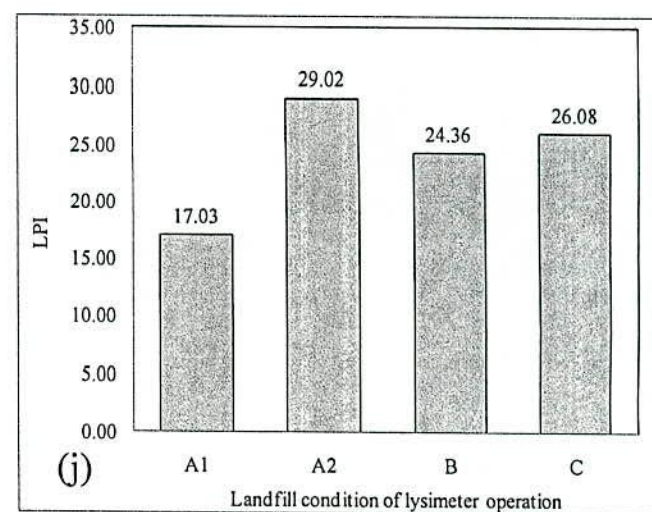
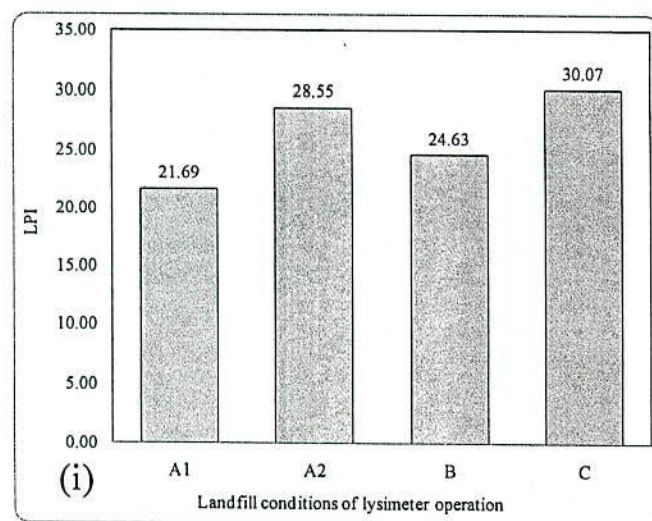
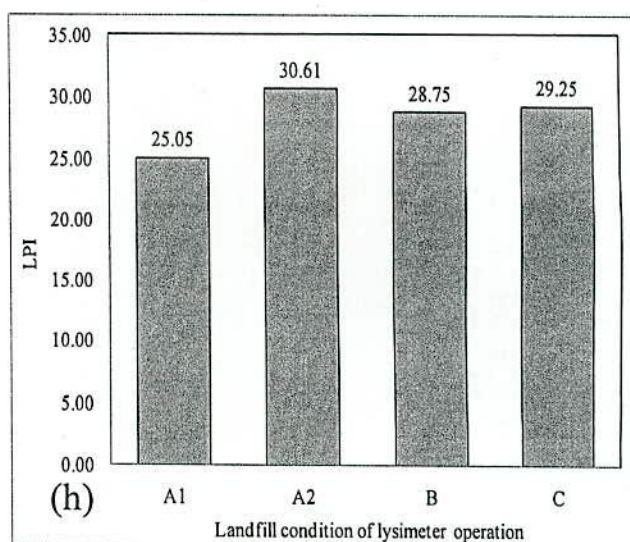
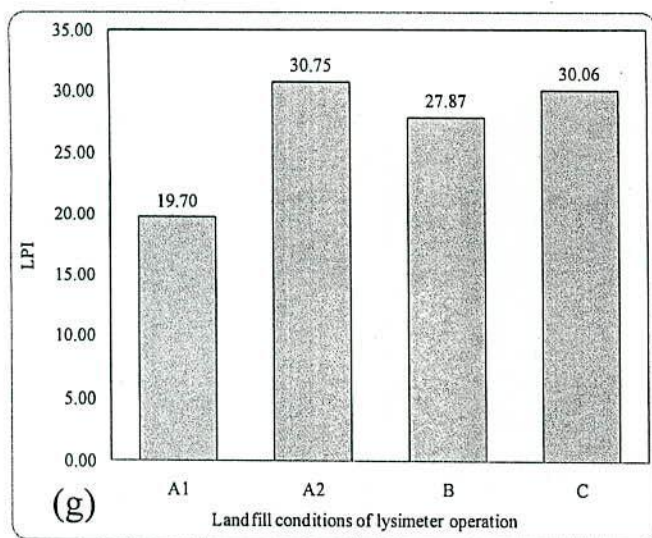
Pollutant variable	Variable weight, w_i	Pollutant concentration, c_i				Individual pollutant rating, p_i				Overall pollutant rating, $w_i p_i$			
		A ₁	A ₂	B	C	A ₁	A ₂	B	C	A ₁	A ₂	B	C
Chromium	0.064	0.06	0.05	0.09	0.04	5	5	5	5	0.32	0.32	0.32	0.32
Lead	0.063	0.235	0.235	0.254	0.215	6	6	6.5	6	0.378	0.378	0.4095	0.378
COD	0.062	2510	1290	1380	402	53	40	41	16	3.286	2.48	2.542	0.992
Mercury		-	-	-	-	-	-	-	-	-	-	-	-
BOD ₅	0.061	1456	594	745	265	34	21	24	10	2.074	1.281	1.464	0.61
Arsenic						-	-	-	-	-	-	-	-
Cyanide		-	-	-	-	-	-	-	-	-	-	-	-
Phenol		-	-	-	-	-	-	-	-	-	-	-	-
Zinc	0.056	0.35	0.46	0.14	0.15	5	5	5	5	0.28	0.28	0.28	0.28
pH	0.055	7.4	7.2	6.78	7.8	5	5	6	5	0.275	0.275	0.33	0.275
TKN	0.053	221	610	360	278	7	19	16	10	0.371	1.007	0.848	0.53
Nickel	0.052	0.06	0.05	0.08	0.04	5.5	5.5	5.5	5.5	0.286	0.286	0.286	0.286
TCB	0.052	109	163	172	97	46	49	50	44	2.392	2.548	2.6	2.288
NH ₄ -N	0.051	187	154	190	187	18	15	19	18	0.918	0.765	0.969	0.918
TDS	0.05	5980	5008	6436	14369	13	12	15	36	0.65	0.6	0.75	1.8
Copper	0.05	0.05	0.05	0.04	0.04	6	5.5	5.5	6	0.3	0.275	0.275	0.3
Chlorides	0.049	2072.00	2520.00	1150.00	1058.0	15	19	19	8.5	0.735	0.931	0.931	0.4165
Total Iron	0.045	5.8	3.90	4.3	2.3	5	5	5	5	0.225	0.225	0.225	0.225
Summation	0.763									12.49	11.651	12.2295	9.6185
Derived LPI										16.37	15.27	16.03	12.61

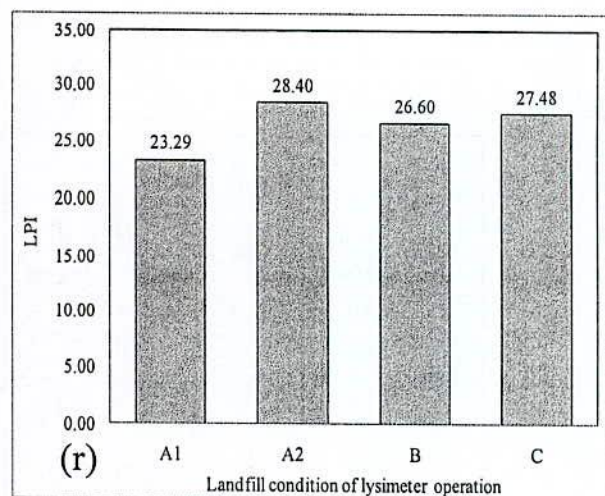
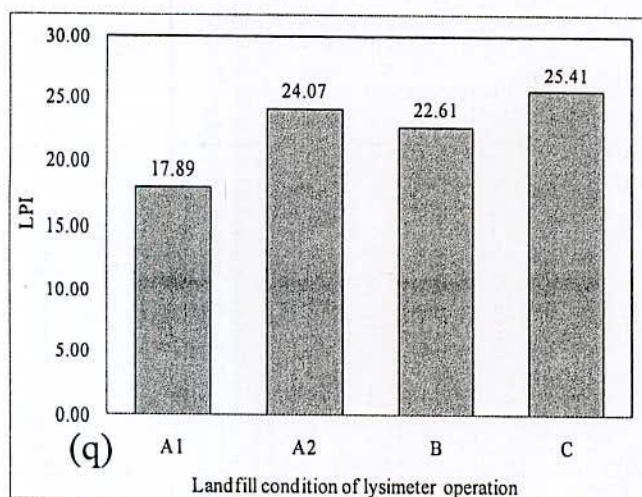
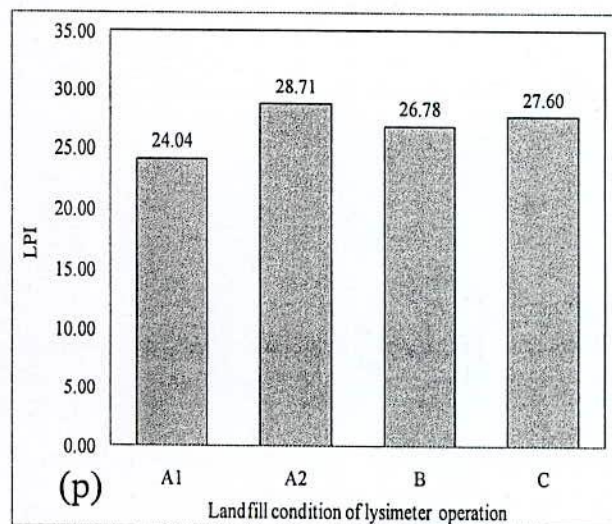
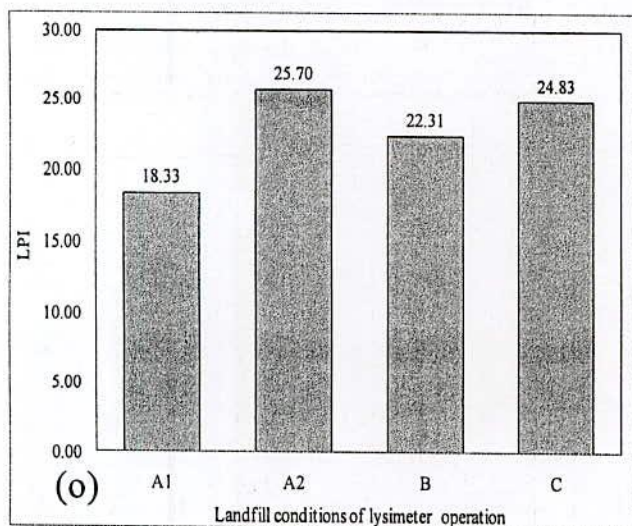
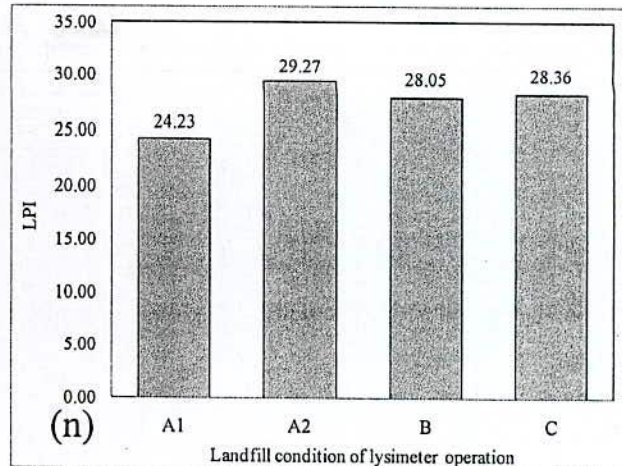
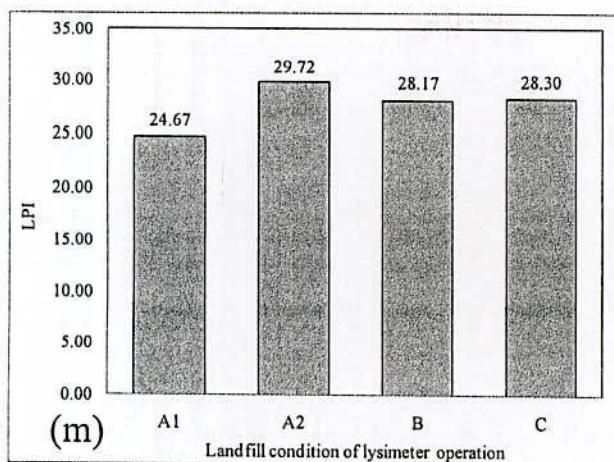
Table C.28: Calculation of LPI at 900 days after filling of MSW in landfill lysimeter

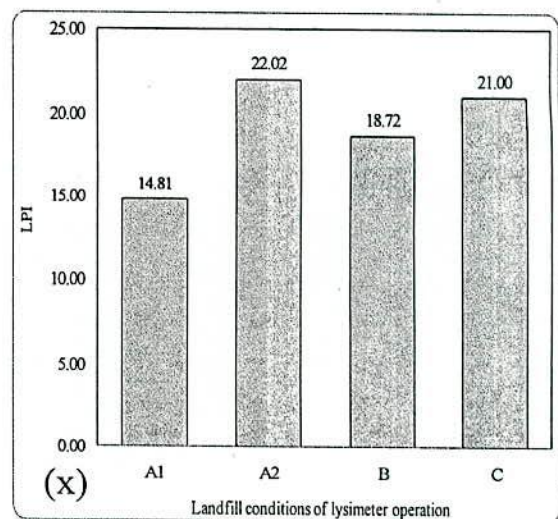
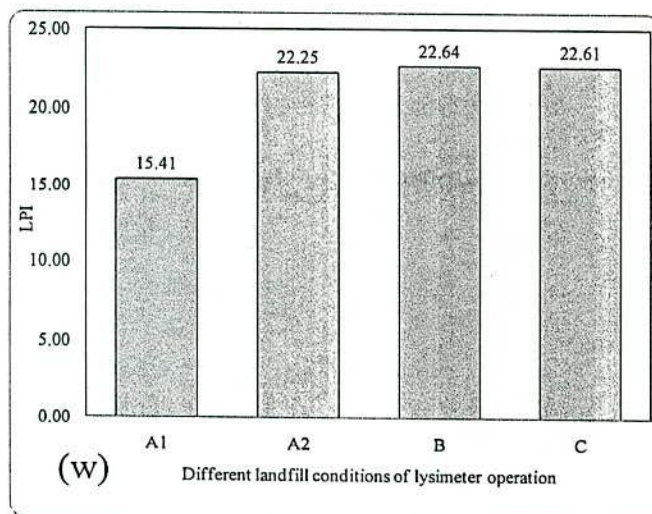
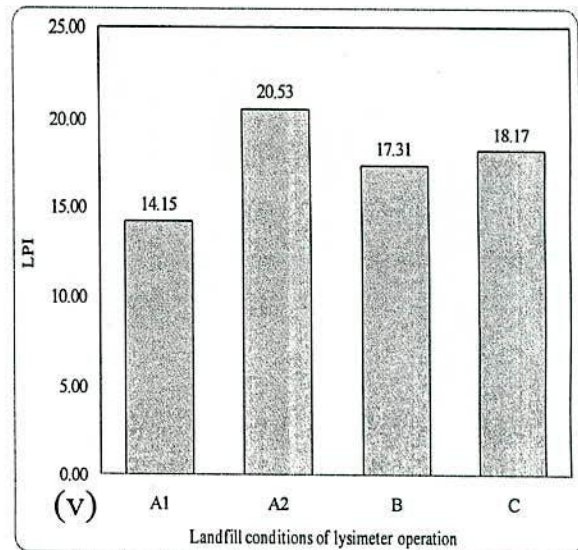
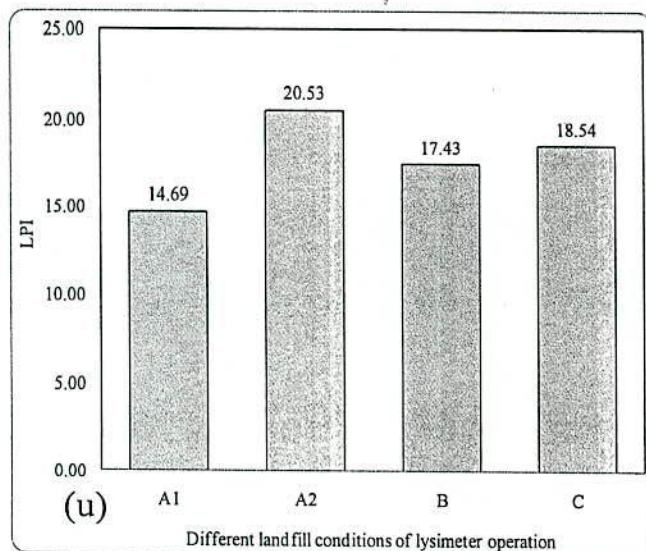
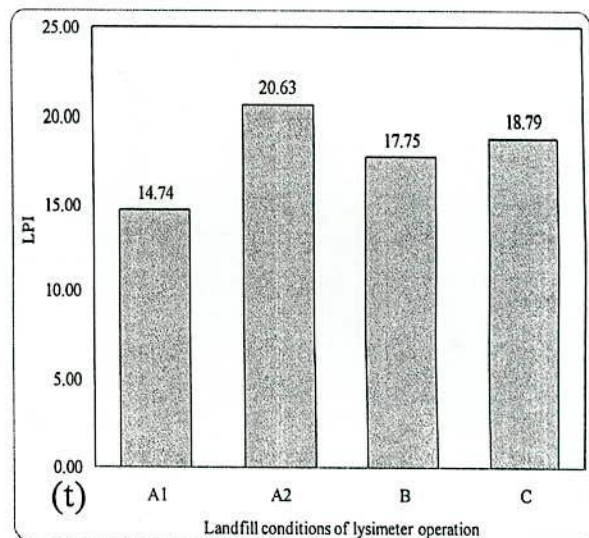
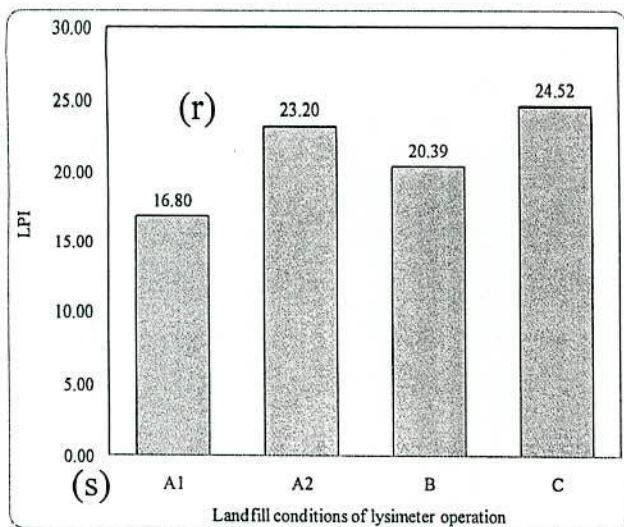
Pollutant variable	Variable weight, w_i	Pollutant concentration, c_i				Individual pollutant rating, p_i				Overall pollutant rating, $w_i p_i$			
		A ₁	A ₂	B	C	A ₁	A ₂	B	C	A ₁	A ₂	B	C
Chromium	0.064	0.049	0.04	0.07	0.065	5	5	5	5	0.32	0.32	0.32	0.32
Lead	0.063	0.118	0.265	0.55	0.476	5.5	6.5	7.5	7	0.3465	0.4095	0.4725	0.441
COD	0.062	846	4022	900	3300	33	63	36	55	2.046	3.906	2.232	3.41
Mercury	-	NA	NA	NA	NA	-	-	-	-	-	-	-	-
BOD ₅	0.061	345	437	490	510	12	15	16	19	0.732	0.915	0.976	1.159
Arsenic	-	NA	NA	NA	NA								
Cyanide	-	NA	NA	NA	NA	-	-	-	-	-	-	-	-
Phenol	-	NA	NA	NA	NA	-	-	-	-	-	-	-	-
Zinc	0.056	1.126	0.92	0.55	0.576	5	5	5	5	0.28	0.28	0.28	0.28
pH	0.055	6.51	7.27	6.45	7.21	7	5	7	5	0.385	0.275	0.385	0.275
TKN	0.053	233	686	402	300	8	22	12	8.5	0.424	1.166	0.636	0.4505
Nickel	0.052	0.055	0.04	0.07	0.065	5.5	5.5	5.5	5.5	0.286	0.286	0.286	0.286
TCB	0.052	122	178	181	104	49	56	56	48	2.548	2.912	2.912	2.496
NH ₄ -N	0.051	196	165	208	198	19	17	20	20	0.969	0.867	1.02	1.02
TDS	0.05	5469	5437	6382	13879	12	12	14	26	0.6	0.6	0.7	1.3
Copper	0.05	0.43	0.07	0.07	0.4	6	5.5	5.5	6	0.3	0.275	0.275	0.3
Chlorides	0.049	2120.00	2376.00	1092.00	1187.00	15	17	9	10	0.735	0.833	0.441	0.49
Total Iron	0.045	5.9	3.2	4.5	2.6	5	5	5.5	5	0.225	0.225	0.2475	0.225
Summation	0.763									10.1965	13.2695	11.183	12.4525
Derived LPI										13.36	17.39	14.66	16.32

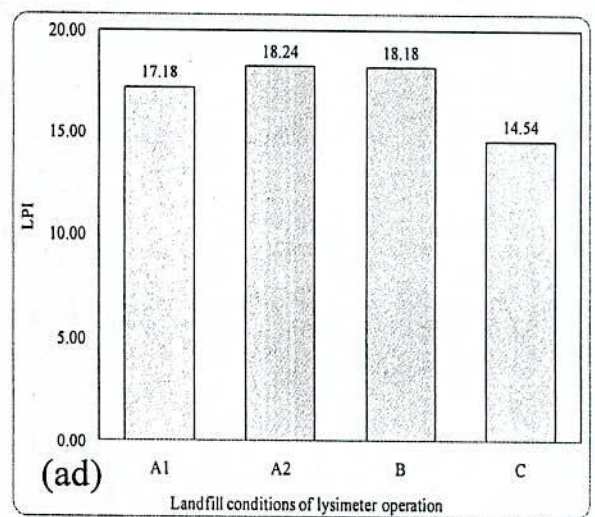
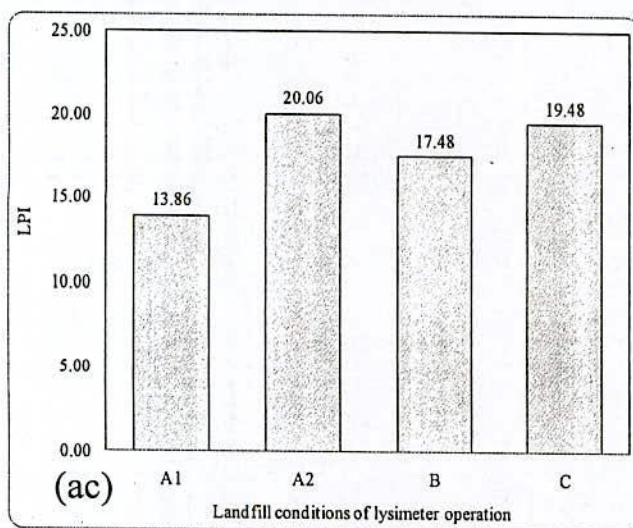
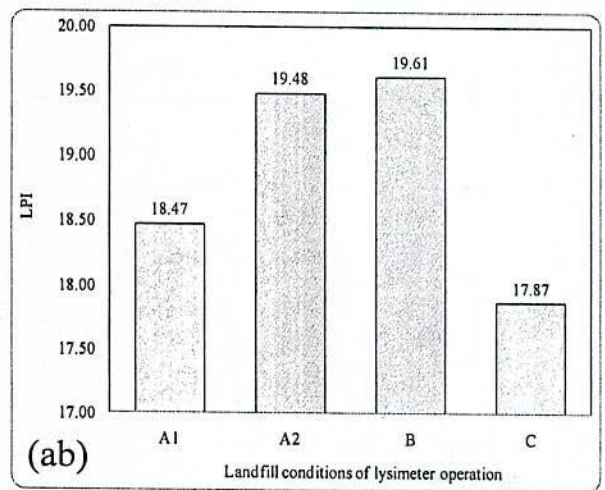
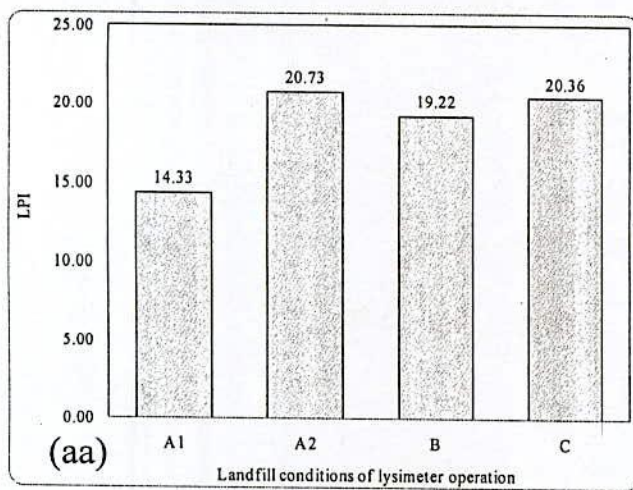
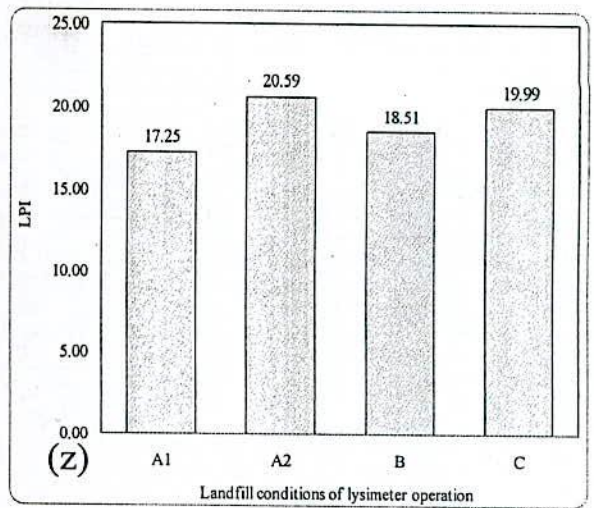
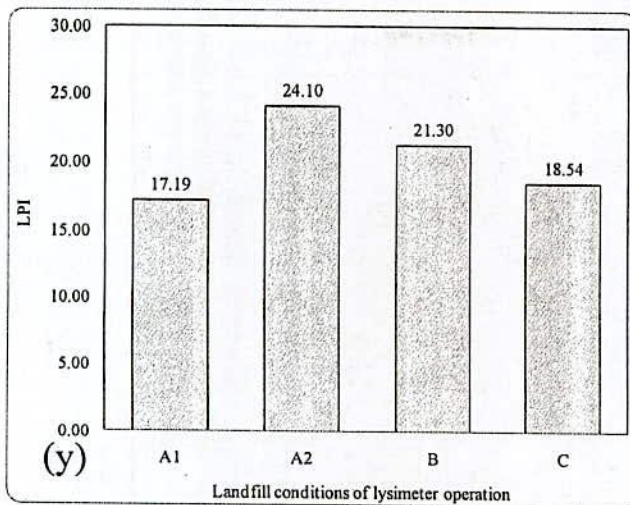
Note: COD=chemical oxygen demand, BOD₅= biological oxygen demand, TKN=total kjeldahl nitrogen, NH₄-N=ammonia nitrogen, TCB= total coliform bacteria and TDS=total dissolve solid. All concentrations are in mg/L, except pH and total coliform bacteria unit (cfu/100ml) and NA= Leachate concentration not available.











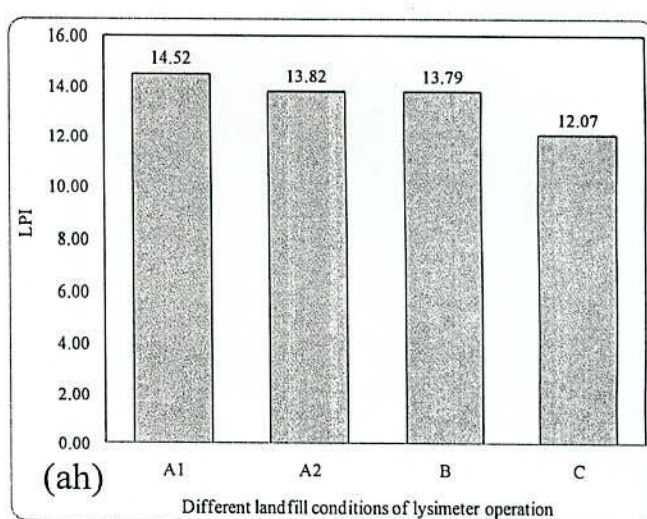
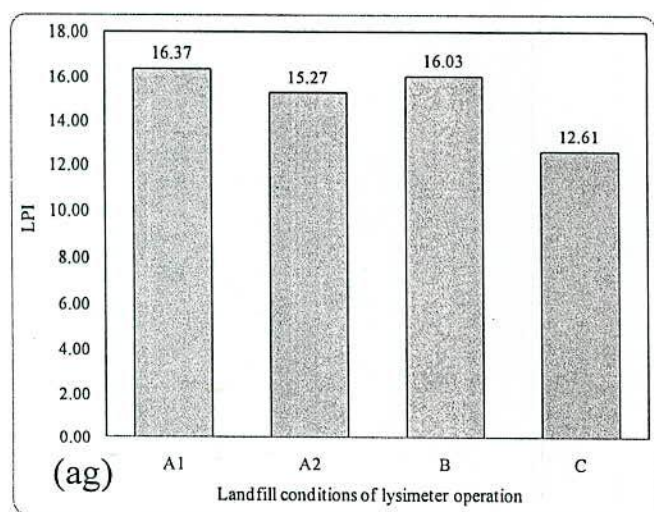
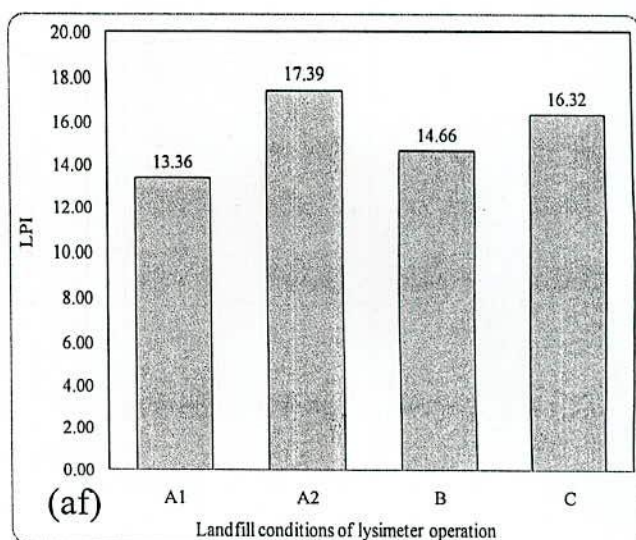
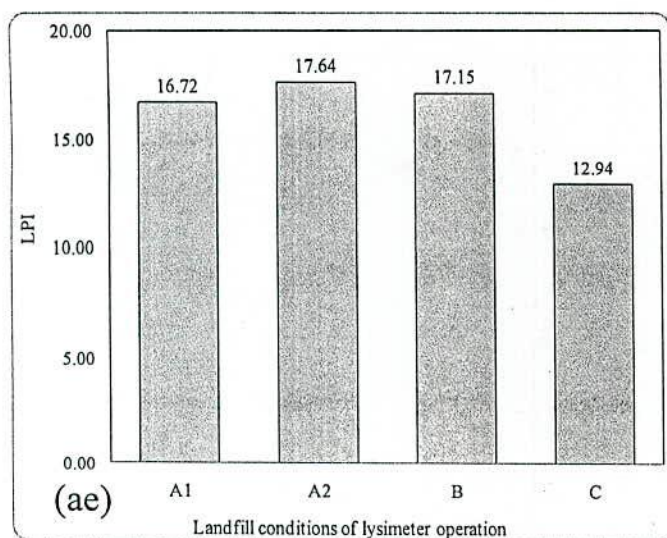


Figure C.1: The Variation of *LPI* at different operational condition of landfill lysimeter and with the increasing of elapsed period of day in (a) 7 (b) 14 (c) 21 (d) 30 (e) 40 (f) 50 (g) 60 (h) 70 (i) 90 (j) 120 (k) 140 (l) 160 (m) 190 (n) 220 (o) 245 (p) 280 (q) 300 (r) 320 (s) 280 (t) 290 (u) 400 (v) 415 (w) 500 (x) 520 (y) 545 (z) 580 (aa) 610 (ab) 630 (ac) 660 (ad) 715 (ae) 750 and (af) 800 (ag) 850 and (ah) 900.

Table C.29: Calculation of sub-LPI and overall LPI at 14 day after filling of MSW in landfill lysimeter

Index	Parameter	Weight factor, w_i	Pollutant concentration, c_i				Individual pollutant rating, p_i				Overall pollutant rating, $w_i p_i$			
			A ₁	A ₂	B	C	A ₁	A ₂	B	C	A ₁	A ₂	B	C
LPI _{organic} (LPI _{or})	COD	0.267	9754	48400	43280	42560	69	91.5	91	91	18.42	24.43	24.30	24.30
	BOD ₅	0.263	2210	2980	2670	2310	41	46	45	42	10.78	12.10	11.84	11.05
	Phenol	0									0.00	0.00	0.00	0.00
	TCB	0.224	6540	8398	7768	7340	85	89	90	90	19.04	19.94	20.16	20.16
	Total	0.754									48.25	56.46	56.29	55.50
Derived LPI_{or}											63.99	74.89	74.66	73.61
LPI _{inorganic} (LPI _{in})	pH	0.214	7.12	8.56	8.5	7.67	6	5	5	5	1.28	1.07	1.07	1.07
	TKN	0.206	1120	2090	1658	1430	38	74	58	49	7.83	15.24	11.95	10.09
	NH ₄ -N	0.198	700	901.3	992.7	965.7	75	96	98	97	14.85	19.01	19.40	19.21
	TDS	0.195	8765	32589	30823	28790	17	76	71	66	3.32	14.82	13.85	12.87
	Cl ⁻	0.187	3320.00	3750.00	2210.00	820.00	27	31	16	8	5.05	5.80	2.99	1.50
	Total	1.000									32.33	55.94	49.26	44.74
Derived LPI_{in}											32.33	55.94	49.26	44.74
LPI _{heavy metal} (LPI _{hm})	Cr	0.125	0.1	0.23	0.21	0.11	5	5	5	5	0.63	0.63	0.63	0.63
	Pb	0.123	0.39	0.6	0.85	0.7	7	7	7.5	7.5	0.86	0.86	0.92	0.92
	Hg	0									0.00	0.00	0.00	0.00
	As	0.119	0.02	0.05	0.02	0.02	5	5	5	5	0.60	0.60	0.60	0.60
	Cd	0									0.00	0.00	0.00	0.00
	Zn	0.11	1.3	1.2	0.91	0.63	5.5	5	5	5	0.61	0.55	0.55	0.55
	Ni	0.102	0.13	0.18	0.15	0.14	5	5	5	5	0.51	0.51	0.51	0.51
	Cu	0.098	1.23	1.46	1.13	1.24	7	7	7	7	0.69	0.69	0.69	0.69
	Fe	0.088	70.13	82.60	91.20	72.00	6.5	6.5	7	6.5	0.57	0.57	0.62	0.57
	Total	0.765									4.45	4.40	4.50	4
Derived LPI_{hm}											5.82	5.75	5.89	5.83
Overall LPI			$(0.175LPI_{or} + 0.257LPI_{in} + 0.391LPI_{hm}) / 0.823$								26.47	36.12	34.05	32.39

Table C.30: Calculation of sub-LPI and overall LPI at 21 day after filling of MSW in landfill lysimeter

Index	Parameter	Weight factor, w_i	Pollutant concentration, c_i				Individual pollutant rating, p_i				Overall pollutant rating, $w_i p_i$			
			A ₁	A ₂	B	C	A ₁	A ₂	B	C	A ₁	A ₂	B	C
LPI _{organic} (LPI _{or})	COD	0.267	10276	47100	42310	45320	71	91.5	91	91	18.96	24.43	24.30	24.30
	BOD ₅	0.263	2180	2754	2520	2209	41	45	44.5	41	10.78	11.84	11.70	10.78
	Phenol	0									0.00	0.00	0.00	0.00
	TCB	0.224	6439	8125	7929	7550	85	89	90	90	19.04	19.94	20.16	20.16
	Total	0.754									48.78	56.20	56.16	55.24
Derived LPI_{or}											64.69	74.54	74.48	73.26
LPI _{inorganic} (LPI _{in})	pH	0.214	6.99	6.93	7.44	7.43	6	6	5	5	1.28	1.28	1.07	1.07
	TKN	0.206	1010	1875	1659	1320.8	33	66	57	45	6.80	13.60	11.74	9.27
	NH ₄ -N	0.198	702.3	865.3	967.2	898.7	80	94	97	95	15.84	18.61	19.21	18.81
	TDS	0.195	6380	33710	29687	22487.9	14	78	69	46	2.73	15.21	13.46	8.97
	Cl ⁻	0.187	3560.60	3890.00	2412.00	1010.00	26	33	18	8.5	4.86	6.17	3.37	1.59
	Total	1.000									31.51	54.87	48.84	39.71
Derived LPI_{in}											31.51	54.87	48.84	39.71
LPI _{heavy metal} (LPI _{hm})	Cr	0.125	0.086	0.19	0.17	0.098	5	5	5	5	0.63	0.63	0.63	0.63
	Pb	0.123	0.32	0.55	0.75	0.62	7	7	9	8	0.86	0.86	1.11	0.98
	Hg	0									0.00	0.00	0.00	0.00
	As	0.119	0.02	0.04	0.02	0.02	5	5	5	5	0.60	0.60	0.60	0.60
	Cn	0									0.00	0.00	0.00	0.00
	Zn	0.11	1.1	1.3	0.86	0.68	5.5	5	5	5	0.61	0.55	0.55	0.55
	Ni	0.102	0.042	0.078	0.064	0.053	5	5	5	5	0.51	0.51	0.51	0.51
	Cu	0.098	0.77	1.36	1.1	0.97	6	7	7	6.5	0.59	0.69	0.69	0.64
	Fe	0.088	72.06	78.42	80.04	40.20	6.5	6.5	6.5	6	0.57	0.57	0.57	0.53
	Total	0.765									4.36	4.40	4.65	4.00
Derived LPI_{hm}											5.699	5.75	6.07	5.79
Overall LPI			$(0.175LPI_{or} + 0.257LPI_{in} + 0.391LPI_{hm}) / 0.823$								26.30	35.72	33.97	30.73

Table C.31: Calculation of sub-LPI and overall LPI at 30 day after filling of MSW in landfill lysimeter

Index	Parameter	Weight factor, w_i	Pollutant concentration, c_i				Individual pollutant rating, p_i				Overall pollutant rating, $w_i p_i$			
			A ₁	A ₂	B	C	A ₁	A ₂	B	C	A ₁	A ₂	B	C
LPI _{organic} (LPI _{or})	COD	0.267	20800	36400	38800	42800	83	88	90	92	22.16	23.50	24.03	24.56
	BOD ₅	0.263	6750	12358	16733	20420	62	68	73	77	16.31	17.88	19.20	20.25
	Phenol	0									0.00	0.00	0.00	0.00
	TCB	0.224	6320	8005	7900	7510	85	87	87	86	19.04	19.49	19.49	19.26
	Total	0.754									57.51	60.87	62.72	64.08
Derived LPI_{or}											76.27	80.73	83.18	84.99
LPI _{inorganic} (LPI _{in})	pH	0.214	6.43	7.5	7.92	7.21	7	5	5	6	1.50	1.07	1.07	1.28
	TKN	0.206	1001	1735	1620	1297	30	62	55	45	6.18	12.77	11.33	9.27
	NH ₄ -N	0.198	687.4	832	955.5	865	80	87	98	93	15.84	17.23	19.40	18.41
	TDS	0.195	7490	5000	7880	17700	16	12	17	43	3.12	2.34	3.32	8.39
	Cl ⁻	0.187	3037	3572	1350	660	25	31	12	8	4.68	5.80	2.24	1.50
	Total	1.000									31.31	39.21	37.36	38.85
Derived LPI_{in}											31.31	39.21	37.36	38.85
LPI _{heavy metal} (LPI _{hm})	Cr	0.125	0.07	0.06	0.09	0.07	5	5	5	5	0.63	0.63	0.63	0.63
	Pb	0.123	0.32	0.4	0.78	0.5	7	7	9	8	0.86	0.86	1.11	0.98
	Hg	0									0.00	0.00	0.00	0.00
	As	0.119	0.02	0.3	0.02	0.02	5	5	5	5	0.60	0.60	0.60	0.60
	Cn	0									0.00	0.00	0.00	0.00
	Zn	0.11	1.3	0.97	0.55	0.58	5.5	5	5	5	0.61	0.55	0.55	0.55
	Ni	0.102	0.075	0.045	0.058	0.045	6	5.5	5.5	5.5	0.61	0.56	0.56	0.56
	Cu	0.098	0.98	0.97	0.09	0.12	7	7	5.5	5.5	0.69	0.69	0.54	0.54
	Fe	0.088	3.2	3.8	3.6	1.5	5.5	5.5	5.5	5	0.48	0.48	0.48	0.44
	Total	0.765									4.47	4.36	4.46	4
Derived LPI_{hm}											5.84	5.70	5.83	5.61
Overall LPI			$(0.175LPI_{or} + 0.257LPI_{in} + 0.391LPI_{hm}) / 0.823$								28.77	32.12	32.12	32.87

Table C.32: Calculation of sub-LPI and overall LPI at 50 day after filling of MSW in landfill lysimeter

Index	Parameter	Weight factor, w_i	Pollutant concentration, c_i				Individual pollutant rating, p_i				Overall pollutant rating, $w_i p_i$			
			A ₁	A ₂	B	C	A ₁	A ₂	B	C	A ₁	A ₂	B	C
LPI _{organic} (LPI _{or})	COD	0.267	320	10240	38040	35550	12	74	89	88	3.20	19.76	23.76	23.50
	BOD ₅	0.263	124	3420	22403	19573	8	55	78	76	2.10	14.47	20.51	19.99
	Phenol	0									0.00	0.00	0.00	0.00
	TCB	0.224	6295	7960	7890	7486	64	87	86	84	14.34	19.49	19.26	18.82
	Total	0.754									19.64	53.71	63.54	62.30
Derived LPI_{or}											26.05	71.23	84.27	82.63
LPI _{inorganic} (LPI _{in})	pH	0.214	8.16	7.47	8.41	8.05	5	5	5	5	1.07	1.07	1.07	1.07
	TKN	0.206	997	1704	1605	1280	30	60	55	44	6.18	12.36	11.33	9.06
	NH ₄ -N	0.198	682	802	943.7	831.2	75	90	97	86	14.85	17.82	19.21	17.03
	TDS	0.195	5590	20150	13790	14590	13	49	34	38	2.54	9.56	6.63	7.41
	Cl ⁻	0.187	2650	1850	570	145	25	13	7	5.5	4.68	2.43	1.31	1.03
	Total	1.000									29.31	43.24	39.55	35.60
Derived LPI_{in}											29.31	43.24	39.55	35.60
LPI _{heavy metal} (LPI _{hm})	Cr	0.125	0.07	0.056	0.03	0.025	5	5	5	5	0.63	0.63	0.63	0.63
	Pb	0.123	0.19	0.39	0.78	0.29	6	7	9	6.5	0.74	0.86	1.11	0.80
	Hg	0									0.00	0.00	0.00	0.00
	As	0.119	0.02	0.03	0.02	0.02	5	5	5	5	0.60	0.60	0.60	0.60
	Cn	0									0.00	0.00	0.00	0.00
	Zn	0.11	0.9	0.23	0.18	0.29	5	5	5	5	0.55	0.55	0.55	0.55
	Ni	0.102	0.075	0.045	0.058	0.045	6	5.5	5.5	5.5	0.61	0.56	0.56	0.56
	Cu	0.098	0.09	0.05	0.06	0.05	5.5	5.5	5.5	5.5	0.54	0.54	0.54	0.54
	Fe	0.088	0.2	0.2	2	1.6	5	5	5	5	0.44	0.44	0.44	0.44
	Total	0.765									4.10	4.17	4.42	4
Derived LPI_{hm}											5.36	5.45	5.77	5.37
Overall LPI			$(0.175LPI_{or} + 0.257LPI_{in} + 0.391LPI_{hm}) / 0.823$								17.24	31.24	33.01	31.24

Table C.33: Calculation of sub-LPI and overall LPI at 60 day after filling of MSW in landfill lysimeter

Index	Parameter	Weight factor, w_i	Pollutant concentration, c_i				Individual pollutant rating, p_i				Overall pollutant rating, $w_i p_i$			
			A ₁	A ₂	B	C	A ₁	A ₂	B	C	A ₁	A ₂	B	C
LPI _{organic} (LPI _{or})	COD	0.267	896	9360	3042	34480	36	78	62	87	9.61	20.83	16.55	23.23
	BOD ₅	0.263	384	5520	2856	12554	12	58	47	68	3.16	15.25	12.36	17.88
	Phenol	0									0.00	0.00	0.00	0.00
	TCB	0.224	6229	7945	7878	7452	84	87	89	86	18.82	19.49	19.94	19.26
	Total	0.754									31.58	55.57	48.85	60.38
Derived LPI_{or}											41.89	73.70	64.79	80.08
LPI _{inorganic} (LPI _{in})	pH	0.214	6.49	6.33	8.5	7.12	6	6.5	5	5	1.28	1.39	1.07	1.07
	TKN	0.206	980	1680	1595	1244	30	60	55	40	6.18	12.36	11.33	8.24
	NH ₄ -N	0.198	675	765	803	820	75	85	90	91	14.85	16.83	17.82	18.02
	TDS	0.195	4490	15740	10610	13160	12	38	24	27	2.34	7.41	4.68	5.27
	Cl ⁻	0.187	1120.00	1270.00	580.00	150.00	9	10	7	5.5	1.68	1.87	1.31	1.03
	Total	1.000									26.34	39.86	36.21	33.62
Derived LPI_{in}											26.34	39.86	36.21	33.62
LPI _{heavy metal} (LPI _{hm})	Cr	0.125	0.07	0.056	0.03	0.025	5	5	5	5	0.63	0.63	0.63	0.63
	Pb	0.123	0.18	0.392	0.78	0.29	6	7	9	6.5	0.74	0.86	1.11	0.80
	Hg	0									0.00	0.00	0.00	0.00
	As	0.119	0.02	0.03	0.02	0.02	5	5	5	5	0.60	0.60	0.60	0.60
	Cd	0									0.00	0.00	0.00	0.00
	Zn	0.11	0.88	0.23	0.17	0.29	5	5	5	5	0.55	0.55	0.55	0.55
	Ni	0.102	0.075	0.045	0.058	0.045	6	5.5	5.5	5.5	0.61	0.56	0.56	0.56
	Cu	0.098	0.09	0.05	0.06	0.05	5.5	5.5	5.5	5.5	0.54	0.54	0.54	0.54
	Fe	0.088	30.80	51.60	53.20	8.67	5.5	6	6	5	0.48	0.53	0.53	0.44
	Total	0.765									4.14	4.26	4.51	4
Derived LPI_{hm}											5.42	5.57	5.89	5.37
Overall LPI			(0.175LPI_{or}+0.257LPI_{in}+0.391LPI_{hm})/0.823								19.70	30.76	27.88	30.08

Table C.34: Calculation of sub-LPI and overall LPI at 120 day after filling of MSW in landfill lysimeter

Index	Parameter	Weight factor, w_i	Pollutant concentration, c_i				Individual pollutant rating, p_i				Overall pollutant rating, $w_i p_i$			
			A ₁	A ₂	B	C	A ₁	A ₂	B	C	A ₁	A ₂	B	C
LPI _{organic} (LPI _{or})	COD	0.267	160.00	6760.00	1440.00	5120.00	8.50	68.00	44.00	67.00	2.27	18.16	11.75	17.89
	BOD ₅	0.263	83.00	3575.00	980.00	2179.00	8.00	51.00	27.00	41.00	2.10	13.41	7.10	10.78
	Phenol	0									0.00	0.00	0.00	0.00
	TCB	0.224	6212.00	7945.00	7898.00	7460.00	85.00	87.00	88.00	86.00	19.04	19.49	19.71	19.26
	Total	0.754									23.41	51.06	38.56	47.94
Derived LPI_{or}											31.05	67.71	51.14	63.58
LPI _{inorganic} (LPI _{in})	pH	0.214	6.75	6.42	7.84	6.30	6.00	7.00	5.00	7.00	1.28	1.50	1.07	1.50
	TKN	0.206	945.00	1637.00	1556.00	1218.00	27.00	58.00	54.00	40.00	5.56	11.95	11.12	8.24
	NH ₄ -N	0.198	610.00	654.00	787.00	698.00	66.00	73.00	88.00	85.00	13.07	14.45	17.42	16.83
	TDS	0.195	4440.00	13440.00	5810.00	8300.00	9.00	34.00	13.00	18.00	1.76	6.63	2.54	3.51
	Cl ⁻	0.187	2440.00	2670.00	1750.00	1300.00	19.00	21.00	13.00	10.00	3.55	3.93	2.43	1.87
	Total	1.000									25.22	38.46	34.58	31.95
Derived LPI_{in}											25.22	38.46	34.58	31.95
LPI _{heavy metal} (LPI _{hm})	Cr	0.125	0.03	0.02	0.04	0.04	5.00	5.00	5.00	5.00	0.63	0.63	0.63	0.63
	Pb	0.123	0.20	0.35	0.58	0.42	6.00	7.00	7.50	7.00	0.74	0.86	0.92	0.86
	Hg	0									0.00	0.00	0.00	0.00
	As	0.119	0.02	0.04	0.02	0.02	5.00	5.00	5.00	5.00	0.60	0.60	0.60	0.60
	Cn	0									0.00	0.00	0.00	0.00
	Zn	0.11	1.20	0.97	0.12	0.11	5.00	5.00	5.00	5.00	0.55	0.55	0.55	0.55
	Ni	0.102	0.07	0.04	0.06	0.05	5.50	5.50	5.50	5.50	0.56	0.56	0.56	0.56
	Cu	0.098	0.12	0.08	0.05	0.08	5.50	5.50	5.50	5.50	0.54	0.54	0.54	0.54
	Fe	0.088	32.00	23.00	45.10	1.50	5.50	5.50	6.00	5.00	0.48	0.48	0.53	0.44
	Total	0.765									4.09	4.22	4.32	4
Derived LPI_{hm}											5.35	5.51	5.65	5.45
Overall LPI			(0.175LPI_{or}+0.257LPI_{in}+0.391LPI_{hm})/0.823								17.02	29.03	24.36	26.09

Table C.35: Calculation of sub-LPI and overall LPI at 160 day after filling of MSW in landfill lysimeter

Index	Parameter	Weight factor, w_i	Pollutant concentration, c_i				Individual pollutant rating, p_i				Overall pollutant rating, $w_i p_i$			
			A_1	A_2	B	C	A_1	A_2	B	C	A_1	A_2	B	C
LPI_{organic} (LPI_{or})	COD	0.267	2880	5800	1920	5280	55	67	49	66	14.69	17.89	13.08	17.62
	BOD ₅	0.263	1550	1760	805	965	35	37	26.5	28	9.21	9.73	6.97	7.36
	Phenol	0									0.00	0.00	0.00	0.00
	TCB	0.224	6187	7855	7802	7356	85	88	88	86	19.04	19.71	19.71	19.26
	Total	0.754									42.93	47.33	39.76	44.25
Derived LPI_{or}											56.94	62.77	52.74	58.69
$LPI_{\text{inorganic}}$ (LPI_{in})	pH	0.214	6.17	6.88	7.61	7.33	7	5	5	5	1.50	1.07	1.07	1.07
	TKN	0.206	937	1625	1560	1210	26	57	55	40	5.36	11.74	11.33	8.24
	NH ₄ -N	0.198	543	597	754	653	58	66	78	74	11.48	13.07	15.44	14.65
	TDS	0.195	4310	12780	6440	9390	10	32	15	21	1.95	6.24	2.93	4.10
	Cl ⁻	0.187	2880.00	2790.00	1010.00	1410.00	23	23	9	11	4.30	4.30	1.68	2.06
	Total	1.000									24.59	36.42	32.45	30.11
Derived LPI_{in}											24.59	36.42	32.45	30.11
$LPI_{\text{heavy metal}}$ (LPI_{hm})	Cr	0.125	0.06	0.03	0.05	0.045	5	5	5	5	0.63	0.63	0.63	0.63
	Pb	0.123	0.213	0.34	0.487	0.35	6	7	7.5	7	0.74	0.86	0.92	0.86
	Hg	0									0.00	0.00	0.00	0.00
	As	0.119	0.02	0.03	0.02	0.02	5	5	5	5	0.60	0.60	0.60	0.60
	Cn	0									0.00	0.00	0.00	0.00
	Zn	0.11	1.13	0.65	0.487	0.35	5	5	5	5	0.55	0.55	0.55	0.55
	Ni	0.102	0.06	0.045	0.065	0.055	5.5	5.5	5.5	5.5	0.56	0.56	0.56	0.56
	Cu	0.098	0.67	0.09	0.04	0.07	7	5.5	5.5	5.5	0.69	0.54	0.54	0.54
	Fe	0.088	10.20	21.70	22.00	5.10	5	5.5	5.5	5	0.44	0.48	0.48	0.44
	Total	0.765									4.20	4.22	4.28	4
Derived LPI_{hm}											5.48	5.51	5.59	5.45
Overall LPI			$(0.175LPI_{or} + 0.257LPI_{in} + 0.391LPI_{hm}) / 0.823$								22.39	27.34	24.00	24.47

Table C.36: Calculation of sub-LPI and overall LPI at 245 day after filling of MSW in landfill lysimeter

Index	Parameter	Weight factor, w_i	Pollutant concentration, c_i				Individual pollutant rating, p_i				Overall pollutant rating, $w_i p_i$			
			A ₁	A ₂	B	C	A ₁	A ₂	B	C	A ₁	A ₂	B	C
LPI _{organic} (LPI _{or})	COD	0.267	960	4120	1490	4860	36	63	44	64	9.61	16.82	11.75	17.09
	BOD ₅	0.263	218	1520	465	1765	9	35	16	31	2.37	9.21	4.21	8.15
	Phenol	0									0.00	0.00	0.00	0.00
	TCB	0.224	5621	6190	6420	6220	83	85	86	85	18.59	19.04	19.26	19.04
	Total	0.754									30.57	45.07	35.22	44.28
Derived LPI_{or}											40.55	59.77	46.71	58.73
LPI _{inorganic} (LPI _{in})	pH	0.214	6.53	7.63	7.38	8.2	7	5	5	5	1.50	1.07	1.07	1.07
	TKN	0.206	845	1603	1521	1137	26	55	52	38	5.36	11.33	10.71	7.83
	NH ₄ -N	0.198	504.9	586.7	697.5	632.8	56	66	76	71	11.09	13.07	15.05	14.06
	TDS	0.195	2110	11572	6170	13420	10	26	14	33	1.95	5.07	2.73	6.44
	Cl ⁻	0.187	2090.00	2150.00	1000.00	1290.00	15	15	8.5	10	2.81	2.81	1.59	1.87
	Total	1.000									22.70	33.34	31.15	31.26
Derived LPI_{in}											22.70	33.34	31.15	31.26
LPI _{heavy metal} (LPI _{hm})	Cr	0.125	0.035	0.04	0.06	0.055	5	5	5	5	0.63	0.63	0.63	0.63
	Pb	0.123	0.321	0.276	0.65	0.45	7	6.5	7.5	7	0.86	0.80	0.92	0.86
	Hg	0									0.00	0.00	0.00	0.00
	As	0.119	0.02	0.03	0.01	0.01	5	5	5	5	0.60	0.60	0.60	0.60
	Cd	0									0.00	0.00	0.00	0.00
	Zn	0.11	1.267	0.765	0.45	0.35	5	5	5	5	0.55	0.55	0.55	0.55
	Ni	0.102	0.045	0.04	0.07	0.065	5.5	5.5	5.5	5.5	0.56	0.56	0.56	0.56
	Cu	0.098	0.32	0.06	0.09	0.13	6	5.5	5.5	5.5	0.59	0.54	0.54	0.54
	Fe	0.088	12	18.1	19.4	2.6	5	5.5	5.5	5	0.44	0.48	0.48	0.44
	Total	0.765									4.22	4.15	4.28	4
Derived LPI_{hm}											5.52	5.43	5.59	5.45
Overall LPI			(0.175LPI_{or}+0.257LPI_{in}+0.391LPI_{hm})/0.823								18.33	25.70	22.32	24.84

Table C.37: Calculation of sub-LPI and overall LPI at 300 day after filling of MSW in landfill lysimeter

Index	Parameter	Weight factor, w_i	Pollutant concentration, c_i				Individual pollutant rating, p_i				Overall pollutant rating, $w_i p_i$			
			A ₁	A ₂	B	C	A ₁	A ₂	B	C	A ₁	A ₂	B	C
LPI _{organic} (LPI _{or})	COD	0.267	800	3726	1400	3400	32	61	39	60	8.54	16.29	10.41	16.02
	BOD ₅	0.263	321	1917	652	2165	12	39	23.5	42	3.16	10.26	6.18	11.05
	Phenol	0									0.00	0.00	0.00	0.00
	TCB	0.224	4870	5438	5100	4987	82	85	84	83	18.37	19.04	18.82	18.59
	Total	0.754									30.07	45.58	35.41	45.66
Derived LPI_{or}											39.88	60.46	46.96	60.55
LPI _{inorganic} (LPI _{in})	pH	0.214	6.33	7.55	7.21	8.27	7	5	5	5	1.50	1.07	1.07	1.07
	TKN	0.206	820	1109	1534	1456	25	36	51	50	5.15	7.42	10.51	10.30
	NH ₄ -N	0.198	487.7	576	686	614	54	60	78	70	10.69	11.88	15.44	13.86
	TDS	0.195	3890	10572	7910	9340	9	22	17	21	1.76	4.29	3.32	4.10
	Cl ⁻	0.187	2150.00	2250.00	1010.00	1810.00	16	16.5	9	13.5	2.99	3.09	1.68	2.52
	Total	1.000									22.09	27.74	32.02	31.85
Derived LPI_{in}											22.09	27.74	32.02	31.85
LPI _{heavy metal} (LPI _{hm})	Cr	0.125	0.036	0.04	0.06	0.07	5	5	5	5	0.63	0.63	0.63	0.63
	Pb	0.123	0.134	0.273	0.55	0.437	5.5	6.5	7.5	7	0.68	0.80	0.92	0.86
	Hg	0									0.00	0.00	0.00	0.00
	As	0.119	0.02	0.03	0.01	0.01	5	5	5	5	0.60	0.60	0.60	0.60
	Cn	0									0.00	0.00	0.00	0.00
	Zn	0.11	1.134	0.9	0.45	0.37	5	5	5	5	0.55	0.55	0.55	0.55
	Ni	0.102	0.046	0.04	0.06	0.065	5.5	5.5	5.5	5.5	0.56	0.56	0.56	0.56
	Cu	0.098	0.36	0.09	0.078	0.1	6	5.5	5.5	5.5	0.59	0.54	0.54	0.54
	Fe	0.088	13.02	15.14	14.52	0.75	5	5	5	5	0.44	0.44	0.44	0.44
	Total	0.765									4.04	4.11	4.23	4
Derived LPI_{hm}											5.28	5.37	5.53	5.45
Overall LPI			(0.175LPI_{or}+0.257LPI_{in}+0.391LPI_{hm})/0.823								17.88	24.07	22.61	25.41

Table C.38: Calculation of sub-LPI and overall LPI at 380 day after filling of MSW in landfill lysimeter

Index	Parameter	Weight factor, w_i	Pollutant concentration, c_i				Individual pollutant rating, p_i				Overall pollutant rating, $w_i p_i$			
			A ₁	A ₂	B	C	A ₁	A ₂	B	C	A ₁	A ₂	B	C
LPI _{organic} (LPI _{or})	COD	0.267	852	4087	900	5300	33	63	36	66	8.81	16.82	9.61	17.62
	BOD ₅	0.263	465	2361	565	2453	15.5	43	19	45	4.08	11.31	5.00	11.84
	Phenol	0									0.00	0.00	0.00	0.00
	TCB	0.224	2130	2987	2730	2650	79	84	83	82	17.70	18.82	18.59	18.37
	Total	0.754									30.58	46.95	33.20	47.83
Derived LPI _{or}											40.56	62.26	44.03	63.43
LPI _{inorganic} (LPI _{in})	pH	0.214	6.51	7.27	6.45	7.21	7	5	7	5	1.50	1.07	1.50	1.07
	TKN	0.206	540	865	1201	980	15	27	36	30	3.09	5.56	7.42	6.18
	NH ₄ -N	0.198	420	540	684	665	44	55	75	70	8.71	10.89	14.85	13.86
	TDS	0.195	4190	6440	2770	9670	10	14	7	21	1.95	2.73	1.37	4.10
	Cl ⁻	0.187	2225.00	2425.00	1100.00	1290.00	15.5	18.5	9	10	2.90	3.46	1.68	1.87
	Total	1.000									18.15	23.71	26.81	27.08
Derived LPI _{in}											18.15	23.71	26.81	27.08
LPI _{heavy metal} (LPI _{hm})	Cr	0.125	0.055	0.04	0.07	0.065	5	5	5	5	0.63	0.63	0.63	0.63
	Pb	0.123	0.126	0.265	0.55	0.476	5.5	6.5	7.5	7	0.68	0.80	0.92	0.86
	Hg	0									0.00	0.00	0.00	0.00
	As	0.119	0.02	0.03	0.01	0.01	5	5	5	5	0.60	0.60	0.60	0.60
	Cn	0									0.00	0.00	0.00	0.00
	Zn	0.11	1.126	0.92	0.55	0.576	5	5	5	5	0.55	0.55	0.55	0.55
	Ni	0.102	0.055	0.04	0.07	0.065	5.5	5.5	5.5	5.5	0.56	0.56	0.56	0.56
	Cu	0.098	0.342	0.123	0.089	0.09	6	5.5	5.5	5.5	0.59	0.54	0.54	0.54
	Fe	0.088	11.4	13	32.5	2.2	5	5	5.5	5	0.44	0.44	0.48	0.44
	Total	0.765									4.04	4.11	4.28	4
Derived LPI _{hm}											5.28	5.37	5.59	5.45
Overall LPI			(0.175LPI _{or} +0.257LPI _{in} +0.391LPI _{hm})/0.823								16.80	23.20	20.39	24.53

Table C.39: Calculation of sub-*LPI* and overall *LPI* at 390 day after filling of MSW in landfill lysimeter

Index	Parameter	Weight factor, w_i	Pollutant concentration, c_i				Individual pollutant rating, p_i				Overall pollutant rating, $w_i p_i$			
			A ₁	A ₂	B	C	A ₁	A ₂	B	C	A ₁	A ₂	B	C
<i>LPI_{organic}</i> (<i>LPI_{or}</i>)	COD	0.267	800	3830	845	5120	33	63	36	55	8.81	16.82	9.61	14.69
	BOD ₅	0.263	345	437	490	510	12	15	16	19	3.16	3.95	4.21	5.00
	Phenol	0									0.00	0.00	0.00	0.00
	TCB	0.224	271	343	325	255	56.5	59	59	50	12.66	13.22	13.22	11.20
	Total	0.754									24.62	33.98	27.04	30.88
<i>Derived LPI_{or}</i>											32.66	45.07	35.86	40.96
<i>LPI_{inorganic}</i> (<i>LPI_{in}</i>)	pH	0.214	6.55	7.53	6.66	7.73	7	5	7	5	1.50	1.07	1.50	1.07
	TKN	0.206	365	1122	676	538	10	40	20	15	2.06	8.24	4.12	3.09
	NH ₄ -N	0.198	412	563.2	702	621	43	59	77	70	8.51	11.68	15.25	13.86
	TDS	0.195	4023	6240	2700	9238	10	14	7	21	1.95	2.73	1.37	4.10
	Cl ⁻	0.187	2370.00	2670.00	1125.00	1432.00	15.5	18.5	9	10	2.90	3.46	1.68	1.87
	Total	1.000									16.92	27.18	23.91	23.99
<i>Derived LPI_{in}</i>											16.92	27.18	23.91	23.99
<i>LPI_{heavy metal}</i> (<i>LPI_{hm}</i>)	Cr	0.125	0.055	0.04	0.07	0.065	5	5	5	5	0.63	0.63	0.63	0.63
	Pb	0.123	0.126	0.265	0.55	0.476	5.5	6.5	7.5	7	0.68	0.80	0.92	0.86
	Hg	0									0.00	0.00	0.00	0.00
	As	0.119	0.01	0.02	0.01	0.01	5	5	5	5	0.60	0.60	0.60	0.60
	Cd	0									0.00	0.00	0.00	0.00
	Zn	0.11	1.126	0.92	0.55	0.576	5	5	5	5	0.55	0.55	0.55	0.55
	Ni	0.102	0.055	0.04	0.07	0.065	5.5	5.5	5.5	5.5	0.56	0.56	0.56	0.56
	Cu	0.098	0.36	0.09	0.078	0.1	6	5.5	5.5	5.5	0.59	0.54	0.54	0.54
	Fe	0.088	10	11.1	16.4	8.6	5	5	5.5	5	0.44	0.44	0.48	0.44
	Total	0.765									4.04	4.11	4.28	4
<i>Derived LPI_{hm}</i>											5.28	5.37	5.59	5.45
<i>Overall LPI</i>			$(0.175LPI_{or} + 0.257LPI_{in} + 0.391LPI_{hm}) / 0.823$								14.73	20.62	17.75	18.79

Table C.40: Calculation of sub-LPI and overall LPI at 400 day after filling of MSW in landfill lysimeter

Index	Parameter	Weight factor, w_i	Pollutant concentration, c_i				Individual pollutant rating, p_i				Overall pollutant rating, $w_i p_i$			
			A ₁	A ₂	B	C	A ₁	A ₂	B	C	A ₁	A ₂	B	C
LPI _{organic} (LPI _{or})	COD	0.267	960	5120	590	4760	33	63	36	55	8.81	16.82	9.61	14.69
	BOD ₅	0.263	340	465	510	576	12	15	16	19	3.16	3.95	4.21	5.00
	Phenol	0									0.00	0.00	0.00	0.00
	TCB	0.224	258	320	310	240	56.5	59	59	50	12.66	13.22	13.22	11.20
	Total	0.754									24.62	33.98	27.04	30.88
Derived LPI_{or}											32.66	45.07	35.86	40.96
LPI _{inorganic} (LPI _{in})	pH	0.214	7.75	8.02	7.84	8.3	5	5	5	5	1.07	1.07	1.07	1.07
	TKN	0.206	378	1220	657	520	10	40	20	15	2.06	8.24	4.12	3.09
	NH ₄ -N	0.198	410	531.9	665	587	42	56	74	66	8.32	11.09	14.65	13.07
	TDS	0.195	4020	6260	2678	9530	10	14	7	21	1.95	2.73	1.37	4.10
	Cl ⁻	0.187	2420.00	2600.00	1125.00	1679.00	18	20	9	10	3.37	3.74	1.68	1.87
	Total	1.000									16.76	26.87	22.89	23.19
Derived LPI_{in}											16.76	26.87	22.89	23.19
LPI _{heavy metal} (LPI _{hm})	Cr	0.125	0.05	0.04	0.06	0.065	5	5	5	5	0.63	0.63	0.63	0.63
	Pb	0.123	0.121	0.251	0.52	0.43	5.5	6.5	7.5	7	0.68	0.80	0.92	0.86
	Hg	0									0.00	0.00	0.00	0.00
	As	0.119	0.01	0.02	0.01	0.01	5	5	5	5	0.60	0.60	0.60	0.60
	Cn	0									0.00	0.00	0.00	0.00
	Zn	0.11	1.2	0.852	0.52	0.58	5	5	5	5	0.55	0.55	0.55	0.55
	Ni	0.102	0.055	0.04	0.07	0.065	5.5	5.5	5.5	5.5	0.56	0.56	0.56	0.56
	Cu	0.098	0.342	0.123	0.089	0.09	6	5.5	5.5	5.5	0.59	0.54	0.54	0.54
	Fe	0.088	9.42	10	13.06	1.42	5	5	5.5	5	0.44	0.44	0.48	0.44
	Total	0.765									4.04	4.11	4.28	4
Derived LPI_{hm}											5.28	5.37	5.59	5.45
Overall LPI			(0.175LPI_{or}+0.257LPI_{in}+0.391LPI_{hm})/0.823								14.68	20.53	17.43	18.54

Table C.41: Calculation of sub-LPI and overall LPI at 415 day after filling of MSW in landfill lysimeter

Index	Parameter	Weight factor, w_i	Pollutant concentration, c_i				Individual pollutant rating, p_i				Overall pollutant rating, $w_i p_i$			
			A ₁	A ₂	B	C	A ₁	A ₂	B	C	A ₁	A ₂	B	C
LPI _{organic} (LPI _{or})	COD	0.267	852	4087	900	3300	33	63	36	55	8.81	16.82	9.61	14.69
	BOD ₅	0.263	345	437	490	510	12	15	16	19	3.16	3.95	4.21	5.00
	Phenol	0									0.00	0.00	0.00	0.00
	TCB	0.224	245	304	300	229	56.5	59	59	50	12.66	13.22	13.22	11.20
	Total	0.754									24.62	33.98	27.04	30.88
Derived LPI_{or}											32.66	45.07	35.86	40.96
LPI _{inorganic} (LPI _{in})	pH	0.214	6.51	7.27	6.45	7.21	7	5	7	5	1.50	1.07	1.50	1.07
	TKN	0.206	378	1130	637	504	10	40	20	15	2.06	8.24	4.12	3.09
	NH ₄ -N	0.198	320	520	655	582	31	56	69	60	6.14	11.09	13.66	11.88
	TDS	0.195	3928	6387	2710	9230	10	14	7	21	1.95	2.73	1.37	4.10
	Cl ⁻	0.187	2342.00	2650.00	1255.00	1290.00	18	20	10	10	3.37	3.74	1.87	1.87
	Total	1.000									15.01	26.87	22.52	22.01
Derived LPI_{in}											15.01	26.87	22.52	22.01
LPI _{heavy metal} (LPI _{hm})	Cr	0.125	0.055	0.04	0.07	0.065	5	5	5	5	0.63	0.63	0.63	0.63
	Pb	0.123	0.126	0.265	0.55	0.476	5.5	6.5	7.5	7	0.68	0.80	0.92	0.86
	Hg	0									0.00	0.00	0.00	0.00
	As	0.119	0.01	0.01	0.01	0.01	5	5	5	5	0.60	0.60	0.60	0.60
	Cd	0									0.00	0.00	0.00	0.00
	Zn	0.11	1.126	0.92	0.55	0.576	5	5	5	5	0.55	0.55	0.55	0.55
	Ni	0.102	0.055	0.04	0.07	0.065	5.5	5.5	5.5	5.5	0.56	0.56	0.56	0.56
	Cu	0.098	0.342	0.123	0.089	0.09	6	5.5	5.5	5.5	0.59	0.54	0.54	0.54
	Fe	0.088	8.6	10.6	14.7	3.2	5	5	5.5	5	0.44	0.44	0.48	0.44
	Total	0.765									4.04	4.11	4.28	4
Derived LPI_{hm}											5.28	5.37	5.59	5.45
Overall LPI			(0.175LPI_{or}+0.257LPI_{in}+0.391LPI_{hm})/0.823								14.14	20.53	17.31	18.17

Table C.42: Calculation of sub-LPI and overall LPI at 500 day after filling of MSW in landfill lysimeter

Index	Parameter	Weight factor, w_i	Pollutant concentration, c_i				Individual pollutant rating, p_i				Overall pollutant rating, $w_i p_i$			
			A_1	A_2	B	C	A_1	A_2	B	C	A_1	A_2	B	C
LPI_{organic} (LPI_{or})	COD	0.267	896	2240	3042	4120	33	52	57	63	8.81	13.88	15.22	16.82
	BOD ₅	0.263	535	1452	1890	1985	20	34	37	39	5.26	8.94	9.73	10.26
	Phenol	0									0.00	0.00	0.00	0.00
	TCB	0.224	234	296	291	217	54	59	58	52	12.10	13.22	12.99	11.65
	Total	0.754									26.17	36.04	37.94	38.73
Derived LPI_{or}											34.70	47.80	50.32	51.36
$LPI_{\text{inorganic}}$ (LPI_{in})	pH	0.214	6.05	7.53	6.66	7.73	7	5	6	5	1.50	1.07	1.28	1.07
	TKN	0.206	356	1098	612	485	10	35	20	16	2.06	7.21	4.12	3.30
	NH ₄ -N	0.198	315	510	634	578	30	56	72	65	5.94	11.09	14.26	12.87
	TDS	0.195	3620	6800	5400	9720	9	15	13	22	1.76	2.93	2.54	4.29
	Cl ⁻	0.187	2672.00	2678.00	1265.00	1225.00	20	20	19	19	3.74	3.74	3.55	3.55
	Total	1.000									14.99	26.03	25.75	25.08
Derived LPI_{in}											14.99	26.03	25.75	25.08
$LPI_{\text{heavy metal}}$ (LPI_{hm})	Cr	0.125	0.05	0.03	0.08	0.07	5	5	5	5	0.63	0.63	0.63	0.63
	Pb	0.123	0.1176	0.256	0.46	0.376	5.5	6.5	7	6.5	0.68	0.80	0.86	0.80
	Hg	0									0.00	0.00	0.00	0.00
	As	0									0.00	0.00	0.00	0.00
	Cn	0									0.00	0.00	0.00	0.00
	Zn	0.11	1.1176	0.476	0.36	0.176	5	5	5	5	0.55	0.55	0.55	0.55
	Ni	0.102	0.05	0.055	0.08	0.07	5.5	5.5	5.5	5.5	0.56	0.56	0.56	0.56
	Cu	0.098	0.98	0.97	0.09	0.12	7	7	5.5	5.5	0.69	0.69	0.54	0.54
	Fe	0.088	12.2	18.9	9.65	8.6	5	5.5	5	5	0.44	0.48	0.44	0.44
	Total	0.646									3.54	3.71	3.58	3.51
Derived LPI_{hm}											5.48	5.74	5.54	5.44
Overall LPI			$(0.175LPI_{or} + 0.257LPI_{in} + 0.33LPI_{hm})/0.762$								15.40	22.24	22.64	22.61

Table C.43: Calculation of sub-LPI and overall LPI at 545 day after filling of MSW in landfill lysimeter

Index	Parameter	Weight factor, w_i	Pollutant concentration, c_i				Individual pollutant rating, p_i				Overall pollutant rating, $w_i p_i$			
			A ₁	A ₂	B	C	A ₁	A ₂	B	C	A ₁	A ₂	B	C
LPI _{organic} (LPI _{or})	COD	0.267	1440	4640	1920	990	44	65	49	37	11.75	17.36	13.08	9.88
	BOD ₅	0.263	865	2526	1150	385	26	45	30	12	6.84	11.84	7.89	3.16
	Phenol	0									0.00	0.00	0.00	0.00
	TCB	0.224	205	267	274	191	55	58	60	52	12.32	12.99	13.44	11.65
	Total	0.754									30.91	42.18	34.41	24.68
Derived LPI_{or}											40.99	55.94	45.64	32.74
LPI _{inorganic} (LPI _{in})	pH	0.214	6.43	7.26	6.98	7.5	7	5.5	6	5	1.50	1.18	1.28	1.07
	TKN	0.206	337	1008	550	443	10	31	16	11	2.06	6.39	3.30	2.27
	NH ₄ -N	0.198	316.2	507.8	623.8	579.7	32	55	72	62	6.34	10.89	14.26	12.28
	TDS	0.195	7800	8790	9980	16880	16	20	22	43	3.12	3.90	4.29	8.39
	Cl ⁻	0.187	2249.00	2649.00	1175.00	1350.00	15.5	20	9.5	10	2.90	3.74	1.78	1.87
	Total	1.000									15.91	26.09	24.90	25.87
Derived LPI_{in}											15.91	26.09	24.90	25.87
LPI _{heavy metal} (LPI _{hm})	Cr	0.125	0.065	0.05	0.07	0.065	5	5	5	5	0.63	0.63	0.63	0.63
	Pb	0.123	0.2164	0.246	0.25	0.15	6	6.5	6.5	5.5	0.74	0.80	0.80	0.68
	Hg	0									0.00	0.00	0.00	0.00
	As	0									0.00	0.00	0.00	0.00
	Cu	0									0.00	0.00	0.00	0.00
	Zn	0.11	0.64	0.4	0.36	0.15	5	5	5	5	0.55	0.55	0.55	0.55
	Ni	0.102	0.065	0.05	0.05	0.04	5.5	5.5	5.5	5.5	0.56	0.56	0.56	0.56
	Cu	0.098	0.975	0.875	0.67	0.43	7	7	6.5	6	0.69	0.69	0.64	0.59
	Fe	0.088	5.20	8.04	11.7	1.50	5	5	5	5	0.44	0.44	0.44	0.44
	Total	0.646									3.60	3.66	3.61	3.44
Derived LPI_{hm}											5.57	5.67	5.59	5.33
Overall LPI			$(0.175LPI_{or} + 0.257LPI_{in} + 0.33LPI_{hm}) / 0.762$								17.19	24.10	21.30	18.55

Table C.44: Calculation of sub-LPI and overall LPI at 630 day after filling of MSW in landfill lysimeter

Index	Parameter	Weight factor, w_i	Pollutant concentration, c_i				Individual pollutant rating, p_i				Overall pollutant rating, $w_i p_i$			
			A ₁	A ₂	B	C	A ₁	A ₂	B	C	A ₁	A ₂	B	C
LPI _{organic} (LPI _{or})	COD	0.267	2880	1520	1560	800	55	45	45	33	14.69	12.02	12.02	8.81
	BOD ₅	0.263	1265	690	845	560	31	24	26.5	21	8.15	6.31	6.97	5.52
	Phenol	0									0.00	0.00	0.00	0.00
	TCB	0.224	171	217	234	152	53	56	58	50	11.87	12.54	12.99	11.20
	Total	0.754									34.71	30.87	31.98	25.53
Derived LPI_{or}											46.03	40.94	42.41	33.86
LPI _{inorganic} (LPI _{in})	pH	0.214	6.43	6.73	6.98	7.11	7	6.5	5	5	1.50	1.39	1.07	1.07
	TKN	0.206	290	867	486	381	10	29	14	10	2.06	5.97	2.88	2.06
	NH ₄ -N	0.198	265	475	545	501	26	49	59	54	5.15	9.70	11.68	10.69
	TDS	0.195	7910	4990	10610	15800	17	12	25	39	3.32	2.34	4.88	7.61
	Cl ⁻	0.187	2875.00	2387.00	1000.00	1250.00	22.5	17	9	9.5	4.21	3.18	1.68	1.78
	Total	1.000									16.23	22.59	22.19	23.20
Derived LPI_{in}											16.23	22.59	22.19	23.20
LPI _{heavy metal} (LPI _{hm})	Cr	0.125	0.045	0.04	0.08	0.07	5	5	5	5	0.63	0.63	0.63	0.63
	Pb	0.123	0.2285	0.25	0.25	0.156	6	6.5	6.5	5.5	0.74	0.80	0.80	0.68
	Hg	0									0.00	0.00	0.00	0.00
	As	0									0.00	0.00	0.00	0.00
	Cd	0									0.00	0.00	0.00	0.00
	Zn	0.11	0.85	0.78	0.35	0.156	5	5	5	5	0.55	0.55	0.55	0.55
	Ni	0.102	0.055	0.05	0.08	0.065	5.5	5.5	5.5	5.5	0.56	0.56	0.56	0.56
	Cu	0.098	0.966	0.866	0.35	0.21	7	7	6	5.5	0.69	0.69	0.59	0.54
	Fe	0.088	3.70	3.40	3.2	1.4	5	5	5	5	0.44	0.44	0.44	0.44
	Total	0.646									3.60	3.66	3.56	3.39
Derived LPI_{hm}											5.57	5.67	5.52	5.25
Overall LPI			$(0.175LPI_{or} + 0.257LPI_{in} + 0.33LPI_{hm}) / 0.762$								18.46	19.48	19.61	17.88

Table C.45: Calculation of sub-LPI and overall LPI at 750 day after filling of MSW in landfill lysimeter

Index	Parameter	Weight factor, w_i	Pollutant concentration, c_i				Individual pollutant rating, p_i				Overall pollutant rating, $w_i p_i$			
			A ₁	A ₂	B	C	A ₁	A ₂	B	C	A ₁	A ₂	B	C
LPI _{organic} (LPI _{or})	COD	0.267	2580	1350	1410	340	54	42	44	12	14.42	11.21	11.75	3.20
	BOD ₅	0.263	1432	943	865	176	34	27.5	26	9	8.94	7.23	6.84	2.37
	Phenol	0									0.00	0.00	0.00	0.00
	TCB	0.224	137	186	200	118	46	56	57	44	10.30	12.54	12.77	9.86
	Total	0.754									33.66	30.99	31.35	15.43
Derived LPI_{or}											44.65	41.10	41.58	20.46
LPI _{inorganic} (LPI _{in})	pH	0.214	7	7.6	7.8	7.7	6	5	5	5	1.28	1.07	1.07	1.07
	TKN	0.206	247	720	417	321	8	20	11	9	1.65	4.12	2.27	1.85
	NH ₄ -N	0.198	201.7	276	354	307	18	29	38	32	3.56	5.74	7.52	6.34
	TDS	0.195	6590	4670	6790	13470	15	12	15	33	2.93	2.34	2.93	6.44
	Cl ⁻	0.187	2102.00	2610.00	1020.00	1248.00	15	20	8.5	9.5	2.81	3.74	1.59	1.78
	Total	1.000									12.23	17.01	15.37	17.47
Derived LPI_{in}											12.23	17.01	15.37	17.47
LPI _{heavy metal} (LPI _{hm})	Cr	0.125	0.06	0.05	0.06	0.04	5	5	5	5	0.63	0.63	0.63	0.63
	Pb	0.123	0.2255	0.24	0.36	0.217	6	6.5	6.5	6	0.74	0.80	0.80	0.74
	Hg	0									0.00	0.00	0.00	0.00
	As	0									0.00	0.00	0.00	0.00
	Cn	0									0.00	0.00	0.00	0.00
	Zn	0.11	0.55	0.5	0.46	0.17	5	5	5	5	0.55	0.55	0.55	0.55
	Ni	0.102	0.065	0.05	0.06	0.045	5.5	5.5	5.5	5.5	0.56	0.56	0.56	0.56
	Cu	0.098	0.54	0.9	0.65	0.5	6	7	6.5	6	0.59	0.69	0.64	0.59
	Fe	0.088	4.3	4.10	3.6	1.2	5	5	5	5	0.44	0.44	0.44	0.44
	Total	0.646									3.50	3.66	3.61	3.50
Derived LPI_{hm}											5.42	5.67	5.59	5.42
Overall LPI			$(0.175LPI_{or} + 0.257LPI_{in} + 0.33LPI_{hm})/0.762$								16.72	17.63	17.16	12.94

Table C.46: Calculation of sub-LPI and overall LPI at 850 day after filling of MSW in landfill lysimeter

Index	Parameter	Weight factor, w_i	Pollutant concentration, c_i				Individual pollutant rating, p_i				Overall pollutant rating, $w_i p_i$			
			A ₁	A ₂	B	C	A ₁	A ₂	B	C	A ₁	A ₂	B	C
LPI _{organic} (LPI _{or})	COD	0.267	2510	1290	1380	402	53	40	41	16	14.15	10.68	10.95	4.27
	BOD ₅	0.263	1456	594	745	265	34	21	24	10	8.94	5.52	6.31	2.63
	Phenol	0									0.00	0.00	0.00	0.00
	TCB	0.224	109	163	172	97	46	49	50	44	10.30	10.98	11.20	9.86
	Total	0.754									33.40	27.18	28.46	16.76
Derived LPI_{or}											44.29	36.05	37.74	22.23
LPI _{inorganic} (LPI _{in})	pH	0.214	7.4	7.2	6.78	7.8	5	5	6	5	1.07	1.07	1.28	1.07
	TKN	0.206	221	610	360	278	7	19	16	10	1.44	3.91	3.30	2.06
	NH ₄ -N	0.198	187	154	190	187	18	15	19	18	3.56	2.97	3.76	3.56
	TDS	0.195	5980	5008	6436	14369	13	12	15	36	2.54	2.34	2.93	7.02
	Cl ⁻	0.187	2072.00	2520.00	1150.00	1058.00	15	19	19	8.5	2.81	3.55	3.55	1.59
	Total	1.000									11.42	13.85	14.82	15.30
Derived LPI_{in}											11.42	13.85	14.82	15.30
LPI _{heavy metal} (LPI _{hm})	Cr	0.125	0.06	0.05	0.09	0.04	5	5	5	5	0.63	0.63	0.63	0.63
	Pb	0.123	0.235	0.235	0.254	0.215	6	6	6.5	6	0.74	0.74	0.80	0.74
	Hg	0									0.00	0.00	0.00	0.00
	As	0									0.00	0.00	0.00	0.00
	Cd	0									0.00	0.00	0.00	0.00
	Zn	0.11	0.35	0.46	0.14	0.15	5	5	5	5	0.55	0.55	0.55	0.55
	Ni	0.102	0.06	0.05	0.08	0.04	5.5	5.5	5.5	5.5	0.56	0.56	0.56	0.56
	Cu	0.098	0.05	0.05	0.04	0.04	6	5.5	5.5	6	0.59	0.54	0.54	0.59
	Fe	0.088	5.8	3.90	4.3	2.3	5	5	5	5	0.44	0.44	0.44	0.44
	Total	0.646									3.50	3.45	3.51	3.50
Derived LPI_{hm}											5.42	5.35	5.44	5.42
Overall LPI			$(0.175LPI_{or} + 0.257LPI_{in} + 0.33LPI_{hm})/0.762$								16.37	15.26	16.02	12.61

Table C.47: Calculation of sub-LPI and overall LPI at 900 day after filling of MSW in landfill lysimeter

Index	Parameter	Weight factor, w_i	Pollutant concentration, c_i				Individual pollutant rating, p_i				Overall pollutant rating, $w_i p_i$			
			A ₁	A ₂	B	C	A ₁	A ₂	B	C	A ₁	A ₂	B	C
LPI _{organic} (LPI _{or})	COD	0.267	2256	1165	1250	256	51	38	39	10	13.62	10.15	10.41	2.67
	BOD ₅	0.263	345	437	490	510	12	15	16	19	3.16	3.95	4.21	5.00
	Phenol	0									0.00	0.00	0.00	0.00
	TCB	0.224	98	145	152	85	48	50	50.5	47	10.75	11.20	11.31	10.53
	Total	0.754									27.53	25.29	25.93	18.20
Derived LPI_{or}											36.51	33.54	34.39	24.13
LPI _{inorganic} (LPI _{in})	pH	0.214	6.51	7.27	6.45	7.21	7	5	7	5	1.50	1.07	1.50	1.07
	TKN	0.206	195	480	312	251	7	9	9	8	1.44	1.85	1.85	1.65
	NH ₄ -N	0.198	190	127.9	192.7	190	19	13	19	19	3.76	2.57	3.76	3.76
	TDS	0.195	4190	6440	2770	9670	10	14	7	21	1.95	2.73	1.37	4.10
	Cl ⁻	0.187	1965.00	2156.00	1001.00	1045.00	15	15.5	9	9	2.81	2.90	1.68	1.68
	Total	1.000									11.46	11.13	10.16	12.26
Derived LPI_{in}											11.46	11.13	10.16	12.26
LPI _{heavy metal} (LPI _{hm})	Cr	0.125	0.055	0.04	0.07	0.065	5	5	5	5	0.63	0.63	0.63	0.63
	Pb	0.123	0.126	0.265	0.55	0.476	5.5	6.5	7.5	7	0.68	0.80	0.92	0.86
	Hg	0									0.00	0.00	0.00	0.00
	As	0									0.00	0.00	0.00	0.00
	Cd	0									0.00	0.00	0.00	0.00
	Zn	0.11	1.126	0.92	0.55	0.576	5	5	5	5	0.55	0.55	0.55	0.55
	Ni	0.102	0.04	0.05	0.045	0.04	5.5	5.5	5.5	5.5	0.56	0.56	0.56	0.56
	Cu	0.098	0.04	0.04	0.04	0.04	5.5	5.5	5.5	5.5	0.54	0.54	0.54	0.54
	Fe	0.088	5.1	3.2	3.9	2.1	5	5	5.5	5	0.44	0.44	0.48	0.44
	Total	0.646									3.39	3.51	3.68	3.58
Derived LPI_{hm}											5.25	5.44	5.70	5.54
Overall LPI			$(0.175LPI_{or} + 0.257LPI_{in} + 0.33LPI_{hm})/0.762$								14.52	13.81	13.79	12.07

Table C.48: Variation of LPI of organic fraction in leachate of open dump and sanitary lysimeter

Days after filling	Variation of LPI of organic fraction in leachate at varying operational condition of landfill lysimeter			
	A ₁	A ₂	B	C
7	69.30	75.77	75.72	74.32
14	63.99	74.89	74.66	73.61
21	64.69	74.54	74.48	73.26
30	76.27	80.73	83.18	84.99
40	63.35	73.30	69.42	70.11
50	26.05	71.23	84.27	82.63
60	41.89	73.70	64.79	80.08
70	63.35	73.30	69.42	70.11
90	54.14	68.43	56.06	82.16
120	31.05	67.71	51.14	63.58
140	63.35	73.30	69.42	70.11
160	56.94	62.77	52.74	58.69
190	63.35	73.30	69.42	70.11
220	63.35	73.30	69.42	70.11
245	40.55	59.77	46.71	58.73
280	63.35	73.30	69.42	70.11
300	39.88	60.46	46.96	60.55
320	63.35	73.30	69.42	70.11
380	40.56	62.26	44.03	63.43
390	32.66	45.07	35.86	40.96
400	32.66	45.07	35.86	40.96
415	32.66	45.07	35.86	40.96
500	34.70	47.80	50.32	51.36
520	32.66	45.07	35.86	40.96
545	40.99	55.94	45.64	32.74
580	32.21	44.47	35.56	40.96
610	30.73	44.47	35.26	40.96
630	46.03	40.94	42.41	33.86
660	30.73	44.18	34.97	40.66
715	45.35	39.30	40.99	20.65
750	44.65	41.10	41.58	20.46
800	30.43	44.18	34.97	40.36
850	44.29	36.05	37.74	22.23
900	36.51	33.54	34.39	24.13

Table C.49: Variation of LPI of inorganic fraction in leachate of open dump and sanitary lysimeter

Days after filling	Variation of LPI of inorganic fraction in leachate at varying operational condition of landfill lysimeter			
	A ₁	A ₂	B	C
7	31.72	57.93	46.67	43.54
14	32.33	55.94	49.26	44.74
21	31.51	54.87	48.84	39.71
30	31.31	39.21	37.36	38.85
40	28.94	38.40	37.36	37.25
50	29.31	43.24	39.55	35.60
60	26.34	39.86	36.21	33.62
70	28.16	39.39	35.94	37.42
90	24.38	36.39	31.77	32.23
120	25.22	38.46	34.58	31.95
140	25.55	38.15	34.12	35.17
160	24.59	36.42	32.45	30.11
190	26.95	36.54	34.09	34.38
220	25.54	35.10	33.70	34.57
245	22.70	33.34	31.15	31.26
280	24.94	33.30	29.64	32.16
300	22.09	27.74	32.02	31.85
320	22.54	32.33	29.05	31.76
380	18.15	23.71	26.81	27.08
390	16.92	27.18	23.91	23.99
400	16.76	26.87	22.89	23.19
415	15.01	26.87	22.52	22.01
500	14.99	26.03	25.75	25.08
520	14.54	27.30	23.86	27.29
545	15.91	26.09	24.90	25.87
580	22.35	23.77	23.43	24.31
610	14.63	23.97	25.67	25.40
630	16.23	22.59	22.19	23.20
660	13.12	22.09	20.71	22.89
715	13.02	20.00	18.74	21.89
750	12.23	17.01	15.37	17.47
800	12.05	14.49	12.34	13.72
850	11.42	13.85	14.82	15.30
900	11.46	11.13	10.16	12.26

Table C.50: Variation of LPI of heavy metal fraction in leachate of open dump and sanitary lysimeter

Days after filling	Variation of LPI of heavy metal fraction in leachate at varying operational condition of landfill lysimeter			
	A ₁	A ₂	B	C
7	5.71	5.69	6.01	5.85
14	5.82	5.75	5.89	5.83
21	5.69	5.75	6.07	5.79
30	5.84	5.70	5.83	5.61
40	5.84	5.70	5.83	5.61
50	5.36	5.45	5.77	5.37
60	5.42	5.57	5.89	5.37
70	5.84	5.70	5.83	5.61
90	5.42	5.57	5.89	5.37
120	5.35	5.51	5.65	5.45
140	5.84	5.70	5.83	5.61
160	5.48	5.51	5.59	5.45
190	5.84	5.70	5.83	5.61
220	5.84	5.70	5.83	5.61
245	5.52	5.43	5.59	5.45
280	5.84	5.70	5.83	5.61
300	5.28	5.37	5.53	5.45
320	5.84	5.70	5.83	5.61
380	5.28	5.37	5.59	5.45
390	5.28	5.37	5.59	5.45
400	5.28	5.37	5.59	5.45
415	5.28	5.37	5.59	5.45
500	5.48	5.74	5.54	5.44
520	5.55	5.66	5.63	5.54
545	5.57	5.67	5.59	5.33
580	5.33	5.44	5.63	5.54
610	5.40	5.59	5.70	5.54
630	5.57	5.67	5.52	5.25
660	5.48	5.67	5.71	5.61
715	5.50	5.67	5.67	5.59
750	5.42	5.67	5.59	5.42
800	5.33	5.44	5.70	5.61
850	5.42	5.35	5.44	5.42
900	5.25	5.44	5.70	5.54

Table C.51: Variation of overall LPI of open dump and sanitary lysimeter

Days after filling	Variation of overall LPI at varying operational condition of landfill lysimeter			
	A ₁	A ₂	B	C
7	27.35	36.91	33.53	32.18
14	26.47	36.12	34.05	32.39
21	26.30	35.72	33.97	30.73
30	28.77	32.12	32.12	32.87
40	25.28	30.29	29.20	29.21
50	17.24	31.24	33.01	31.24
60	19.70	30.76	27.88	30.08
70	25.04	30.59	28.75	29.26
90	21.70	28.56	24.64	30.09
120	17.02	29.03	24.36	26.09
140	24.22	30.21	28.19	28.56
160	22.39	27.34	24.00	24.47
190	24.66	29.70	28.18	28.31
220	24.22	29.26	28.05	28.37
245	18.33	25.70	22.32	24.84
280	24.03	28.69	26.79	27.62
300	17.88	24.07	22.61	25.41
320	23.28	28.39	26.60	27.49
380	16.80	23.20	20.39	24.53
390	14.73	20.62	17.75	18.79
400	14.68	20.53	17.43	18.54
415	14.14	20.53	17.31	18.17
500	15.40	22.24	22.64	22.61
520	14.81	22.01	18.72	21.01
545	17.19	24.10	21.30	18.55
580	17.24	20.59	18.51	20.00
610	14.33	20.72	19.22	20.37
630	18.46	19.48	19.61	17.88
660	13.85	20.05	17.49	19.49
715	17.19	18.23	18.19	14.55
750	16.72	17.63	17.16	12.94
800	13.36	17.39	14.66	16.33
850	16.37	15.26	16.02	12.61
900	14.52	13.81	13.79	12.07

Table C.52: Estimating errors involved in calculating LPI values due to nonavailability of data (Parameters with high weight factors ignored)

Pollutant (1)	Pollutan t weight, w_i (2)	Pollutan t concent ration, c_i (3)	Subi ndex value , p_i (4)	LPI with selected parameters ($w_i p_i$)														
				18 (5)	17 (6)	16 (7)	15 (8)	14 (9)	13 (10)	12 (11)	11 (12)	10 (13)	9 (14)	8 (15)	7 (16)	6 (17)	5 (18)	4 (19)
Cr	0.064	1.75	6.5	0.416	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pb	0.063	0.68	9	0.567	0.567	-	-	-	-	-	-	-	-	-	-	-	-	-
COD	0.062	8425	70	4.34	4.34	4.34	-	-	-	-	-	-	-	-	-	-	-	-
Hg	0.062	0.4	59	3.658	3.658	3.658	3.658	-	-	-	-	-	-	-	-	-	-	-
BOD ₅	0.061	1398	35	2.135	2.135	2.135	2.135	2.135	-	-	-	-	-	-	-	-	-	-
As	0.061	0.01	5.5	0.335	0.335	0.3355	0.3355	0.335	0.335	-	-	-	-	-	-	-	-	-
Cn	0.058	1.3	10	0.58	0.58	0.58	0.58	0.58	0.58	0.58	-	-	-	-	-	-	-	-
Phenol	0.057	4	8.5	0.484	0.484	0.4845	0.4845	0.484	0.484	0.4845	0.484	-	-	-	-	-	-	-
Zn	0.056	1.3	5	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	-	-	-	-	-	-
pH	0.055	7.3	6	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	-	-	-	-	-
TKN	0.053	3000	98	5.194	5.194	5.194	5.194	5.194	5.194	5.194	5.194	5.194	5.194	5.14	-	-	-	-
Ni	0.052	0.23	8	0.416	0.416	0.416	0.416	0.416	0.416	0.416	0.416	0.416	0.416	0.41	0.416	-	-	-
TCB	0.052	8000	92	4.784	4.784	4.784	4.784	4.784	4.784	4.784	4.784	4.784	4.784	4.78	4.784	4.784	-	-
NH ₄ -N	0.051	1300	100	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	-
TDS	0.05	12540	28	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
Cu	0.05	0.98	7	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Chloride	0.048	3597	30	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44
Iron	0.045	82	9.5	0.427	0.427	0.4275	0.4275	0.427	0.427	0.4275	0.427	0.4275	0.427	0.43	0.427	0.427	0.427	0.427
Summation	1.000			32.23	31.82	31.255	26.915	23.25	21.12	20.786	20.20	19.722	19.44	19.1	13.91	13.50	8.718	3.618
Total weight				1.000	0.936	0.873	0.811	0.749	0.688	0.627	0.569	0.512	0.456	0.40	0.348	0.296	0.244	0.193
Derived LPI				32.23	33.99	35.801	33.187	31.05	30.70	33.152	35.51	38.519	42.63	47.6	39.99	45.61	35.72	18.74
Percent error				0.000	5.459	11.055	2.945	3.683	4.770	2.835	10.15	19.484	32.25	47.8	24.05	41.49	10.82	41.85

Table C.53: Estimating errors involved in calculating LPI values due to nonavailability of data (Parameters with highest sub-index values ignored)

Pollutant (1)	Pollutant weight, w_i (2)	Pollutant concentrati on, c_i (3)	Subindex value, p_i (4)	LPI with selected parameters ($w_i p_i$)								
				18 (5)	17 (6)	16 (7)	15 (8)	14 (9)	13 (10)	12 (11)	11 (12)	10 (13)
Cr	0.064	1.75	6.5	0.416	0.416	0.416	0.416	0.416	0.416	0.416	0.416	0.416
Pb	0.063	0.68	9	0.567	0.567	0.567	0.567	0.567	0.567	0.567	0.567	0.567
COD	0.062	8425	70	4.34	4.34	4.34	4.34	N.C	N.C	N.C	N.C	N.C
Hg	0.062	0.4	59	3.658	3.658	3.658	3.658	3.658	N.C	N.C	N.C	N.C
BOD ₅	0.061	1398	35	2.135	2.135	2.135	2.135	2.135	2.135	N.C	N.C	N.C
As	0.061	0.01	5.5	0.3355	0.3355	0.3355	0.3355	0.3355	0.3355	0.3355	0.3355	0.3355
Cn	0.058	1.3	10	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58
Phenol	0.057	4	8.5	0.4845	0.4845	0.4845	0.4845	0.4845	0.4845	0.4845	0.4845	0.4845
Zn	0.056	1.3	5	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28
pH	0.055	7.3	6	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33
TKN	0.053	3000	98	5.194	5.194	N.C	N.C	N.C	N.C	N.C	N.C	N.C
Ni	0.052	0.23	8	0.416	0.416	0.416	0.416	0.416	0.416	0.416	0.416	0.416
TCB	0.052	8000	92	4.784	4.784	4.784	N.C	N.C	N.C	N.C	N.C	N.C
NH ₄ -N	0.051	1300	100	5.1	N.C	N.C	N.C	N.C	N.C	N.C	N.C	N.C
TDS	0.05	12540	28	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	N.C
Cu	0.05	0.98	7	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Chlorides	0.048	3597	30	1.44	1.44	1.44	1.44	1.44	1.44	1.44	N.C	N.C
Total Iron	0.045	82	9.5	0.4275	0.4275	0.4275	0.4275	0.4275	0.4275	0.4275	0.4275	0.4275
Summation	1.000			32.238	27.138	21.944	17.160	12.820	9.162	7.027	5.587	4.187
Total weight				1.000	0.949	0.896	0.844	0.782	0.720	0.659	0.611	0.561
Derived LPI				32.238	28.596	24.491	20.331	16.393	12.724	10.662	9.143	7.463
Percent error				0.000	11.296	24.031	36.933	49.149	60.529	66.926	71.638	76.851

Note: All concentrations are in mg/L except for pH and total coliform bacteria (cfu/100mL)

N.C= parameter not considered

Table C.54: Estimating errors involved in calculating LPI values due to nonavailability of data (Parameters with lowest sub-index values ignored)

Pollutant (1)	Pollutant weight, w_i (2)	Pollutant concentration, c_i (3)	Subindex value, p_i (4)	LPI with selected parameters ($w_i p_i$)								
				18 (5)	17 (6)	16 (7)	15 (8)	14 (9)	13 (10)	12 (11)	11 (12)	10 (13)
Cr	0.064	1.75	6.5	0.416	0.416	0.416	0.416	N.C	N.C	N.C	N.C	N.C
Pb	0.063	0.68	9	0.567	0.567	0.567	0.567	0.567	0.567	0.567	0.567	N.C
COD	0.062	8425	70	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34
Hg	0.062	0.4	59	3.658	3.658	3.658	3.658	3.658	3.658	3.658	3.658	3.658
BOD ₅	0.061	1398	35	2.135	2.135	2.135	2.135	2.135	2.135	2.135	2.135	2.135
As	0.061	0.01	5.5	0.3355	0.3355	N.C	N.C	N.C	N.C	N.C	N.C	N.C
Cn	0.058	1.3	10	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58
Phenol	0.057	4	8.5	0.4845	0.4845	0.4845	0.4845	0.4845	0.4845	0.4845	N.C	N.C
Zn	0.056	1.3	5	0.28	N.C	N.C	N.C	N.C	N.C	N.C	N.C	N.C
pH	0.055	7.3	6	0.33	0.33	0.33	N.C	N.C	N.C	N.C	N.C	N.C
TKN	0.053	3000	98	5.194	5.194	5.194	5.194	5.194	5.194	5.194	5.194	5.194
Ni	0.052	0.23	8	0.416	0.416	0.416	0.416	0.416	0.416	N.C	N.C	N.C
TCB	0.052	8000	92	4.784	4.784	4.784	4.784	4.784	4.784	4.784	4.784	4.784
NH ₄ -N	0.051	1300	100	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1
TDS	0.05	12540	28	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
Cu	0.05	0.98	7	0.35	0.35	0.35	0.35	0.35	N.C	N.C	N.C	N.C
Chlorides	0.048	3597	30	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44
Total Iron	0.045	82	9.5	0.4275	0.4275	0.4275	0.4275	0.4275	0.4275	0.4275	0.4275	0.4275
Summation	1.000			32.238	31.958	31.622	31.292	30.876	30.526	30.110	29.626	29.059
Total weight				1.000	0.944	0.883	0.828	0.764	0.714	0.662	0.605	0.542
Derived LPI				32.24	33.85	35.81	37.79	40.41	42.75	45.48	48.97	53.61
Percent error				0.00	5.01	11.09	17.23	25.36	32.62	41.09	51.90	66.31

Note: All concentrations are in mg/L except for pH and total coliform bacteria (cfu/100mL), N.C= parameter not considered.

Table C.55: Estimating errors involved in calculating LPI values due to nonavailability of data (Parameters with highest and lowest sub-index values ignored simultaneously)

Pollutant (1)	Pollutant weight, w_i (2)	Pollutant concentration, c_i (3)	Subindex value, p_i (4)	LPI with selected parameters ($w_i p_i$)				
				18 (5)	14 (6)	16 (7)	12 (8)	10 (9)
Cr	0.064	1.75	6.5	0.416	0.416	0.416	0.416	N.C
Pb	0.063	0.68	9	0.567	0.567	0.567	0.567	0.567
COD	0.062	8425	70	4.34	4.34	4.34	N.C	N.C
Hg	0.062	0.4	59	3.658	3.658	3.658	3.658	N.C ^a
BOD ₅	0.061	1398	35	2.135	2.135	2.135	2.135	2.135
As	0.061	0.01	5.5	0.3355	0.3355	N.C	N.C	N.C
Cn	0.058	1.3	10	0.58	0.58	0.58	0.58	0.58
Phenol	0.057	4	8.5	0.4845	0.4845	0.4845	0.4845	0.4845
Zn	0.056	1.3	5	0.28	N.C	N.C	N.C	N.C
pH	0.055	7.3	6	0.33	0.33	0.33	N.C	N.C
TKN	0.053	3000	98	5.194	5.194	N.C	N.C	N.C
Ni	0.052	0.23	8	0.416	0.416	0.416	0.416	0.416
TCB	0.052	8000	92	4.784	4.784	4.784	4.784	4.784
NH ₄ -N	0.051	1300	100	5.1	N.C	N.C	N.C	N.C
TDS	0.05	12540	28	1.4	1.4	1.4	1.4	1.4
Cu	0.05	0.98	7	0.35	0.35	0.35	0.35	0.35
Chlorides	0.048	3597	30	1.44	1.44	1.44	1.44	1.44
Total Iron	0.045	82	9.5	0.4275	0.4275	0.4275	0.4275	0.4275
Summation	1.000			32.238	26.858	21.328	16.658	12.584
Total weight				1.000	0.893	0.779	0.662	0.536
Derived LPI				32.24	30.08	27.38	25.16	23.48
Percent error				0.00	6.71	15.07	21.94	27.17

Note: All concentrations are in mg/L except for pH and total coliform bacteria (cfu/100mL)

N.C= parameter not considered

Appendix-D

Data and Graphical Representation for Phytoremediation and Chemical Treatment of Leachate

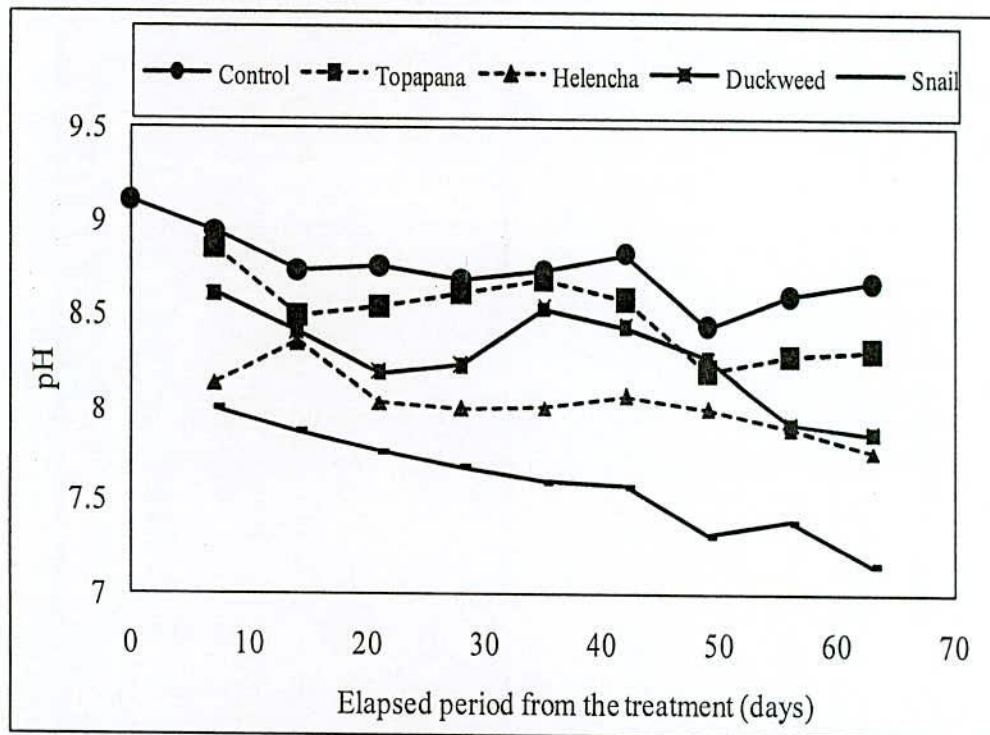


Figure D.1: Variation of pH against different treatment on leachate of 50 concentration

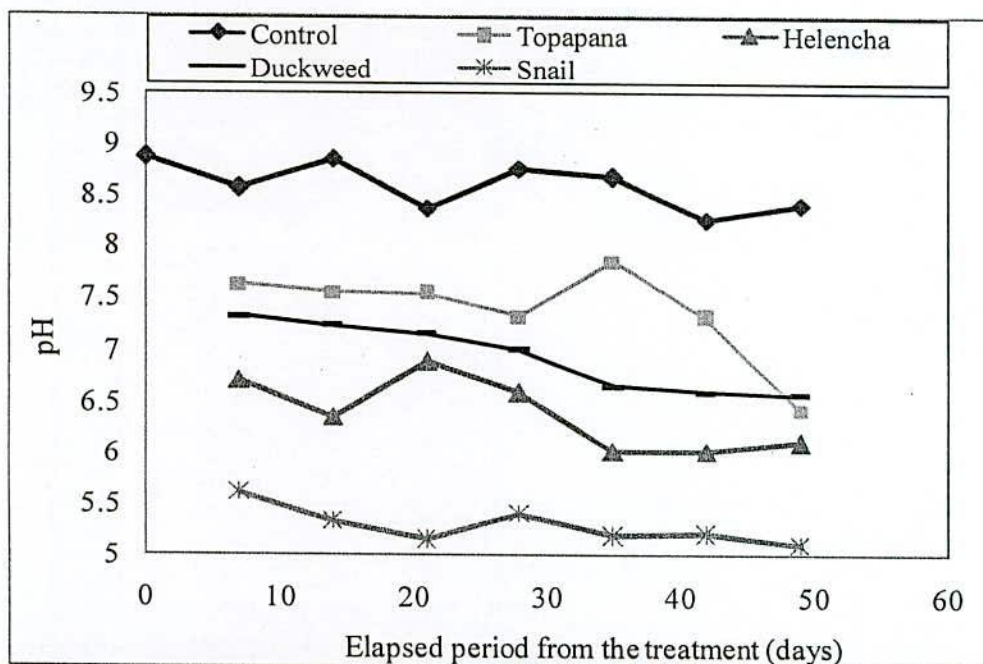


Figure D.2: Variation of pH against of different treatment on leachate of 20 concentration

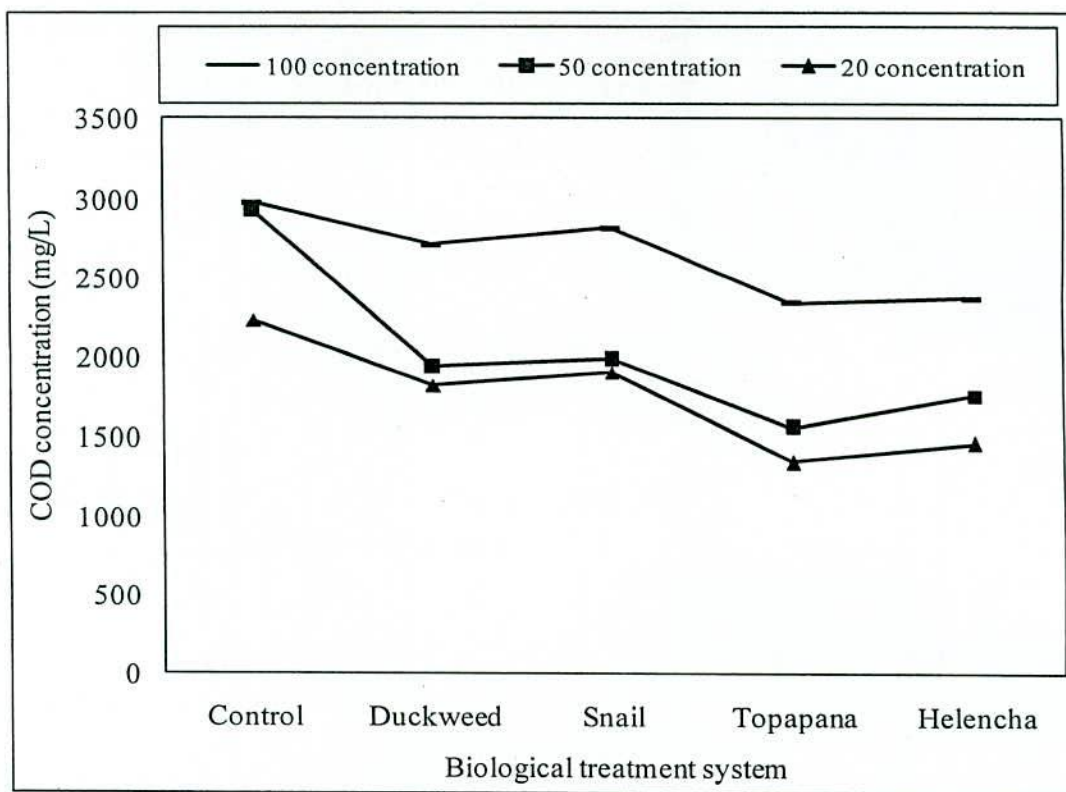


Figure D.3: Comparison of COD among different treatment system after 7 days

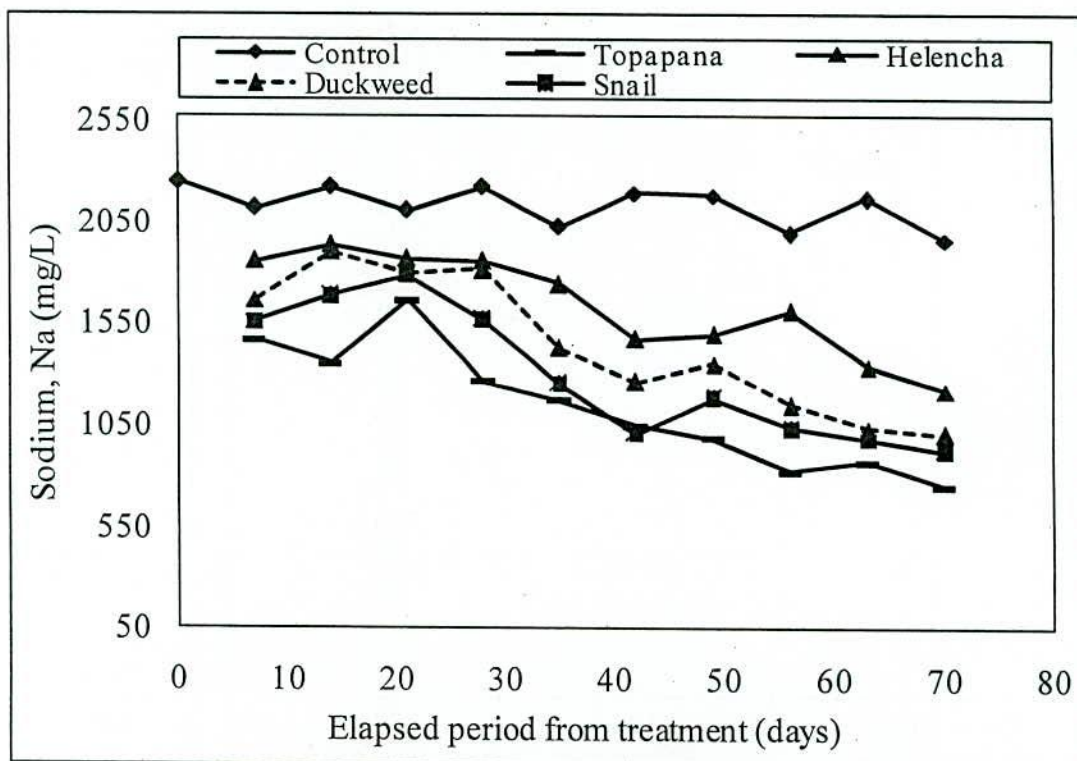


Figure D.4: Variation of Na against of different treatment on leachate of 50 concentration

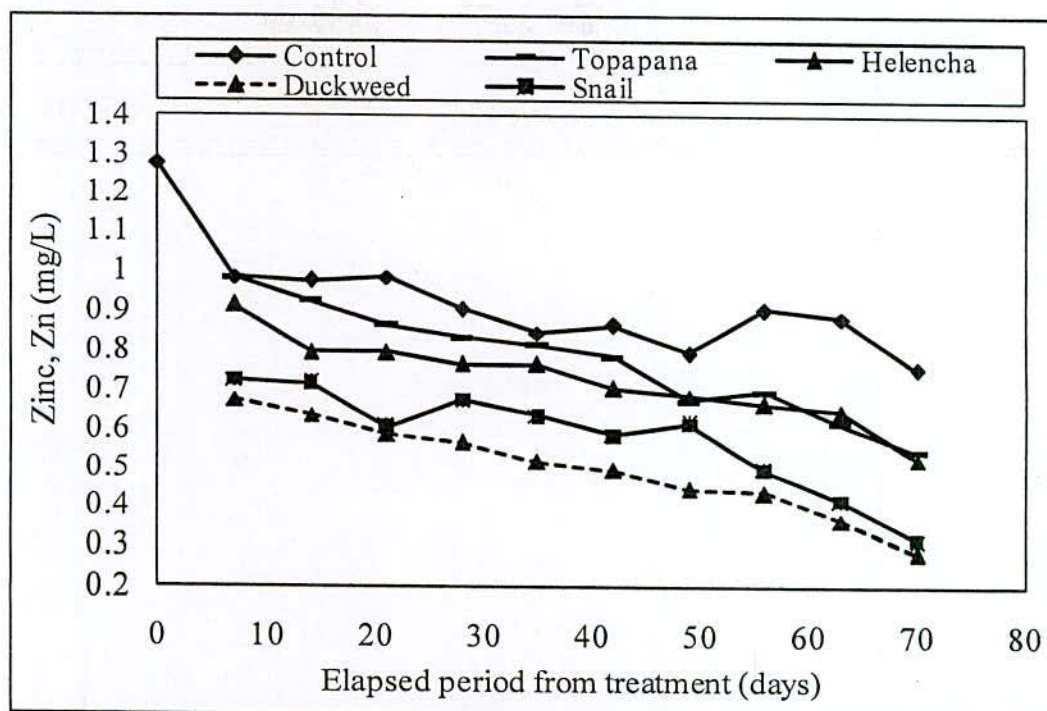


Figure D.5: Variation of Zn against of different treatment on leachate of 50 concentration

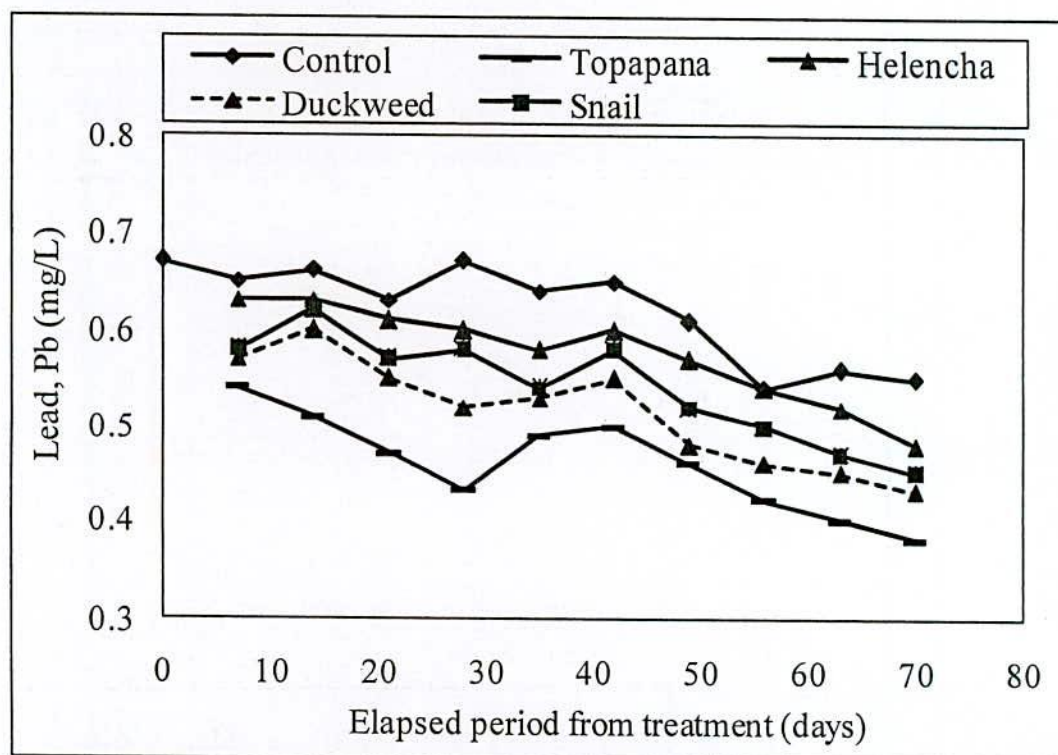


Figure D.6: Variation of Pb against of different treatment on leachate of 100 concentration

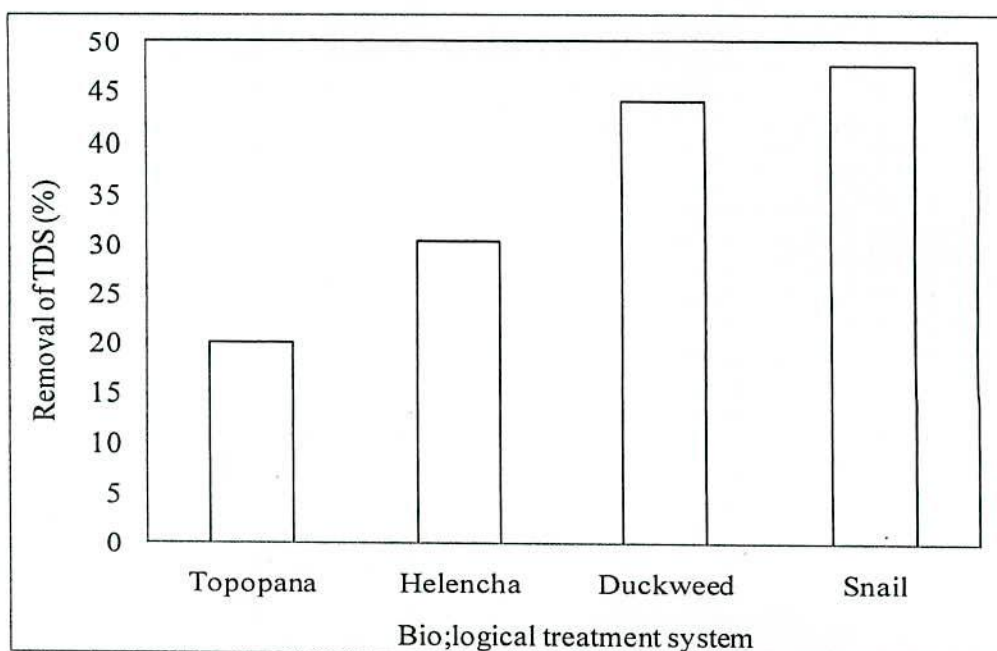


Figure D.7: Percentage reduction of TDS in leachate of 100 concentration after 28 day from treatment

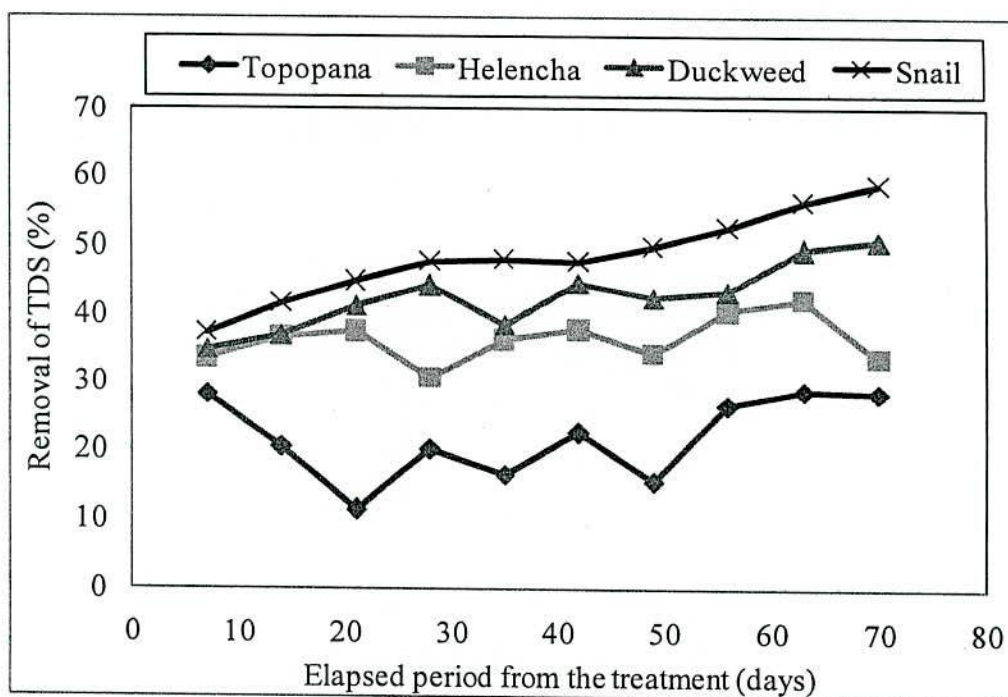


Figure D.8: Percentage reduction of TDS in leachate of 100 concentration at varying elapsed period

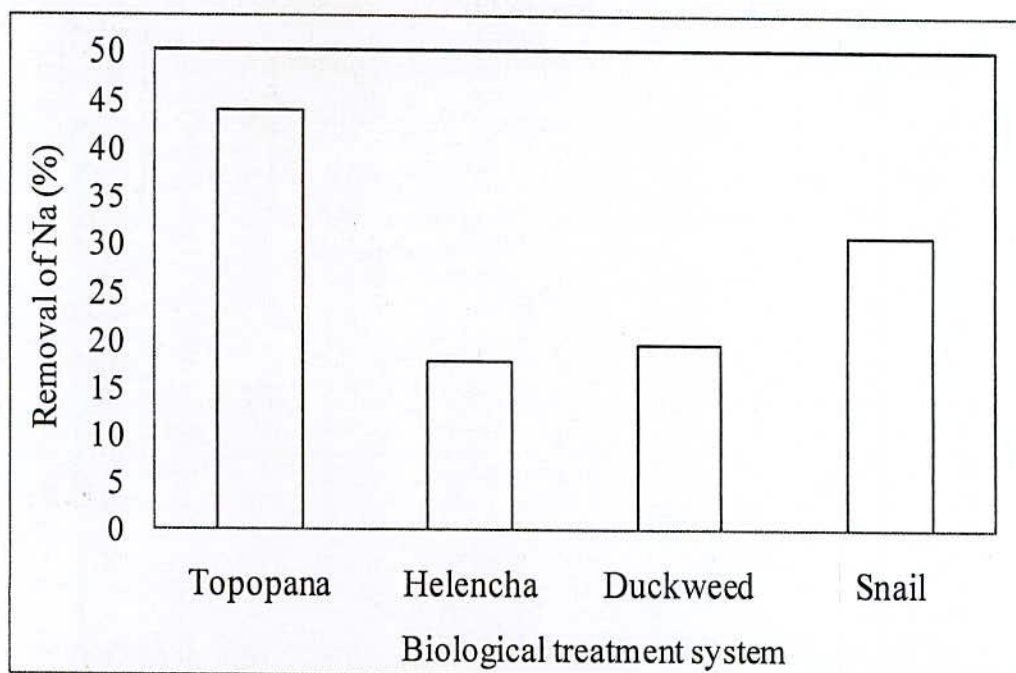


Figure D.9: Percentage reduction of Na in leachate of 50 concentration after 28 days from treatment

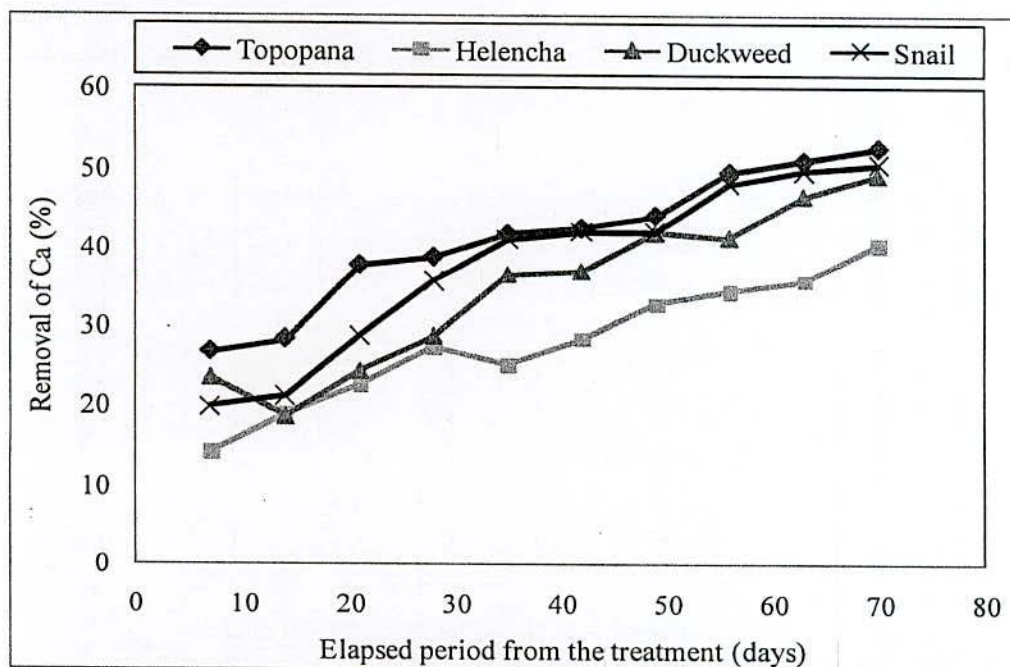


Figure D.10: Percentage reduction of Ca in leachate of 100 concentration at varying elapsed period

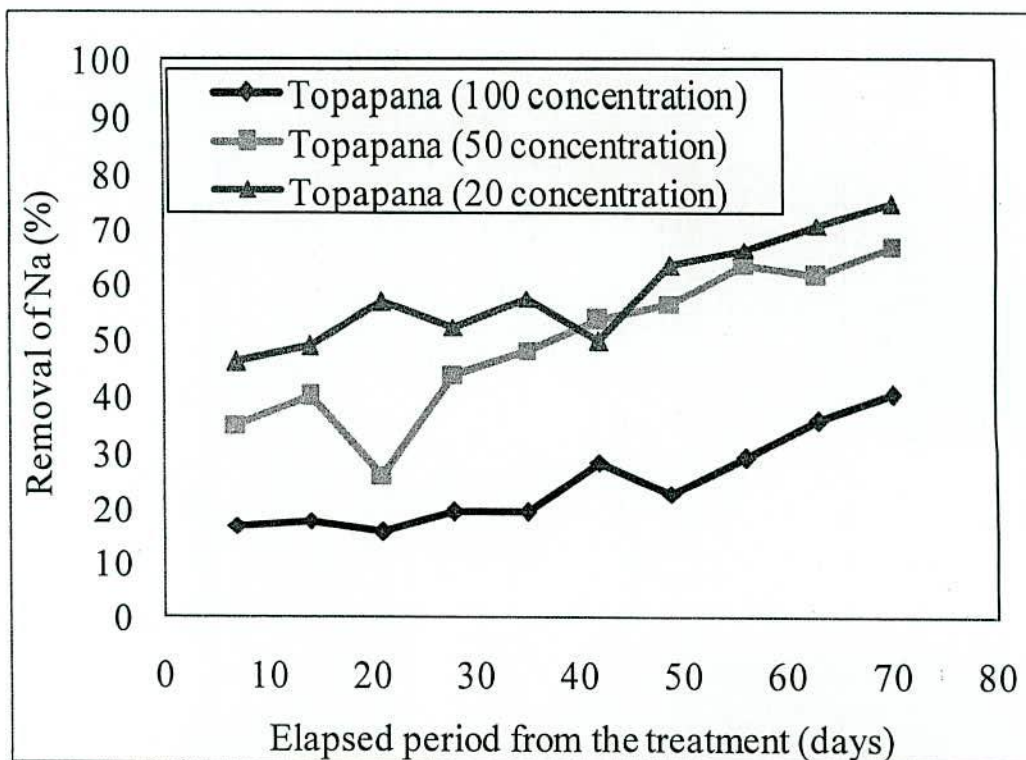


Figure D.11: Percentage reduction efficiency of Na in leachate for topapana at varying concentration

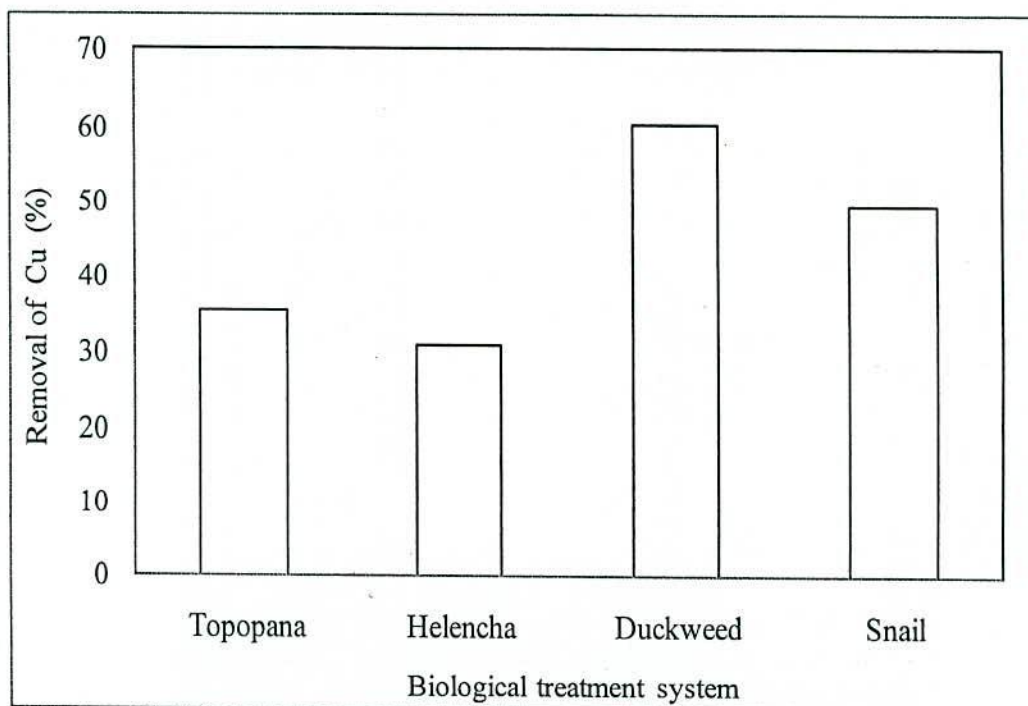


Figure D.12: Percentage reduction of Cu in leachate of 20 concentration after 28 days from treatment

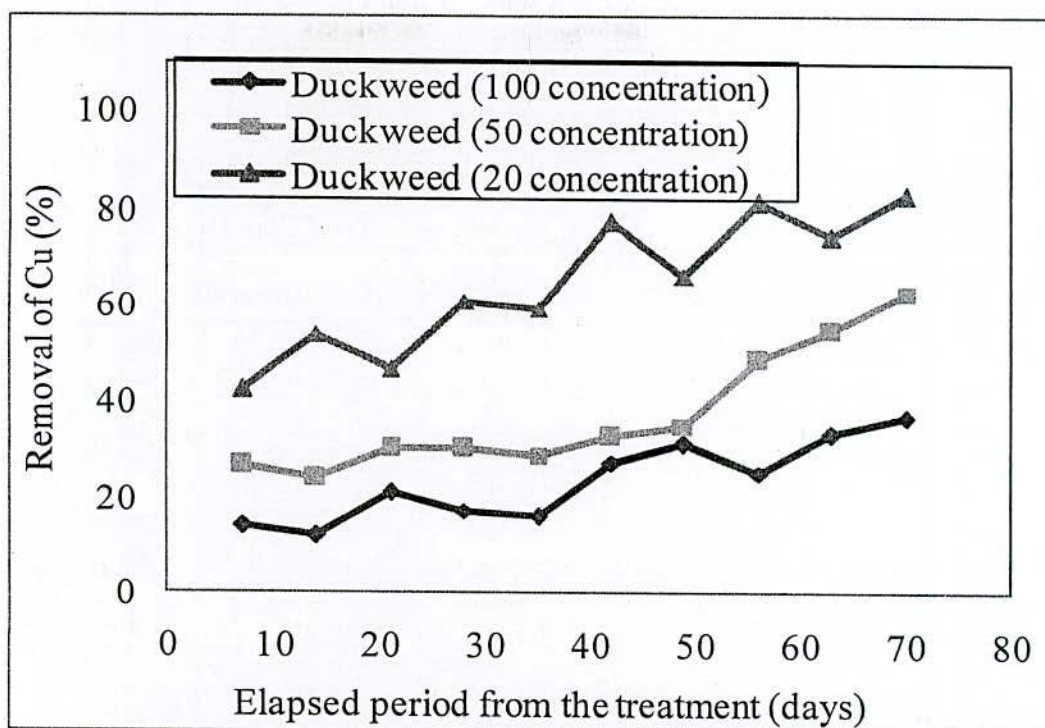


Figure D.13: Percentage reduction efficiency of Cu in leachate for duckweed at varying concentration

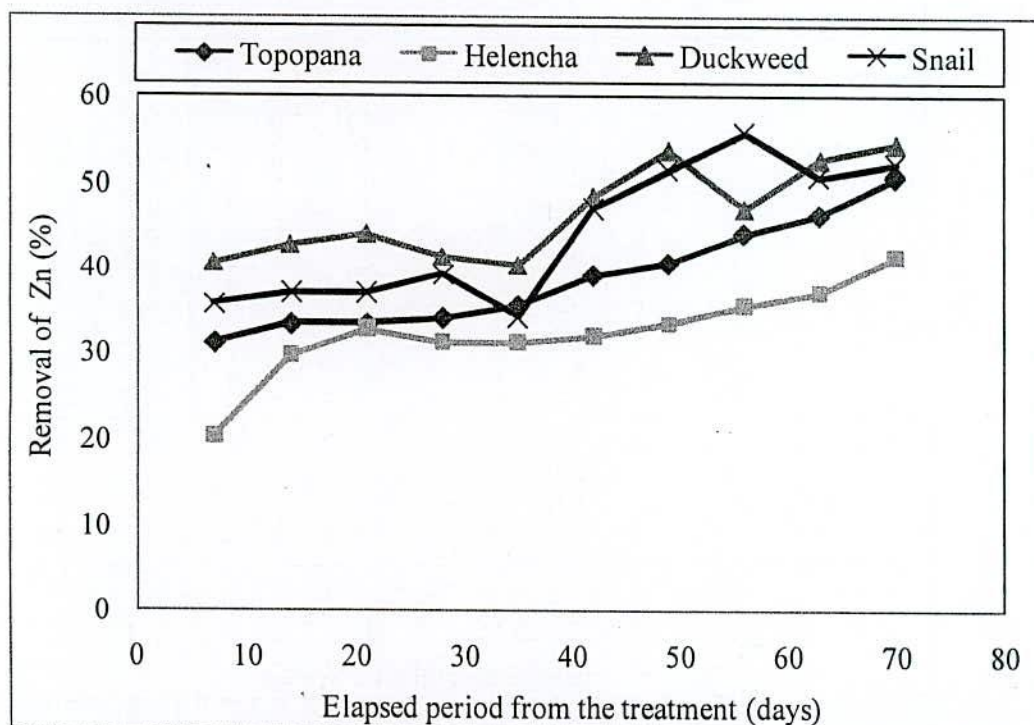


Figure D.14: Percentage reduction of Zn in leachate of 100 concentration at varying elapsed period

Table D.1: Results of concentration dosage for treating of leachate using FeCl₃

Parameter	EQ A A	EQ A B	Raw leachate	Concentration (mg/L) of treated leachate at varying chemical dosage (500mL)						
				0.5	1	1.5	2	3	4	4.5
Turbidity			106	52.3	7.58	5.29	6.83	7.82	20.6	21.5
Colour			2190	520.0	456.0	297.0	355.0	420.0	401.0	520.0
COD			510	345.0	272.0	255.0	268.0	282.0	310.0	380.0
BOD ₅			487	350	312	286	298	301	313	335
NH ₄ -N			402	176	126	101	154	163	165	160
TSS			750	190.0	170.0	140.0	310.0	410.0	420.0	520.0
Ca			214	103.0	12.0	0.0	10.0	14.0	28.0	35.0
K			1444	469.0	367.0	0.0	256.0	356.0	567.0	798.0
Na			1489	986.0	567.0	0.0	235.0	543.0	976.0	987.0
Mg			226.58	165.0	89.0	45.0	56.0	76.0	98.0	156.0
Cu	0.2	1.0	0.213	0.128	0.09	0.0	0.07	0.092	0.112	0.097
Zn	1.0	1.0	0.595	0.265	0.30	0.04	0.20	0.267	0.223	0.437
Cd	0.01	0.02	0.043	0.023	0.0013	0.0	0.012	0.027	0.029	0.034
Ni			0.058	0.026	0.03	0.0	0.004	0.027	0.022	0.044
Pb	0.01	0.5	0.235	0.126	0.11	0.0	0.12	0.127	0.122	0.147

Table D.2: Results of removal efficiency of pollutant in leachate using FeCl₃

Parameter	Raw leachate	Removal efficiency (%) of pollutant in leachate at varying chemical dosage (500mL)						
		0.5	1	1.5	2	3	4	4.5
Turbidity	106	51	93	95	94	93	81	80
Colour	2190	76	79	86	84	81	82	76
COD	510	32	47	50	47	45	39	25
BOD ₅	487	28	36	41	39	38	36	31
NH ₄ -N	402	56	69	75	62	59	59	60
TSS	750	75	77	81	59	45	44	31
Ca	214	52	94	100	95	93	87	84
K	1444	68	75	100	82	75	61	45
Na	1489	34	62	100	84	64	34	34
Mg	226.58	27	61	80	75	66	57	31
Cu	0.213	47	63	100	71	62	54	60
Zn	0.595	55	56	93	66	55	63	27
Cd	0.043	47	97	100	72	37	33	21
Ni	0.058	55	48	100	93	53	62	24
Pb	0.235	46	53	100	49	46	48	37

Table D.3: Results of concentration of treated leachate with various pH at optimum dosages of FeCl₃

Parameters	EQA A	EQA B	Untreated leachate	Concentration (mg/L) of treated leachate with various pH at optimum dosages of FeCl ₃					
				pH 4	pH 5	pH 6	pH 7	pH 8	pH 9
Turbidity			106	28.72	21.54	11.42	6.36	8.48	13.6
Colour			2190	540.0	358.40	306.60	262.80	306.0	350.40
COD			510	301.0	285.0	264.0	255.0	268.0	295.0
BOD ₅			487	357	317	309	295	300	310
NH ₄ -N			402	178	149	143	134	137	141
TSS			750	200.0	180.0	165.0	157.50	172.50	187.50
Ca			214.10	34.0	28.0	12.0	9.0	12.0	14.0
K			1444.20	364.0	256.0	245.0	201.0	236.0	268.0
Na			1488.70	317.0	259.0	227.0	201.0	256.0	236.0
Mg			226.58	83.0	48.0	44.0	32.0	90.0	96.0
Cu	0.2	1.0	0.213	0.40	0.40	0.40	0.30	0.50	0.50
Zn	1.0	1.0	0.595	0.160	0.115	0.105	0.100	0.120	0.127
Cd	0.01	0.02	0.040	0.021	0.012	0.011	0.0	0.002	0.015
Ni			0.060	0.031	0.022	0.011	0.0	0.012	0.015
Pb	0.01	0.5	0.24	0.120	0.100	0.021	0.0	0.022	0.017

Table D.4: Results of removal efficiency at varying pH with optimum concentration using FeCl₃

Parameters	Untreated leachate	Removal efficiency (%) at varying pH with optimum concentration using FeCl ₃					
		pH 4	pH 5	pH 6	pH 7	pH 8	pH 9
Turbidity	106	73	80	89	94	92	87
Colour	2190	75	84	86	88	86	84
COD	510	41	44	48	50	47	42
BOD ₅	487	27	35	37	39	38	36
NH ₄ -N	402	56	63	64	67	66	65
TSS	750	73	76	78	79	77	75
Ca	214.10	84	87	94	96	94	93
K	1444.20	75	82	83	86	84	81
Na	1488.70	79	83	85	86	83	84
Mg	226.58	63	79	81	86	60	58
Cu	0.213	81	80	81	81	79	76
Zn	0.595	73	81	82	83	80	79
Cd	0.040	51	72	74	100	95	65
Ni	0.060	47	62	81	100	79	74
Pb	0.24	49	57	91	100	91	93

Table D.5: Results of concentration dosage for treating of leachate using PAC

Parameter	EQ A A	EQ A B	Raw leachate	Concentration (mg/L) of treated leachate at varying chemical dosage (500mL)						
				0.5	1	1.5	2	3	4	4.5
Turbidity			106	45.2	29.8	25.9	11.3	45.2	90.8	95.3
Colour			2190	370.0	290.0	310.0	305.0	420.0	610.0	800.0
COD			510	384.0	305.0	311.0	302.0	364.0	405.0	430.0
BOD ₅			487	355.0	317.0	298.0	296.0	308.0	318.0	340.0
NH ₄ -N			402	176.0	132.0	134.0	126.0	169.0	174.0	185.0
TSS			750	184.0	165.0	165.0	155.0	260.0	320.0	370.0
Ca			214	81.0	15.0	18.0	16.0	30.0	36.0	50.0
K			1444	520.0	420.0	431.0	242.0	420.0	602.0	886.0
Na			1489	1012.0	233.0	266.0	267.0	587.0	1001.0	1104.0
Mg			226.58	156.0	30.0	34.0	32.0	80.0	103.0	112.0
Cu	0.2	1.0	0.213	0.2	0.0	0.0	0.1	0.1	0.1	0.1
Zn	1.0	1.0	0.595	0.3	0.1	0.1	0.1	0.3	0.4	0.5
Cd	0.01	0.02	0.043	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ni			0.058	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pb	0.01	0.5	0.235	0.1	0.1	0.1	0.1	0.1	0.1	0.1

Table D.6: Results of removal efficiency of pollutant in leachate using PAC

Parameter	Raw leachate	Removal efficiency (%) of pollutant in leachate at varying chemical dosage (500mL)						
		0.5	1	1.5	2	3	4	4.5
Turbidity	106	57	72	76	89	57	14	10
Colour	2190	83	87	86	86	81	72	63
COD	510	25	40	39	41	29	21	16
BOD ₅	487	27	35	39	39	37	35	30
NH ₄ -N	402	56	67	67	69	58	57	54
TSS	750	75	78	78	79	65	57	51
Ca	214	62	93	92	93	86	83	77
K	1444	64	71	70	83	71	58	39
Na	1489	32	84	82	82	61	33	26
Mg	226.58	31	87	85	86	65	55	51
Cu	0.213	38	84	81	77	59	54	46
Zn	0.595	51	83	83	85	53	41	21
Cd	0.043	27	72	70	72	37	47	21
Ni	0.058	48	60	79	78	62	41	24
Pb	0.235	53	49	49	53	48	37	40

Table D.7: Results of concentration of treated leachate with various pH at optimum dosages of PAC

Parameters	EQA A	EQA B	Untreated leachate	Concentration (mg/L) of treated leachate with various pH at optimum dosages					
				<i>pH 4</i>	<i>pH 5</i>	<i>pH 6</i>	<i>pH 7</i>	<i>pH 8</i>	<i>pH 9</i>
Turbidity			106	19.04	12.72	10.6	9.54	13.78	15.9
Colour			2190	350.4	324.12	284.7	262	302	328.5
COD			510	352	338	320	278	328	345
BOD ₅			487	359	321	302	300	310	320
NH ₄ -N			402	179	164	153	143	149	165
TSS			750	202.5	195	180	152.5	187.5	202.5
Ca			214.10	36	26	18	12	16	18
K			1444.20	479	402	250	236	251	420
Na			1488.70	498	376	259	235	256	265
Mg			226.58	76	52	40	21	67	87
Cu	0.2	1.0	0.213	0.053	0.041	0.039	0.032	0.047	0.049
Zn	1.0	1.0	0.595	0.27	0.22	0.115	0.11	0.12	0.24
Cd	0.01	0.02	0.040	0.012	0.014	0.011	0.003	0.0021	0.016
Ni			0.060	0.027	0.0221	0.011	0.008	0.011	0.016
Pb	0.01	0.5	0.24	0.11	0.1	0.021	0.01	0.0321	0.0315

Table D.8: Results of removal efficiency at varying pH with optimum concentration using PAC

Parameters	Untreated leachate	Removal efficiency (%) at varying pH with optimum concentration					
		<i>pH 4</i>	<i>pH 5</i>	<i>pH 6</i>	<i>pH 7</i>	<i>pH 8</i>	<i>pH 9</i>
Turbidity	106	82	88	90	91	87	85
Colour	2190	84	85	87	88	86	85
COD	510	31	34	37	45	36	32
BOD ₅	487	26	34	38	38	36	34
NH ₄ -N	402	55	59	62	64	63	59
TSS	750	73	74	76	80	75	73
Ca	214.10	83	88	92	94	93	92
K	1444.20	67	72	83	84	83	71
Na	1488.70	67	75	83	84	83	82
Mg	226.58	66	77	82	91	70	62
Cu	0.213	75	81	82	85	78	77
Zn	0.595	55	63	81	82	80	60
Cd	0.040	72	67	74	93	95	63
Ni	0.060	53	62	81	86	81	72
Pb	0.24	53	57	91	96	86	87

Table D.9: Results of concentration dosage for treating of leachate using FeSO₄

Parameter	EQ A A	EQ A B	Raw leachate	Concentration (mg/L) of treated leachate at varying chemical dosage (500mL)						
				0.5	1	1.5	2	3	4	4.5
Turbidity			106	60.2	7.9	7.1	7.4	10.2	20.4	22.1
Colour			2190	2005	503	284	328	380	416	494
COD			510	384	355	345	352	366	388	395
BOD ₅			487	359	320	302	302	310	320	356
NH ₄ -N			402	172	132	134	132	169	171	180
TSS			750	210	170	160	330	520	700	715
Ca			214	78	21	17	24	32	40	48
K			1444	538	290	240	300	410	621	830
Na			1489	830	320	270	430	610	850	1010
Mg			226.58	150	51	38	41	62	68	98
Cu	0.2	1.0	0.213	0.13	0.048	0.042	0.063	0.096	0.12	0.15
Zn	1.0	1.0	0.595	0.24	0.19	0.11	0.23	0.29	0.36	0.48
Cd	0.01	0.02	0.043	0.02	0.013	0.011	0.023	0.027	0.026	0.023
Ni			0.058	0.045	0.035	0.023	0.031	0.022	0.013	0.021
Pb	0.01	0.5	0.235	0.2	0.06	0.01	0.1	0.12	0.12	0.2029

Table D.10: Results of removal efficiency of pollutant in leachate using FeSO₄

Parameter	Raw leachate	Removal efficiency (%) of pollutant in leachate at varying chemical dosage (500mL)						
		0.5	1	1.5	2	3	4	4.5
Turbidity	106	43	93	93	93	90	81	79
Colour	2190	8	77	87	85	83	81	77
COD	510	25	30	32	31	28	24	23
BOD ₅	487	26	34	38	38	36	34	27
NH ₄ -N	402	57	67	67	67	58	57	55
TSS	750	72	77	79	56	31	7	5
Ca	214	64	90	92	89	85	81	78
K	1444	63	80	83	79	72	57	43
Na	1489	44	79	82	71	59	43	32
Mg	226.58	34	77	83	82	73	70	57
Cu	0.213	46	80	83	74	60	51	38
Zn	0.595	60	68	82	61	51	39	19
Cd	0.043	53	70	74	47	37	40	47
Ni	0.058	22	40	60	47	62	78	64
Pb	0.235	15	74	96	57	49	49	14

Table D.11: Results of concentration of treated leachate with various pH at optimum dosages of FeSO₄

Parameters	EQA A	EQA B	Untreated leachate	Concentration (mg/L) of treated leachate with various pH at optimum dosages					
				pH 4	pH 5	pH 6	pH 7	pH 8	pH 9
Turbidity			106	34.8	29.6	19.54	8.42	11.54	17.66
Colour			2190	548	520	350.4	120	372.3	416.1
COD			510	345	324	330	320	374	367
BOD ₅			487	367	342	332	312	317	332
NH ₄ -N			402	182	164	153	154	155	168
TSS			750	254	210	187.5	154	195	198
Ca			214.10	32	20	14	11	18	21
K			1444.20	376	256	250	176	298	256
Na			1488.70	289	270	278	179	278	310
Mg			226.58	78	65	42	12	66	62
Cu	0.2	1.0	0.213	0.06	0.055	0.05	0.039	0.05	0.055
Zn	1.0	1.0	0.595	0.19	0.135	0.128	0.11	0.128	0.132
Cd	0.01	0.02	0.040	0.019	0.01343	0.011	0.003	0.013	0.018
Ni			0.060	0.03	0.0221	0.014	0.009	0.011	0.019
Pb	0.01	0.5	0.24	0.029	0.039	0.021	0.011	0.0321	0.038

Table D.12: Results of removal efficiency at varying pH with optimum concentration using FeSO₄

Parameters	Untreated leachate	Removal efficiency (%) at varying pH with optimum concentration					
		pH 4	pH 5	pH 6	pH 7	pH 8	pH 9
Turbidity	106	67	72	82	92	89	83
Colour	2190	75	76	84	95	83	81
COD	510	32	36	35	37	27	28
BOD ₅	487	25	30	32	36	35	32
NH ₄ -N	402	55	59	62	62	61	58
TSS	750	66	72	75	79	74	74
Ca	214.10	85	91	93	95	92	90
K	1444.20	74	82	83	88	79	82
Na	1488.70	81	82	81	88	81	79
Mg	226.58	66	71	81	95	71	73
Cu	0.213	72	74	76	82	76	74
Zn	0.595	68	77	78	82	78	78
Cd	0.040	56	69	74	93	70	58
Ni	0.060	48	62	76	84	81	67
Pb	0.24	88	83	91	95	86	84

Table D.13: Results of concentration dosage for treating of leachate using $\text{Al}_2(\text{SO}_4)_3$

Parameter	EQ A A	EQ A B	Raw leachate	Concentration (mg/L) of treated leachate at varying chemical dosage (500mL)						
				0.5	1	1.5	2	3	4	4.5
Turbidity			106	10.2	8.42	9.2	12.9	19.2	26.6	34.2
Colour			2190	310	260	340	370	410	440	490
COD			510	380	305	325	345	380	405	415
BOD ₅			487	-	-	-	-	-	-	-
NH ₄ -N			402	-	-	-	-	-	-	-
TSS			750	170	160	170	190	240	310	340
Ca			214	78	12	20	25	30	35	45
K			1444	455	215	263	288	399	542	812
Na			1489	986	233	258	420	541	960	990
Mg			226.58	147	26	39	41	80	100	102
Cu	0.2	1.0	0.213	0.128	0.04	0.05	0.07	0.09215	0.112	0.16
Zn	1.0	1.0	0.595	0.265	0.1	0.15	0.21	0.26	0.33	0.437
Cd	0.01	0.02	0.043	0.02	0.01	0.015	0.02	0.027	0.027	0.024
Ni			0.058	0.035	0.025	0.03	0.031	0.032	0.037	0.021
Pb	0.01	0.5	0.235	0.1	0.06	0.1	0.1	0.12	0.147	0.19

Table D.14: Results of removal efficiency of pollutant in leachate using $\text{Al}_2(\text{SO}_4)_3$

Parameter	Raw leachate	Removal efficiency (%) of pollutant in leachate at varying chemical dosage (500mL)						
		0.5	1	1.5	2	3	4	4.5
Turbidity	106	90	92	91	88	82	75	68
Colour	2190	86	88	84	83	81	80	78
COD	510	25	40	36	32	25	21	19
BOD ₅	487	-	-	-	-	-	-	-
NH ₄ -N	402	-	-	-	-	-	-	-
TSS	750	77	79	77	75	68	59	55
Ca	214	64	94	91	88	86	84	79
K	1444	68	85	82	80	72	62	44
Na	1489	34	84	83	72	64	36	33
Mg	226.58	35	89	83	82	65	56	55
Cu	0.213	47	84	79	71	62	54	34
Zn	0.595	55	83	75	65	56	45	27
Cd	0.043	53	77	65	53	37	37	44
Ni	0.058	40	57	48	47	45	36	64
Pb	0.235	57	74	57	57	49	37	19

Table D.15: Results of concentration of treated leachate with various pH at optimum dosages of $\text{Al}_2(\text{SO}_4)_3$

Parameters	EQA A	EQA B	Untreated leachate	Concentration (mg/L) of treated leachate with various pH at optimum dosages					
				pH 4	pH 5	pH 6	pH 7	pH 8	pH 9
Turbidity			106	18.04	12.72	10.6	11	13.78	14.9
Colour			2190	365	332	302	245	312	347
COD			510	345	317	315	300	330	332
BOD ₅			487	-	-	-	-	-	-
NH ₄ -N			402	-	-	-	-	-	-
TSS			750	247	195	180	139	187.5	234
Ca			214.10	36	26	18	10	16	18
K			1444.20	320	267	250	220	251	276
Na			1488.70	345	320	289	223	287	265
Mg			226.58	60	52	42	17	66	76
Cu	0.2	1.0	0.213	0.047	0.042	0.032	0.029	0.047	0.043
Zn	1.0	1.0	0.595	0.127	0.12	0.115	0.09	0.12	0.121
Cd	0.01	0.02	0.040	0.019	0.01343	0.011	0.003	0.012	0.016
Ni			0.060	0.029	0.0221	0.014	0.008	0.011	0.018
Pb	0.01	0.5	0.24	0.1	0.1	0.021	0.013	0.0321	0.032

Table D.16: Results of removal efficiency at varying pH with optimum concentration using $\text{Al}_2(\text{SO}_4)_3$

Parameters	Untreated leachate	Removal efficiency (%) at varying pH with optimum concentration					
		pH 4	pH 5	pH 6	pH 7	pH 8	pH 9
Turbidity	106	83	88	90	90	87	86
Colour	2190	83	85	86	89	86	84
COD	510	32	38	38	41	35	35
BOD ₅	487	-	-	-	-	-	-
NH ₄ -N	402	-	-	-	-	-	-
TSS	750	67	74	76	81	75	69
Ca	214.10	83	88	92	95	93	92
K	1444.20	78	82	83	85	83	81
Na	1488.70	77	79	81	85	81	82
Mg	226.58	74	77	81	92	71	66
Cu	0.213	78	80	85	86	78	80
Zn	0.595	79	80	81	85	80	80
Cd	0.040	56	69	74	93	72	63
Ni	0.060	50	62	76	86	81	69
Pb	0.24	57	57	91	94	86	86

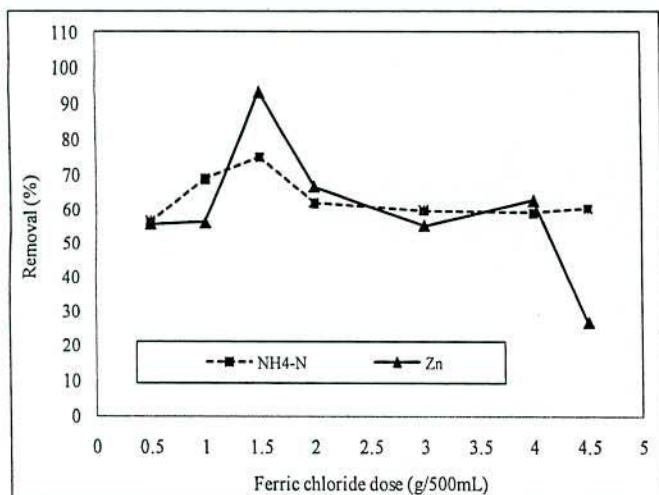


Figure D.15: Effect of concentration of FeCl_3 for removing $\text{NH}_4\text{-N}$ and Zn in leachate.

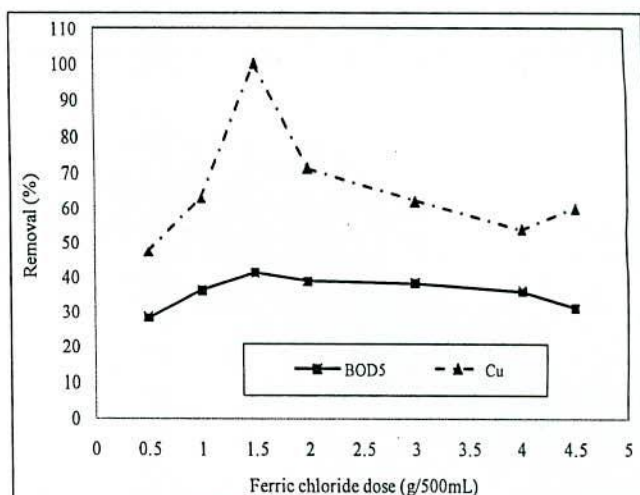


Figure D.16: Effect of concentration of FeCl_3 for removing BOD_5 and Ca in leachate.

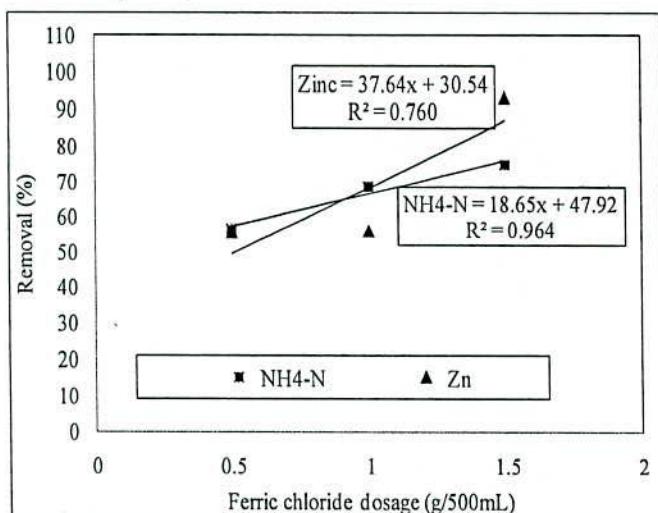


Figure D.15 (a): Regression for $\text{NH}_4\text{-N}$ and Zn using FeCl_3 at different dosages approached OpCD.

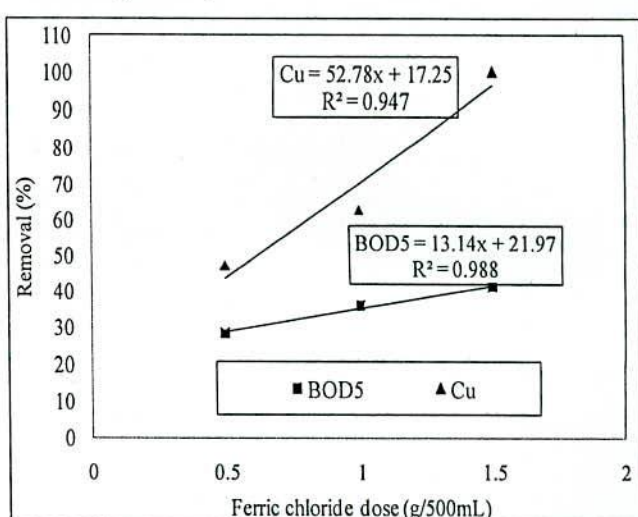


Figure D.16 (a): Regression for BOD_5 and Ca using FeCl_3 at different dosages approached OpCD.

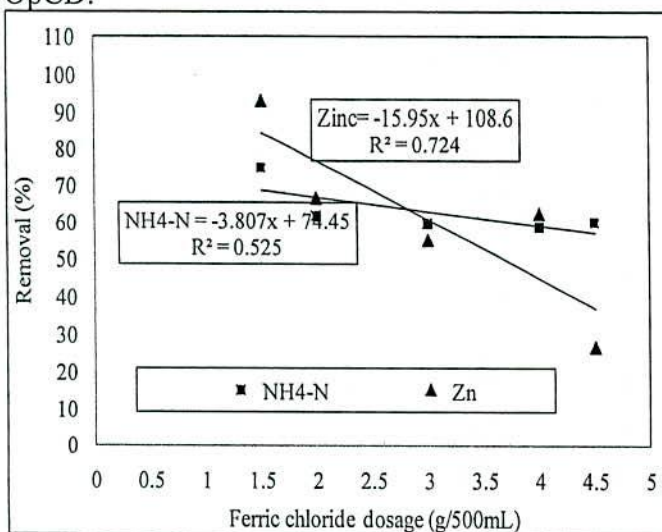


Figure D.15 (b): Regression for $\text{NH}_4\text{-N}$ and Zn using FeCl_3 at different dosages after the OpCD.

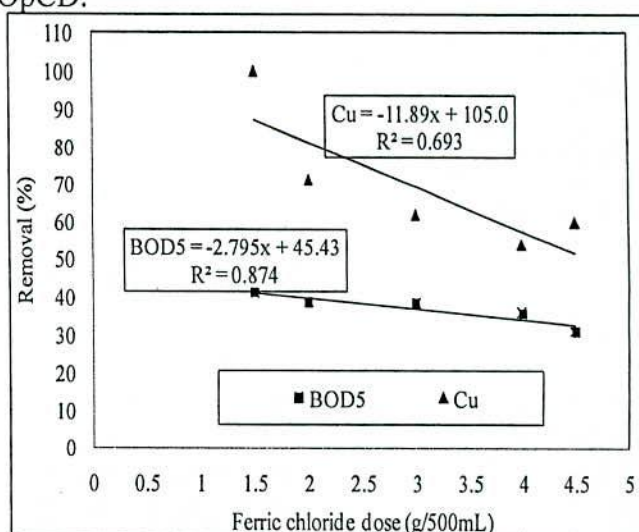


Figure D.16 (b): Regression for BOD_5 and Ca using FeCl_3 at different dosages after the OpCD.

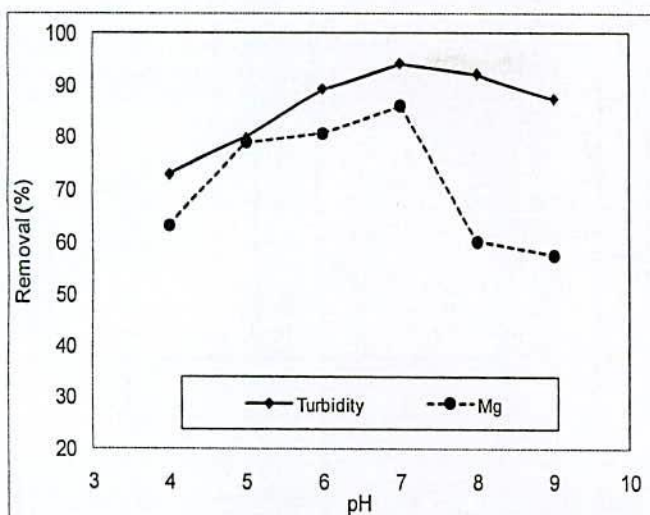


Figure D.17: Effect of pH of FeCl_3 for removing turbidity and Mg in leachate.

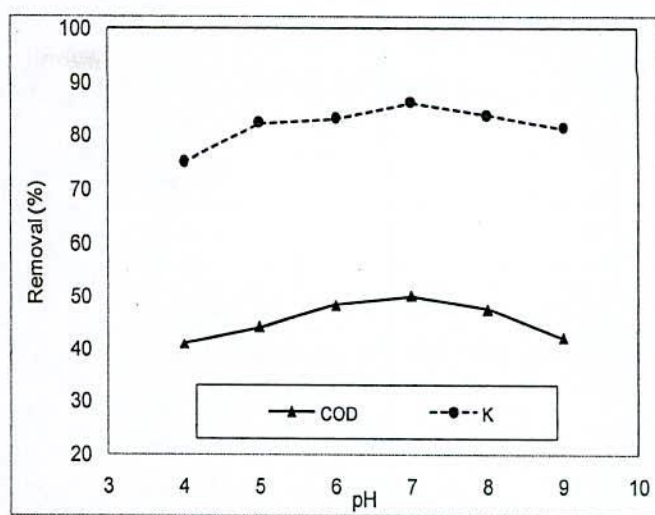


Figure D.18: Effect of pH of FeCl_3 for removing COD and K in leachate.

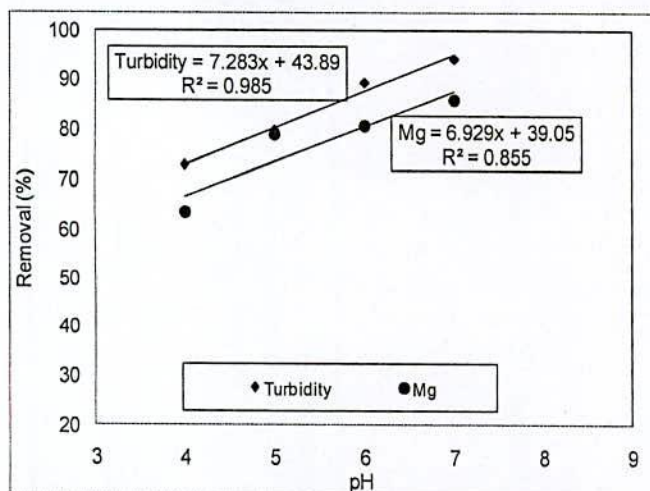


Figure D.17 (a): Regression for turbidity and Mg using FeCl_3 at varying pH approached OpCD.

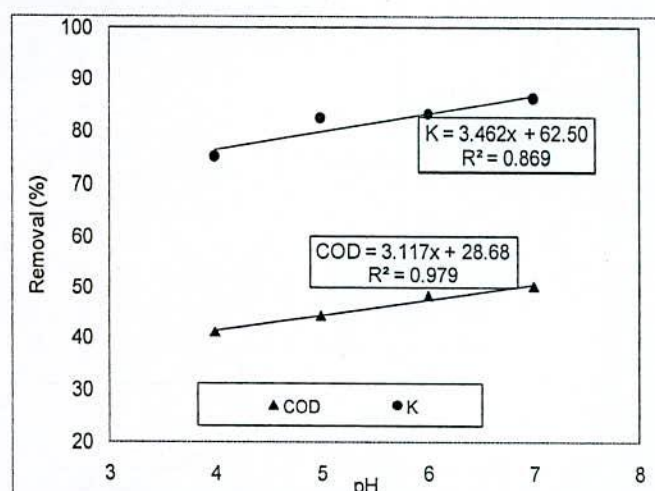


Figure D.18 (a): Regression for COD and K using FeCl_3 at varying pH approached OpCD.

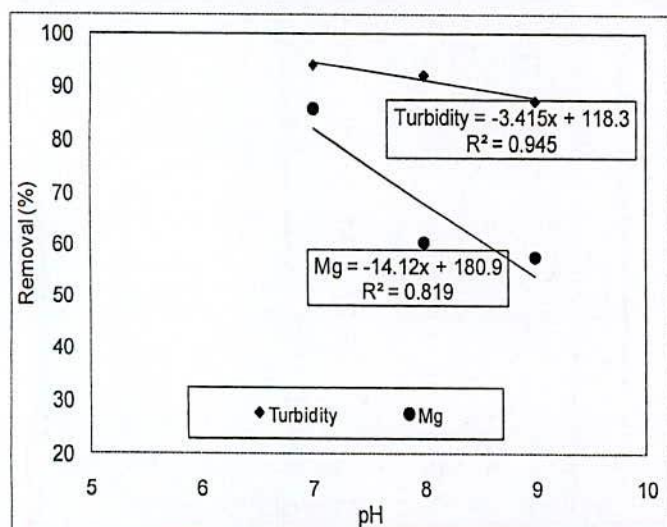


Figure D.17 (b): Regression for turbidity and Mg using FeCl_3 at varying pH after OpCD.

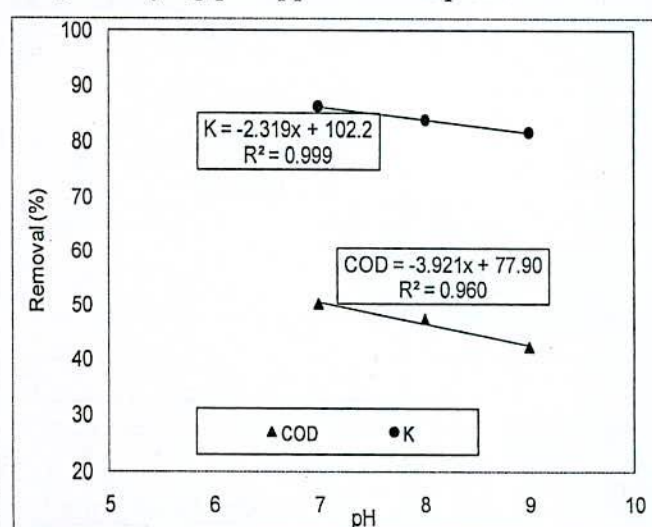


Figure D.18 (b): Regression for COD and K using FeCl_3 at varying pH after OpCD.

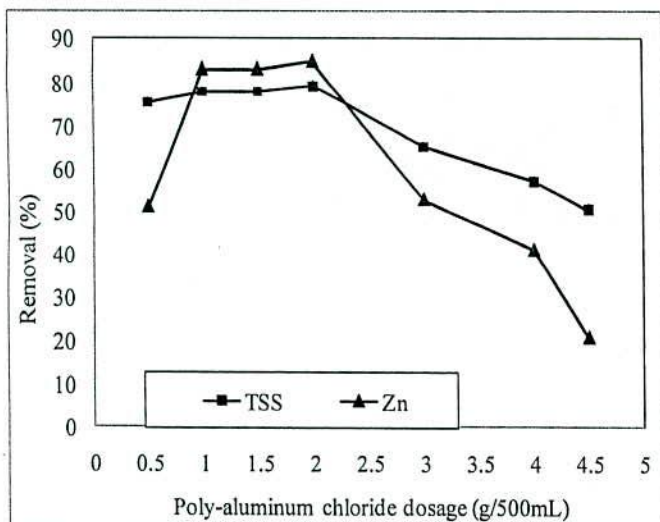


Figure D.19: Effect of concentration of PAC for removing TSS and Zn in leachate.

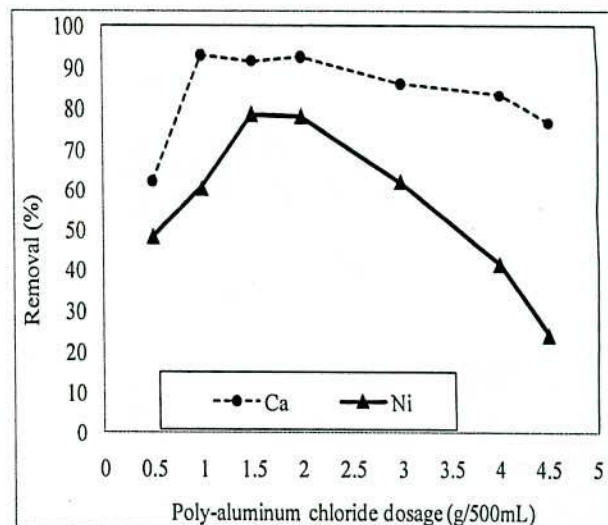


Figure D.20: Effect of concentration of FeCl_3 for removing Ca and Ni in leachate.

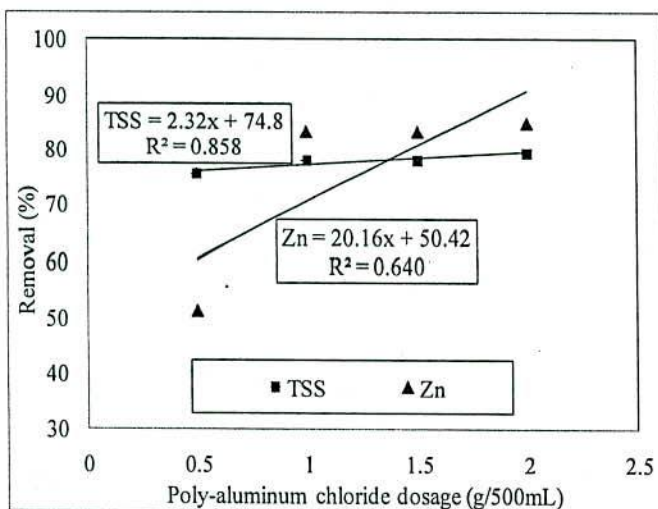


Figure D.19 (a): Regression for TSS and Zn using PAC at different dosages approached OpCD.

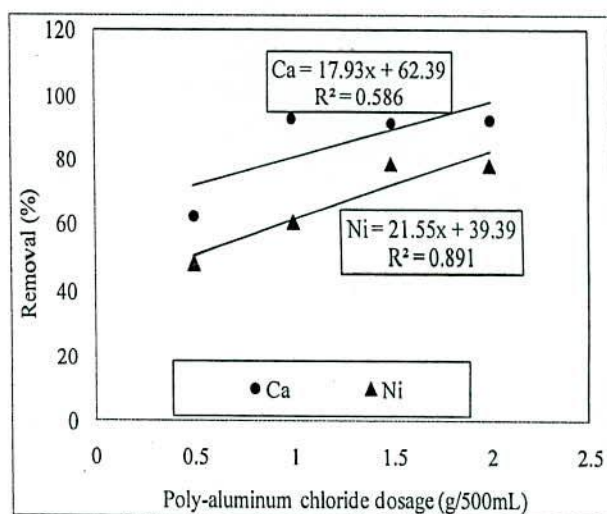


Figure D.20 (a): Regression for Ca and Zn using PAC at different dosages approached OpCD.

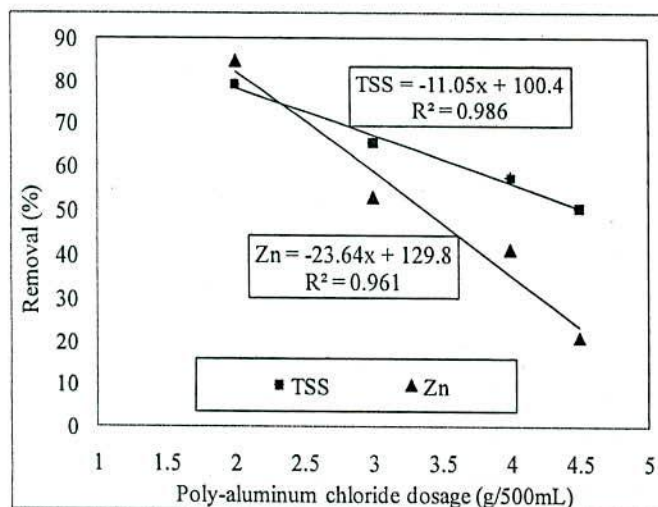


Figure D.19 (b): Regression for TSS and Zn using PAC at different dosages after OpCD.

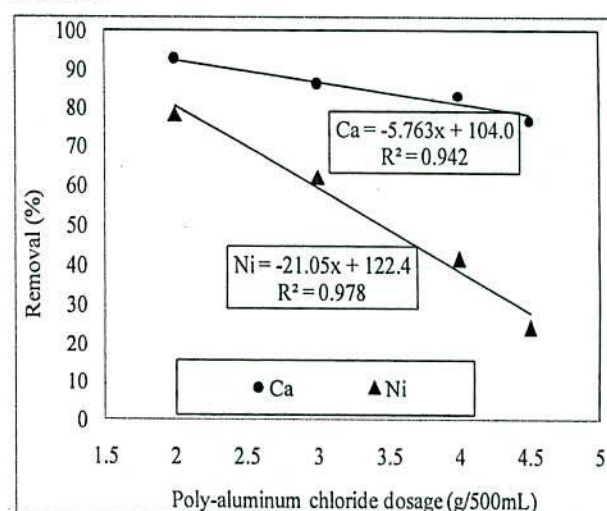


Figure D.20 (b): Regression for Ca and Ni using PAC at different dosages after OpCD.

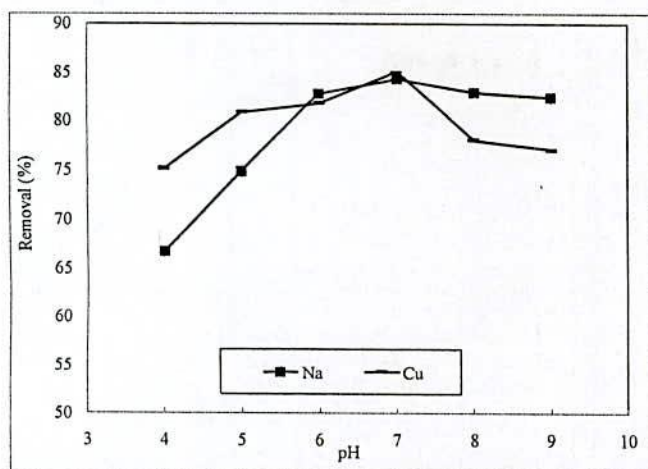


Figure D.21: Effect of pH of PAC for removing Na and Cu in leachate.

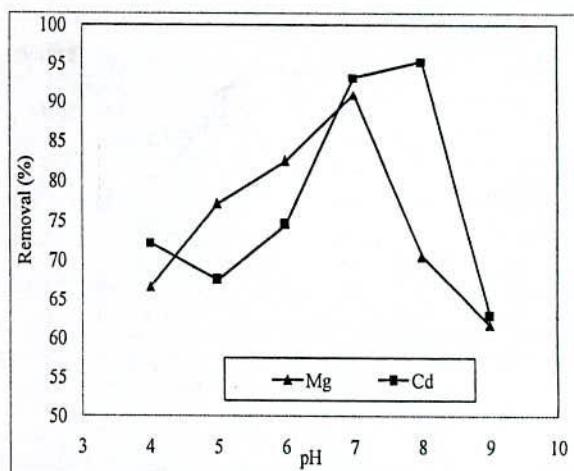


Figure D.22: Effect of pH of PAC for removing Mg and Cd in leachate.

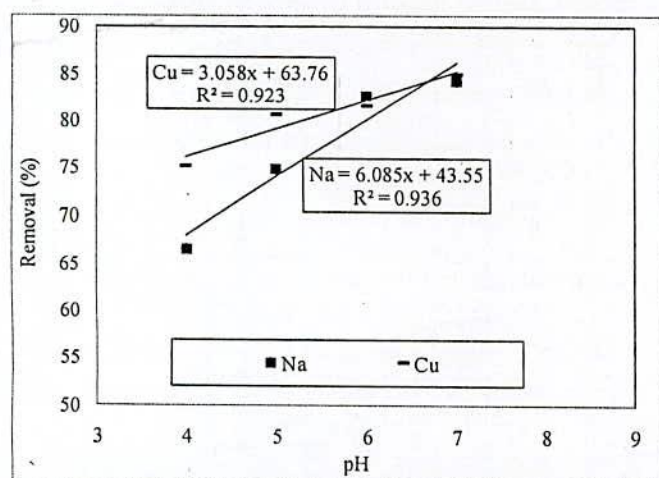


Figure D.21 (a): Regression for Na and Cu using PAC at varying pH approached OpCD.

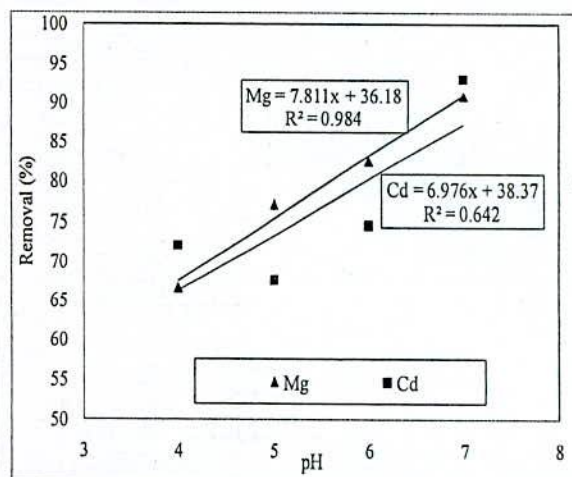


Figure D.22 (a): Regression for Mg and Cd using PAC at varying pH approached OpCD.

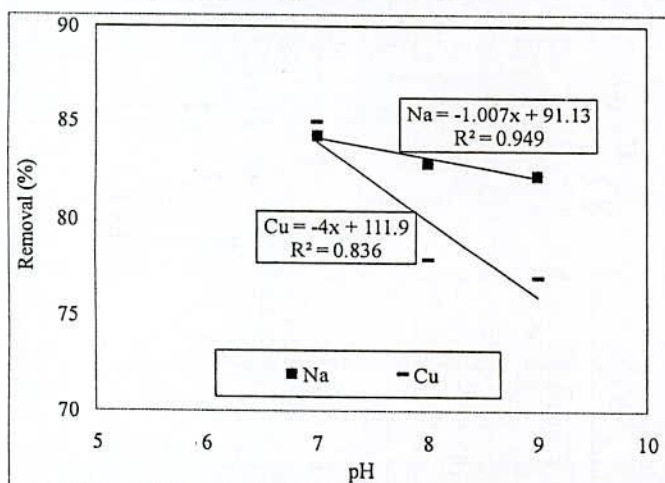


Figure D.21 (b): Regression for Na and Cu using PAC at varying pH after OpCD.

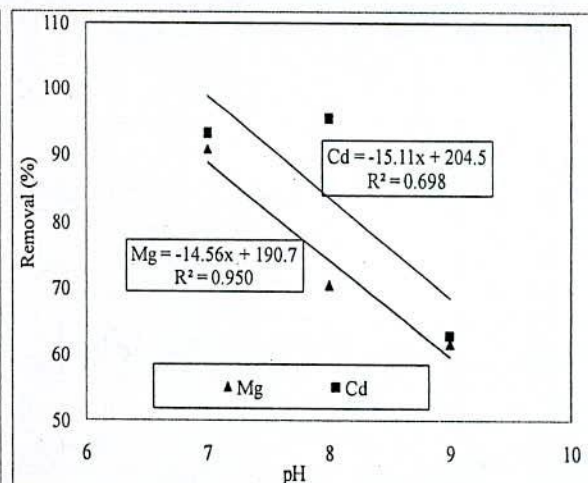


Figure D.22 (b): Regression for Mg and Cd using PAC at varying pH after OpCD.

Table D.17: Calculation of LPI of lysimeter treated leachate and maximum leachate discharge standards

Leachate parameters	weight factor, w_i					Leachate disposal standards, c_i				Treated lysimeter leachate concentration				Treated leachate sub-index, p_i				Treated lysimeter leachate sub-index, p_i				Treated leachate pollutant rating (w_i, p_i)				Treated lysimeter leachate pollutant rating (w_i, p_i)			
	Bangladesh	India	Germany	Hong Kong	Lysimeter	Bangladesh	India	Germany	Hong Kong	A ₁	A ₂	B	C	Bangladesh	India	Germany	Hong Kong	A ₁	A ₂	B	C	Bangladesh	India	Germany	Hong Kong	A ₁	A ₂	B	C
Cr	0.064	0.064	0.064	0.064	0.064	0.5	2	0.5	0.1	0.05	0.04	0.08	0.07	5	9	5	5	5	5	5	5	0.32	0.580	0.32	0.32	0.32	0.32	0.32	0.3
Pb	0.063	0.063	0.063	0.063	0.063	0.1	0.1	0.5	0.1	0	0	0	0	5	5	6	5	5	5	5	5	0.315	0.320	0.378	0.32	0.32	0.32	0.32	0.3
COD	0.062	0.062	0.062	0.062	0.062	200	250	200	200	55	85	60	57	9	10	9	9	6	8	6	6	0.558	0.620	0.558	0.56	0.37	0.5	0.37	0.4
Hg	0.062	0.062	0.062	0.062		0.01	0.01	0.01	0.02					5	6	6	6					0.31	0.370	0.372	0.37	0	0	0	0
BOD ₅	0.061	0.061	0.061	0.061	0.061	50	30	20	800	85	102	88	80	7	6	6	25	8	9	8	7	0.427	0.370	0.366	1.53	0.49	0.55	0.49	0.4
As	0.061	0.061	-	-	0.061	0.2	0.2			0.01	0.04	0.03	0.02	5	5	0	0	5	5	5	5	0.305	0.310	0	0	0.30	0.31	0.30	0.3
CN	0.058	0.058	-	-	-	0.1	0.2							5	6	0	0					0.29	0.350	0	0	0	0	0	0
Phenol*	0.057	0.057	-	-	-	1	1							5	5	0	0					0.285	0.290	0	0	0	0	0	0
Zn	0.056	0.056	0.056	0.056	0.056	5	5	2	0.6	1.13	0.92	0.55	0.58	6	6	5	5	5	5	5	5	0.336	0.340	0.28	0.28	0.28	0.28	0.28	0.3
pH	0.055	0.055	0.055	0.055	0.055	6-9	5.5-9.0	5.5-8.5	5-7.5	6.1	6.27	6.45	6.21	5	5	5	5	5	5	5	5	0.275	0.280	0.275	0.28	0.28	0.28	0.28	0.3
TKN	0.053	0.053	0.053	0.053	0.053	100	100	70	100	95	180	112	51	6	6	5	6	5	6	5	5	0.318	0.320	0.265	0.32	0.27	0.32	0.27	0.3
Ni	0.052	0.052	0.052	0.052	0.052	1	3	1	0.6	0	0	0	0	6	10	6	5	5	5	5	5	0.312	0.520	0.312	0.26	0.26	0.26	0.26	0.3
TCB	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NH ₄ -N	0.051	0.051	0.051	0.051	0.051	50	50	30	5	27	45	25	33	7	7	6	5	5	5	5	5	0.357	0.360	0.306	0.26	0.26	0.26	0.26	0.3
TDS	0.05	0.05	0.05	0.05	0.05	2100	2100	600	500	980	1100	1002	780	7	7	5	5	5	5	5	5	0.35	0.350	0.25	0.25	0.25	0.25	0.25	0.3
Cu	0.05	0.05	0.05	0.05	0.05	0.5	3	0.5	1	0.04	0.04	0.04	0.04	5	18	5	7	5	5	5	5	0.25	0.900	0.25	0.35	0.25	0.25	0.25	0.3
Cl-	0.048	0.048	0.048	0.048	0.048	600	1000	800	850	540	900	602	511	5	8	6	6	5	6	5	5	0.24	0.390	0.288	0.29	0.24	0.29	0.24	0.2
Fe	0.045	0	0	0	0.045	2				5.1	3.2	3.3	2.1	5	-			5	5	5	5	0.225	-	0	0	0.23	0.23	0.23	0.2
Total	0.948	0.903	0.727	0.727	0.771																	5.473	6.670	4.22	5.34	4.1	4.39	4.1	4
LPI																						5.773	7.386	5.80	7.38	5.32	5.69	5.32	5.24