Division of Engineering and Science
Department of Civil Engineering

Prediction of Pollutant Leaching From Landfill

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This thesis is presented for the Degree of
Doctor of Philosophy (Civil Engineering)
of
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DECLARATION

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university. To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgement has been made.

The following publications have resulted from the work carried out. Copies of selected published or in print papers are presented in Appendix 1. Copies of published refereed conference papers are presented in Appendix 2.

Refereed Paper:

1. Aik Heng Lee, Hamid Nikraz and Yung Tse Hung, Liners For Waste, Handbook For Environmental and Waste Management, World Scientific Publishing Co, Singapore, 2010.

2. Aik Heng Lee, Hamid Nikraz and Yung Tse Hung, Influence of Waste Age on Landfill Leachate Quality, International Journal of Environmental Science and Development (In Print).

Refereed Conference Paper:

1. Aik Heng Lee, Hamid Nikraz and Yung Tse Hung, Benchmarking Heavy Contamination For Brownfield in Malaysia, Proceeding of Internation Conference on Chemical, Biological and Environmental Engineering, Singapore, 2009.

2. Aik Heng Lee, Hamid Nikraz and Yung Tse Hung, Characterization of Acetogenic and Methanogenic Leachate Generated from a Sanitary Landfill Site, Proceeding of International Conference on Environmental Engineering and Technology, Bali, 2010.

3. Aik Heng Lee, Hamid Nikraz and Yung Tse Hung, Study of Carbonaceous and Nitrogenous Pollutants in Leachate of a Sanitary Landfill Site, Proceeding of 2010 International Engineering and Application, Singapore, 2010.

4. Aik Heng Lee, Hamid Nikraz and Yung Tse Hung, Effect of Temperature on Performance of a Sanitary Landfill Site, Proceeding of International Conference of Biology, Environment and Chemistry, Hong Kong, 2010.

ABSTRACT

Landfill is continued to be the most common approach to solid waste disposal. On contrary, landfill practice is still common with increase in water pollution due to leaching of pollutants.

Leachate generation from landfill can be defined into two phases, firstly soluble salt produced due to aerobic decomposition or acetogenic phase and secondly methane and carbon dioxide due to anaerobic decomposition or methanogenic phase.

Characterization of landfill leachate is used in design to achieve low hydraulic conductivity or decrease permeability as leachate percolating through the waste strata and most important is used to predict level of pollutant in leachate which depend on factors such as temperature, precipitation and waste age. It is therefore crucial for landfill design to take into consideration of factors affecting leachate quality.

The purpose of this research is to develop a correlation relationship of factors affecting leachate quality to predict pollutants from landfill which are determined by temperature, precipitation and waste age. The objective of this research is to determine, based the relationship developed and calibration of data obtained from literature review, the optimization of design that reduce pollutants in leachate generated from landfill taking into consideration of basic factors of temperature, precipitation and waste age of landfill.

Results of the study revealed that there is a good correlation of pollutants leaching from landfill to the factors of temperature, precipitation and waste age. Higher pollutant concentration is found in average age landfill than the mature age landfill site mainly due to transition from acetogenic phase to methanogenic phase of pollutant decomposition. It is also anticipated that as carbonaceous organic matter decrease in leachate, nitrogeneous organic matter removal is activated in the mature landfill.

Using Multiple Regression Analysis Method, mathematic model known as Pollutant Prediction Model is developed to correlate relationship of pollutants to factor affecting leachate quality in the landfill site in terms of temperature, precipitation and waste age.

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LIST OF NOTATIONS

A = area of geomembrane through which diffusion occurs (L^2)

b = variables constant

C = dissolved concentration (ML^3)

c = concentration in liner (ML^{-3})

d = drop height

f = mass flux ($ML^{-2}\ T^{-1}$)

G = specific gravity

H = landfill height

h = landfill height

I = Impact resistance

k = first prder reaction rate coefficient (T^{-1})

T = thickness

t = time (T)

y = pollutant parameters predicted for the leachate

z = distance parallel to diffusion direction

x_1 = temperature as factor affecting leachate quality (^{0}C)

x_2 = precipitation of factor affecting leachate quality (mm)

x_3 = waste age as factor affecting leachate quality (year)

σ_{allow} = allowable strength

Τ = Shear strength

σ_p = puncture strength

δ_u = friction with material above

β = slope angle

γ = Unit weight

α = subsidence angle

Φ = friction angle

n_c = effective porosity (-)

f = mass flux ($ML^{-2}\ T^{-1}$)

D_g = Diffusion coefficient in the liner (L^2T^{-1})

c_g = concentration of penetrant in the landfill (ML^{-3})

S_{gf} = solubility, partitioning or Henry's coefficient (-)

c_f = equilibrium concentration in the adjacent fluid C_f (ML^{-3})

LIST OF NOTATIONS

S_a = experimental determined constant
P_g = S_{gf}
Δc_f = difference in concentration in the fluid on either side of the liner
c_{fo} = initial concentration of fluid in the source reservoir (ML^{-3})
c_{fF} = final equilibrium concentration in the source and reservoir
V_s , V_r = volumes of the source and the reservoir (L^3)
t_{GM} = thickness of geomembrane
$\Sigma V_i c_i$ = mass removed by sampling events (M)
D_{xx}, = Dispersion coefficient (L^2T^{-1})
D_{yy} = Dispersion coefficient (L^2T^{-1})
D_{yx}, = Dispersion coefficient (L^2T^{-1})
D_{xy} = Dispersion coefficient (L^2T^{-1})
ϑ_x ϑ_y = velocity component in x and y direction (LT^{-1})

CHAPTER 1

INTRODUCTION

1.0 Landfill and Leachate Contamination

Landfill is major source of groundwater and land contamination that can cause adverse impacts to the environment. Pollutants leaching from landfill in leachate if not properly handled will diffuse and contaminate soil and groundwater. The constituent of pollutants in leachate can be categorized into three types namely organic matter, inorganic matter such as sulfides, chlorides and heavy metals, and xenobiotic organic compounds such as aromatic hydrocarbons and dioxins.

The extend of contamination from the leachate depends on the type of control measures used at the landfill site. Nevertheless, pollutants in the leachate of different composition have different impacts on the environment. Even under controlled conditions such as those of a well planned and well managed landfill, leachate may percolate or penetrate through natural ground and may still contaminate groundwater and ultimate contaminate fresh water supplies over time.

The landfill has a natural way of regulating constituents and organisms present in leachate due to complex sequence of physically, chemically and biologically mediated forces. However, the effectiveness of this natural neutralizing effect is dependant on various factors such as concentration quantity and type of pollutants. A combination of several processes determines the effectiveness. Firstly water infiltrates into the landfill dilutes leachate as it percolates down the waste strata thus gradually weakening the pollutant as it percolates down the waste. Secondly, the waste may absorb the pollutant keeping it in place by making it sticks in extremely thin layers of molecules to the surfaces of solid or liquid particles in the waste. Thirdly, temperature and naturally occurring chemicals in the waste may cause the pollutant to precipitate and separate from the leachate solution. Fourthly, the waste strata acts as a filter for suspended particles and separates these particles from the leachate as it percolates. As electrical charges are present in each particle of waste, removal or separation of minerals and other substances are subsequently dissolved in leachate. Finally, leachate percolating through the waste strata spreads out from the landfill cell to the surrounding.

Other forces may react with leachate as it percolates through the soil which may change the chemistry and pollutant strength of leachate. Physical forces such as filtration, adsorption, advection and dispersion, chemical forces such as oxidation, reduction, hydrolysis and biological forces such as microbial degradation plays an important role in changing the pollutant strength of leachate.

Although these reactions are subject to the waste strata in the landfill, climatic condition such as temperature and precipitation and some of the reactions can also cause adverse impacts to the environment especially those that can increase complexity of the original pollutant.

1.1 Leachate Generation

Leachate generation from landfill can be defined into two phases, firstly soluble salts produced due to aerobic decomposition or acetogenic phase, and secondly methane and carbon dioxide due to anaerobic decomposition or methanogenic phase.

The extent of pollution from the leachate depends on the operation control used in landfill. Nevertheless, pollutants in the leachate of different composition have different impacts on the environment. Even under controlled conditions such as those of a well planned and well managed landfill, leachate may percolate or penetrate through natural ground and may still contaminate groundwater and ultimate contaminate fresh water supplies over time.

The content of leachate generated from most landfill is subject to several factors such as climatic condition, infiltration and waste age. As leachate percolates through waste strata layers that undergo various decomposition, high amounts of both organic matter and inorganic matter are found to be higher than those in groundwater.

Both temperature and water content in landfill will affect the rate of waste decomposition which is usually lower in dry weather condition. Higher organic matter is anticipated in acetogenic phase whereas inorganic matter is lower in methanogenic phase due to lower organic matter and higher pH.

Leachate is typically generated from a landfill deposited with waste contain wide spectrum of composition of pollutants both dissolved and suspended. As precipitation percolating through the landfill, water once in contact becomes contaminated however is assisted by decomposition of bacteria and fungi present in turn release by products of decomposition and rapidly consume any available oxygen. This biodegradation process utilize major portion of organic matter contained in the waste. This rapid decomposition cause temperature to rise and pH to fall which many metal ions normally relatively insoluble at neutral pH become dissolved.

Under normal condition of aerobic stage follow by anaerobic stage, carbonaceous organic removal is essentially completed and residual carbonaceous matters that are non-biodegradable change the composition thus producing a wide range of other matters include complex mixture of organic acids, alcohols, simple sugar, carbon dioxide and others.

As carbonaceous concentration in leachate decreases ammonia nitrogen concentration increases resulting from the hydrolysis and fermentation of nitrogen containing fraction of biodegradable matters. This is followed by nitrification of ammonia nitrogen when a significant portion of non-ammonia nitrogen is readily converted usually measured as nitrogen concentration.

The environmental risk posed due to leachate generation can be mitigated by having properly designed and engineered landfill site such as lying of impermeable liners made of geotextiles or engineered clays that reduce the release of pollutants in order to meet sustainability requirement. Landfill configuration and leachate quality generation have been reported in numerous technical reports.

1.2 Significant of Research

The characteristics of leachate generated from the landfill site are highly subjective and variable depending on several factors such as waste age, waste type, climate condition, precipitation rate, compaction, landfill design and operation.

Several research studies have been conducted to investigate into the characterization of pollutants leaching from landfill and the various activities taking place inside the landfill lead to landfill stabilization due to physical, chemical and biological factors within the landfill environment that influence changes of leachate quality. The leachate quality is enhanced by its movement through two major phases, mainly acetonogenic constituents of leachate primarily organic in nature tend to decompose and stabilize over time while non-biodegradable methanogenic constituents such as heavy metals will stay after waste stabilization and found in leachate in high concentration.

Many studies have been undertaken to characterize landfill leachate and in most cases these leachate characterizations are presented as a range of various pollutants in term of pH, BOD (Biochemical Oxygen Demand), COD (Chemical Oxygen Demand), ammonia, chloride, lead, cadmium, iron and zinc that undergone both acetogenic and methanogenic phases that affect soil and groundwater qualities. Although major studies have been done on pollution range but because of leachate variability, these ranges can cover several orders of magnitude. There is little emphasis on characterization study done based on correlation relationship using statistical study and development model that can be used to predict effective design and efficient pollutant leaching from landfill.

With the recent advent of modern landfill technology using liner, leachate characterization is now becoming more meaningful and useful information in landfill engineering design and operation for pollution control due to leaching of pollutant.

Due to variability of pollutants present in leachate, prediction of leachate characteristic over time be difficult as prediction at the time which each phase begins and end is not possible. Study of leachate based on landfill age may make it possible to understand the waste decomposition more readily and consequently make leachate characterazation more predictable.

The purpose of this research is to study the impact of climatic condition such as temperature and precipitation yield various pollutant removal that undergone both acetogenic and methanogenic phases taking into consideration of waste age of the landfill.

1.3 Scope and Purpose of Research

The scope of this research include the study of the leachate characterization and the prediction of pollutant leaching from landfill. The purpose of this research is to develop a correlation relationship to predict pollutants that are leached out from landfills which are determined by various factors such as temperature, precipitation and age of waste. The main objective of this research is to determine the relationship developed from calibration of data obtained from literation review, and field data recorded in order to characterize leachate for prediction of pollutants contain in leachate taking into consideration of basic properties and factors influencing the characterization of leachate include climatic conditions and waste age. Desirable characterazation for landfill leachate will be identified and performance of leachate characteristic will be compared with that performed under various factors. Pollutant Prediction Model thus developed will provide as an useful tool for the design and management of landfill leachates and also provide an insight for prediction of future trends in leachate quality of landfill site for design and operation of leachate management facilities and support.

CHAPTER 2

LITERATURE REVIEW

2.0 Type of Landfills

Landfill is generally dumpsite used for the disposal of solid wastes as depicted in Figure 2.1. It is the cheapest and most simple method for the disposal of wastes subject that adequate land is made available for the intended use of the landfill. However, a dumpsite used for the disposal of wastes by the landfilling method has to be carefully selected and designed for its intended use. Normally wastes that are disposed in the landfill has to be compacted to reduce volume and to be covered at the end of day. Of concern with the use of landfill may result in various environmental issues such as leachate generation. In general, there are three types of landfill used for waste management purposes. The types of landfill are categorized as depicted in Table 2.1 according to waste types.

Figure 2.1

Leachate Migration In Landfill

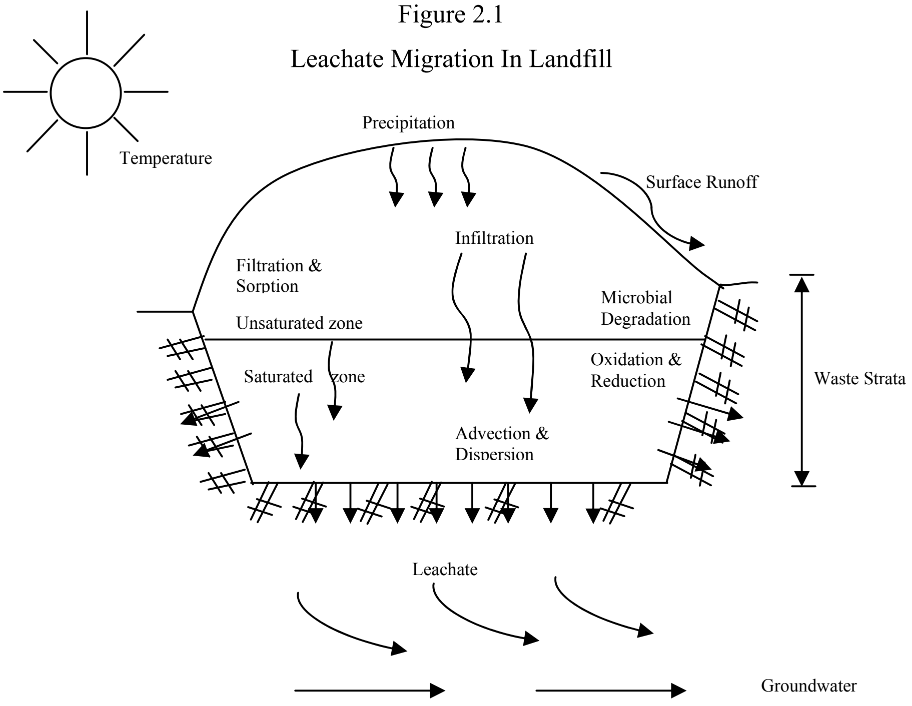


Table 2.1

Type of Landfill

Type of Landfill	Description
1. Inert Landfill	Landfill is used for waste that is not interacted with other substances
2. Non-inert and Non Hazardous Landfill	Landfill is lined and is equipped with leachate collection system, air pollution system and is compartmented. It is typically meant for domestic waste and non-dangerous industrial wastes
3. Hazardous Landfill	Landfill is used for dangerous and hazardous waste

2.1 Leachate Generation

Leachate can be generated by several potential sources include gravity drainage, ponded water, rain, infiltration and groundwater inflow. Leachate generation that cause water pollution is not gaining much attention until 1965 when leachate causing harmful impact to water course is studied in depth (Boyle and Ham, 1974).

Leachate percolating waste above groundwater table cause pollutant migration to groundwater from waste whereas leachate leaches through waste strata at near shore and past pollutant transport known as tidal flushing. The transfer of pollutants is subject to a combination of physical, chemical and biological processes from the waste to the percolating leachate and thus made composition of leachates from different waste fills having similar characteristics (Pohland and Harper 1985).

2.2 Leachate Characterization

Leachate is the liquid percolation that drains through the waste in the landfill varies widely depend on waste type and the waste age (Christensen et al.; 1994, Lema et al.; 1988; Lu et al, 1985; Pohland and Harper 1985). Typically, the leachate can be characterized into three major groups as shown in Table 2.2. The three major groups are mainly organic matters, inorganic matters and xenobiotic organic compounds. Beside these, other compounds are also likely present in the leachate such as arsenate, barium, borate, cobalt, lithium, mercury, selenate and sulfide however in small quantity and of less significant level.

Table 2.2

Pollutants In Leachate

Group of Pollutants In Leachate	**Components**
1. Organic matters	Acids, Alcohols, aldehydres and others usually quantified as BOD, COD, Other Volatile fatty acid and refractory compound include fulvic-like and humic like compounds
2. Inorganic matters	Sulfate, chloride, ammonium, calcium, magnesium, sodium, potassium , hydrogen carbonate, iron and manganese and heavy metal like lead, nickel, copper, cadmium, chromium and zinc
3. Xenobiotic organic compounds	Aromatic hydrocarbon, phenols, chlorinated aliphatics, pesticides and plastizers include PCB, Dioxin, PAH, etc.

2.2.1 Organic Matters

The organic matters are organic molecules of varied origin and composition in leachate that are measured in terms of BOD and COD. Generally, BOD:COD ratio is used to describe the organic composition in the leachate (Kjeldsen and Christopherson, 2001).

Both BOD and COD are commonly used to measure organic matter content in leachate with some reporting BOD and COD values of 20 to 57,000 mg/L and 140 to 15,2000 mg/L respectively. It is anticipitated that BOD and COD value decrease over time most likely attribute to a combination of reduction of organic pollutants that are leaching and the increase availability of biodegradable organic matter (Assmuth and Standberg, 1993; Kjeldsen and Christophersen, 2001).

2.2.2 Inorganic Matters

The inorganic matters such as ammonia, calcium, chloride, hydrogen carbonate, iron, magnesium, manganese, potassium and sulfate are found in most landfill leachate and mostly experience wash out in landfill instead of sorption and precipitation. Heavy metals such as cadmium, chromium, copper, lead, nickel and zinc are found generally low however varied from different landfills (Ehrig 1983, 1988; Krug and Ham, 1997).

Various heavy metals are often found in the leachate and these include cadmium, chromium, copper, lead, mercury, nickel and zinc (Lema et al., 1988; Lu et al., 1985; Pohland and Harper, 1985). These metals are normally generated from soluble components found in the waste or from the physical processes such as corrosion and complexation. In the leachate, heavy metal becomes less soluble as pH increase and the hydrogen ion will affect indirectly the metal solubility by dissociate with acid to yield precipitant anion and reduction-oxidation reactions (Gould et al., 1989). It is also reported that some moderate to high molecular weight humic-like substance formed from organic matter in the waste tend to form strong complexes with heavy metals that tends to increase metal solubility (Gould et al., 1989). It is however also reported that formation of metal sulfides under anaerobic condition due to reaction of metals with sulfide also eliminate majority of heavy metals in leachate (Chian and DeWalle, 1976).

It is also reported that specific conductance is a gross indicator of the total concentration of inorganic matter or ion present in leachate. These primary metals usually contribute to specific conductance include calcium, magnesium, sodium and potassium (Johansen and Carlson, 1996). It is also noted that specific conductance decreases with time due to subsequent depletion of inorganic matters in the waste (Krug and Ham, 1995).

2.2.3 Xenobiotic Organic Compounds

Xenobiotic organic matters in leachate are found to be particularly low in concentration in municipal landfill leachate consists of soluble waste components. Some other decomposed products includes aromatic compounds, chlorinated aromatic compounds, amino-aromatic compounds, halogenated aliphatic compounds, alcohols, nitro-aromatic compounds, heterocyclic compounds, sulfur substituted aromatic compounds, polyaromatic hydrocarbons, polychlorinated biphenyls, organophosphates, ketones, ethers, phthalates and phcnols are found in small quantity. (Albaiges et al., 1986; Brown and Donnelly, 1988; Schulz and Kjeldsen, 1988).

2.3 Phases of Waste Stabilization Affecting Leachate

In the landfill, wastes once contained decompose at least in four phases comprising various biological and chemical reactions as depicted in Table 2.3. The four phases are the early acetogenic or aerobic phase, the acetogenic or anaerobic phase, the early methanogenic phase, and the mature methanogenic phase (Christensen and Kjeldsen, 1995, Bozkurt et al, 200).

Table 2.3

Phases of Waste Decomposition In Landfill

Waste Decomposition Phases	Waste Decomposition Reaction
1 Early Acetogenic / Aearobic Phase	• Occur only in early few days as long as oxygen is available • Leachate mainly generated from waste compaction and precipitation
2 Acetogenic / Anaerobic Phase	• Occur only once oxygen in the waste is depleted • Leachate generated after fermentation reaction on waste by bacteria to intermediate acid, ammonia, hydrogen and carbon dioxide by microbial conversion under anaerobic conditions • Highest BOD and COD are anticipated and mainly acidic
3 Early Methanogenic Phase	• Occur when sufficient quantities of methane is generated and pH is approaching neutral due to conversion of acid to methane and carbon dioxide by methanogenic bacteria • BOD:COD values begin to reduce and as soluble substrate is depleting
4 Mature Methanogenic Phase	• Occur as methane generation reach its highest rate as soluble substrate is significantly reduced • pH continue to increase and BOD:COD ratio decrease tremendously due to highest consumption of soluble substrate

2.3.1 Early Acetogenic / Aerobic Phase

In the early days of waste placement in landfill usually known as the early acetogenic or aerobic phase, oxygen present is consumed rapidly resulting in increase of waste temperature and carbon dioxide due to degradation of organic matter by aerobic microorganism (Barlaz and Ham 1993). As there is limited of oxygen in the waste, aerobic decomposition is responsible for only a small portion of biodegradation within the landfill. Leachate is also generated due to precipitation of the waste in the landfill cell.

2.3.2 Acetogenic / Anaerobic Phase

Subsequent to the acetogenic aerobic phase, fermentation reaction takes place as waste in the landfill cell becomes anerobic. In this anaerobic phase, the biodegrable organic matter in the waste are decomposed and are converted to intermediate acid, ammonia, hydrogen and carbon dioxide by microbial conversion with the aid of bacteria (Zehnder, 1982). These bacteria are mainly the fermentative bacteria which ferment and convert monosaccharides to alcohols and carbonxylic acids. The acetogenic bacteria present subsequent convert these alcohols and carboxylic acid to acetate, carbon dioxide and hydrogen and the methanogens then begin to convert these products to carbon dioxide and methane. It is also reported that there is likely decrease in pH value and follow by metal mobilization resulting in chemical aggressive leachate and a decrease in sorptive capacity of the waste (Barlaz et al.; 1990 Pohland and Harper 1986; Bookter and Ham, 1982).

2.3.3 Earltly Methanogenic Phase

As the waste begin to become neutral and the intermediate acids accumulated are converted to carbon dioxide and methane by methanogenic bacteria in this early methanogenic phase. Reducing condition takes place will pose the solubility of inorganic thus causing precipitation or dissolution of these constituentes such as reduction of sulfate and nitrate to sulfides and ammonia respectively. Both BOD and COD values are tend to reduce since most are converted to gas. The pH value in leachate is elevated in this phase thus become a good growth condition for methanogenic bacteria. Heavy metals are removed by complexation and precipitation and remaining degradable organics are continue to be decomposed slowly over years.The methane generation rate will increase to maximum level and decrease subsequently until depletion of soluble substrate in the stable methanogenic phase. In this phase, the BOD:COD ratio is anticipated to reach 0.1 or lower as soluble substrate is consumed and exhausted (Barlaz and Ham 1993; Christensen et al., 1994).

2.3.4 Mature Methanorgenic Phase

Once the landfill is full and final cover is placed, the decomposition of waste is still on going and the generation of leachate is anticipated to decrease as time go. It is usually presumed that the landfill will be stable after 30 years from the closure (Barlaz et al., 1990).

2.4 Leachate Composition

Typically, composition of leachate generated from the landfill is subject to waste age and other factors such as waste type and landfill approach used. As leachate percolates through waste strata layers that undergo various decompositions several studies had reported that leachate may contain high amount of both organic matter and inorganic matters with average concentration of thousand folds higher than those found in groundwater (Barlaz and Ham, 1993; Reinhart and Grosh, 1990). The concentration of these pollutants may vary over phases of waste decomposition in landfill as the leachate generated is anticipated to have low pH and high concentration of ready biodegrable organic pollutant in the early acetogenic phase follow by early methanogenic phase with high pH and lower concentration of biodegrable organic content to the later mature methanogenic phase with higher pH and in waste. This is represented by higher BOD:COD ratio in the acetogenic phase as compare to the methanogenic phase (Christensen and Kjeldsen, 1989; Barlaz et al, 1989).

It is also reported that water content in the landfill will affect the rate of waste decomposition and the time taken for methane generation to reach zero (Barlaz et al., 1990; Chrtistensen et al., 1992). Waste decomposition is anticipated to be slower in dry weather condition with infiltration of 500mm or less. In most engineering design, recycling of leachate in landfill is used to boost the water content up to 50% and to ensure sufficient quantity of substrate and bacteria are present.

The composition of typical leachate quality is depicted in Table 2.4 and Table 2.5 which illustrated changes of several parameters over time as the waste is decomposed (Andreottola and Cannas, 1992; Chu et al., 1994; Robinson, 1995; Ehrig, 1980; Ehrig, 1983; Garland and Mosher, 1975; Johanson and Carison, 1976; Karstensen, 1989; Lu et al, 1985; Naturuardsverket, 1989; Owen and Manning, 1997; and Robinson and Maris, 1979).

Organic matter in leachate consists of various organic degradable constituents ranging from small volatile acids to refractory fulvic and humic like compound. Higher dissolved organic matter

Table 2.4

Composition of Landfill Leachate

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

* (Values in mg/l unless otherwise stated)

Table 2.5

Composition of Leachate During Acetogenic Phase and Methanogenic Phase

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

is anticipated in the acetogenic phase when compared to those in methanogenic phase. Like the dissolved organic matter, the concentration of inorganic matter is much depend on the stabilization of landfill. It is also reported that the inorganic matters are lower in methanogenic phase due to lower organic matter and higher pH (Assmuth and Standberg, 1993; Kjeldsen and Christopherson, 2001).

As waste in the landfill contains organic matter that has good sorptive capacity for metal immobilization, the presence of heavy metals in the leachate is anticipated to be relatively low. The low concentration of heavy metal is probably due to the presence of sulfide formed from sulfate reduction during waste decomposition (Kylefors et al, 1999).

Wide spectrum of xenobiotic organic compounds are found in landfill leachate depends on waste composition, waste age and landfill approach. Typical xenobiotic organic compounds are halogenated hydrocarbons and monoaromatic hydrocarbons.

2.5 Factors Affecting Leachate Quality

In general, leachate composition is very much depend on climatic conditions (i.e. temperature, precipitation, etc) and waste age. Leachate of acetogenic phase as compared to methanogenic leachate is anticipated to have higher concentration of both organic and inorganic pollutants that leach through the underlying strata (Lema et al, 1988).

2.5.1 Temperature

Landfill ambient temperature is largely an uncontrollable factor that influence leachate quality due to fluctuating seasonal temperature variation (Lu et al., 1985). Temperature affects both bacterial growth and chemical reactions in the landfill. Each particular microorganism possesses its optimum growth temperature and any temperature change will retard the growth due to enzyme deactivation and cell rupture.

Temperature also pose effect to solubility of many salts such as NaCl and $Ca_3\ (PO_4)_2$ as temperature increase. It is also reported that numerous compound in leachate such as $CaCo_3$ and $CaSO_4$ show a decrease in solubility as temperature increase (Lu et al., 1985).

2.5.2 Precipitation

The intensity of the decomposition of waste in the landfill is significantly influenced by climatic conditions such as the amount of precipitation in addition to quality of the installed surface cover and the temperature in the waste strata. Precipitation is thus one of the significant factor influencing waste decomposition and leachate quality (Klink and Ham, 1982). Precipitation enhances moisture in the landfill that play a role as reactant in the hydrolysis reactions, transportation of enzymes and nutrients, dissolution of metabolites, pH buffering, dilution of inhibitory compounds, surface area exposure for microbial attack and control of microbial cell swelling (Noble and Arnold, 1991). Also it is reported that high moisture flow rates can flush soluble organic and microbial cell out of the landfill so that lesser role is taken by microbial activity in determining leachate quality (Mc Bean et al, 1990).

2.5.3 Waste Age

As landfill age increased, variation of leachate quality is expected mainly due to stabilization of organic matter. Study indicated that pollutant concentration is usually achieved peak level in the early lifespan of landfill that is within 2-3 years follow by gradual declining trend in later years for most of the constituents in terms of organic indicators such as BOD, COD, TOC and microorganisms (Mc Bean et al, 1995; Lu et al, 1985).

Landfill leachate from older landfill may exhibit steady decreases in constituent concentration due to continued flushing of the landfill as heavy metals, organic nitrogen, total solids and suspended solids (Akyurek, 1995; Chian and DeWalle, 1977).

2.6 Environmental Impacts

Generally, environmental issues related to improper landfills are groundwater pollution and soil contamination. Once waste is buried in landfill, the action of ever-present water cause many physical, chemical and biochemical processes to take place. Leachate is produced when a sizeable portion of the buried wastes in the landfill becomes saturated with water from external sources. The major potential environmental impacts anticipated due to leachate generation are pollution caused to groundwater and surface water. The severity of impact to environment becomes significant if landfill is not build with engineering solution such as liners and leachate collection systems. Impact due to the leachate plume is reviewed and the its potential effect causing oxygen depletion that change the nature of fauna and flora is also reported (Assumuth et al., 1993; Lema et, al, 1988 Lu et al, 1985, Qasim and Chiang 1994) .

2.6.1 Potential Impacts

When waste decomposes with the action of water, the resulting leachate percolates downwards. As it does so, it absorbs more chemical compound and micro organisms naturally present in the waste. The constituents of leachate in terms of organics matter such as volatile organic compounds, inorganic matter such as acids, sulfides and chlorides, heavy metals and xenobiotic organic compounds such as aromatic hydrocarbon and dioxins. The chemicals and micro-organisms contained in leachate are potentially harmful due to gradual degradation of subsurface water. They can cause adverse impacts to the environment and endanger life. Even under controlled condition, such as present in a well-planned and well run landfill, leachate may percolate or penetrate through the natural ground and contaminate groundwater and underground fresh water supplies. The environmental impact is significant particularly those without engineering control such as liners and leachate collection system (Lema at al., 1988; Lu et al., 1985; Pohland and Harper, 1985).

2.6.2 Impacts To Nature

Naturally, the ground has a way of neutralizing infiltration of chemicals and organisms contained in leachate. This is done by weakening the content or amount of contamination percolate by the leachate as it drains down the soil. The major potential effects of these environmental impacts include depletion of oxygen to natural water sources and toxicity cause to fauna and flora in the aquatic environment (Lema et al, 1988).

2.7 Liners

Liners are commonly used in applications ranging from landfill covers and bottom liners to secondary containment systems, decorative ponds and wastewater lagoon. In landfills, liner used to minimize contamination from the landfill by controlling and isolating the leachate generated in the landfill as shown in Figure 2.2. Various types of liners can be used for landfill sites. However, several considerations shall be given in the selection of the liners for the landfill site include permeability, strength factor and shear factor (Van Santvoort, 1994).

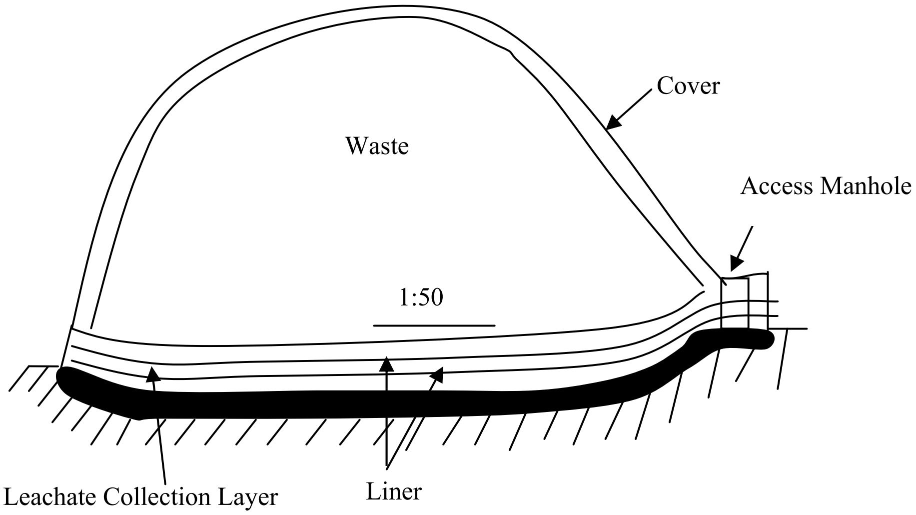


Figure 2.2
Typical Landfill With Liner

2.7.1 Types of Liners

Landfills liners are served as a barrier between the waste in the cell and the surrounding environment and to channel off the leachate to collection and treatment facilities so prevent water pollution. Thus, the main function of liner is to provide an impermeable barrier using various materials with high values of elastic modulus, chemical and weathering resistances, yield and puncture strength. The materials used include clay, geomembranes such as HDPEC (High Density Polyethylene), PVC (Polyvinylchloride), PP (Polypropylene), geotextiles, geosynthetic clay liner and geonet as shown in Table 2.6 (Rollings et al., 1996).

Table 2.6

Components of Liners

Component	Materials	Advantages	Disadvantages
Clay	Compacted clay	Good for groundwater protection from clay	Fracture can be caused by chemical attack, drying out, freezing-thawing
Geomembranes/Flexible Membrane Liner (FML)	Made of various plastic materials include PE, PVC, PP and HDPE	Strong, high chemical resistant impermeable to water	Clogging due to trap particles
Geotextiles	Made of woven or nonwonven textile sheeting	Effective water movement	Clogging due to trap particles
Geosynthetic Clay Liner (GCL)	Made of thin clay layer between two layers of geotextiles	Easy installation	Less Impact by freezing-thawing
Geonet	Made of plastic net	Effective water movement	Clogging due to trap particles

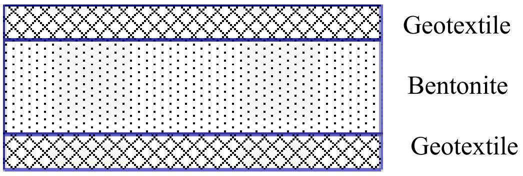
Clay is one of the most economical liner material used in most landfill application due to its low permeability, low diffusivity, ductility, chemical compatibility, chemical retardation, internal and interface shear strength and good constructability. However it is affected by factors such as construction requirement and soil composition and post construction changes (USEPA 1990).

Modified clay such as bentonite is used to replace clay due to its mineralogy usually in term of percentage of sodium and/or calcium montmorillonite, moisture content and operation requirement to improve permeability.

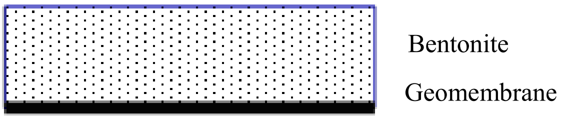
Synthetic liners are used as an alternative to clay such as geomembrane and geotextile because of low volume consumption and easy availability. The rapid acceptance of synthetic liners in the engineering application is due to their high strength, chemical compatibility and thicknesses up to as thin as 1mm.

For selection of an effective liner for landfill, important criteria include hydraulic conductivity, shear strength, chemical resistance and other performance characteristics such as free and confined swelling and rate of creep. Liner with low hydraulic conductivity is to ensure low permeability (i.e. rate of infiltration) through waste and strong shear strength is to ensure maximum stress of liner without losing structural integrity.

Geosynthetic Clay Liners (GCL) is one of the newest liner technology used in municipal solid waste landfill application due to its low hydraulic permeability, easy installation and swelling property. Typically configuration of GCL consists mainly of modified clay i.e. bentonite either sandwiched between two sheets of geotextile or bonded to a geomembrane as shown in Figure 2.3. A geotextile which is woven or nonwoven sheet material is less impervious to liquid and more resistance to penetration damage when compared to a geomembrane which is a polymeric sheet material.



Bentonite Sandwiched Between Two Geotextiles



Bentonite Glued to Geomembrane

Figure 2.3
Typical Configuration of GCL

GCL offers a good substitute to other conventional landfill liners such as CCL (Compacted Clay Liner) due to fast and easy installation, low permeability due to low conductivity, good swelling properties and cost effective in the absence of clay material as depicted in Table 2.7 (Daniel et al., 1993). Modified clay or bentonite of GCL is an excellent absorbent that attracts positively changed water particles that hydrates rapidly when expose to leachate that maximizing capacity at the same time better environment protection.

Typically there are five types of architecture used for landfill liners that can be described as single, double and composite as shown in Table 2.8.

Table 2.7

Comparison of CCL and GCL

Compacted Clay Liner	**Geosynthetic Clay Liner**
Thick (0.6-1.5m)	Thin (<10mm)
Field Constructed	Manufactured
Hard to build correctly	Easy to build (unroll and place)
Impossible to puncture	Possible to damage and puncture
Constructed with heavy equipment	Light construction equipment required
Often required test pad at each site	Repeated field testing not needed
Site specific data on soil needed	Manufactured product : data available
Large leachate-attenuation capacity	Small leachate-attenuation capacity
Large thickness, takes up space	Little space is wasted
Cost is highly variable	More predictable cost
Soil has low tensile strength	Higher tensile strength
Can desiccate and crack	Cannot crack until wetted
Difficult to repair	Not difficult to repair
Vulnerable to freeze-thaw damage	Less susceptible to freeze-thaw damage
Performance depends highly on quality of construction	Hydraulic properties are less sensitive to construction variabilities
Slow construction	Much faster construction

Table 2.8

Types of Liners

Liner Type	**Composition**	**Function**	**Application**
Single Liner	Clay liner, Geosynthetic clay liners or Geomembranes	Sufficient to prevent insoluble leachate migration	Suitable for municipal solid waste landfill
Single composite Liner	Two or more difference material of low permeability such as clay liner with geomembrane	Effective to control leachate migration with clay liner or geomembrane	Suitable for municipal solid waste landfill
Double Liners	Two single liners, two composite liners or a single liner with a composite liner	Primary liner is to collect leachate while secondary liner serve as back up	Suitable for hazardous waste landfill
Double Composite Liner	Two composite liners place one above the other	Ensure sufficient collection of leachate and no leakage	Suitable for hazardous waste landfill

A single liner normally consists of a clay liner or CCL, a geomembrane or a GCL is used in landfill for construction waste which is cost effective to build and maintain.

A composite liner consists of combination of geomembrane with clay liners so to limit leachate migration is usually used in municipal solid waste landfills.

A double liner consists of either two single liners, two composite liners or a combination of a single and a composite liner in such a way that the upper liner can collect the leachate and the lower liner can act as back up for leakage. Double liners are used in either municipal solid waste landfills or hazardous waste landfills.

In addition, a leachate collection system consists of sand and gravel is used to drain the leachate from the landfill to collection ponds for storage and treatment. Also, a protective layer consisting of soil, sand and gravel or a layer of soft waste (e.g. organic waste, paper, rubber and others) is used to cushion liner to avoid damage as shown in Figure 2.4 (Rollings, et al, 1996).

2.7.2 Liner Failure

Generally, the two failure modes of liners are leakage and liner destruction. Leakage occurs in liners through lost of material permeability or hole damage cause leachate or even waste to release to the environment. Liner destruction on the other takes place due to extensive membrane movement or loss of mechanical properties caused by phenomena include creep and puncture.

Creep is defined as a deformation of material over a prolonged time period under constant pressure (ASTM, 1993; Cazzuffi et al., 1997; ASTM, 1993). It is load, temperature and time dependence and is related to most mechanical deformation such as compression, tensile, torsion and flexure. However only compressive and tensile creep are anticipated in the geomembrane due to material used. The three phases of creep behavior are observed namely primary with strain increases but strain rate decrease, secondary with both strain and strain rate remain constant and tertiary with material rupture due to rapid increase of strain and strain rate. The typical creep curve for landfill line is depicted in Figure 2.5.

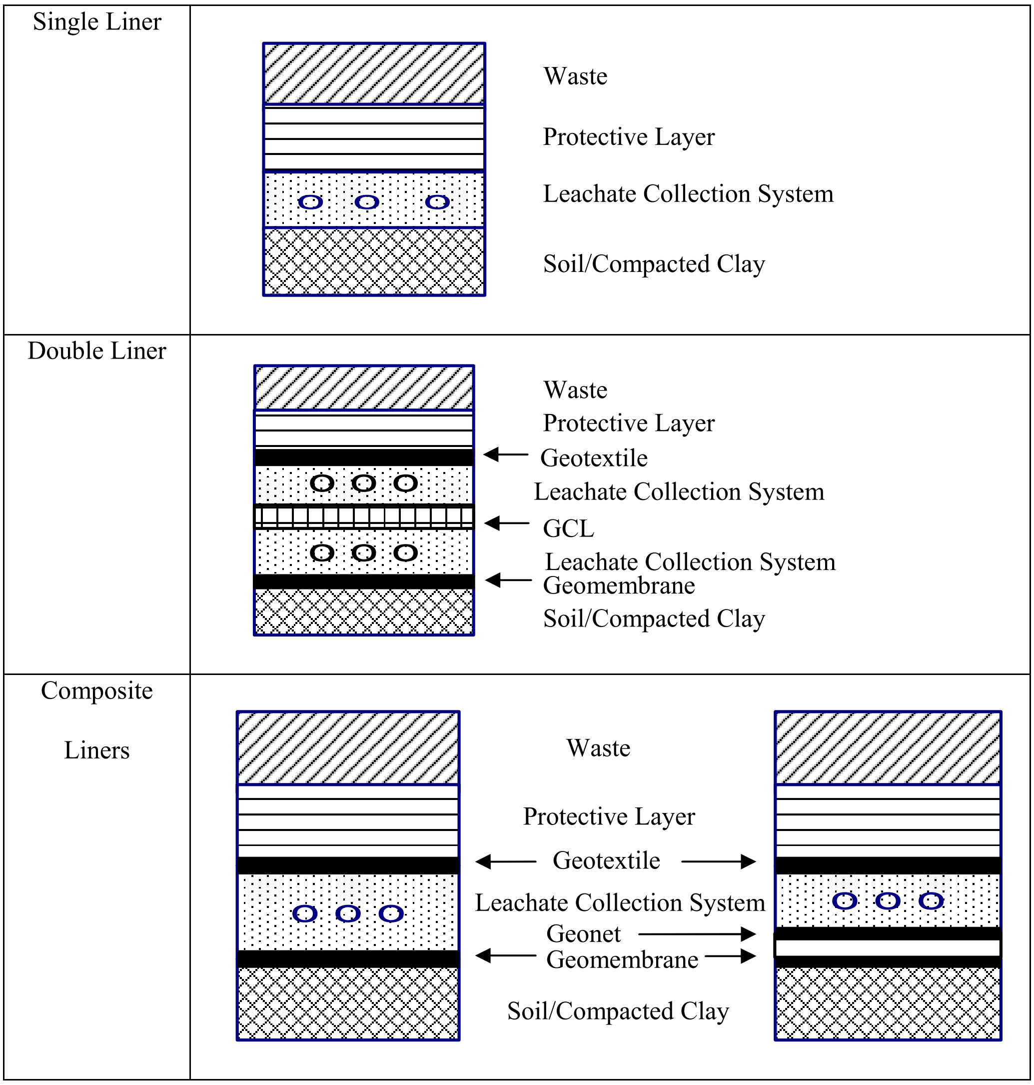


Figure 2.4

Cross Section of Liner

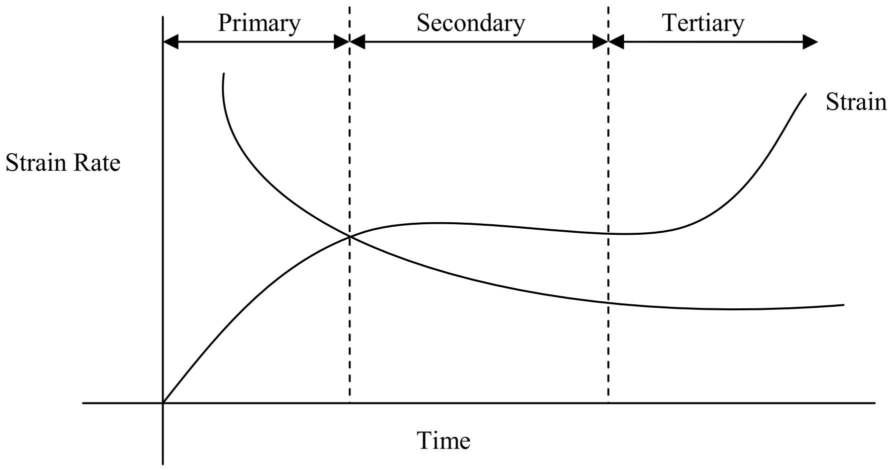


Figure 2.5
Typical Creep Curve

Puncture is one of the most common and serious type of damage to the landfill liner. Puncture phenomena cannot be assessed easily and are subject to short term as well as long-term puncture forces. Short term forces normally occur during installation of leachate collection layer while long term forces occur due to over burden loads of waste.

There are two types of puncture phenomenon namely static and dynamic. The liner usually experiences dynamic puncture phenomenon due to fall height during installation and is usually short term. Static puncture phenomenon is due to contact with static normal stress and can be short term such as traffic load and long term such as waste load. Figure 2.6 depicts the puncture resistance summation of two different components of liner (Artieres et al., 1995).

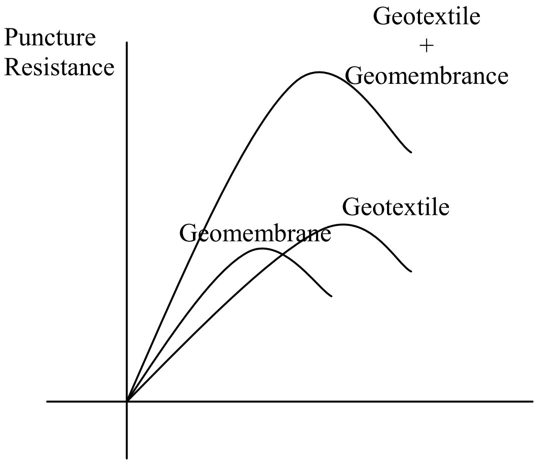


Figure 2.6
Puncture Resistance of Liners

2.7.3 Liner Design

Typically liner design involves the material selection and thickness computation based on various factors include type of pollutants, environmental and climatic conditions material availability and legal requirements and cost provision. The composition of liners for waste usually consists of a compacted subsoil layer overlain by compacted clay layers and geosynthetic materials with different combination of materials all depend on application requirement.

The design flow of liner as depicted in Figure 2.7 is broadly cover in 5 steps. Each of the design steps must be documented in detail so that decision can be made to finalize design for application.

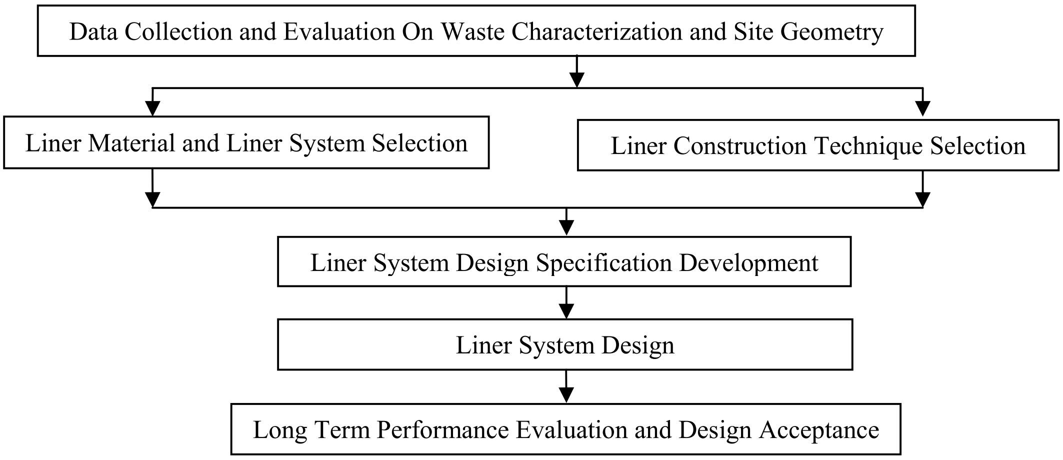


Figure 2.7

Design Flow For Liner System

Step 1 Data Collection and Evaluation – The collection of data pertaining to waste characterization such as waste type and strength and site geometry such as water bodies and chemistry must be conducted for engineering evaluation to establish benchmarking references for liner system and technique selection.

Step 2 Selection of Liner System and Construction Technique – Relevant screening on type of liner material for leachate control and cover design to minimize pollutant release that meet acceptable limit must be carried out. Also study of various available construction technology for liner placement must be conducted to ensure accurate placement of liner so that necessary density and rate of liner application can be derived.

Step 3 Liner System Specification Development – Next is to develop design specification so that design effectiveness of the liner system is ensured. The design specification is to be outlined so that the liner system constructed can meet specific performance criteria at minimum cost.

Step 4 Liner System Design - The liner system is then designed with appropriate engineering criteria in reducing pollutant release thus achieve the intended liner function. The design involves mainly the determination of liner thickness required taking into consideration of physical and chemical properties of pollutant and the material of liner selected.

Step 5 Long Term Performance Evaluation and Design Acceptance - It is crucial for the liner system designed to be evaluated for long term performance on its inherent ability to maintain the design effectiveness throughout the entire life cycle of the liner system. The design of liner system is accepted for application as long as the compatibility of liner material and pollutant present is reached so that design characteristic can be assured for extended period of time.

Table 2.9 illustrate the template develop for specific guidance for design of liner system for waste landfill.

Adequate considerations are to be given for liner system design to prevent leakage, geogrids for leak collection and a good protection layer to prevent puncture phenomenon and to reduce creep, stress cracking and aging phenomenon. The design consists of site selection, geometric layout, geotechnical consideration, cross-section determination, geomembrane material selection, thickness determination, side-slope and cover soil details, anchor trench details, seam type decision, seam testing strategy, design of connection and appurtenances , leak scenarios and correction measures and proper quality assurances (Koerner, 1994).

Problems selecting to the liner design are identified to guide designing engineer as shown in Table 2.10 (Richardson et al., 1987).

Table 2.9

Liner System Design Template

1 Baseline Data	• Waste Source • Waste Characterization - pH, conductivity, total solids - organic matters - inorganic matters - heavy metal • Site Geometry and Environment - Geotechnical Aspect - Groundwater and Surface Water - Climate • Legal Requirement - Legislative and Regulatory
2 Liner system Selection	• Liner materials Resistant - Compacted modified subsoil - Compacted clay - Geomembranes - Geosynthetic - Composite materials • Liner System - Leachate Collection System - Cover - Wall and trenches • Engineering Techniques - Compaction and re-compaction - Lift - Water Content
3 Liner System Design Specification	• Liner thickness • Liquid & flow through • Hydraulic conductivity • Strength and puncture resistance • Shrink-swell properties
4 Liner System Design	• Liner thickness • Pollutant flux • Pollutant removal
5 Long Term Performance Evaluation	• Design effectiveness • Liner compatibility

Table 2.10

Problem associated With Liner Design

Problem	**Liner Stress**	**Required Properties**		**Typical Factor of Safety**
		Geomembrane	**Landfill**	
Liner Self weight	Tensile	$G, t, \sigma_{allow}, \delta_L$	β, H	10 to 100
Weight of filling	Tensile	$t, \sigma_{allow}, \delta_L, \delta_u$	β, h, H, γ	0.5 to 10
Impact during construction	Impact	I	D, W	0.1 to 5
Weight of Landfill	Compression	σ_{allow}	γ, H	10 to 50
Puncture	Puncture	σ_p	γ, H, P, A_p	0.5 to 10
Anchorage	Tensile	$t, \sigma_{allow}, \delta_L, \delta_u$	β, γ, Φ	0.7 to 5
Settlement of landfill	Shear	τ, δ_u	β, γ, H	10 to 100
Subsidence under landfill	Tensile	$t, \sigma_{allow}, \delta_L,$ δ_u, χ	α, γ, H	0.3 to 10

Where :

Geomembrane Properties

G = specific gravity

T = thickness

σ_{allow} = allowable strength

τ = Shear strength

I = Impact resistance

σ_p = puncture strength

δ_u = friction with material above

Landfill Properties

β = slope angle

H = landfill height

γ = Unit weight

h = lift height

α = subsidence angle

Φ = friction angle

d = drop height

Design features are to take into consideration of a safety analysis for liner system as depicted in Table 2.11 (Heibrock, 1995).

Table 2.11

Requirement of A Safe Liner System

Requirement	Properties that need to be Checked	Site Specific influences
Stability The liner system should be stable with respect to the mechanical influences without significant change in its leachate behavious	Shear resistance cohesion (residual/non-residual values)	Mechanical influences: • Forces resulting from deformation • Forces resulting from overburden loads and inclination • Forces resulting from construction procedures
Imperviousness Pollution migration through the liner system should be comparable to that for a definable standard size	a) Permeability of the liner system hydraulic conductivity, diffusion coefficient retention capacity b) Sensitivity of the system to imperfections	• Hydraulic gradient • Kind of pollution • Amount of soluble pollutant • Concentration of pollutant in solution • Temperature If a composite liner is considered • Kind of clay • Zone of higher permeability • Deformation or desiccation • Over burden loads
Resistance If proved that the lining system being exposed to the site specific influences is still stable and sufficiently impermeable Combination of influences should be considered	Resistance to leachate Resistance to gas Resistance to temperature Hydraulic resistance Resistance to exposure	Chemical influences: • Kind of composition of leachate • Duration of exposure Thermal influences: • Low/high temperature • Duration of exposure Hydraulic influences: • Forces resulting from water movement • Climate, hydrogeology of the site

2.7.4 Liner Installation and Maintenance

The criteria to be selected in engineering practice for installation and maintenance is crucial to ensure effective use of liner in landfill.

Proper installation of landfill liner is to be carried out with care by competent workmenship to follow the design work. A proper and detail quality control and management plan are to be put in place for operation throughout the entire lifespan of the landfill liner system to monitoring long term performance with respect to liner integrity and landfill stability.

2.7.5 Mathematic Prediction For Prevention of Pollutant Migration

The latest engineering design of landfill system is to limit pollutant migration so to minimize impact to surrounding environment. The typical landfill system consists of a leachate collection system to control the leachate head acting on the liner and to collect and remove leachate. The leachate collection system comprises mainly a gentextile with granular layer and perforated pipes. The landfill liner can range from a clay layer to a liner system of one or more geomembrane and/or compacted clay liner or geosynthetic clay liner. Composite liners comprising of a geomembrane over compacted clay have been widely adopted in many standard landfill designs (Rollings et al. 1996). The effectiveness and efficiency of liner performance is based on the several factors such as different potential transport mechanisms include advection (the movement of containment with leachate flow) and diffusion (the movement of molecules or ions from high concentration to low concentration regine) and the potential attenuation mechanisms include biodegradation, sorption and dilution (Rowe, 1998).

Diffusion is defined as the movement of molecules or ions due to own random kinetic activity from areas of higher concentration to areas of lower concentration. This movement in porous media is given by Fick's Law (Rowe, 1998) as :-

$$f = -n_c D_c \frac{\partial c}{\partial z}$$

where

f = mass flux ($ML^{-2}\ T^{-1}$)

n_c = effective porosity (-)

c = concentration in liner (ML^{-3})

z = distance parallel to diffusion direction

Most liners such as geomembrane is not a conventional porous medium as the pore size is large relative to both water and contaminant molecules. The diffusion of penetrant molecules through a geomembrane therefore can be represented by Fick's law as :-

$$f = -\ D_g \frac{\partial c_g}{\partial z}$$

where

f = mass flux ($ML^{-2}\ T^{-1}$)

D_g = Diffusion coefficient in the liner (L^2T^{-1})

c_g = concentration of penetrant in the landfill (ML^{-3})

z = distance parallel to diffusion direction

Taking into the conservation mass governing differential equation for transient diffusion as :-

$$\frac{\partial c_g}{\partial t} = -\ D_g \frac{\partial^2 c_g}{\partial z^2}$$

When a liner is in contact with liquid/leachate for a sufficient time a final equilibrium which take place in the liner as per Henry's Law (Rogers, 1985; Naylor, 1989):-

$$c_g = S_{gf}c_f$$

where

c_g = final equilibrium concentration in the liner (ML^{-3})

S_{gf} = solubility, partitioning or Henry's coefficient (-)

c_f = equilibrium concentration in the adjacent fluid C_f (ML^{-3})

Alternatively, it can take a non-linear as Langmuir form

$$c_g = \frac{S_a b c_f}{1 + b c_f}$$

where

S_a = experimental determined constant

b = variables constant

Assume that the pollutant permeant is not interact with the liner yield

$$f = -D_g \frac{\partial c_g}{\partial z} = S_{gf} D_g \frac{\partial c_f}{\partial z} = -P_g \frac{\partial c_f}{\partial z}$$

where

$P_g = S_{gf}$

P_g is thus referred as the permeability which the mass flux across a landfill is given by

$$f = S_{gf} D_g \frac{\Delta c_f}{t_{GM}}$$

$$= P_g \frac{\Delta c_f}{t_{GM}}$$

where

Δc_f = difference in concentration in the fluid on either side of the liner

As transient contaminant transport is controlled by the diffusion coefficient D_g instead of the permeability, P_g, the Henry Coefficient S_{gf} is defined when an equilibrium is reached (Rowe et al., 1997) as :-.

$$S_{gf} = \frac{c_{fo} V_g c_{fF} (V_s + V_r) - \Sigma V_i c_i}{A t_{GM} c_{fF}}$$

where

c_{fo} = initial concentration of fluid in the source reservoir (ML^{-3})

c_{fF} = final equilibrium concentration in the source and reservoir

V_s, V_r = volumes of the source and the reservoir (L^3)

A = area of geomembrane through which diffusion occurs (L^2)

t_{GM} = thickness of geomembrane

$\Sigma V_i c_i$ = mass removed by sampling events (M)

Advection and diffusion is an important transport mechanisms of leachate for well designed and operated landfills. The rate of advection and diffusion will depend on the level of physical action that occur in the liner and the level of biodegradation of organic contaminants in the landfill.

Advection is the transport or migration of leachate constituents as a result of holes or physical defects in the geomembranes liner and flow through pores of underlying soil layer due to the influence of hydraulic head. Daray’s law can also be used to compute the advective flux for liner.

The advection dispersion, equation with a first order reaction is expressed as (Zheng et al., 2002)

$$\frac{\partial c}{\partial t} = D_{xx} \frac{\partial^2 c}{\partial x^2} + D_{xy} \frac{\partial^2 c}{\partial \alpha \partial y} + D_{yy} \frac{\partial^2 c}{\partial y^2} - \vartheta_x \frac{\partial c}{\partial x} - \vartheta_y \frac{\partial c}{\partial y} - kC$$

where

C = dissolved concentration (ML^3)

t = time (T)

k = first prder reaction rate coefficient (T^{-1})

D_{xx}, D_{yy}, D_{yx}, D_{xy} = Dispersion coefficient (L^2T^{-1})

ϑ_x ϑ_y = velocity component in x and y direction (LT^{-1})

2.8 Modelling Approaches For Leachate Prediction

Generally model is defined as a real prediction system that simulates the excitation response relations that are of interest (Bear, 2001). Models can be classified as deterministic or stochastic, mechanistic or functional and numerical or analytical which can be applied based on spation scale (pore scale or global scale), temporal scale (instanstaneous or decades), level of complexity (scientific or decision making) and level of integrity (holistic or reduc tioristic).

Generally the modeling approaches can be represented by two extremeness or more with various combinations from fully data oriented approach based on field measurement to fully process oriented approach based on physical processes (Stowa et al, 1999) as shown in Figure 2.8.

The features of the various modeling approaches consists of neural networks, soft hubrid models, deterministic numerical models and numerical models and data assimilation are explained in Table 2.12.

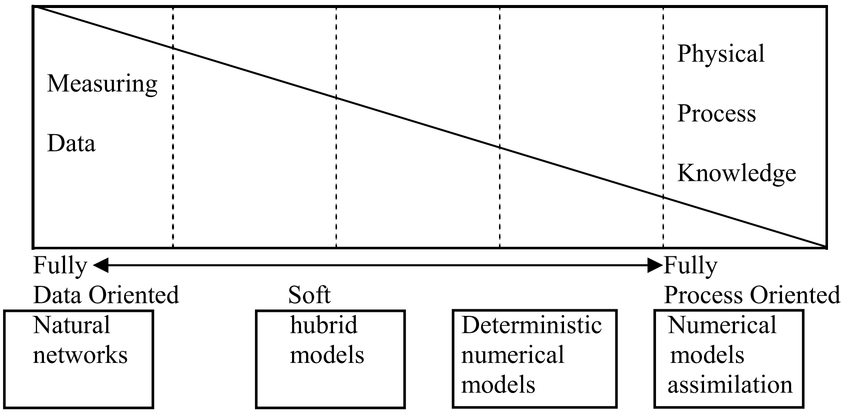


Figure 2.8 Modelling Approaches

Table 2.12

Types of Model Approaches

Model Approach	Features of Model Approaches
Neutral Networks Model	Model correlate empirical relationship between cause (input data) and effect (output data) through the calibration process for future prediction
Hybrid Model	Model correlate input and output data that include physical processes such as conservation of equation
Deterministic Numerical Model	Model focus on physical processes knowledge
Numerical Model and Data Assimilation	Model focus with data assismilation focus on physical processes knowledge and integrate with data about physical process knowledge

CHAPTER 3

METHODOLOGY

3.0 Introduction

The leachate data used in this study is based on the performance result of a landfill site at Toronto for a period of six years spreading from 2004 to 2009. The landfill layout is as shown in Figure 3.1 where the sampling locations are also depicted. Two research criteria are used to identify the landfill for this study namely landfill is unlined and at least six years of performance data have to made available, so that consideration of climatic condition in terms of temperature, precipitation and waste age can be investigated.

The landfill site selected for this research has a total area of 129.7 hectares comprising of original landfill area of 20.60 hectares operating in 1985-1991, the Interim Landfill area of 9.6 hectares operating in 1994-2006 and the remaining as Long-term Expansion area operating since 2006. The landfill is deposited with wastes of solid, non-hazardous industrial, commercial and institutional waste from municipalities and business.

Performance data are selected and categorized from three locations of leachate samplings in order to account for all factors of influences needed for this study. Three sampling stations have been identified for the study to reflect the variation in leachate quality. Sampling data of Final Leachate Holding Tank over a period of six year are selected to evaluate the leachate quality variation with time reflecting the overall landfill performance that experience both acetogenic and methanogenic phases. Sampling data of MH19 and is known as the Average Age Leachate

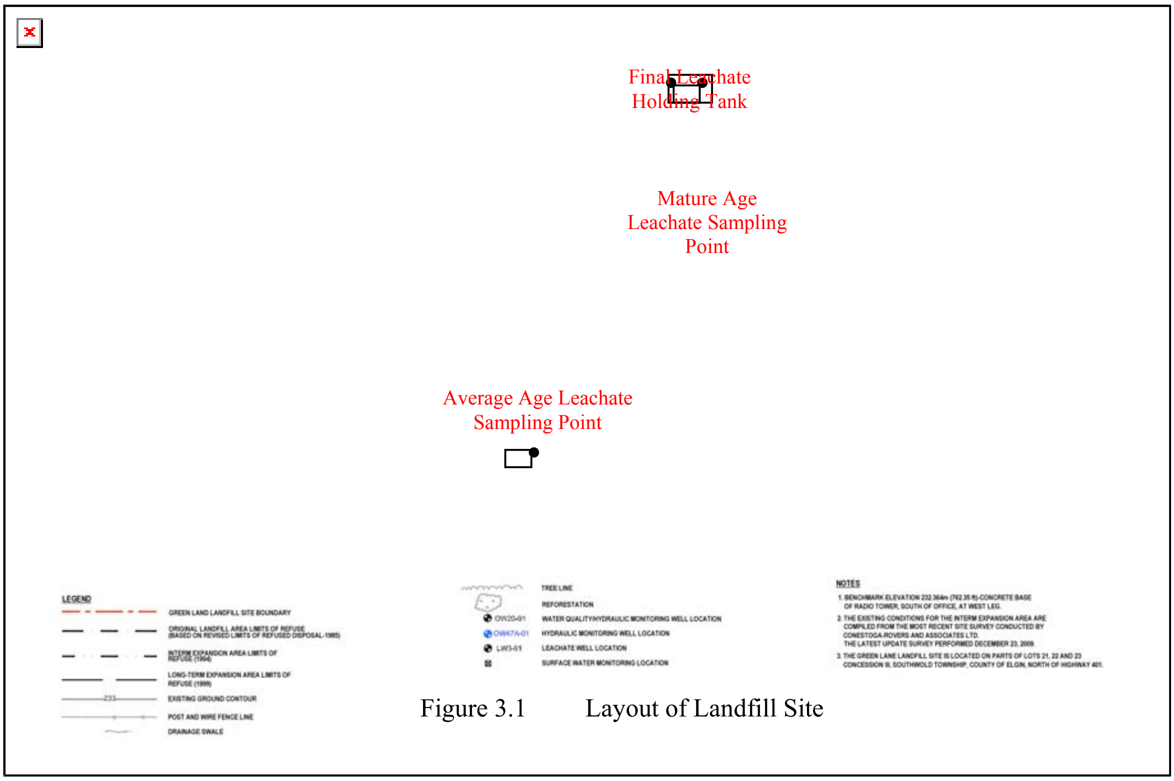


Figure 3.1 Layout of Landfill Site









Sampling Point to reflect the quality of less mature part of the landfill while sampling data of MH11 or known as the Mature Age Landfill Sampling Point to depict the leachate quality of mature part of the landfill. Table 3.1 depict the temperature and precipitation observed at the landfill site.

Table 3.1

Climatic Data At Landfill Site

Parameter	**Year**	**Month**											
		1	2	3	4	5	6	7	8	9	10	11	12
Temperature													
High	2004	9	10.5	18.2	25	27.5	31.8	30.5	29.9	29.1	27.2	15	10
	2005	18	7.3	12.9	28	24.9	34.6	35.5	34	32	26.1	19.1	4.4
	2006	10	6	16	17	33	33	34	36	27	22	16	12
	2007	11	4	15	25	29	34	34	35	32	32	15	3
	2008	15	6	11.7	23	24.1	30.4	30	29.4	29.7	24.4	17.4	6.1
	2009	3.2	9.1	17.9	26.5	28.6	29.1	26.8	29.9	25.5	16.5	18.5	8.1
Low	2004	-23	-19	-10.3	-7	-2	6.6	11.4	9.3	5.5	0.7	-4.6	-24
	2005	-24.2	-15	-14.2	0	-0.4	22.1	12.4	13	6.4	-0.3	-13.3	-15.2
	2006	-13	-11	-10	-4	3	8	13	13	5	1	-2	-10
	2007	-17	-20	-22	-7	4	7	12	11	5	0	-9	-11
	2008	-17	-18.2	-13.4	-3.6	3.1	9	12.9	10.9	8.1	-2.1	-9.6	-12.4
	2009	-21.2	-19.9	-14.9	-1.2	2.2	7.1	12.5	11.6	6.5	-0.2	-1.6	-15.3
Precipitation	2004	50.6	22.5	63.2	62.4	98.8	67.5	121.1	60	25.7	35	61	96.6
	2005	71.7	69.9	38.3	98.3	14.9	32.5	18.5	139.4	244.3	46.3	104.8	60.1
	2006	45.6	45.5	56.9	64	66	68.9	76.6	84.2	74.2	67	70.3	65.5
	2007	45.6	45.5	56.9	64	66	68.9	76.6	84.2	74.2	67	70.3	65.5
	2008	45.6	45.5	56.9	64	66	68.9	76.6	84.2	74.2	67	70.3	65.5
	2009	69	61	66	64	74	69	74	69	74	61	71	66

Table 3.2 through Table 3.4 depict the performance data of leachate collected at Final Leachate Holding Tank where composite leachates are collected from the entire landfill site.

The carbonaceous organic matters were evaluated in terms of BOD, COD and DOC while the nitrogenous organic matters were evaluated in terms of TKN, ammonia, nitrite and nitrate.

Other parameters includer alkalinity calcium, chloride, conductivity, hardness, iron, magnesium, pH, sodium, sulfate, suspended solids, and xenobiotic organic compounds such as phenols were also evaluated. All parameters are analyzed in term of maximum and minimum value with mean (χ) and standard deviation (σ) obtained over the period of six years taking into

Table 3.2

Carbonaceous Pollutants in Leachate of Final Leachate Holding Tank

Parameter	**Year**	**Month**											
		1	2	3	4	5	6	7	8	9	10	11	12
BOD/COD ratio	2004	0.07	0.08	0.1	0.09	0.07	0.06	0.07	0.06	0.07	0.13	0.19	0.15
	2005	0.8	0.15	0.59	0.22	0.15	0.08	0.06	0.06	0.1			
	2006	0.23	0.11	0.14	0.09	0.13	0.09	0.12	0.08	0.21	0.09	0.09	0.13
	2007	0.55	0.12	0.49	0.8	0.28	0.14	0.06	0.09	0.14	0.08	0.1	0.11
	2008	0.22	0.12	0.21	0.19	0.49	0.11	0.11	0.09	0.39	0.27	0.28	0.22
	2009	0.48	0.41	0.44	0.18	0.23	0.34	0.11	0.14	0.14	0.11	0.12	0.11
Performance Data													
BOD	2004	31	53	38	53	65	53	55	60	61	160	90	120
	2005	120	170	1080	120	140	67	75	59	78	0	0	0
	2006	120	78	74	59	110	59	67	58	120	59	50	74
	2007	1800	50	430	2500	200	114	60	135	125	100	92	95
	2008	545	140	224	118	810	62	60	40	270	100	80	97
	2009	2600	320	1500	83.2	135	233	58.6	116	101	58.5	74	78
COD	2004	480	690	410	640	1000	990	800	1000	1000	1300	490	850
	2005	150	1200	1840	550	990	830	1230	970	780	0	0	0
	2006	540	730	540	680	840	720	580	730	570	660	610	570
	2007	3300	450	890	3160	720	850	1000	1500	890	1260	1000	910
	2008	2500	1200	1100	628	1680	580	590	470	700	370	290	450
	2009	5470	790	3430	480	603	692	561	880	771	578	630	718
DOC	2004	1200	190	150	200	380	340	298	320	322	400	280	336
	2005	300	287	510	320	600	480	825	645	185	0	0	0
	2006	148	126	133	155	277	193	158	152	200	220	160	160
	2007	900	120	300	780	280	240	249	410	260	380	300	215
	2008	515	350	270	170	600	132	195	120	98	112	89	140
	2009	1340	262	590	138	150	257	54	313	503	288	125	240

Table 3.3

Nitrogenous Pollutants in Leachate of Final Leachate Holding Tank

Parameter	**Year**	**Month**											
		1	2	3	4	5	6	7	8	9	10	11	12
Performance Data													
Ammonia	2004	230	270	140	240	330	270	300	330	300	290	320	250
	2005	200	200	180	200	340	300	450	370	290	0	0	0
	2006	120	212	170	240	270	240	190	220	46	190	190	160
	2007	140	150	110	200	230	310	320	440	230	380	310	210
	2008	360	330	280	210	220	215	299	125	119	92	85	148
	2009	250	220	168	194	174	231	227	288	319	244	290	314
Nitrate	2004	<0.5	<0.5	0.51	<0.3	<1	<0.3	<0.5	<0.3	<1	<0.3	<0.5	<0.3
	2005	<0.3	<0.3	<1	<0.5	<1	<0.5	<1	<1	<1	0	0	0
	2006	<0.5	<1	<1	<0.5	<2	<2	<2	<2	0.1	<2	<1	<2
	2007	<0.5	<1	<1	<2	<2	<2	<2	<2	<2	<2	<2	<2
	2008	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
	2009	2	2	2	2	2	2	2	2	1	2	2	2
Nitrite	2004	<1	<0.5	0.45	<0.3	<1	<1	<0.5	<1	<1	<1	<1	<1
	2005	<0.5	<0.5	<1	<0.5	<1	<1	<1	<1	<1	0	0	0
	2006	<0.5	<1	<1	<0.5	<2	<2	<2	<2	<0.1	<2	<1	<2
	2007	<0.5	<1	<1	<2	<2	<2	<2	<2	<2	<2	<2	<2
	2008	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
	2009	2	2	2	2	2	2	2	2	1	2	2	2
Total Kjeldahl Nitrogen	2004	240	580	170	290	390	300	300	430	320	300	360	520
	2005	260	250	220	300	480	400	610	700	408	0	0	0
	2006	120	275	300	300	355	280	265	272	110	350	220	320
	2007	175	164	157	309	320	368	372	607	335	520	410	270
	2008	430	340	340	290	340	350	240	140	120	98	99	200
	2009	340	250	190	233	248	263	347	359	321	341	354	387

Table 3.4

Other Pollutants in Leachate of Final Leachate Holding Tank

Parameter	**Year**	**Month**											
		1	2	3	4	5	6	7	8	9	10	11	12
Performance Data													
Alkalinity	2004	2700	2700	1600	2800	3400	2500	3200	3200	3100	3500	3500	2800
	2005	2400	2700	3100	3100	3400	3300	4700	3300	2700	0	0	0
	2006	1200	2000	1500	2300	2400	2400	2000	2300	740	1900	2150	1600
	2007	1700	1600	1400	2200	3100	3100	3400	3800	2900	3900	3400	2500
	2008	2800	3200	2500	2200	2400	2420	1900	1200	1260	1300	980	1570
	2009	2600	2500	1660	2200	2380	2680	2660	3040	3060	3030	2860	3700
Calcium	2004	150	130	170	200	150	178	187	133	112	210	170	243
	2005	240	253	641	411	392	275	307	132	155	0	0	0
	2006	268	155	117	152	89	117	148	141	261	132	20.8	139
	2007	433	144	177	286	225	154	110	130	146	125	120	112
	2008	1020	128	135	148	270	162	138	263	213	154	127	165
	2009	598	339	338	270	293	335	246	336	283	263	269	261
Chloride	2004	580	290	440	640	960	760	833	929	879	886	765	685
	2005	627	678	719	660	978	800	1160	630	761	0	0	0
	2006	505	573	449	632	681	668	515	640	243	584	569	390
	2007	454	360	310	665	759	811	1040	1350	886	1220	990	806
	2008	834	990	687	620	868	814	720	438	421	419	386	548
	2009	721	682	432	591	589	561	660	721	599	797	743	851
Conductivity	2004	6900	7900	4500	6000	7600	7100	6590	7310	7620	8690	7700	6330
	2005	5520	5640	33200	33200	49300	8420	12100	10600	8740	0	0	0
	2006	4150	5650	4090	5470	5760	5370	5070	5640	3160	5020	5310	4110
	2007	4710	3630	3430	6070	6290	7130	8160	11300	7700	10200	8750	6140
	2008	7730	8690	6430	5850	7050	6230	5450	3750	3730	3900	3090	4500
	2009	6930	6240	4640	5050	5290	5970	6340	6760	6500	6630	6780	7160
Hardness	2004	828	901	762	882	869	914	1010	630	660	1100	920	1040
	2005	1070	1140	2110	1530	1580	1300	1560	840	880	0	0	0
	2006	1070	730	610	740	660	650	780	740	1050	780	300	610
	2007	1680	770	870	1340	1200	1000	930	1050	960	860	970	740
	2008	3720	960	980	890	1230	880	740	1020	860	730	520	750
	2009	2060	1270	1210	1070	1140	1310	1130	1310	1180	1130	1130	1130
Iron	2004	11	25	5.1	3.4	4.5	3.8	4.9	4.86	9.6	2.45	2.57	2.27
	2005	3.37	3.12	2.67	2.88	4.12	5.17	6.76	5.92	4.36	0	0	0
	2006	4.31	3.37	4.49	7.1	4.8	4	4.3	3.9	13.6	5.2	0.67	4.5
	2007	14.9	4.6	5.3	17.7	5.7	3.5	2.3	6	14.1	18.6	4.4	2.3
	2008	241	2.4	4.4	3.3	10	2.2	2.1	36.9	3.6	1.9	2.67	3
	2009	9.1	1.6	16.7	1.96	3.26	4.13	1.71	3.98	1.93	<5.0	2	2.69
Magnesium	2004	110	140	82	93	120	114	132	71.2	91.1	140	121	106
	2005	113	122	125	122	146	149	194	125	120	0	0	0
	2006	97.6	84.2	77.5	88	107	86	101	95	98	57	59.4	64
	2007	144	100	104	151	155	149	160	180	144	132	164	113
	2008	280	154	137	127	130	116	97	88	79	83	18.4	82
	2009	138	103	90	97.4	68.3	116	125	115	116	116	111	115
pH	2004	6.9	6.9	7	6.9	7.2	7	6.9	7.1	6.9	7.03	6.96	7.17
	2005	7.13	6.84	7.09	7.23	6.97	6.95	7.59	7.08	6.99	0	0	0
	2006	7.66	7.12	7.42	7.21	6.93	7.08	7.07	7.24	6.88	7.25	8.35	7.05
	2007	6.99	7.13	6.7	7.32	7.27	7.33	7.35	7.24	7.08	7.74	7.53	7.29
	2008	7.06	7.47	7.47	7.47	7.59	7.38	7.48	7.3	7.27	6.82	7.78	7.52
	2009	6.57	7.07	7.18	7.24	7.55	7.47	7.41	7.53	7.43	7.47	7.27	7.61
Phenols	2004	16	25	9	10	<1	25	64	12	83	203	150	203
	2005	195	178	945	247	228	135	292	203	208	0	0	0
	2006	48	164	221	142	310	264	271	177	30	87	170	316
	2007	428	185	431	528	204	9	76	94	212	19	193	160
	2008	321	271	271	261	554	141	116	12	220	100	89	208
	2009	930	622	763	141	221	339	29.2	210	453	153	107	540
Phosphorus	2004	1.2	2.2	0.15	1.4	1.5	1.8	1.5	4	1.8	1.8	2.2	4
	2005	1.4	1.6	2.2	3.1	4.4	4.6	4	3	40	0	0	0
	2006	1.4	1.9	0.8	4.4	4	1.8	1.1	1.4	3	1	0.8	1.2
	2007	4	0.9	0.8	1.8	1.3	1.6	1.4	3.1	1.7	3.1	1.8	1.1
	2008	1.3	1.7	1.7	2	2.3	2.3	1.7	1.4	0.8	0.8	0.6	1.4
	2009	12	3.1	3.3	2.47	3.25	6.18	4.02	6.18	4.93	3.66	5.21	5.57
Sodium	2004	590	880	440	540	860	833	700	520	582	923	788	631
	2005	632	660	609	773	951	769	1360	899	708	0	0	0
	2006	416	483	428	453	696	545	524	569	273	380	1020	310
	2007	532	425	311	590	662	811	920	1240	979	1151	974	530
	2008	888	515	515	550	800	640	550	380	332	230	305	378
	2009	627	540	370	470	408	547	566	631	625	601	647	716
Sulphate	2004	31	260	130	60	25	9.1	<10	43	120	23	17	29
	2005	11	23	<20	8	<20	<10	<20	<20	<20	0	0	0
	2006	485	90	102	41	<40	<40	<40	59	427	114	22	<40
	2007	408	20	66	90	<40	<40	<40	71	<40	<40	<40	51
	2008	111	<40	<40	46	57	<40	<40	117	277	<40	90	111
	2009	471	<40	402	61.8	42.1	<40	<40	<40	<20	<40	<40	<40
Total Suspended Solid	2004	43	70	27	8	22	16.3	11	17	25	15	11	<1
	2005	4	12	44	35	480	16	29	18	14	0	0	0
	2006	35	18	20	83	44	30	19	14	190	31	4	25
	2007	90	30	60	68	64	18	13	92	32	55	17	9
	2008	140	120	120	22	340	24	24	1000	56	41	95	30
	2009	44	18	250	12.8	29	70	8	96	15.2	14.4	6.8	10

consideration of influential factors such as climatic conditions in terms of temperature and precipitation and also the waste age.

Performance data are obtained from the Mature Age Leachate Sampling Point where leachate is collected from the part landfill that is in operation of over fifteen years while at the Average Age Leacate Sampling Point leachate is collected from the part of landfill that is in operation of over five years in additional to the Final Leachate Holding Tank where leachate is collected from the entire landfill. In this context, the overall performance data of the Mature Age Sampling Leachate Point and the Average Age Leachate Sampling Point are exhibited in Tables 3.5 and 3.6 respectively. The parameters evaluated in this study take into consideration of carbonaceous parameters include BOD, COD and DOC, nitrogeneous parameters include ammonia, nitrate, nitirte, TKN and other parameters include alkalinity, calcium, chloride, conductivity, hardness, iron, magnesium, pH, phenols, phosphorus, sodium, sulphate and total suspended solids.

Table 3.7 depicts the selected performance data from the Mature Age Leachate Sampling Point where four sets of data are identified for model study purposes to reflect the effect of climatic conditions posed to the mature landfill operation. Data number 1 reflect the performance data of mature landfill experiencing both normal temperature and normal precipitation as compared to data set 2 where landfill experiencing both high temperature and high precipitation. On the other hand, data number 3 and 4 reflect the experience of only high temperature and high precipitation respectively.

Table 3.5

Overall Performance Data of Landfill Leachate in Mature Age Sampling Leachate Point

	5/28/ 1996	11/26/ 1996	5/12/ 1997	11/25/ 1997	5/5/ 1998	11/9/ 1998	5/19/ 1999	5/2/ 2000	5/3/ 2001	11/9/ 2001	5/13/ 2002	5/15/ 2003	5/20/ 2004	5/10/ 2005	5/10/ 2006	5/10 /2007	5/6/ 2008	5/4/ 2009
Data																		
Carbonaceous																		
BOD	122	106	173	278	269	253	91.2	104	40.8	143	61.9	36.0	79.0	160	120	505	870	113
COD	803	867	1070	1110	829	1020	844	793	690	409	664	690	1100	790	840	1180	1510	549
DOC	254	449	503	352	309	-	162	146	205	137	212	160	400	650	226	410	500	150
Nitrogenous																		
Ammonia	337	238	300	343	268	523	155	301	296	78.5	225	250	320	310	280	200	96.0	160
Nitrate	0.10	0.10	0.10	0.99	0.1	0.5	0.50	0.04	0.12	0.04	0.07	0.50	1.0	1	2	2	2	2.0
Nitrite	0.10	0.10	0.10	0.10	0.1	0.5	0.50	0.10	0.10	0.10	0.1	1.0	1.0	1	2	2	2	2.0
Total Kjeldahl Nitrogen	337	249	311	362	269	663	211	321	305	90.3	231	340	360	360	384	276	150	261
Others																		
Alkalinity	2615	2841	3160	3320	1680	3540	2090 J	2720	2460	1190	2590	960	3400	4100	2300	2500	1200	2200
Calcium	273	205	184	108	151	110	98.0	126	62.4	177	233	110	180	405	140	211	180	321
Chloride	670	874	834	1110	816	1100	811	826	777	349	715	410	910	955	682	598	275	519
Conductivity	6400	4500	11400	10400	7850	10400	-	7840	-	-	6000	6930	7410	7870	5660	5540	3390	5040
Hardness	1332	1130	1000	858	1120	1160	925	933	468	823	1070	645	1000	1630	770	1100	760	1240
Iron	32.6	19.4	17.8	13.7	17.5	18.8	13.0	18.8	3.89	6.09	3.13	12	4.6	4.33	3.7	5.1	5	2.92
Magnesium	158	150	132	143	181	215	165	150	75.7	92.6	120	90	140	151	103	138	80	106
pH	6.7	7.1	6.97	6.99	6.77	6.91	-	6.75	-	-	7.38	6.86	6.95	6.63	6.68	7.01	6.27	7.00
Phenols	78	567	28	15	29	35	19	16	21	20	30	7	1.0	260	326	640	951	115
Phosphorus	0.60	1.10	1.52	0.20	12.6	2.11	1.61	2.21	1.04	0.60	1.25	1.00	1.80	4.20	7.00	1.20	0.70	3.02
Sodium	496	910	779	607	1030	960	895	960	370	297	700	540	960	938	734	517	290	401
Sulphate	156	771	25.7	31.5	26.2	22.0	13.4	7.03	60.3	93.6	22.5	22.0	40.0	20	40	40	40	40
Total Suspended Solid	140	20	102	30	36	75	105	66	141 J	150	22	248	39.0	54	56	48	65	53.5

Table 3.6

Overall Performance Data of Landfill Leachate in Average Age Sampling Leaching Point

	5/10/2005	5/10/2006	5/10/2007	5/6/2008	5/4/2009
Data					
Carbonaceous					
BOD	3220	6350	25	550	13.1
COD	5550	9600	500	2330	226
DOC	1750	3490	170	700	90.0
Nitrogenous					
Ammonia	480	200	140	520	103
Nitrate	1	2	2	2	2.0
Nitrite	1	2	2	2	2.0
Total Kjeldahl Nitrogen	880	309	203	820	162
Others					
Alkalinity	5400	3400	2100	5200	1510
Calcium	628	1060	163	130	126
Chloride	1410	848	439	1180	322
Conductivity	12100	7850	4540	9600	3440
Hardness	2300	3360	1090	850	799
Iron	73.8	71.2	5.7	6	3.84
Magnesium	179	175	166	130	118
pH	6.52	5.92	6.61	6.75	6.80
Phenols	1020	1720	6	1170	3
Phosphorus	12.0	17.0	0.90	4.60	0.128
Sodium	1370	749	393	1030	279
Sulphate	138	509	139	40	158
Total Suspended Solid	240	160	60	47	37.0

Table 3.7

Selected Performance Data of Landfill Leachate in Mature Age Sampling Leachate Point For Modelling

Data Number	1	2	3	4
Nature	• Mature Landfill • Average Temperature • Average Precipitation	• Mature Landfill • High Temperature • High Precipitation	• Mature Landfill • High Temperature • Average Precipitation	• Mature Landfill • High Precipitation • Average Temperature
Date	5/10/2008	5/10/2006	5/10/2007	5/4/2009
Carbonaceous				
BOD	810	110	200	135
COD	1680	840	720	603
DOC	600	277	280	150
Nitrogenous				
Ammonia	220	270	230	174
Nitrate	<2	<2	<2	2
Nitrite	<2	<2	<2	2
Total Kjeldahl Nitrogen	340	355	320	248
Others				
Alkalinity	2400	2400	3100	2380
Calcium	270	89	225	293
Chloride	868	681	759	589
Conductivity	7050	5760	6290	5290
Hardness	1230	660	1200	1140
Iron	10	4.8	5.7	3.26
Magnesium	130	107	155	68.3
pH	7.59	6.93	7.27	7.55
Phenols	554	310	204	221
Phosphorus	2.3	4	1.3	3.25
Sodium	800	696	662	408
Sulphate	57	<40	<40	42.1
Total Suspended Solid	340	44	64	29
Model Reference	x_3	$x_7 = x_1\ x_2\ x_3$	$x_5 = x_1\ x_3$	$x_6 = x_2\ x_3$

Table 3.8 depicts the selected performance data at the Average Age Leachate Sampling Point where four sets of data are identified for model study purposes to reflect the climatic condition posed to the new or average age landfill operation. Data number 5 reflects the performance data of average age landfill experience both high temperature and high precipitation as compare to data

number 6 and 7 reflects the experience of average age mature landfill at high temperature and high precipitation

Table 3.8

Selected Performance Data of landfill Leachate in Average Age Sampling Leachate Point For Modelling

Data Number	5	6	7	8
Nature	• Average Age Landfill • High Temperature • High Precipitation	• Average Age Landfill • High Temperature • Average precipitation	• Average Age Landfill • Average Temperature • High Precipitation	• Average Age Landfill • Average Temperature • Average Precipitation
Parameter	5/10/2009	5/10/2009	5/10/2009	5/6/2005
Carbonaceous				
BOD	13.1	25	6350	3220
COD	226	500	9600	5550
DOC	90	170	3490	1750
Nitrogenous				
Ammonia	103	140	200	480
Nitrate	<2	<2	<2	1
Nitrite	<2	<2	<2	1
Total Kjeldahl Nitrogen	162	203	309	880
Others				
Alkalinity	1510	2100	3400	5400
Calcium	126	0.001	1060	628
Chloride	322	439	848	1410
Conductivity	3440	4540	7850	12100
Hardness	799	1090	3360	2300
Iron	3.84	5.7	71.2	73.8
Magnesium	118	0.01	175	179
pH	6.80	6.61	5.92	6.52
Phenols	0.003	0.006	1.720	1.02
Phosphorus	4.6	0.90	17	12
Sodium	1030	3.93	749	1370
Sulphate	40	139	509	138
Total Suspended Solid	47	60	160	240
Model Reference	$x_4 = x_1 x_2$	x_1	x_2	x_0

respectively where data number 8 reflects the average age landfill at both average temperature and average precipitation.

3.1 Methods

Data from the Final Leachate Holding Tank that reflect the performance of the entire landfill site are evaluated over a period of six years to assess the characteristic of pollutants leaching out.

The carbonaceous pollutants are evaluated in terms of BOD, COD and DOC. The nitrogeneous pollutants matters such as ammonia, nitrate, nitrite and TKN are evaluated. Others pollutants such as calcium, chloride, iron, magnesium, sodium and sulfate of the landfill leachate and xenobiotic organic compounds include phenols are also evaluated.

Data analysis is performed using the ANALYSE-IT and Microsoft Excel Tools and various graphical and statistical techniques such as chronological analysis, analysis of variance and cluster analysis are used to characterize leachate from this landfill site. In order to identify trends in pollutant levels, a plot of each parameter versus time is developed. Every pollutant measured in the study period of six years is used to create the graphs respectively.

Data from both the Mature Age Leachate Sampling Point and the Average Age Leachate Sampling Point are evaluated over fifteen years and five years to assess the differences in characteristic of old and young landfills. All parameters are analyzed in term of maximum and minimum value with mean (χ) and standard deviation (σ) over the period of data collection.

A multiple regression approach is used together with data collection to obtain correlation relationship in order to develop mathematic model to predict pollutants leaching from landfill to factors influencing landfill performance include climatic conditions such as temperature and precipitation and landfill waste age.

In this model development, x_1, x_2 and x_3 denotes factor affecting leachate quality in terms of temperature, precipitation and age of landfill respectively. The interaction of these factors are represented as :

$$x_4 = x_1 x_2$$

$$x_5 = x_1 x_3$$

$$x_6 = x_2 x_3$$

$$x_7 = x_1 x_2 x_3$$

Based on all these assumption, the dependent variable, y. which is linearly related to all the above independent variables, x_1, x_2, x_3, x_4, x_5, x_6 and x_7 are used to predict the pollutants leach out from the landfil. This relationship can be represented as

$$y_i = \alpha + \beta_1 x_{i1} + \beta_2 x_{i2} + \ldots\ldots\ldots\ldots + \beta_7 x_{i7} \tag{3.1}$$

thus to estimate α and the partial regression coefficient by the approach of least squares and utilized the least squares surface

$$y_i = a + b_1 x_{i1} + b_2 x_{i2} + \ldots\ldots\ldots\ldots + b_7 x_{i7} \tag{3.2}$$

in order to predict y.

The model development is designed with eight factors as follows:-

$$\begin{aligned} y_1 &= a + b_1 x_{11} + \ldots\ldots\ldots\ldots + b_7 x_{17} \\ y_2 &= a + b_1 x_{21} + \ldots\ldots\ldots\ldots + b_7 x_{27} \\ &\vdots \\ y_1 &= a + b_1 x_{81} + \ldots\ldots\ldots\ldots + b_7 x_{87} \end{aligned} \tag{3.3}$$

leads to the structural matrix :

$$M = \begin{pmatrix} 1 & x_{11} & x_{12} \ldots\ldots\ldots\ldots\ldots\ldots\ldots x_{17} \\ 1 & x_{21} & x_{22} \ldots\ldots\ldots\ldots\ldots\ldots\ldots x_{27} \\ \vdots & & \\ 1 & x_{81} & x_{82} \ldots\ldots\ldots\ldots\ldots\ldots\ldots x_{87} \end{pmatrix} \tag{3.4}$$

Minimizing

$$Q = \sum_{i=1}^{8} (y_i - y_i)^2 = \sum_{i=1}^{8} (y_1 - a - b_1 x_{i1} - \ldots\ldots\ldots . - b_i x_{i7})^2 \tag{3.5}$$

Solve for a, b_1 , b_2 , ………..b_7 in which

$$\frac{\partial Q}{\partial a} = -2 \sum_{i=1}^{8} (y_i - y_i) = 0 \tag{3.6}$$

$$\frac{\partial Q}{\partial b_j} = -2 \sum_{i=1}^{8} (y_i - y_i) x_{ij} = 0 \tag{3.7}$$

$i = 1, 2, \ldots\ldots\ldots\ldots, 8 \qquad j = 1, 2, \ldots\ldots\ldots\ldots, 7$

Thus having

$$8a + \left(\sum_{i=1}^{8} x_{i1}\right) b_1 + \left(\sum_{i=1}^{8} x_{i2}\right) b_2 + \left(\sum_{i=1}^{8} x_{i7}\right) b_7 = \sum_{i=1}^{8} y_i$$

$$\left(\sum_{i=1}^{8} x_{i1}\right) a + \left(\sum_{i=1}^{8} x_{i1}^{2}\right) b_1 + \left(\sum_{i=1}^{8} x_{i1}\, x_{i2}\right) + \ldots + \left(\sum_{i=1}^{8} x_{i1}\, x_{i7}\right) b_7 = \sum_{i=1}^{8} x_{i1}\, y_i$$

$$\vdots \qquad \vdots \qquad \vdots \qquad \vdots \qquad \vdots$$

$$\left(\sum_{i=1}^{8} x_{i7}\right) a + \left(\sum_{i=1}^{8} x_{i1}\, x_{i7}\right) b_1 + \ldots\ldots\ldots\ldots\ldots\ldots\ldots + \left(\sum_{i=1}^{8} x_{i7}^{2}\right) b_7 = \sum_{i=1}^{8} x_{i7}\, y_i \tag{3.8}$$

Thus, the coefficient of matrix become

$$A = \begin{pmatrix} 8 & \sum\limits_{i=1}^{8} x_{i1} & \sum\limits_{i=1}^{8} x_{i2} \ \ldots\ldots\ldots\ldots\ldots & \sum\limits_{i=1}^{8} x_{i7} \\ \sum\limits_{i=1}^{8} x_{i1} & \sum\limits_{i=1}^{8} x_{i1}^{\ 2} & \sum\limits_{i=1}^{8} x_{i1}\ x_{i2} \ \ldots\ldots\ldots & \sum\limits_{i=1}^{8} x_{i1}\ x_{i7} \\ \vdots & \vdots & \vdots & \vdots \\ \sum\limits_{i=1}^{8} x_{i7} & \sum\limits_{i=1}^{8} x_{i1}\ x_{i7} \ \ldots\ldots\ldots & \ldots\ldots\ldots\ldots\ldots & \sum\limits_{i=1}^{8} x_{i7}^{\ 2} \end{pmatrix}$$

$$= \begin{pmatrix} 1 & 1 & 1 \ldots\ldots\ldots & 1 \\ & & & \\ x_{11} & x_{21} & x_{31} & x_{81} \\ \vdots & \vdots & \vdots & \vdots \\ x_{17} & x_{27} & x_{37} & x_{87} \end{pmatrix} \begin{pmatrix} 1 & x_{11} & x_{12} \ldots\ldots\ldots\ldots x_{17} \\ 1 & x_{21} & x_{22} \ldots\ldots\ldots\ldots x_{27} \\ 1 & x_{31} & x_{32} \ldots\ldots\ldots\ldots x_{37} \\ \vdots & & \vdots \\ 1 & x_{81} & x_{82} \ldots\ldots\ldots\ldots x_{87} \end{pmatrix}$$

$$= \mathbf{M}\ \mathbf{M}^{\mathbf{T}}$$

Let

$x_{ij} = 1$ or $x_{ij} = -1$

$$\sum_{i} x_{ij} = 0$$

$$\sum_{i} x_{ij} = 0$$

$$\sum_{i} x_{ik}\, x_{ij} = 0$$

Where

$i = 1, 2, \ldots\ldots\ldots\ldots 8$

$j = 1, 2, \ldots\ldots\ldots\ldots 7$

$k = 1, 2, \ldots\ldots\ldots\ldots 7$

$j \neq k$

Then

$$A = \begin{pmatrix} 8 & & & & 0 \\ & 8 & & & \\ & & \cdot & & \\ & & & \cdot & \\ & & & & \cdot \\ 0 & & & & 8 \end{pmatrix}$$

considered left hand side of equation (8), let

$$= \begin{pmatrix} \sum\limits_{i=1}^{8} y_1 \\ \sum\limits_{i=1}^{8} x_{i1} \; y_{-i} \\ \vdots \\ \sum\limits_{i=1}^{8} x_{i7} \; y_{-i} \end{pmatrix} = \begin{pmatrix} B_O \\ B_1 \\ \vdots \\ B_7 \end{pmatrix}$$

From Equation (8)

$$b = A^{-1}B \qquad\qquad b' = (a, b_1 \ldots\ldots\ldots b_7)$$

$$a = \frac{1}{8} \sum_i y_i = \frac{B_O}{8}$$

$$b_j = \frac{1}{8} \sum_i x_{ij} \, y_i = \frac{B_j}{8}$$

The data collected from both Average Age Leachate Sampling Point and Mature Age Leachate Sampling Point are used to calibrate the model developed and simulate the prediction model for landfill leachate characterization. It is anticipated that the Pollution Prediction Model using the multiple regression thus developed can be used to predict pollutants leaching from the landfill taking into consideration of factor affecting performance in term of temperature, precipitation and age of landfill.

The research methodology of this study are designed to identify correlation relationship of pollutants to factors affecting leachate quality and to develop prediction models to determine the effects of climate and landfill age on leachate quality.

CHAPTER 4

RESULTS AND DISCUSSION

4.0 Pollutants Leaching from Landfill

Results of this study cover the establishment of correlation relationship and the development of Pollution Prediction Model to predict pollutant leaching from landfill take into consideration of factor affecting leachate quality such as climatic condition include temperature and precipitation and waste age.

4.1 Characterization of Pollutants in Leachate from Landfill

Landfill designed with an engineered hydraulic trap to contain and collect leachate to minimize groundwater impact as shown in Figure 4.1 is used in this study. It is also equipped with proper drainage to ensure good surface water management. At this site, leachate is recirculated with the intention to control strata moisture for effective waste decomposition. This water recirculation is particularly important to ensure sufficient moisture movement through the waste strata to stimulate effectiveness of waste degradation.

Over the six years period of analysis, moderate temperature ranging from 3 to 36 ^{o}C and moderate rainfall ranging from 25.7 to 244.3 mm as depicted in Table 4.1 and Figure 4.2 and Figure 4.3 respectively are observed at this landfill site. It is thus suggested that good climatic condition are observed most of the time.

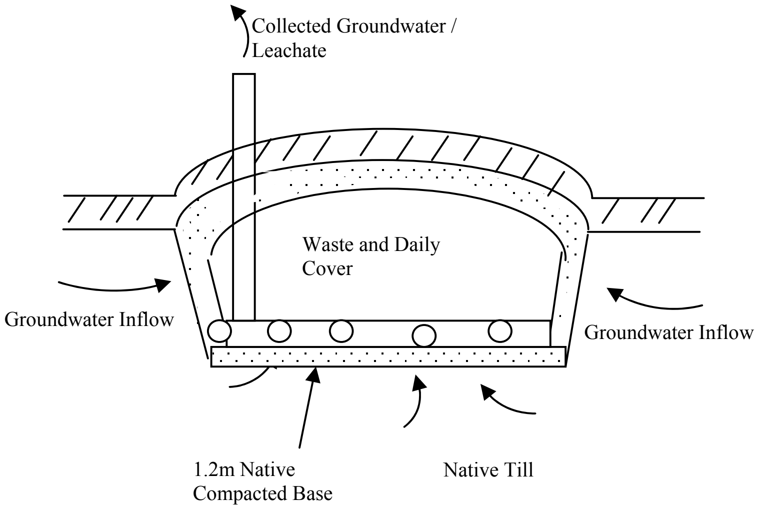


Figure 4.1

Landfill with Hydraulic Trap

Generally, leachate is generated due to precipitation percolating through the waste layers in the landfill where a series of physical, chemical and biological reactions are taken place. The mechanism of these reactions reduce the complexity of leachate eventually diffuse from the landfill.

Table 4.1

Climatic Data At Landfill Site

Parameter	Max Value	Min Value	Mean	Standard Deviation
Temperature (^{0}C)				
Low	12.9	-24.2	-2.7	11.6
High	36	3	25.4	34.7
Precipitation (mm)	244.3	14.9	67.7	29.4

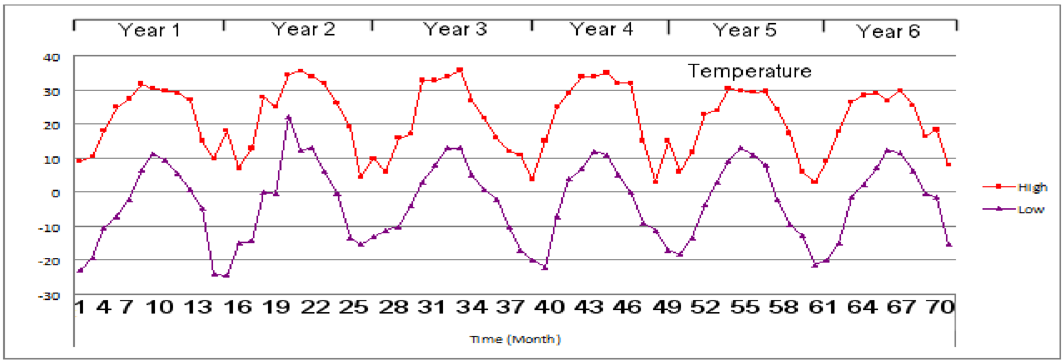


Figure 4.2 Temperature Over The Study Period

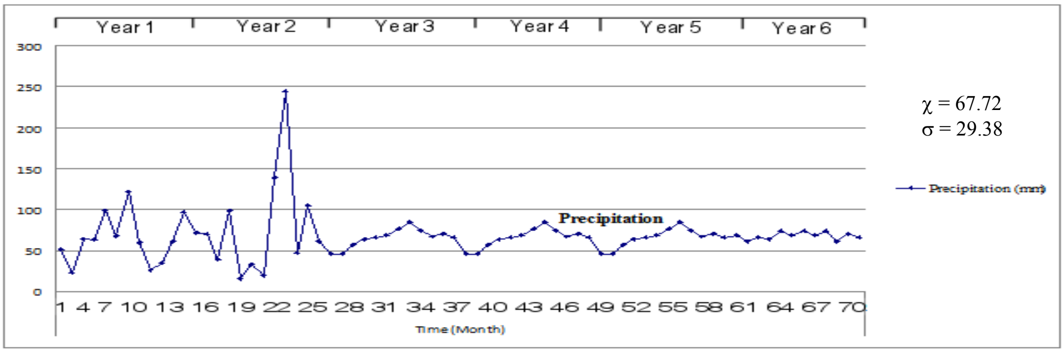


Figure 4.3 Precipitation Over The Study Period

4.1.1 Carbonaceous Pollutants in Leachate of Final Leachate Holding Tank

The wide range of composition found in the leachate is mainly attributed to the decomposition of carbonaceous organic matter by acetogenic bacteria converting insoluble organic matter to soluble organic matter and methanogenic bacteria converting soluble organic matter to methane and carbon dioxide. Like most mature landfill site, the removal of organic matter is essentially completed as depicted by relatively low values of BOD, COD and DOC. As depicted in Table 4.2 and Figure 4.4, minimum value of BOD, COD and DOC of 31, 150 and 54 mg/l with mean values of 250.4, 986.2 and 320.8 mg/l respectively were achieved. Peak values of BOD, COD and DOC of 2600, 3430 and 1340 mg/l were however observed due to incomplete waste decomposition. The low concentration of carbonaceous organic matter in terms of BOD and COD achieved is likely caused by the active degradation of waste taken place that cause stimulation of methanogenesis which is also illustrated by increase pH value observed in the period.

There is no significant observable increasing and descreasing trend noted in all values of BOD, COD and DOC. BOD values ranged from 31 to 2600 mg/l, COD values ranged from 150 and 3430 mg/l and DOC ranged from 54 to 1340 mg/l. Both ranges of the BOD and COD values are in the order of magnitude similar to values reported in the literature. Lower values of BOD and COD concentrations obtained are good indication of degradation of organic matters. Slightly higher carbonaceous pollutants in year 4 and year 6 are possibly due to opening of new cells where new cells are activated so Final Leachate Holding Tank is receiving combined leachates from newer and older part the landfill site.

It is also observed that low BOD:COD ratios of less than 0.1 are observed most of the time. BOD:COD ratio is found to be most reliable and useful indicator to relate the organic matter content in leachate to landfill performance. Typical range of BOD:COD ratio of 0.06 to 0.80 with average value of 0.58 for acetogenic leachate and 0.06 for methanogenic leachate are reported in the literature. Over the six years study period, BOD:COD ratios in this landfill are observed to be in the range of 0.06-0.8. Results reveal that low value of biodegradability suggested decomposition of organic matter in leachate is nearly completed indicating transition from acetogenic phase to methanogenic phase in the landfill. BOD is a measurement for biological content thus BOD:COD ratio is a good indicator of biological organic matter in the leachate indirectly reflect the waste age in the landfill. It is however anticipated that low BOD:COD ratio

Table 4.2

Carbonaceous Pollutant Concentration in Final Leachate Holding Tank

Parameter	Maximum value	Minimum Value	Mean	Standard Deviation
BOD (mg/l)	2600.0	31.0	250.4	503.8
COD (mg/l)	3430.0	150.0	986.2	833.8
DOC (mg/l)	1340.0	54.0	320.8	243.1
BOD:COD Ratio	0.8	0.06	0.19	0.17
pH	8.35	6.57	7.22	0.29

Figure 4.4 Carbonaceous Pollutant Concentration in Final Leachate Holding Tank

in leachate made subsequent biological treatment less effective. This chronologic pattern of BOD:COD ratio is of significant important as the values reflect the comparison of acetogenic and methanogenic phase achieved with average ratio of 0.58 and 0.06 respectively.

4.1.2 Nitrogeneous Pollutants in Leachate of Final Leachate Holding Tank

As the carbonaceous organic concentration decreases in the leachate, nitrogeneous concentration such as ammonia nitrogen increases causing activation of nitrification and denitrification to taken place in the waste strata. It is reported that typical range of ammonia nitrogen of 46-450 mg/l with an average value of 238.8 mg/l can be found in leachate composition.

Table 4.3 depicts the low value of nitrogenous matter in term of ammonia, nitrite, nitrate and TKN of 46, 0.3, 0.3 and 98 mg/l with mean values of 238.8, 1.462, 1.394 and 313.4 mg/l respectively however with peak values of 450, 2, 2 and 700 mg/l.

Due to decreasing carbonaceous organic matter in the leachate, ammonia nitrogen is anticipated to occur at relatively higher concentration as compared to carbonaceous concentration such as BOD or COD that demand large amount of oxygen. Figure 4.5 showed significantly fluctuating NH_3-N value with increasing trend of nitrate, nitrite and TKN signify occurrence of nitrification and denitrification taken place as the landfill is getting mature.

Table 4.3

Nitrogenous Pollutant Concentration in Final Leachate Holding Tank

Parameter	Maximum value	Minimum Value	Mean	Standard Deviation
Ammonia (mg/l)	450	46.0	238.8	82.0
Nitrite (mg/l)	2	0.3	1.462	0.629
Nitrate (mg/l)	2	0.3	1.394	0.707
TKN (mg/l)	700	98.0	313.4	121.9

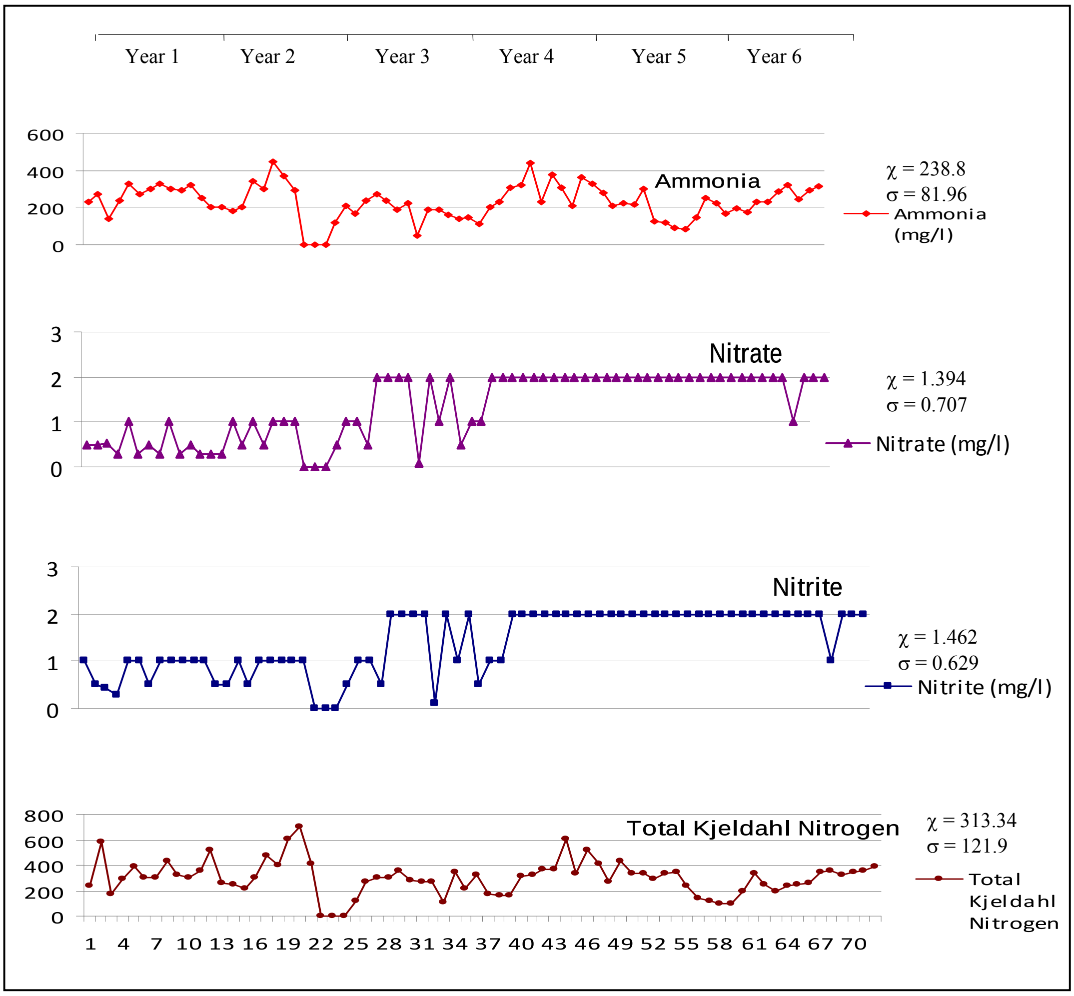


Figure 4.5 Nitrogenous Pollutant Concentration in Final Leachate Holding Tank

4.1.3 Other Pollutants in Leachate of Final Leachate Holding Tank

In the active decomposing waste strata in the landfill, non-conservative constituents in leachate such as metal ions which are relatively insoluble at neutral pH become dissolved as pH falls in the leachate except conservative constituents like chloride, sulfate and other residue of decomposition.

These values are depicted in Table 4.4 and Figure 4.6. Results reveal that more non-biodegradable residues are released in the leachate as the dissolved organic matter in the leachate decreases.

Both Table 4.4 and Figure 4.6 showed no significant observable increasing and decreasing trend of other pollutants concentrations in the leachate. Calcium values ranged from 20.8 to 1020 mg/l are observed to be relatively low as compared to those reported value of 10 to 7200 mg/l in the literature. Chloride values ranged from 243 to 1350 mg/l are comparable to those reported value of 2120 mg/l. Low iron values are achieved in the range of 0.67 to 241 mg/l as compared to range of 20-2100 mg/l and 3-2800 mg/l for acetogenic and methanogenic phases respectively. This is a good indication of occurrence of methanogenic phase in this landfill site.

Magnesium values ranged from 18.4 to 280 mg/l as compared the reported range of 50-1150 mg/l and 40-350 mg/l for acetogenic phase and methanogenic phase respectively. Sodium values ranged from 230 to 1360 mg/l as compared to reported value of 1340 mg/l. Sulfate values ranged from 9.1 to 485 mg/l as compared to reported range 7 of 70-1750 mg/l and 10-420 mg/l for acetogenic and methanogenic phases respectively.

Table 4.4

Other Pollutant Concentration in Final Leachate Holding Tank

Parameter	**Maximum value**	**Minimum Value**	**Mean**	**Standard Deviation**
Calcium (mg/l)	1020	20.8	224.6	146.2
Chloride (mg/l)	1350	243.0	687.7	217.3
Iron (mg/l)	241	0.67	9.348	28.91
Magnesium (mg/l)	280	18.4	115.2	36.58
Sodium (mg/l)	1360	230.0	633.3	231.6
Sulfate (mg/l)	485	9.1	81.75	111.4
Phenol (mg/l)	945	1.0	220.9	200.3

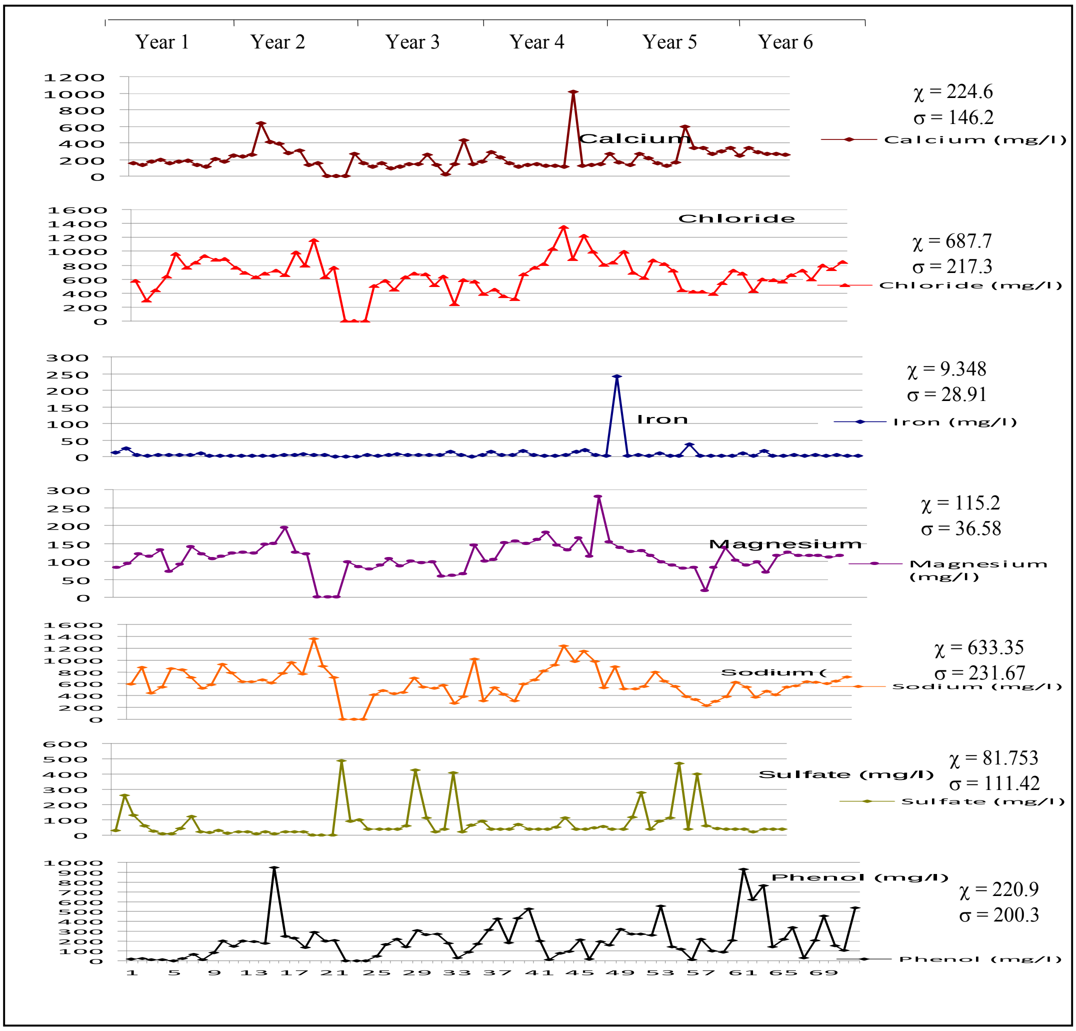


Figure 4.6 Other Pollutant Concentration in Final Leachate Holding Tank

4.2 Acetogenic and Methanogenic Leachates

In this study, results obtained reveal that mixed leachates generated from this landfill are anticipated to undertake various stages of decomposition particularly change from acetogenic phase with high organic strength leachate to methanogenic stage where organic matters are actively converted to landfill gas. It is also inferred that the recirculation of leachate at this landfill has enhanced decomposition and made leachate characteristics to be more predictable.

4.2.1 Phases of Decomposition

The trend result also reveals as water passes through waste strata layer in this landfill, it triggers and activates waste decomposition due to present of microorganisms.

The trend also reveals that major processes involved in the decomposition within this landfill waste strata are extensive and broad and the overlapping phases of decomposition consist of four phases are also taken place.

Phases 1 and 2 of the decomposition involves aerobes in which aerobic decomposition occur rapidly that consumes up almost all oxygen present in the waste strata over a short period of time.

Phase 3 of the decomposition involves anaerobic and facultative microorganisms (i.e. acetogenic bacteria) that hydrolyse and ferment cellulose and other putrescible matters resulting in production of simpler and soluble organic matter with high BOD and ammonia nitrogen.

Phase 4 of the decomposition involves more sensitive and slower growing methanogenic bacteria and use up these soluble organic matter in turn generating carbon dioxide and methane as well as other trace constituents.

In order to explain well the trend of performance data obtained from this landfill site, the decomposition are assumed to carry out in two phases, firstly soluble organic matter produced due to aerobic decomposition or acetogenic phase and secondly methane and carbon dioxide produce due to anaerobic decomposition or methanogenic phase.

During acetogenic phase, it is assumed that microorganisms convert insoluble organic compounds to acetic acid, carbon dioxide and hydrogen by acetogenic bacteria. As illustrated in the data obtained in this landfill, leachate generated in the acetogenic phase typically are characterized by high BOD value, high BOD:COD ratio illustrating a high concentration of soluble organic matters that are biodegradable and pH value that is acidic and high ammonia concentration. Such aggressive nature of reaction prompts dissolution of other components in wastes resulting in high concentration of iron, magnesium, zinc and calcium.

On the other hand, microorganisms in methanogenic phase as shown in the data obtained that can remove soluble organic matter are assumed to be gradually established due to absence of oxygen. The decomposition is transited to methanogenic phase thus thrives to convert soluble organic matter to methane and carbon dioxide thus release as landfill gas. As depicted in the data trend, methanogenic leachate generated is characterized by low BOD value and low ratio of BOD:COD with high concentration of ammonical nitrogen and inorganic matters such as iron, sodium, potassium, sulphate and chloride due to active dissolution.

4.2.2 BOD : COD Ratio

BOD:COD ratio is a good indicator for degradation of organic matter that differentiate the acetogenic phrase from methanogenic phase in this landfill which trickles leachate. Figure 4.7 depicts the ratio of BOD:COD spread over the six years in the landfill studied.

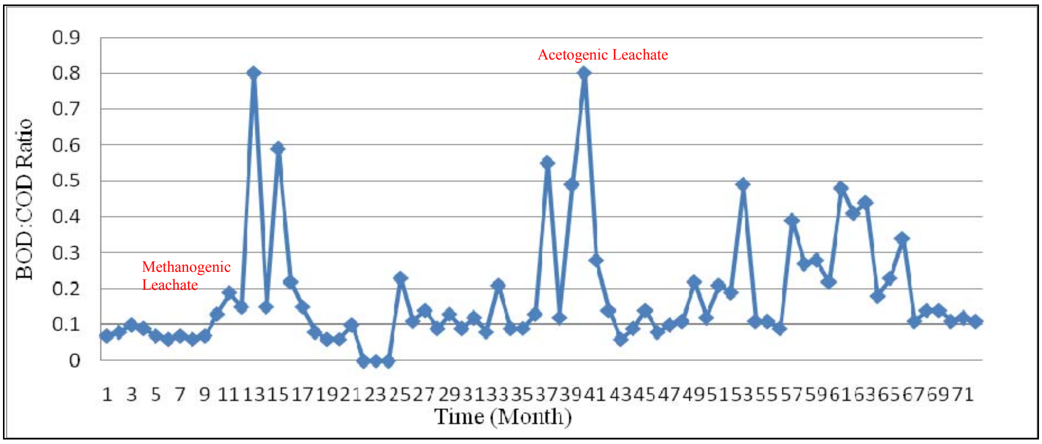


Figure 4.7 Ratio of BOD:COD Over 6 Years Duration

The ratio of BOD:COD computed for the landfill exhibited that more than 90% of time leachate in the landfill experienced methanogenic phase.

The results of leachate generated containing low ratio of BOD:COD indicate that the decomposition is stabilized, biological active and dynamically in equilibrium.

4.3 Factors Affecting Leachate Characteristics

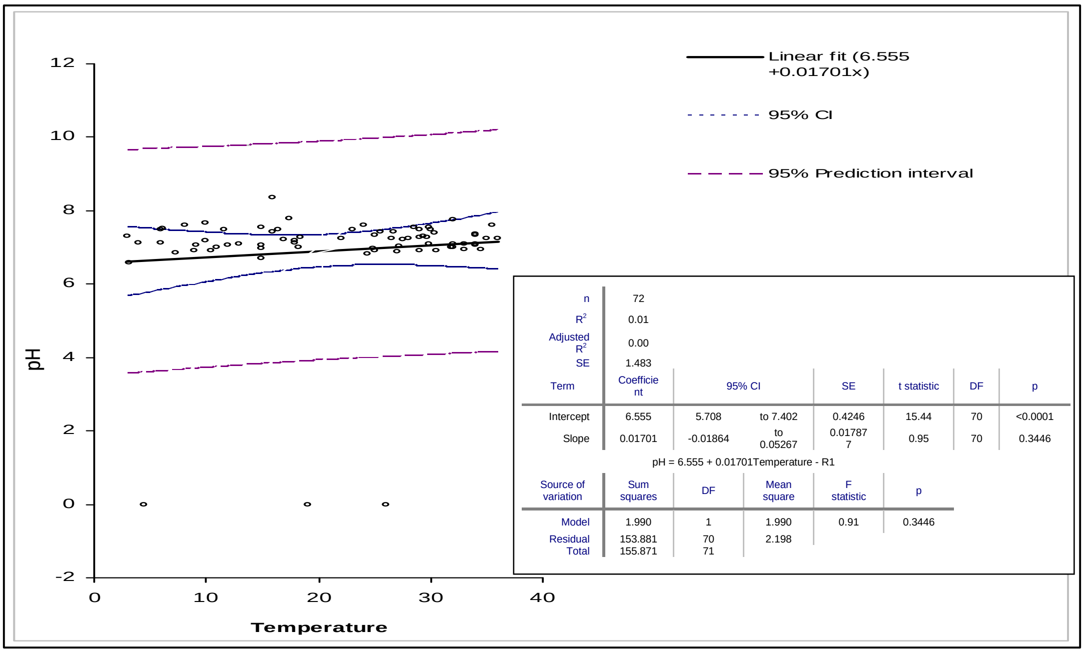
Results of evaluation also revealed that the intensity of decomposition is significantly affected by various external factors such as climatic conditions in terms of environmental temperature and precipitation and waste age.

4.3.1 Temperature

Leachate temperature in landfill is affected by the climatic temperature due to fluctuation of ambient temperature. Temperature poses impact to bacterial growth and chemical reaction. Bacterial growth is constraint by particular individual optimum growth temperature and any temperature will retard growth due to its enzyme deactivation and cell wall rupture. Also, temperature poses solubility of many compounds either increase or decrease that affect the quality of leachate. It is also reported that numerous compounds in leachate such as $CaCO_3$ and $CaSO_4$ show a decrease in solubility as temperature increase.

Correlation relationship of leachate concentration to temperature is evaluated in terms of physical properties of pH, alkalinity, hardness, conductivity and total suspended solid; organic matters of BOD, COD and DOC; inorganic matters of sulphate, chloride, ammonia, calcium, magnesium, sodium, iron, nitrate, nitrite and TKN and xenobiotic organic compounds of phenols.

From the analysis as shown in Figure 4.8, the equation for a straight line forced through the data with **pH = 6.555 + 0.01701 Temperature**. The r^2 value also depicts that 1% of the total variation about the pH mean is explained by the regression line. The confidence interval for the slope show that with 95% confidence the data value for the slope lines somewhere between -0.01864 to 5.708.



n	72
R^2	0.01
Adjusted R^2	0.00
SE	1.483

Term	Coefficient	95% CI		SE	t statistic	DF	p
Intercept	6.555	5.708	to 7.402	0.4246	15.44	70	<0.0001
Slope	0.01701	-0.01864	to 0.05267	0.017877	0.95	70	0.3446

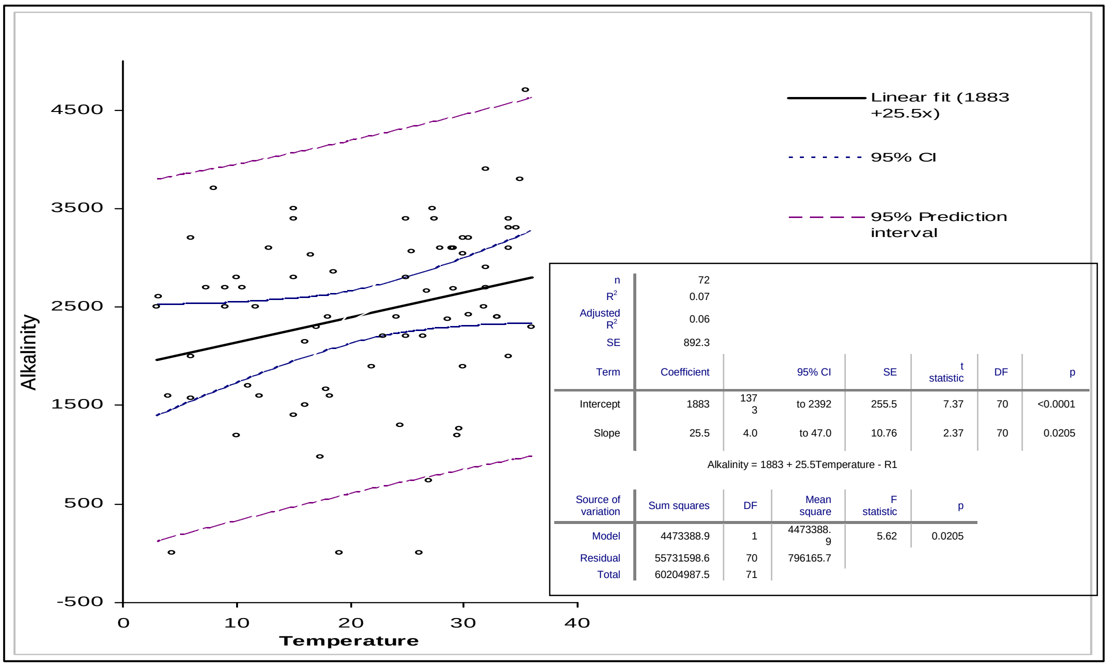
pH = 6.555 + 0.01701Temperature - R1

Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	1.990	1	1.990	0.91	0.3446
Residual	153.881	70	2.198		
Total	155.871	71			

Figure 4.8 pH of Leachate Versus Temperature

Figure 4.9 depicts the correlation of alkalinity of leachate to temperature of **Alkalinity = 1883 + 25.5 Temperature**. The r^2 value also indicates that about 7% of the total variation about the alkalinity mean and the confidence interval for the slope shows that 95% confidence of the data value lies somewhere between 1373 to 2392.

Figure 4.10 shows the correlation of hardness of leachate to temperature of **Hardness = 1053 – 2.46 Temperature**. The r^2 values depicts about 1% of the total variation about hardness mean and the 95% confidence interval spread from – 14.42 to 762 with negative correlation coefficient reveals that there is higher temperature.



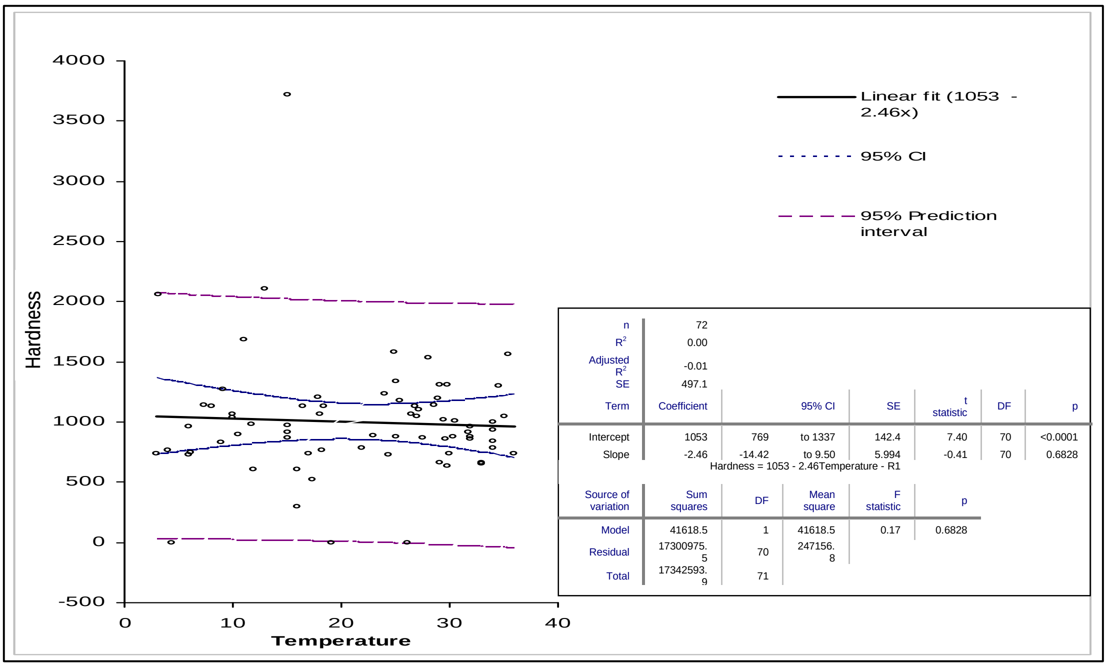
n	72
R^2	0.07
Adjusted R^2	0.06
SE	892.3

Term	Coefficient		95% CI	SE	t statistic	DF	p
Intercept	1883	1373	to 2392	255.5	7.37	70	<0.0001
Slope	25.5	4.0	to 47.0	10.76	2.37	70	0.0205

Alkalinity = 1883 + 25.5Temperature - R1

Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	4473388.9	1	4473388.9	5.62	0.0205
Residual	55731598.6	70	796165.7		
Total	60204987.5	71			

Figure 4.9 Alkalinity of Leachate Versus Temperature



n	72
R^2	0.00
Adjusted R^2	-0.01
SE	497.1

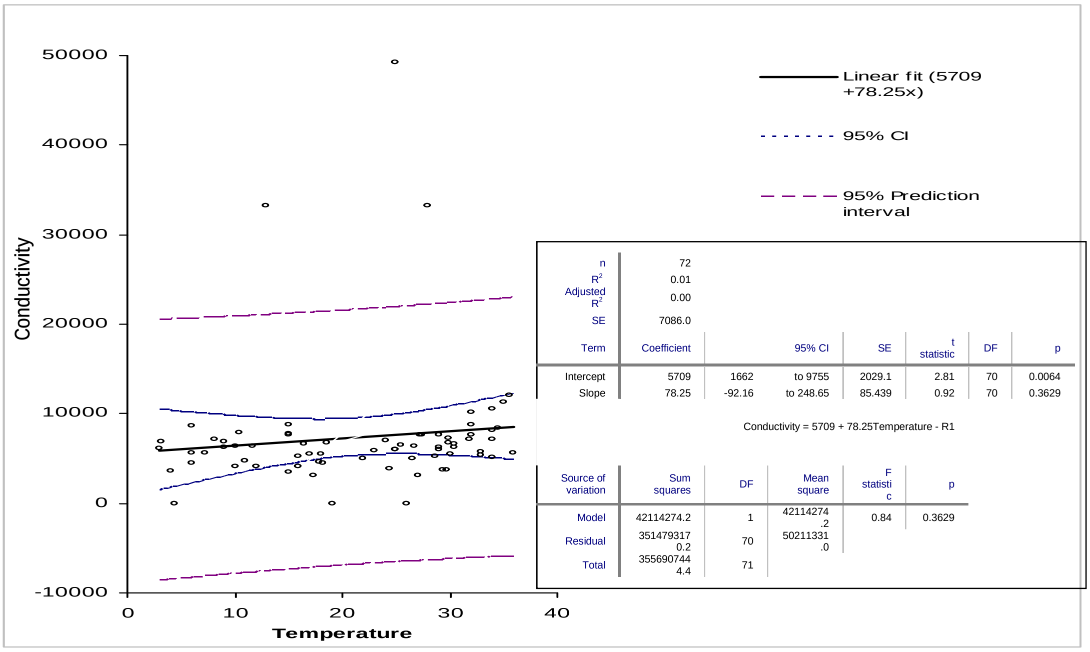
Term	Coefficient		95% CI	SE	t statistic	DF	p
Intercept	1053	769	to 1337	142.4	7.40	70	<0.0001
Slope	-2.46	-14.42	to 9.50	5.994	-0.41	70	0.6828

Hardness = 1053 - 2.46Temperature - R1

Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	41618.5	1	41618.5	0.17	0.6828
Residual	17300975.5	70	247156.8		
Total	17342593.9	71			

Figure 4.10 Hardness of Leachate Versus Temperature

Figure 4.11 shows the correlation equation of **Conductivity = 5709 + 78.25 Temperature** with r^2 value of 1%. The 95% confidence interval for the slope spread from - 92.16 to 1662.



n	72
R^2	0.01
Adjusted R^2	0.00
SE	7086.0

Term	Coefficient	95% CI		SE	t statistic	DF	p
Intercept	5709	1662	to 9755	2029.1	2.81	70	0.0064
Slope	78.25	-92.16	to 248.65	85.439	0.92	70	0.3629

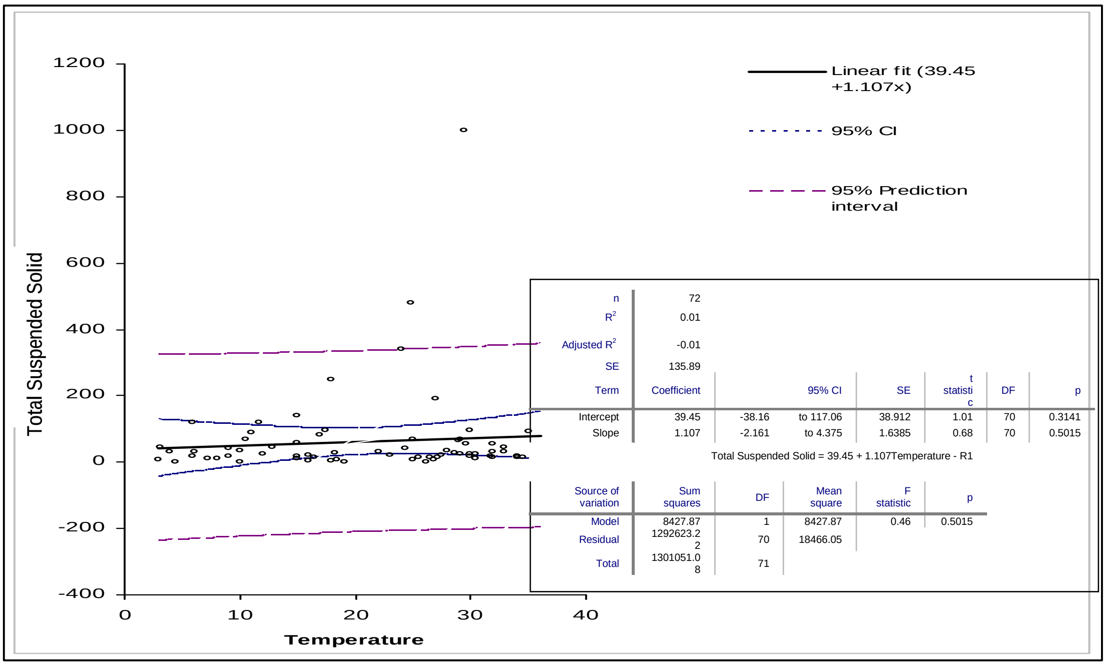
Conductivity = 5709 + 78.25Temperature - R1

Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	42114274.2	1	42114274.2	0.84	0.3629
Residual	3514793170.2	70	50211331.0		
Total	3556907444.4	71			

Figure 4.11 Conductivity of Leachate Versus Temperature

The correlation of total suspended solids to temperature is shown in Figure 4.12 with the equation of **Total Suspended Solid = 39.45 + 1.107 Temperature**. The r^2 value obtained shows 1% of the total variation about the total suspended solids mean is explained by the regression line. The confidence interval for the slope shows that 95% confidence extend from – 2.161 to 117.06 mg/l.

Figure 4.13 depicts the correlation of BOD to temperature illustrating the equation of **BOD = 475.8 – 10.89 Temperature**. The r^2 value shows that about 5% of the total variation about the temperature mean is explained by the regression line. The confidence interval for the slope shows



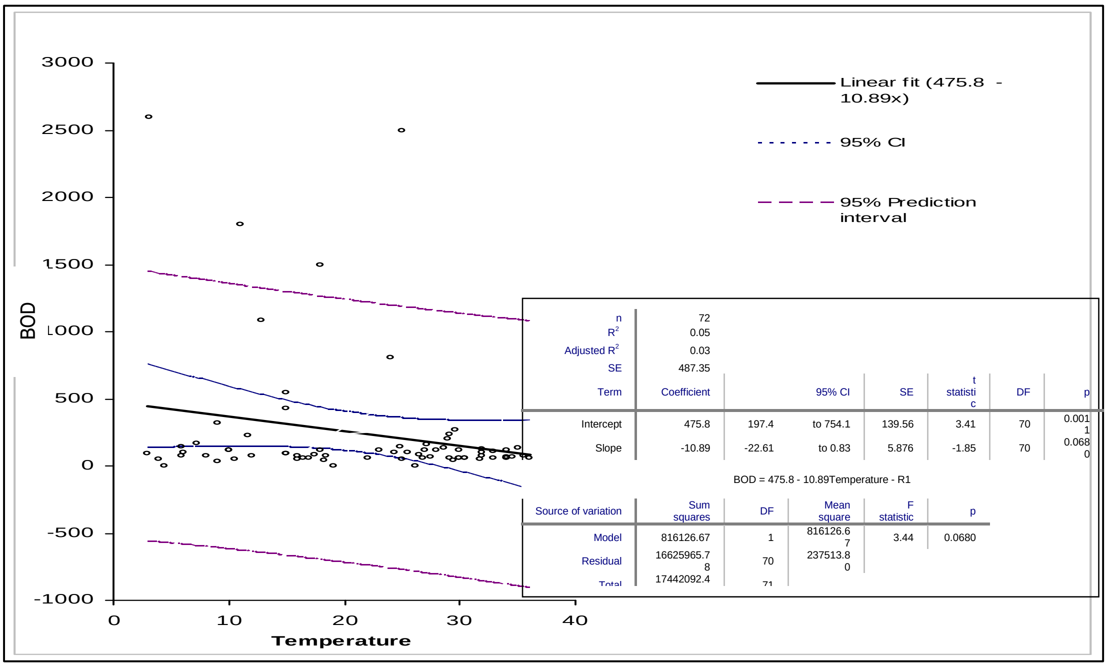
n	72
R^2	0.01
Adjusted R^2	-0.01
SE	135.89

Term	Coefficient	95% CI		SE	t statistic	DF	p
Intercept	39.45	-38.16	to 117.06	38.912	1.01	70	0.3141
Slope	1.107	-2.161	to 4.375	1.6385	0.68	70	0.5015

Total Suspended Solid = 39.45 + 1.107Temperature - R1

Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	8427.87	1	8427.87	0.46	0.5015
Residual	1292623.22	70	18466.05		
Total	1301051.08	71			

Figure 4.12 Total Suspended Solid of Leachate Versus Temperature



n	72
R^2	0.05
Adjusted R^2	0.03
SE	487.35

Term	Coefficient	95% CI		SE	t statistic	DF	p
Intercept	475.8	197.4	to 754.1	139.56	3.41	70	0.0011
Slope	-10.89	-22.61	to 0.83	5.876	-1.85	70	0.0680

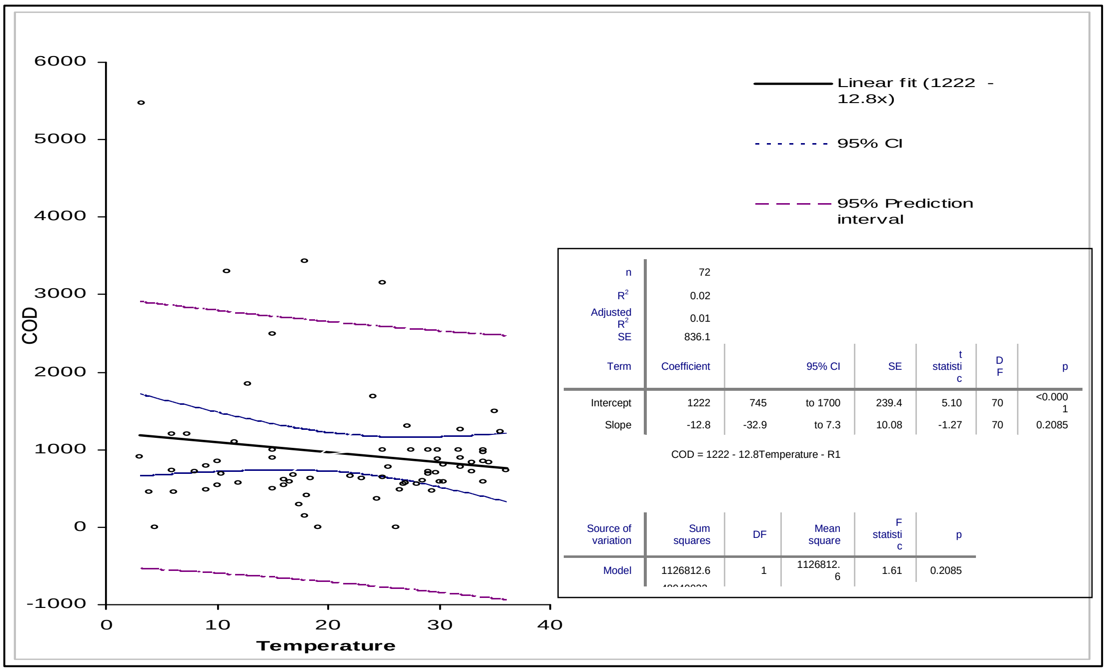
BOD = 475.8 - 10.89Temperature - R1

Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	816126.67	1	816126.67	3.44	0.0680
Residual	16625965.78	70	237513.80		
Total	17442092.4	71			

Figure 4.13 BOD of Leachate Versus Temperature

that with 95% confidence the data value for the slope lines somewhere between 197.4 to 754.1 mg/l. The correlation coefficient was statistically highly and significantly different from zero. The negative value indicates that there is an inverse relationship between BOD and temperature i.e. higher temperature show a lower BOD value.

The correlation of COD to temperature shows like wise to BOD correlation to temperature as depicted in Figure 4.14. The equation of **COD = 1222 – 12.8 Temperature** with r^2 of 2%. The confidence interval spread from 745 to 1700 mg/l. Negative slope also illustrate an inverse relationship between COD and temperature.



n	72
R^2	0.02
Adjusted R^2	0.01
SE	836.1

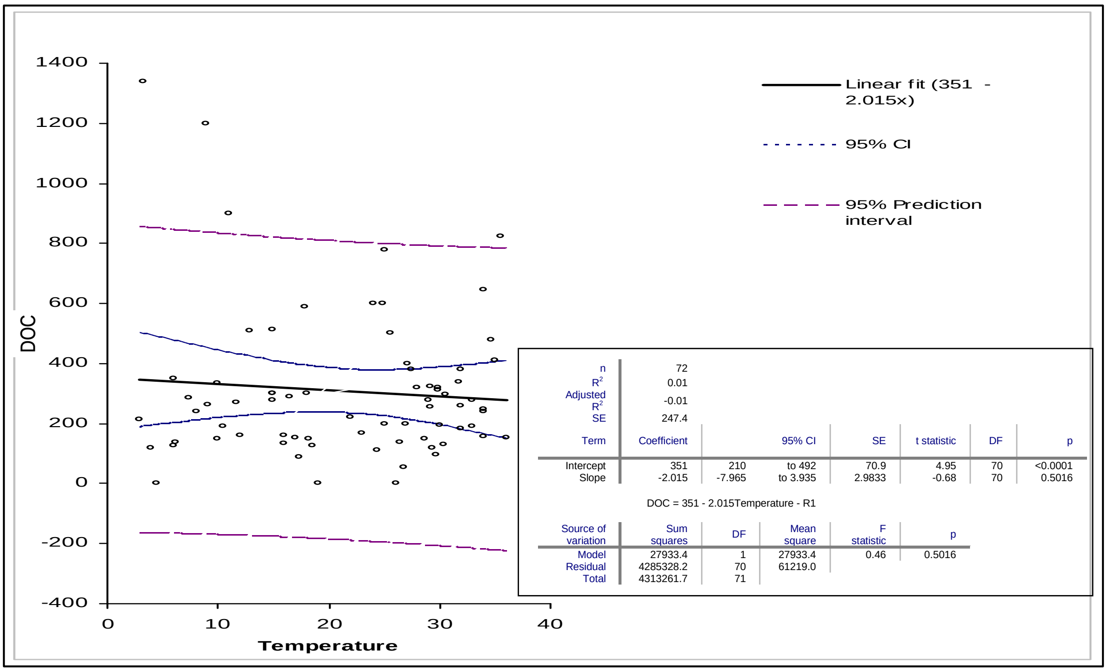
Term	Coefficient		95% CI	SE	t statistic	DF	p
Intercept	1222	745	to 1700	239.4	5.10	70	<0.0001
Slope	-12.8	-32.9	to 7.3	10.08	-1.27	70	0.2085

COD = 1222 - 12.8Temperature - R1

Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	1126812.6	1	1126812.6	1.61	0.2085

Figure 4.14 COD of Leachate Versus Temperature

Figure 4.15 again illustrate the similar trend like BOD and COD for correlation of DOC to temperation. The equation of **DOC = 351 – 2.015 Temperature** is obtained with r^2 value of 1%. The 95% confidence interval spread form 210 to 492 mg/l with negative correlation coefficient reveal that there is an inverse relationship to lower DOC values at higher temperature.



	n	72
	R^2	0.01
	Adjusted R^2	-0.01
	SE	247.4

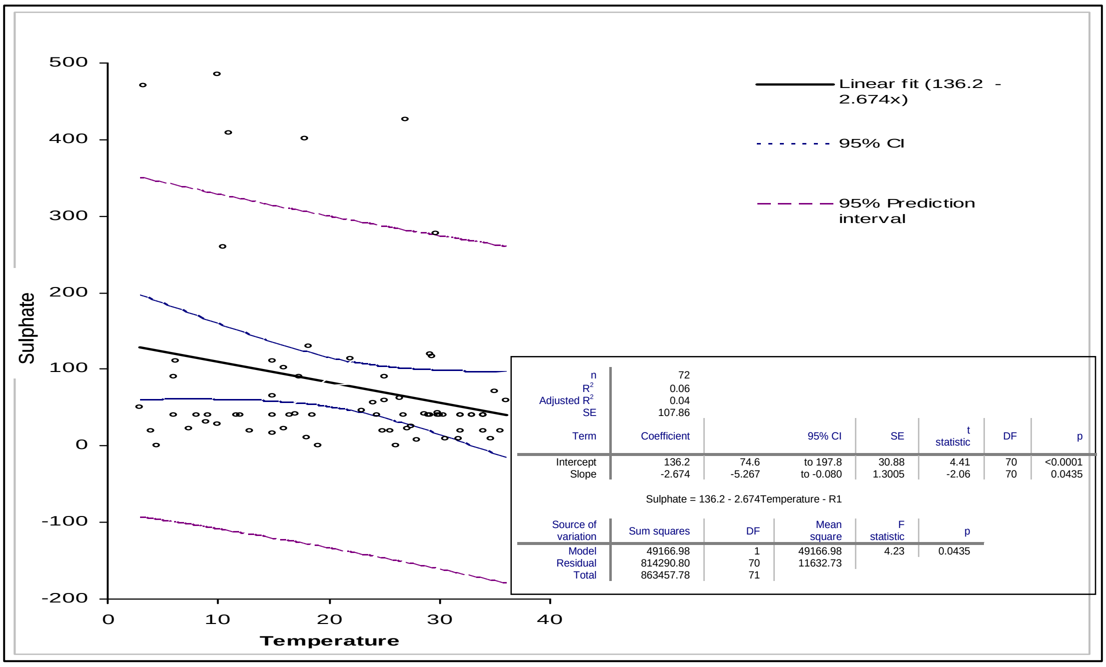
Term	Coefficient	95% CI		SE	t statistic	DF	p
Intercept	351	210	to 492	70.9	4.95	70	<0.0001
Slope	-2.015	-7.965	to 3.935	2.9833	-0.68	70	0.5016

DOC = 351 - 2.015Temperature - R1

Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	27933.4	1	27933.4	0.46	0.5016
Residual	4285328.2	70	61219.0		
Total	4313261.7	71			

Figure 4.15 DOC of Leachate Versus Temperature

The correlation of sulphate to temperature is shown in Figure 4.16 and the equation obtained is **Sulphate = 136.2 – 2.674 Temperature**. The r^2 value also indicates that about 6% of the total variation about the sulphat mean and the 95% confidence interval spread between 74.6 to 197.8 mg/l.



n	72
R^2	0.06
Adjusted R^2	0.04
SE	107.86

Term	Coefficient	95% CI		SE	t statistic	DF	p
Intercept	136.2	74.6	to 197.8	30.88	4.41	70	<0.0001
Slope	-2.674	-5.267	to -0.080	1.3005	-2.06	70	0.0435

Sulphate = 136.2 - 2.674Temperature - R1

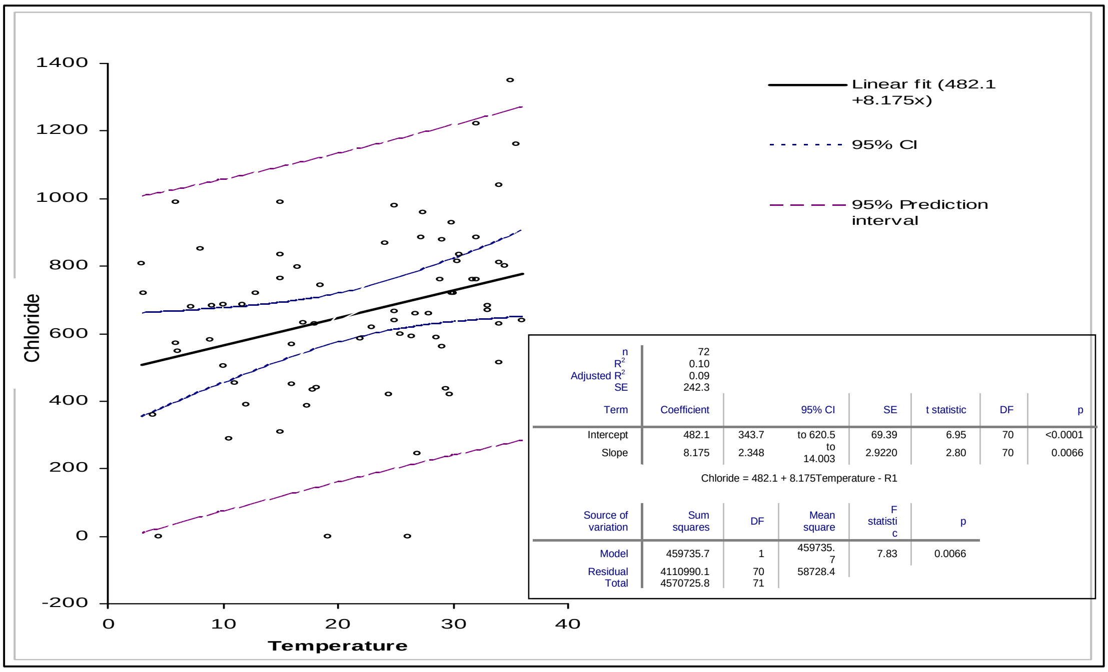
Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	49166.98	1	49166.98	4.23	0.0435
Residual	814290.80	70	11632.73		
Total	863457.78	71			

Figure 4.16 Sulphate of Leachate Versus Temperature

Figure 4.17 depicts the correlation of chloride to temperature. The equation obtained is **Chloride = 482.1 + 8.175 Temperature** with r^2 value of 10%. The 95% confidence interval spreads from 343.7 to 620.5 mg/l.

Figure 4.18 depicts the correction of ammonia to temperature. The equation obtained is **Ammonia = 164.4 + 2.98 Temperature** with r^2 value of 10%. The 95% confidence interval spreads from 113.3 to 215.5 mg/l.

Figure 4.19 shows the correlation of calcium to temperature. The equation is **Calcium = 257.3 – 1.946 Temperature** with r^2 value of 2%. The confidence interval spreads between 171.7 and 342.9 mg/l and the negative correlation reveal that there is an inverse relationship.



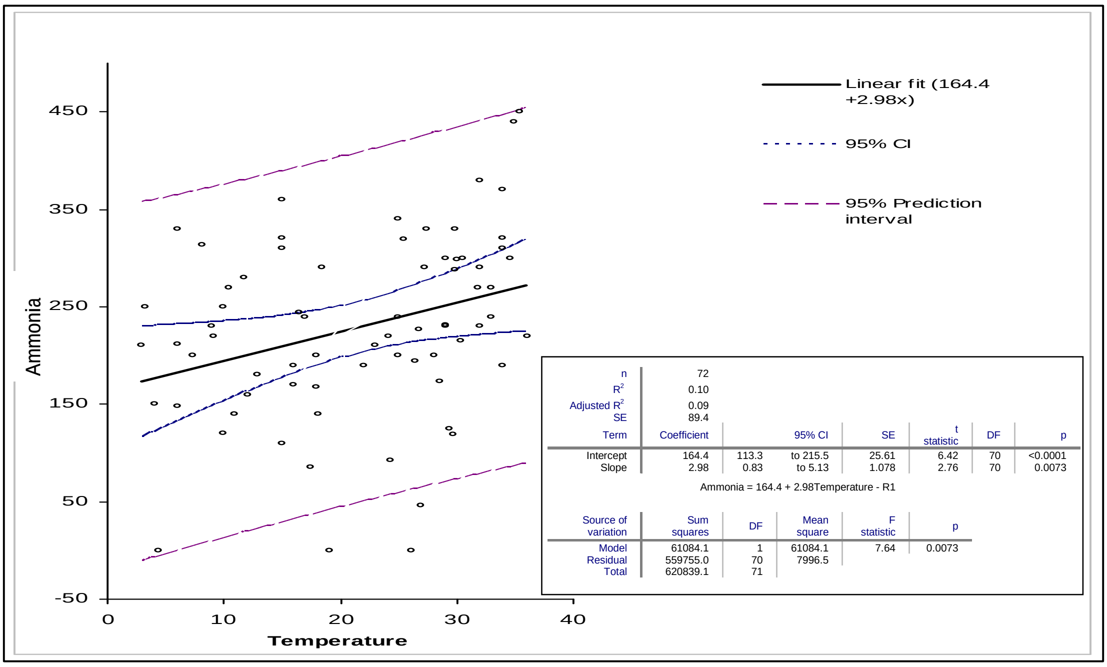
n	72
R^2	0.10
Adjusted R^2	0.09
SE	242.3

Term	Coefficient		95% CI	SE	t statistic	DF	p
Intercept	482.1	343.7	to 620.5	69.39	6.95	70	<0.0001
Slope	8.175	2.348	to 14.003	2.9220	2.80	70	0.0066

Chloride = 482.1 + 8.175Temperature - R1

Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	459735.7	1	459735.7	7.83	0.0066
Residual	4110990.1	70	58728.4		
Total	4570725.8	71			

Figure 4.17 Chloride of Leachate Versus Temperature



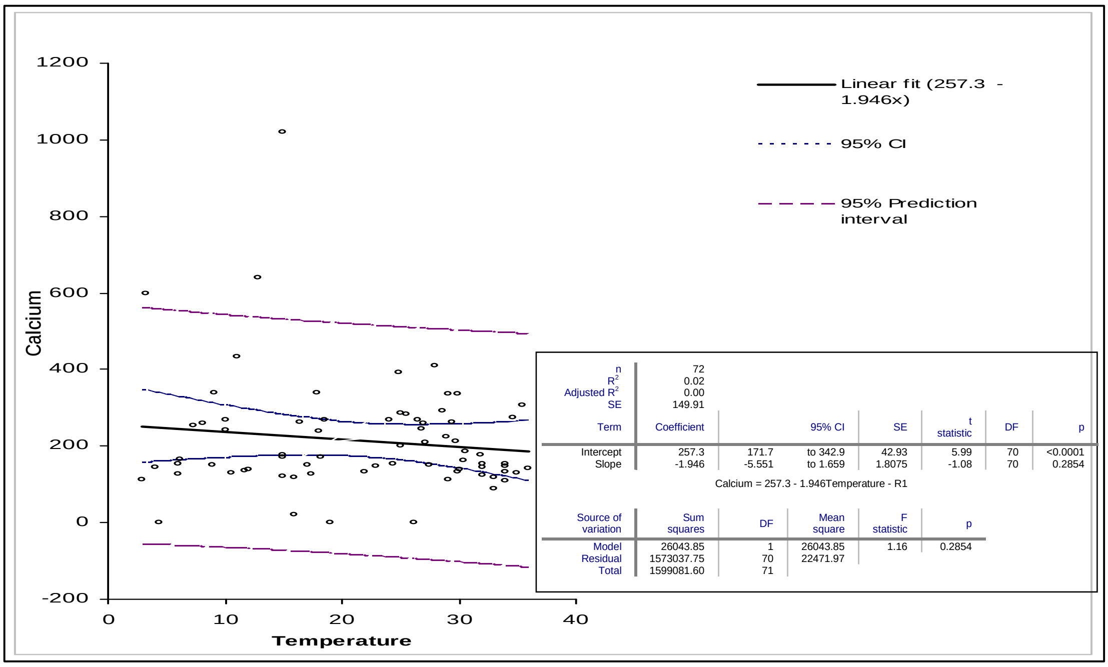
n	72
R^2	0.10
Adjusted R^2	0.09
SE	89.4

Term	Coefficient		95% CI	SE	t statistic	DF	p
Intercept	164.4	113.3	to 215.5	25.61	6.42	70	<0.0001
Slope	2.98	0.83	to 5.13	1.078	2.76	70	0.0073

Ammonia = 164.4 + 2.98Temperature - R1

Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	61084.1	1	61084.1	7.64	0.0073
Residual	559755.0	70	7996.5		
Total	620839.1	71			

Figure 4.18 Ammonia of Leachate Versus Temperature



n	72
R^2	0.02
Adjusted R^2	0.00
SE	149.91

Term	Coefficient	95% CI		SE	t statistic	DF	p
Intercept	257.3	171.7	to 342.9	42.93	5.99	70	<0.0001
Slope	-1.946	-5.551	to 1.659	1.8075	-1.08	70	0.2854

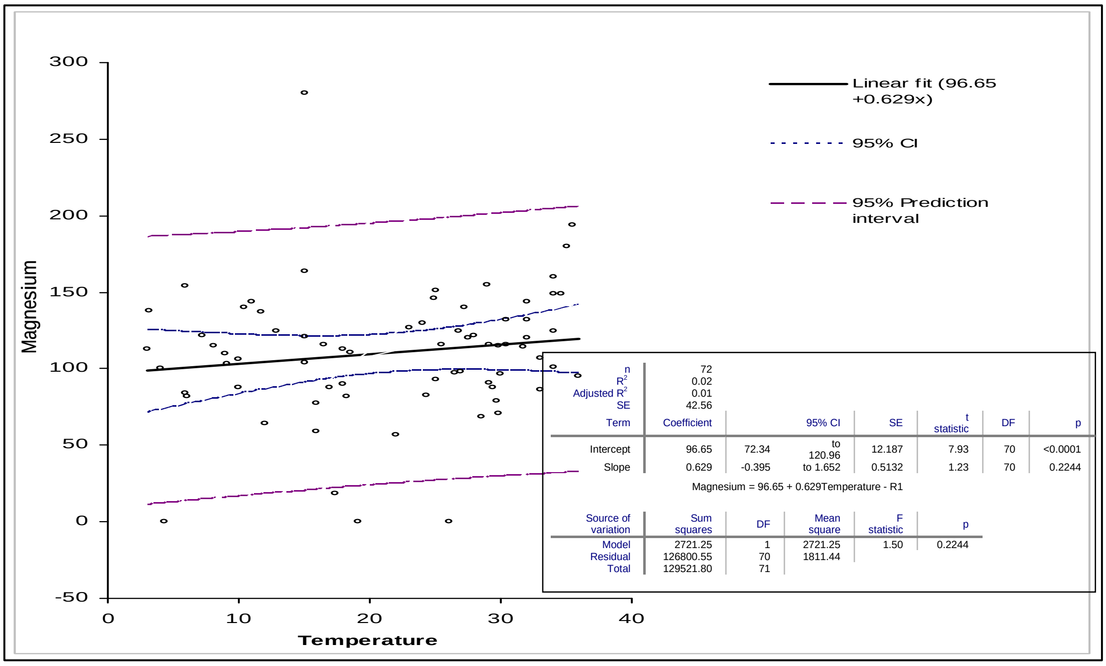
Calcium = 257.3 - 1.946Temperature - R1

Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	26043.85	1	26043.85	1.16	0.2854
Residual	1573037.75	70	22471.97		
Total	1599081.60	71			

Figure 4.19 Calcium of Leachate Versus Temperature

Figure 4.20 illustrates the correlation of magnesium in the leachate to temperature. The equation of **Magnesium = 96.65 + 0.629 Temperature** with r^2 value of 2% is obtained. The 95% confidence interval lies between 72.34 to 120.96 mg/l.

Figure 4.21 depicts the correlation of sodium to temperature with equation of **Sodium = 417.8 + 8.737 Temperature**. The r^2 value of 11% is obtained and the 95% confidence interval spreads from 276.7 to 559.0. Figure 4.22 illustrates the correlation of iron to temperature with equation of **Iron = 12.87 – 0.1809 Temperature** with r^2 value of 10%. The 95% confidence interval spreads from – 3.40 to 29.15 mg/l.



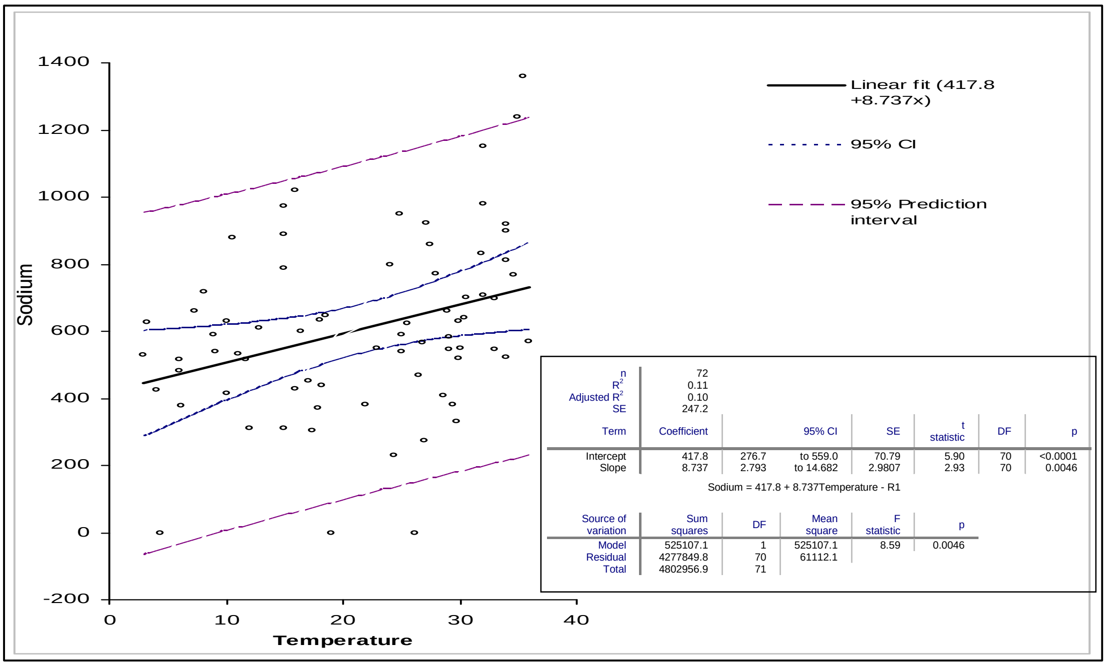
n	72
R^2	0.02
Adjusted R^2	0.01
SE	42.56

Term	Coefficient	95% CI		SE	t statistic	DF	p
Intercept	96.65	72.34	to 120.96	12.187	7.93	70	<0.0001
Slope	0.629	-0.395	to 1.652	0.5132	1.23	70	0.2244

Magnesium = 96.65 + 0.629Temperature - R1

Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	2721.25	1	2721.25	1.50	0.2244
Residual	126800.55	70	1811.44		
Total	129521.80	71			

Figure 4.20 Magnesium of Leachate Versus Temperature



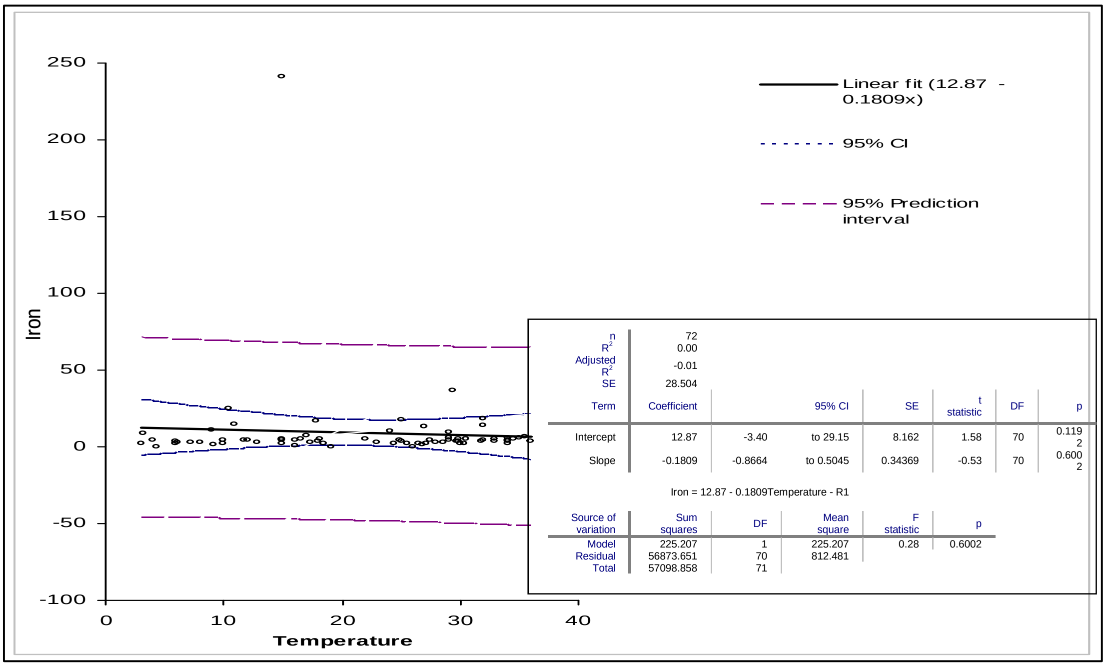
n	72
R^2	0.11
Adjusted R^2	0.10
SE	247.2

Term	Coefficient	95% CI		SE	t statistic	DF	p
Intercept	417.8	276.7	to 559.0	70.79	5.90	70	<0.0001
Slope	8.737	2.793	to 14.682	2.9807	2.93	70	0.0046

Sodium = 417.8 + 8.737Temperature - R1

Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	525107.1	1	525107.1	8.59	0.0046
Residual	4277849.8	70	61112.1		
Total	4802956.9	71			

Figure 4.21 Sodium of Leachate Versus Temperature



n	72
R^2	0.00
Adjusted R^2	-0.01
SE	28.504

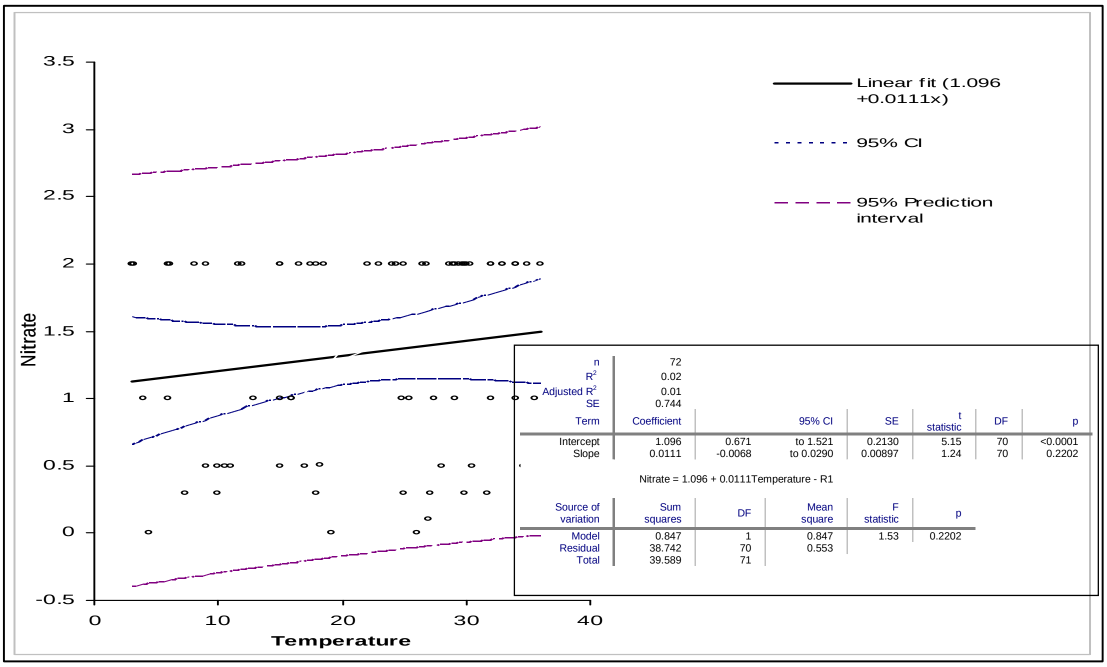
Term	Coefficient	95% CI		SE	t statistic	DF	p
Intercept	12.87	-3.40	to 29.15	8.162	1.58	70	0.1192
Slope	-0.1809	-0.8664	to 0.5045	0.34369	-0.53	70	0.6002

Iron = 12.87 - 0.1809Temperature - R1

Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	225.207	1	225.207	0.28	0.6002
Residual	56873.651	70	812.481		
Total	57098.858	71			

Figure 4.22 Iron of Leachate Versus Temperature

The correlations of nitrate and nitrite in the leachate to temperature are shown in Figured 4.23 and Figure 4.24 respectively. The equations obtained are **Nitrate = 1.096 + 0.0111 Temperature** and **Nitrite = 1.154 + 0.0114 Temperature** with r^2 values of 2% and 3% respectively. The respective 95% confidence interval spreads between 0.671 to 1.521 and 0.767 to 1.541. Also, the correlation equation of **TKN = 219.8 + 3.72 Temperature** is obtained with r^2 values of 7%. The 95% confidence interval spreads between 145.1 to 294.5. Figure 4.26 depicts the correlation of **Phenol = 330.8 – 5.5 Temperature** with r^2 value of 7%. The 95 confidence interval spreads from 219.4 to 442.1 mg/l.



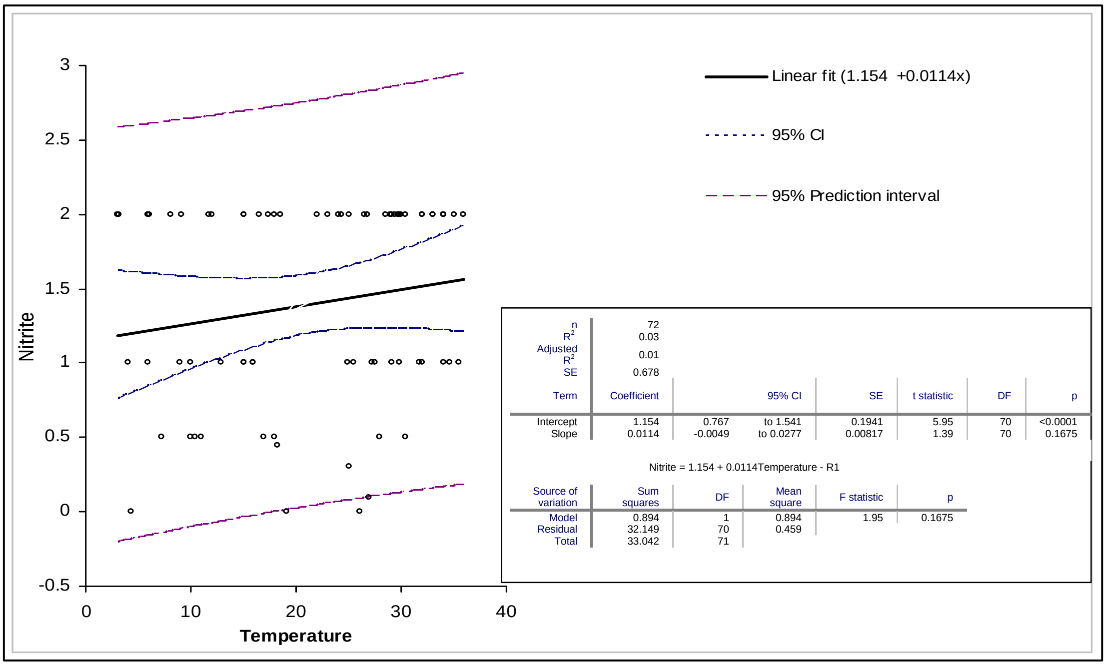
n	72
R^2	0.02
Adjusted R^2	0.01
SE	0.744

Term	Coefficient	95% CI		SE	t statistic	DF	p
Intercept	1.096	0.671	to 1.521	0.2130	5.15	70	<0.0001
Slope	0.0111	-0.0068	to 0.0290	0.00897	1.24	70	0.2202

Nitrate = 1.096 + 0.0111Temperature - R1

Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	0.847	1	0.847	1.53	0.2202
Residual	38.742	70	0.553		
Total	39.589	71			

Figure 4.23 Nitrate of Leachate Versus Temperature



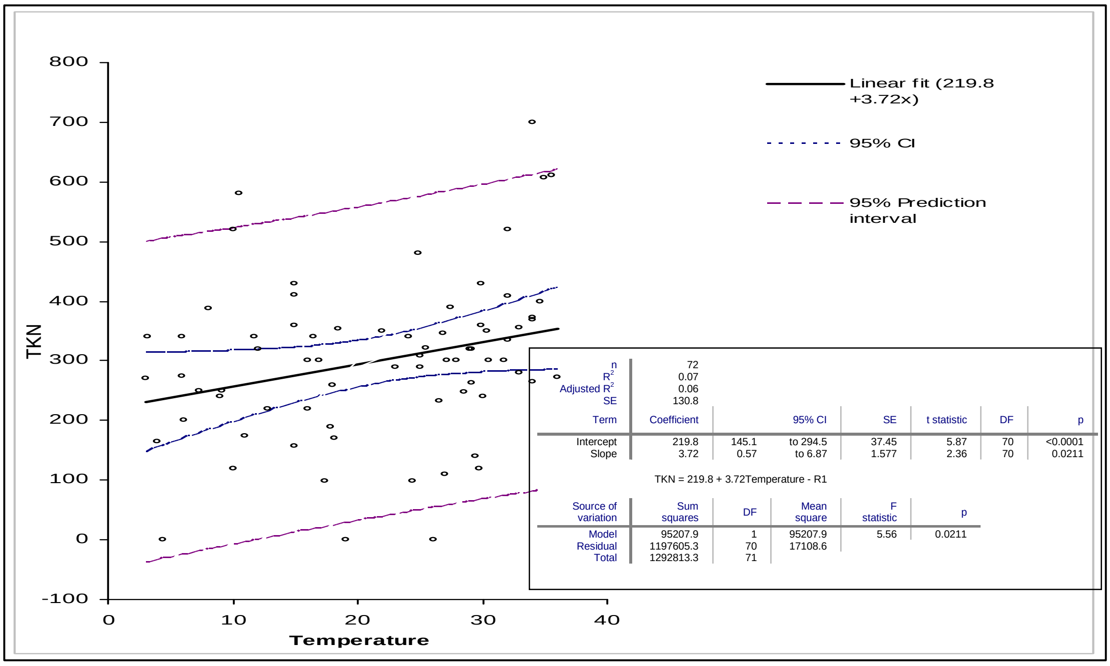
n	72
R^2	0.03
Adjusted R^2	0.01
SE	0.678

Term	Coefficient	95% CI		SE	t statistic	DF	p
Intercept	1.154	0.767	to 1.541	0.1941	5.95	70	<0.0001
Slope	0.0114	-0.0049	to 0.0277	0.00817	1.39	70	0.1675

Nitrite = 1.154 + 0.0114Temperature - R1

Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	0.894	1	0.894	1.95	0.1675
Residual	32.149	70	0.459		
Total	33.042	71			

Figure 4.24 Nitrite of Leachate Versus Temperature



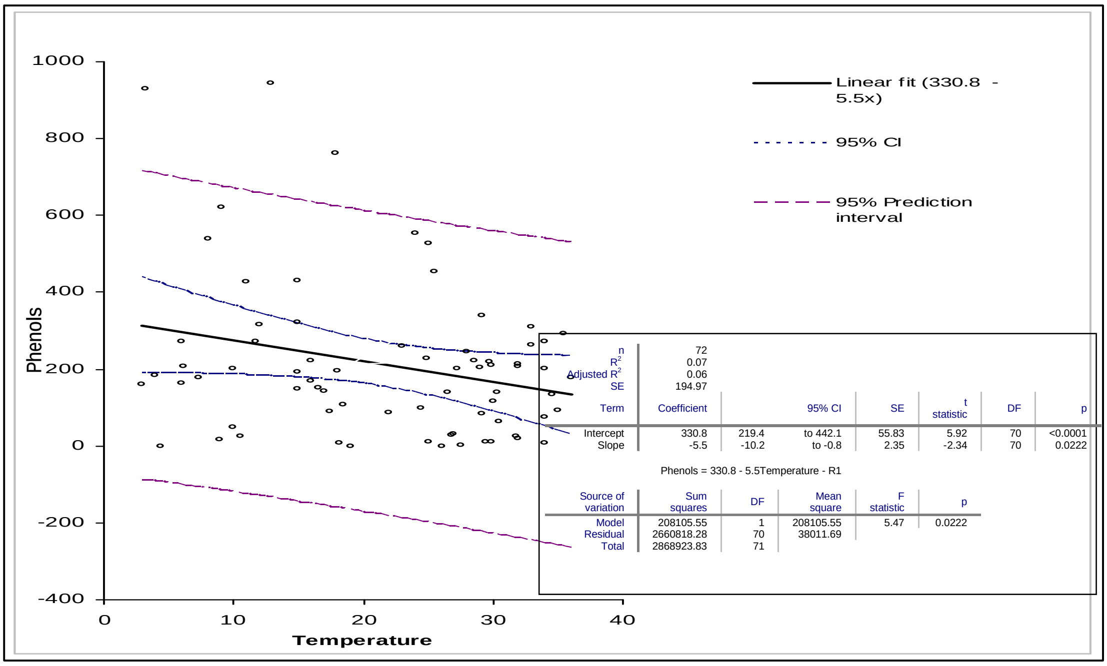
n	72
R^2	0.07
Adjusted R^2	0.06
SE	130.8

Term	Coefficient	95% CI		SE	t statistic	DF	p
Intercept	219.8	145.1	to 294.5	37.45	5.87	70	<0.0001
Slope	3.72	0.57	to 6.87	1.577	2.36	70	0.0211

TKN = 219.8 + 3.72Temperature - R1

Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	95207.9	1	95207.9	5.56	0.0211
Residual	1197605.3	70	17108.6		
Total	1292813.3	71			

Figure 4.25 TKN of Leachate Versus Temperature



n	72
R^2	0.07
Adjusted R^2	0.06
SE	194.97

Term	Coefficient	95% CI		SE	t statistic	DF	p
Intercept	330.8	219.4	to 442.1	55.83	5.92	70	<0.0001
Slope	-5.5	-10.2	to -0.8	2.35	-2.34	70	0.0222

Phenols = 330.8 - 5.5Temperature - R1

Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	208105.55	1	208105.55	5.47	0.0222
Residual	2660818.28	70	38011.69		
Total	2868923.83	71			

Figure 4.26 Phenols of Leachate Versus Temperature

As many as 19 linear regression equation are derived for the correlation of pollution to temperature as follows:-

$$\text{pH} = 6.555 + 0.01701\ \text{Temperature} \tag{4.1}$$

$$\text{Alkalinity} = 1883 + 25.5\ \text{Temperature} \tag{4.2}$$

$$\text{Hardness} = 1053 - 2.46\ \text{Temperature} \tag{4.3}$$

$$\text{Conductivity} = 5709 + 78.25\ \text{Temperature} \tag{4.4}$$

$$\text{Total Suspended Solid} = 39.45 + 1.107\ \text{Temperature} \tag{4.5}$$

$$\text{BOD} = 475.8 - 10.89\ \text{Temperature} \tag{4.6}$$

$$\text{COD} = 1222 - 12.8\ \text{Temperature} \tag{4.7}$$

$$\text{DOC} = 351 - 2.015\ \text{Temperature} \tag{4.8}$$

$$\text{Sulphate} = 136.2 - 2.674\ \text{Temperature} \tag{4.9}$$

$$\text{Chloride} = 482.1 + 8.175\ \text{Temperature} \tag{4.10}$$

$$\text{Ammonia} = 164.4 + 2.98\ \text{Temperature} \tag{4.11}$$

$$\text{Calcium} = 257.3 - 1.946\ \text{Temperature} \tag{4.12}$$

$$\text{Magnesium} = 96.65 + 0.629\ \text{Temperature} \tag{4.13}$$

$$\text{Sodium} = 417.8 + 8.737\ \text{Temperature} \tag{4.14}$$

$$\text{Iron} = 12.87 - 0.1809\ \text{Temperature} \tag{4.15}$$

$$\text{Nitrate} = 1.096 + 0.0111\ \text{Temperature} \tag{4.16}$$

$$\text{Nitrite} = 1.154 + 0.0114\ \text{Temperature} \tag{4.17}$$

$$\text{TKN} = 219.8 + 3.72\ \text{Temperature} \tag{4.18}$$

$$\text{Phenol} = 330.8 - 5.5\ \text{Temperature} \tag{4.19}$$

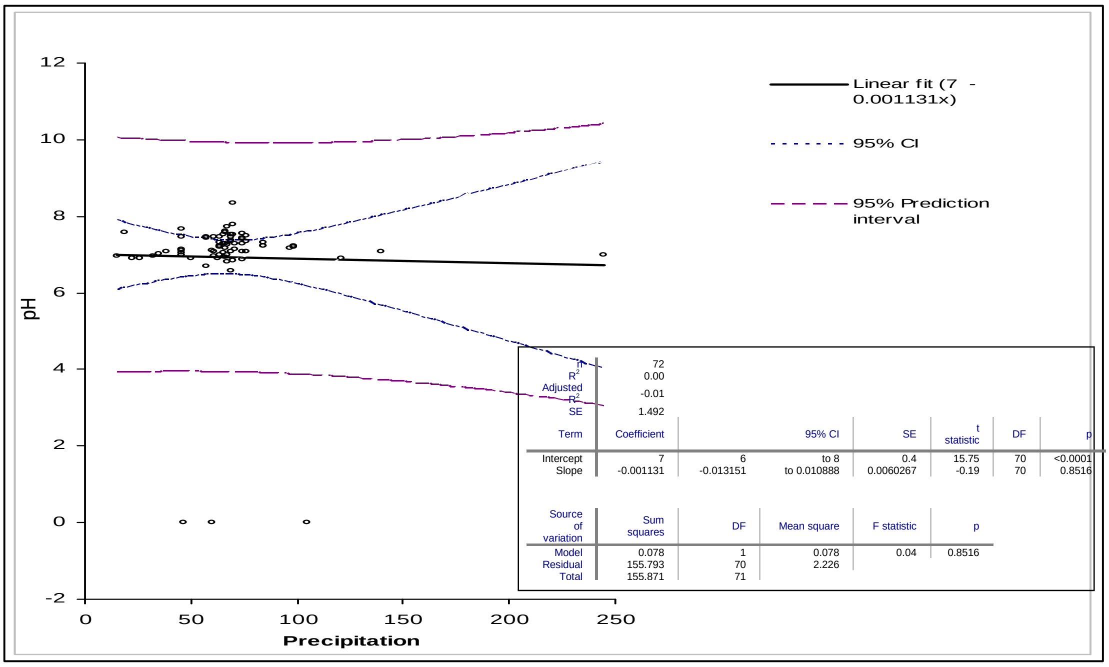
From the data evaluation as depicted in Figures 4.8 to 4.26, all physical properties (r^2>0.07) of leachate, all contents in term of organic matters (r^2>0.01), inorganic matters (r^2>0.02) and xenobiotic organic compounds of phenols (r^2>0.07) depict that there are some degree of significance of correlation relationship of leachate to temperature in the environment. This can be explained by the active decomposition rate in the waste due to high temperature that facilitates both biological and chemical reactions inside the waste mass.

4.3.2 Precipitation

The dilution of leachate in the landfill is significantly affected by the climatic precipitation which is one of the significant factor influences waste stabilization and leachate quality. Moisture within landfill play an important role as a reactant in the hydrolysis reaction, nutrient and enzyme movement, dissolve metabolites, provide pH buffering and medium for microbial activities. Excess dilution of leachate can also result in increase washout of soluble organic and microbial growth and to certain extent some of the major pollutants in the landfill. Thus, the precipitation in the ambient of landfill is important as it directly affect stabilization rates within the landfills.

Correlation relationship of leachate concentration due to precipitation is again evaluated in terms of physical properties of pH, alkalinity, hardness, conductivity and total suspended solids, organic matters of BOD, COD and DOC, in organic matters of sulphate, chloride, ammonia, calcium, magnesium, sodium, iron, nitrate, nitrite and TKN and xenobiotic organic compounds of phenols.

Figure 4.27 depicts the correlation of pH of leachate to precipitation with an equation of **pH = 7 – 0.001 Precipitation**. The r^2 values also illustrates that 1% of the total variation about the pH mean is explained by the regression line. The confidence interval for the slope shows that with 95% confidence interval the data values for the slope spreads between 6 to 8.



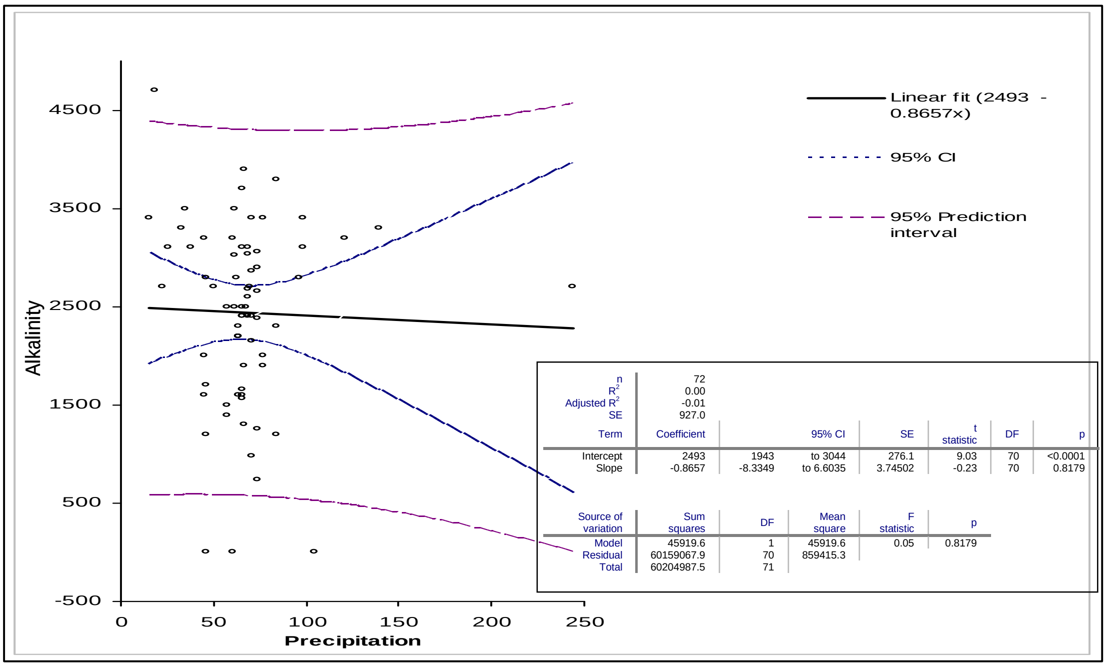
n	72
R^2	0.00
Adjusted R^2	-0.01
SE	1.492

Term	Coefficient	95% CI	SE	t statistic	DF	p
Intercept	7	6 to 8	0.4	15.75	70	<0.0001
Slope	-0.001131	-0.013151 to 0.010888	0.0060267	-0.19	70	0.8516

Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	0.078	1	0.078	0.04	0.8516
Residual	155.793	70	2.226		
Total	155.871	71			

Figure 4.27 pH of Leachate Versus Precipitation

Figure 4.28 illustrates the correlation of alkalinity of leachate to precipitation with an equation of **Alkalinity = 2493 – 0.8657 Precipitation**. The r^2 value also depicts 1% of the total variation about the alkalinity mean is explained by the regression line. The 95% confidence interval for the slope shown that the data values for the slope spreads between 1945 to 3044. The negative correction also an inverse relationship of lower alkalinity value at higher precipitation.



n	72
R^2	0.00
Adjusted R^2	-0.01
SE	927.0

Term	Coefficient		95% CI	SE	t statistic	DF	p
Intercept	2493	1943	to 3044	276.1	9.03	70	<0.0001
Slope	-0.8657	-8.3349	to 6.6035	3.74502	-0.23	70	0.8179

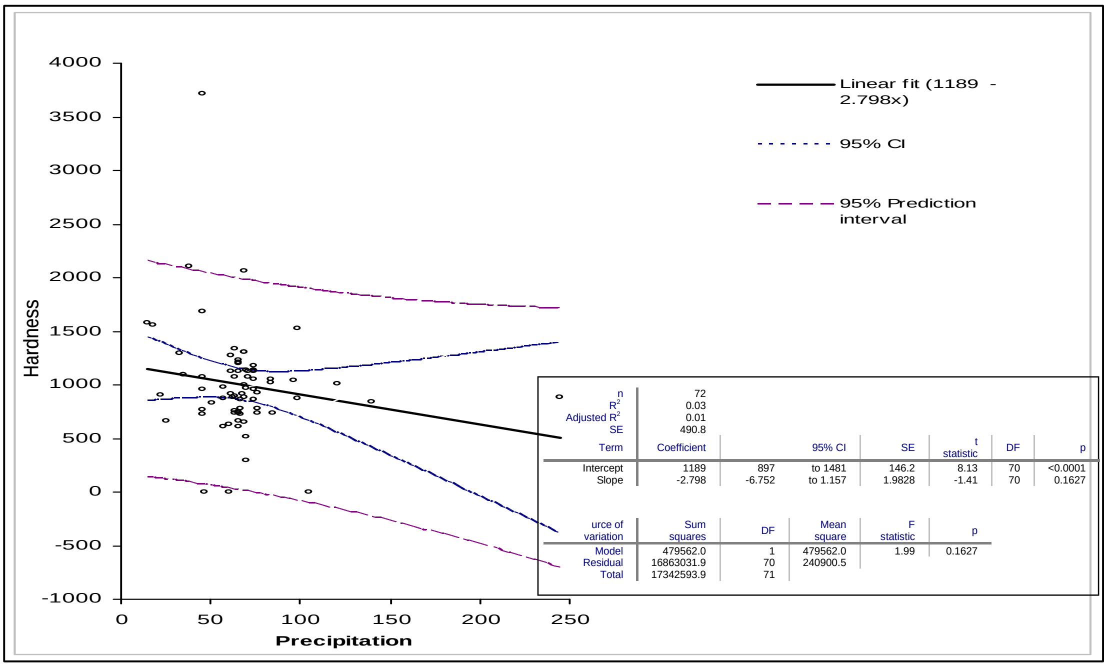
Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	45919.6	1	45919.6	0.05	0.8179
Residual	60159067.9	70	859415.3		
Total	60204987.5	71			

Figure 4.28 Alkalinity of Leachate Versus Precipitation

The correlation of hardness of leachate to precipitation is depicted in Figure 4.29 with an equation of **Hardness = 1189 – 2.798 Precipitation**. The r^2 value of 3% is also obtained for the slope and the 95% confidence interval spread from 897 to 1481 mg/l.

Figure 4.30 depicts the correlation of conductivity of leachate to precipitation with an equation of **Conductivity = 9516 – 31.22 Precipitation**. The r^2 value of 2% is obtained and the 95% confirmation interval spreads from 5318 to 1371.5 mg/l.

The correlation of total suspended solids of leachate to precipitation as illustrated in Figure 4.31 is **Total Suspended Solids = 86.42 – 0.3398 Precipitation**. The r^2 value of 1% is obtained and the 95% confidence interval spreads between 5.66 to 167.18 mg/l.

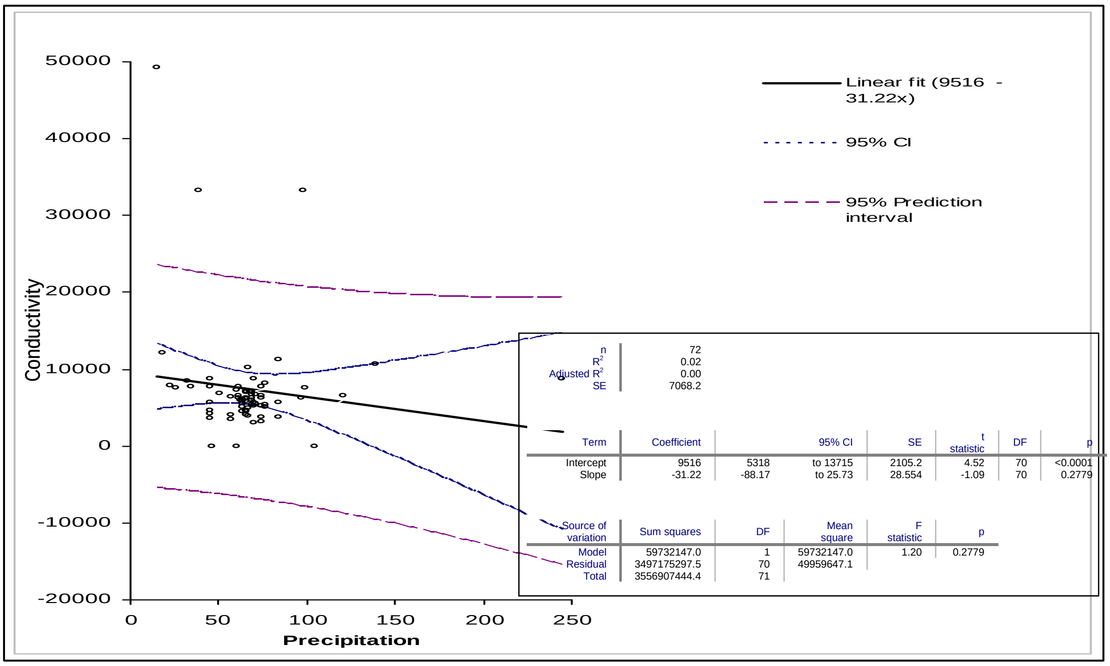


n	72
R^2	0.03
Adjusted R^2	0.01
SE	490.8

Term	Coefficient	95% CI		SE	t statistic	DF	p
Intercept	1189	897	to 1481	146.2	8.13	70	<0.0001
Slope	-2.798	-6.752	to 1.157	1.9828	-1.41	70	0.1627

urce of variation	Sum squares	DF	Mean square	F statistic	p
Model	479562.0	1	479562.0	1.99	0.1627
Residual	16863031.9	70	240900.5		
Total	17342593.9	71			

Figure 4.29 Hardness of Leachate Versus Precipitation

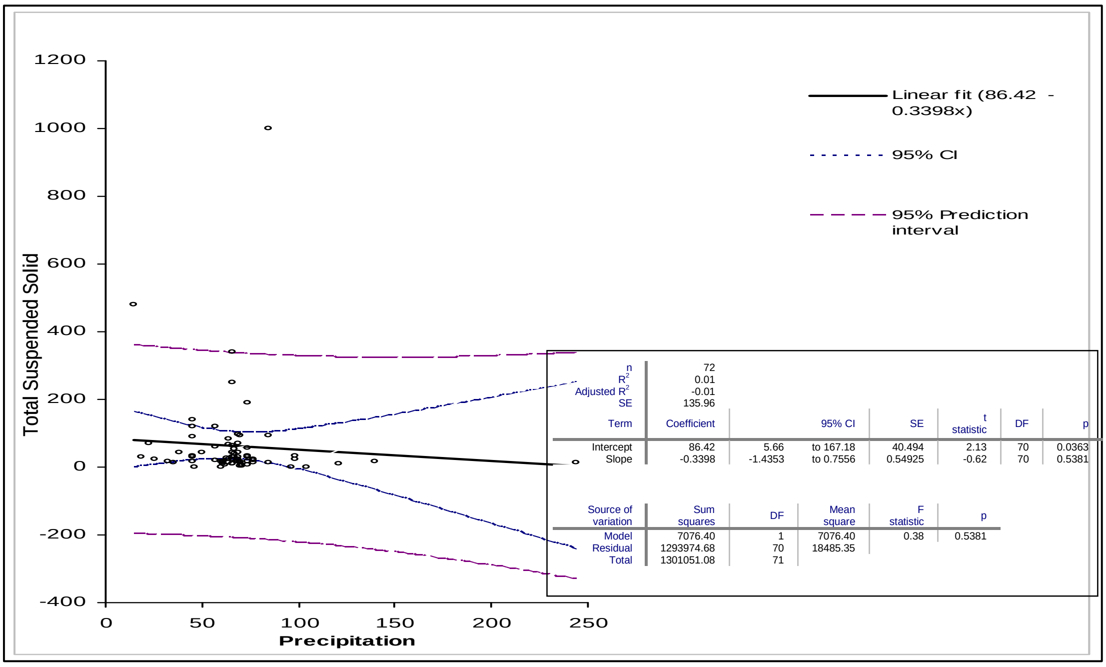


n	72
R^2	0.02
Adjusted R^2	0.00
SE	7068.2

Term	Coefficient	95% CI		SE	t statistic	DF	p
Intercept	9516	5318	to 13715	2105.2	4.52	70	<0.0001
Slope	-31.22	-88.17	to 25.73	28.554	-1.09	70	0.2779

Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	59732147.0	1	59732147.0	1.20	0.2779
Residual	3497175297.5	70	49959647.1		
Total	3556907444.4	71			

Figure 4.30 Conductivity of Leachate Versus Precipitation



n	72
R^2	0.01
Adjusted R^2	-0.01
SE	135.96

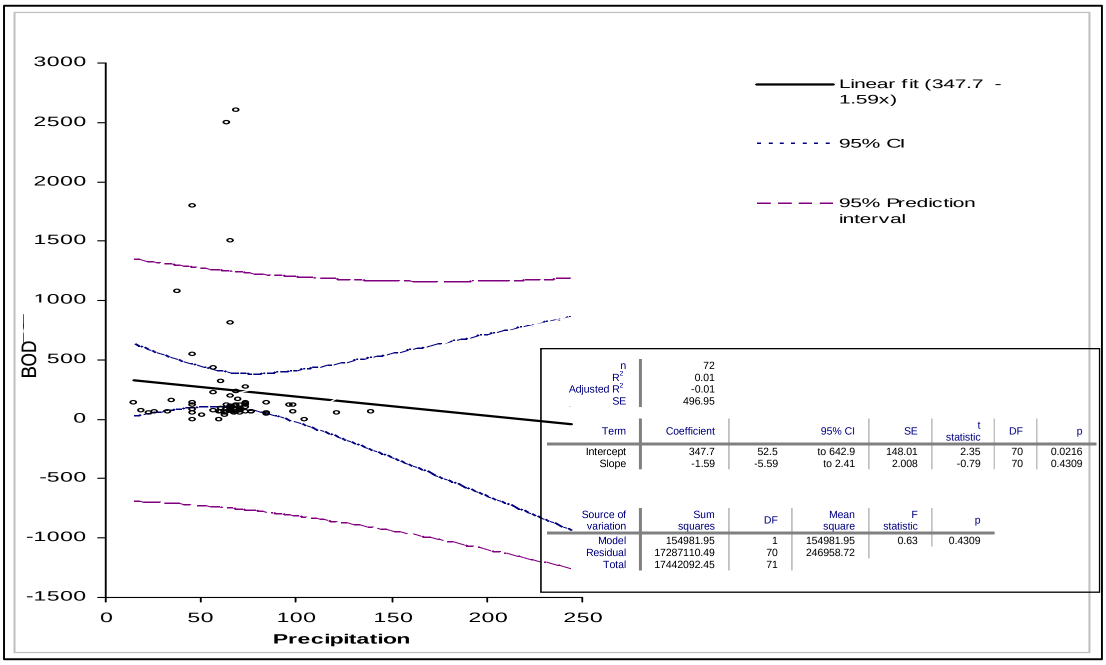
Term	Coefficient	95% CI		SE	t statistic	DF	p
Intercept	86.42	5.66	to 167.18	40.494	2.13	70	0.0363
Slope	-0.3398	-1.4353	to 0.7556	0.54925	-0.62	70	0.5381

Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	7076.40	1	7076.40	0.38	0.5381
Residual	1293974.68	70	18485.35		
Total	1301051.08	71			

Figure 4.31 Total Suspended Solid of Leachate Versus Precipitation

Figure 4.32 illustrate the correlation of BOD of leachate to precipitation with an equation of **BOD = 347.7 – 1.59 Precipitation**. The r^2 value also indicate that about 1% of the total variation about the BOD mean is explained by the regression line. The confidence interval for the slope shows that 95% confidence the data values for the slope lines between 52.5 to 642.9 mg/l.

Figure 4.33 and Figure 4.34 depicts the correlation of COD and DOC of leachate to precipitation with equations of **COD = 1131 – 2.751 Precipitation** and **DOC = 392.9 – 1.263 Precipitation**. The r^2 values of both 1% are obtained within 95% confidence interval lies between 631 to 1631 and 247.1 to 538.7 mg/l respectively.

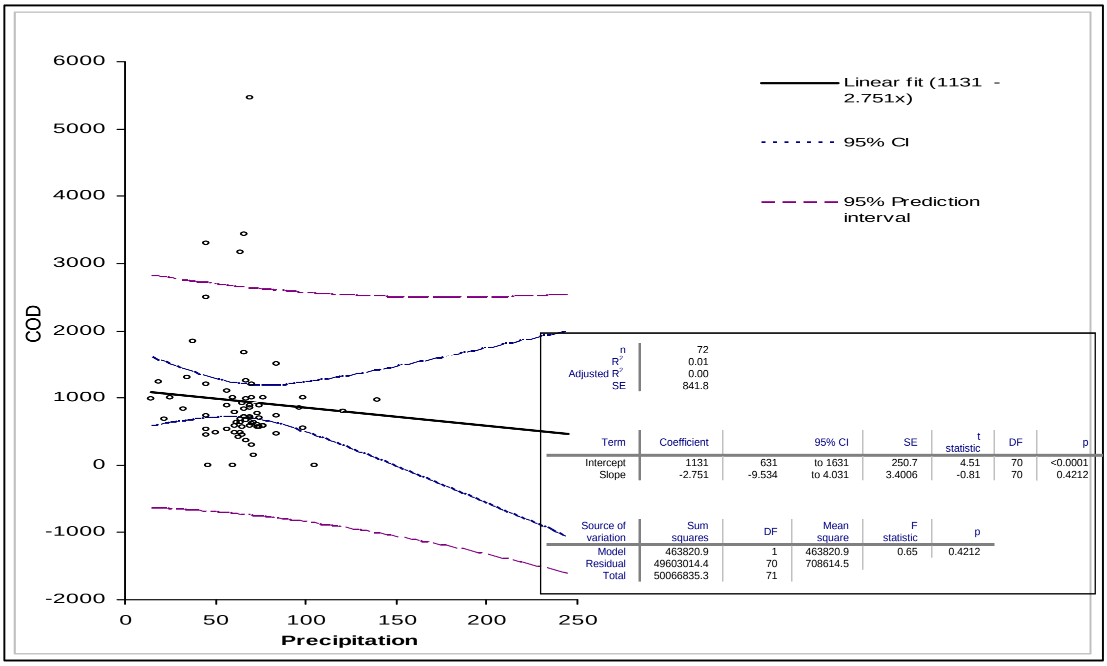


n	72
R^2	0.01
Adjusted R^2	-0.01
SE	496.95

Term	Coefficient	95% CI		SE	t statistic	DF	p
Intercept	347.7	52.5	to 642.9	148.01	2.35	70	0.0216
Slope	-1.59	-5.59	to 2.41	2.008	-0.79	70	0.4309

Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	154981.95	1	154981.95	0.63	0.4309
Residual	17287110.49	70	246958.72		
Total	17442092.45	71			

Figure 4.32 BOD of Leachate Versus Precipitation

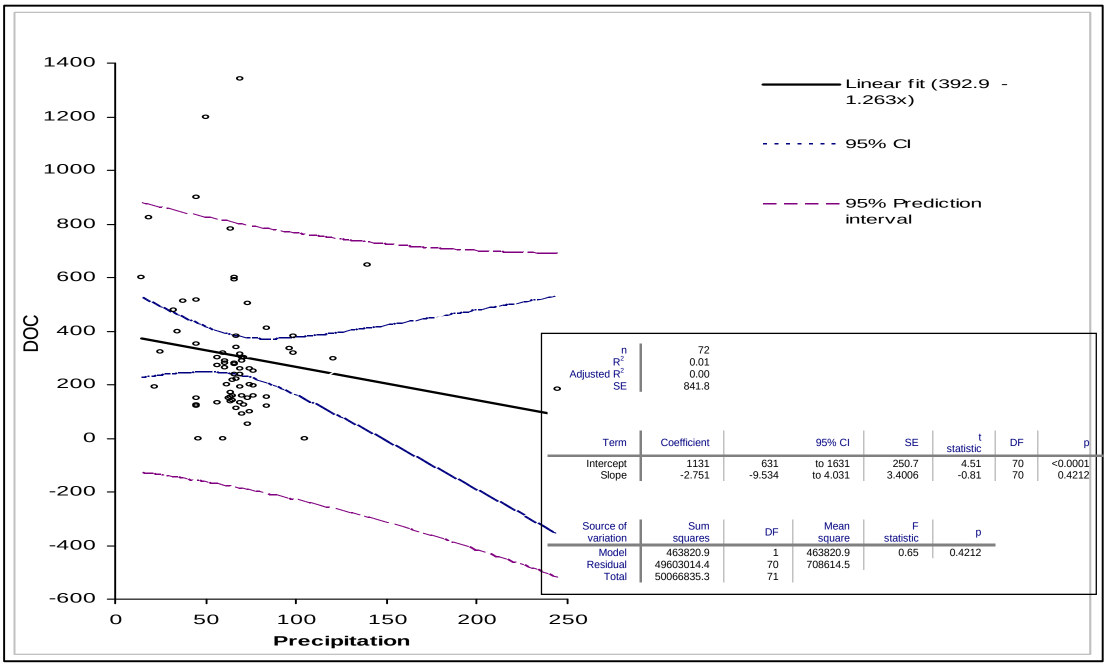


n	72
R^2	0.01
Adjusted R^2	0.00
SE	841.8

Term	Coefficient	95% CI		SE	t statistic	DF	p
Intercept	1131	631	to 1631	250.7	4.51	70	<0.0001
Slope	-2.751	-9.534	to 4.031	3.4006	-0.81	70	0.4212

Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	463820.9	1	463820.9	0.65	0.4212
Residual	49603014.4	70	708614.5		
Total	50066835.3	71			

Figure 4.33 COD of Leachate Versus Precipitation



n	72
R^2	0.01
Adjusted R^2	0.00
SE	841.8

Term	Coefficient		95% CI	SE	t statistic	DF	p
Intercept	1131	631	to 1631	250.7	4.51	70	<0.0001
Slope	-2.751	-9.534	to 4.031	3.4006	-0.81	70	0.4212

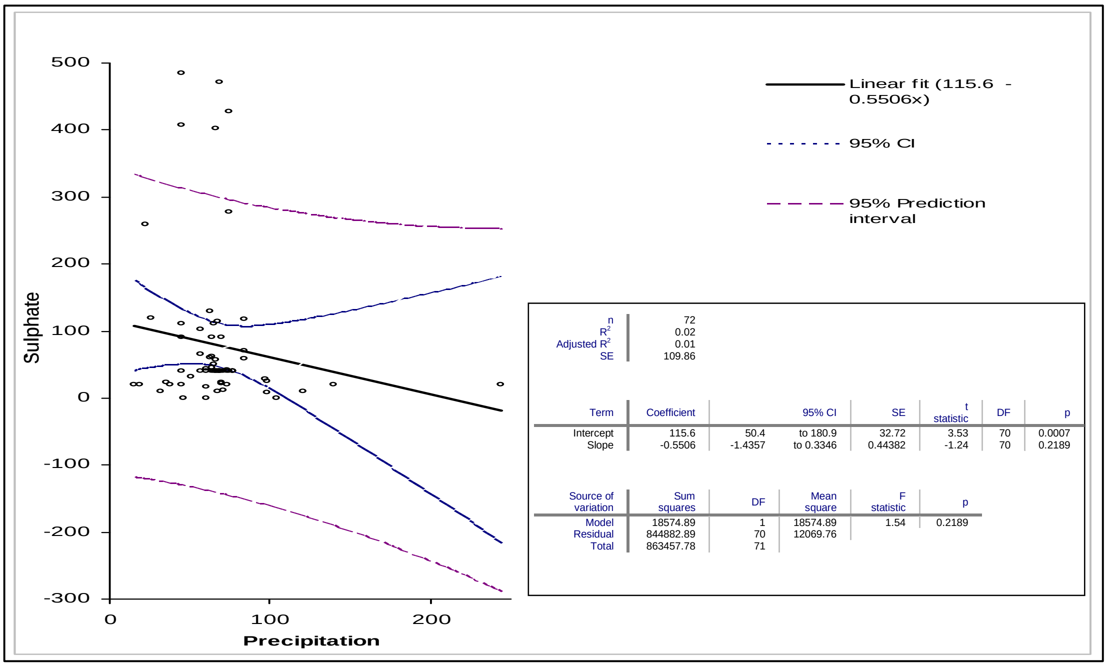
Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	463820.9	1	463820.9	0.65	0.4212
Residual	49603014.4	70	708614.5		
Total	50066835.3	71			

Figure 4.34 DOC of Leachate Versus Precipitation

The correlation of sulphate in leachate to precipitation as illustrated in Figure 4.35 is **Sulphate = 115.6 – 0.5506 Precipitation**. The r^2 values of 2% is obtained and 95 confidence interval spreads between 50.4 to 180.9 mg/l.

Figure 4.36 depicts the correction of chloride of leachate to precipitation with an equation of **Chloride = 660.5 – 0.02075 Precipitation**. The r^2 value of 1% is obtained and the 95% confidence interval lies between 508.7 to 812.3 mg/l with negative correlation.

Figure 4.37 depicts the correlation of ammonia of leachate to precipitation with an equation **Ammonia = 224.2 + 0.069 Precipitation**. The r^2 value of 1% is obtained and the 95% confidence interval spreads somewhere between 168.3 to 280.1 mg/l.

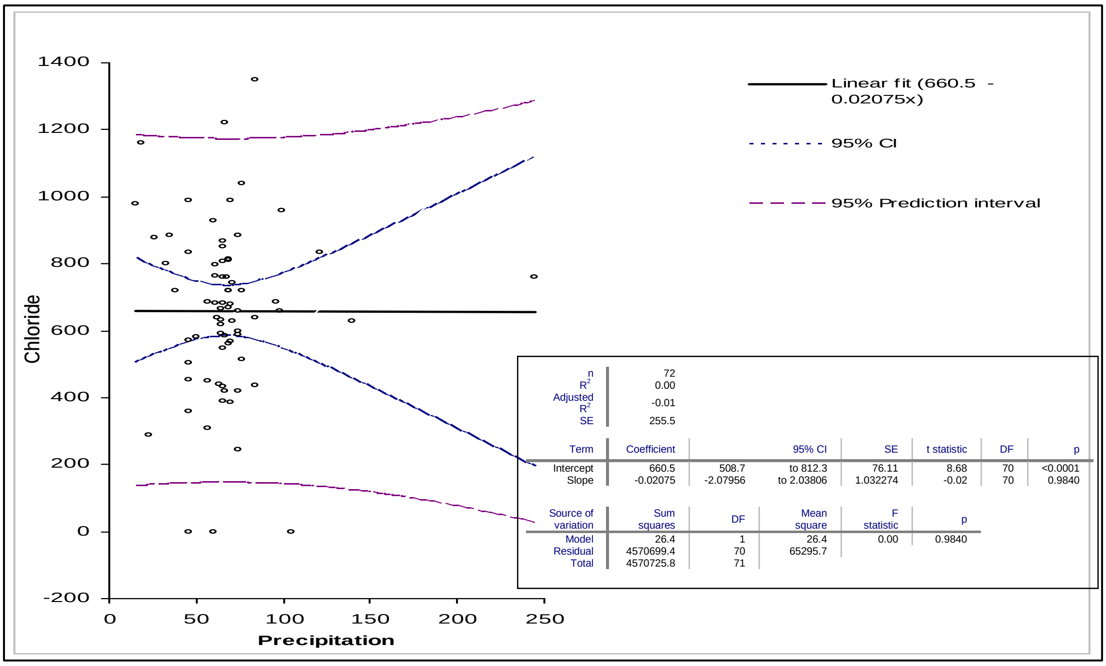


n	72
R^2	0.02
Adjusted R^2	0.01
SE	109.86

Term	Coefficient		95% CI	SE	t statistic	DF	p
Intercept	115.6	50.4	to 180.9	32.72	3.53	70	0.0007
Slope	-0.5506	-1.4357	to 0.3346	0.44382	-1.24	70	0.2189

Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	18574.89	1	18574.89	1.54	0.2189
Residual	844882.89	70	12069.76		
Total	863457.78	71			

Figure 4.35 Sulphate of Leachate Versus Precipitation

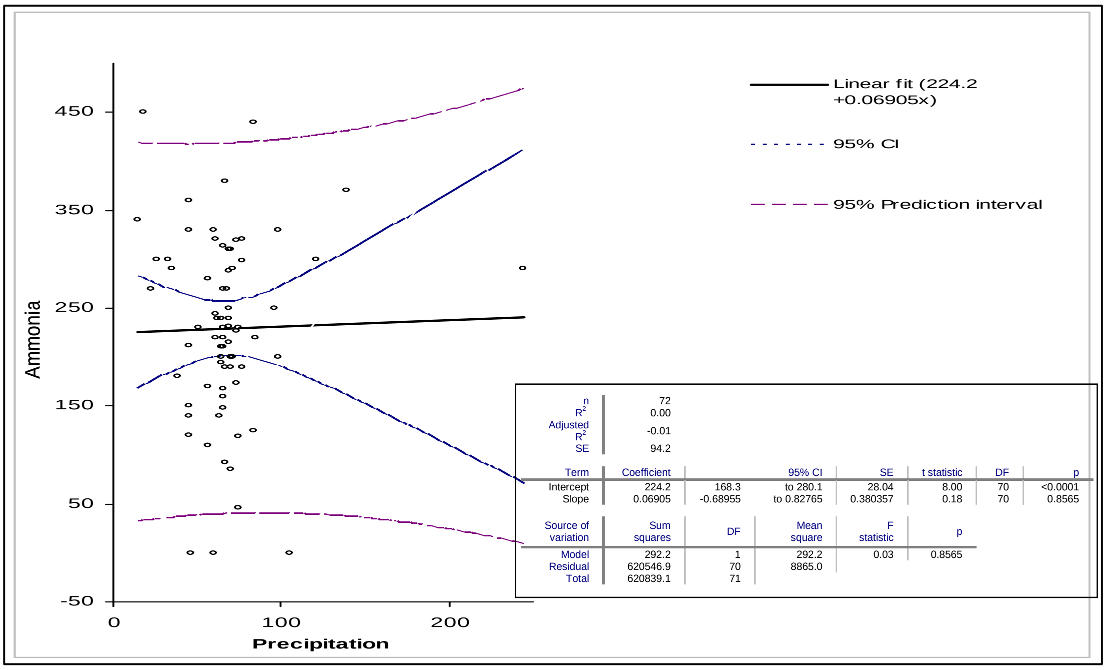


n	72
R^2	0.00
Adjusted R^2	-0.01
SE	255.5

Term	Coefficient		95% CI	SE	t statistic	DF	p
Intercept	660.5	508.7	to 812.3	76.11	8.68	70	<0.0001
Slope	-0.02075	-2.07956	to 2.03806	1.032274	-0.02	70	0.9840

Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	26.4	1	26.4	0.00	0.9840
Residual	4570699.4	70	65295.7		
Total	4570725.8	71			

Figure 4.36 Chloride of Leachate Versus Precipitation



n	72
R^2	0.00
Adjusted R^2	-0.01
SE	94.2

Term	Coefficient	95% CI		SE	t statistic	DF	p
Intercept	224.2	168.3	to 280.1	28.04	8.00	70	<0.0001
Slope	0.06905	-0.68955	to 0.82765	0.380357	0.18	70	0.8565

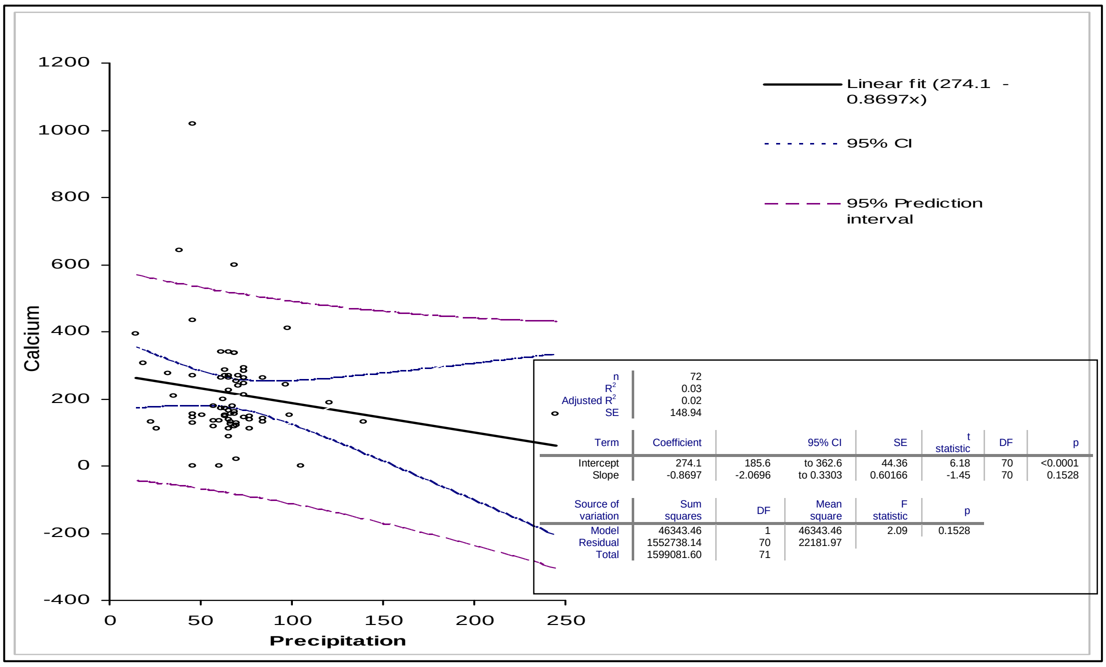
Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	292.2	1	292.2	0.03	0.8565
Residual	620546.9	70	8865.0		
Total	620839.1	71			

Figure 4.37 Ammonia of Leachate Versus Precipitation

Figure 4.38 illustrates the correlation of calcium of leachate to precipitation with an equation of **Calcium – 274.4 – 0.8697 Precipitation**. The r^2 value of 3% is obtained and the 95 confidence interval spreads between 185.6 to 362.6 mg/l.

Figure 4.39 show the correlation of magnesium of leachate to precipitation with an equation of **Magnesium = 120 – 0.1437 Precipitation**. The r^2 value of 1% is obtained and the 95% confidence interval spread between 95 to 145 mg/l.

The correlation of sodium of leachate to precipitation is depicted in Figure 4.40 with an equation of **Sodium = 612.9 – 0.08829 Precipitation**. The r^2 value of 1% is obtained and the 95% confidence interval spread between 457.3 to 768.5 mg/l.

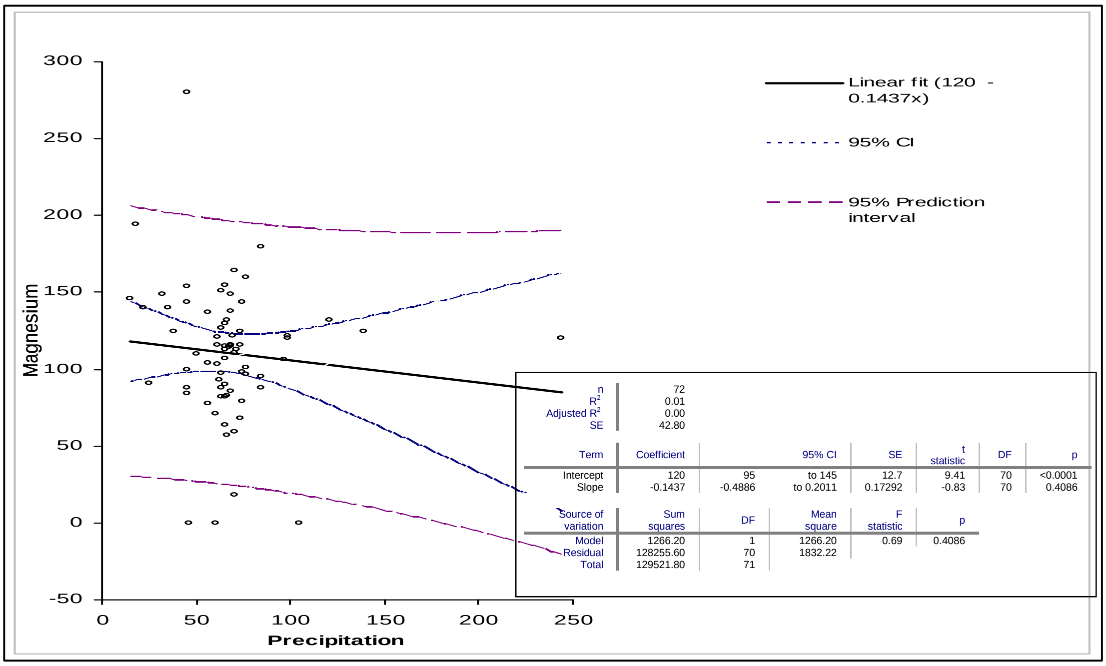


n	72
R^2	0.03
Adjusted R^2	0.02
SE	148.94

Term	Coefficient	95% CI		SE	t statistic	DF	p
Intercept	274.1	185.6	to 362.6	44.36	6.18	70	<0.0001
Slope	-0.8697	-2.0696	to 0.3303	0.60166	-1.45	70	0.1528

Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	46343.46	1	46343.46	2.09	0.1528
Residual	1552738.14	70	22181.97		
Total	1599081.60	71			

Figure 4.38 Calcium of Leachate Versus Precipitation

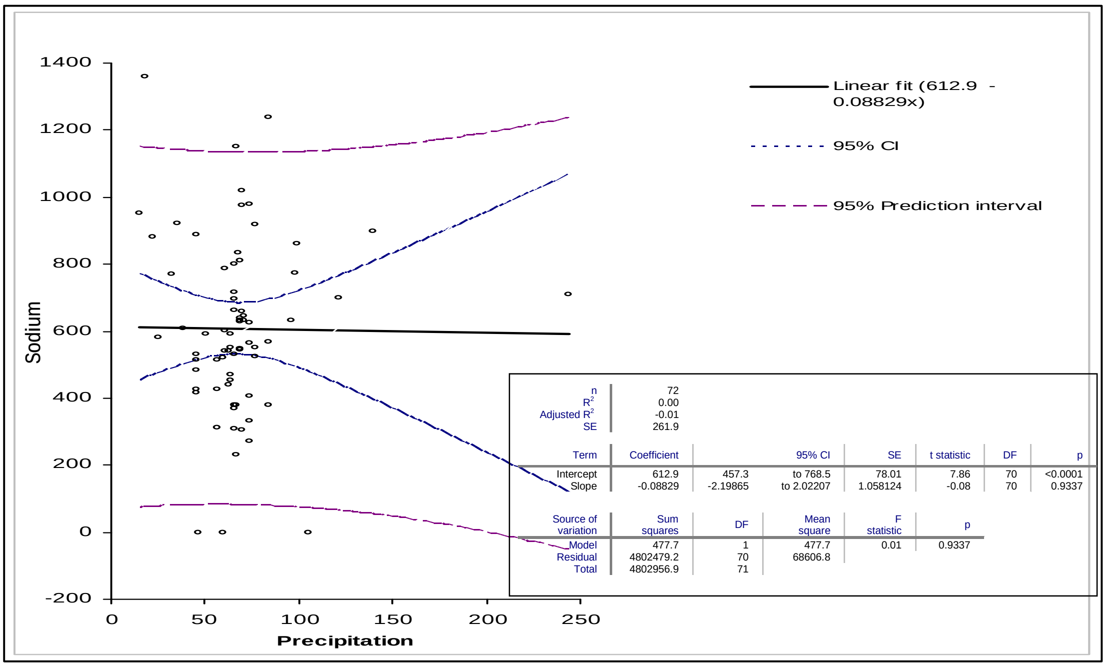


n	72
R^2	0.01
Adjusted R^2	0.00
SE	42.80

Term	Coefficient	95% CI		SE	t statistic	DF	p
Intercept	120	95	to 145	12.7	9.41	70	<0.0001
Slope	-0.1437	-0.4886	to 0.2011	0.17292	-0.83	70	0.4086

Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	1266.20	1	1266.20	0.69	0.4086
Residual	128255.60	70	1832.22		
Total	129521.80	71			

Figure 4.39 Magnesium of Leachate Versus Precipitation



n	72
R^2	0.00
Adjusted R^2	-0.01
SE	261.9

Term	Coefficient	95% CI		SE	t statistic	DF	p
Intercept	612.9	457.3	to 768.5	78.01	7.86	70	<0.0001
Slope	-0.08829	-2.19865	to 2.02207	1.058124	-0.08	70	0.9337

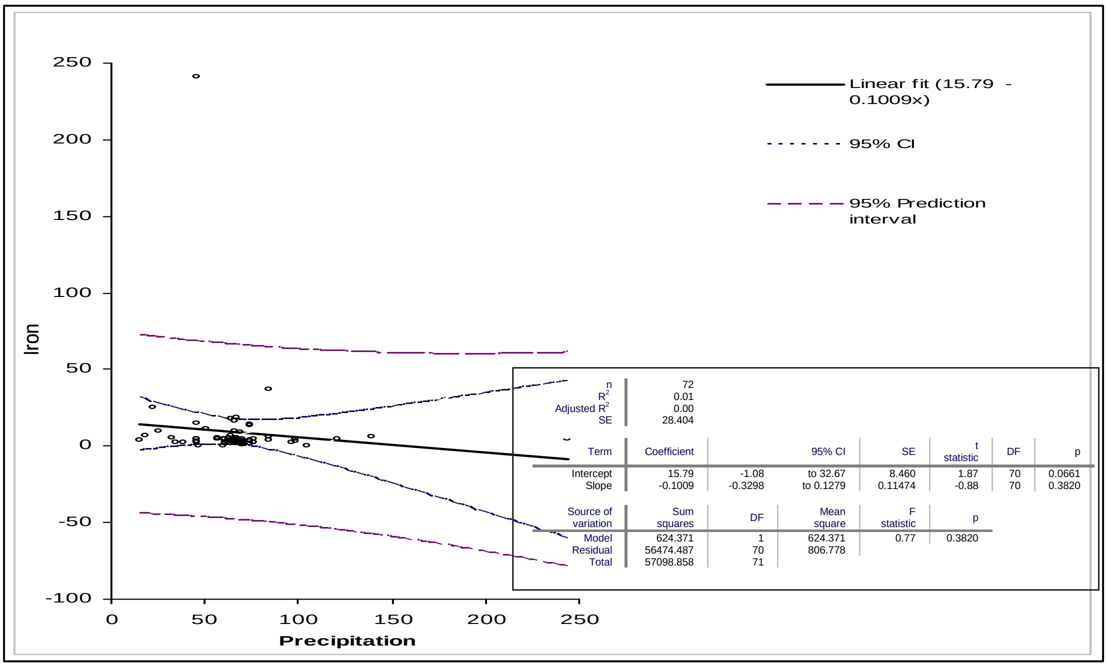
Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	477.7	1	477.7	0.01	0.9337
Residual	4802479.2	70	68606.8		
Total	4802956.9	71			

Figure 4.40 Sodium of Leachate Versus Precipitation

The correlation of iron of leachate of precipitation is shown in Figure 4.41 with an equation of **Iron = 15.79 – 0.1009 Precipitation**. The r^2 value of 1% and the 95% confidence interval spreads between – 1.08 to 32.87 mg/l.

Figure 4.42 and Figure 4.43 depict the correlation of nitrate and nitrite of leachate to Precipitation with equations of **Nitrate = 1.28 + 0.0008 Precipitation** and **Nitrite = 1.384 + 0.0002 Precipitation**. The r^2 values obtained are both 1% with 95% confidence interval spreads between 0.83 to 1.73 mg/l and 0.976 to 1.792 mg/l respectively.

The correlation of TKN of leachate to precipitation is depicted in Figure 4.44 with an equation of **TKN = 275.2 + 0.3704 Precipitation**. The r^2 value of 1% is obtained and the 95% confidence interval spreads between 194.8 to 355.7 mg/l.

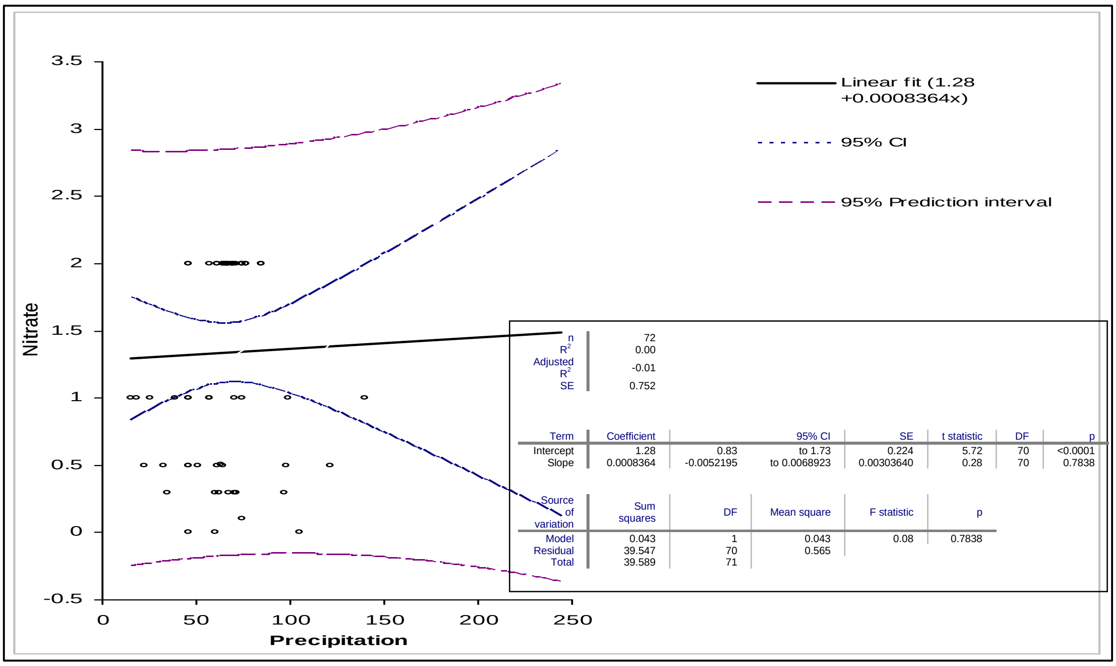


n	72
R^2	0.01
Adjusted R^2	0.00
SE	28.404

Term	Coefficient		95% CI	SE	t statistic	DF	p
Intercept	15.79	-1.08	to 32.67	8.460	1.87	70	0.0661
Slope	-0.1009	-0.3298	to 0.1279	0.11474	-0.88	70	0.3820

Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	624.371	1	624.371	0.77	0.3820
Residual	56474.487	70	806.778		
Total	57098.858	71			

Figure 4.41 Iron of Leachate Versus Precipitation

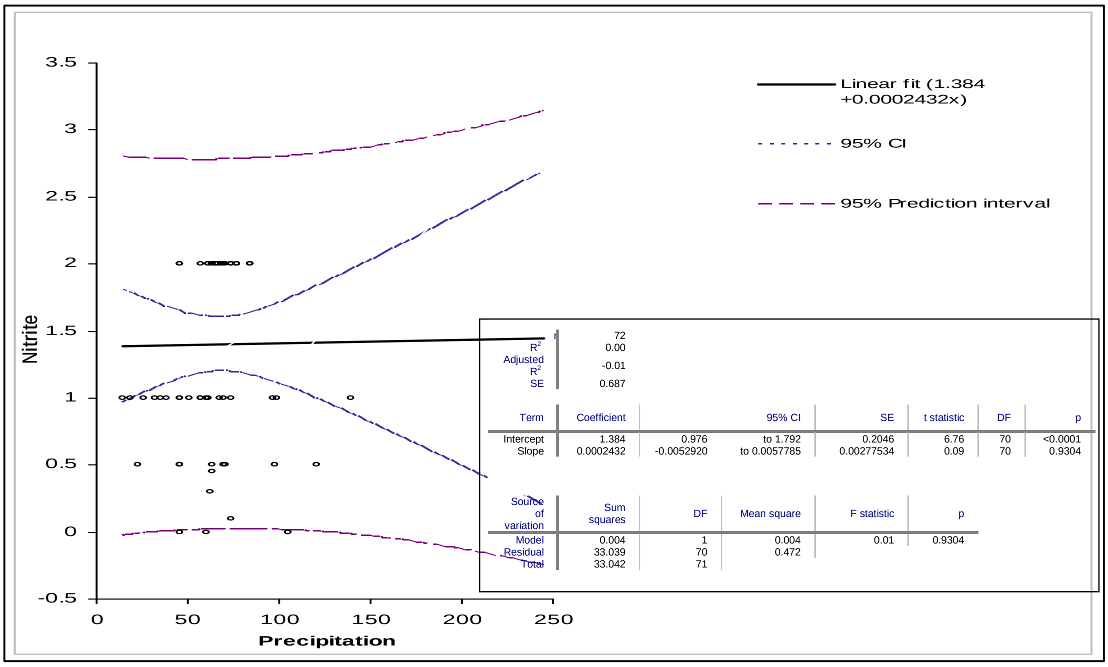


n	72
R^2	0.00
Adjusted R^2	-0.01
SE	0.752

Term	Coefficient		95% CI	SE	t statistic	DF	p
Intercept	1.28	0.83	to 1.73	0.224	5.72	70	<0.0001
Slope	0.0008364	-0.0052195	to 0.0068923	0.00303640	0.28	70	0.7838

Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	0.043	1	0.043	0.08	0.7838
Residual	39.547	70	0.565		
Total	39.589	71			

Figure 4.42 Nitrate of Leachate Versus Precipitation

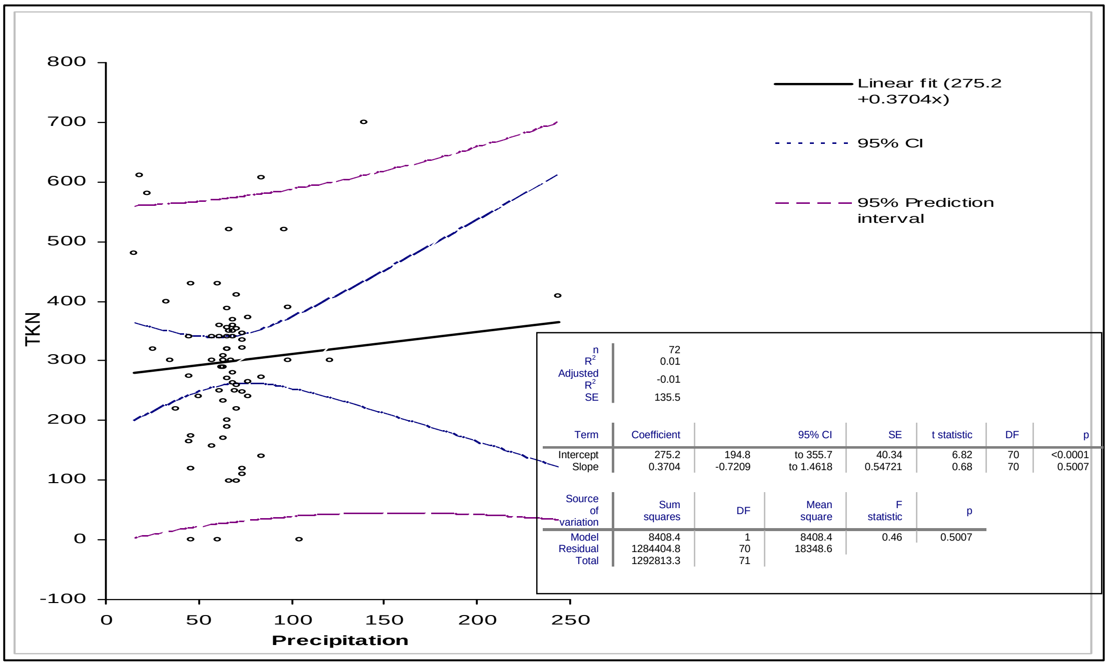


n	72
R^2	0.00
Adjusted R^2	-0.01
SE	0.687

Term	Coefficient		95% CI	SE	t statistic	DF	p
Intercept	1.384	0.976	to 1.792	0.2046	6.76	70	<0.0001
Slope	0.0002432	-0.0052920	to 0.0057785	0.00277534	0.09	70	0.9304

Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	0.004	1	0.004	0.01	0.9304
Residual	33.039	70	0.472		
Total	33.042	71			

Figure 4.43 Nitrite of Leachate Versus Precipitation



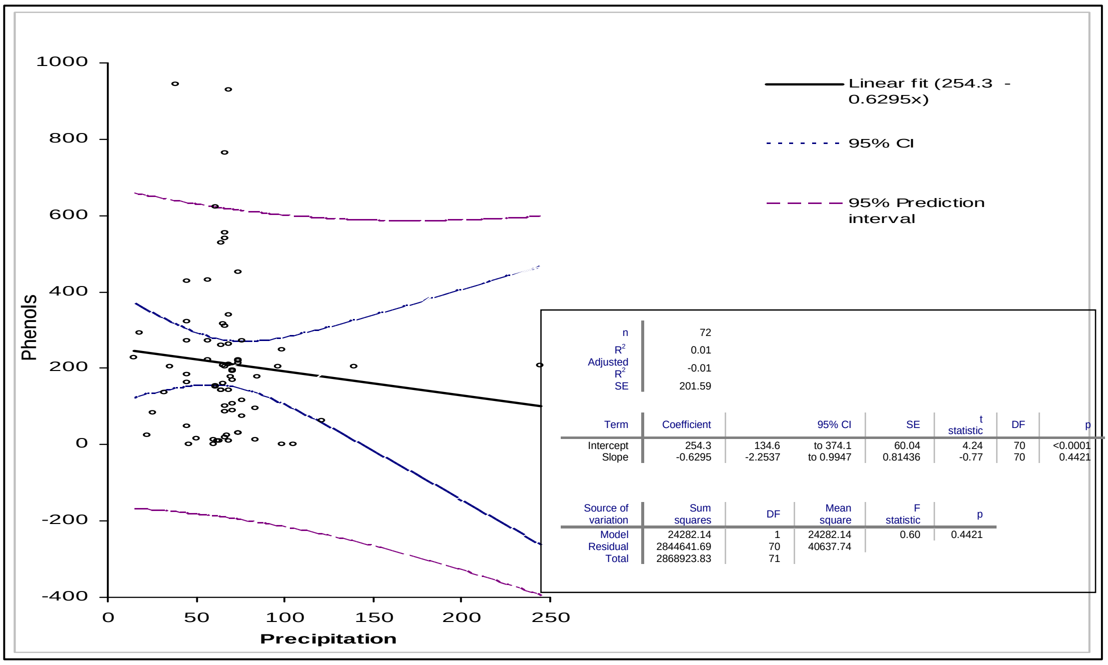
n	72
R^2	0.01
Adjusted R^2	-0.01
SE	135.5

Term	Coefficient		95% CI	SE	t statistic	DF	p
Intercept	275.2	194.8	to 355.7	40.34	6.82	70	<0.0001
Slope	0.3704	-0.7209	to 1.4618	0.54721	0.68	70	0.5007

Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	8408.4	1	8408.4	0.46	0.5007
Residual	1284404.8	70	18348.6		
Total	1292813.3	71			

Figure 4.44 TKN of Leachate Versus Precipitation

Figure 4.45 depicts the correlation of phenols of leachate to precipitation with an equation of **Phenol = 254.3 – 0.6295 Precipitation**. The r^2 value of 1% and 95% confidence interval spread between 134.6 to 374.1 mg/l.



n	72
R^2	0.01
Adjusted R^2	-0.01
SE	201.59

Term	Coefficient	95% CI		SE	t statistic	DF	p
Intercept	254.3	134.6	to 374.1	60.04	4.24	70	<0.0001
Slope	-0.6295	-2.2537	to 0.9947	0.81436	-0.77	70	0.4421

Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	24282.14	1	24282.14	0.60	0.4421
Residual	2844641.69	70	40637.74		
Total	2868923.83	71			

Figure 4.45 Phenols of Leachate Versus Precipitation

From the data evaluation as depicted in Figures 4.27 – 4.45 all physical properties (r^2>0.01), all organic matter (r^2>0.01), all inorganic matters (r^2>0.01) and xenobiotic organic compounds of phenols (r^2>0.01) reveals that there is less significance of correlation relationship of leachate to precipitation as compared to temperature in the environment. Thus can be explained by the fact that sufficient moisture content is achieved to maintain waste stabilization rate within the landfill by leachate recirculation thus ambient precipitation plays a lesser role in determining leachate quality.

As many as 19 equation are derived for the correlation of pollution to precipitation as follows:-

pH = 7 – 0.001 Precipitation (4.20)

Alkalinity = 2493 – 0.8657 Precipitation (4.21)

Hardness = 1189 – 2.798 Precipitation (4.22)

Conductivity = 9516 – 31.22 Precipitation (4.23)

Total Suspended Solids = 86.42 – 0.3398 Precipitation (4.24)

BOD = 347.7 – 1.59 Precipitation (4.25)

COD = 1131 – 2.751 Precipitation (4.26)

DOC = 392.9 – 1.263 Precipitation (4.27)

Sulphate = 115.6 – 0.5506 Precipitation (4.28)

Chloride = 660.5 – 0.02075 Precipitation (4.29)

Ammonia = 224.2 + 0.069 Precipitation (4.30)

Calcium – 274.4 – 0.8697 Precipitation (4.31)

Magnesium = 120 – 0.1437 Precipitation (4.32)

Sodium = 612.9 – 0.08829 Precipitation (4.33)

Iron = 15.79 – 0.1009 Precipitation (4.34)

Nitrate = 1.28 + 0.0008 Precipitation (4.35)

Nitrite = 1.384 + 0.0002 Precipitation (4.36)

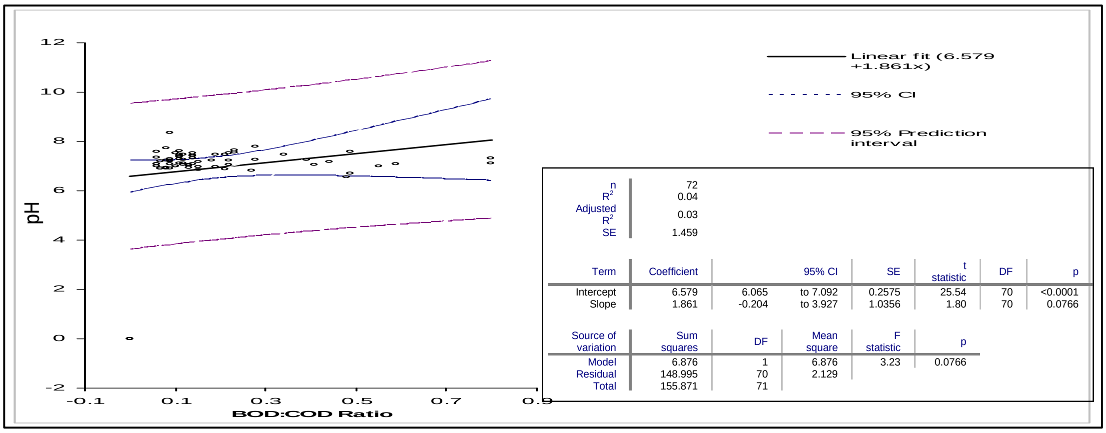
TKN = 275.2 + 0.3704 Precipitation (4.37)

Phenol = 254.3 – 0.6295 Precipitation (4.38)

4.3.3 Waste Age

Duration of waste placement in landfill determine the extent of microbial activity that affect the quality of leachate. Due to variability of waste placement, general assumption is to be made to determine the relationship of waste age and leachate quality. BOD:COD ratio typically is a measurement use to describe the organic composition in the leachate appear to be a good representation of waste stabilization transiting from early acetogenic phase to mature methanogenic phase in landfill. The ratio is found to be most useful in reflecting the composition of organic matter in leachate as it relates to the age of waste in the landfill. As BOD is predominantly a biochemical parameter, it generally reflects biodegradability of organic matter in leachate thus making BOD:COD ratio a good indicator of the proportion of biochemically degradable organic matter to total organic matter. The reflects that waste age describes well the acetogenic phase to methanogenic phase.

Figure 4.46 depicts the correlations of pH to BOD:COD of leachate with an equation of **pH = 6.579 + 1.861 BOD:COD**. The r^2 value show 40% of the total variation about the BOD:COD mean is explained by the regression line. The confidence interval for the slope shows that with 95% confidence the data value for the slope line somewhere between 6.085 to 7.092.



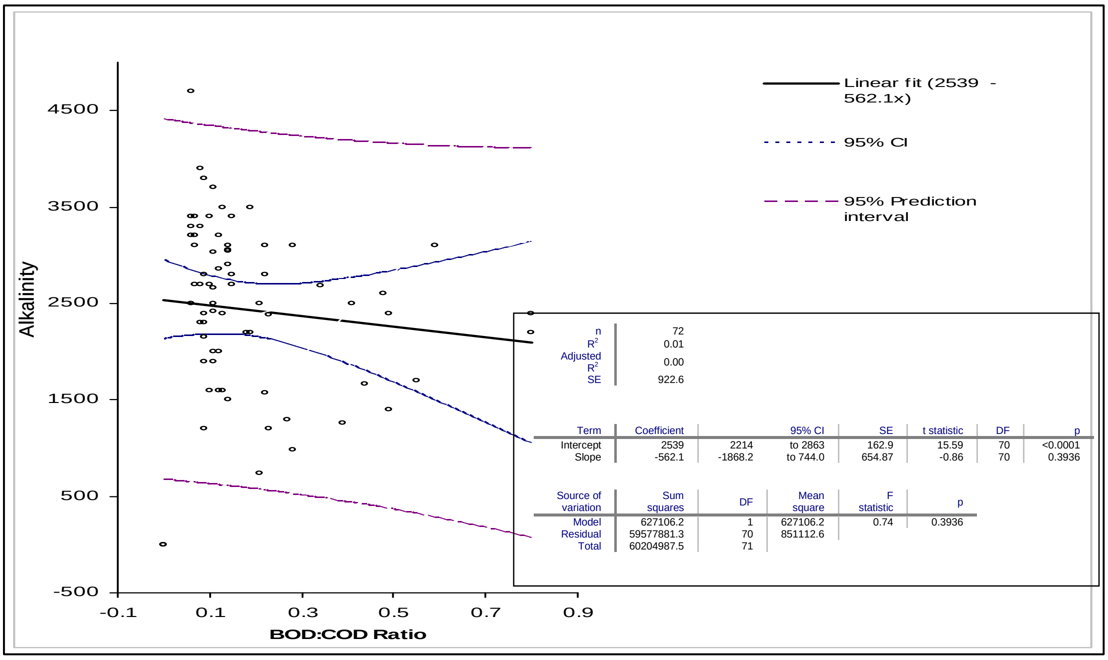
n	72
R^2	0.04
Adjusted R^2	0.03
SE	1.459

Term	Coefficient		95% CI	SE	t statistic	DF	p
Intercept	6.579	6.065	to 7.092	0.2575	25.54	70	<0.0001
Slope	1.861	-0.204	to 3.927	1.0356	1.80	70	0.0766

Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	6.876	1	6.876	3.23	0.0766
Residual	148.995	70	2.129		
Total	155.871	71			

Figure 4.46 pH of Leachate Versus BOD:COD Ratio

Figure 4.47 depicts the alkalinity to BOD:COD of leachate with an equation of **Alkalinity = 2539 – 562.1 BOD:COD**. The r^2 value of 1% is obtained and the 95% confident interval lies between 2214 to 2863.



n	72
R^2	0.01
Adjusted R^2	0.00
SE	922.6

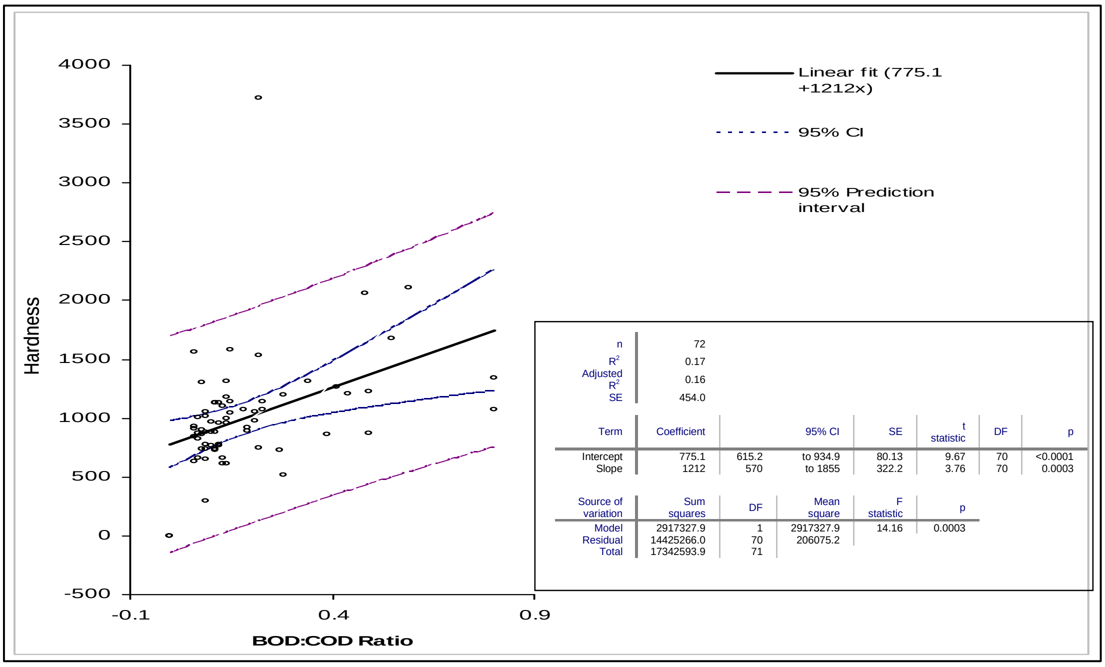
Term	Coefficient		95% CI	SE	t statistic	DF	p
Intercept	2539	2214	to 2863	162.9	15.59	70	<0.0001
Slope	-562.1	-1868.2	to 744.0	654.87	-0.86	70	0.3936

Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	627106.2	1	627106.2	0.74	0.3936
Residual	59577881.3	70	851112.6		
Total	60204987.5	71			

Figure 4.47 Alkalinityof Leachate Versus BOD:COD Ratio

Figure 4.48 shows the hardness to BOD:COD of leachate with an equation of **Hardness = 775.1 + 1212 BOD:COD**. The r^2 values of 17% is obtained and the 95% confident interval lies between 615.2 to 934.9.

Figure 4.49 illustrates the conductivity to BOD:COD leachate with an equation of **Conductivity = 6890 + 3850 BOD:COD**. The r^2 value of 1% is obtained and the 95% confident interval lies between 4190 to 9189.

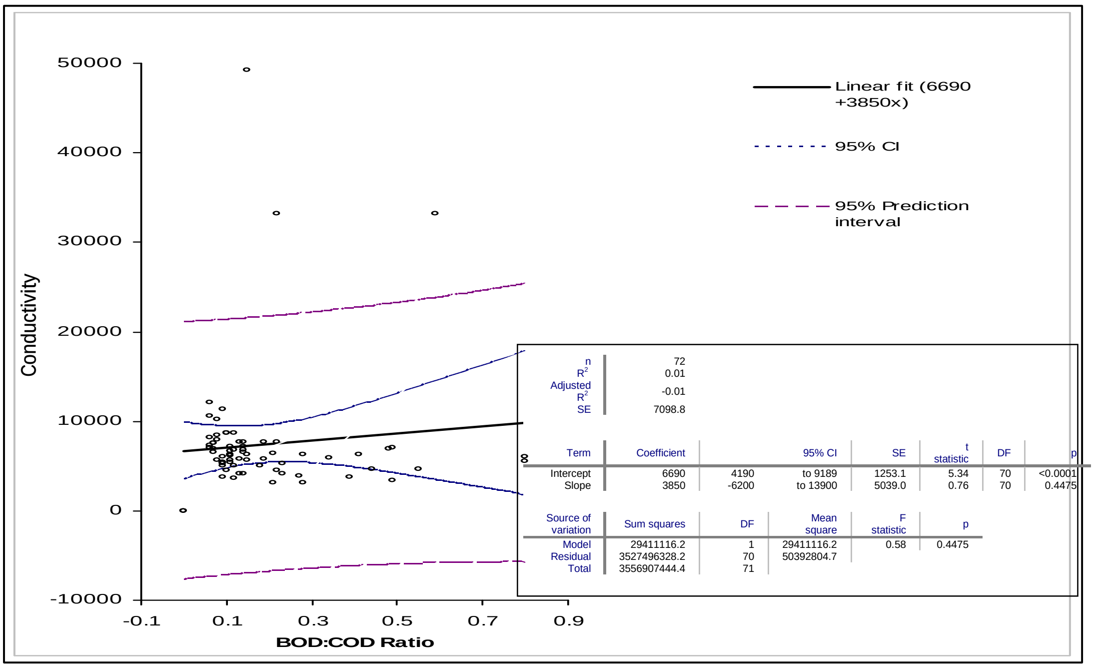


n	72
R^2	0.17
Adjusted R^2	0.16
SE	454.0

Term	Coefficient		95% CI	SE	t statistic	DF	p
Intercept	775.1	615.2	to 934.9	80.13	9.67	70	<0.0001
Slope	1212	570	to 1855	322.2	3.76	70	0.0003

Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	2917327.9	1	2917327.9	14.16	0.0003
Residual	14425266.0	70	206075.2		
Total	17342593.9	71			

Figure 4.48 Hardness of Leachate Versus BOD:COD Ratio



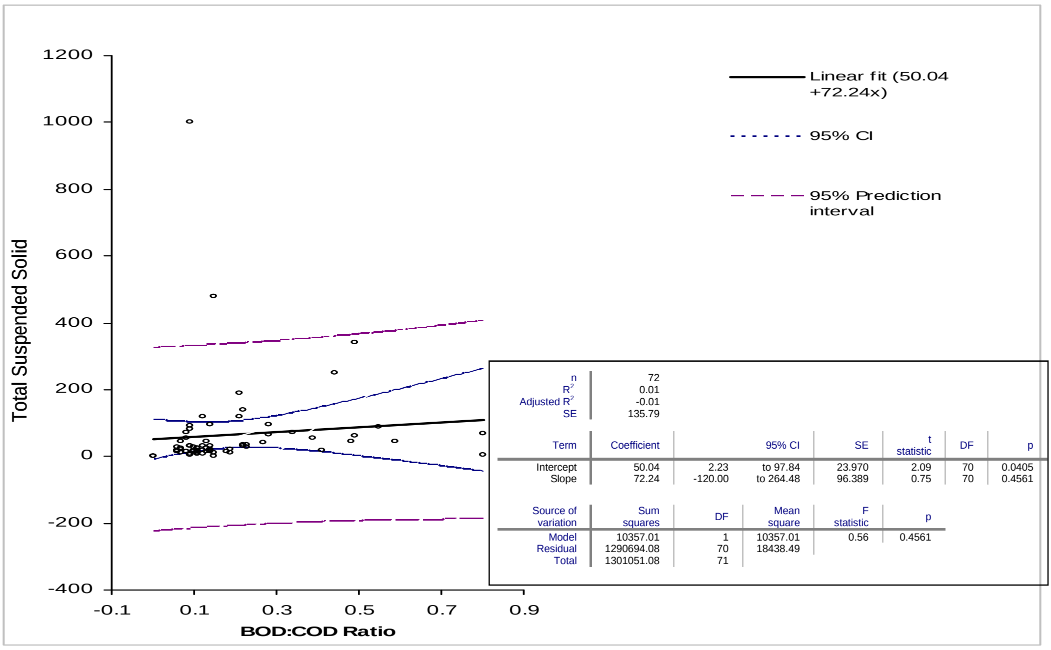
n	72
R^2	0.01
Adjusted R^2	-0.01
SE	7098.8

Term	Coefficient		95% CI	SE	t statistic	DF	p
Intercept	6690	4190	to 9189	1253.1	5.34	70	<0.0001
Slope	3850	-6200	to 13900	5039.0	0.76	70	0.4475

Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	29411116.2	1	29411116.2	0.58	0.4475
Residual	3527496328.2	70	50392804.7		
Total	3556907444.4	71			

Figure 4.49 Conductivity of Leachate Versus BOD:COD Ratio

The correlation of total suspended solids to BOD:COD of leachate is depicted in Figure 4.50 with an equation **Total Suspended Solids = 50.04 + 72.24 BOD:COD**. The r^2 value of 1% and the 95% confident interval lies between 2.23 to 97.84.



n	72
R^2	0.01
Adjusted R^2	-0.01
SE	135.79

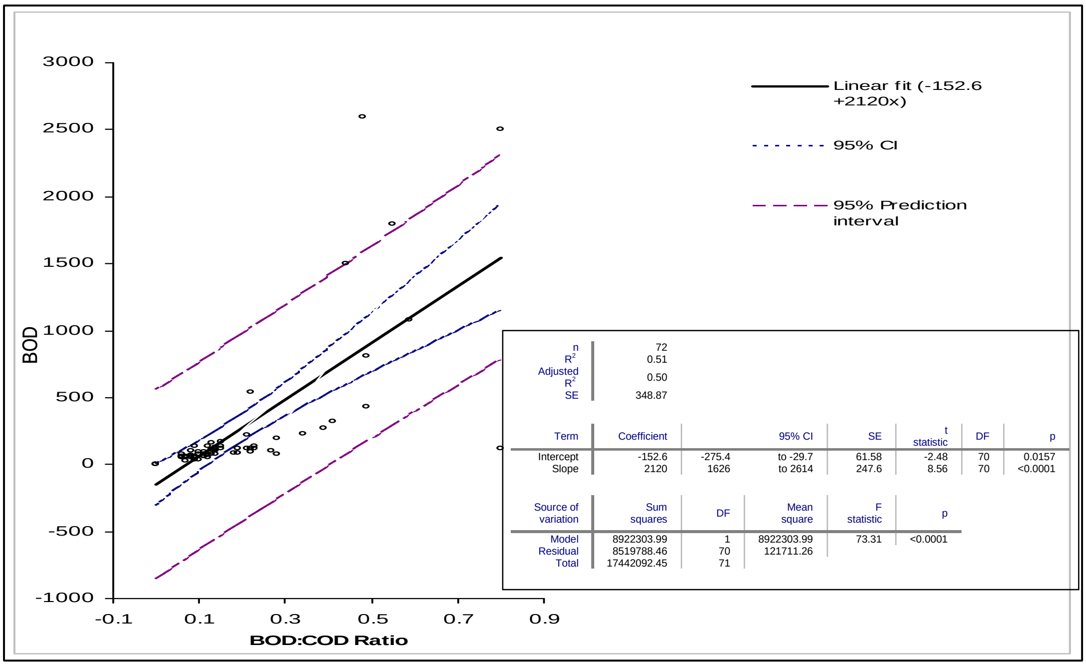
Term	Coefficient	95% CI		SE	t statistic	DF	p
Intercept	50.04	2.23	to 97.84	23.970	2.09	70	0.0405
Slope	72.24	-120.00	to 264.48	96.389	0.75	70	0.4561

Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	10357.01	1	10357.01	0.56	0.4561
Residual	1290694.08	70	18438.49		
Total	1301051.08	71			

Figure 4.50 Total Suspended Solid of Leachate Versus BOD:COD Ratio

Figure 4.51 depicts BOD to BOD:COD of leachate with an equation **BOD = 152 + 2120 BOD:COD**. The r^2 value of 51% is obtained and the 95% confidence interval lies between – 275.4 to – 29.7 mg/l.

The correlation of COD and DOC to BOD:COD of leachate are depicted in Figure 4.52 and Figure 4.53 with equations of **COD = 481.3 + 2505 BOD:COD** and **DOC = 207.2 + 541.6 BOD:COD**. The r^2 value of 25% and 13% with the 95% confidence interval spreads between 223.2 to 739.4 mg/l and 125.9 to 288.4 mg/l respectively.

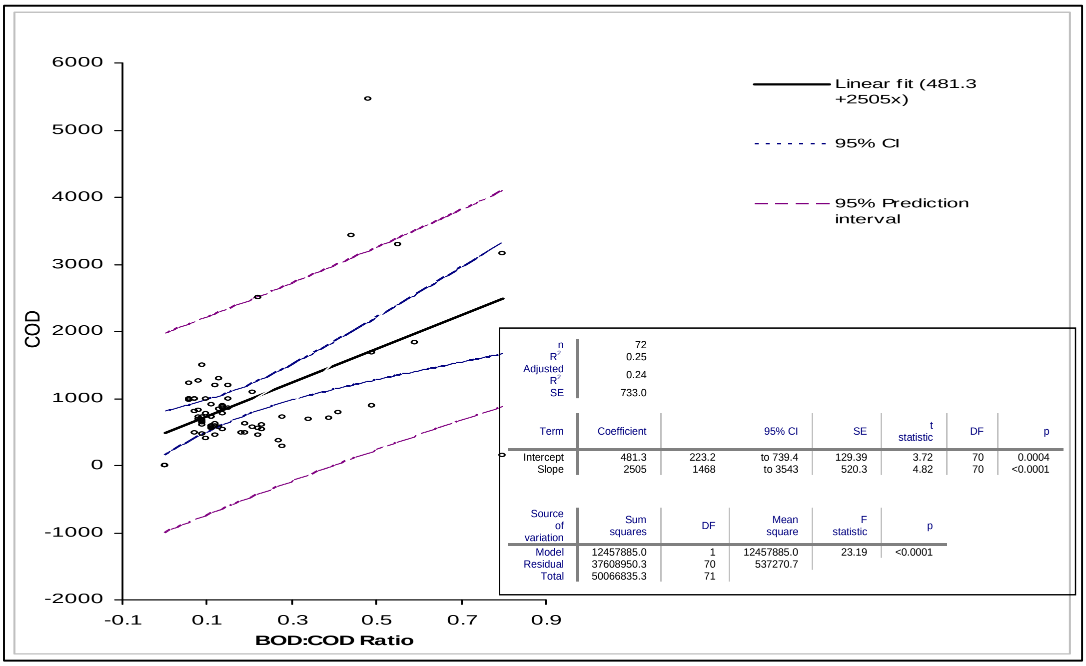


n	72
R^2	0.51
Adjusted R^2	0.50
SE	348.87

Term	Coefficient	95% CI		SE	t statistic	DF	p
Intercept	-152.6	-275.4	to -29.7	61.58	-2.48	70	0.0157
Slope	2120	1626	to 2614	247.6	8.56	70	<0.0001

Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	8922303.99	1	8922303.99	73.31	<0.0001
Residual	8519788.46	70	121711.26		
Total	17442092.45	71			

Figure 4.51 BOD of Leachate Versus BOD:COD Ratio

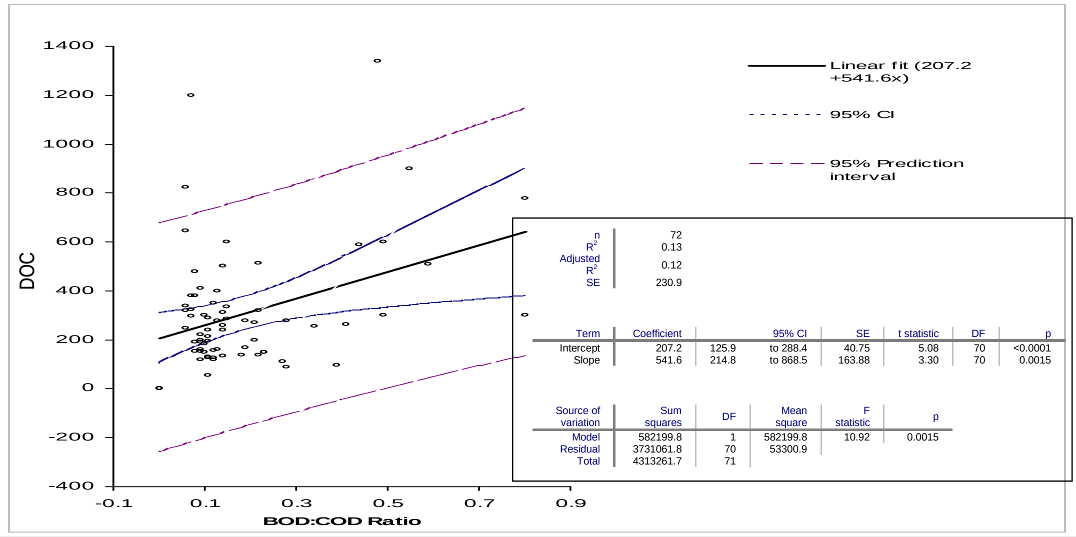


n	72
R^2	0.25
Adjusted R^2	0.24
SE	733.0

Term	Coefficient	95% CI		SE	t statistic	DF	p
Intercept	481.3	223.2	to 739.4	129.39	3.72	70	0.0004
Slope	2505	1468	to 3543	520.3	4.82	70	<0.0001

Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	12457885.0	1	12457885.0	23.19	<0.0001
Residual	37608950.3	70	537270.7		
Total	50066835.3	71			

Figure 4.52 COD of Leachate Versus BOD:COD Ratio



n	72
R^2	0.13
Adjusted R^2	0.12
SE	230.9

Term	Coefficient		95% CI	SE	t statistic	DF	p
Intercept	207.2	125.9	to 288.4	40.75	5.08	70	<0.0001
Slope	541.6	214.8	to 868.5	163.88	3.30	70	0.0015

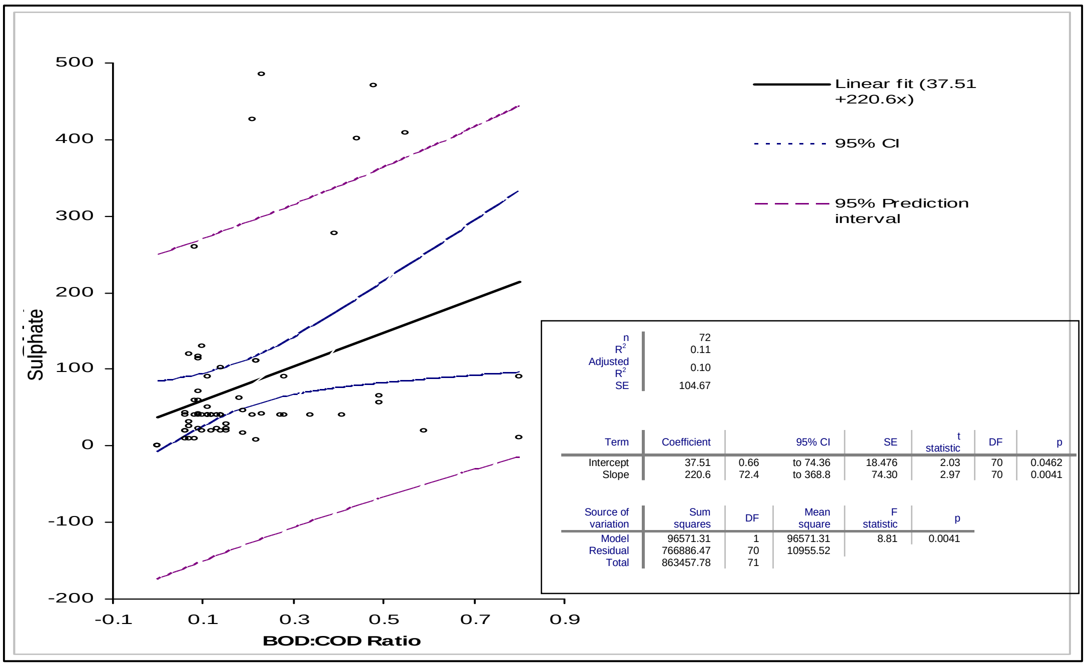
Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	582199.8	1	582199.8	10.92	0.0015
Residual	3731061.8	70	53300.9		
Total	4313261.7	71			

Figure 4.53 DOC of Leachate Versus BOD:COD Ratio

Figure 4.54 depicts the correlation of Sulphate to BOD:COD of leachate with an equation of **Sulphate = 37.51 + 220.8 BOD:COD**. The r^2 value of 11% is obtained and the 95% confident interval spread from 0.66 to 74.36 mg/l.

Figure 4.55 depicts to correlation of chloride to BOD:COD ratio of leachate with an equation of **Chloride = 683.2 – 130.6 BOD:COD**. The r^2 value of 1% is obtained and the 95% confident interval spread between 593.6 to 772.9 mg/l. Negative correlation achieved reveals that there is an inverse relationship of lower chloride value at higher BOD:COD ratio.

The correlation of ammonia to BOD:COD of leachate is depicted in Figure 4.56 with an equation of **Ammonia = 250.6 – 117.2 BOD:COD**. The r^2 value of 4% is obtained and the 95% confident interval lied somewhere between 216.2 to 283.0 mg/l.

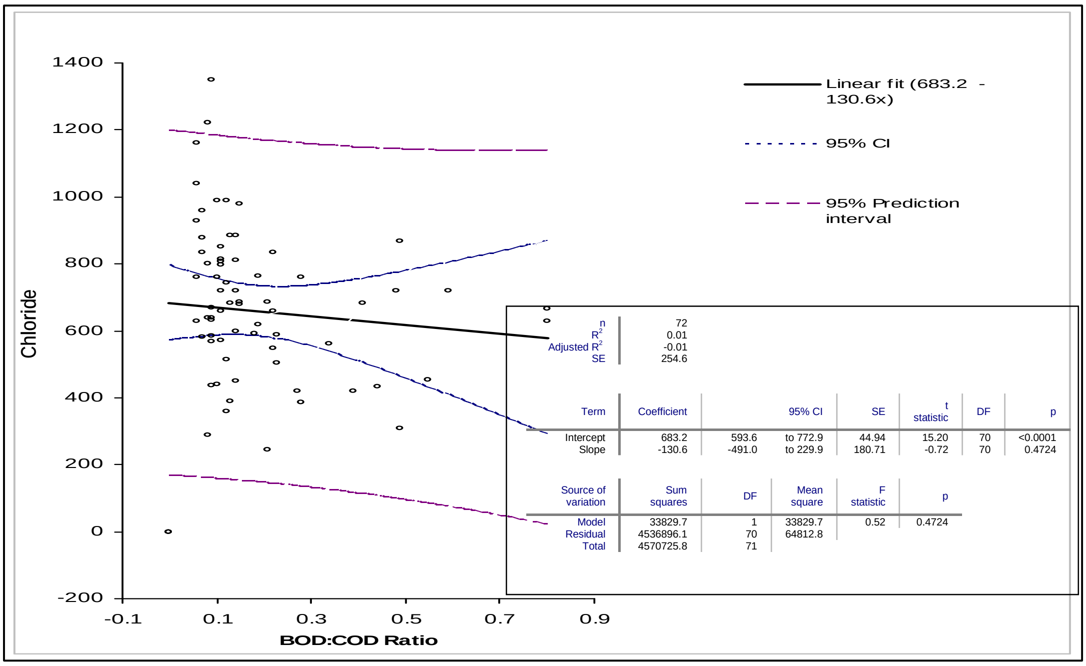


n	72
R^2	0.11
Adjusted R^2	0.10
SE	104.67

Term	Coefficient		95% CI	SE	t statistic	DF	p
Intercept	37.51	0.66	to 74.36	18.476	2.03	70	0.0462
Slope	220.6	72.4	to 368.8	74.30	2.97	70	0.0041

Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	96571.31	1	96571.31	8.81	0.0041
Residual	766886.47	70	10955.52		
Total	863457.78	71			

Figure 4.54 Sulphate of Leachate Versus BOD:COD Ratio

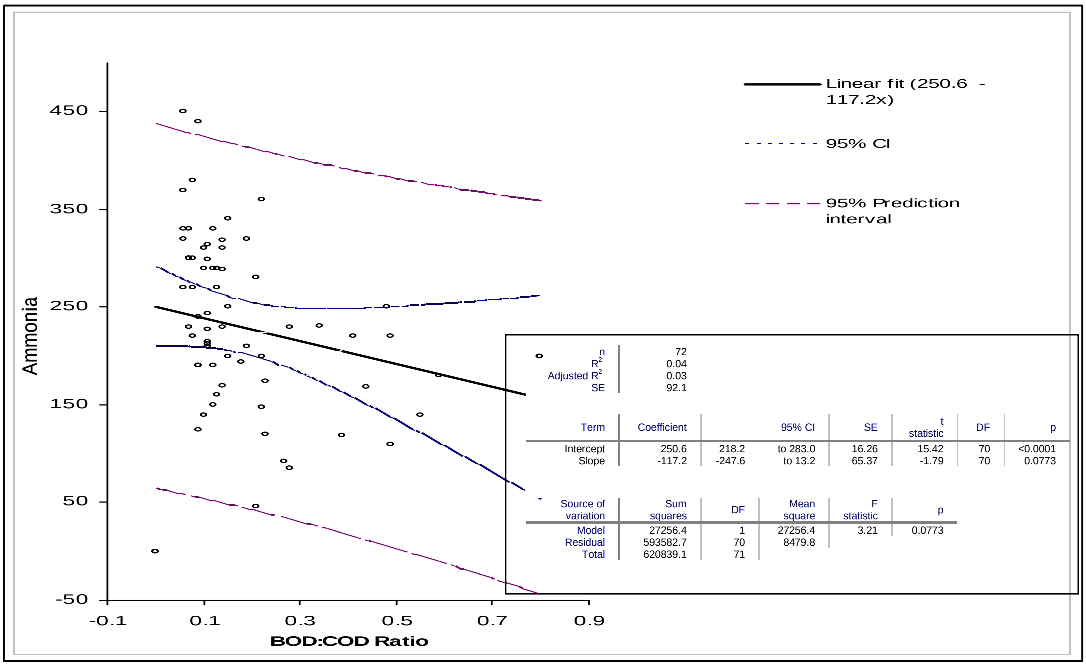


n	72
R^2	0.01
Adjusted R^2	-0.01
SE	254.6

Term	Coefficient		95% CI	SE	t statistic	DF	p
Intercept	683.2	593.6	to 772.9	44.94	15.20	70	<0.0001
Slope	-130.6	-491.0	to 229.9	180.71	-0.72	70	0.4724

Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	33829.7	1	33829.7	0.52	0.4724
Residual	4536896.1	70	64812.8		
Total	4570725.8	71			

Figure 4.55 Chloride of Leachate Versus BOD:COD Ratio



n	72
R^2	0.04
Adjusted R^2	0.03
SE	92.1

Term	Coefficient	95% CI		SE	t statistic	DF	p
Intercept	250.6	218.2	to 283.0	16.26	15.42	70	<0.0001
Slope	-117.2	-247.6	to 13.2	65.37	-1.79	70	0.0773

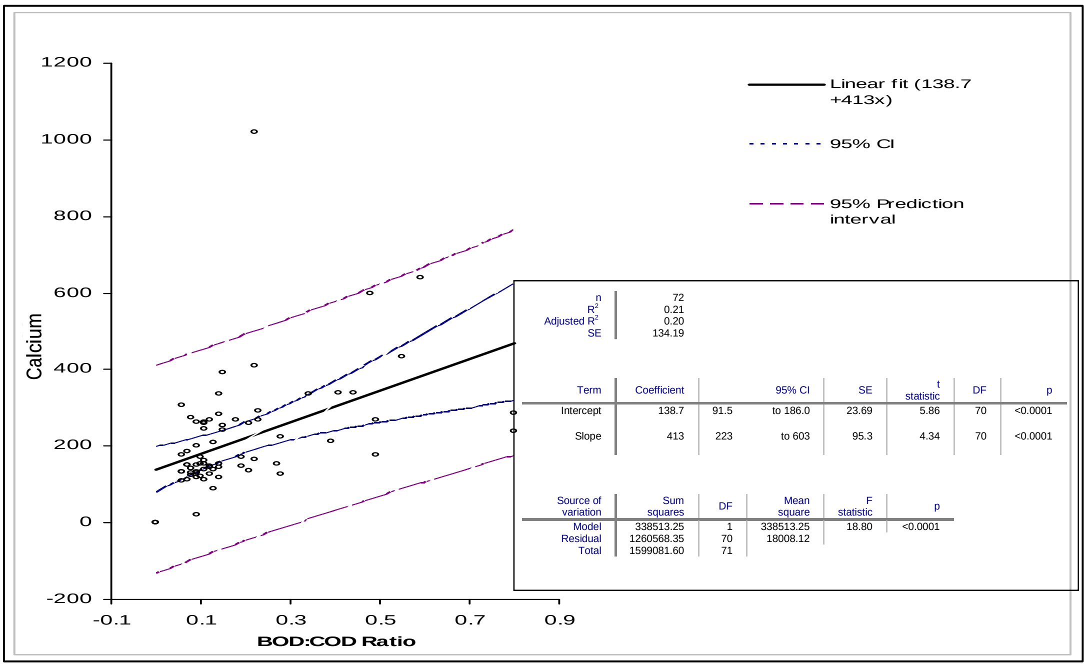
Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	27256.4	1	27256.4	3.21	0.0773
Residual	593582.7	70	8479.8		
Total	620839.1	71			

Figure 4.56 Ammonia of Leachate Versus BOD:COD Ratio

Figure 4.57 depicts the correlation of calcium to BOD:COD ratio of leachate with an equation of **Calcium = 138.7 + 413 BOD:COD**. The r^2 value of 21% is obtained and the 95% confidence interval spreads between 91.5 to 186.0 mg/l.

Figure 4.58 illustrates the correlation of magnesium to BOD:COD of leachate with an equation of **Magnesium = 102.5 + 42.13 BOD:COD**. The r^2 value obtained is 3% and the 95% confident interval lies between 87.5 to 117.4 mg/l.

Figure 4.59 depicts the correlation of sodium to BOD:COD ratio of leachate with an equation of **Sodium = 635.8 – 156 BOD:COD**. The r^2 value of 1% is obtained and the 95% confident interval lies between 544.1 to 727.8 mg/l. Negative correlation reveals that there is an inverse relationship of lower sodium at higher BOD:COD.

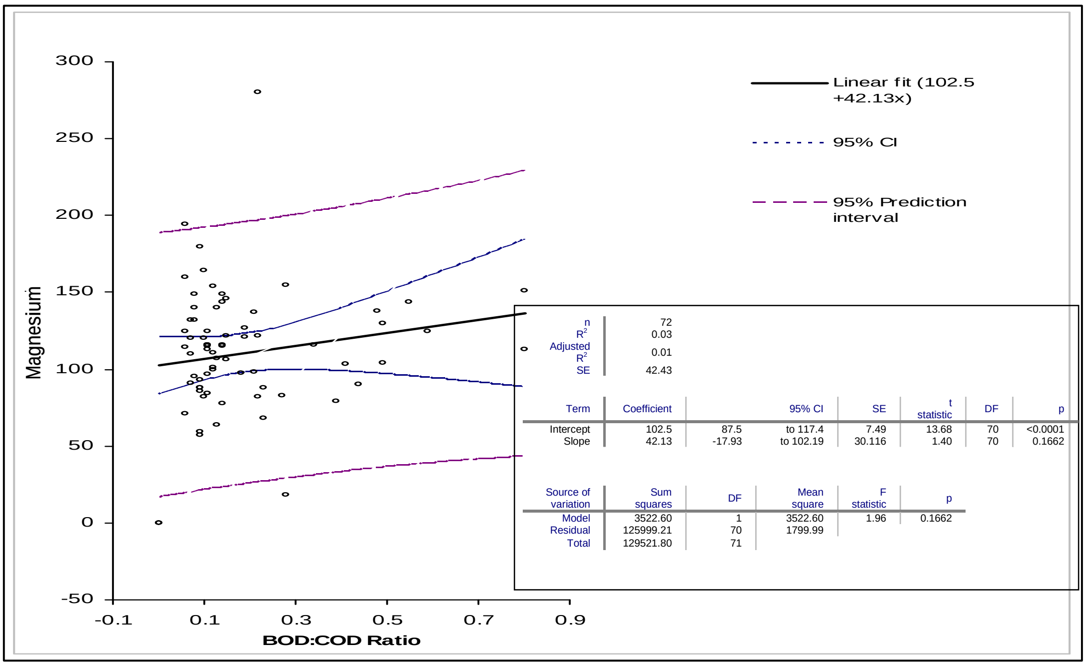


n	72
R^2	0.21
Adjusted R^2	0.20
SE	134.19

Term	Coefficient		95% CI	SE	t statistic	DF	p
Intercept	138.7	91.5	to 186.0	23.69	5.86	70	<0.0001
Slope	413	223	to 603	95.3	4.34	70	<0.0001

Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	338513.25	1	338513.25	18.80	<0.0001
Residual	1260568.35	70	18008.12		
Total	1599081.60	71			

Figure 4.57 Calcium of Leachate Versus BOD:COD Ratio

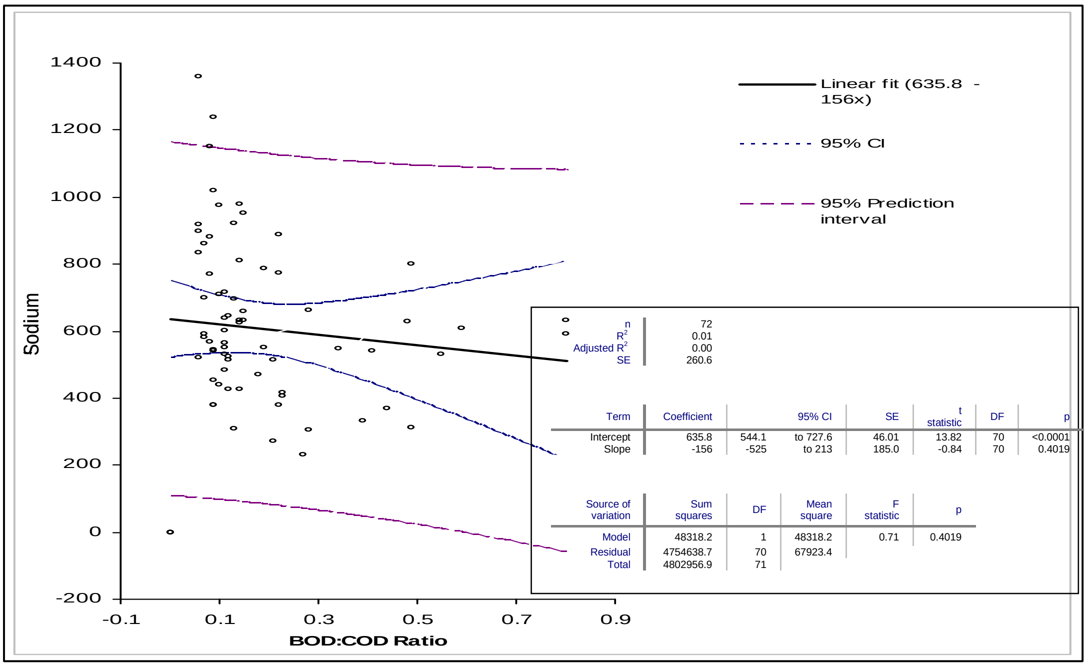


n	72
R^2	0.03
Adjusted R^2	0.01
SE	42.43

Term	Coefficient		95% CI	SE	t statistic	DF	p
Intercept	102.5	87.5	to 117.4	7.49	13.68	70	<0.0001
Slope	42.13	-17.93	to 102.19	30.116	1.40	70	0.1662

Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	3522.60	1	3522.60	1.96	0.1662
Residual	125999.21	70	1799.99		
Total	129521.80	71			

Figure 4.58 Magnesium of Leachate Versus BOD:COD Ratio



n	72
R^2	0.01
Adjusted R^2	0.00
SE	260.6

Term	Coefficient	95% CI		SE	t statistic	DF	p
Intercept	635.8	544.1	to 727.6	46.01	13.82	70	<0.0001
Slope	-156	-525	to 213	185.0	-0.84	70	0.4019

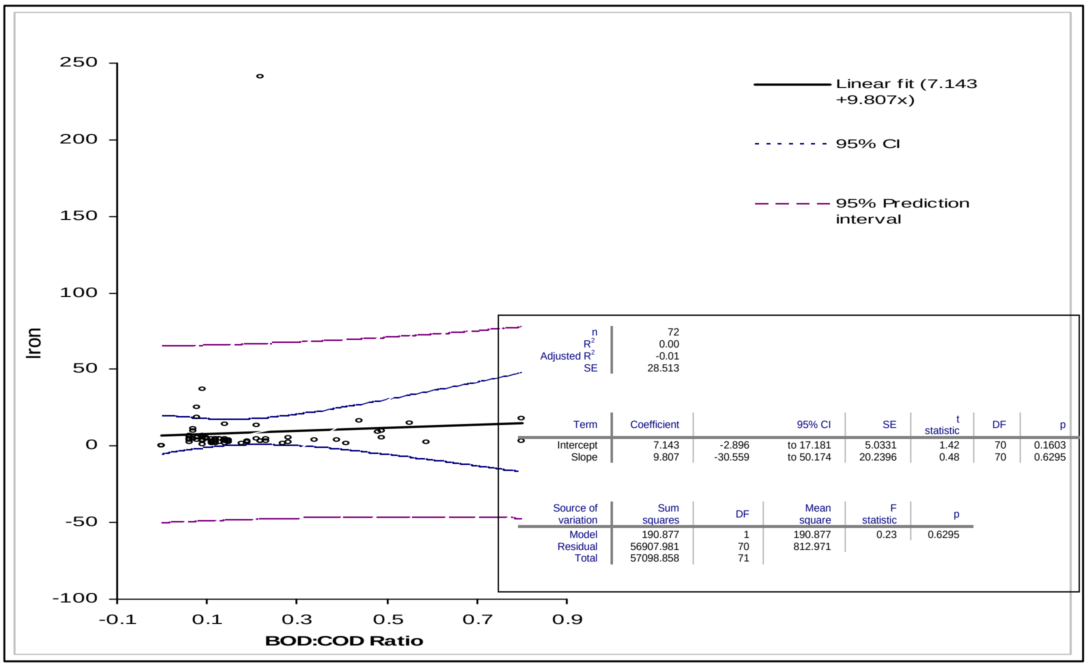
Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	48318.2	1	48318.2	0.71	0.4019
Residual	4754638.7	70	67923.4		
Total	4802956.9	71			

Figure 4.59 Sodium of Leachate Versus BOD:COD Ratio

Figure 4.60 Illustrates the correlation of iron to BOD:COD ratio of leachate with an equation of **Iron = 7.143 + 9.807 BOD:COD**. The r^2 value of 1% is obtained and the 95% confident interval spread between – 2.896 to 17.181 mg/l.

The correlations of Nitrate and Nitrite to BOD:COD ratio of leachate are depicts in Figure 4.61 and Figure 4.62 with equation of **Nitrate = 1.216 + 0.6509 BOD:COD** and **Nitrite = 1.301 + 0.5375 BOD:COD** of 2% and 2% with the 95% confident intervals spreads between 0.954 to 1.478 mg/l and 1.061 to 1.541 mg/l respectively.

Figure 4.63 shows the correlation of TKN to BOD:COD ratio of leachate with an equation of **TKN = 328.5 – 152.4 BOD:COD**. The r^2 value of 4% is obtained and the 95% confident interval spreads between 281.5 to 375.5 mg/l

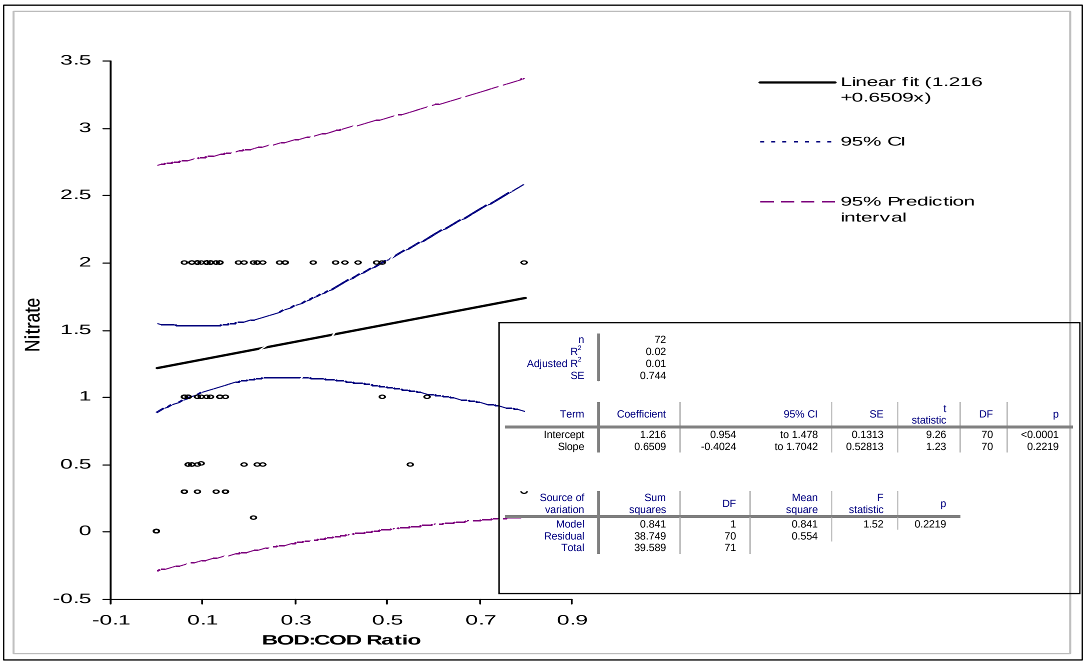


n	72
R^2	0.00
Adjusted R^2	-0.01
SE	28.513

Term	Coefficient	95% CI		SE	t statistic	DF	p
Intercept	7.143	-2.896	to 17.181	5.0331	1.42	70	0.1603
Slope	9.807	-30.559	to 50.174	20.2396	0.48	70	0.6295

Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	190.877	1	190.877	0.23	0.6295
Residual	56907.981	70	812.971		
Total	57098.858	71			

Figure 4.60 Iron of Leachate Versus BOD:COD Ratio

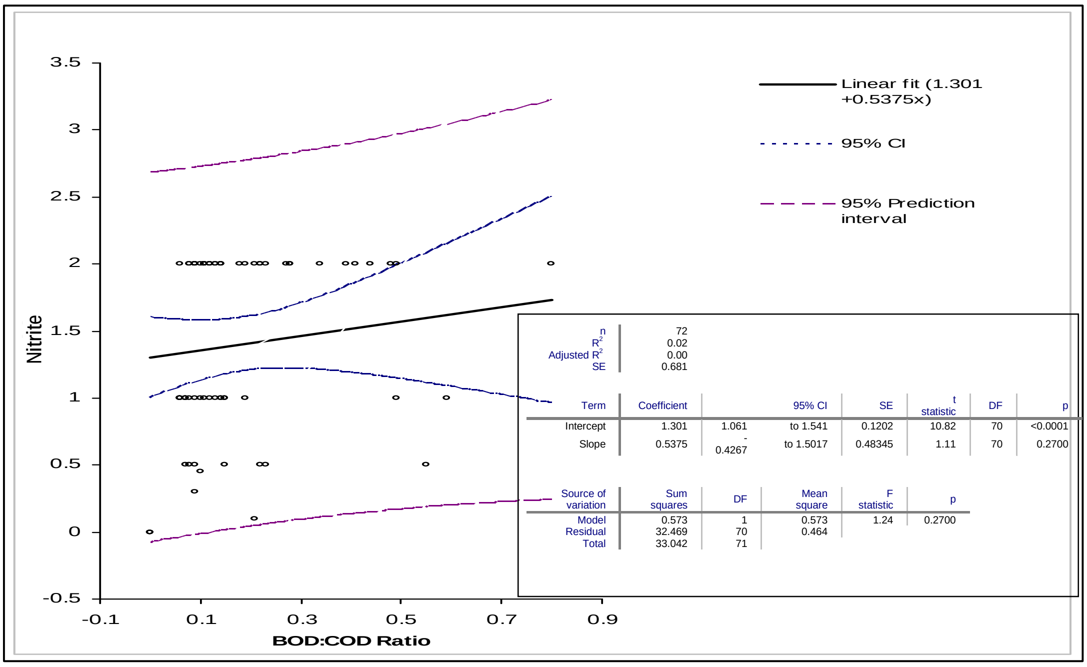


n	72
R^2	0.02
Adjusted R^2	0.01
SE	0.744

Term	Coefficient	95% CI		SE	t statistic	DF	p
Intercept	1.216	0.954	to 1.478	0.1313	9.26	70	<0.0001
Slope	0.6509	-0.4024	to 1.7042	0.52813	1.23	70	0.2219

Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	0.841	1	0.841	1.52	0.2219
Residual	38.749	70	0.554		
Total	39.589	71			

Figure 4.61 Nitrate of Leachate Versus BOD:COD Ratio

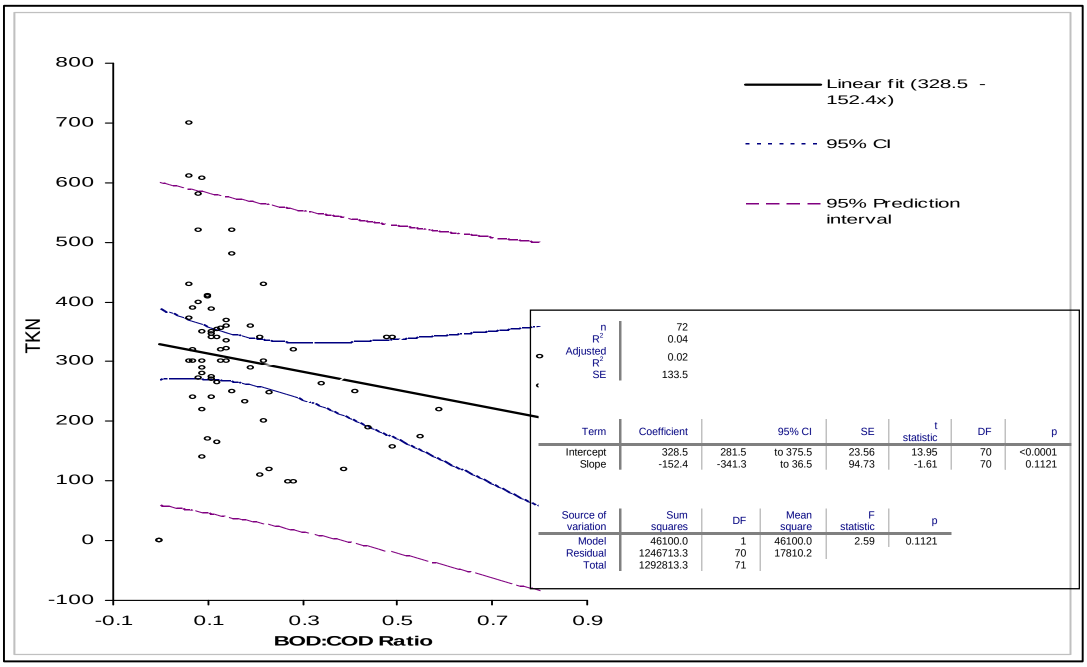


n	72
R^2	0.02
Adjusted R^2	0.00
SE	0.681

Term	Coefficient		95% CI	SE	t statistic	DF	p
Intercept	1.301	1.061	to 1.541	0.1202	10.82	70	<0.0001
Slope	0.5375	-0.4267	to 1.5017	0.48345	1.11	70	0.2700

Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	0.573	1	0.573	1.24	0.2700
Residual	32.469	70	0.464		
Total	33.042	71			

Figure 4.62 Nitrite of Leachate Versus BOD:COD Ratio



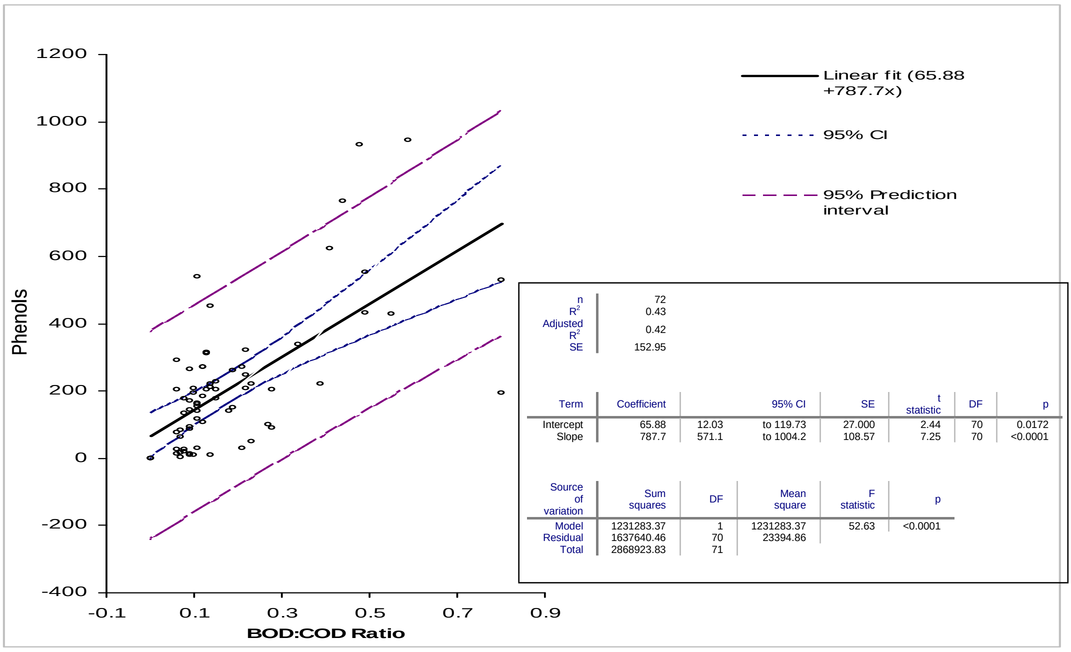
n	72
R^2	0.04
Adjusted R^2	0.02
SE	133.5

Term	Coefficient		95% CI	SE	t statistic	DF	p
Intercept	328.5	281.5	to 375.5	23.56	13.95	70	<0.0001
Slope	-152.4	-341.3	to 36.5	94.73	-1.61	70	0.1121

Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	46100.0	1	46100.0	2.59	0.1121
Residual	1246713.3	70	17810.2		
Total	1292813.3	71			

Figure 4.63 TKN of Leachate Versus BOD:COD Ratio

Figure 4.64 depicts the correlation of phenol to BOD:COD ratio of leachate with an equation of **Phenol = 65.89 + 787.7 BOD:COD**. The r^2 value of 43% is obtained and the 95% confident interval spreads between 12.03 to 119.73 mg/l.



n	72
R^2	0.43
Adjusted R^2	0.42
SE	152.95

Term	Coefficient		95% CI	SE	t statistic	DF	p
Intercept	65.88	12.03	to 119.73	27.000	2.44	70	0.0172
Slope	787.7	571.1	to 1004.2	108.57	7.25	70	<0.0001

Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	1231283.37	1	1231283.37	52.63	<0.0001
Residual	1637640.46	70	23394.86		
Total	2868923.83	71			

Figure 4.64 Phenols of Leachate Versus BOD:COD Ratio

As many as 19 equations are derived for the correlation of pollutants to BOD:COD as follows:-

pH = 6.579 + 1.861 BOD:COD (4.39)

Alkalinity = 2539 – 562.1 BOD:COD (4.40)

Hardness = 775.1 + 1212 BOD:COD (4.41)

Conductivity = 6890 + 3850 BOD:COD (4.42)

Total Suspended Solids = 50.04 + 72.24 BOD:COD (4.43)

$$BOD = 152 + 2120\ BOD:COD \quad (4.44)$$

$$COD = 481.3 + 2505\ BOD:COD \quad (4.45)$$

$$DOC = 207.2 + 541.6\ BOD:COD \quad (4.46)$$

$$Sulphate = 37.51 + 220.8\ BOD:COD \quad (4.47)$$

$$Chloride = 683.2 - 130.6\ BOD:COD \quad (4.48)$$

$$Ammonia = 250.6 - 117.2\ BOD:COD \quad (4.49)$$

$$Calcium = 138.7 + 413\ BOD:COD \quad (4.50)$$

$$Magnesium = 102.5 + 42.13\ BOD:COD \quad (4.51)$$

$$Sodium = 635.8 - 156\ BOD:COD \quad (4.52)$$

$$Iron = 7.143 + 9.807\ BOD:COD \quad (4.53)$$

$$Nitrate = 1.216 + 0.6509\ BOD:COD \quad (4.54)$$

$$Nitrite = 1.301 + 0.5375\ BOD:COD \quad (4.55)$$

$$TKN = 328.5 - 152.4\ BOD:COD \quad (4.56)$$

$$Phenol = 65.89 + 787.7\ BOD:COD \quad (4.57)$$

From the data evaluation as illustrated in Figure 4.46 – 4.64, all physical properties ($r^2<0.4$); all organic matters ($r^2<0.51$); all inorganic matters ($r^2<0.21$) and xenobiotic organic compounds of phenol ($r^2<0.43$) reveals that quality of leachate correlates well to waste age expressed in terms of BOD:COD ratio. This can be explained that microbial degradation depend greatly on the composition of both organic and inorganic constituents in the waste experiencing different exposure of acetogenic and methanogenic phases.

4.4 Modeling For Prediction of Leachate from Landfill Site

Numerous models had been developed to predict the performance of landfill using liner without taking into consideration of landfill leachate performance within the cell. In this study, performance of leachates from both the Mature Age Leachate Sampling Point and the Average Age Leachate Sampling Point were investigated to gauge the factors of influence include temperature, precipitation and landfill age in order to develop a mathematic model known as Pollutant Prediction Model to predict pollutants leach from landfill site.

Evaluation are analysed prior to model development based on overall performance data obtained from the Mature Age Leachate Sampling Point where leachate is collected from the part of mature landfill area of greater than fifteen years age and the Average Age Leachate Sampling Point where leachate is collected from part of greater than five years in comparison to leachate from the Final Leachate Holding Tank where leachate is collected from entire landfill.

The parameters evaluated include carbonaceous parameters such as BOD, COD and DOC, nitrogeneous parameters include ammonia, nitrate, nitrite, TKN and other parameters include alkalinity, calcium, chloride, conductivity, hardness, iron, magnesium, pH, phenols, phosphorus, sodium, sulphate and total suspended solids.

Leachate quality is significantly influenced by the waste age or length of time after waste filled. It is reported that leachate quality achieved at maximum after two or three years and decline subsequently (McBean et al, 199); Lu et al., 1985). Also there is reporting that leachate from young landfill will be high in BOD and COD and decline subsequently to level off after 10 years (Akyurek, 1995).

4.4.1 Carbonaceous Pollutants of Average Age and Mature Age Leachates

Data of carbonaceous pollutants in leachate of landfill over five years from the Average Age Leachate Sampling Point is depicted in Table 4.5 and Figure 4.65.

The mean value for BOD, COD and DOC is 2031.62, 3641.2 and 1240 mg/l with standard deviation of 2754.85, 3949.71 and 1421.41 mg/l respectively. Maximum and minimum BOD, COD and DOC values obtained are 6350, 9600 and 3490 mg/l and 13.1, 226 and 90 mg/l respectively. The value of BOD and COD obtained is correlated well to the reported BOD and COD ranges of 4000-40,000 mg/l and 6,000-60,000 mg/l respectively for acetonogenic leachate (Ehrig, 1983, 1988). This observation suggests that the performance data obtained from the Average Age Leachate Sampling Point or new landfill of five years which is still experiencing the acetogenic phrase at the landfill and is still active. Higher organic matter content is expected in this leachate due to generation of dissolved and solubilized organic matter.

Table 4.5

Carbonaceous Pollutant Concentration in Average Age Leachate Sampling Point

Parameter	**Maximum value**	**Minimum Value**	**Mean**	**Standard Deviation**
BOD (mg/l)	6350	13.1	2031.62	2754.85
COD (mg/l)	9600	226	3641.2	3949.71
DOC (mg/l)	3490	90	1240	1421.41
BOD:COD Ratio	0.66	0.05		
pH	6.80	5.92	6.52	0.35

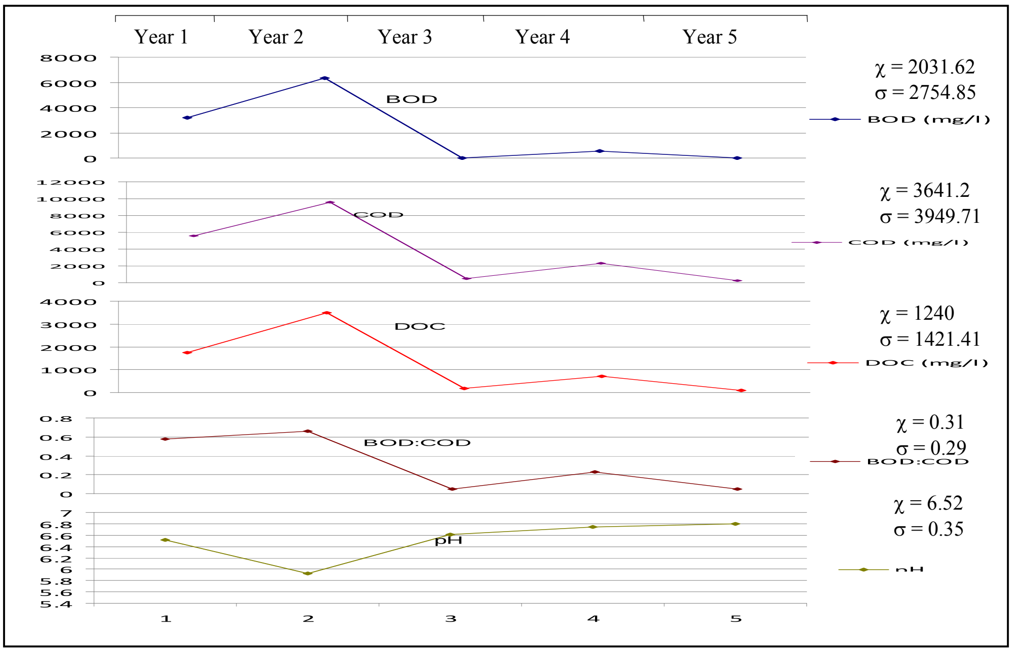


Figure 4.65 Carbonaceous Pollutant Concentration in Average Age Leachate Sampling Point

On the other hand, data of carbonaceous pollutants in leachate of landfill over fifteen years from Mature Age Leachate Sampling Point is depicted in Table 4.6 and Figure 4.66. The mean value for BOD, COD and DOC is 195.83, 875.44 and 290.28 mg/l with standard deviation of 202.45, 256.80 and 167.14 mg/l respectively. Maximum and minimum BOD, COD and DOC values obtained are 870, 1510 and 650 mg/l and 61.90, 409 and 137 mg/l respectively. The values of BOD and COD achieved are well correlated to the reported value of BOD and COD ranges of 20-550 mg/l and 500-4500 mg/l respectively for methanogenic leachates (Ehrig, 1983, 1988) which further suggest that mature leachate produce lower organic matter content with clear indication that efficient degradation of dissolved organic matter can be well achieved.

Table 4.6

Carbonaceous Pollutant Concentration in Mature Age Leachate Sampling Point

Parameter	**Maximum value**	**Minimum Value**	**Mean**	**Standard Deviation**
BOD (mg/l)	870	61.90	195.83	202.45
COD (mg/l)	1510	409	875.44	256.80
DOC (mg/l)	650	137	290.28	167.14
BOD/COD Ratio	0.57	0.05		
pH	7.38	6.27	5.72	2.64

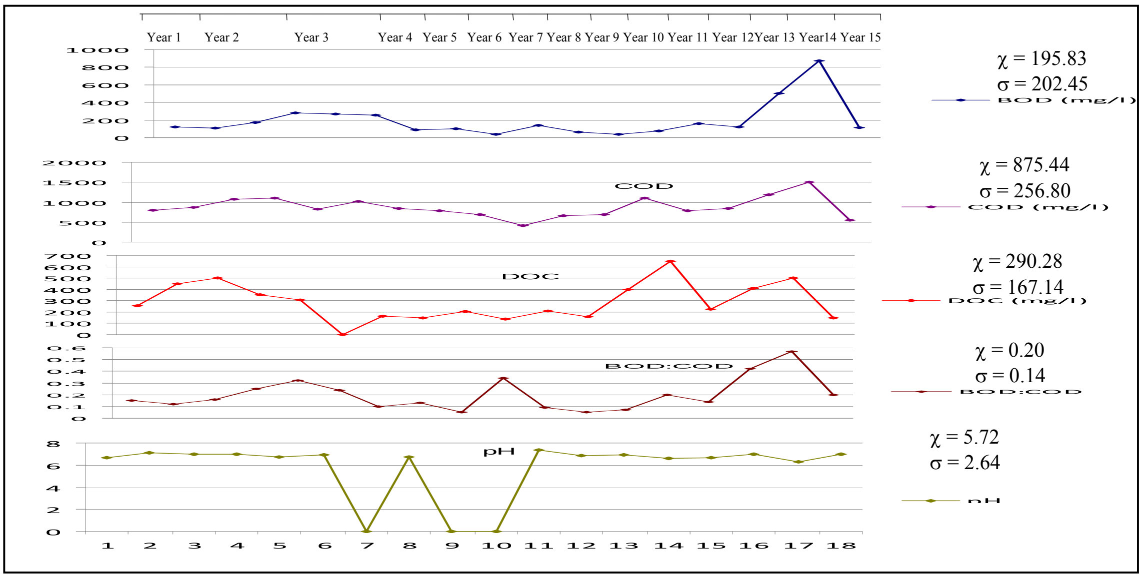


Figure 4.66 Carbonaceous Pollutant Concentration in Mature Age Leachate Sampling Point

4.4.2 Nitrogeneous Pollutants of Average Age and Mature Age Leachate

Performance data of nitrogeneous pollutants in leachate of landfill over five years from the Average Age Leachate Sampling Point is illustrated in Table 4.7 and Figure 4.67. The mean value for ammonia, nitrite, nitrate and TKN is 288.6, 1.8, 1.8 and 474.80 mg/l with standard deviation of 196.57, 0.45, 0.45 and 347.33 mg/l respectively. Maximum and minimum values for ammonia, nitrite, nitrate and TKN are 520, 2, 2, 880 mg/l and 103, 1, 1 and 162 mg/l respectively. The presence of ammonia and organic nitrogen are mainly due to their generation from decomposition of organic matters which are stable in anaerobic condition thus explained the presence of high percentage of soluble nitrogen compounds found in the leachate (McBean et al, 1995).

Table 4.7

Nitrogenous Pollutant Concentration in Average Age Leachate Sampling Point

Parameter	**Maximum value**	**Minimum Value**	**Mean**	**Standard Deviation**
Ammonia (mg/l)	520	103	288.60	196.57
Nitrite (mg/l)	2	1	1.8	0.45
Nitrate (mg/l)	2	1	1.8	0.45
TKN (mg/l)	880	162	474.80	347.33

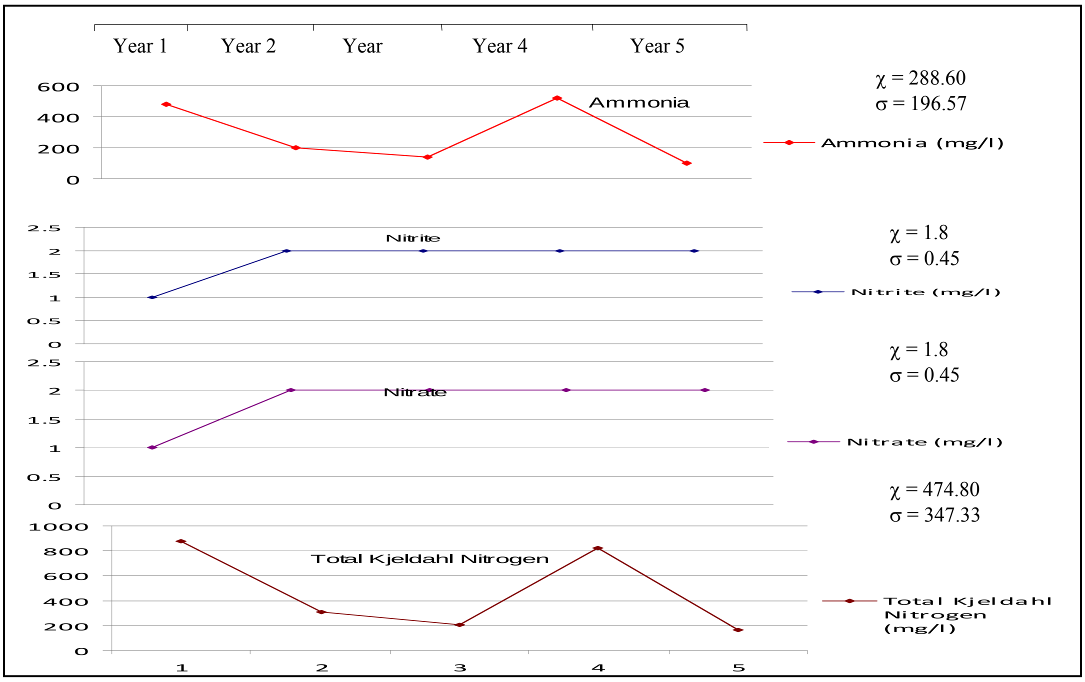


Figure 4.67 Nitrogeous Pollutant Concentration in Average Age Leachate Sampling Point

On the other hand, of nitrogeneous pollutants in leachate of landfill over fifteen years from the Mature Age Leachate Sampling Point is shown in Table 4.8 and Figure 4.68. The mean value for ammonia, nitrite, nitrate and TKN is 260.03, 0.72, 0.73 and 304.46 mg/l with standard deviation of 102.73, 0.78, 0.77 and 118.29 mg/l respectively. Maximum and minimum values for ammonia, nitrite, nitrate and TKN are 523, 2, 2 and 663 mg/l and 78.50, 0.10, 0.10 and 90.30 mg/l respectively. It is reported that the range of ammonia nitrogen concentration spread from 200 to 2000 mg/l showing no decreasing trend in concentration with time. It is also believed that ammonia is mainly released from the decomposition of organic matter such as protein (Robinson, 1995; Burton and Watson. Craik, 1998). Thus ammonia appear to be a good indication of organic nitrogen in the leachate.

Table 4.8

Nitrogenous Pollutant Concentration in Mature Age Leachate Sampling Point

Parameter	**Maximum value**	**Minimum Value**	**Mean**	**Standard Deviation**
Ammonia (mg/l)	523	78.50	260.03	102.73
Nitrite (mg/l)	2	0.10	0.72	0.78
Nitrate (mg/l)	2	0.10	0.73	0.77
TKN (mg/l)	663	90.30	304.46	118.29

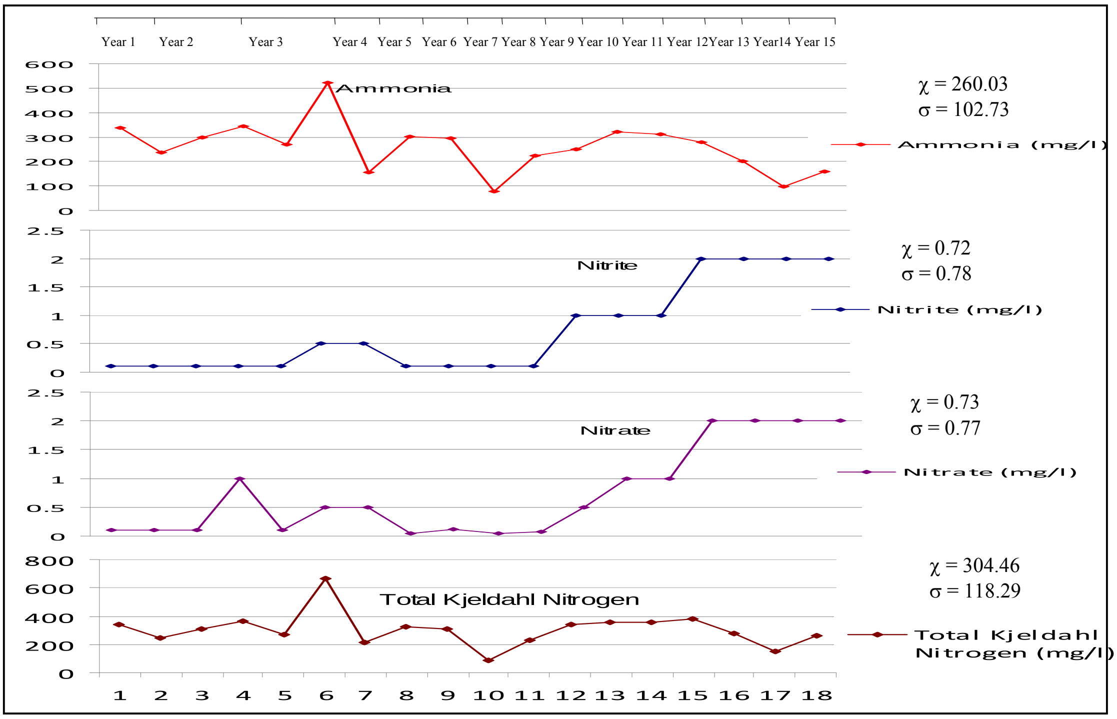


Figure 4.68 Nitrogeous Pollutant Concentration in Mature Age Leachate Sampling Point

4.4.3 Other Pollutants of Average Age and Mature Age Leachate

Data of other pollutants in leachate of landfill over five years from the Average Age Leachate Sampling Point is depicted in Table 4.9 and Figure 4.69. The mean value of calcium, chloride, iron, magnesium, sodium, sulfate and phenol is 421.40, 893.80, 32.11, 153.60, 764.20, 196.80 and 783.60 mg/l with standard deviation of 415.16, 466.29, 36.90, 27.75, 450.31, 180.53 and 757.6 mg/l respectively.

Table 4.9

Other Pollutant Concentration in Average Age Leachate Sampling Point

Parameter	**Maximum value**	**Minimum Value**	**Mean**	**Standard Deviation**
Calcium (mg/l)	1060	126	421.40	415.16
Chloride (mg/l)	1410	322	893.80	466.29
Iron (mg/l)	73.80	3.84	32.11	36.90
Magnesium (mg/l)	179	118	153.60	27.75
Sodium (mg/l)	1370	279	764.20	450.31
Sulfate (mg/l)	509	40	196.80	180.53
Phenol (mg/l)	1720	3	783.80	757.633

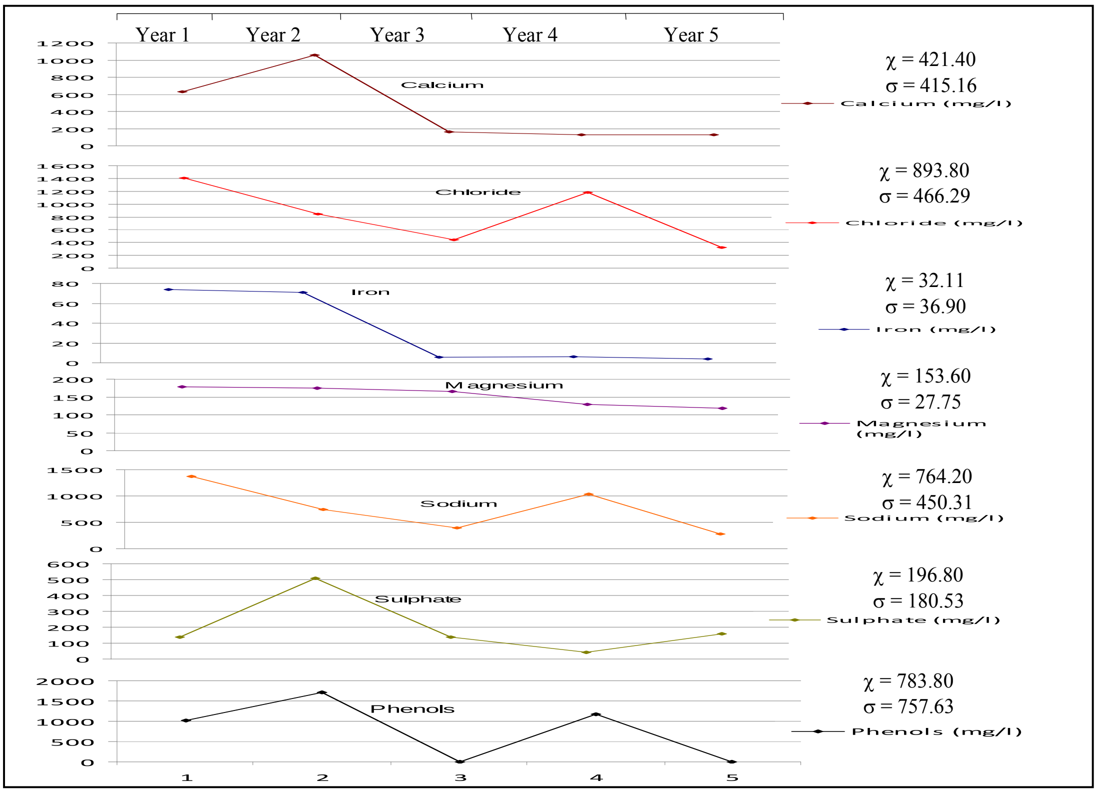


Figure 4.69 Other Pollutant Concentration in Average Age Leachate Sampling Point

Also, data of other pollutants over fifteen years from the Mature Age Leachate Sampling Point is depicted in Table 4.10 and Figure 4.70. The mean value for calcium, chloride, iron, magnesium, sodium, sulfate and phenol is 181.91, 735.06, 11.24, 132.79, 688, 81.73 and 175.44 mg/l with standard deviation of 85.54, 235.58, 8.30, 36.88, 253.61, 175.46 and 274.41 mg/l respectively. There is observed difference of these parameters between acetogenic phase and methanogenic phase likely due to the effects of sorption, complexation and precipitation. Decreasing trend in concentration with time of these pollutants could be also due to washout by leaching as reported in some study (Ehrig 1983, 1988).

Table 4.10

Other Pollutant Concentration in Mature Age Leachate Sampling Point

Parameter	**Maximum value**	**Minimum Value**	**Mean**	**Standard Deviation**
Calcium (mg/l)	405	62.40	181.91	85.54
Chloride (mg/l)	1100.	275	735.06	235.58
Iron (mg/l)	32.5	2.92	11.24	8.30
Magnesium (mg/l)	215	75.70	132.79	36.88
Sodium (mg/l)	1030	297	688	253.61
Sulfate (mg/l)	771	7.03	81.73	175.46
Phenol (mg/l)	951	1	175.44	274.41

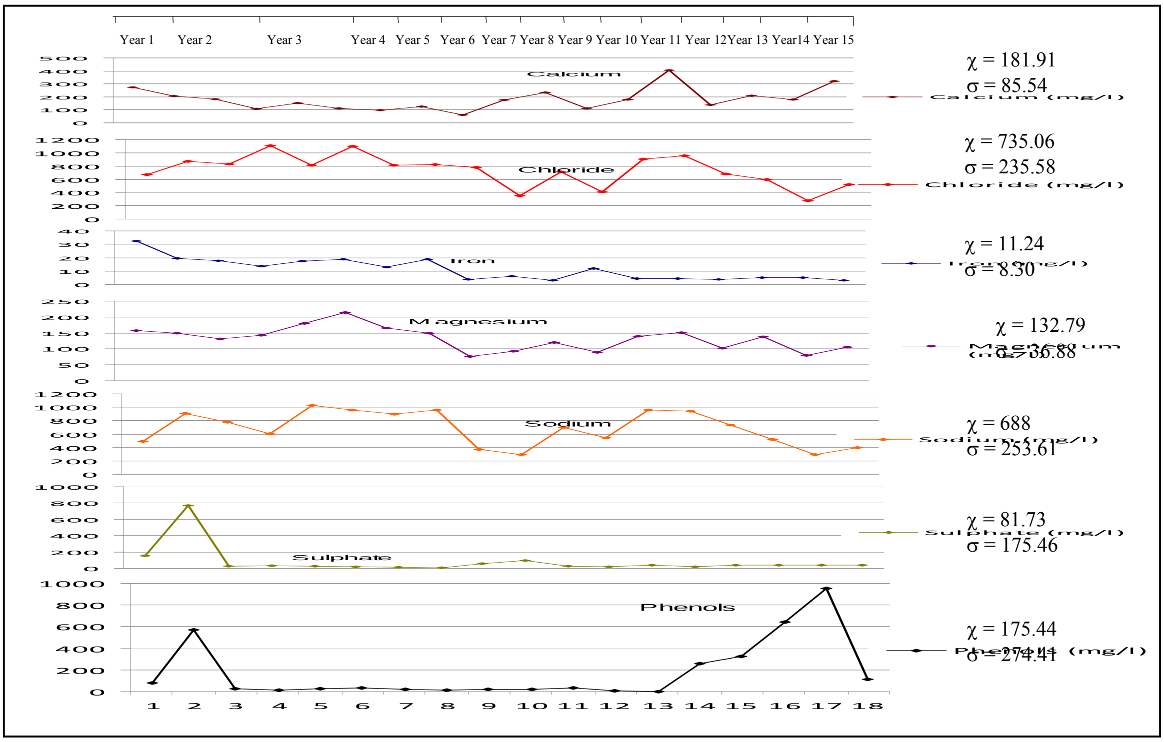


Figure 4.70 Other Pollutant Concentration in Mature Age Leachate Sampling Point

The multiple regression model developed for this study fit a multiple liner regression model include independent variables x as factors affecting leachate quality in predicting the dependent variable y as the parameters of leachate quality. The objective of the modeling is to find the best equation that adequately outline pollutant for the prediction. This equation for each pollutant will be projected with all of the independent variable identified. The dependent and independent variables are listed bellows:-

y = pollutant parameters predicted for the leachate
x_1 = temperature as factor affecting leachate quality (^{0}C)
x_2 = precipitation of factor affecting leachate quality (mm)
x_3 = waste age as factor affecting leachate quality (year)

The best regression equation is not necessarily the equation that explains most of the variance in y but is illustrated as follows:-

(i) The equation will be the one with all the relevant variables required for pollutant prediction purposes
(ii) The equation is simple and interpretable
(iii) The equation cover all correlation relationship among variables for pollutant prediction purposes.

The model developed can be easily used for prediction of each pollutant contained in leachate using model working table as shown in Figure 4.71.

The derived equations for the prediction of each pollutant are depicted in Table 4.11 to 4.30 respectively.

For BOD, the equation derived is:-

$$y = 1313.26 + 1125.49\, x_1 - 372.49\, x_2 + 1112.51\, x_3 - 443.76\, x_1 x_2 + 1233.74\, x_1 x_3 - 436.74\, x_2 x_3 - 312.01\, x_1 x_2 x_3 \tag{4.58}$$

For COD, the equation derived is:-

$$y = 2404.37 + 1705.62\, x_1 - 540.37\, x_2 + 1649.62\, x_3 - 544.62\, x_1 x_2 + 1815.37\, x_1 x_3 - 625.62\, x_2 x_3 - 314.37\, x_1 x_2 x_3 \tag{4.59}$$

For DOC, the equation derived is:-

$$y = 867 + 648\, x_1 - 262\, x_2 + 522\, x_3 - 293\, x_1 x_2 + 583\, x_1 x_3 - 207\, x_2 x_3 - 108\, x_1 x_2 x_3 \tag{4.60}$$

For Ammonia, the equation derived is:-

$$y = 234.12 + 48.37\, x_1 - 3.37\, x_2 + 31.62\, x_3 + 30.87\, x_1 x_2 + 25.87\, x_1 x_3 + 29.12\, x_2 x_3 + 83.37\, x_1 x_2 x_3 \tag{4.61}$$

For Nitrite, the equation derived is:-

$$y = 1.75 - 0.25\, x_1 - 0.25\, x_2 x_3 - 0.25\, x_1 x_2 x_3 \tag{4.62}$$

For Nitrate, the equation derived is:-

$$y = 1.75 - 0.25\, x_1 - 0.25\, x_2 x_3 - 0.25\, x_1 x_2 x_3 \tag{4.63}$$

For Total Kjeldahl Nitrogen, the equation derived is:-

$$y = 354.37 + 83.62\, x_1 + 25.87\, x_2 + 79.37\, x_3 + 77.62\, x_1 x_2 + 77.12\, x_1 x_3 + 61.37\, x_2 x_3 + 120.62\, x_1 x_2 x_3 \tag{4.64}$$

For Alkalinity, the equation derived is:-

$$y = 2938.75 - 811.25\, x_1 - 61.25\, x_2 + 213.75\, x_3 + 61.25\, x_1 x_2 + 436.25\, x_1 x_3 + 363.75\, x_2 x_3 + 636.25\, x_1 x_2 x_3 \tag{4.65}$$

For Calcium, the equation derived is:-

$$y = 321.25 + 202\ x_1 - 80\ x_2 + 167.24\ x_3 - 129.24\ x_1 x_2 + 153.50\ x_1 x_3 - 31.50\ x_2 x_3 + 24.74\ x_1 x_2 x_3 \qquad (4.66)$$

For Chloride, the equation derived is:-

$$y = 721.62 + 191.37\ x_1 - 29.37\ x_2 + 93.87\ x_3 + 40.87\ x_1 x_2 + 122.12\ x_1 x_3 + 79.87\ x_2 x_3 + 189.62\ x_1 x_2 x_3 \qquad (4.67)$$

For Conductivity, the equation derived is:-

$$y = 6447.50 + 1527.50\ x_1 - 42.50\ x_2 + 815\ x_3 + 387.50\ x_1 x_2 + 1185\ x_1 x_3 + 550\ x_2 x_3 + 1230\ x_1 x_2 x_3 \qquad (4.68)$$

For Hardness, the equation derived is:-

$$y = 1457.37 + 480.12\ x_1 - 135.12\ x_2 + 349.87\ x_3 - 107.37\ x_1 x_2 + 542.62\ x_1 x_3 - 122.62\ x_2 x_3 - 164.87\ x_1 x_2 x_3 \qquad (4.69)$$

For Iron, the equation derived is:-

$$y = 21.32 + 17.43\ x_1 + 0.78\ x_2 + 16.81\ x_3 + 0.20\ x_1 x_2 + 16.93\ x_1 x_3 - 0.10\ x_2 x_3 + 0.40\ x_1 x_2 x_3 \qquad (4.70)$$

For Magnesium, the equation derived is:-

$$y = 121.25 + 5\ x_1 - 12.49\ x_2 + 22.49\ x_3 - 24.24\ x_1 x_2 + 28.24\ x_1 x_3 + 17.24\ x_2 x_3 + 21.49\ x_1 x_2 x_3 \qquad (4.71)$$

For pH, the equation derived is:-

$$y = 6.89 + 0.02\ x_1 + 0.16\ x_2 + 0.08\ x_3 - 0.19\ x_1 x_2 + 0.21\ x_1 x_3 - 0.15\ x_2 x_3 - 0.18\ x_1 x_2 x_3 \qquad (4.72)$$

For Phenols, the equation derived is:-

$$y = 0.51 + 0.24\ x_1 - 0.09\ x_2 + 0.25\ x_3 - 0.14\ x_1 x_2 + 0.36\ x_1 x_3 - 0.16\ x_2 x_3 + 0.05\ x_1 x_2 x_3 \qquad (4.73)$$

For Phosphorus, the equation derived is:-

$$y = 58.21 + 54.26\,x_1 - 53.54\,x_2 - 48.065\,x_3 - 52.49\,x_1\,x_2 - 49.91\,x_1\,x_3 + 51.69\,x_2\,x_3 + 51.84\,x_1\,x_2\,x_3 \qquad (4.74)$$

For Sodium, the equation derived is:-

$$y = 717.86 + 47.36\,x_1 + 12.36\,x_2 + 252.88\,x_3 - 90.63\,x_1\,x_2 + 41.38\,x_1\,x_3 + 216.88\,x_2\,x_3 + 171.88\,x_1\,x_2\,x_3 \qquad (4.75)$$

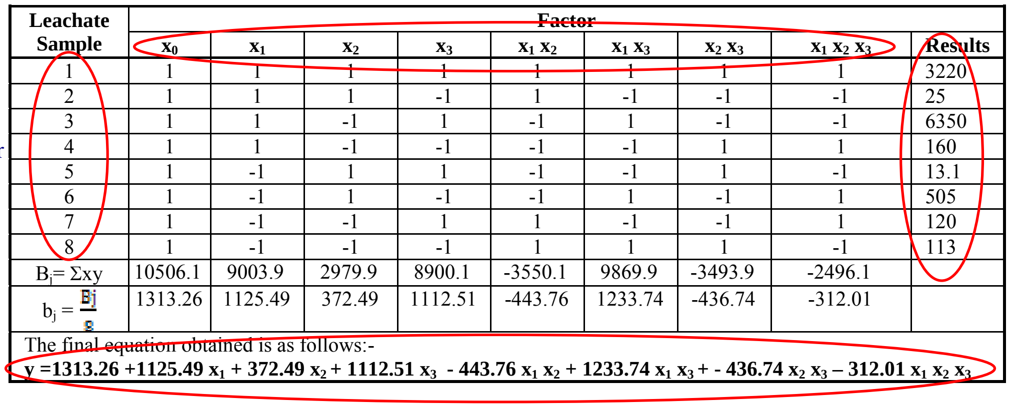
For Sulphate, the equation derived is:-

$$y = 120.75 + 80.75\,x_1 - 31.50\,x_2 + 61\,x_3 - 31.50\,x_1\,x_2 + 61\,x_1\,x_3 - 61.25\,x_2\,x_3 - 61.25\,x_1\,x_2\,x_3 \qquad (4.76)$$

For Total Suspended Solid, the equation derived is:-

$$y = 89.81 + 38.68\,x_1 + 8.93\,x_2 + 35.93\,x_3 + 12.56\,x_1\,x_2 + 35.56\,x_1\,x_3 + 8.81\,x_2\,x_3 + 9.68\,x_1\,x_2\,x_3 \qquad (4.77)$$

Independent variables and the combination



Leachate Sample	Factor								
	x_0	x_1	x_2	x_3	$x_1\,x_2$	$x_1\,x_3$	$x_2\,x_3$	$x_1\,x_2\,x_3$	Results
1	1	1	1	1	1	1	1	1	3220
2	1	1	1	-1	1	-1	-1	-1	25
3	1	1	-1	1	-1	1	-1	-1	6350
4	1	1	-1	-1	-1	-1	1	1	160
5	1	-1	1	1	-1	-1	1	-1	13.1
6	1	-1	1	-1	-1	1	-1	1	505
7	1	-1	-1	1	1	-1	-1	1	120
8	1	-1	-1	-1	1	1	1	-1	113
$B_j = \Sigma xy$	10506.1	9003.9	2979.9	8900.1	-3550.1	9869.9	-3493.9	-2496.1	
$b_j = \frac{B_j}{8}$	1313.26	1125.49	372.49	1112.51	-443.76	1233.74	-436.74	-312.01	

The final equation obtained is as follows:-

$$y = 1313.26 + 1125.49\,x_1 + 372.49\,x_2 + 1112.51\,x_3 - 443.76\,x_1\,x_2 + 1233.74\,x_1\,x_3 + - 436.74\,x_2\,x_3 - 312.01\,x_1\,x_2\,x_3$$

8 leachate samples identified for performance data

Performance data

Equation derived for pollutant prediction purposes

Figure 4.71 Model Working Table For Equation Deriviation

Table 4.11

Model Prediction for BOD in Leachate

Parameter : BOD

Leachate Sample	Factor								
	x_0	x_1	x_2	x_3	$x_1 x_2$	$x_1 x_3$	$x_2 x_3$	$x_1 x_2 x_3$	**Results**
1	1	1	1	1	1	1	1	1	3220
2	1	1	1	-1	1	-1	-1	-1	25
3	1	1	-1	1	-1	1	-1	-1	6350
4	1	1	-1	-1	-1	-1	1	1	160
5	1	-1	1	1	-1	-1	1	-1	13.1
6	1	-1	1	-1	-1	1	-1	1	505
7	1	-1	-1	1	1	-1	-1	1	120
8	1	-1	-1	-1	1	1	1	-1	113
$B_j = \Sigma xy$	10506.1	9003.9	-2979.9	8900.1	-3550.1	9869.9	-3493.9	-2496.1	
$b_j = \frac{B_j}{8}$	1313.26	1125.49	-372.49	1112.51	-443.76	1233.74	-436.74	-312.01	

The final equation obtained is as follows:-

$$\mathbf{y = 1313.26 + 1125.49\, x_1 - 372.49\, x_2 + 1112.51\, x_3 - 443.76\, x_1 x_2 + 1233.74\, x_1 x_3 - 436.74\, x_2 x_3 - 312.01\, x_1 x_2 x_3}$$

Table 4.12

Model Prediction for COD in Leachate

Parameter : COD

Leachate Sample	Factor								
	x_0	x_1	x_2	x_3	$x_1 x_2$	$x_1 x_3$	$x_2 x_3$	$x_1 x_2 x_3$	**Results**
1	1	1	1	1	1	1	1	1	5550
2	1	1	1	-1	1	-1	-1	-1	500
3	1	1	-1	1	-1	1	-1	-1	9600
4	1	1	-1	-1	-1	-1	1	1	790
5	1	-1	1	1	-1	-1	1	-1	226
6	1	-1	1	-1	-1	1	-1	1	1180
7	1	-1	-1	1	1	-1	-1	1	840
8	1	-1	-1	-1	1	1	1	-1	549
$B_j = \Sigma xy$	19235	13645	-4323	13197	-4357	14523	-5005	-2515	
$b_j = \frac{B_j}{8}$	2404.37	1705.62	-540.37	1649.62	-544.62	1815.37	-625.62	-314.37	

The final equation obtained is as follows:-

$$\mathbf{y = 2404.37 + 1705.62\, x_1 - 540.37\, x_2 + 1649.62\, x_3 - 544.62\, x_1 x_2 + 1815.37\, x_1 x_3 - 625.62\, x_2 x_3 - 314.37\, x_1 x_2 x_3}$$

Table 4.13

Model Prediction for DOC in Leachate

Parameter : DOC

Leachate Sample	**Factor**								
	x_0	x_1	x_2	x_3	$x_1 x_2$	$x_1 x_3$	$x_2 x_3$	$x_1 x_2 x_3$	**Results**
1	1	1	1	1	1	1	1	1	1750
2	1	1	1	-1	1	-1	-1	-1	170
3	1	1	-1	1	-1	1	-1	-1	3490
4	1	1	-1	-1	-1	-1	1	1	650
5	1	-1	1	1	-1	-1	1	-1	90
6	1	-1	1	-1	-1	1	-1	1	410
7	1	-1	-1	1	1	-1	-1	1	226
8	1	-1	-1	-1	1	1	1	-1	150
$B_j = \Sigma xy$	6936	5184	-2096	4176	-2344	4664	-1656	-864	
$b_j = \frac{B_j}{8}$	867	648	-262	522	-293	583	-207	-108	
The final equation obtained is as follows:- **$y = 867 + 648 x_1 - 262 x_2 + 522 x_3 - 293 x_1 x_2 + 583 x_1 x_3 - 207 x_2 x_3 - 108 x_1 x_2 x_3$**									

Table 4.14

Model Prediction for Ammonia in Leachate

Parameter : Ammonia

Leachate Sample	**Factor**								
	x_0	x_1	x_2	x_3	$x_1 x_2$	$x_1 x_3$	$x_2 x_3$	$x_1 x_2 x_3$	**Results**
1	1	1	1	1	1	1	1	1	480
2	1	1	1	-1	1	-1	-1	-1	140
3	1	1	-1	1	-1	1	-1	-1	200
4	1	1	-1	-1	-1	-1	1	1	310
5	1	-1	1	1	-1	-1	1	-1	103
6	1	-1	1	-1	-1	1	-1	1	200
7	1	-1	-1	1	1	-1	-1	1	280
8	1	-1	-1	-1	1	1	1	-1	160
$B_j = \Sigma xy$	1873	387	-27	253	247	207	233	667	
$b_j = \frac{B_j}{8}$	234.12	48.37	-3.37	31.62	30.87	25.87	29.12	83.37	
The final equation obtained is as follows:- **$y = 234.12 + 48.37 x_1 – 3.37 x_2 + 31.62 x_3 + 30.87 x_1 x_2 + 25.87 x_1 x_3 + 29.12 x_2 x_3 + 83.37 x_1 x_2 x_3$**									

Table 4.15

Model Prediction for Nitrite in Leachate

Parameter : Nitrite

Leachate Sample	**Factor**								
	x_0	x_1	x_2	x_3	$x_1 x_2$	$x_1 x_3$	$x_2 x_3$	$x_1 x_2 x_3$	**Results**
1	1	1	1	1	1	1	1	1	1
2	1	1	1	-1	1	-1	-1	-1	<2
3	1	1	-1	1	-1	1	-1	-1	<2
4	1	1	-1	-1	-1	-1	1	1	1
5	1	-1	1	1	-1	-1	1	-1	<2
6	1	-1	1	-1	-1	1	-1	1	2
7	1	-1	-1	1	1	-1	-1	1	2
8	1	-1	-1	-1	1	1	1	-1	2
$B_j = \Sigma xy$	14	-2	0	0	0	0	-2	-2	
$b_j = \frac{B_j}{8}$	1.75	-0.25	0	0	0	0	-0.25	-0.25	

The final equation obtained is as follows:-

$y = 1.75 - 0.25 x_1 - 0.25 x_2 x_3 - 0.25 x_1 x_2 x_3$

Table 4.16

Model Prediction for Nitrate in Leachate

Parameter : Nitrate

Leachate Sample	**Factor**								
	x_0	x_1	x_2	x_3	$x_1 x_2$	$x_1 x_3$	$x_2 x_3$	$x_1 x_2 x_3$	**Results**
1	1	1	1	1	1	1	1	1	1
2	1	1	1	-1	1	-1	-1	-1	<2
3	1	1	-1	1	-1	1	-1	-1	<2
4	1	1	-1	-1	-1	-1	1	1	1
5	1	-1	1	1	-1	-1	1	-1	<2
6	1	-1	1	-1	-1	1	-1	1	2
7	1	-1	-1	1	1	-1	-1	1	2
8	1	-1	-1	-1	1	1	1	-1	2
$B_j = \Sigma xy$	14	-2	0	0	0	0	-2	-2	
$b_j = \frac{B_j}{8}$	1.75	-0.25	0	0	0	0	-0.25	-0.25	

The final equation obtained is as follows:-

$y = 1.75 - 0.25 x_1 - 0.25 x_2 x_3 - 0.25 x_1 x_2 x_3$

Table 4.17

Model Prediction for Total Kjeldahl Nitrogen in Leachate

Parameter : Total Kjeldahl Nitrogen

Leachate Sample	Factor								
	x_0	x_1	x_2	x_3	$x_1 x_2$	$x_1 x_3$	$x_2 x_3$	$x_1 x_2 x_3$	**Results**
1	1	1	1	1	1	1	1	1	880
2	1	1	1	-1	1	-1	-1	-1	203
3	1	1	-1	1	-1	1	-1	-1	309
4	1	1	-1	-1	-1	-1	1	1	360
5	1	-1	1	1	-1	-1	1	-1	162
6	1	-1	1	-1	-1	1	-1	1	276
7	1	-1	-1	1	1	-1	-1	1	384
8	1	-1	-1	-1	1	1	1	-1	261
$B_j = \Sigma xy$	2835	669	207	635	621	617	491	965	
$b_j = \frac{B_j}{8}$	354.37	83.62	25.87	79.37	77.62	77.12	61.37	120.62	

The final equation obtained is as follows:-

$y = 354.37 + 83.62\ x_1 + 25.87\ x_2 + 79.37\ x_3 + 77.62\ x_1 x_2 + 77.12\ x_1 x_3 + 61.37\ x_2 x_3 + 120.62\ x_1 x_2 x_3$

Table 4.18

Model Prediction for Alkalinity in Leachate

Parameter : Alkalinity

Leachate Sample	Factor								
	x_0	x_1	x_2	x_3	$x_1 x_2$	$x_1 x_3$	$x_2 x_3$	$x_1 x_2 x_3$	**Results**
1	1	1	1	1	1	1	1	1	5400
2	1	1	1	-1	1	-1	-1	-1	2100
3	1	1	-1	1	-1	1	-1	-1	3400
4	1	1	-1	-1	-1	-1	1	1	4100
5	1	-1	1	1	-1	-1	1	-1	1510
6	1	-1	1	-1	-1	1	-1	1	2500
7	1	-1	-1	1	1	-1	-1	1	2300
8	1	-1	-1	-1	1	1	1	-1	2200
$B_j = \Sigma xy$	23510	6490	-490	1710	490	3490	2910	5090	
$b_j = \frac{B_j}{8}$	2938.75	811.25	-61.25	213.75	61.25	436.25	363.75	636.25	

The final equation obtained is as follows:-

$y = 2938.75 - 811.25\ x_1 - 61.25\ x_2 + 213.75\ x_3 + 61.25\ x_1 x_2 + 436.25\ x_1 x_3 + 363.75\ x_2 x_3 + 636.25\ x_1 x_2 x_3$

Table 4.19

Model Prediction for Calcium in Leachate

Parameter : Calcium

Leachate Sample	**Factor**								
	x_0	**x_1**	**x_2**	**x_3**	**$x_1 x_2$**	**$x_1 x_3$**	**$x_2 x_3$**	**$x_1 x_2 x_3$**	**Results**
1	1	1	1	1	1	1	1	1	628
2	1	1	1	-1	1	-1	-1	-1	0.001
3	1	1	-1	1	-1	1	-1	-1	1060
4	1	1	-1	-1	-1	-1	1	1	405
5	1	-1	1	1	-1	-1	1	-1	126
6	1	-1	1	-1	-1	1	-1	1	211
7	1	-1	-1	1	1	-1	-1	1	140
8	1	-1	-1	-1	1	1	1	-1	0.001
$B_j = \Sigma xy$	2570	1616	-640	1337.99	-1033.99	1228	-252	197.99	
$b_j = \frac{Bj}{8}$	321.25	202	-80	167.24	-129.24	153.50	-31.50	24.74	

The final equation obtained is as follows:-

$y = 321.25 + 202\ x_1 - 80\ x_2 + 167.24\ x_3 – 129.24\ x_1 x_2 + 153.50\ x_1 x_3 - 31.50\ x_2 x_3 + 24.74\ x_1 x_2 x_3$

Table 4.20

Model Prediction for Chloride in Leachate

Parameter : Chloride

Leachate Sample	**Factor**								
	x_0	**x_1**	**x_2**	**x_3**	**$x_1 x_2$**	**$x_1 x_3$**	**$x_2 x_3$**	**$x_1 x_2 x_3$**	**Results**
1	1	1	1	1	1	1	1	1	1410
2	1	1	1	-1	1	-1	-1	-1	439
3	1	1	-1	1	-1	1	-1	-1	848
4	1	1	-1	-1	-1	-1	1	1	955
5	1	-1	1	1	-1	-1	1	-1	322
6	1	-1	1	-1	-1	1	-1	1	598
7	1	-1	-1	1	1	-1	-1	1	682
8	1	-1	-1	-1	1	1	1	-1	519
$B_j = \Sigma xy$	5773	1531	-235	751	327	977	639	1517	
$b_j = \frac{Bj}{8}$	721.62	191.37	-29.37	93.87	40.87	122.12	79.87	189.62	

The final equation obtained is as follows:-

$y = 721.62 + 191.37\ x_1 – 29.37\ x_2 + 93.87\ x_3 + 40.87\ x_1 x_2 + 122.12\ x_1 x_3 + 79.87\ x_2 x_3 + 189.62\ x_1 x_2 x_3$

Table 4.21

Model Prediction for Conductivity in Leachate

Parameter : Conductivity

Leachate	**Factor**								
Sample	x_0	x_1	x_2	x_3	$x_1\ x_2$	$x_1\ x_3$	$x_2\ x_3$	$x_1\ x_2\ x_3$	**Results**
1	1	1	1	1	1	1	1	1	12100
2	1	1	1	-1	1	-1	-1	-1	4540
3	1	1	-1	1	-1	1	-1	-1	7850
4	1	1	-1	-1	-1	-1	1	1	7410
5	1	-1	1	1	-1	-1	1	-1	3440
6	1	-1	1	-1	-1	1	-1	1	5540
7	1	-1	-1	1	1	-1	-1	1	5660
8	1	-1	-1	-1	1	1	1	-1	5040
$B_j = \Sigma xy$	51580	12220	-340	6520	3100	9480	4400	9840	
$b_j = \frac{B_j}{8}$	6447.50	1527.50	-42.50	815	387.50	1185	550	1230	

The final equation obtained is as follows:-

$$\mathbf{y = 6447.50 + 1527.50\, x_1 - 42.50\, x_2 + 815\, x_3 + 387.50\, x_1 x_2 + 1185\, x_1 x_3 + 550\, x_2 x_3 + 1230\, x_1 x_2 x_3}$$

Table 4.22

Model Prediction for Hardness in Leachate

Parameter : Hardness

Leachate	**Factor**								
Sample	x_0	x_1	x_2	x_3	$x_1\ x_2$	$x_1\ x_3$	$x_2\ x_3$	$x_1\ x_2\ x_3$	**Results**
1	1	1	1	1	1	1	1	1	2300
2	1	1	1	-1	1	-1	-1	-1	1090
3	1	1	-1	1	-1	1	-1	-1	3360
4	1	1	-1	-1	-1	-1	1	1	1000
5	1	-1	1	1	-1	-1	1	-1	799
6	1	-1	1	-1	-1	1	-1	1	1100
7	1	-1	-1	1	1	-1	-1	1	770
8	1	-1	-1	-1	1	1	1	-1	1240
$B_j = \Sigma xy$	11659	3841	-1081	2799	-859	4341	-981	-1319	
$b_j = \frac{B_j}{8}$	1457.37	480.12	-135.12	349.87	-107.37	542.62	-122.62	-164.87	

The final equation obtained is as follows:-

$$\mathbf{y = 1457.37 + 480.12\, x_1 - 135.12\, x_2 + 349.87\, x_3 - 107.37\, x_1 x_2 + 542.62\, x_1 x_3 - 122.62\, x_2 x_3 - 164.87\, x_1 x_2 x_3}$$

Table 4.23

Model Prediction for Iron in Leachate

Parameter : Iron

Leachate Sample	Factor								
	x_0	x_1	x_2	x_3	$x_1 x_2$	$x_1 x_3$	$x_2 x_3$	$x_1 x_2 x_3$	**Results**
1	1	1	1	1	1	1	1	1	73.8
2	1	1	1	-1	1	-1	-1	-1	5.7
3	1	1	-1	1	-1	1	-1	-1	71.2
4	1	1	-1	-1	-1	-1	1	1	4.33
5	1	-1	1	1	-1	-1	1	-1	3.84
6	1	-1	1	-1	-1	1	-1	1	5.1
7	1	-1	-1	1	1	-1	-1	1	3.7
8	1	-1	-1	-1	1	1	1	-1	2.92
$B_j = \Sigma xy$	170.59	139.47	6.29	134.49	1.65	135.45	-0.81	3.27	
$b_j = \frac{B_j}{8}$	21.32	17.43	0.78	16.81	0.20	16.93	-0.10	0.40	

The final equation obtained is as follows:-

$$\mathbf{y = 21.32 + 17.43\, x_1 + 0.78\, x_2 + 16.81\, x_3 + 0.20\, x_1 x_2 + 16.93\, x_1 x_3 - 0.10\, x_2 x_3 + 0.40\, x_1 x_2 x_3}$$

Table 4.24

Model Prediction for Magnesium in Leachate

Parameter : Magnesium

Leachate Sample	Factor								
	x_0	x_1	x_2	x_3	$x_1 x_2$	$x_1 x_3$	$x_2 x_3$	$x_1 x_2 x_3$	**Results**
1	1	1	1	1	1	1	1	1	179
2	1	1	1	-1	1	-1	-1	-1	0.01
3	1	1	-1	1	-1	1	-1	-1	175
4	1	1	-1	-1	-1	-1	1	1	151
5	1	-1	1	1	-1	-1	1	-1	118
6	1	-1	1	-1	-1	1	-1	1	138
7	1	-1	-1	1	1	-1	-1	1	103
8	1	-1	-1	-1	1	1	1	-1	106
$B_j = \Sigma xy$	970.01	40.01	-99.99	179.99	-193.99	225.99	137.99	171.99	
$b_j = \frac{B_j}{8}$	121.25	5	-12.49	22.49	-24.24	28.24	17.24	21.49	

The final equation obtained is as follows:-

$$\mathbf{y = 121.25 + 5\, x_1 - 12.49\, x_2 + 22.49\, x_3 - 24.24\, x_1 x_2 + 28.24\, x_1 x_3 + 17.24\, x_2 x_3 + 21.49\, x_1 x_2 x_3}$$

Table 4.25

Model Prediction for pH in Leachate

Parameter : pH

Leachate Sample	**Factor**								
	x_0	x_1	x_2	x_3	$x_1 x_2$	$x_1 x_3$	$x_2 x_3$	$x_1 x_2 x_3$	**Results**
1	1	1	1	1	1	1	1	1	6.52
2	1	1	1	-1	1	-1	-1	-1	6.61
3	1	1	-1	1	-1	1	-1	-1	7.92
4	1	1	-1	-1	-1	-1	1	1	6.63
5	1	-1	1	1	-1	-1	1	-1	6.80
6	1	-1	1	-1	-1	1	-1	1	7.01
7	1	-1	-1	1	1	-1	-1	1	6.68
8	1	-1	-1	-1	1	1	1	-1	7.0
$B_j = \Sigma xy$	55.17	0.19	-1.29	0.67	-1.55	1.73	-1.27	-1.49	
$b_j = \frac{B_j}{8}$	6.89	0.02	-0.16	0.08	-0.19	0.21	-0.15	-0.18	

The final equation obtained is as follows:-

$y = 6.89 + 0.02\, x_1 + 0.16\, x_2 + 0.08\, x_3 - 0.19\, x_1 x_2 + 0.21\, x_1 x_3 - 0.15\, x_2 x_3 – 0.18\, x_1 x_2 x_3$

Table 4.26

Model Prediction for Phenols in Leachate

Parameter : Phenols

Leachate Sample	**Factor**								
	x_0	x_1	x_2	x_3	$x_1 x_2$	$x_1 x_3$	$x_2 x_3$	$x_1 x_2 x_3$	**Results**
1	1	1	1	1	1	1	1	1	1.02
2	1	1	1	-1	1	-1	-1	-1	0.006
3	1	1	-1	1	-1	1	-1	-1	1.720
4	1	1	-1	-1	-1	-1	1	1	0.26
5	1	-1	1	1	-1	-1	1	-1	0.003
6	1	-1	1	-1	-1	1	-1	1	0.64
7	1	-1	-1	1	1	-1	-1	1	0.326
8	1	-1	-1	-1	1	1	1	-1	0.115
$B_j = \Sigma xy$	4.09	1.92	-0.75	2.04	-1.15	2.90	-1.29	0.40	
$b_j = \frac{B_j}{8}$	0.51	0.24	-0.09	0.25	-0.14	0.36	-0.16	0.05	

The final equation obtained is as follows:-

$y = 0.51 + 0.24\, x_1 – 0.09\, x_2 + 0.25\, x_3 – 0.14\, x_1 x_2 + 0.36\, x_1 x_3 – 0.16\, x_2 x_3 + 0.05\, x_1 x_2 x_3$

Table 4.27

Model Prediction for Phosphorus in Leachate

Parameter : Phosphorus

Leachate	**Factor**								
Sample	x_0	x_1	x_2	x_3	$x_1 x_2$	$x_1 x_3$	$x_2 x_3$	$x_1 x_2 x_3$	**Results**
1	1	1	1	1	1	1	1	1	12
2	1	1	1	-1	1	-1	-1	-1	0.90
3	1	1	-1	1	-1	1	-1	-1	17
4	1	1	-1	-1	-1	-1	1	1	420
5	1	-1	1	1	-1	-1	1	-1	4.6
6	1	-1	1	-1	-1	1	-1	1	1.2
7	1	-1	-1	1	1	-1	-1	1	7
8	1	-1	-1	-1	1	1	1	-1	3.02
$B_j = \Sigma xy$	465.72	434.08	-428.32	-384.52	-419.88	-399.28	413.52	414.68	
$b_j = \frac{B_j}{\text{[illegible]}}$	58.21	54.26	-53.54	-48.065	-52.49	-49.91	51.69	51.84	

The final equation obtained is as follows:-

$$\mathbf{y = 58.21 + 54.26\, x_1 - 53.54\, x_2 - 48.065\, x_3 - 52.49\, x_1 x_2 - 49.91\, x_1 x_3 + 51.69\, x_2 x_3 + 51.84\, x_1 x_2 x_3}$$

Table 4.28

Model Prediction for Sodium in Leachate

Parameter : Sodium

Leachate	**Factor**								
Sample	x_0	x_1	x_2	x_3	$x_1 x_2$	$x_1 x_3$	$x_2 x_3$	$x_1 x_2 x_3$	**Results**
1	1	1	1	1	1	1	1	1	1370
2	1	1	1	-1	1	-1	-1	-1	3.93
3	1	1	-1	1	-1	1	-1	-1	749
4	1	1	-1	-1	-1	-1	1	1	938
5	1	-1	1	1	-1	-1	1	-1	1030
6	1	-1	1	-1	-1	1	-1	1	517
7	1	-1	-1	1	1	-1	-1	1	734
8	1	-1	-1	-1	1	1	1	-1	401
$B_j = \Sigma xy$	5742.93	378.93	98.93	2023.07	-725.07	331.07	1735.07	1375.07	
$b_j = \frac{B_j}{\text{[illegible]}}$	717.86	47.36	12.36	252.88	-90.63	41.38	216.88	171.88	

The final equation obtained is as follows:-

$$\mathbf{y = 717.86 + 47.36\, x_1 + 12.36\, x_2 + 252.88\, x_3 - 90.63\, x_1 x_2 + 41.38\, x_1 x_3 + 216.88\, x_2 x_3 + 171.88\, x_1 x_2 x_3}$$

Table 4.29

Model Prediction for Sulphate in Leachate

Parameter : Sulphate

Leachate Sample	Factor								
	x_0	x_1	x_2	x_3	$x_1 x_2$	$x_1 x_3$	$x_2 x_3$	$x_1 x_2 x_3$	**Results**
1	1	1	1	1	1	1	1	1	138
2	1	1	1	-1	1	-1	-1	-1	139
3	1	1	-1	1	-1	1	-1	-1	509
4	1	1	-1	-1	-1	-1	1	1	20
5	1	-1	1	1	-1	-1	1	-1	40
6	1	-1	1	-1	-1	1	-1	1	40
7	1	-1	-1	1	1	-1	-1	1	40
8	1	-1	-1	-1	1	1	1	-1	40
$B_j = \Sigma xy$	966	646	-252	488	-252	488	-490	-490	
$b_j = \frac{B_j}{8}$	120.75	80.75	-31.50	61	-31.50	61	-61.25	-61.25	

The final equation obtained is as follows:-

$y = 120.75 + 80.75\,x_1 - 31.50\,x_2 + 61\,x_3 - 31.50\,x_1 x_2 + 61\,x_1 x_3 - 61.25\,x_2 x_3 - 61.25\,x_1 x_2 x_3$

Table 4.30

Model Prediction for Total Suspended Solid in Leachate

Parameter : Total Suspended Solid

Leachate Sample	Factor								
	x_0	x_1	x_2	x_3	$x_1 x_2$	$x_1 x_3$	$x_2 x_3$	$x_1 x_2 x_3$	**Results**
1	1	1	1	1	1	1	1	1	240
2	1	1	1	-1	1	-1	-1	-1	60
3	1	1	-1	1	-1	1	-1	-1	160
4	1	1	-1	-1	-1	-1	1	1	54
5	1	-1	1	1	-1	-1	1	-1	47
6	1	-1	1	-1	-1	1	-1	1	48
7	1	-1	-1	1	1	-1	-1	1	56
8	1	-1	-1	-1	1	1	1	-1	53.5
$B_j = \Sigma xy$	718.50	309.50	71.50	287.50	100.50	284.50	70.50	77.50	
$b_j = \frac{B_j}{8}$	89.81	38.68	8.93	35.93	12.56	35.56	8.81	9.68	

The final equation obtained is as follows:-

$y = 89.81 + 38.68\,x_1 + 8.93\,x_2 + 35.93\,x_3 + 12.56\,x_1 x_2 + 35.56\,x_1 x_3 + 8.81\,x_2 x_3 + 9.68\,x_1 x_2 x_3$

Table 4.31

Summary of Equation Derived From Pollutant Prediction Model For

Prediction of Pollutant Leaching From Landfill

Pollutants	Equation Derived
BOD	$y = 1313.26 + 1125.49 x_1 - 372.49 x_2 + 1112.51 x_3 - 443.76 x_1 x_2 + 1233.74 x_1 x_3 - 436.74 x_2 x_3 – 312.01 x_1 x_2 x_3$
COD	$y = 2404.37 + 1705.62 x_1 – 540.37 x_2 + 1649.62 x_3 – 544.62 x_1 x_2 + 1815.37 x_1 x_3 – 625.62 x_2 x_3 – 314.37 x_1 x_2 x_3$
DOC	$y = 867 + 648 x_1 - 262 x_2 + 522 x_3 - 293 x_1 x_2 + 583 x_1 x_3 - 207 x_2 x_3 - 108 x_1 x_2 x_3$
Ammonia	$y = 234.12 + 48.37 x_1 – 3.37 x_2 + 31.62 x_3 + 30.87 x_1 x_2 + 25.87 x_1 x_3 + 29.12 x_2 x_3 + 83.37 x_1 x_2 x_3$
Nitrite	$y = 1.75 - 0.25 x_1 - 0.25 x_2 x_3 - 0.25 x_1 x_2 x_3$
Nitrate	$y = 1.75 - 0.25 x_1 - 0.25 x_2 x_3 - 0.25 x_1 x_2 x_3$
TKN	$y = 354.37 + 83.62 x_1 + 25.87 x_2 + 79.37 x_3 + 77.62 x_1 x_2 + 77.12 x_1 x_3 + 61.37 x_2 x_3 + 120.62 x_1 x_2 x_3$
Alkalinity	$y = 2938.75 – 811.25 x_1 – 61.25 x_2 + 213.75 x_3 + 61.25 x_1 x_2 + 436.25 x_1 x_3 + 363.75 x_2 x_3 + 636.25 x_1 x_2 x_3$
Calcium	$y = 321.25 + 202 x_1 - 80 x_2 + 167.24 x_3 – 129.24 x_1 x_2 + 153.50 x_1 x_3 - 31.50 x_2 x_3 + 24.74 x_1 x_2 x_3$
Chloride	$y = 721.62 + 191.37 x_1 – 29.37 x_2 + 93.87 x_3 + 40.87 x_1 x_2 + 122.12 x_1 x_3 + 79.87 x_2 x_3 + 189.62 x_1 x_2 x_3$
Conductivity	$y = 6447.50 + 1527.50 x_1 – 42.50 x_2 + 815 x_3 + 387.50 x_1 x_2 + 1185 x_1 x_3 + 550 x_2 x_3 + 1230 x_1 x_2 x_3$
Hardness	$y = 1457.37 + 480.12 x_1 – 135.12 x_2 + 349.87 x_3 - 107.37 x_1 x_2 + 542.62 x_1 x_3 - 122.62 x_2 x_3 - 164.87 x_1 x_2 x_3$
Iron	$y = 21.32 + 17.43 x_1 + 0.78 x_2 + 16.81 x_3 + 0.20 x_1 x_2 + 16.93 x_1 x_3 - 0.10 x_2 x_3 + 0.40 x_1 x_2 x_3$
Magnesium	$y = 121.25 + 5 x_1 – 12.49 x_2 + 22.49 x_3 – 24.24 x_1 x_2 + 28.24 x_1 x_3 + 17.24 x_2 x_3 + 21.49 x_1 x_2 x_3$
pH	$y = 6.89 + 0.02 x_1 + 0.16 x_2 + 0.08 x_3 - 0.19 x_1 x_2 + 0.21 x_1 x_3 - 0.15 x_2 x_3 – 0.18 x_1 x_2 x_3$
Phenols	$y = 0.51 + 0.24 x_1 – 0.09 x_2 + 0.25 x_3 – 0.14 x_1 x_2 + 0.36 x_1 x_3 – 0.16 x_2 x_3 + 0.05 x_1 x_2 x_3$
Phosphorus	$y = 58.21 + 54.26 x_1 – 53.54 x_2 – 48.065 x_3 – 52.49 x_1 x_2 – 49.91 x_1 x_3 + 51.69 x_2 x_3 + 51.84 x_1 x_2 x_3$
Sodium	$y = 717.86 + 47.36 x_1 + 12.36 x_2 + 252.88 x_3 – 90.63 x_1 x_2 + 41.38 x_1 x_3 + 216.88 x_2 x_3 + 171.88 x_1 x_2 x_3$
Sulphate	$y = 120.75 + 80.75 x_1 – 31.50 x_2 + 61 x_3 – 31.50 x_1 x_2 + 61 x_1 x_3 – 61.25 x_2 x_3 – 61.25 x_1 x_2 x_3$
TSS	$y = 89.81 + 38.68 x_1 + 8.93 x_2 + 35.93 x_3 + 12.56 x_1 x_2 + 35.56 x_1 x_3 + 8.81 x_2 x_3 + 9.68 x_1 x_2 x_3$

As many as 20 equations are derived from the Pollutant Prediction Model developed. The independent variables used in the derivation are the factors affecting leachate quality include x_1 (temperature), x_2 (precipitation) and x_3 (waste age) and also the cross relationship include x_4 (x_1 x_2), x_5 (x_1 x_3), x_6 (x_2 x_3), x_7 (x_1 x_2 x_3).

The independent variables are identified as predictor variable due to their influence to dependent variable (y). The dependent variable (y) can be those parameters of pollutant useful to be predicted for leachate generated from landfill site.

As pointed out in this study, factor of influence include climatic condition such as temperature and precipitation in addition to waste age appear to have impact on the characteristic of pollutants leaching out from the landfill. Although it is not possible to produce totally accurate prediction, the Pollution Prediction Model allow the engineer to estimate likely leachate quality based on estimation made on a set of predictor variable identified. Having the predictor variables in consideration of landfill design and operation make the prediction of pollutant leaching out from the landfill possible that are all likely influenced by factors and some combination of several factors believed to affect the landfill performance in term of correlation and the regression line.

CHAPTER 5

CONCLUSION

The purpose of this research is to characterize pollutants leaching out from landfill and to correlate leachate quality to factors of influence to landfill performance. The study employs performance data obtained from Toronto Landfill Site as landfill leachate data to develop correlation relationship and mathematic model known as Pollutant Prediction Model. Various statistical techniques such as regression analysis and cluster analysis are used to characterize the leaching pollutants from the landfill under influence of factors such as temperature, precipitation and waste age. In general, these factors of influence appear to have impact on the characteristic of pollutant leaching out from the landfill. The following conclusion may be drawn from results of this research:-

The constituent of pollutants in leachate can be categorized into three types namely organic matter, inorganic matter and xenobiotic organic compounds.

The wide range of pollutant composition found in the leachate is mainly attributed from the decomposition of carbonaceous organic matter by acetogenic bacteria converting insoluble organic matter to soluble organic matter and methanogenic bacteria converting soluble organic matter to methane and carbon dioxide.

The study reveals that in an actively decomposing waste landfill, leachate generated can be characterized as acetogenic leachate and methanogenic leachate that depict the degree of waste stabilization in the landfill.

Leachate from the average age landfill posses significantly higher concentration of organic pollutants than leachate from the mature age landfill as depicted in values of BOD, COD and DOC of leachate generated from the landfill.

BOD:COD ratio of leachate is a good indicator for degrees of both biological and chemical decompositions that are taken place in the landfill under changing ambience conditions. It is thus suggested that BOD:COD ratio can be taken as an indicator of degradation of organic matter in landfill.

Acetogenic leachates are typically characterized by its high BOD value and high BOD:COD ratio due to rapid hydrolysis of insoluble organic matters that make it readily degradable while methanogenic leachates are characterized by its relatively low BOD value and low BOD:COD ratios due to active dissolution of soluble organic matters present as well as inorganic matter.

As the carbonaceous organic concentration decreases in leachate ammonia nitrogen concentration resulting from the hydrolysis and fermentation of nitrogen containing fraction of biodegrable matters. This is followed by nitrification of ammonia nitrogen when a significant portion of non-ammonia nitrogen is readily converted usually measured as nitrogen concentration.

In the active decomposing waste layer in the landfill, non-conservative constituents in leachate such as metal ions which are relatively insoluble at neutral pH become dissolved as pH falls in the leachate except conservative constituents like chloride, sulfate and other residue of decomposition.

The study also reveals that the waste decomposition in landfill is influenced by climatic condition such as temperature and precipitation based on correlation relationship established. The intensity of decomposition is observed to be significantly affected by amount of precipitation and intensity of temperature inside the waste strata of landfill site. Rises in temperature accelerate decomposition while precipitations slow down decomposition to anaerobic condition.

Results of study reveal some degree of significance of relationship between temperature and quality of pollutant leaching out from landfill. This can be explained by the active decomposition of waste due to higher temperature that facilities both biological and chemical reactions inside the waste strata.

Results obtained also show less significance of correlation relationship of precipitation to leachate quality as compared to temperature in the environment. This can be explained by the fact that sufficient moisture content is achieved to maintain waste stabilization rate in the landfill by leachate recirculation causing a lesser role to be played by ambient precipitation in determining leachate quality.

Results also reveal that leachate quality correlates well with waste age expressed in terms of BOD:COD ratio. This is largely due to microbial degradation of both organic and inorganic constituents in the waste experiencing different exposure of acetogenic and methanogenic phases.

As pointed out in this study, factors of influence include climatic condition such as temperature and precipitation in addition to waste age appear to have impact on characteristic of pollutants leaching out from the landfill. Although it is not possible to produce totally accurate prediction, the Pollution Prediction Model developed allow the design engineer to estimate likely leachate quality based on estimation using a set of predictor variables identified. Having the predictor variables for landfill design and operation make the prediction of pollutant leaching out from the landfill possible. The influences of factors and some combination of several factors on the landfill performance are predicted based on correlation as in accordance to the regression lines obtained.

It is concluded that this study provides some useful information for the design of landfill and the management of leachate that made prediction more realistic for future improvement. Temperature and waste age are attributed as significant factors to ensure waste stabilization in the landfill is achieved to produce a better quality of leachate. Proper operational control to ensure water balance by leachate recirculation and good surface water management at landfill site in leau of climatic precipitation is also important consideration for landfill to produce good leachate quality

CHAPTER 6

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Appendix 1
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Chapter 8

Chapter Title: LINERS FOR WASTE

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LINERS FOR WASTES

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ABSTRACT

Leachate from waste landfill is attracting attention due to environmental impacts related to pollution of groundwater and surface water. Typically four groups of leachate pollutants namely dissolved organic matters, inorganic matters, heavy metals and xenobiotic organic compounds vary in concentration during acid phase and methanogenic phase required landfill to be lined. Several types of liners consists of clay, geomembranes, geotextiles, geosynthetic clay liner and geonet are generally used in municipal solid waste which have to take into considerations of hydraulic conductivity, shear strength, chemical compatibility and resistant to creep and puncture.

Key words: Leachate, landfill, pollutants, dissolved organic matters, inorganic matters, heavy metals, xenobiotic organic compounds, clay, geomembranes, geotextiles, geosynthetic clay liner, geonet, environmental pollution.

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LINERS FOR WASTES

Lee Aik Heng, Hamid Nikraz and Yung Tse Hung

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LINERS FOR WASTE

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1. LANDFILLS

1.1 Type of Landfills

Landfill is generally dumpsite used for the disposal of solid wastes. It is the cheapest and most simple method for the disposal of wastes subject that adequate land is made available for the intended use of the landfill. However, a dumpsite used for the disposal of wastes by the landfilling method has to be carefully selected and designed for its intended use. Normally wastes that are disposed in the landfill has to be compacted to reduce volume and to be covered at the end of day. Of concern with the use of landfill may result in various environmental issues such as leachate generation. In general, there are three types of landfill used for waste management purposes. The types of landfill are categorized as depicted in Table 1 according to waste types.

Table 1

Type of Landfill

Type of Landfill	Description
Type I Inert Landfill	Landfill is used for waste that is not interacted with other substances
Type II Non-inert and Non hazardous Landfill	Landfill is lined and is equipped with leachate collection system, air pollution system and is compartmented. It is typically meant for domestic waste and non-dangerous industrial wastes
Type III Hazardous Landfill	Landfill is used for dangerous and hazardous waste

1.2 Leachate Generation

Leachate is the liquid percolation that drains through the waste in the landfill varies widely depend on waste type and the waste age. Typically, the leachate can be characterized into four major groups as shown in Table 2. The four major groups are mainly dissolved organic matters, inorganic matters, heavy metals, and xenobiotic organic compounds. Beside these, other compounds are also likely present in the leachate such as arsenate, barium, borate, cobalt, lithium, mercury, selenate and sulfide however in small quantity and of less significant level.

Leachate can be generated by several potential sources include gravity drainage, ponded water, rain, infiltration and groundwater inflow. Leachate percolating waste above groundwater table cause contaminant migration to groundwater from waste whereas leachate leaches through waste at near shore and past contaminant transport known as tidal flushing,

The dissolved organic matters are organic molecules of varied origin and composition in leachate that are measured in terms of BOD (Biochemical Oxygen Demand), TOC (Total Organic Carbon) and COD (Chemical Oxygen Demand). Generally, BOD/COD ratio is used to describe the organic composition in the leachate.

The inorganic matters such as ammonia, calcium, chloride, hydrogen carbonate, iron, magnesium, manganese, potassium and sulfate are found in most landfill leachate and mostly experience wash out in landfill instead of sorption and precipitation. Heavy metals such as cadmium, chromium, copper, lead, nickel and zinc are found generally low however varied from different landfills. Xenobiotic organic compounds such as aromatic hydrocarbon are found to be particularly low in concentration in municipal landfill leachate.

Table 2

Pollutants In Leachate

	Group of Pollutants In Leachate	Components
1	Dissolved organic matters	Acids, Alcohols, aldehydres and others usually quantified as COD (Chemical Oxygen Demand), TOC (Total Organic Carbon), Other Volatile fatty acid and refractory compound include fulvic-like and humic like compounds
2	Inorganic matters	Sulfate, chloride, ammonium, calcium, magnesium, sodium, potassium , hydrogen carbonate, iron and manganese
3	Heavy metals	Lead, nickel, copper, cadmium, chromium and zinc
4	Xenobiotic organic compounds	Aromatic hydrocarbon, phenols, chlorinated aliphatics, pesticides and plastizers include PCB, Dioxin, PAH, etc.

In the landfills, wastes once contained decompose at least in four phases comprising various biological and chemical reactions as depicted in Table 3. The four phases are the aerobic phase, the anaerobic acid phase, the early methanogenic phase, and the mature anaerobic acid phase.

Table 3

Phases of Waste Decomposition In Landfill

Waste Decomposition Phases	Waste Decomposition Reaction
1 Aearobic Phase	• Occur only in early few days as long as oxygen is available • Leachate mainly generated from waste compaction and precipitation
2 Anaerobic Phase	• Occur only once oxygen in the waste is depleted • Leachate generated after fermentation reaction on waste by bacteria to methane and carbon dioxide under anaerobic conditions • Highest COD and BOD are anticipated and mainly acidic
3 Early Methanogenic Phase	• Occur when sufficient quantities of methane is generated and pH is approaching neutral due to conversion of acid to methane and carbon dioxide by methanogenic bacteria • COD and BOD values begin to reduce and COD to BOD ratio increase as soluble substrate is depleting
4 Mature Methanogenic Phase	• Occur as methane generation reach its highest rate as soluble substrate is significantly reduced • pH continue to increase and COD to BOD ratio increase tremendously due to highest consumption of soluble substrate

In the early days of landfill usually known as the aerobic phase, oxygen present is consumed rapidly resulting in increase of waste temperature and carbon dioxide. Leachate is also generated due to precipitation of the waste in the landfill cell.

Subsequent to the aerobic phase, fermentation reaction takes place as waste in the landfill cell becomes anerobic. In this anaerobic phase, the biodegrable contents in the waste are decomposed and are converted to methane and carbon dioxide with the aid of bacteria. These bacteria are mainly the fermentative bacteria which ferment and convert monosaccharides to alcohols and carbonxylic acids. The acetogenic bacteria present subsequent convert these alcohols and carboxylic acid to acetate, carbon dioxide and hydrogen and the methanogens then convert these products to carbon dioxide and methane.

In the presence of methane, the waste becomes neutral and the acids accumulated are converted to carbon dioxide and methane by methanogenic bacteria in this early methanogenic phase. The methane generation rate will increase to maximum level and decrease subsequently until depletion of soluble substrate in the stable methanogenic phase. In this phase, the BOD/COD is anticipated to reach 0.1 or lower as soluble substrate is consumed and exhausted (1).

Once the landfill is full and final cover is placed, the decomposition of waste is still on going and the generation of leachate is anticipated to decrease as time go. It is usually presumed that the landfill will be stable after 30 years from the closure.

Typically, composition of leachate generated from the landfill is subject to waste age and other factors such as waste type and landfill approach used. As leachate percolates through waste strata layers that undergo various decompositions several studies had reported that leachate may contain high amount of both dissolved organic matter and inorganic matters with average concentration of thousand folds higher that those found in groundwater (2-3). The concentration of these pollutants may vary over phases of waste decomposition in landfill as leachate generated is anticipated to have low pH and high concentration of ready biodegrable organic pollutant in the early acid phase follow by early methanogenic phase with high pH and lower concentration of biodegrable organic content to the later mature methanogenic phase with higher pH and in waste. This is represented by higher BOD/COD ratio in the acid phase as compare to the methanogenic phase.

It is also reported that water content in the landfill will affect the rate of waste decomposition and the time taken for methane generation to reach zero (4). Waste decomposition is anticipated to be slower in dry weather condition with infiltration of 500m or less. In most engineering design, recycling of leachate in landfill is used to boost the water content up to 50% and to ensure sufficient quantity of substrate and bacteria are present.

The composition of typical leachate quality is depicted in Table 4 (5) and Table 5 (5) which illustrate changes of several parameters over time as the waste is decomposed.

Table 4

Composition of Landfill Leachate (5)

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

* (Values in mg/l unless otherwise stated)

Table 5

Composition of Leachate During Acid Phase and Methanogenic Phase (5)

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

Dissolved organic matter in leachate consists of various organic degradable constituents ranging from small volatile acids to refractory fulvic and humic like compound (6). Higher dissolved organic matter is anticipated in the acid phase when compared to those in methanogenic phase. Like the dissolved organic matter, the concentration of inorganic matter is much depend on the stabilization of landfill. It is also reported (7) that the inorganic matters are lower in methanogenic phase due to lower dissolved organic matter and higher pH.

As waste in the landfill contains organic matter that has good sorptive capacity for metal immobilization, the presence of heavy metals in the leachate is anticipated to be relatively low. The low concentration of heavy metal is probably due to the presence of sulfide formed from sulfate reduction during waste decomposition (8).

Wide spectrum of xenobiotic organic compounds are found in landfill leachate depends on waste composition waste age and landfill approach. Typical xenobiotic organic compounds are halogenated hydrocarbons and monoaromatic hydrocarbons.

In general, leachate composition is very much depend on waste composition, waste age and if the landfill is lined. Leachate of acid phase as compared to methanogenic leachate is anticipated to have higher concentration of both organic and inorganic pollutants that leach through the underlying strata.

1.3 Environmental Impacts

Generally, environmental issues related to improper landfills are groundwater pollution and soil contamination. Once waste is buried is a landfill, the action of ever-present water cause many physical, chemical and biochemical, reactions to take place. Leachate is produced when a sizeable portion of the buried wastes in the landfill becomes saturated with water from external sources. When waste decomposes with the action of water, the resulting leachate percolates downwards. As it does so, it absorbs more chemical compound and micro organisms naturally present in the waste. The constituents of leachate can be categorized into four types namely dissolved organics matter such as volatile organic compounds, total petroleum hydrocarbons, inorganic matter such as acids, sulfides and chlorides, heavy metals such as Cu, Fe, Sn, Pb, Cd, B, Hg and xenobiotic organic compounds such as aromatic hydrocarbon and dioxins. The chemicals and micro-organisms contained in leachate are potentially harmful due to gradual degradation of subsurface water. They can cause adverse impacts to the environment and endanger life. Even under controlled condition, such as present in a well-planned and well run sanitary landfill, leachate may percolate or penetrate through the natural ground and contaminate groundwater and underground fresh water supplies. The environmental impact is significant particularly those without engineering control such as liners and leachate collection system.

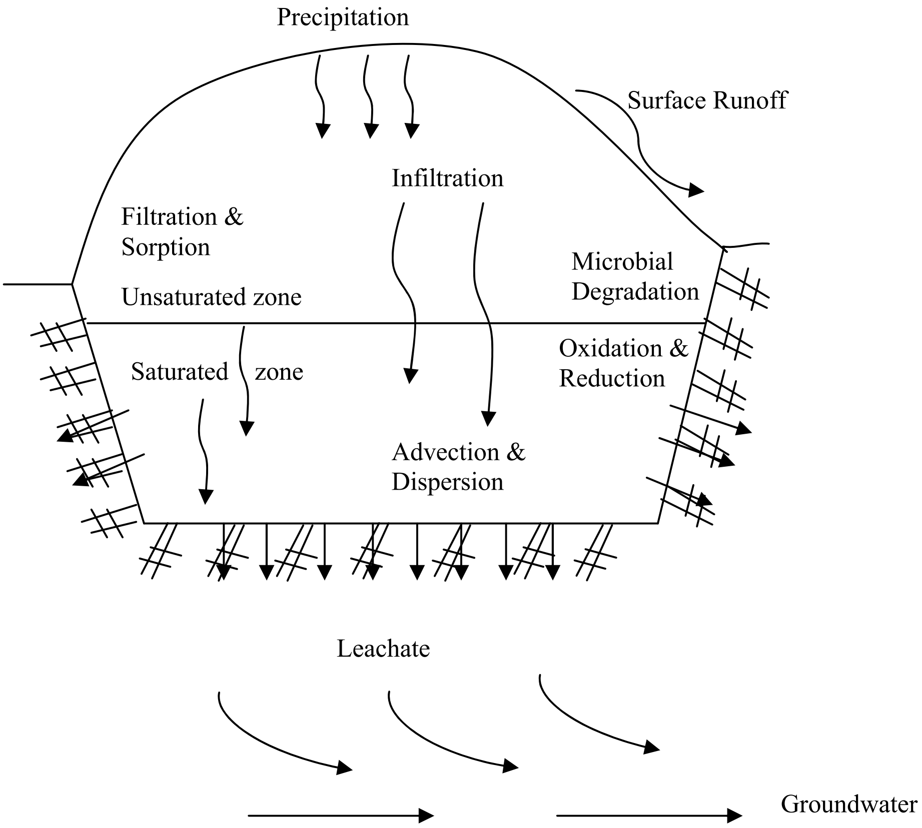
Naturally, the ground has a way of neutralizing infiltration of chemicals and organisms contained in leachate. This is done by weakening the content or amount of contamination percolate by the leachate as it drains down the soil. The major potential effects of these environmental impacts include depletion of oxygen to natural water sources and toxicity cause to fauna and flora in the aquatic environment. Six occurrences are anticipated to moderate leachate.

First, the infiltration of water in the soil dilutes leachate. Second, the soil may absorb the pollutant so that they stick in extremely thin films of molecules to the surfaces of solid or liquid particles in the soil. Third, temperature and naturally occurring chemicals in the soil may cause the pollutant to precipitate or separate from the leachate solution. Forth, the soil serves as filter of suspended particles from the leachate. Fifth, ion exchanges occur due to electrical charges of soil particles, resulting in the removal or separation of minerals and other substances dissolved in the leachate. Finally, leachate is diluted by dispersion being spread out over a wide surface area.

Various factors may also react with leachate during percolation which may yield changes in chemistry and pollutant strength reduction as shown in Figure 1. These factors maintain the forms of physical forces include filtration, sorption, advection and dispersion, chemical forces such as oxidation-reduction, precipitation-dissolution, adsorption-desorption, hydrolysis and ion-exchange and biological forces such as microbial degradation. However, these reactions are affected by ground material, ground hydraulic condition and leachate chemistry. Even though these reactions have the capacity to reduce pollution impact, it is also anticipated that some reactions such as microbial degradation can cause negative impact include increase of toxicity from the original pollutant.

Figure 1

Leachate Migration In Landfill

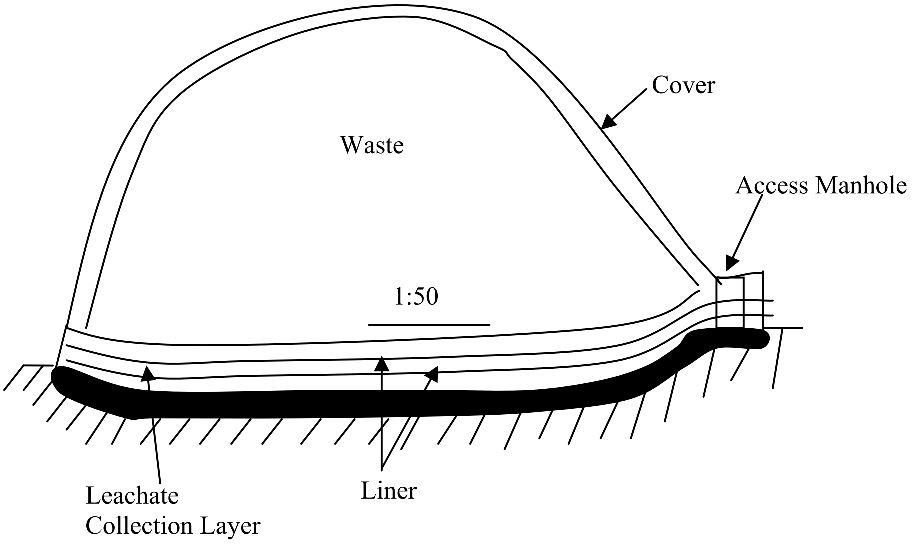


2. LINERS

Liners are commonly used in applications ranging from landfill covers and bottom liners to secondary containment systems, decorative ponds and wastewater lagoon. In landfills, liner used to minimize contamination from the landfill by controlling and isolating the leachate generated in the landfill as shown in Figure 2. Various types of liners can be used for landfill sites. However, several considerations shall be given in the selection of the liners for the landfill site include permeability, strength factor and shear factor.

Figure 2

Typical Landfill With Liner



2.1 Types of Liners

Landfills liners are served as a barrier between the waste in the cell and the surrounding environment and to channel off the leachate to collection and treatment facilities so prevent water pollution. Thus, the main function of liner is to provide an impermeable barrier using various materials with high values of elastic modulus, chemical and weathering resistances, yield and puncture strength. The materials used include clay, geomembranes such as HDPEC (High Density Polyethylene), PVC (Polyvinylchloride), PP (Polypropylene), geotextiles, geosynthetic clay liner and geonet as shown in Table 6.

Table 6

Components of Liners

Component	Materials	Advantages	Disadvantages
Clay	Compacted clay	Good for groundwater protection from clay	Fracture can be caused by chemical attack, drying out, freezing-thawing
Geomembranes/Flexible Membrane Liner (FML)	Made of various plastic materials include PE, PVC, PP and HDPE	Strong, high chemical resistant impermeable to water	Clogging due to trap particles
Geotextiles	Made of woven or nonwonven textile sheeting	Effective water movement	Clogging due to trap particles
Geosynthetic Clay Liner (GCL)	Made of thin clay layer between two layers of geotextiles	Easy installation	Less Impact by freezing-thawing
Geonet	Made of plastic net	Effective water movement	Clogging due to trap particles

Clay is one of the most economical liner material used in most landfill application due to its low permeability, low diffusivity, ductility, chemical compatibility, chemical retardation, internal and interface shear strength and good constructability. However it is affected by factors such as construction requirement and soil composition and post construction changes (9).

Modified clay such as bentonite is used to replace clay due to its mineralogy usually in term of percentage of sodium and/or calcium montmorillonite, moisture content and operation requirement to improve permeability.

Synthetic liners are used as an alternative to clay such as geomembrane and geotextile because of low volume consumption and easy availability. The rapid acceptance of synthetic liners in the engineering application is due to their high strength, chemical compatibility and thicknesses up to as thin as 1mm.

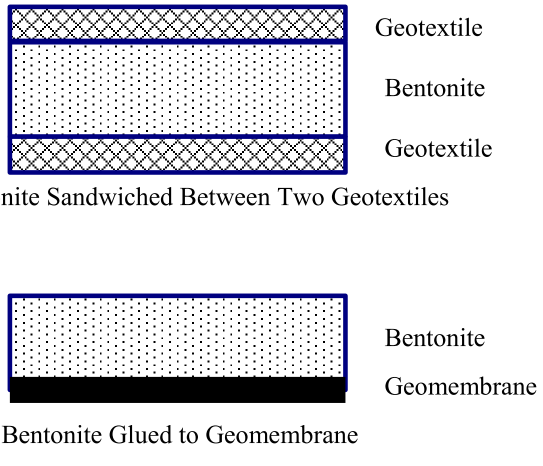
For selection of an effective liner for landfill, important criteria include hydraulic conductivity, shear strength, chemical resistance and other performance characteristics such as free and confined swelling and rate of creep. Liner with low hydraulic conductivity is to ensure low permeability (i.e. rate of infiltration) through waste and strong shear strength is to ensure maximum stress of liner without losing structural integrity.

Geosynthetic Clay Liners (GCL) is one of the newest liner technology used in municipal solid waste landfill application due to its low hydraulic permeability, easy installation and swelling property. Typically configuration of GCL consists mainly of modified clay i.e. bentonite either sandwiched between two sheets of geotextile or bonded to a geomembrane as shown in Figure 3. A geotextile which is woven or nonwoven sheet material is less impervious to liquid and more resistance to penetration damage when compared to a geomembrane which is a polymeric sheet material.

GCL offers a good substitute to other conventional landfill liners such as CCL (Compacted Clay Liner) due to fast and easy installation, low permeability due to low conductivity, good swelling properties and cost effective in the absence of clay material as depicted in Table 7 (10). Modified clay or bentonite of GCL is an excellent absorbent that attracts positively changed water particles that hydrates rapidly when expose to leachate that maximizing capacity at the same time better environment protection.

Figure 3

Typical Configuration of GCL



Bentonite Sandwiched Between Two Geotextiles

Bentonite Glued to Geomembrane

Table 7

Comparison of CCL and GCL (10)

Compacted Clay Liner	Geosynthetic Clay Liner
Thick (0.6-1.5m)	Thin (<10mm)
Field Constructed	Manufactured
Hard to build correctly	Easy to build (unroll and place)
Impossible to puncture	Possible to damage and puncture
Constructed with heavy equipment	Light construction equipment required
Often required test pad at each site	Repeated field testing not needed
Site specific data on soil needed	Manufactured product : data available
Large leachate-attenuation capacity	Small leachate-attenuation capacity
Large thickness, takes up space	Little space is wasted
Cost is highly variable	More predictable cost
Soil has low tensile strength	Higher tensile strength
Can desiccate and crack	Cannot crack until wetted
Difficult to repair	Not difficult to repair
Vulnerable to freeze-thaw damage	Less susceptible to freeze-thaw damage
Performance depends highly on quality of construction	Hydraulic properties are less sensitive to construction variabilities
Slow construction	Much faster construction

Typically there are five types of architecture used for landfill liners that can be described as single, double and composite as shown in Table 8.

A single liner normally consists of a clay liner or CCL, a geomembrane or a GCL is used in landfill for construction waste which is cost effective to build and maintain.

Table 8

Types of Liners

Liner Type	Composition	Function	Application
Single Liner	Clay liner, Geosynthetic clay liners or Geomembranes	Sufficient to prevent insoluble leachate migration	Suitable for domestic solid waste and non-dangerous industrial waste landfill
Single composite Liner	Two or more difference material of low permeability such as clay liner with geomembrane	Effective to control leachate migration with clay liner or geomembrane	Suitable for municipal solid waste and non-dangerous industrial waste landfill
Double Liners	Two single liners, two composite liners or a single liner with a composite liner	Primary liner is to collect leachate while secondary liner serves as back up	Suitable for hazardous waste landfill
Double Composite Liner	Two composite liners place one above the other	Ensure sufficient collection of leachate and no leakage	Suitable for hazardous waste landfill

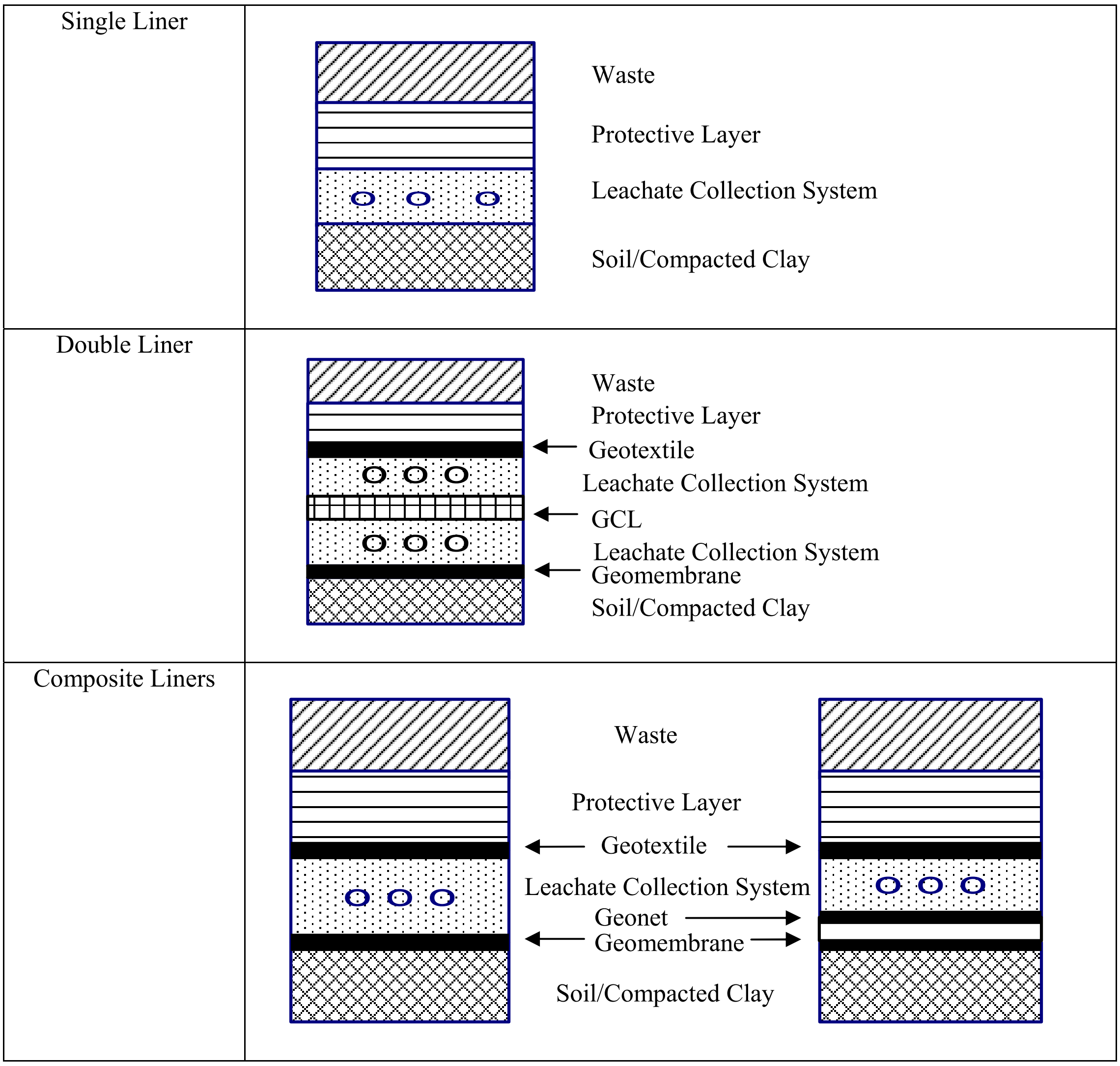
A composite liner consists of combination of geomembrane with clay liners so to limit leachate migration is usually used in municipal solid waste landfills.

A double liner consists of either two single liners, two composite liners or a combination of a single and a composite liner in such a way that the upper liner can collect the leachate and the lower liner can act as back up for leakage. Double liners are used in either municipal solid waste landfills or hazardous waste landfills.

In addition, a leachate collection system consists of sand and gravel is used to drain the leachate from the landfill to collection ponds for storage and treatment. Also, a protective layer consisting of soil, sand and gravel or a layer of soft waste (e.g. organic waste, paper, rubber and others) is used to cushion liner to avoid damage as shown in Figure 4.

Figure 4

Cross Section of Liner



2.2 Liner Failure

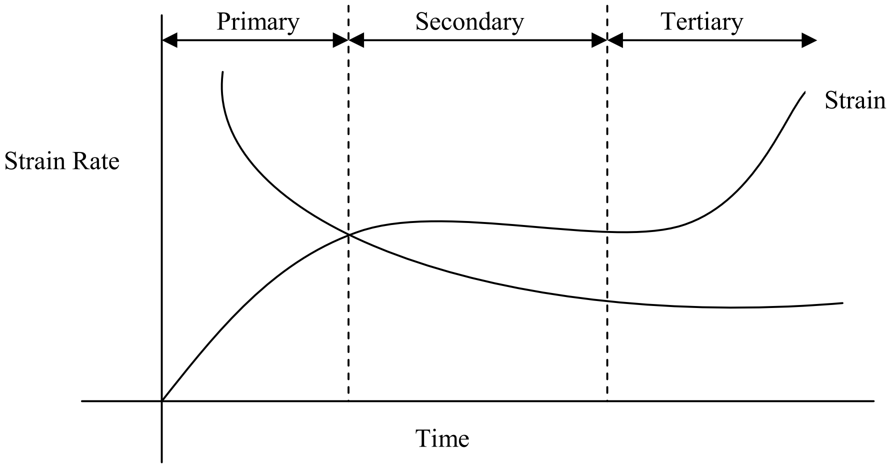
Generally, the two failure modes of liners are leakage and liner destruction. Leakage occurs in liners through lost of material permeability or hole damage cause leachate or even waste to release to the environment. Liner destruction on the other takes place due to extensive membrane movement or loss of mechanical properties caused by phenomena include creep and puncture.

Creep is defined as a deformation of material over a prolonged time period under constant pressure (11-12). It is load, temperature and time dependence and is related to most mechanical deformation such as compression, tensile, torsion and flexure. However only compressive and tensile creep are anticipated in the geomembrane due to material used. The three phases of creep behavior are observed namely primary with strain increases but strain rate decrease, secondary with both strain and strain rate remain constant and tertiary with material rupture due to rapid increase of strain and strain rate. The typical creep curve for landfill liner is depicted in Figure 5.

Puncture is one of the most common and serious type of damage to the landfill liner. Puncture phenomena cannot be assessed easily and are subject to short term as well as long-term puncture forces. Short term forces normally occur during installation of leachate collection layer while long term forces occur due to over burden loads of waste.

Figure 5

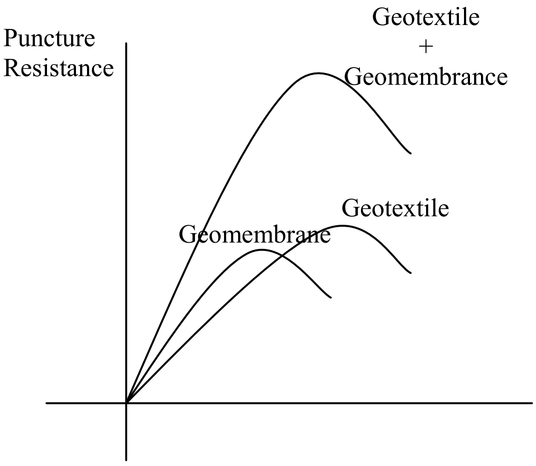
Typical Creep Curve (12)



There are two types of puncture phenomenon namely static and dynamic. The liner usually experiences dynamic puncture phenomenon due to fall height during installation and is usually short term. Static puncture phenomenon is due to contact with static normal stress and can be short term such as traffic load and long term such as waste load. Figure 6 depicts the puncture resistance summation of two different components of liner (13).

Figure 6

Puncture Resistance of Liners (13)



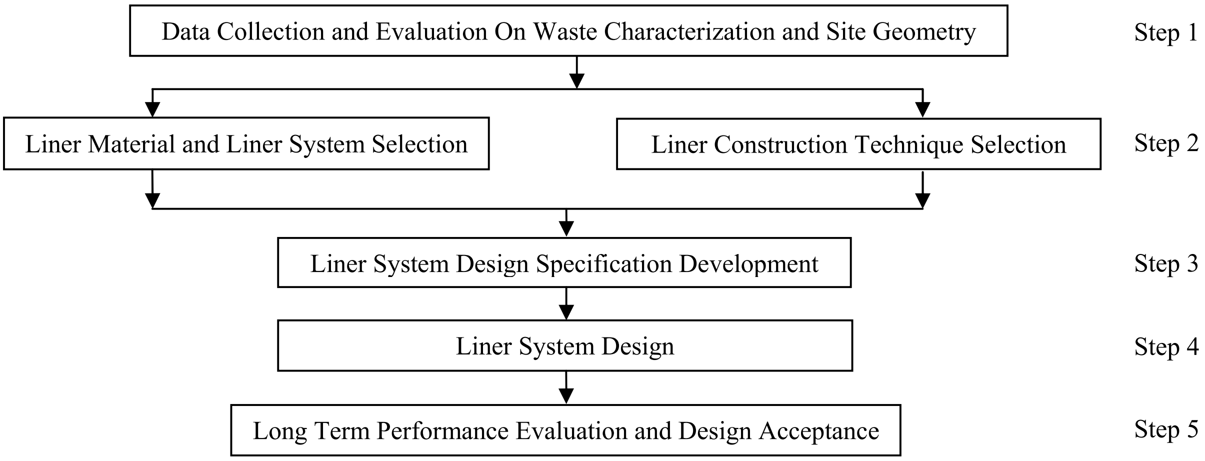
2.3 Liner Design

Typically liner design involves the material selection and thickness computation based on various factors include type of pollutants, environmental and climatic conditions material availability and legal requirements and cost provision. The composition of liners for waste usually consists of a compacted subsoil layer overlain by compacted clay layers and geosynthetic materials with different combination of materials all depend on application requirement.

The design flow of liner as depicted in Figure 7 is broadly covered in 5 steps. Each of the design steps must be documented in detail so that decision can be made to finalize design for application.

Figure 7

Design Flow For Liner System



Step 1 Data Collection and Evaluation – The collection of data pertaining to waste characterization such as waste type and strength and site geometry such as water bodies and chemistry must be conducted for engineering evaluation to establish benchmarking references for liner system and technique selection.

Step 2 Selection of Liner System and Construction Technique – Relevant screening on type of liner material for leachate control and cover design to minimize pollutant release that meet acceptable limit must be carried out. Also study of various available construction technology for liner placement must be conducted to ensure accurate placement of liner so that necessary density and rate of liner application can be derived.

Step 3 Liner System Specification Development – Next is to develop design specification so that design effectiveness of the liner system is ensured. The design specification is to be outlined so that the liner system constructed can meet specific performance criteria at minimum cost.

Step 4 Liner System Design - The liner system is then designed with appropriate engineering criteria in reducing pollutant release thus achieve the intended liner function. The design involves mainly the determination of liner thickness required taking into consideration of physical and chemical properties of pollutant and the material of liner selected.

Step 5 Long Term Performance Evaluation and Design Acceptance - It is crucial for the liner system designed to be evaluated for long term performance on its inherent ability to maintain the design effectiveness throughout the entire life cycle of the liner system. The design of liner system is accepted for application as long as the compatibility of liner material and pollutant present is reached so that design characteristic can be assured for extended period of time.

Table 9 illustrate the template developed for specific guidance for design of liner system for waste landfill.

Table 9

Liner System Design Template

1	Baseline Data	• Waste Source • Waste Characterization - pH, conductivity, total solids - organic matters - inorganic matters - heavy metal • Site Geometry and Environment - Geotechnical Aspect - Groundwater and Surface Water - Climate • Legal Requirement - Legislative and Regulatory
2	Liner system Selection	• Liner materials Resistant - Compacted modified subsoil - Compacted clay - Geomembranes - Geosynthetic - Composite materials • Liner System - Leachate Collection System - Cover - Wall and trenches • Engineering Techniques - Compaction and re-compaction - Lift - Water Content
3	Liner System Design Specification	• Liner thickness • Liquid & flow through • Hydraulic conductivity • Strength and puncture resistance • Shrink-swell properties
4	Liner System Design	• Liner thickness • Pollutant flux • Pollutant removal
5	Long Term Performance Evaluation	• Design effectiveness • Liner compatibility

Adequate considerations are to be given for liner system design to prevent leakage, geogrids for leak collection and a good protection layer to prevent puncture phenomenon and to reduce creep, stress cracking and aging phenomenon. The design consists of site selection, geometric layout, geotechnical consideration, cross-section determination, geomembrane material selection, thickness determination, side-slope and cover soil details, anchor trench details, seam type decision, seam testing strategy, design of connection and appurtenances , leak scenarios and correction measures and proper quality assurances (14).

Problems selecting to the liner design are identified to guide designing engineer as shown in Table 10 (15).

Table 10

Problem associated With Liner Design (15)

Problem	Liner Stress	Required Properties		Typical Factor of Safety
		Geomembrane	Landfill	
Liner Self weight	Tensile	G, t, σ_{allow}, δ_L	β, H	10 to 100
Weight of filling	Tensile	t, σ_{allow}, δ_L, δ_u	β, h, H, γ	0.5 to 10
Impact during construction	Impact	I	D, W	0.1 to 5
Weight of Landfill	Compression	σ_{allow}	γ, H	10 to 50
Puncture	Puncture	σ_p	γ, H, P, A_p	0.5 to 10
Anchorage	Tensile	t, σ_{allow}, δ_L, δ_u	β, γ, Φ	0.7 to 5
Settlement of landfill	Shear	τ , δ_u	β, γ, H	10 to 100
Subsidence under landfill	Tensile	t, σ_{allow}, δ_L, δ_u, χ	α, γ, H	0.3 to 10

Where :

Geomembrane Properties

G = specific gravity

T = thickness

σ_{allow} = allowable strength

τ = Shear strength

I = Impact resistance

σ_p = puncture strength

δ_u = friction with material above

Landfill Properties

β = slope angle

H = landfill height

γ = Unit weight

h = lift height

α = subsidence angle

Φ = friction angle

d = drop height

Design features are to take into consideration of a safety analysis for liner system as depicted in Table 11 (16).

Table 11

Requirement of A Safe Liner System (16)

Requirement	Properties that need to be Checked	Site Specific influences
Stability The liner system should be stable with respect to the mechanical influences without significant change in its leachate behavious	Shear resistance cohesion (residual/non-residual values)	Mechanical influences: • Forces resulting from deformation • Forces resulting from overburden loads and inclination • Forces resulting from construction procedures
Imperviousness Pollution migration through the liner system should be comparable to that for a definable standard size	a) Permeability of the liner system hydraulic conductivity, diffusion coefficient retention capacity b) Sensitivity of the system to imperfections	• Hydraulic gradient • Kind of pollution • Amount of soluble pollutant • Concentration of pollutant in solution • Temperature If a composite liner is considered • Kind of clay • Zone of higher permeability • Deformation or desiccation • Over burden loads
Resistance If proved that the lining system being exposed to the site specific influences is still stable and sufficiently impermeable Combination of influences should be considered	Resistance to leachate Resistance to gas Resistance to temperature Hydraulic resistance Resistance to exposure	Chemical influences: • Kind of composition of leachate • Duration of exposure Thermal influences: • Low/high temperature • Duration of exposure Hydraulic influences: • Forces resulting from water movement • Climate, hydrogeology of the site

2.4 Liner Installation and Maintenance

The criteria to be selected in engineering practice for installation and maintenance is crucial to ensure effective use of liner in landfill.

Proper installation of landfill liner is to be carried out with care by competent workmenship to follow the design work. A proper and detail quality control and management plan are to be put in place for operation throughout the entire lifespan of the landfill liner system to monitoring long term performance with respect to liner integrity and landfill stability.

2.5 Prevention of Contaminant Migration

The latest engineering design of landfill system is to limit contaminant migration so to minimize impact to surrounding environment. The typical landfill system consists of a leachate collection system to control the leachate head acting on the liner and to collect and remove leachate. The leachate collection system comprises mainly a gentextile with granular layer and perforated pipes. The landfill liner can range from a clay layer to a liner system of one or more geomembrane and/or compacted clay liner or geosynthetic clay liner. Composite liners comprising of a geomembrane over compacted clay have been widely adopted in many standard landfill designs [9]. The effectiveness and efficiency of liner performance is based on the several factors such as different potential transport mechanisms include advection (the movement of containment with leachate flow) and diffusion (the movement of molecules or ions from high concentration to low concentration regine) and the potential attenuation mechanisms include biodegradation, sorption and dilution (17).

Diffusion is defined as the movement of molecules or ions due to own random kinetic activity from areas of higher concentration to areas of lower concentration. This movement in porous media is given by Fick's Law (17) as :-

$$f = -n_c D_c \frac{\partial c}{\partial z}$$

where

f = mass flux ($ML^{-2} T^{-1}$)

n_c = effective porosity (-)

c = concentration in liner (ML^{-3})

z = distance parallel to diffusion direction

Most liners such as geomembrane is not a conventional porous medium as the pore size is large relative to both water and contaminant molecules. The diffusion of penetrant molecules through a geomembrane therefore can be represented by Fick's law as :-

$$f = - D_g \frac{\partial c_g}{\partial z}$$

where

f = mass flux ($ML^{-2} T^{-1}$)

D_g = Diffusion coefficient in the liner (L^2T^{-1})

c_g = concentration of penetrant in the landfill (ML^{-3})

z = distance parallel to diffusion direction

Taking into the conservation mass governing differential equation for transient diffusion as :-

$$\frac{\partial c_g}{\partial t} = - D_g \frac{\partial^2 c_g}{\partial z^2}$$

When a liner is in contact with liquid/leachate for a sufficient time a final equilibrium which take place in the liner as per Henry's Law (18-19):-

$$c_g = S_{gf} c_f$$

where

c_g = final equilibrium concentration in the liner (ML^{-3})

S_{gf} = solubility, partitioning or Henry's coefficient (-)

c_f = equilibrium concentration in the adjacent fluid C_f (ML^{-3})

Alternatively, it can take a non-linear as Langmuir form

$$c_g = \frac{S_a b c_f}{1 + b c_f}$$

where

S_a = experimental determined constant

b = variables constant

Assume that the pollutant permeant is not interact with the liner yield

$$f = -D_g \frac{\partial c_g}{\partial z} = S_{gf} D_g \frac{\partial c_f}{\partial z} = -P_g \frac{\partial c_f}{\partial z}$$

where

$P_g = S_{gf}$

P_g is thus referred as the permeability which the mass flux across a landfill is given by

$$f = S_{gf} D_g \frac{\Delta c_f}{t_{GM}}$$

$$= P_g \frac{\Delta c_f}{t_{GM}}$$

where

Δc_f = difference in concentration in the fluid on either side of the liner

As transient contaminant transport is controlled by the diffusion coefficient D_g instead of the permeability, P_g, the Henry Coefficient S_{gf} is defined when an equilibrium is reached (20) as :-.

$$S_{gf} = \frac{c_{fo} V_g c_{fF} (V_s + V_r) - \Sigma V_i c_i}{A t_{GM} c_{fF}}$$

where

c_{fo} = initial concentration of fluid in the source reservoir (ML^{-3})

c_{fF} = final equilibrium concentration in the source and reservoir

V_s , V_r = volumes of the source and the reservoir (L^3)

A = area of geomembrane through which diffusion occurs (L^2)

t_{GM} = thickness of geomembrane

$\Sigma V_i c_i$ = mass removed by sampling events (M)

Advection and diffusion is an important transport mechanisms of leachate for well designed and operated landfills. The rate of advection and diffusion will depend on the level of physical action that occur in the liner and the level of biodegradation of organic contaminants in the landfill.

Advection is the transport or migration of leachate constituents as a result of holes or physical defects in the geomembranes liner and flow through pores of underlying soil layer due to the influence of hydraulic head. Darcy's law can also be used to compute the advective flux for liner.

The advection dispersion, equation with a first order reaction is expressed as (21)

$$\frac{\partial c}{\partial t} = D_{xx} \frac{\partial^2 c}{\partial x^2} + D_{xy} \frac{\partial^2 c}{\partial \alpha \partial y} + D_{yy} \frac{\partial^2 c}{\partial y^2} - \vartheta_x \frac{\partial c}{\partial x} - \vartheta_y \frac{\partial c}{\partial y} - kC$$

where

C = dissolved concentration (ML^3)

t = time (T)

k = first prder reaction rate coefficient (T^{-1})

D_{xx}, D_{yy}, D_{yx}, D_{xy} = Dispersion coefficient (L^2T^{-1})

ϑ_x ϑ_y = velocity component in x and y direction (LT^{-1})

3. CONCLUSION

This chapter presents technical guidance for liners usage to enhance containment of pollutants in landfill. It is suggested that liner that prevent containment release from landfill to surrounding environment must be properly designed, installed, constructed and operated. Liner must also be selected from physical, chemical and biological aspects. Various options of liner including clay liner, various geosynthetic such as geomembrane, geotextile and geonet, GCL and granular leachate collection system are considered for landfill application to minimize contamination cause to environment. Performance of liners is subject to factors such as waste composition, waste age and waste decomposition.

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Influence of Waste Age On Landfill Leachate Quality

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***Abstract*-The influence of waste age on the characteristic of leachate from a landfill site where young and mature waste cells were investigated over a period of six years to evaluate the impact of waste age on quality of leachate generated. Results of the study revealed that the leachate quality is affected by waste age due to its impacts to bacterial growth and chemical reaction in the waste mass of landfill.**

Keywords: leachate, sanitary landfill, bacterial growth, chemical reaction landfill, waste age

I. INTRODUCTION

Leachate is the liquid percolation that drains through the waste in the landfill varies widely depend on waste type and the waste age (Christensen et al., 1994; Lema et al., 1988; Lu et al., 1985; Pohland and Harper 1985). Typically, the leachate can be characterized into three major groups as shown in Table 1. The three major groups are mainly organic matters, inorganic matters and xenobiotic organic compounds. Beside these, other compounds are also likely present in the leachate such as arsenate, barium, borate, cobalt, lithium, mercury, selenate and sulfide however in small quantity and of less significant level.

Table 1
Pollutants In Leachate

Group of Pollutants In Leachate		Components
1	Organic matters	Acids, alcohols, aldehydres and others usually quantified as COD (Chemical Oxygen Demand), BOD (Biochemical Oxyegn Demand), DOC (Dissolved Organic Carbon), Other Volatile fatty acid and refractory compound include fulvic-like and humic like compounds
2	Inorganic matters	Sulfate, chloride, ammonium, calcium, magnesium, sodium, potassium , hydrogen carbonate, iron and manganese and heavy metal like lead, nickel, copper, cadmium, chromium and zinc
3	Xenobiotic organic compounds	Aromatic hydrocarbon, phenols, chlorinated aliphatics, pesticides and plastizers include PCB, Dioxin, PAH, etc

Leachate quality is significantly influenced by the waste age or length of time after waste fill. It is reported that leaching quality achieved at maximum after two or three years and decline subsequently (McBean et al, 1991; Lu et al., 1985). Also there is reporting that leachate from young landfill will be high in BOD and COD and decline subsequently to level off after 10 years (Akyurek, 1995).

The purpose of this paper is to study the impact of waste age on quality of leachate leaching out from sanitary that yield various pollutant that post environmental pollution to soil and groundwater.

II. MATERIAL AND METHOD

The leachate data used in this study was obtained from the performance results of a landfill site at Toronto over a period of five years and fifteen years for the average age and mature age part of landfill respectively. The leachate composition was typical of both new and mature landfills. The landfill is deposited with wastes of solid, non-hazardous, industrial, commercial and institutional waste from municipalities and business.

The parameters evaluated include carbonaceous parameters such as BOD, COD and DOC, nitrogeneous parameters include ammonia, nitrate, nitrite, TKN and other parameters include alkalinity, calcium, chloride, conductivity, hardness, iron, magnesium, pH, phenols, phosphorus, sodium, sulphate and total suspended solids.

Characteristic of leachate are analyzed statistically in term of linear regression on performance data obtained over the period of five and fifteen years for new and mature landfill.

III. RESULT AND DISCUSSION

In this study, landfill of both young and mature waste cells that are designed with a typical engineered hydraulic trap as shown in Figure 1 to contain and collect leachate to minimize groundwater impact. The young and old waste cells if are in operation of five and fifteen years respectively.

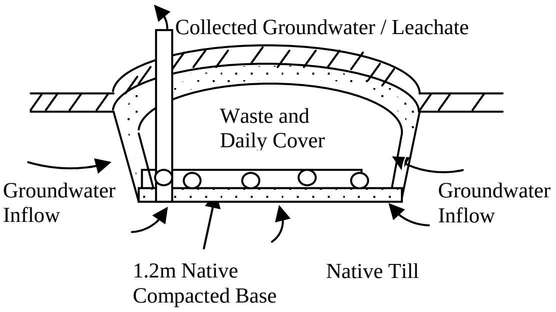

Figure 1 Landfill with Hydraulic Trap

Data of carbonaceous pollutants in leachate of young waste cell of landfill is depicted in Table 2 and Figure 2.

The mean value for BOD, COD and DOC is 2031.62, 3641.2 and 1240 mg/l with standard deviation of 2754.85, 3949.71 and 1421.41 mg/l respectively. Maximum and minimum BOD, COD and DOC values obtained are 6350, 9600 and 3490 mg/l and 13.1, 226 and 90 mg/l respectively. The value of BOD and COD obtained is correlated well to the reported BOD and COD ranges of 4000-40,000 mg/l and 6,000-60,000 mg/l respectively for acetonogenic leachate typically from young landfill (Ehrig, 1983, 1988). This observation suggests that the performance data obtained from the new landfill of five years which is still experiencing the acetogenic phrase at the landfill that is still active. Higher organic matter content is expected in this leachate due to generation of dissolved and solubilized organic matter.

Table 2

Carbonaceous Pollutant Concentration in Average Age Leachate Sampling Point

Parameter	**Maximum value**	**Minimum Value**	**Mean**	**Standard Deviation**
BOD (mg/l)	6350	13.1	2031.62	2754.85
COD (mg/l)	9600	226	3641.2	3949.71
DOC (mg/l)	3490	90	1240	1421.41
BOD:COD Ratio	0.66	0.05	0.31	0.29
pH	6.80	5.92	6.52	0.35

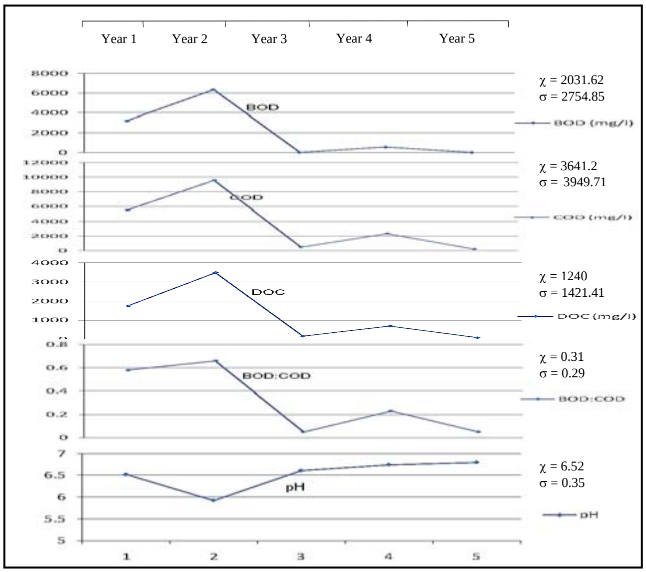

Figure 2 Carbonaceous Pollutant Concentration in Average Age Leachate Sampling Point

On the other hand, data of carbonaceous pollutant in leachate of landfill over fifteen years is depicted in Table 3 and Figure 3. The mean value for BOD, COD and DOC is 195.83, 875.44 and 290.28 mg/l with standard deviation of 202.45, 256.80 and 167.14 mg/l respectively. Maximum and minimum BOD, COD and DOC values obtained are 870, 1510 and 650 mg/l and 61.90, 409 and 137 mg/l respectively. The values of BOD and COD achieved are well correlated to the reported value of BOD and COD ranges of 20-550 mg/l and 500-4500 mg/l respectively for methanogenic leachates (Ehrig, 1983, 1988) which further suggest that mature leachate produce lower organic matter content with clear indication that efficient degradation of dissolved organic matter can be well achieved.

Table 3

Carbonaceous Pollutant Concentration in Mature Age Leachate Sampling Point

Parameter	**Maximum value**	**Minimum Value**	**Mean**	**Standard Deviation**
BOD (mg/l)	870	61.90	195.83	202.45
COD (mg/l)	1510	409	875.44	256.80
DOC (mg/l)	650	137	290.28	167.14
BOD/COD Ratio	0.57	0.05	0.20	0.14
pH	7.38	6.27	5.72	2.64

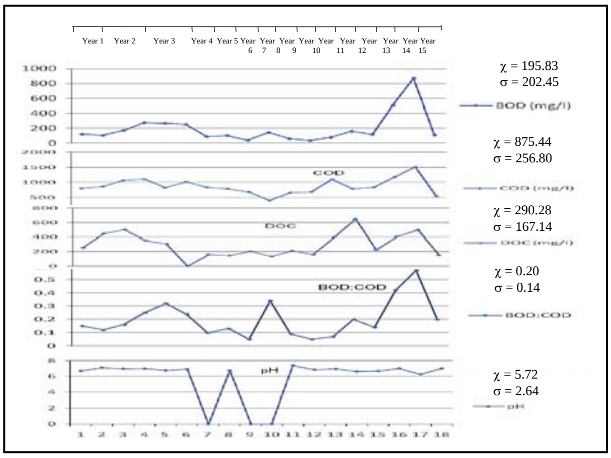

Figure 3 Carbonaceous Pollutant Concentration in Mature Age Leachate Sampling Point

Performance data of nitrogeneous pollutants in leachate of new waste cell of landfill is illustrated in Table 4 and Figure 4. The mean value for ammonia, nitrite, nitrate and TKN is 288.6, 1.8, 1.8 and 474.80 mg/l with standard deviation of 196.57, 0.45, 0.45 and 347.33 mg/l respectively. Maximum and minimum values for ammonia, nitrite, nitrate and TKN are 520, 2, 2, 880 mg/l and 103, 1, 1 and 162 mg/l respectively. The presence of ammonia and organic nitrogen are mainly due to their generation from decomposition of organic matters which are stable in anaerobic condition thus explained the presence of high percentage of soluble nitrogen compounds found in the leachate (McBean et al, 1995).

Table 4

Nitrogenous Pollutant Concentration in Average Age Leachate Sampling Point

Parameter	**Maximum value**	**Minimum Value**	**Mean**	**Standard Deviation**
Ammonia (mg/l)	520	103	288.60	196.57
Nitrite (mg/l)	2	1	1.8	0.45
Nitrate (mg/l)	2	1	1.8	0.45
TKN (mg/l)	880	162	474.80	347.33

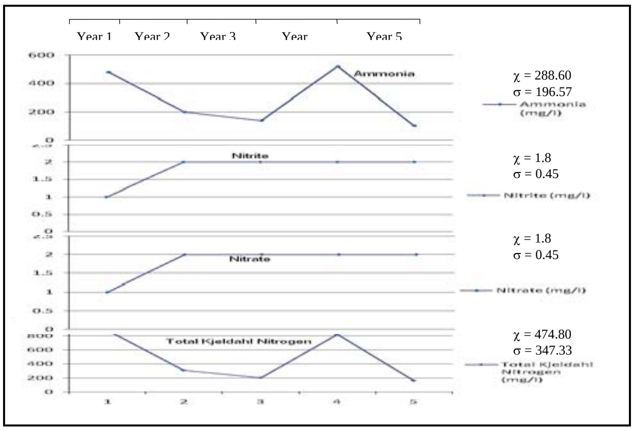

Figure 4 Nitrogeneous Pollutant Concentration in Average Age Leachate Sampling Point

On the other hand, nitrogeneous pollutants in leachate of the mature waste cell landfill is shown in Table 5 and Figure 5. The mean value for ammonia, nitrite, nitrate and TKN is 260.03, 0.72, 0.73 and 304.46 mg/l with standard deviation of 102.73, 0.78, 0.77 and 118.29 mg/l respectively. Maximum and minimum values for ammonia, nitrite, nitrate and TKN are 523, 2, 2 and 663 mg/l and 78.50, 0.10, 0.10 and 90.30 mg/l respectively. It is reported that the range of ammonia nitrogen concentration spread from 200 to 2000 mg/l showing no decreasing trend in concentration with time. It is also believed that ammonia is mainly released from the decomposition of organic matter such as protein (Robinson, 1995; Burton and Watson-Craik, 1998). Thus ammonia appear to be a good indication of organic nitrogen in the leachate.

Table 5

Nitrogenous Pollutant Concentration in Mature Age Leachate Sampling Point

Parameter	Maximum value	Minimum Value	Mean	Standard Deviation
Ammonia (mg/l)	523	78.50	260.03	102.73
Nitrite (mg/l)	2	0.10	0.72	0.78
Nitrate (mg/l)	2	0.10	0.73	0.77
TKN (mg/l)	663	90.30	304.46	118.29

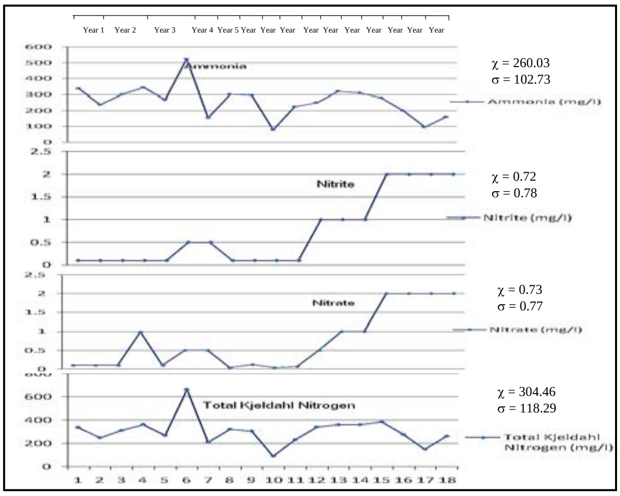

Figure 5 Nitrogeneous Pollutant Concentration in Mature Age Leachate Sampling Point

Data of other pollutants in leachate of the new waste cell landfill is depicted in Table 6 and Figure 6. The mean value of calcium, chloride, iron, magnesium, sodium, sulfate and phenol is 421.40, 893.80, 32.11, 153.60, 764.20, 196.80 and 783.60 mg/l with standard deviation of 415.16, 466.29, 36.90, 27.75, 450.31, 180.53 and 757.6 mg/l respectively.

Table 6

Other Pollutant Concentration in Average Age Leachate Sampling Point

Parameter	Maximum value	Minimum Value	Mean	Standard Deviation
Calcium (mg/l)	1060	126	421.40	415.16
Chloride (mg/l)	1410	322	893.80	466.29
Iron (mg/l)	73.80	3.84	32.11	36.90
Magnesium (mg/l)	179	118	153.60	27.75
Sodium (mg/l)	1370	279	764.20	450.31
Sulfate (mg/l)	509	40	196.80	180.53
Phenol (mg/l)	1720	3	783.80	757.633

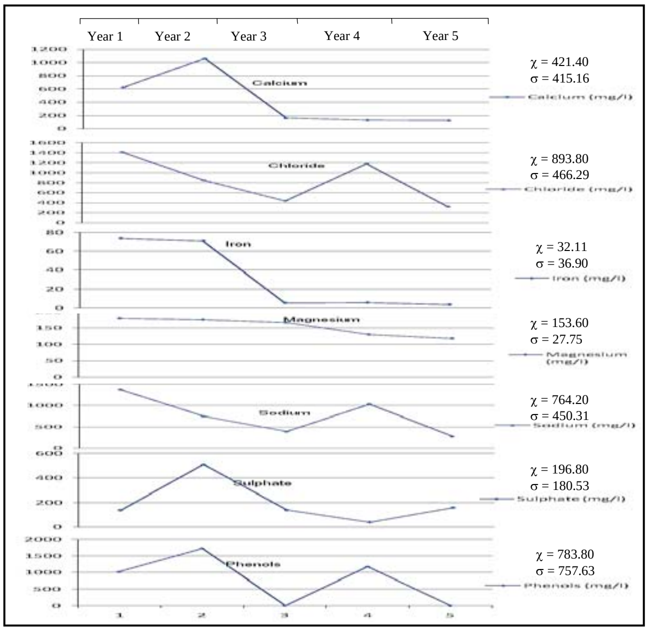

Figure 6 Other Pollutant Concentration in Average Age Leachate Sampling Point

Also, data of other pollutants over 15 years from the mature waste cell is depicted in Table 4.10 and Figure 7. The mean value for calcium, chloride, iron, magnesium, sodium, sulfate and phenol is 181.91, 735.06, 11.24, 132.79, 688, 81.73 and 175.44 mg/l with standard deviation of 85.54, 235.58, 8.30, 36.88, 253.61, 175.46 and 274.41 mg/l respectively. There is observed difference of these parameters between acenogenic phase and methanogenic phase likely due to the effects of sorption, complexation and precipitation. Decreasing trend in concentration with time of these pollutants could be also due to washout by leaching as reported in some study (Ehrig 1983, 1988).

Table 7

Other Pollutant Concentration in Mature Age Leachate Sampling Point

Parameter	**Maximum value**	**Minimum Value**	**Mean**	**Standard Deviation**
Calcium (mg/l)	405	62.40	181.91	85.54
Chloride (mg/l)	1100	275	735.06	235.58
Iron (mg/l)	32.5	2.92	11.24	8.30
Magnesium (mg/l)	215	75.70	132.79	36.88
Sodium (mg/l)	1030	297	688	253.61
Sulfate (mg/l)	771	7.03	81.73	175.46
Phenol (mg/l)	951	1	175.44	274.41

Figure 7 Other Pollutant Concentration in Mature Age Leachate Sampling Point

IV. CONCLUSION

Leachate generation in sanitary landfill is a complex combination of physical, chemical and biological processes whereby waste age has impact to performance of landfill that generate leachate. Results reveal that leachate quality correlates well with the waste age. This is largely due to microbial degradation of both organic and inorganic constituents in the waste experience different exposure of acetogenic and methanogenic phases.

V. ACKNOWLEDGEMENTS

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Appendix 2
Referred Conference Paper

Benchmarking Heavy Metal Contamination for Brownfield in Malaysia

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Abstract

Malaysia has over 10,000 brownfield sites which have yet to be registered. In fact there is limited information and controls on soil and groundwater contamination from these brownfield sites. In this study, four brownfield sites were examined in terms of the soil and groundwater quality to benchmark the heavy metal contents to be used as indicators of soil and groundwater contamination and to derive suggested benchmarking reference for remedial action to be taken. It also described briefly the possible remediation techniques to clean up the heavy metals in brownfield sites and the need for registration of brownfield sites towards sustainable development.

Keywords: Brownfield, soil quality, groundwater quality, heavy metal contamination and remediation.

1. Introduction

Due to urbanization and increasing land values there is a dire need to ensure that potential land is strategized for development purposes. Potential of redeveloping brownfields has prompted the need to have proper management strategies that can identify, document and catologue these brownfields to assist decision makers and planning agencies to make appropriate decisions so that environmental risks can be minimized for brownfields to be redeveloped.

Currently, in Malaysia there is no full listing and registration for brownfield sites and also there are no standards for soil and groundwater quality [1]. The brownfield sites may contain low contaminants such as debris to highly hazardous substance such as heavy metals, volatile organic substances, radioactive material and others that may contain in the ground due to man activities.

It is estimated there are over 10,000 brownfield sites exist in Malaysia. Some of these sites are developed, abandoned and some with potentials for redevelopment. Brownfields are analogue to contaminated sites that have been used for industrial, commercial, warehousing or other purposes that may be contaminated due to the presence of hazardous substances, pollutants or contaminants and usually existing in areas occupied by industrial activities, waste dumping, petrol and oil storage. The site of the brownfield sites varies from small premises to larger ones depending on the nature and type of activities at site.

The contaminants encountered at brownfields generally include heavy metals such as As, Cd, Co, Cr, Cu, Hg, Ni, Pb, Zn, VOC such as benzene, toluene and SVOC such as PAH and others.

Heavy metals cannot be chemically degraded and can affect all groups of organism and ecosystem processes [2-6] which are generally originating not only from industrial activities but also agriculture activities such as fertilizer application [7]. Heavy metals therefore are good indicators for contamination of brownfield sites.

The geology in Malaysia generally consists of granite, sedimentary rocks, shale, sandstone and limestone whereby heavy metals are also grounded in natural form. Heavy metals however can be introduced further to the land through fertilizer application, soil remediation and can cause contamination as well. On top of these activities, heavy metals are further introduced by other man activities namely industrial activities.

This study was therefore conducted with the aim to determine available heavy metals found in brownfields so as to benchmark the baseline with typical agriculture soil so relevant benchmarking references of heavy metal contamination can be established for remedial action to be taken.

2. Materials and method

2.1. Soil and groundwater sampling

Twenty soil samples obtained from four brownfield sites in Malaysia were evaluated to assess the range of heavy metals in the soil and groundwater at the brownfield sites. The four brownfield sites as depicted in Table 1 involve namely (i) Site 1 that is an industrial land in proximity to heavy manufacturing industries; (ii) Site 2 that is a site in proximity to motor vehicle repairs; (iii) Site 3 that is a site in proximity to high technology industrial activities; and (iv) Site 4 that is a site in close proximity to sanitary landfill.

Brownfield Site	Number of Samples	Type of Activity	Surrounding Land Use
Site 1	3	Heavy Industry	Heavy industrial activities
Site 2	9	Mechanical Workshop	Industrial, housing, warehousing
Site 3	2	High Technology Industry	High technology industrial activities
Site 4	6	Sanitary Landfill	Agriculture, landfill

Table 1 : Description of brownfield sites

Both test pits and borehole drilling were used in the sampling program. Soil samples were also taken from each test pit for classification of the soil profile. Soil samples collected during sampling were placed in pre-cleaned jars, sealed and labeled prior sending to laboratory for analytical purposes.

Groundwater wells were established in each test pit and left for 24 hours to ensure stability of the groundwater levels before measuring the groundwater levels. The monitoring wells were purged by removing one full well volumes of water. Groundwater samples were obtained with use of a bailer. The groundwater were then collected in 1000 ml bottles, labeled and sealed prior sending to laboratory for analytical purposes.

2.2. Analysis

The soil and groundwater samples were sent to laboratory for analysis. All samples were preserved according to the analytical requirement. The testing methods used are in accordance to APHA (American Public Health Association) 19th Edition 1995 as shown in Table 2.

Parameters Tested	Testing Method
As	APHA 3114C – Continuous Hydride Generation
Cd	APHA 3111B
Co	APHA 3111B
Cr	APHA 3111B
Cu	APHA 3111B
Hg	APHA 3112B – Cold Vapor Atomic Absorption Spectrometric
Ni	APHA 3111B
Pb	APHA 3111B
Zn	APHA 3111B

Note : APHA – American Public Health Association, 19th Edition 1995

Table 2 : Testing methods and parameters tested

The analytical results obtained from the soil and groundwater sampling programs were analyzed and compared to the selected references for soil and groundwater.

By way of this analogue, the significance of the heavy metal contamination in the soil and groundwater at the brownfield sites can be quantified with the relevant references.

3. Results and discussions

3.1. Heavy metals in soil

Table 3 provides a summary of the heavy metal concentrations found at the brownfield sites. The results were also compared with the soil investigation level published by the Ministry of Agriculture and the Dutch Reference Values. Fig. 1 provides a comparison of the heavy metal contents at the four brownfield sites.

Heavy Metals	Site 1	Site 2	Site 3	Site 4	Malaysia Reference *	Dutch Reference	
						S Value **	I Value ***
As	0.03	0.1	0.43-0.63	0.26-1.13	60	29	55
Cd	0.03-0.08	0.03	0.87-22.25	NA	0.3	0.8	12
Co	0.63-0.85	NA	1.35-2.56	NA	10	9	240
Cr	0.003	0.05-3.1	1.28.23.36	12.26-29.21	60	100	380
Cu	0.36-0.70	3.8-11.7	0.97-13.10	0.1-6.6	50	36	190
Hg	0.01	0.01	0.70	0.7	0.35	0.3	10
Ni	0.005	1.3-10.7	1.0-2.91	NA	45	35	210
Pb	0.26-0.29	12.1-46.5	0.10-10.56	3.31-11.29	65	85	530
Zn	NA	12.4-96.2	NA	NA	95	140	720

Note : Values indicate range detected at each site

* Soil investigation level published by Ministry of Agriculture Malaysia

** S Values (Target Values) – Below this value regard as being multi functional and land suitable for all usage

*** I Values (Intervention Values) - Above these values the soil is regard as a 'serious case of pollution' and some form of measures are to be adopted

NA – Not Available

NR – No Recommendation

Table 3 : Summary of soil analysis (mg/kg)

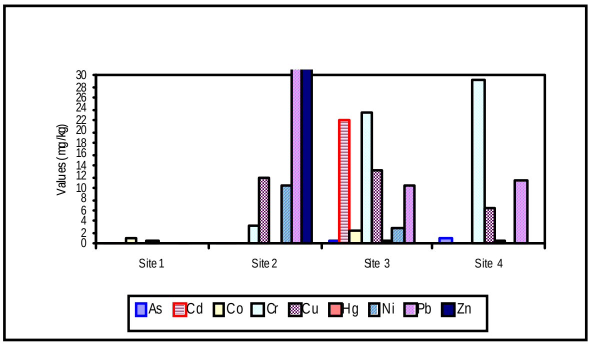

Fig. 1: Metal concentrations in the soil at brownfield sites

As values ranging from 0.03 to 0.63 mg/kg were detected at the brownfield sites. The values were within the Malaysian reference as well as within the Dutch reference.

Cd values ranging from 0.03 to 22.25 mg/kg were detected at the brownfield sites. Cd values at site 1, site 2 and site 4 were within the Malaysian reference as well as the Dutch reference. Cd values at site 3 however exceeded these references.

Co values ranging from 0.63 to 2.56 mg/kg were detected at the brownfield sites. The values were within the Malaysian reference and the Dutch reference.

Cr values ranging from 0.003 to 29.21 mg/kg were detected at these sites which were within the two references used for comparison purposes.

Cu values ranging from 0.1 to 13.10 mg/kg were detected at these brownfield sites which were also within the references used for comparison purposes.

Hg values ranging from 0.01 to 0.7 mg/kg were detected at the brownfield sites. Hg values at site 3 and site 4 exceeded the Malaysian reference. Hg levels at these sites were also detected to be above the Dutch S Values and below the Dutch I Values for intervention purposes.

Ni values ranging from 0.005 to 10.7 mg/kg were detected at the brownfield sites which were within the Malaysian reference and the Dutch reference.

Pb values ranging from 0.10 to 46.5 mg/kg were detected at the brownfield sites which were within the Malaysian reference and the Dutch reference.

Lastly, Zn of 12.4 to 96.2 mg/kg were detected at site 2 which were detected to be above the Malaysian reference and the Dutch reference.

In the summary based on the analysis conducted, the heavy metal concentrations detected at the brownfield site can be used as a good indicator to assess the level of contamination of the brownfield sites. The study to compare the extend of the heavy metal contamination can be used to benchmark heavy metal contamination for remedial actions.

3.2. Heavy metals in groundwater

Table 4 provides a summary of the groundwater analysis at the four brownfield sites while Fig. 2 depicts the metal concentrations in the groundwater at the brownfield sites. Comparisons with the NDWQ (National Drinking Water Quality) and the Dutch reference values were also made.

Heavy Metals	**Site 1**	**Site 2**	**Site 3**	**Site 4**	**Malaysia Reference ***	**Dutch Reference**	
						S Value **	**I Value *****
As	0.3	0.01	0.001-0.005	0.001-0.006	0.05	0.01	0.06
Cd	0.2	0.003	0.006	0.003	0.005	0.0004	0.006
Co	0.2-3.67	NA	0.002	NA	NR	0.006	0.03
Cr	0.3	0.01	0.001-0.063	0.01-0.7	0.05	0.001	0.03
Cu	1.36-2.39	0.01	0.001	0.01-0.34	1	0.015	0.075
Hg	1	0.01	0.001	0.001-0.006	0.001	0.00005	0.0003
Ni	0.5	NA	0.001-0.003	NA	NR	0.015	0.003
Pb	2.0	0.03	0.148-0.196	0.09-0.21	0.1	0.015	0.075
Zn	NA	0.38-0.51	NA	NA	1.5	0.065	0.7

Note : Values indicate range detected at each site

* National Drinking Water Quality, Ministry of Health Malaysia

** S Values (Target Values) – Below this value regard as being multi functional and land suitable for all usage

*** I Values (Intervention Values) - Above these values the soil is regard as a 'serious case of pollution' and some form of measures are to be adopted

NA – Not Available

NR – No Recommendation

Table 4 : Summary of groundwater analysis (mg/l)

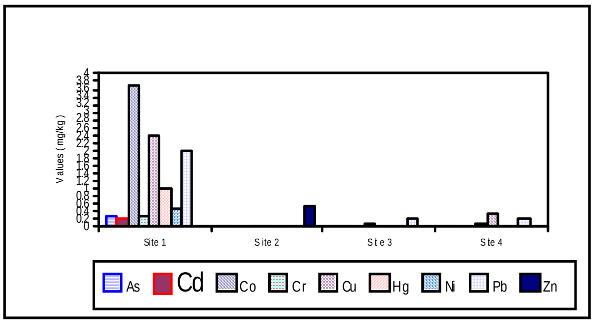

Fig. 2 : Metal concentrations in groundwater at brownfield sites

As values ranging from 0.001 to 0.3 mg/l were detected at the brownfield sites. As values at site 1 were above the NDWQ as well as above the Dutch S Values.

Cd values ranging from 0.003 to 0.2 mg/l were detected in the groundwater at these brownfield sites. Cd values at site 1 were detected to be above the selected reference while Cd values at site 3 were above the Dutch S Values.

Co values ranging from 0.002 to 3.67 mg/l were detected in the groundwater samples. Co values at site 1 were detected above the Dutch I Values.

Cr values ranging from 0.001 to 0.3 mg/l were detected in the groundwater samples. Cr values at site 1 were detected above the NDWQ and Dutch Reference while Cr values at site 2 were found to be above the Dutch S Values. At site 4, Cr values were above the NDWQ and Dutch I values.

Cu values ranging from 0.001 to 2.39 mg/l were detected in the groundwater samples. Cu values at site 1 were above the selected references while at site 3 Cu values were above the Dutch I for intervention purposes.

Hg values ranging from 0.001 to 1 mg/l were detected in the groundwater samples. Hg values at site 1 were detected above the selected while Hg values at site 2 and site 3 were above the Dutch S Values. Hg values at site 4 were above the Dutch S Values.

Ni values ranging from 0.001 to 0.5 mg/l were detected in the groundwater samples. Ni values at site 1 were above the Dutch I Values for intervention purposes.

Pb values ranging from 0.03 to 2.0 mg/l were detected in the groundwater samples. Site 1, site 2 and site 3 showed Pb values in the groundwater to be above the NDWQ and Dutch I values for intervention.

Zn values ranging from 0.38 to 0.51 mg/l were detected in the groundwater samples which were found to be above the Dutch S Values.

Thus, from the above analysis, it can be summarized that the heavy metals detected in the groundwater are good indicators to be used to assess the level of contamination in the brownfield sites.

3.3. Benchmarking reference of heavy metal contamination for brownfield

A suggested reference was derived from the study to provide a benchmark for remedial actions required to be taken as shown in Table 5.

Heavy Metals	Value In Soil (mg/kg)	Value In Groundwater (mg/l)
As	5	0.05
Cd	10	0.005
Co	5	0.1
Cr	30	0.05
Cu	20	1.0
Hg	0.3	0.002
Ni	20	0.002
Pb	50	0.2
Zn	95	1.5

Table 5 : Suggested reference for benchmarking heavy metal contamination in brownfield for remedial action to be taken

This provides as an alternative reference value for benchmarking soil and groundwater contamination in brownfields which had exposed to contaminants such as industrial pollutant or leaching of metal ions from nearby sources.

3.4. Remediation for heavy metal contamination

Various considerations are to be given after evaluating the contaminants found above the suggested reference derived. Nevertheless, a consistent and common framework is required to address the issues. For this purpose a hierarchy of remedial actions is proposed so that the brownfield site can be redeveloped for other purposes. The remedial techniques involve onsite treatment or offsite treatment as depicted in Fig. 3.

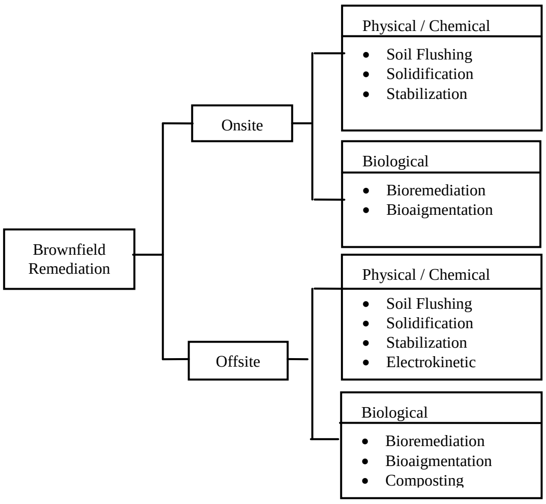

Fig. 3 : Remediation for heavy metal contamination in brownfield

The remediation techniques include physical chemical treatment involving soil flushing and solidification method applicable depending on the heavy metal contaminants found at site. Biological treatment involving bioremediation and bioaugmentation whereby heavy metals are removed by use of microorganism.

4. Conclusions

The study aims to derive reference for benchmarking heavy metals at brownfield sites which serves as a good indicator for heavy metal contamination for the brownfield sites.

Further studies however are to conducted for the brownfield sites as a move towards registration of the brownfield as an additional approach towards sustainable development in Malaysia.

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CHARACTERIZATION OF ACETOGENIC AND METHANOGENIC LEACHATES GENERATED FROM A SANITARY LANDFILL SITE

AIK HENG LEE, HAMID NIKRAZ and YUNG TSE HUNG

Abstract—Decomposition processes take place in landfill generate leachates that can be categorized mainly of acetogenic and methanogenic in nature. BOD:COD ratio computed in this study for a landfill site over a 3 years duration revealed as a good indicator to identify acetogenic leachate from methanogenic leachate. Correlation relationships to predict pollutant level taking into consideration of climatic condition are derived.

Keywords—Acetogenic Leachate, Methanogenic Leachate, BOD:COD Ratio.

I. INTRODUCTION

LANDFILLS are major sources of groundwater and land contamination that can cause adverse impacts to the environment. Perforation of pollutants due to waste disposal which passes through as leachate if not properly handled will diffuse through the landfills and contaminate soils and groundwater if left unchecked. The constituents of leachate can be categorized into four types namely organic matter, inorganic matter, heavy metal and xenobiotic organic compounds [1].

The extent of contamination from the leachate depends on the type of control measures used in landfill. Nevertheless, pollutants in the leachate of different composition have different impacts on the environment. Even under controlled conditions such as those of a well planned and well managed landfill, leachate may percolate or penetrate through natural ground and may still contaminate groundwater and ultimate contaminate fresh water supplies over time. The environmental impact is most significant particularly those landfills without integration of engineering controls such as liners and leachate collection system.

The content of leachate generated from most landfill is subject to several factors such as climatic condition, infiltration and waste type. As leachate percolates through waste strata layers that undergo various decomposition high amounts of both organic matter and inorganic matters are found to be higher than those in groundwater [2]-[3].

Both temperature and water content in landfill will affect the rate of waste decomposition which is usually lower in dry weather condition. Dissolved organic matter in leachate consists of various organic and inorganic constituents. Higher organic matter is anticipated in acetogenic phase whereas inorganic matter is lower in methanogenic phase due to lower dissolved organic matter and higher pH [4]-[8].

Leachate content generated from waste landfill can be broadly categorized as organic matters, inorganic matter, xenobiotic organic compounds and other compounds due to various conditions such as weather, infiltration, gravity drainage and groundwater inflow. The strength of leachate is depend on decomposition processes comprising of biological and chemical reactions which vary from pH and high concentration of biodegradable organic pollutant in early methanogenic phase to high pH and lower concentration of biodegradable organic content in later methanogenic phase.

The purpose of this paper is to study the impact of temperature and precipitation on landfill performance that yield various pollutant removal experiencing both acetogenic and methanogenic phases.

II. MATERIALS AND METHOD

Performance data from a landfill site in Toronto, Canada was evaluated over a period of 3 years to assess the range of pollutant in the leachate. The performance data is depicted in **Table 1**.

The dissolved organic matters were evaluated in terms of BOD (Biochemical Oxygen Demand), COD (Chemical Oxygen Demand) and DOC (Dissolved Organic Carbon). The

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inorganic matters such as ammonia, calcium, chloride, iron, magnesium, sodium and sulfate of the landfill leachate were evaluated and xenobiotic organic compounds such as phenols were also evaluated. Statistical study using regression analysis to establish correlation relationship to evaluate pollutants from landfill that are leached out from this traditional waste landfill using clay liner taking into consideration of basic properties and factors influencing landfill performance include climatic conditions such as temperature and precipitation and also the organic content of leachate in terms of BOD:COD ratio.

TABLE 1
PERFORMANCE DATA OF LANDFILL SITE

Parameter	Year	Month											
		1	2	3	4	5	6	7	8	9	10	11	12
Temperature													
High	1	9	10.5	18.2	25	27.5	31.8	30.5	29.9	29.1	27.2	15	10
	2	18	7.3	12.9	28	24.9	34.6	35.5	34	32	26.1	19.1	4.4
	3	10	6	16	17	33	33	34	36	27	22	16	12
	4	11	4	15	25	29	34	34	35	32	32	15	3
	5	15	6	11.7	23	24.1	30.4	30.0	29.4	29.7	24.4	17.4	6.1
Low	1	-23	-19	-10.3	-7	-2	6.6	11.4	9.3	5.5	0.7	-4.6	-24
	2	-24.2	-15	-14.2	0	-0.4	22.1	12.4	13	6.4	-0.3	-13.3	-15.2
	3	-13	-11	-10	-4	3	8	13	13	5	1	-2	-10
	4	-17	-20	-22	-7	4	7	12	11	5	0	-9	-11
	5	-17	-18.2	-13.4	-3.6	3.1	9.0	12.9	10.9	8.1	-2.1	-9.6	-12.4
Precipitation	1	50.6	22.5	63.2	62.4	98.8	67.5	121.1	60	25.70	35	61	96.6
	2	71.70	69.90	38.30	98.30	14.90	32.50	18.50	139.40	244.30	46.30	104.80	60.10
	3	45.6	45.5	56.9	64.0	66.0	68.9	76.6	84.2	74.2	67.0	70.3	65.5
	4	45.6	45.5	56.9	64.0	66.0	68.9	76.6	84.2	74.2	67.0	70.3	65.5
	5	45.6	45.5	56.9	64.0	66.0	68.9	76.6	84.2	74.2	67.0	70.3	65.5
BOD/COD ratio	1	0.07	0.08	0.10	0.09	0.07	0.06	0.07	0.06	0.07	0.13	0.19	0.15
	2	0.80	0.15	0.59	0.22	0.15	0.08	0.06	0.06	0.10			
	3	0.23	0.11	0.14	0.09	0.13	0.09	0.12	0.08	0.21	0.09	0.09	0.13
	4	0.55	0.12	0.49	0.8	0.28	0.14	0.06	0.09	0.14	0.08	0.1	0.11
	5	0.22	0.12	0.21	0.19	0.49	0.11	0.11	0.09	0.39	0.27	0.28	0.22
Performance Data													
Alkalinity	1	2700	2700	1600	2800	3400	2500	3200	3200	3100	3500	3500	2800
	2	2400	2700	3100	3100	3400	3300	4700	3300	2700	0	0	0
	3	1200	2000	1500	2300	2400	2400	2000	2300	740	1900	2150	1600
	4	1700	1600	1400	2200	3100	3100	3400	3800	2900	3900	3400	2500
	5	2800	3200	2500	2200	2400	2420	1900	1200	1260	1300	980	1570
Ammonia	1	230	270	140	240	330	270	300	330	300	290	320	250
	2	200	200	180	200	340	300	450	370	290	0	0	0
	3	120	212	170	240	270	240	190	220	46.0	190	190	160
	4	140	150	110	200	230	310	320	440	230	380	310	210
	5	360	330	280	210	220	215	299	125	119	92	85	148
BOD	1	31	53	38	53	65	53	55	60	61	160	90	120
	2	120	170	1080	120	140	67	75	59	78	0	0	0
	3	120	78	74	59	110	59	67	58	120	59	50	74
	4	1800	50	430	2500	200	114	60	135	125	100	92	95
	5	545	140	224	118	810	62	60	40	270	100	80	97
COD	1	480	690	410	640	1000	990	800	1000	1000	1300	490	850
	2	150	1200	1840	550	990	830	1230	970	780	0	0	0
	3	540	730	540	680	840	720	580	730	570	660	610	570
	4	3300	450	890	3160	720	850	1000	1500	890	1260	1000	910
	5	2500	1200	1100	628	1680	580	590	470	700	370	290	450
Calcium	1	150	130	170	200	150	178	187	133	112	210	170	243
	2	240	253	641	411	392	275	307	132	155	0	0	0
	3	268	155	117	152	89	117	148	141	261	132	20.8	139
	4	433	144	177	286	225	154	110	130	146	125	120	112
	5	1020	128	135	148	270	162	138	263	213	154	127	165
Chloride	1	580	290	440	640	960	760	833	929	879	886	765	685
	2	627	678	719	660	978	800	1160	630	761	0	0	0
	3	505	573	449	632	681	668	515	640	243	584	569	390
	4	454	360	310	665	759	811	1040	1350	886	1220	990	806
	5	834	990	687	620	868	814	720	438	421	419	386	548
Conductivity	1	6900	7900	4500	6000	7600	7100	6590	7310	7620	8690	7700	6330
	2	5520	5640	33200	33200	49300	8420	12100	10600	8740	0	0	0
	3	4150	5650	4090	5470	5760	5370	5070	5640	3160	5020	5310	4110
	4	4710	3630	3430	6070	6290	7130	8160	11300	7700	10200	8750	6140
	5	7730	8690	6430	5850	7050	6230	5450	3750	3730	3900	3090	4500
DOC	1	1200	190	150	200	380	340	298	320	322	400	280	336
	2	300	287	510	320	600	480	825	645	185	0	0	0
	3	148	126	133	155	277	193	158	152	200	220	160	160
	4	900	120	300	780	280	240	249	410	260	380	300	215
	5	515	350	270	170	600	132	195	120	98	112	89	140
Hardness	1	828	901	762	882	869	914	1010	630	660	1100	920	1040
	2	1070	1140	2110	1530	1580	1300	1560	840	880	0	0	0
	3	1070	730	610	740	660	650	780	740	1050	780	300	610
	4	1680	770	870	1340	1200	1000	930	1050	960	860	970	740
	5	3720	960	980	890	1230	880	740	1020	860	730	520	750
Iron	1	11	25	5.1	3.4	4.5	3.8	4.9	4.86	9.6	2.45	2.57	2.27
	2	3.37	3.12	2.67	2.88	4.12	5.17	6.76	5.92	4.36	0	0	0
	3	4.31	3.37	4.49	7.1	4.8	4.0	4.3	3.9	13.6	5.2	0.67	4.5
	4	14.9	4.6	5.3	17.7	5.7	3.5	2.3	6	14.1	18.6	4.4	2.3
	5	241	2.4	4.4	3.3	10	2.2	2.1	36.9	3.6	1.9	2.67	3
Magnesium	1	110	140	82	93	120	114	132	71.2	91.1	140	121	106
	2	113	122	125	122	146	149	194	125	120	0	0	0
	3	97.6	84.2	77.5	88	107	86	101	95	98	57	59.4	64
	4	144	100	104	151	155	149	160	180	144	132	164	113
	5	280	154	137	127	130	116	97	88	79	83	18.4	82
Nitrate	1	<0.5	<0.5	0.51	<0.3	<1	<0.3	<0.5	<0.3	<1	<0.3	<0.5	<0.3
	2	<0.3	<0.3	<1	<0.5	<1	<0.5	<1	<1	<1	0	0	0
	3	<0.5	<1	<1	<0.5	<2	<2	<2	<2	0.1	<2	<1	<2
	4	<0.5	<1	<1	<2	<2	<2	<2	<2	<2	<2	<2	<2
	5	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Nitrite	1	<1	<0.5	0.45	<0.3	<1	<1	<0.5	<1	<1	<1	<1	<1
	2	<0.5	<0.5	<1	<0.5	<1	<1	<1	<1	<1	0	0	0
	3	<0.5	<1	<1	<0.5	<2	<2	<2	<2	<0.1	<2	<1	<2
	4	<0.5	<1	<1	<2	<2	<2	<2	<2	<2	<2	<2	<2
	5	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
pH	1	6.9	6.9	7.0	6.9	7.2	7	6.9	7.1	6.9	7.03	6.96	7.17
	2	7.13	6.84	7.09	7.23	6.97	6.95	7.59	7.08	6.99	0	0	0
	3	7.66	7.12	7.42	7.21	6.93	7.08	7.07	7.24	6.88	7.25	8.35	7.05
	4	6.99	7.13	6.7	7.32	7.27	7.33	7.35	7.24	7.08	7.74	7.53	7.29
	5	7.06	7.47	7.47	7.47	7.59	7.38	7.48	7.3	7.27	6.82	7.78	7.52
Phenols	1	16	25	9	10	<1	25	64	12	83	203	150	203
	2	195	178	945	247	228	135	292	203	208	0	0	0
	3	48	164	221	142	310	264	271	177	30	87	170	316
	4	428	185	431	528	204	9	76	94	212	19	193	160
	5	321	271	271	261	554	141	116	12	220	100	89	208
Phosphorus	1	1.2	2.2	0.15	1.4	1.5	1.8	1.5	4	1.8	1.8	2.2	4
	2	1.4	1.6	2.2	3.1	4.4	4.6	4	3	40	0	0	0
	3	1.40	1.90	0.80	4.40	4.00	1.80	1.10	1.40	3.00	1.00	0.80	1.20
	4	4	0.9	0.8	1.8	1.3	1.6	1.4	3.1	1.7	3.1	1.8	1.1
	5	1.3	1.7	1.7	2	2.3	2.3	1.7	1.4	0.8	0.8	0.6	1.4
Sodium	1	590	880	440	540	860	833	700	520	582	923	788	631
	2	632	660	609	773	951	769	1360	899	708	0	0	0
	3	416	483	428	453	696	545	524	569	273	380	1020	310
	4	532	425	311	590	662	811	920	1240	979	1151	974	530
	5	888	515	515	550	800	640	550	380	332	230	305	378
Sulphate	1	31	260	130	60	25	9.1	<10	43	120	23	17	29
	2	11	23	<20	8	<20	<10	<20	<20	<20	0	0	0
	3	485	90	102	41	<40	<40	<40	59	427	114	22	<40
	4	408	20	66	90	<40	<40	<40	71	<40	<40	<40	51
	5	111	<40	<40	46	57	<40	<40	117	277	<40	90	111
Total Kjeldahl Nitrogen	1	240	580	170	290	390	300	300	430	320	300	360	520
	2	260	250	220	300	480	400	610	700	408	0	0	0
	3	120	275	300	300	355	280	265	272	110	350	220	320
	4	175	164	157	309	320	368	372	607	335	520	410	270
	5	430	340	340	290	340	350	240	140	120	98	99	200
Total Suspended Solid	1	43	70	27	8	22	16.3	11	17	25	15	11	<1
	2	4	12	44	35	480	16	29	18	14	0	0	0
	3	35	18	20	83	44	30	19	14	190	31	4	25
	4	90	30	60	68	64	18	13	92	32	55	17	9
	5	140	120	120	22	340	24	24	1000	56	41	95	30

III. RESULTS AND DISCUSSIONS

As water passes through waste strata layer in landfill it triggers and activates decomposition due to present of microorganisms. The decomposition can be defined in two phases, firstly soluble organic matter produced due to aerobic decomposition or acetogenic phase and secondly methane and carbon dioxide produce due to anaerobic decomposition or methanogenic phase.

During acenogenic phase microorganisms convert insoluble organic compounds to acetic acid, carbon dioxide and hydrogen by acetogenic bacteria. Leachate generated in the phase typically are characterized by high BOD value, high BOD:COD ratio illustrating a high concentration of soluble organic matters that are biodegradable and pH value that is acidic and high ammonia concentration. Such aggressive nature of leachate prompts dissolution of other components in wastes resulting in high concentration of iron, magnesium, zinc and calcium.

On the other hand, microorganisms in methanogenic phase that can remove soluble organic matter are gradually established due to absence of oxygen. The decomposition in this phase thrives to convert soluble organic matter to methane and carbon dioxide thus release as landfill gas. Methanogenic leachate generated is typically characterized by low BOD value and low ratio of BOD:COD with high concentration of ammonical nitrogen and inorganic matters such as iron, sodium, potassium, sulphate and chloride due to active dissolution.

BOD:COD ratio is thus defined as an indicator for degradation of organic matter that differentiate the acetogenic phrase from methanogenic phase in landfill which trickling leachate. Figure 1 depicts the ratio of BOD:COD spread over the 3 years in the landfill studied.

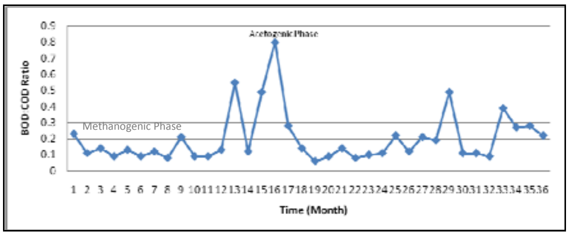


Fig. 1 Ratio of BOD:COD Over 3 Years Duration

The ratio of BOD:COD computed for the landfill exhibited that more than 90% of time leachate in the landfill experienced methanogenic phase.

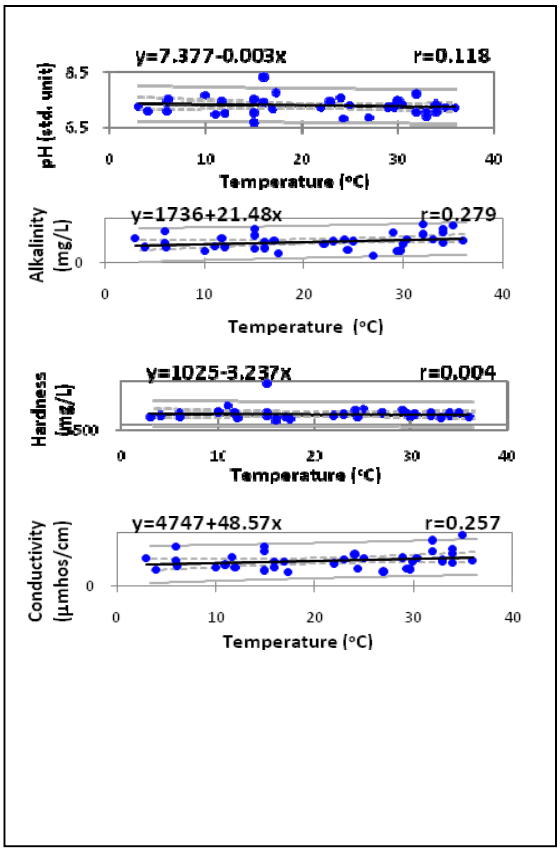
The results of leachate generated containing low ratio of BOD:COD indicate that the decomposition is stabilized and is biological active and is dynamically in equilibrium.

It is reported that the intensity of decomposition is significantly affected by various external forces such as climatic conditions in terms of environmental temperature and precipitation [9].

Correlation relationship of leachate concentration to temperature is evaluated in terms of physical properties of pH, alkalinity, hardness, conductivity and total suspended solid; dissolved organic matters of BOD, COD and DOC; inorganic matters of sulphate, chloride, ammonia, calcium, magnesium, sodium, iron, nitrate, nitrite and Total Kjeldahl Nitrogen and xenobiotic organic compounds of phenols.

From the data evaluation as depicted in Figures 2 to 5, all physical properties (r>0.118) except hardness (r=0.004), all inorganic matters (r>0.100) except iron (r=0.071) and xenobiotic organic compounds of phenols (r=0.200) depict there is some degree of significance of correlation relationship of leachate to temperature in the environment. This can be explained by the active decomposition rate in the waste due to high temperature that facilitates both biological and chemical reaction inside the mass.

Figure 2 Physical Properties of Leachate Versus Temperature



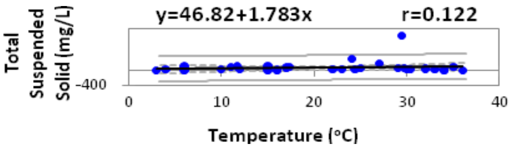


Figure 3 Dissolved Organic Matters of Leachate Versus Temperature

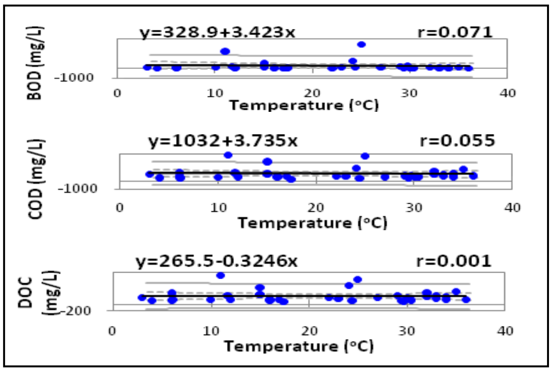
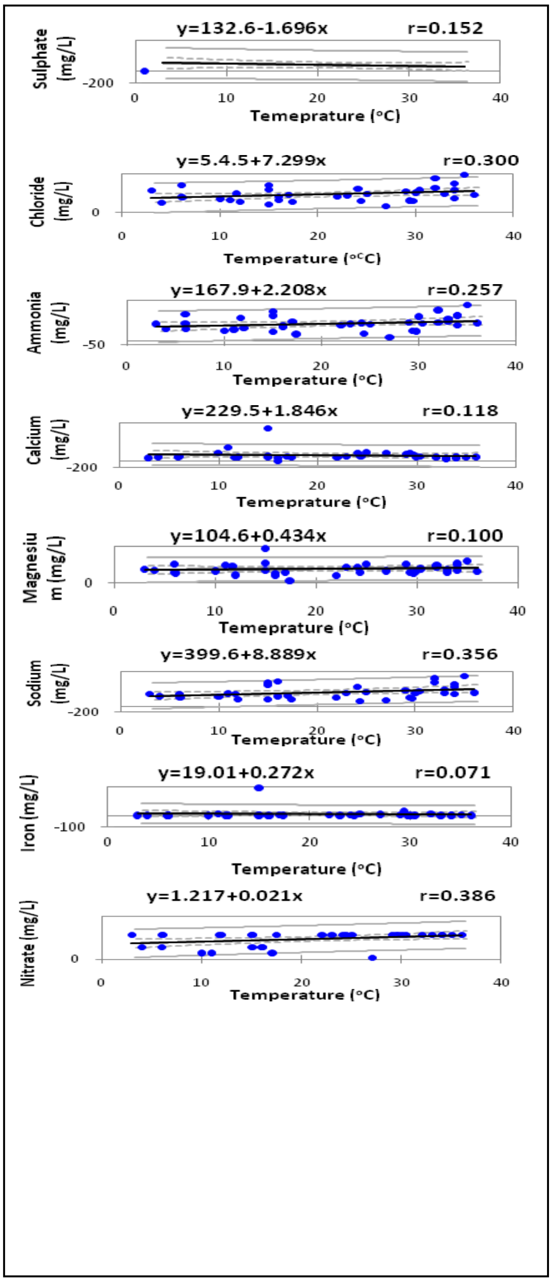


Figure 4 Inorganic Matters of Leachate Versus Temperature



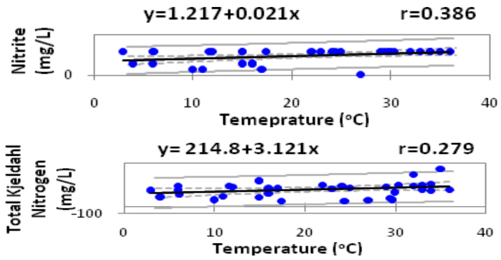
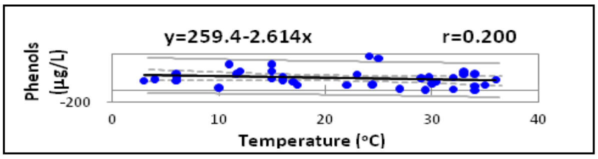


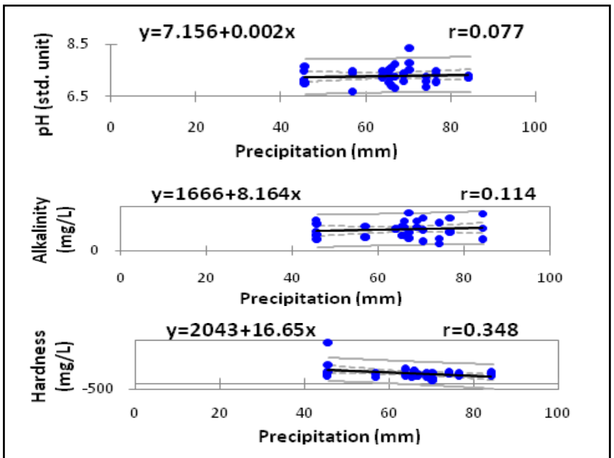
Figure 5 Xenobiotic Organic Compounds of Leachate Versus Temperature



Figures 6 to 9 depict the correlation relationship of leachate concentration to precipitation. Results illustrate that all physical properties (r>0.114) except pH (r=0.077); all dissolved organic matters (r>0.257); all inorganic matters (r>0.118) except ammonia (r=0.077) and xenobiotic organic compound of phenol (r=0.339) are relatively quite correlated to precipitation as excessive precipitation is likely to slow down decomposition rate in the waste environment which leachate is percolated through.

BOD:COD ratio is also evaluated to established the correlation relationship to leachate concentration obtained from the landfill. Figures 10 to 13 depict the correlation relationship of leachate concentration to BOD:COD ratio. Results reveals that all physical properties (r>0.146) except total suspended solid (r=0.045); dissolved organic matters (r>0.633); inorganic matter (r>0.118) except iron (r=0.063) and xenobiotic organic compound (r=0.688) are correlated significantly to BOD:COD ratio computed for the leachate concentration obtained for the landfill in this study.

Figure 6 Physical Properties of Leachate Versus Precipitation



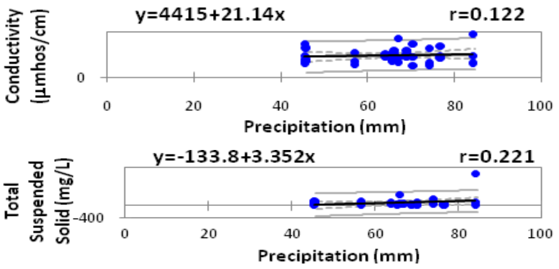


Figure 7 Dissolved Organic Matters of Leachate Versus Precipitation

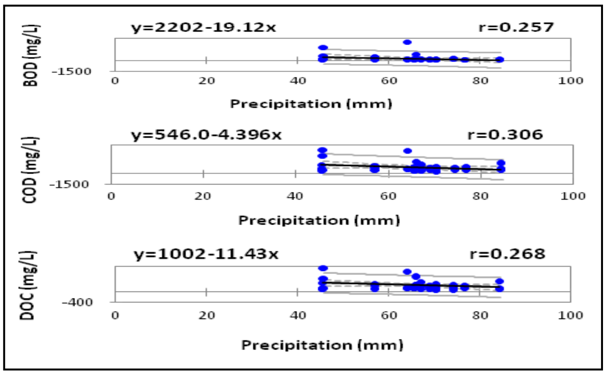
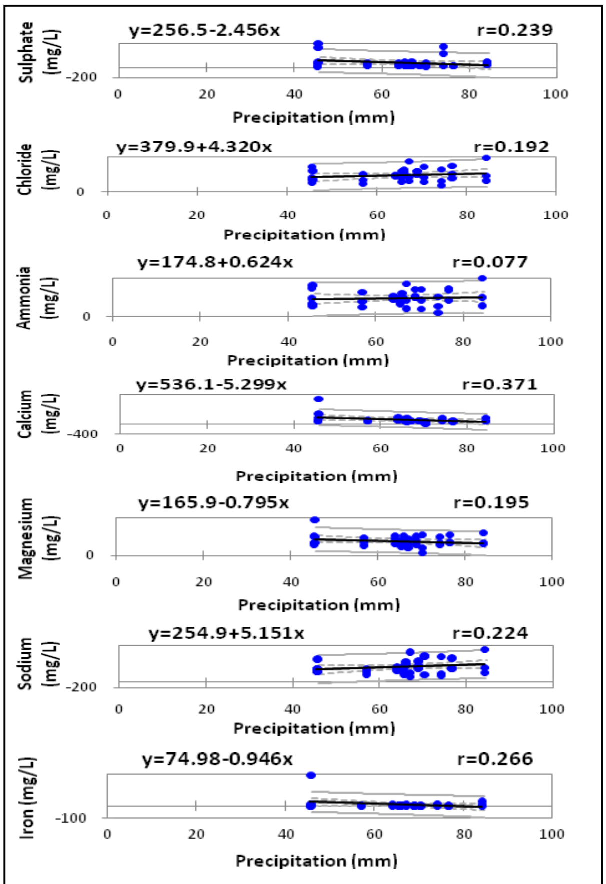


Figure 8 Inorganic Matters of Leachate Versus Precipitation



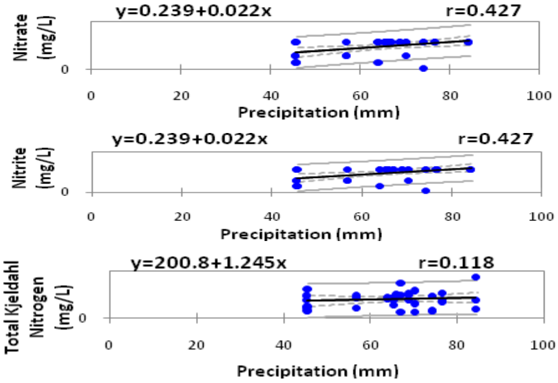


Figure 9 Xenobiotic Organic Compounds of Leachate Versus Precipitation

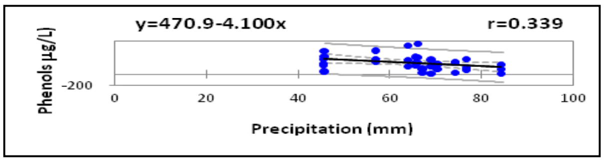


Figure 10 Physical Properties of Leachate Versus BOD:COD Ratio

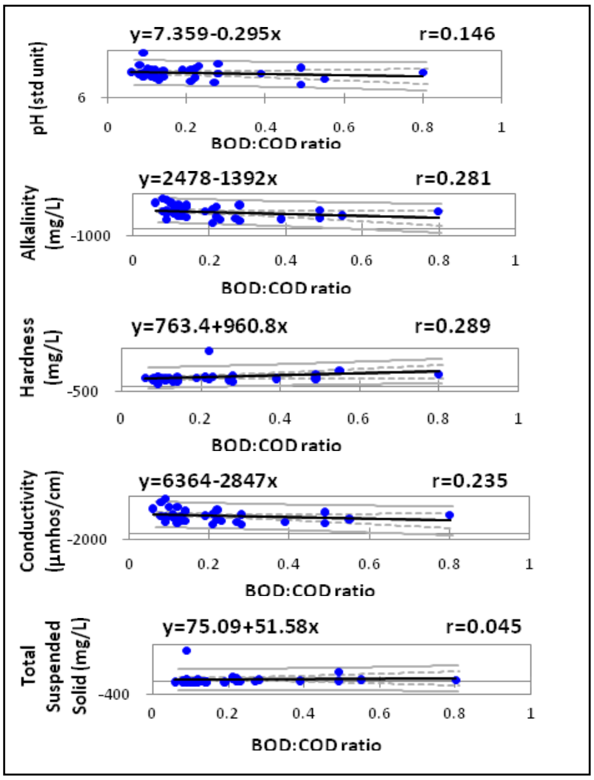
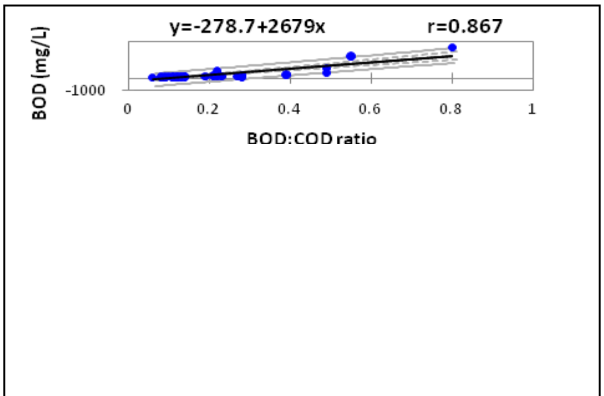


Figure 11 Dissolved Organic Matters of Leachate Versus BOD:COD Ratio



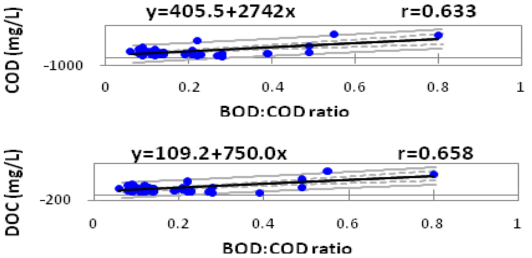


Figure 12 Inorganic Matters of Leachate Versus BOD:COD Ratio

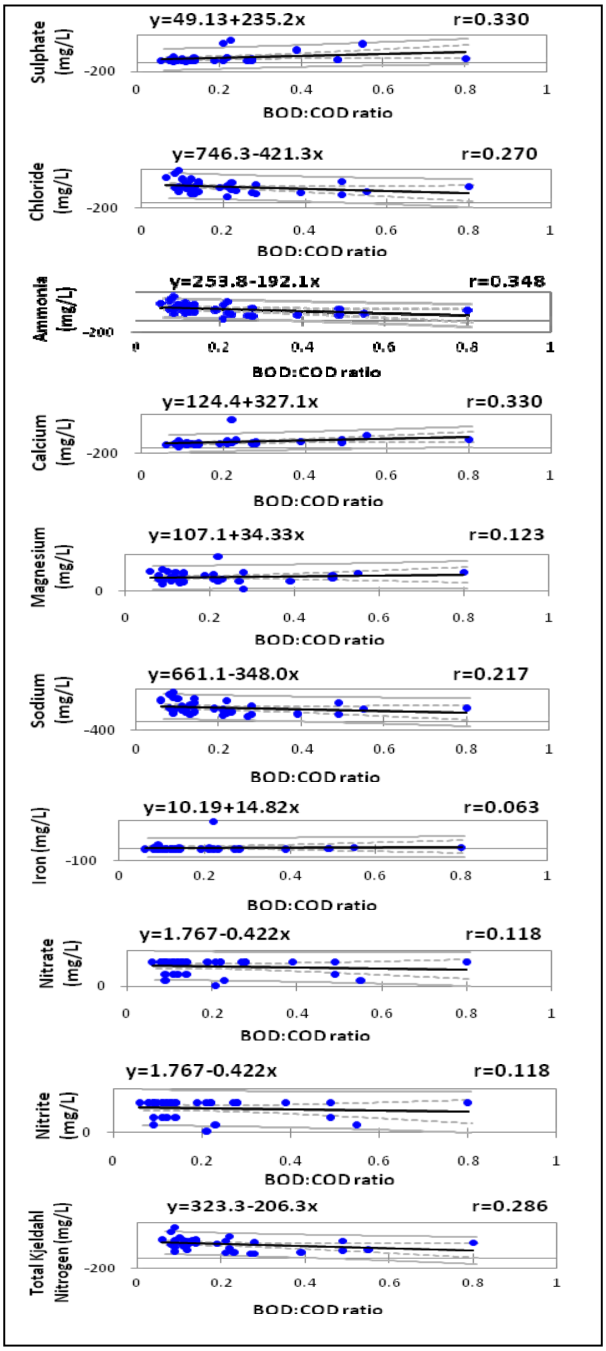
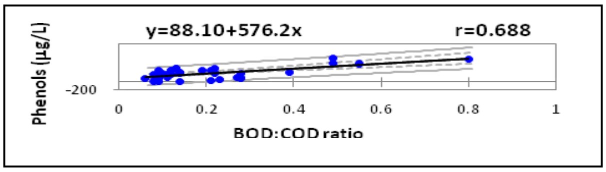


Figure 13 Xenobiotic Organic Compounds of Leachate Versus BOD:COD Ratio



IV. CONCLUSION

The study concluded that in an actively decomposing waste landfill, leachate generated can be characterized as acetogenic and methanogenic and BOD:COD ratio of leachate is a good indicator to illustrate the degree of stabilization in landfill. The BOD:COD ratio of leachate computed indicate if sufficient biological and chemical decomposition as well as biodegradion are carried out under changing ambience conditions in the landfill body. It is referred that decreasing BOD:COD ratio is taken as an indicator of degradion of organic substrate due to decomposition.

Acetogenic leachates are typically characterized by its high BOD value and high BOD:COD ratio due to rapid hydrolysis of insoluble organic matters that make it readily degradable. On the other hands, methanogenic leachates are characterized by its relatively low BOD values and low ratios of BOD:COD due to the active dissolution of soluble organic matters present as well as inorganic matter, sulphate, chloride and calcium.

The study also reveals that the waste decomposition in landfill is influenced by climatic condition such as temperature and precipitation based on correlation relationship established. The intensity of decomposition is observed to be significantly affected by amount of precipitation and the temperature inside the landfill mass. Rises in temperature accelerate decomposition while precipitations slow down decomposition to anaerobic condition.

ACKNOWLEDGMENT

A special acknowledgment of appreciation is given to Mr. George South of City of Toronto Municipality for his assistance given.

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Study Of Carbonaceous And Nitrogenous Pollutants In Leachate Of A Sanitary Landfill Site

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Abstract. The characteristics of leachate from a mature landfill site were investigated over a period of six years to provide useful information for the design and management of landfill leachate. Data analysis revealed that low carbonaceous and nitrogenous pollutants can be achieved with proper groundwater and surface water management and also recirculation of leachate to control stabilization of decomposition in the waste layers.

Keywords: carbonaceous pollutants; nitrogenous pollutants; landfill leachate and decomposition

1. Introduction

Leachate is typically generated from a landfill deposited with waste contain wide spectrum of composition of pollutant both dissolved and suspended. As precipitation percolating through the landfill, water once in contact becomes contaminated however is assisted by decomposition of bacteria and fungi present in turn release by products of decomposition and rapidly consume any available oxygen. This biodegradation process utilize major portion of organic matter contained in the waste. This rapid decomposition cause temperature to rise and pH to fall which many metal ions normally relatively insoluble at neutral pH become dissolved.

Under normal condition of aerobic stage follow by anaerobic stage, carbonaceous organic removal is essentially completed and residue carbonaceous matters that are non-biodegradable which change the composition producing a wide range of other matters include complex mixture of organic acids, alcohols, simple sugar, carbon dioxide and other.

As carbonaceous concentration in leachate decreases ammonia nitrogen concentration increases resulting from the hydrolysis and fermentation of nitrogen containing fraction of biodegradable matters. This is followed by nitrification of ammonia nitrogen when a significant portion of non-ammonia nitrogen is readily converted usually measured as nitrogen concentration such as TKN.

The environmental risk posed due to leachate generation can be mitigated by properly designed and engineered landfill site such as lying of impermeable liners made of geotextiles or engineered clays that reduce the release of pollutants in order to meet sustainability requirement. Landfill configuration and leachate quality generation have been reported in numerous technical reports [1]-[4].

The purpose of this paper is to study the characteristic of carbonaceous and nitrogenous pollutant contain in leachate of a sanitary landfill site taking into consideration of operating condition such as climatic condition.

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2. Material and Method

The leachate data used in this study was obtained from the performance results of a landfill site at Toronto over a period of 6 (six) years spread from 2004 to 2009. The leachate composition was typical of a mature landfill. The landfill is deposited with wastes of solid, non-hazardous, industrial, commercial and institutional waste from municipalities and business.

The carbonaceous organic matters were evaluated in terms of BOD (Biochemical Oxygen Demand), COD (Chemical Oxygen Demand) and DOC (Dissolved Organic Carbon). The nitrogenous organic matters were evaluated in terms of TKN (Total Kjeldahl Nitrogen), ammonia, nitrite and nitrate.

Other inorganic matters such as calcium, chloride, iron, magnesium, sodium sulfate and xenobiotic organic compounds such as phenols were also evaluated.

Characteristic of both carbonaceous and nitrogenous content are analyzed in term of maximum and minimum value with mean ($\bar{\chi}$) and standard deviation (σ) obtained over the period of six years taking into consideration of influential factors such as climatic conditions.

3. Results and Discussion

Several technical studies have been reported on leachate quality but most are varied within range due to different magnitude of consideration taken [5]-[8]. This variability in leachate quality has caused the prediction of leachate quality over function of time difficult.

In this study, landfill that is designed with an engineered hydraulic trap as shown in Figure 1 to contain and collect leachate to minimize groundwater impact. It is also equipped with surface water management. Leachate recirculation is practiced with the intention to control waste decomposition thus make the prediction of leachate quality more readily. This is particularly important to ensure moisture movement through the waste layer especially to stimulate effect on methanogenesis.

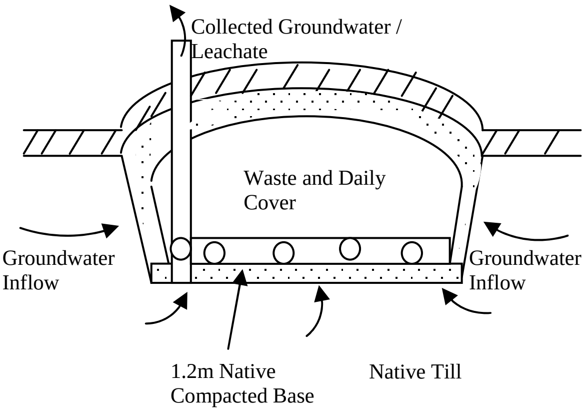

Figure 1 Landfill with Hydraulic Trap

Over the six years period of analysis, the climate of moderate rainfall ranging from 25.7 to 244.3 mm as depicted in Figure 2 tend to produce relatively low pollution levels compared to most reported values in leachate of other landfill. It is thus suggested that moisture content due to relatively moderate precipitation appear to have adverse impact to leachate quality. The moisture serves also as a good reactant in the hydrolysis reaction in landfill.

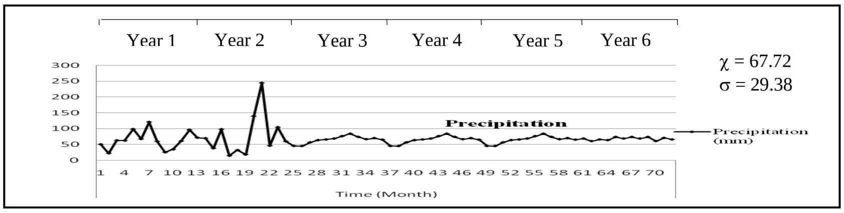

Figure 2 Precipitation Over The Study period

Generally, leachate is generated due to precipitation percolating through the waste layers deposited and became contaminated within the landfill where a series of reaction physically, chemically and biologically are taken place. The mechanism of these reactions however reduce the complexity of leachate eventually remove from the landfill.

The wide range of composition found in the leachate is mainly attributed to the decomposition of carbonaceous material by acetogenic bacteria converting insoluble to soluble organic matter and methanogenic bacteria converting soluble organic matter to methane and carbon dioxide. Like most mature landfill site, the organic matter removal is essentially completed which is characterized by relatively low values of BOD, COD and DOC. As depicted in Table 1 and Figure 3, minimum value of BOD, COD and DOC of 31, 150 and 54 mg/l with mean values of 250.4, 986.2 and 320.8 mg/l respectively were achieved. Peak values of BOD, COD and DOC of 2600, 3430 and 1340 mg/l were however observed due to hydraulic instability. The low concentration of carbonaceous organic matter, especially in term of BOD and COD, is likely caused by the effect of dilution. Another effect is also likely due to stimulation of methanogenesis as can be supported by the increase pH value throughout the period.

TABLE 1

Carbonaceous Pollutant Concentration In The Leachate

Parameter	Maximum value	Minimum Value	Mean	Standard Deviation
BOD (mg/l)	2600	31.0	250.4	503.8
COD (mg/l)	3430	150.0	986.2	833.8
DOC (mg/l)	1340	54.0	320.8	243.1
BOD/COD Ratio	0.8	0.06	0.19	0.17
pH	8.35	6.57	7.22	0.29

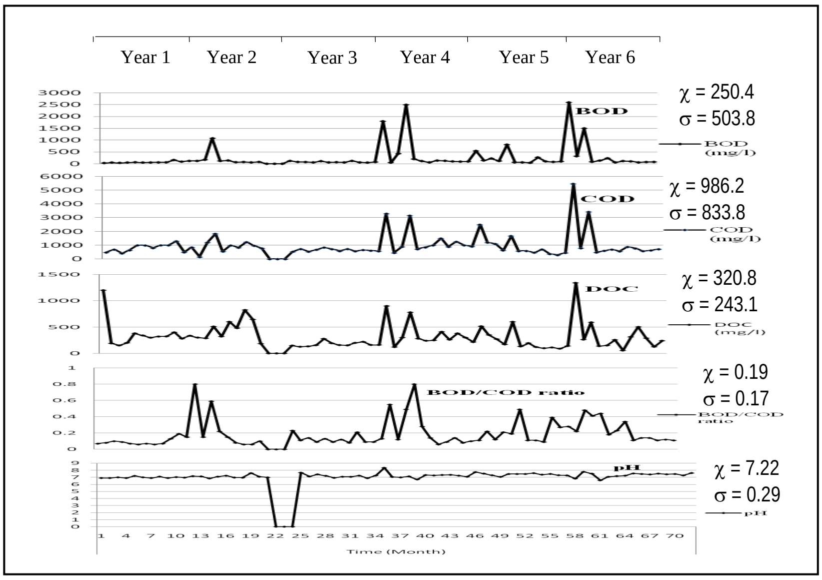

Figure 3 Carbonaceous Pollutant Concentration In The Leachate

It is also observed that low BOD/COD ratios of mostly less than 0.1 were achieved as depicted. The BOD/COD ratio is found to be most reliable and useful to relate the organic matter composition in leachate. Typical range of BOD/COD ratios of 0.02 to 0.80 is reported with averages of 0.58 and 0.06 for acetogenic and methanogenic respectively [6]. Over the study period, BOD/COD ratios in the range of 0.06-0.8 are observed. The results reflects that low biodegradability of the organic matter in the leachate is attained as BOD is a measurement for biological content thus BOD/COD ratio is an indicator of biologically degradable organic matter to total organic matter. It is anticipated that low BOD/COD ratio in leachate made subsequent biological treatment not effective.

As the organic concentration decreases in the leachate, ammonia nitrogen concentration increases caused high activity of nitrification in the waste bed especially in the mature landfill. It is also reported that ammonia nitrogen in the range of 50-2200 mg/l with average of 740 mg/l can be found in leachate composition [6].

Table 2 depicts the low value of nitrogenous matter in term of ammonia, nitrite and TKN of 46, 0.3, 0.3 and 98 mg/l with mean values of 238.8, 1.462, 1.394 and 313.4 mg/l respectively however with peak values of 450, 2, 2 and 700 mg/l.

TABLE 2

Nitrogenous Pollutant Concentration In The Leachate

Parameter	Maximum value	Minimum Value	Mean	Standard Deviation
Ammonia (mg/l)	450	46.0	238.8	82.0
Nitrite (mg/l)	2	0.3	1.462	0.629
Nitrate (mg/l)	2	0.3	1.394	0.707
TKN (mg/l)	700	98.0	313.4	121.9

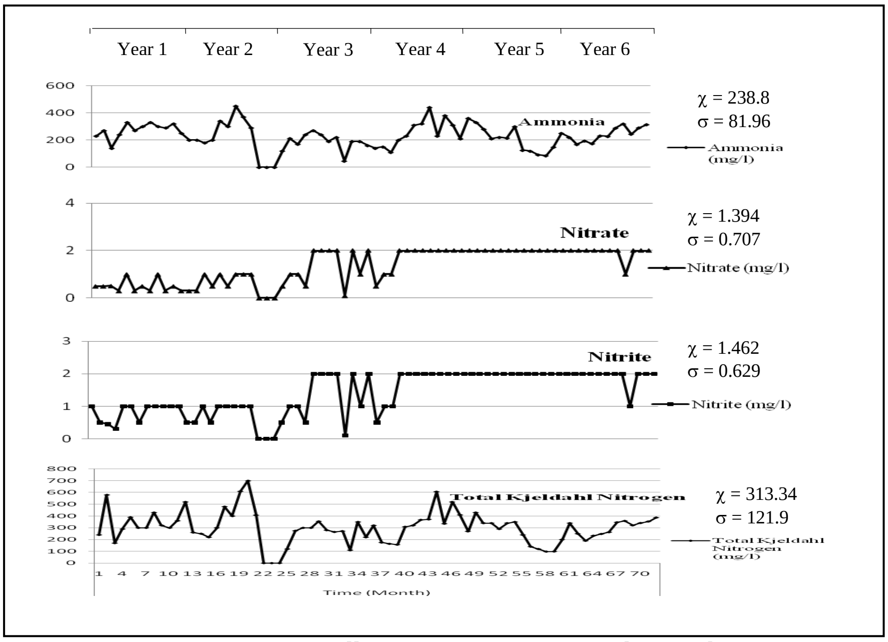

Figure 4 Nitrogenous Pollutant Concentration In The Leachate

Due to diffusion effect through some unbroken matter in the waste layer, ammonia nitrogen is anticipated to be occurred at higher concentration as compared to carbonaceous concentration such as COD that demand large amount of oxygen.

In this active decomposing waste layer of landfill, pH falls and non-conservative constituents in leachate such as metal ions which are relatively insoluble at neutral pH can become dissolved in the leachate except conservative constituents like chloride, sulfate and other residue of decomposition. These values are depicted in Table 3 and Figure 5. The results also reveal that with decrease in organic matter in the leachate, more non-biodegradable residues are released in the leachate.

TABLE 3

Other Pollutant Concentration In The Leachate

Parameter	Maximum value	Minimum Value	Mean	Standard Deviation
Calcium (mg/l)	1020	20.8	224.6	146.2
Chloride (mg/l)	1350	243.0	687.7	217.3
Iron (mg/l)	241	0.67	9.348	28.91
Magnesium (mg/l)	280	18.4	115.2	36.58
Sodium (mg/l)	1360	230.0	633.3	231.6
Sulfate (mg/l)	485	9.1	81.75	111.4
Phenol (mg/l)	945	1.0	220.9	200.3

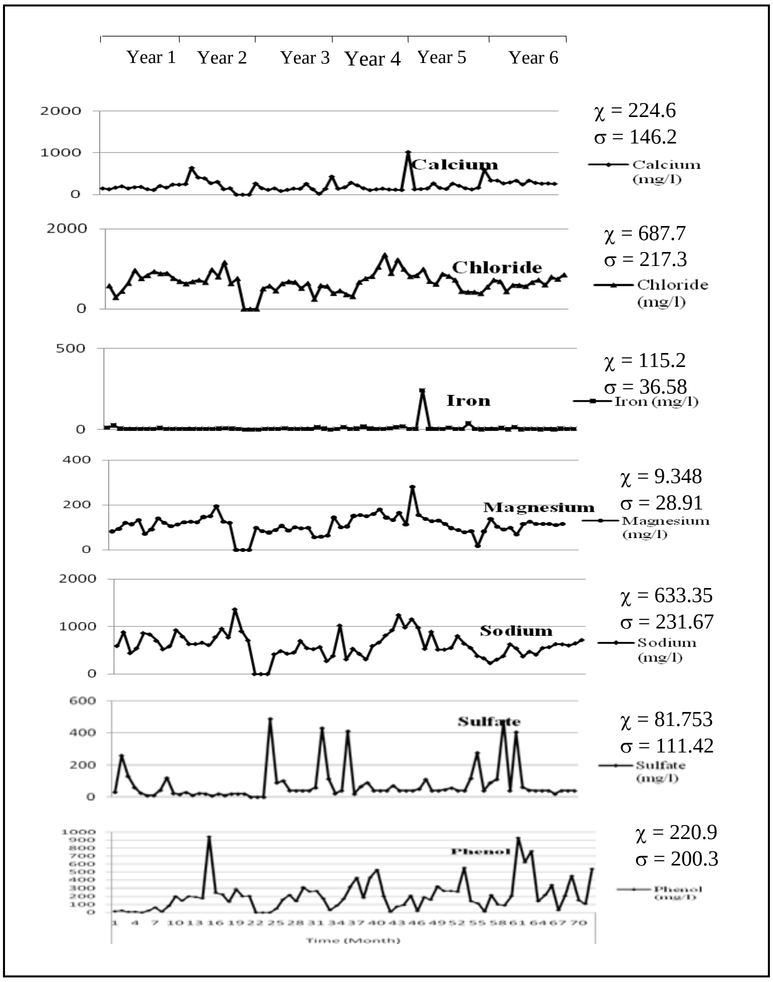

Figure 5 Other Pollutant Concentration In The Leachate

In general, mixed leachates from a mature landfill are anticipated to undertake various stages of decomposition particularly change from early acetogenic condition where high organic strength leachate are generated to later methanogenic stage where these organic matters are actively converted to landfill gas. It is also inferred that the recirculation of leachate at the landfill is likely put decomposition of waste under better control thus made leachate characteristics more predictable.

4. Conclusion

It is concluded that study on a well control landfill site can provide useful information for the design and management of landfill leachate that made prediction more realistic for future trends. Moisture is also attributed as the most significant factor to ensure waste stabilization. Proper operational control to ensure water balance by leachate recirculation couple with climatic precipitation is important consideration for landfill to produce good leachate quality.

5. Acknowledgements

A special acknowledgment of appreciation is given to Mr. George South of City of Toronto Municipality for his assistance given.

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Effect Of Temperature On Performance Of A Sanitary Landfill

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***Abstract*-The effect of temperature on the characteristic of leachate from a mature landfill site was investigated over a period of six years to evaluate the impact of climatic temperature on quality of leachate generated. Results of the study revealed that the leachate quality is affected by climatic temperature due to its impacts to bacterial growth and chemical reaction in the waste mass of landfill.**

Keywords: temperature, leachate, sanitary landfill, bacterial growth, chemical reaction

I. INTRODUCTION

Leachate can be generated by several potential sources include gravity drainage, ponded water, rain, infiltration and groundwater inflow. Leachate generation that caused water pollution was not gaining much attention until 1965 when leachate causing harmful impact to water course was studied in depth (1-4).

Leachate percolateing waste above groundwater and table causes contaminant to migrate to groundwater. The transfer of contaminants is subject to a combination of physical, chemical and biological processes from the waste to the percolating leachate and thus made composition of leachates from different waste fills having similar characteristics (5-6).

Leachate temperature in landfill is affected by climatic temperature due to fluctuation of ambient temperature as temperature poses impact to bacterial growth and chemical reaction. Bacterial growth is constraint by particular individual bacterial optimum growth temperature and any temperature change will retard growth due to its enzyme deactivation and cell wall rupture. Beside this, temperature also poses impact to solubility of many compounds to increase or decrease that affect the quality of leachate. It is also reported that numerous compounds in leachate such as $CaCO_3$ and $CaSO_4$ show decrease in solubility as temperature increase (7-10).

The purpose of this paper is to study the effect of temperature on quality of leachate generated from a sanitary landfill.

II. MATERIAL AND METHOD

The leachate data used in this study was obtained from the performance results of a landfill site at Toronto over a period of 6 (six) years spread from 2004 to 2009. The leachate composition was typical of a mature landfill. The landfill is deposited with wastes of solid, non-hazardous, industrial, commercial and institutional waste from municipalities and business.

The parameters were evaluated in terms of pH, TSS (Total Suspended Solids), BOD (Biochemical Oxygen Demand), COD (Chemical Oxygen Demand) and DOC (Dissolved Organic Carbon), TKN (Total Kjeldahl Nitrogen), ammonia, nitrite and nitrate.

Characteristic of leachate are analyzed statistically in term of linear regression on performance data obtained over the period of six years.

III. RESULT AND DISCUSSION

In this study, landfill that is designed with an engineered hydraulic trap as shown in Figure 1 to contain and collect leachate to minimize groundwater impact.

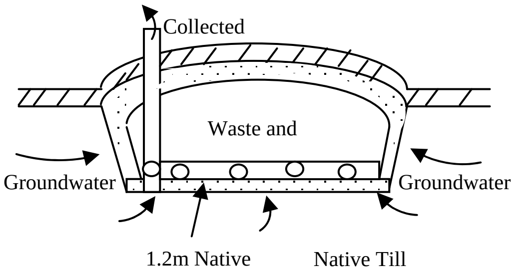
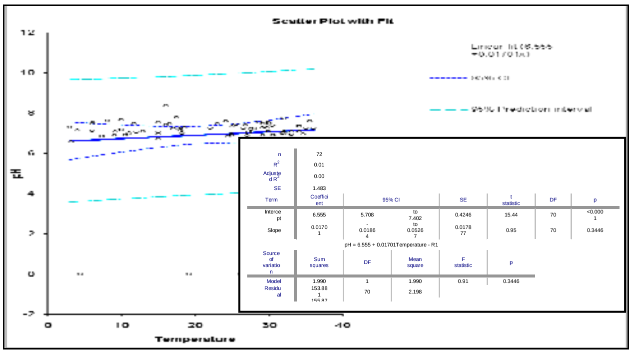


Figure 1 Landfill with Hydraulic Trap

Correlation relationship of leachate concentration to temperature is evaluated in terms of pH, TSS, BOD, COD, DOC, ammonia, nitrate, nitrite, TKN and phenols.

From the analysis as shown in Figure 2, the equation for a straight line forced through the data with pH = 6.555 + 0.01701 Temperature. The r^2 value also depicts that 10% of the total variation about the pH mean is explained by the regression line. The confidence interval for the slope show that with 95% confidence the data value for the slope lines somewhere between -0.01864 to 5.708.



n	72
R^2	0.01
Adjusted R^2	0.00
SE	1.483

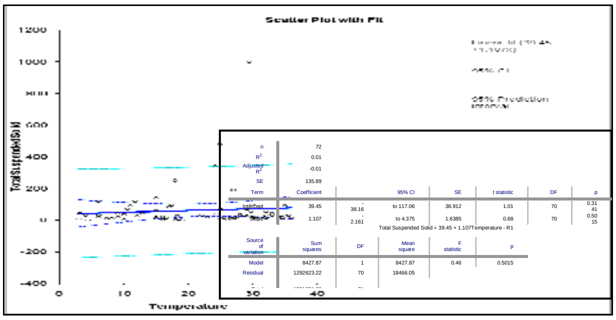
Term	Coefficient	95% CI	SE	t statistic	DF	p
Intercept	6.555	5.708 to 7.402	0.4246	15.44	70	<0.0001
Slope	0.01701	-0.01864 to 0.05267	0.017877	0.95	70	0.3446

pH = 6.555 + 0.01701Temperature - R1

Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	1.990	1	1.990	0.91	0.3446
Residual	153.881	70	2.198		

Figure 2 pH of Leachate Versus Temperature

The correlation of TSS to temperature is shown in Figure 3 with the equation of TSS = 39.45 + 1.107 Temperature. The r^2 value obtained shows 10% of the total variation about the temperature mean is explained by the regression line. The confidence interval for the slope shows that 95% confidence extend from – 2.161 mg/L to 117.06 mg/L



n	72
R^2	0.01
Adjusted R^2	-0.01
SE	135.89

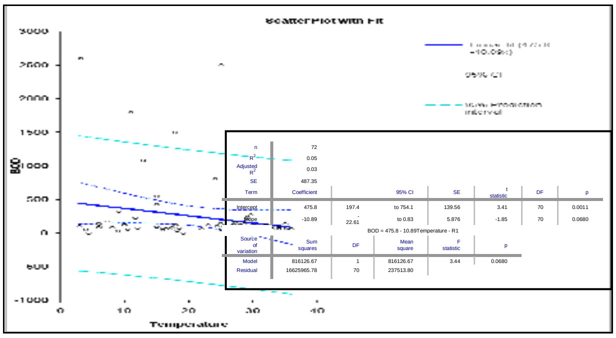
Term	Coefficient	95% CI	SE	t statistic	DF	p
Intercept	39.45	-38.16 to 117.06	38.912	1.01	70	0.3141
Slope	1.107	-2.161 to 4.375	1.6385	0.68	70	0.5015

Total Suspended Solid = 39.45 + 1.107Temperature - R1

Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	8427.87	1	8427.87	0.46	0.5015
Residual	1292623.22	70	18466.05		

Figure 3 Total Suspended Solid of Leachate Versus Temperature

Figure 4 depicts the correlation of BOD to temperature illustrating the equation of BOD = 475.8 – 10.89 Temperature. The r^2 value shows that about 30% of the total variation about the temperature mean is explained by the regression line. The confidence interval for the slope shows that with 95% confidence the data value for the slope lines somewhere between 197.4 mg/L to 754.1 mg/L. The correlation coefficient was statistically high and significant different from zero. The negative value indicates that there is an inverse relationship between BOD and temperature i.e. higher temperature show a lower BOD value.



n	72
R^2	0.05
Adjusted R^2	0.03
SE	487.35

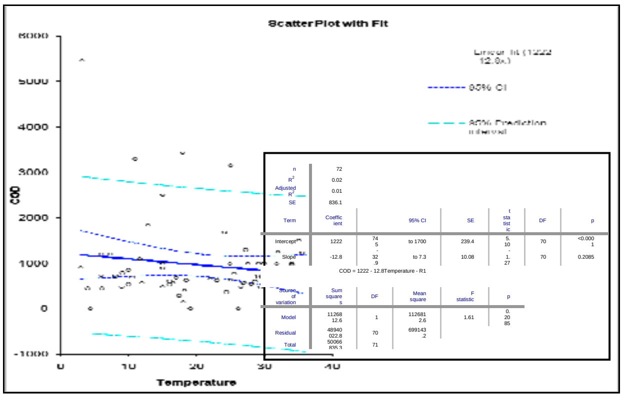
Term	Coefficient	95% CI	SE	t statistic	DF	p
Intercept	475.8	197.4 to 754.1	139.56	3.41	70	0.0011
Slope	-10.89	-22.61 to 0.83	5.876	-1.85	70	0.0680

BOD = 475.8 - 10.89Temperature - R1

Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	816126.67	1	816126.67	3.44	0.0680
Residual	16625965.78	70	237513.80		

Figure 4 BOD of Leachate Versus Temperature

The correlation of COD to temperature shows likewise to BOD correlation to temperature as depicted in Figure 5. The equation of COD = 1222 – 12.8 Temperature with r^2 of 20%. The confidence interval spread from 745 mg/L to 1700 mg/L. Negative slope also illustrate an inverse relationship between COD and temperature.



n	72
R^2	0.02
Adjusted R^2	0.01
SE	836.1

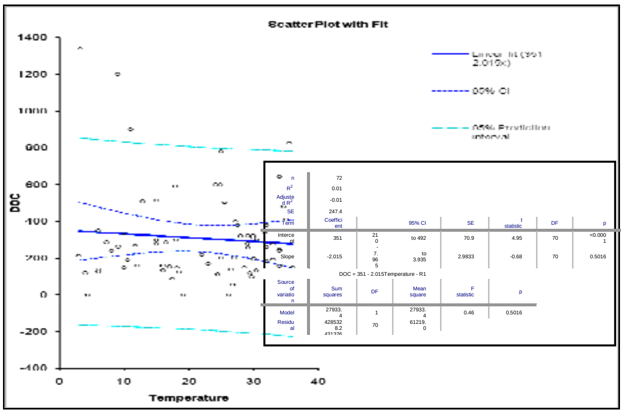
Term	Coefficient	95% CI	SE	t statistic	DF	p
Intercept	1222	745 to 1700	239.4	5.10	70	<0.0001
Slope	-12.8	-32.9 to 7.3	10.08	-1.27	70	0.2085

COD = 1222 - 12.8Temperature - R1

Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	1126812.6	1	1126812.6	1.61	0.2085
Residual	48940022.8	70	699143.2		
Total	50066835.3	71			

Figure 5 COD of Leachate Versus Temperature

Figure 6 again illustrate the similar trend like BOD and COD for correlation of DOC to temperation. The equation of DOC = 351 – 2.015 Temperature is obtained with r^2 value of 10%. The 95% confidence interval spread form 210 mg/L to 492 mg/L with negative correlation coefficient reveal that there is an inverse relationship to lower DOC values at higher temperature.



n	72
R^2	0.01
Adjusted R^2	-0.01
SE	247.4

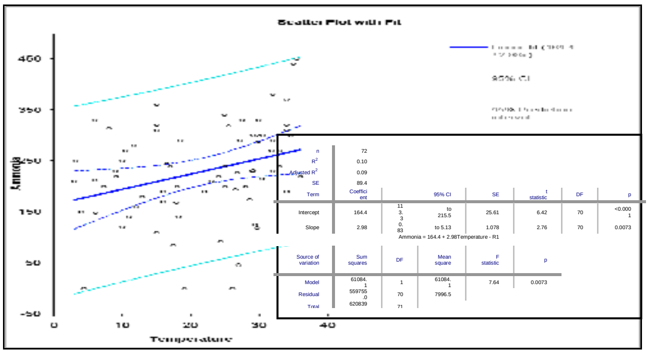
Term	Coefficient	95% CI	SE	t statistic	DF	p
Intercept	351	210 to 492	70.9	4.95	70	<0.0001
Slope	-2.015	-7.965 to 3.935	2.9833	-0.68	70	0.5016

DOC = 351 - 2.015Temperature - R1

Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	27933.4	1	27933.4	0.46	0.5016
Residual	4285328.2	70	61219.0		

Figure 6 DOC of Leachate Versus Temperature

Figure 7 depicts the correlation of ammonia to temperature. The equation obtained is Ammonia = 164.4 + 2.98 Temperation with r^2 value of 10%. The 95% confidence interval spreads from 113.3 mg/L to 215.5 mg/L.



n	72
R^2	0.10
Adjusted R^2	0.09
SE	89.4

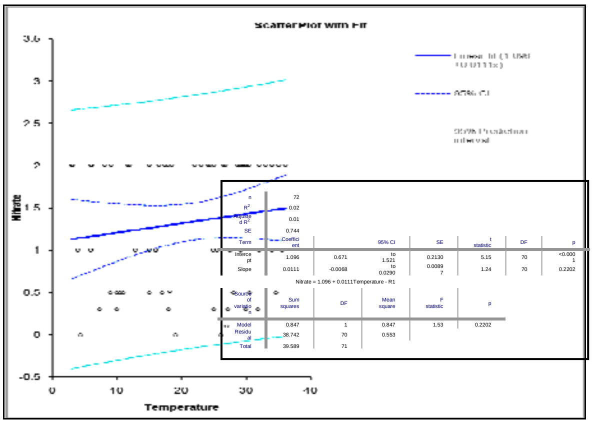
Term	Coefficient	95% CI	SE	t statistic	DF	p
Intercept	164.4	113.3 to 215.5	25.61	6.42	70	<0.0001
Slope	2.98	0.83 to 5.13	1.078	2.76	70	0.0073

Ammonia = 164.4 + 2.98Temperature - R1

Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	61084.1	1	61084.1	7.64	0.0073
Residual	559755.0	70	7996.5		
Total	620839	71			

Figure 7 Ammonia of Leachate Versus Temperature

The correlations of nitrate and nitrite in the leachate to temperature are shown in Figures 8 and 9 respectively. The equations obtained are Nitrate = 1.096 + 0.0111 Temperature and Nitrite = 1.154 + 0.0114 Temperation with r^2 values of 2% and 3% respectively. The respective 95% confidence interval spreads between 0.671 mg/L to 1.521 mg/L and 0.767 mg/L to 1.541 mg/L. Also, the correlation equation of TKN = 219.8 + 3.72 Temperation is obtained with r^2 values of 7%. The 95% confidence interval spreads between 145.1 mg/L to 294.5 mg/L.



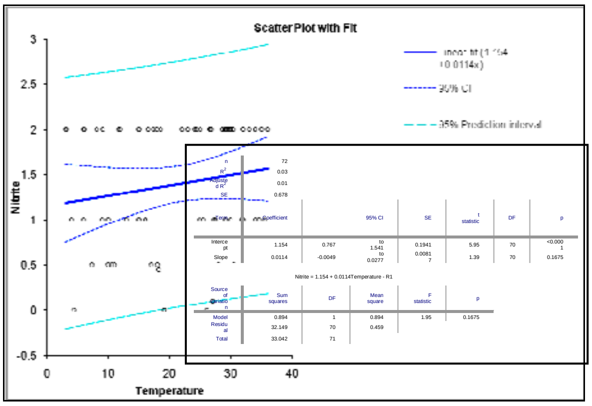
n	72
R^2	0.02
Adjusted R^2	0.01
SE	0.744

Term	Coefficient	95% CI		SE	t statistic	DF	p
Intercept	1.096	0.671	to 1.521	0.2130	5.15	70	<0.0001
Slope	0.0111	-0.0068	to 0.0290	0.00897	1.24	70	0.2202

Nitrate = 1.096 + 0.0111Temperature - R1

Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	0.847	1	0.847	1.53	0.2202
Residual	38.742	70	0.553		
Total	39.589	71			

Figure 8 Nitrate of Leachate Versus Temperature



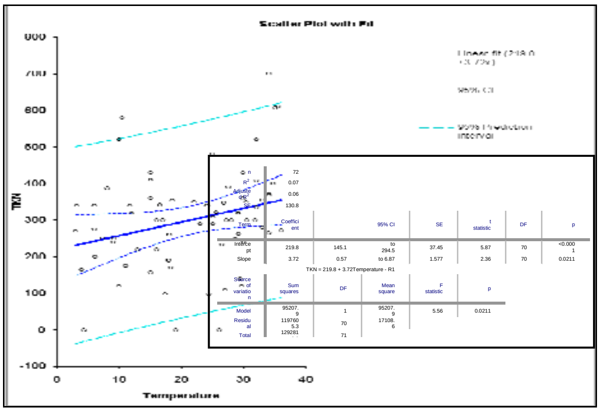
n	72
R^2	0.03
Adjusted R^2	0.01
SE	0.678

Term	Coefficient	95% CI		SE	t statistic	DF	p
Intercept	1.154	0.767	to 1.541	0.1941	5.95	70	<0.0001
Slope	0.0114	-0.0049	to 0.0277	0.00817	1.39	70	0.1675

Nitrite = 1.154 + 0.0114Temperature - R1

Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	0.894	1	0.894	1.95	0.1675
Residual	32.149	70	0.459		
Total	33.042	71			

Figure 9 Nitrite of Leachate Versus Temperature



n	72
R^2	0.07
Adjusted R^2	0.06
SE	130.8

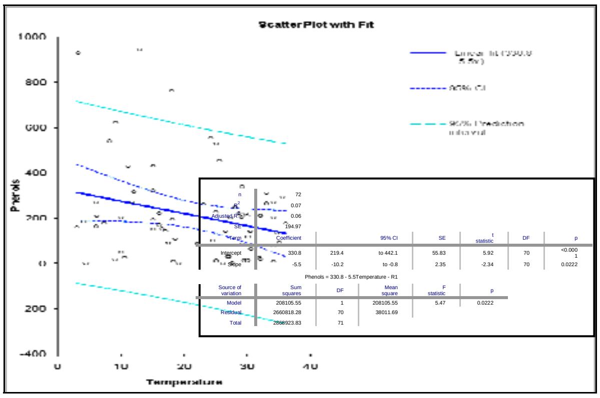
Term	Coefficient	95% CI		SE	t statistic	DF	p
Intercept	219.8	145.1	to 294.5	37.45	5.87	70	<0.0001
Slope	3.72	0.57	to 6.87	1.577	2.36	70	0.0211

TKN = 219.8 + 3.72Temperature - R1

Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	95207.9	1	95207.9	5.56	0.0211
Residual	1197605.3	70	17108.6		
Total	129281	71			

Figure 10 Total Kjeldahl Nitrogen of Leachate Versus Temperature

Figure 11 depicts the correlation of Phenol = 330.8 – 5.5 temperation with r^2 value of 7%. The 95 confidence interval spreads from 219.4 mg/L to 442.1 mg/L.



n	72
R^2	0.07
Adjusted R^2	0.06
SE	194.97

Term	Coefficient	95% CI		SE	t statistic	DF	p
Intercept	330.8	219.4	to 442.1	55.83	5.92	70	<0.0001
Slope	-5.5	-10.2	to -0.8	2.35	-2.34	70	0.0222

Phenols = 330.8 - 5.5Temperature - R1

Source of variation	Sum squares	DF	Mean square	F statistic	p
Model	208105.55	1	208105.55	5.47	0.0222
Residual	2660818.28	70	38011.69		
Total	2868923.83	71			

Figure 11 Phenols of Leachate Versus Temperature

From the data evaluation as depicted in Figures 2 to 11, all properties evaluated with $r^2>0.1$ revealed that there is some degree of significance of correlation relationship of leachate to temperature in the environment. This can be explained by the active decomposition rate in the waste due to high temperature that facilitates both biological and chemical reaction inside the waste mass.

IV. CONCLUSION

Leachate generation in sanitary landfill is a complex combination of physical, chemical and biological processes whereby climatic condition particularly temperature has impact to performance of landfill that generate leachate. The result of study reveals that temperature is largerly an incontrollable factor that influenced leachate quality of the sanitary landfill mainly due to temperature reaction on bacterial growth and chemical reaction in the waste mass.

V. ACKNOWLEDGEMENTS

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