# PHYSICOCHEMICAL ASSESSMENT OF LEACHATE AND BIOGAS GENERATION POTENTIAL IN LANDFILL SITES OF NEPAL

A PhD Dissertation

Submitted in partial fulfilment of the requirements for

the Doctor of Philosophy degree in Environmental Science

By

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## DEDICATION

("Dedicated to my parents")

#### DECLARATION

I, Bikash Adhikari, hereby declare that the work presented herein is genuine work done originally by me and has not been published or submitted elsewhere for the requirement of a degree programme. Any literature, data or works done by others and cited within this dissertation has been given due acknowledgement and listed in the reference section.

Signature

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## CERTIFICATION

Title of the dissertation: **Physicochemical Assessment of Leachate and Biogas Generation Potential in Landfill Sites of Nepal** by Er. Bikash Adhikari, under the supervision of Professor Dr. Sanjay Nath Khanal, DESE, Kathmandu University, Dhulikhel, Nepal is

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#### ABSTRACT

Leachate analysis is one of the vital aspects of landfill operation and management. However very limited studies are found conducted in Nepal in this regards. The fact that the existing literature has not examined major concern like physicochemical constituents which have caused major problems in making leachate treatment plants operational – all the plants are non-functional – speaks out why further study is required in Nepal. Understanding of the constituents in terms of their age, functionality, waste characteristics and seasons will generate data which in turn will prove useful to construct treatment plants based on the type of MSW site. This study is focused on qualitative characteristics of leachate and its variation due to age, functionality, seasons and feeding amount. Similarly the study of biogas generated from MSW site is significant from methodological perspective. Existing studies in Nepal have deployed ultimate analysis. The present study uses proximate analysis for estimating potential biogas generation.

The objective of this research was to study the qualitative aspects of landfill leachate and to estimate potential biogas and energy generation from landfill sites. Leachate parameters were quantified in relation to seasons, waste composition, functionality and ages of landfill sites (LFS). The studied landfills were Sisdole (operational and intermediate age), Aletar (closed and young age), Pokhara (operational and intermediate age), Dang (operational and intermediate age) and Gokarna (closed and mature age) landfill sites of Nepal. Gas estimates were calculated for three operational landfills namely Sisdole, Dang and Pokhara. Leachate and waste samples were collected at 2 months interval for a year. Samples were collected on March, May, July, September, November of 2013 and January of 2014 from all studied sites. 1 litre leachate sample from the leachate collection pond and four trenches at each landfill were collected on the standard sampling bottles each time. Waste sample of 100 kg from 3 vehicles at Dang, 5 at Pokhara and 7 at Sisdole LFS was taken at each sampling time. Composition study of the waste was done using the waste reduction method on site. The wastes were segregated as organic waste, plastics, paper, glass, rubber/leather, textile, metal, construction and demolition waste and others. The fractional minute particles remained after the compositions were sampled for proximate analysis. Proximate analysis of the solid waste was done for moisture content and volatile solids percentage. Total Nitrogen was measured using Kjeldahl Digestion method. Organic matter was estimated using Walkley and Black method in which the organic matter / carbon in the sample was determined by wet oxidation method. C:N ratio was also calculated. Through moisture content and volatile solids biogas generation potential was calculated using MATLAB software.

pH, DO and temperature were measured in field. 5ml conc.HNO<sub>3</sub> was used for the preservation of metals and Chloride was used to preserve COD of the sample. Leachate samples were collected from the same locations at every sampling time. BOD, COD, BOD/COD ratio, Fe, Cu, Pb, Zn, Cd, Cr, Hg, Ni, Cl, Ca, NH<sub>3</sub> and H<sub>2</sub>S were analyzed according to APHA - 2012. Data were assembled into four seasons namely pre-monsoon (March, April, May), monsoon (June, July August), post-monsoon (September, October, November) and winter seasons (December, January, February) of Nepal using Principle Component Analysis (PCA). A One way ANOVA tool was used in SPSS to analysis the data obtained from lab analysis. The results were presented in terms of age, functionality and seasons.

The organic component of wastes was found high as 61.6%, 52.5% and 65% at Sisdole, Pokhara and Dang LFS respectively. The pH value ranged from 6.5 to 8.7 in studied sites. Highest pH was found in Gokarna and lowest at Pokhara. The BOD and COD value ranged from 85.2 mg/L to 1046 mg/L and 969.4 mg/L to 9153.2 mg/L respectively in studied sites. Highest BOD was found in Dang and lowest at Gokarna. Highest COD was found in Pokhara and lowest in Gokarna. The concentration of iron ranged from 0.96 – 5.28 mg/L in studied sites. Highest concentration was found in Sisdole and lowest in Gokarna. The concentration of Cu, Pb, Ni and Zn were ranged from 0 – 0.5 mg/L in all studied sites in all seasons whereas concentration of Hg, Cr and Cd were almost not detectable. The concentration of Ca ranged from 94 – 454.9 mg/L. The yearly average amount of NH<sub>3</sub> were found to be 69.035 mg/L, 99 mg/L, 108.08 mg/L, 130 mg/L and 23.75 mg/L in Aletar, Dang, Pokhara, Sisdole and Gokarna respectively. Highest concentration was found in Pokhara and lowest in Gokarna. The yearly average amount of H<sub>2</sub>S ranged from 18 - 105.25 mg/L. Highest concentration was found in Sisdole and lowest in Gokarna.

Seasonally, pH was significantly difference in all sites except Gokarna which is closed and mature LFS. Gradual increase of pH from pre-monsoon to winter seasons and as per age was observed. BOD and COD significantly decrease from pre-monsoon to winter seasons in all except in Gokarna. It could also be due to increased age of the landfill too. Concentration of BOD and COD was higher where the amount of organic waste content was higher. BOD/COD ratio was 0.02 (mature) to 0.3 (young). Low ratio reflects the low biodegradability in landfills. Among metals and heavy metals, concentration of Fe decreases from premonsoon to winter. This could be due to increased age of landfill and increased pH as seasons changes. Others metals like Ni, Pb and Zn were detected in young and intermediate aged LFS.

For old aged LFS, concentration of Fe, Cu, Cr, Hg, Ni, Pb, Cd and Zn were within the threshold values recommended by WHO (2012) guidelines. These parameters were leachout earlier as this landfill is running in stabilization phase. H<sub>2</sub>S and NH<sub>3</sub> were high in intermediate than in young and mature aged LFS with no seasonal variation in all LFS. High H<sub>2</sub>S signifies higher anaerobic decomposition. High NH<sub>3</sub> signifies the ammonification process in LFS. It can be concluded that age, seasonal variation, waste characteristics and feeding amount of the sanitary landfills had great effects on the quality of formed landfill leachate. Compared to the standard set by WHO (2012), all the physicochemical components except pH were observed to have significantly high value in young and intermediate aged LFS. In contrast to other researchers, the concentration of leachate in young aged but closed LFS behaves likes intermediate aged leachate. As the concentration of contaminants in the leachate is found to be high, fresh landfill leachate is recommended to use treatment prior to disposal. Characterization of the unprocessed leachate is the fundamental step leading to the selection of efficient treatment techniques. The present study found biological treatment methods to be effective for freshly produced leachate under the condition that the concentration of the metals suffices for the growth of microorganism. The results obtained have high concentration of the metals and metal ions as compared to the metals concentration threshold of inhibitory effect on heterotrophic organisms' growth. It can be concluded that due to the concentration of heavy metals in young, intermediate and operational landfill is not suitable for the biological treatment as primary treatment units. First municipality's authorities or plants operators need to bring the concentration of metals and accordingly operators can go for the biological treatment.

Yearly average value of moisture content for Sisdole, Pokhara and Dang Landfill Site were 69.03%, 85%, 82% respectively. The moisture content is high in monsoon seasons in all LFS and these values were seasonally significantly difference (P < 0.05). The volatile solids ranged from 39.63% - 44.41% in studied sites. Dang has highest value of volatile solid and Pokhara has the lowest value. Average value of volatile solids for Sisdole, Pokhara and Dang LFS were 44.41%, 39.63%, 58.47% respectively. The difference was statistically insignificant (p > 0.05) in different seasons within the same LFS. Values of C:N ratio of Sisdole, Pokhara and Dang landfill site were 18.82, 19.03 and 19.62 respectively. The difference was statistically insignificant (p > 0.05). An equation was developed for biogas generation. Biogas generation in lit/kg/day can be expressed as; ((1-( $\alpha$ )/ $\beta$ ) ( $\gamma$ )/ $\beta$  \* Biogas Yield) Where  $\alpha$  = moisture %,  $\beta$  = 100 (scale coefficient) and  $\gamma$  = volatile solids %. The biogas potential at these landfill sites were 12158 cum, 852 cum and 169 cum of biogas per day in Sisdole, Pokhara

and Dang LFS respectively. 4.68, 0.33 and 0.07 MW energy per day can be generated from these amounts of biogas produced in Sisdole, Pokhara and Dang LFS respectively. It was found that there is high possibility of production of biogas in Sisdole, Pokhara and Dang landfill sites. Proper gas collection system can be the source of income from these landfill sites and help to mitigate the adverse impact of methane that is being released from these landfill sites.

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## LIST OF ACRONYMS

ADB	Asian Development Bank
AEPC	Alternative Energy Promotion Centre
ALFS	Aletar Landfill Site
ANOVA	Analysis of Variance
BOD	Biological Oxygen Demand
СВО	Community Based Organization
COD	Chemical Oxygen Demand
DLFS	Dang Landfill Site
DMG	Department of Mines and Geology
EIA	Environment Impact Assessment
EPA	Environmental Protection Agency
EP	Extraction Procedure
FAO	Food and Agriculture Organization
FC	Field Capacity
GLFS	Gokarna Landfill Site
HDPE	High Density Polyethylene
HELP	Hydrologic Evaluation of Landfill Performance
IAP	Integration Action Plan
IEE	Initial Environmental Examination
IFS	International Foundation for Science
KMC	Kathmandu Metropolitan City
KU	Kathmandu University
LFS	Landfill Sites
MATLAB	Matrix Laboratory
MLSS	Mixed Liquor Suspended Solids Volatile
MLVSS	Mixed Liquor Volatile Suspended Solids
MoEST	Ministry of Environment, Science and Technology
MRF	Material Recovery Facilities
MSW	Municipal Solid Waste
NARC	Nepal Agriculture Research Center

NESS	National Environment and Scientific Services
PCA	Principle Component Analysis
PLFS	Pokhara Landfill Site
PWS	Phases of Waste Stabilization
PWP	Permanent Wilting Point
SCS	Soil Conservation Services
SHC	Saturated Hydraulic Conductivity
SIDA	Swedish International Development Agency
SLFS	Sisdole Landfill Site
SRB	Sulphate Reduction Bacteria
SWM	Solid Waste Management
SWMRMC	Solid Waste Management and Resource Mobilization Center
SWMTSC	Solid Waste Management and Technical Support Center
TCLP	Toxicity Characteristic Leaching Procedure
USDA	United States Department of Agriculture
VDC	Village Development Committee
VFA	Volatile Fatty Acid
VOA	Volatile Organic Acid
WP	Wilting Point
XOC	Xenobiotic Organic Compound

#### Chapter 1

#### **INTRODUCTION**

### 1.1 General

Solid waste is the discarded or useless solid materials produced in a given area and time. Solid waste is a relative term. The same things or materials can be the waste for one and resource to the other. Solid waste is the function of time and individual. Solid wastes are waste materials that are not recycled, that remain after processing at a material recovery facility (MRF), or that remain after the recovery of conversion products and/or energy (ADB, 2013). Human settlements, industrial, institutional and commercial areas as well as agriculture activities are the major sources of the solid waste. From primal society, living beings have used the resources of the earth for survival and dispose of wastes. In early times, the disposal of wastes did not create a significant problem, because the population was small and the amount of land available for the assimilation capacity was large (Manandhar et al., 2014). Indications of recycling may still be seen in the primitive, yet sensible, agricultural practices in many of the developing nations where farmers recycle solid wastes for fuel or fertilizer values (Hoornweg, 2012). The quantity and the frequency of the waste generation go with the rise in the population of any area. Ten years ago there were 2.9 billion urban residents who generated about 0.64 kg of MSW per person per day (0.68 billion tonnes per year) in world (Manandhar, 2015). The World Bank and Asian Development Bank (ADB) have estimated that by the end of 2014 these amounts have increased to about 3.02 billion residents generating 1.2 kg per person per day (1.31 billion tonnes per year) (ADB, 2013). By 2025 this will likely increase to 4.3 billion urban residents generating about 1.42 kg/capita/day of municipal solid waste, about 2.2 billion tonnes per year (Hoornweg, 2012). Over 95% of this waste is disposed off in landfills, open dumps, on riverbanks, directly into the sea, or just combusted on site because of insufficient waste collection and final disposal systems. Meanwhile Europe and industrialized countries go for high-tech solutions (e.g. modern incineration technologies) (Manandhar, 2015). There is still a huge demand for proper landfilling in developing countries and country like Nepal. Facing the accelerated generation of solid waste caused by an ever-increasing population, migration from countryside, urbanization, and industrialization, the problem has become one of the primary environmental issues in low and middle-income Asian countries (Adhikari et al., 2014). The refuse produced by the urban dwellers is comprehensibly heterogeneous. The city communities produce both organic and inorganic waste. However, the garbage resulting from agriculture and industrial

activities are more homogeneous in nature (Adhikari et al., 2013). Issue of waste comes up with health and environmental concerns. The ill-managed or unmanaged solid waste threatens human health and environment. Environmental and health risks associated to open dumping are related to release of methane, carbon dioxide and other gases to the atmosphere, settlings and risks of avalanches, leachate generation and risks of surface and groundwater pollution and offensive odour. Those are also the reasons that put landfilling in the bottom of the waste management hierarchy in the industrial world. However, there is no feasible alternative to landfilling in developing countries (Vasanti et al., 2008). In a short and middle term perspective, landfilling is likely to be the most appropriate and cost-effective final disposal option for solid waste in developing countries (Vasanti et al., 2008). The indiscriminate littering and improper waste handling causes variety of complications that results in impurity of water, festering of pests and rodents, which carries various diseases (Adhikari et al., 2013). Lack of proper solid waste management pollutes surrounding environment, threatens human health and status of quantic creatures (Vasanti et al., 2008). Despite the possible safety hazards from fire or explosion due to the gas formed in the landfill site or waste dump, the lack of proper waste management also increases greenhouse gas (GHG) emissions thereby contributing to climate change. The proper disposal of the collected waste in landfill is the only solution of above mentioned problems (Mohajeri et al., 2010).

#### 1.1.1 Solid Waste Generation in Nepal

Nepal is situated in the Himalayan belt has a geometric growing population with high urbanization rate. Factors like lack of proper solid waste management practices, leakage of hazardous substances to soil and surrounding aquatic systems, and health problems are causing problems connected to municipal solid waste (MSW). There are differences in waste generation and composition within and between urban areas and semirural areas of Nepal. The baseline survey conducted by the solid waste management and technical support centre (SWMTSC), Nepal in support of Asian Development Bank (ADB) in 2011 generated that an average per capita household waste generation rate of 0.17 kg/capita/day. The same study also uncovered that the household waste generation rates vary with the economic status and climatic conditions in Nepal. Households in Terai municipalities generate nearly 80% more waste than those in mountain region municipalities (ADB, 2013). It is estimated that waste from households in general contributes about 50%–75% whereas institutional and commercial contribution is 20%- 40% of the total MSW generated in Nepal (ADB, 2013). From ADB (2013) report data analysis reveals waste composition as organic waste 66%, followed by plastics 12%, and paper and paper products 9%. The average MSW generation was found to

be 0.317 kg/capita/day. MSW generation in municipalities of Nepal was estimated at about 1,435 tons/day and 524,000 tons/year (ADB, 2013). This indicates great potential for producing leachate in landfill sites of Nepal as landfill leachate depends upon the waste composition (Adhikari et al., 2014). At present in Nepal out of 191 municipalities only 6 municipalities have landfill sites. At these six landfill sites there is provision of leachate collection and leachate treatment but plants are not functioning at all. These cause the serious health and environmental problems in nearby areas, streams and rivers. This study aims at analysis the qualitative aspects of leachate produced in some existing landfill sites of Nepal and to explore its potential for biogas generation. Investigations were conducted from different landfill sites for one year period. Based on the study, some leachate treatment options and potential for biogas generation are recommended.

#### **1.2 SWM Acts and Regulations**

Government of Nepal prepared Solid Waste Management and Resource Mobilization Act, 2044 (1987 AD) and was passed and enforced in 1987 AD. Several amendments and other several acts were enforced in Nepal. National policy on solid waste management was prepared on 1996 which aimed for tackling the emerging problems related to solid waste management raised from urbanization and changing city. The policy deals with waste management in municipal and urban areas. This policy is still active. The main objectives of this policy are to make solid waste management simple and effective, to minimize the impact of solid waste on environment and public health, to convert solid waste as resource, to include private sector participation in solid waste management, and to improve public participation by increasing public awareness on sanitation.

On 1997, Environment Protection Act (EPA) 1997 and the Environment Protection Rules (EPR), 1997 have enforced Initial Environmental Examination (IEE) and Environment Impact Assessment (EIA) legally binding to the prescribed projects. The Act (Section 7) prohibits any type of pollution created by the projects that may cause significant adverse impacts on the environment, or any such act that is likely to be hazardous to public and people's health, or any act that disposes or causes to be disposed sound, heat, radioactive rays and wastes from any mechanical devices, industrial enterprises, or other places contrary to the prescribed standards. Government of Nepal on 15th June 2011 AD has enforced Municipal Waste Management Act 2011 (2068 BS) to amend and consolidate the laws relating to solid waste by minimizing solid waste generation at source, re-using & processing the waste and providing for proper disposal of the solid waste. The objectives of the Act are to maintain clean and

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healthy environment by minimizing the adverse effects of solid waste on public health and the environment. All responsible for construction, operation and management of infrastructures for collection, transportation, treatment and final disposal of solid waste, including construction of transfer stations, treatment plants, etc. has been provided to Metropolitan City/Municipality/VDC.

#### **1.3 Justification for Study**

Landfilling and incineration are the most common methods of MSW disposal in high income countries. In low income countries, on the other hand, reliable quantitative and qualitative data on the disposal methods are inadequate; and open dumping prevails as the most common practice. The practice of MSW disposal largely falls under the later type. Open dumping and the direct dispose of solid waste into the river system can be seen commonly. Given that safe and reliable long-term disposal of solid waste residues is an important component of integrated waste management, failure to manage the waste properly will seriously pollute the environment. The future consequences are likely to be more acute because of rapid urbanization and subsequent increase in the number of municipalities. The increase in landfill for the disposal of municipal solid waste demands examination of various facets related to the management. Two major by-products from the MSW disposal sites, namely leachate and biogas demand special attention. For landfill management and operation, effective leachate and gas management is a most. However, in most cases such arrangement are not made and even if present, they are not or partially functional. So generation of scientific information on leachate quality and the understanding of different influencing factors help operation and management of new landfill sites as well as upgradation of existing ones (Oman and Junestedt, 2008). Like in other developing countries, municipal wastes comprise mostly organic matters along with other constitute depending upon economic status and life style of the concern population. Literature reviews prevails that (Renou et al., 2008, Bialowiec et al., 2012, Bashir et al., 2010 and Akinbile et al., 2012) parameters of leachate are one of major concern and their characteristics and patterns are to be understood for suggesting effective landfill sites operation and management. In this context, this study focuses on those concerned physicochemical leachate parameters based on waste composition and feeding; changes due to seasons and functionality status are also investigated. Similar studies were also conducted in Malaysia (Aziz et al., 2004), France (Tabet et al., 2002), South Korea (Cho et al., 2002), Hong Kong (Li et al., 2001), Sri Lanka (Kamaruddin et al., 2013). In Nepal, leachate quality studies are very limited. Most studies in Nepal focused on Quantification of leachate and waste composition. So far only, Manandhar (2015), Panthee, (2008), CKV

(2002) studies could be documented in leachate quantification, waste composition and impact of leachate on water sources respectively and in general they do not cover aspects mentioned above. Renau et al., (2008) has concluded that for BOD, COD greater than 1000 mg/L, biological treatment plant is the best option. Similarly Cokgor et al., (2009) have resolved that the concentration of the metals in leachate must be between 0.1 to 1 mg/L to maintain proper F:M ratio for biological treatment. Furthermore Fafizul and Alamgir (2012) have stated that the type of leachate treatment plants depends upon leachate composition. The fact that the existing literature has not examined major concern like physicochemical constituents which have caused major problems in making leachate treatment plants operational – all the plants are non-functional – speaks out why further study is required in Nepal. Therefore there is a distinct gap of scientific information on understanding the leachate quality and its treatment in Nepalese context. Understanding of the constituents in terms of their age, waste characteristics and seasons will generate data which in turn will prove useful to construct treatment plants based on the type of MSW site (Mojiri et al., 2014). Hence the study is proposed to study the leachate composition in terms of age, functionality, seasons and feeding amount. It is assumed that one prototype of treatment plant will not serve different field sites having different characteristics (Mojiri et al., 2014). However, understanding of physicochemical parameter of leachate from different field sites will be helpful for a viable leachate treatment system.

The study of biogas generated from MSW site is significant from methodological perspective. Existing studies in Nepal have deployed ultimate analysis of solid waste in which biogas generation from MSW site is calculated from carbon, hydrogen, nitrogen, sulphur and oxygen content in MSW (AEPC, 2014). Chance of error in ultimate analysis is high because of numerous parameters required for the study (Igoni et al., 2007). On top of that, ultimate analysis demands for a complex procedure. Hence a suitable alternative analysis method could be more useful for biogas generation estimate in Nepalese landfills. Some researchers (Gil et al., 2006 & UWM, 2012) have highlighted moisture content and volatile solids influence the biogas generation in landfills. Therefore the present study also uses analysis of moisture content and volatile solids in landfills for potential biogas generation. In the context when a single approach has been dominant when a widely accepted alternative approach has been in practice, the data generated from this approach might provide insights for further considerations.

### 1.4 Objective of the Research

The main objective of this research is to have knowledge on leachate quality in different landfill and potential for biogas generation from waste with energy. The outcome of the analyses will be used to evaluate and predict the landfill performance and will also be useful to study design and operation of landfills in Nepalese context and recommend the design options.

The specific objectives are as follows:

- To investigate the leachate quality in different ages and status (operational and closed) of landfill sites
- To study the influence of waste composition, seasonal variation and landfill characteristics on leachate quality
- > To evaluate biogas generation potential from landfill

### **1.5 Scope of Research**

The present research focuses on two major by-products generated during decomposition of MSW in landfill sites i.e. leachate and biogas. Characteristics of landfill leachate vary depending upon a number of variables like composition, depth, decomposition, degree of compaction, landfill design and operation, liner (top and base) design and operation, filling procedures, obtainability of moisture content, accessible oxygen, rate of water movement and temperature of MSW (El-Fadel et al., 2002), this study examines MSW sites with reference to age, seasons, waste characteristics and functionality. This study, based on five different landfills sites –Dang, Pokhara, Sisdole, Aletar and Gokarna – focuses on leachate quality according to age, functionality, waste composition and seasonal variation.

Additionally, the three MSW sites namely Sisdole, Pokhara and Dang are selected to analyse bio gas generation capacity because of the fact that these sites are operational. This will generate information about waste to energy relation in different ages of landfill sites.

#### Chapter 2

#### LITERATURE REVIEW

#### 2.1 Water Balance and Leachate in Landfills

Leachate is the liquid that extracts solutes, suspended solids or any other component of the wastes as it passes through different layers of landfill. Leachate differs in composition according to the age of landfill and the type of the waste that it contains (Adhikari et al., 2014). The rate of the production of the leachate can be found out by performing the value of a water balance. The water balance includes all the sources of water entering and leaving the landfill site, water used for the biochemical reaction and the water lost in the form of vapour from the landfill site (Tatsi et al., 2003). The primary of sources of water are water entering the fill through the cover (precipitation), moisture in the cover material, groundwater inflow and inherent moisture in the solid waste and also the water formed as a by-product of decomposition of the wastes. Water leaves the landfill in the form of saturated vapour in the landfill gas, and through transpiration. The remainder of the water is either stored by the wastes or becomes leachate. The various components of a water balance for a landfill are presented in the figure 2.1. The vegetation on the cover utilizes water to build plant tissue and results in water loss by transpiration. The total amount of moisture that can be stored in a unit volume of soil is a function of two variables the field capacity (FC) and the wilting point (WP) of the soil. The FC of a soil is defined as the quantity of liquid that remains in the pore space following a prolonged period of gravitational drainage (Tatsi et al., 2003). The WP of a soil is defined as the quantity of water that remains in a soil after plants are no longer capable of extracting any more water. The difference between the field capacity and the wilting point is equivalent to the quantity of moisture that can be stored in a particular type of soil (Mahojeri et al., 2010). Since a potential major contributor to the formation of leachate is precipitation, an estimation of its infiltration into the cover is an important aspect of establishing the water balance on the landfill system as shown in figure 2.1.

The components of the water balance for a landfill can be expressed by the following equation if groundwater infiltration is insignificant (Tatsi et al., 2003):

MC = change in the quantity of moisture stored in the landfill (kg/m<sup>3</sup>);

 $W_{sw}$  = quantity of water in the incoming solid waste (the moisture content of solid waste ranges from 30% to 60% in developing countries, depending on the location) (kg/m<sup>3</sup>)

 $W_c$  = quantity of water in the cover material (kg/m<sup>3</sup>)  $W_p$  = quantity of water from precipitation and other outside sources (kg/m<sup>3</sup>)  $W_{RO}$  = quantity of water from precipitation diverted as runoff (kg/m<sup>3</sup>)  $W_{Ifg}$  = quantity of water utilized in formation of landfill gas (on order of 0.2 kg/m<sup>3</sup> of gas)  $W_v$  = quantity of water lost as saturated vapour with the landfill gas (on the order of 0.04 kg/m<sup>3</sup> of gas)

 $W_{evap}$  = quantity of water lost due to evapotranspiration (kg/m<sup>3</sup>)

 $W_{\text{leach}}$  = quantity of water leaving the (control volume) landfill as leachate (kg/m<sup>3</sup>).



Leachate (Wleach)

Figure 2.1: Water balance for landfill sites

Landfill leachates are one of the most significant pollution problems caused by Municipal Solid Waste landfill. The characteristics of Leachate can be explained in terms of many chemicals like Organic matters, inorganic matters and xenobiotic organic compounds. Inside landfill many complex events occur which can be classified as physical, chemical and biological process (Renoua et al., 2008). As outcome of these processes, waste is disintegrated or transformed and when the water flows through the transformed waste, it contains leached with the water which include inorganic soluble matters, soluble biodegraded matters of complex organic processes, soluble matters from chemical reactions and inorganic

fine suspended and colloidal solid. Leachate generated in this way are affected by many factors like quality of solid waste, degree of compaction in landfill, age of waste, climatic condition and hydrogeological condition of landfill site, pH, chemical and biological process occurs during degradation (Adhikari et al., 2014).

After the closing of landfill site also, the harmful and contaminated leachate production continues for 30 - 50 years (Wang et al., 2002). The main component of leachate is organic matters though it also contains ammonia-nitrogen, heavy metals, inorganic salts and chlorinated organic pigments (Wang et al., 2002, Renoua et al., 2008). These are the major threat to the surrounding pollution mainly soil and water pollution. These pollutants can be categorized into organic matters, such as COD (chemical oxygen demand), BOD (biological oxygen demand) and TOC (total organic carbon); specific organic compounds, inorganic compounds and heavy metals. The stabilization of the waste occurs in acetogenic, early methanegonic, late methanegonic and stabilization successive and distinctive phases (Adhikari et al., 2013, Tatsi et al., 2003). Landfill contains areas of refuse of varying ages and states of decomposition. Thus, where leachate from older methanogenic refuse is mixed with leachate from fresher refuse in the acid phase, it is not possible to relate leachate composition to process within the waste layers. Furthermore, where leachate from refuse in the acid phase percolates through well-decomposed refuse, the leachate can be expected to reflect the composition of methanogenic leachate (Kjeldsen et al., 1993). This is because the high COD of the acid phase leachate will be consumed as the leachate passes through the well decomposed, and thus, there is carbon limited refuse. In cases where leachate is released to groundwater, such as in the case of older landfills that are not lined, the spatial distribution of the leachate quality is especially important to evaluate the leaching to the underlying strata. This requires a large number of sampling points (Kjeldsen et al., 1993).

#### 2.2 Phases of Waste Stabilization (PWS)

The composition of leachate greatly depends on the age of the landfill and the process occurring in that age. After the study of many landfill sites, we can conclude that the stabilization of the waste occurs in five successive and distinctive phases. The rate of decomposition and the production of biogas differ from phase to phase, which shows that the activity of microorganism is different in different phases in landfill. That also depends on the environments created inside the landfill, that is, physical, chemical, climatic and microbial conditions (Christensen et al., 2002). The phases experienced by degrading wastes are described below. Figure 2.2 illustrates the sequential phases of landfill stabilization. As the

landfill cannot fill at a time, it contains many cells and section and experiences different pressure condition. It implies that there may occur different phases simultaneously in one landfill (Aziz et al., 2010).



Figure 2.2: Landfill showing general trends in gas and leachate quality development (McBean and Rovers, 1998)

#### 2.2.1 Phase I - Initial Adjustment Phase

In this phase solid waste gains moisture inside landfill. Accumulation of moisture is important to trigger the microbial activity; this is known by initial lag time. These preliminary changes in landfill environment help to create the advantageous situation for biochemical disintegration. In this phase, aerobic decomposition of organic matters occurs to change organic matters to  $CO_2$ ,  $H_2O$  and partially degraded organics with considerable temperature rise (Mor et al., 2006).

As only limited oxygen is available inside the landfill and also air flow inside are confined, only small portion of waste is decomposed aerobically. The leachate generated in this phase is mostly due to moisture containing in waste but not by the decomposition. Moisture of waste squeezed out due to the pressure applied during compaction and deposition of more waste (Construction of cell). This type of leachate contains suspended fine particles, highly soluble salts and microbs from aerobic decomposition process (Mor et al., 2006, Bhambulkar et al., 2011).

#### 2.2.2 Phase II - Transition Phase

As the oxygen presence in waste is limited, aerobic decomposition ends soon and starts anaerobic decomposition in this phase. Heat generated by aerobic decomposition and decrease in moisture contains in waste favors the anaerobic environment. Reduction environment is developed, changing electron acceptors from oxygen to nitrate and sulfate and oxygen converted to carbon dioxide. At the end of this phase, measurable concentrations of COD (480 to18000 mg/L) and volatile organic acids (VOA) (100 to 3000 mg/L) can be detected in the leachate (Aziz et al., 2010, Kargi et al., 2003).

#### 2.2.3 Phase III - Acid Formation Phase

In this phase production of VOAs, ammonia, hydrogen and CO<sub>2</sub> is high due to hydrolysis and biodegradation of organic matters by microorganism. In this phase strict and facultative microorganism are active for the disintegration processes (Ludvigsenet et al., 1999). These facultative bacteria help to disintegrate waste so that redox potential of the waste decreases, which favors the growth of methanogenic microorganism that causes the decline of pH value resulting chemically active leachate and decreases in sportive capacity of residual waste (Ludvigsenet et al., 1999). The highest concentrations of BOD (1000 to57700 mg/L), COD (1500 to 71100 mg/L), and specific conductance (1600 to 17100 mhos/cm) occur during the acid formation phase (Mor et al., 2006). The main characteristic of this phase is the growth of acidogenic bacteria and large degradation of substrate and nutrients (Christensen et al., 1998).

#### **2.2.4 Phase IV - Methane Fermentation Phase**

This phase starts after 4 to 10 years and endures for several years (Kale et al., 2010). In this phase, complex organic acids are consumed by methane-forming consortia (methanogenic bacteria) and change those intermediate acids to methane and CO<sub>2</sub> that effects on solubility characteristics of inorganic salts and precipitates those salts. For example, reduction of sulfate and nitrate to sulfides and ammonia. During this, concentration of COD and BOD decrease because much of the organic acids are converted to gas (Mor et al., 2006). During anaerobic decomposition process, some organic compounds are not decomposed. They remain as residues in landfill and are very important constituents for adsorption and complicated reactions (Mayakaduwa et al., 2012). The pH level increases in this phase but hinders bicarbonate buffering system which supports the activity of methanogenic bacteria. These bacteria slowly but effectively decompose for many years and degrade residual organic matters. During this process heavy metal are gradually removed by precipitation (Robinson et al., 1991, Welikannage et al., 2012).

#### 2.2.5 Phase V - Maturation Phase

This phase is stabilized phase of organic compounds. This phase is characterized by the low biological activity. After the completion of methanogenic phase, gas production reduces and leachate strength becomes constant at very low concentration but residual matters continues in

decomposition in very slow manner forming humic-like matters (Robinson et al., 1991, Koh et al., 2012, Langler, 2004).

The factors like quality of waste, environment of the leachate interaction, age of solid waste, design of landfill and way of operation of landfill effects on the leachate characteristics (Robinson et al., 1991). Although the stabilization of waste proceeds in different sequential phases, in full-scale landfill operation it is virtually impossible to identify all stages. The early phase of the waste degradation is acidogenic phase which can be defined by BOD/COD ratio larger or equal to 0.1 and sulfate level between 70 and 1750 mg/L (Ehring, 1988). The lasting phase of methanogenic process is distinguished by BOD/COD ratio 0.1 and sulfate value between 10 and 420 mg/L (Ehring, 1988). BOD/COD ratio indicates remaining amount of biologically decomposable organic matters to total organic matters remaining. This phase decreases with the increase in landfill age and many organic matters could be leached from the residual wastes (Cossu et al., 1998).

#### **2.3 Factors Affecting the Landfill Leachate**

Usually leachate quality is highly variable in most of the sites. The extent of variation in leachate quality can be attributed to many interacting factors such as composition, depth, moisture content, dissolved oxygen, design and operation of landfill sites, and age of waste. Scientists and researchers have mentioned the following factors for variation in leachate quality in general.

#### 2.3.1 Waste Composition

There is generally a variation in composition and characteristics of MSW. In general, the composition of waste determines the extent of biological activity within the landfill sites (Wimalasuriya et al., 2011, Zouboulis et al., 2004). The waste such as Rubbish, food and garden wastes, and crop and animal residues contribute to the organic material in leachate in most of the cases and, inorganic constituents in leachate are often derived from ash wastes and construction and demolition debris derived from different sources (Christensen et al., 1996). Ahmed and Lan (2012) found that increased quantities of paper in solid waste resulted in a decreased rate of waste decomposition in landfill sites. Lignin, the primary component of paper but it is resistant to anaerobic decomposition. Because of the variability of solid waste, only general assumptions can be made about the relationship between waste composition and leachate quality of the landfill sites (Ahmed et al., 2012).

#### 2.3.2 Depth of Waste

Some researchers (Tatsi et al., 2002, Kang et al., 2002,) reported that greater concentrations of constituents are found in leachate from deeper landfill sites. But deeper landfills require more water to reach saturation. Similarly, it requires a longer time for decomposition, and distribution. Water entering the landfill will travel down through the waste collected in the landfills. Generally when the water percolates through the landfill, it contacts the refuse and leaches chemicals from the wastes. Landfills of greater depth offer greater contact times between the liquid and solid phases which increase leachate strength (Tranler et al., 2005).

#### 2.3.3 Moisture Availability

Water is one of the most important factors influencing waste stabilization and leachate quality of landfill site. But moisture addition has been demonstrated repeatedly to have a stimulating effect on methanogenesis (Burnes et al., 2004) although some researchers indicate that it is the movement of moisture through the waste of landfill site (Shuokr et al., 2010, Zouboulis et al., 2004). Moisture within the landfill serves as a reactant in the hydrolysis reactions. Similarly, it transports nutrients and enzymes, dissolves metabolites, provides pH buffering, dilutes inhibitory compounds, exposes surface area to microbial attack, and controls microbial cell swelling (Shuokr et al., 2010). Some of the researchers (Shuokr et al., 2010, Trihalomethanes, 2004, Tatsi et al., 2002) stated that high moisture flow rates can flush soluble organics and microbial cells out of the landfill. In such cases microbial activity plays a lesser role in determining leachate quality. Similarly, high moisture application rates can remove the majority of waste contaminants early in the life of the fill in most of the cases. But under low flow rate conditions, anaerobic microbial activity is the significant factor governing leachate organic strength as mentioned by the researchers (McBean and Rovers, 1998).

#### 2.3.4 Available Oxygen

Availability of free oxygen in a landfill sites dictates the type of decomposition (i.e. anaerobic or aerobic). At the initial stage, aerobic decomposition occurs. The degradation may continue to occur at, and just below, the surface of the fill where oxygen is available (Amokrane et al., 1997). As a result of aerobic decomposition, chemicals released differ greatly from those produced during anaerobic degradation of the wastes in landfills (Bagchi A, 1990, Kilic et al., 2007).

#### 2.3.5 Temperature

Temperature in the landfill sites is a largely uncontrollable factor influencing leachate quality. It has been shown to fluctuate with seasonal ambient temperature variations in the fills (Barnes et al., 2010). In general, temperature affects bacterial growth and chemical reactions within the landfill. Decrease in optimum temperature, will decrease growth due to enzyme deactivation and cell wall rupture. Similarly, solubility of many salts [e.g.  $Ca_3$  (PO4)<sub>2</sub> and NaCl] increases with available temperature. But compounds in leachate, such as  $CaCO_3$  and  $CaSO_4$ , show a decrease in solubility with increasing temperature in landfills (Christensen et al., 1996).

#### 2.3.6 Processed Waste

Leachate characteristics can greatly be affected by shredding or baling of waste. Leachate from shredded waste is highly contaminated during early stages of waste stabilization. However, it is less contaminated during later phases and leachate from unshredded waste (Rivas et al., 2003). Some researchers also agreed that leachate from shredded landfills has significantly higher concentrations of pollutants than leachate from unshredded ones. Generally, the higher strength leachate can be attributed to increased surface area and, consequently, increased rates of bio-degradation in shredded wastes (landfills) (Robinson, H 2007). However, there is contradiction on this statement (Trabelsi et al., 2009). Field capacity (i.e. maximum moisture that can be retained without continuous downward percolation by gravity) was delayed for shredded waste landfills. However, the rate of pollutant removal, solid waste decomposition, and cumulative mass of pollutants released per unit volume of leachate was significantly increased when compared to unshredded waste fills (Chu et al., 1994). Similarly, baling resulted in large volumes of dilute leachate and waste required a longer period to stabilize (as compared to unbaled wastes). In general, baling of wastes can enhance leachate production by decreasing the elapsed time before leaching. It also reduces the moisture-retention ability of the waste, and increases the overall volume of the leachate produced (Aderemi et al., 2011). However, once the field capacity of the shredded or baled refuse is attained, the cumulative mass of pollutant removal per unit volume of solid waste would be the same (Aderemi et al., 2011).

#### 2.3.7 Age of Landfill

Quality of leachate is greatly influenced by the duration of time. There is limited quantity of chemicals in the waste. Thus, leachate quality reaches a peak after approximately two to three years followed by a gradual decline in ensuing years (Asadi, 2008). In general, leachate from new landfills will be high in BOD and COD and will then gradually decline during 10 years (Asadi, 2008). But all contaminants do not peak at the same time. Because of biodegradable nature, organic compounds decrease more rapidly than inorganic ones with increasing age of the landfill (Chiang et al., 2001). Inorganic compounds are removed as a result of washout by

infiltrating rainwater in most of the cases (Chiang et al., 2001). However, organic compounds decrease in concentration through decomposition as well as washout. The rapid decrease in the concentration of sulfate is a result of predominately anaerobic condition in the landfill. Similarly, pH increases with time. It reflects the decrease in concentration of the partially ionized free volatile fatty acids (Adhikari et al., 2013). In general, variations in leachate quality with age should be expected throughout the landfill life because organic matter will continue to undergo stabilization (Adhikari et al., 2013).

#### 2.3.8 Toxicity

Some researchers (Barnes et al., 2004, Ahn et al., 2002) investigated acute and genetic toxicity of municipal landfill leachate. The results of acute and genetic toxicity showed that leachate from municipal solid waste landfills are just as toxic as leachate from landfills of residential and hazardous wastes (Ahn et al., 2002). Leachate from MSW landfills more or less contained the same hazardous constituents as found in other hazardous waste landfills.

#### 2.4 Landfill Processes

In this section, different dimensions of landfill process are discussed. Touching upon the physical and chemical process of the land filling briefly, the main focus will be the biological process of proper waste dumping. Nevertheless, biological process is greatly influenced by physical and chemical process (Aziz et al., 2011).

#### 2.4.1 Physical

Broadly, there are 3 aspects of physical process of landfill; compaction, dissolution and absorption are the steps involved in physical process of the fill. The process of settlement and compression goes together. Similarly, dissolution and transport are closely associated phenomena, although not to the same degree as compression and settlement. All components of the buried fills are subjected to these three processes. Compaction is the process that starts with the compression and size reduction of the particles by compacting mechanism and it goes on after the waste is in place (Welikannage et al., 2009). The continuing compression is due to the weight of the wastes and that of the soil cover (burden). Sifting of soil and other fines are responsible for some consolidation. Settling of the completed fill is an end result of compression. This settling is in addition to the settlement brought about by other reactions (e.g., loss of mass due to chemical and biological decomposition).

The amount of water that enters a landfill has important bearing on physical reactions. Water acts as a medium for the dissolution of soluble substances and for the transport of untreated materials. The untreated materials consist of animate and inanimate particulates. Of the physical phenomena, adsorption is one of the more important processes because it brings about the immobilization of living and non-living substances that could pose a problem if allowed to reach the external environment. It could play an important part in the containment of viruses and pathogens and of some chemical compounds (Robinson, H, 2007).

Adsorption does have its limits, one of which is its questionable permanency. One or several factors can alter permanency. For example, it can be altered by the effect of biological and chemical decomposition on adsorption sites. Absorption is another of the physical phenomena that takes place in a fill (Silva et al., 2013). It is significant in large part because it immobilizes dissolved pollutants by immobilizing the water that could transport them and suspended pollutant particulates out of the confines of the landfill. Absorption is the process whereby substances are taken in by capillarity. Municipal waste is attributable to its cellulosic content. However, it should be recognized that, accepting fills located in arid regions, eventually all absorbent material in a fill becomes saturated. Consequently, absorption may be regarded as being only a delaying action as far as pollutant release is concerned.

#### 2.4.2 Chemical

Oxidation is one of the two major forms of chemical reaction in a landfill. Obviously, the extent of the oxidation reactions is rather limited because the reactions depend upon the presence of oxygen trapped in the landfill when the landfill is made. Ferrous metals are the components likely to be affected (Rafizul et al., 2012).

The second major form of chemical reaction includes the reactions that are due to the presence of organic acids and carbondioxide (CO<sub>2</sub>) synthesized in the biological processes and dissolved in water (H<sub>2</sub>O). Reactions involving organic acids and dissolved CO<sub>2</sub> are typical acid-metal reactions (Rafizul et al., 2012). Products of these reactions are largely the metallic ions and salts in the liquid contents of the fill. The acids lead to the solubalization and, hence, mobilization of materials that otherwise would not be sources of pollution (Chan et al., 2002). The dissolution of CO<sub>2</sub> in water deteriorates the quality of the water, especially in the presence of calcium and magnesium (Aziz et al., 2011).

#### 2.4.3 Biological

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

i. The organic fraction is rendered biologically stable and doesn't constitutes a potential source of nuisances.

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

The wide varieties of landfill components that can be broken down biologically constitute the biodegradable organic fraction of MSW (Asadi, 2008). This fraction includes the garbage fraction, paper and paper products, and "natural fibres" (fibrous material of plant or animal origin). Biological decomposition may take place either aerobically or anaerobically (Welikannage et al., 2009). Both modes come into play sequentially in a typical fill, in that the aerobic mode precedes the anaerobic mode. Although both modes are important, anaerobic decomposition exerts the greater and longer lasting influence in terms of associated landfill characteristics (Shuokr et al., 2010).

*Aerobic decomposition:* The greater part of decomposition that occurs directly after the wastes are buried is aerobic. It continues to be aerobic until all of the oxygen  $(O_2)$  in the interstitial air has been removed. The duration of the aerobic phase is quite brief and depends upon the degree of compaction of the wastes, as well as the moisture content since the moisture displaces air from the interstices (Renoua et al., 2008). Microbes active during this phase include obligate as well as some facultative aerobes. Because the ultimate end products of biological aerobic decomposition are  $CO_2$  and  $H_2O$ , adverse environmental impact during the aerobic phase is minimal. Although intermediate breakdown products may be released, their amounts and contribution to pollution usually are small (Renoua et al., 2008).

Anaerobic decomposition: When the oxygen supply in a landfill site is depleted, most of the biodegradable organic matter eventually is subjected to anaerobic breakdown. This anaerobic decomposition is biologically much the same as that in the anaerobic digestion of sewage sludge (Wang et al., 2000). Microbial organisms responsible for anaerobic decomposition include both facultative and obligate anaerobes. Unfortunately, the breakdown products of anaerobic decomposition can exert a highly unfavorable impact on the environment unless they are carefully managed. The products can be classified into two main groups: volatile organic acids and gases (Renoua et al., 2008). Most of the acids are malodorous and of the

short-chain fatty-acid type. In addition to chemical reactions with other components, the acids serve as substrates for methane-producing microbes. The two principal gases formed are methane (CH<sub>4</sub>) and CO<sub>2</sub> (Renoua et al., 2008). Gases in trace amounts are hydrogen sulphide (H<sub>2</sub>S), hydrogen (H<sub>2</sub>) and nitrogen (N<sub>2</sub>).

The nature, rate, and extent of biological decomposition in a fill are greatly influenced by the environmental factors that affect all biological activities. The nature of biological decomposition determines the nature of the decomposition products. The principal factors that influence biological decomposition in a conventional fill are moisture, temperature, and the microbial nutrient content and degree of resistance of the waste to microbial attack (Adhikari et al., 2013). Moisture is a limiting factor in a fill at moisture content levels of 55% to 60% or lower, because microbial activity is increasingly inhibited as the moisture drops below the 55% level. The activity of most microbes increase with rise in temperature until a level of about 40°C is reached. For some types of microbes, the upper temperature is on the order of 55° to 65°C. Because temperatures in tropical regions are more favourable, decomposition can be expected to proceed more rapidly and to a greater extent. With respect to nutrients, wastes characterized by a high percentage of putrescible matter approach the ideal in terms of decomposition (Tatsi et al., 2003).



Figure 2.3: Biological decomposition process in a landfill (Trankler et al., 2005)

### 2.5 Leachate Sample Collection Technique

Since there is variation in the composition of leachate due to the factors like waste composition, waste age, landfilling technology, leachate sample collection techniques may

also influence the measured leachate quality (Adhikari et al., 2014). For example, colloids have a high affinity for heavy metals thus the concentration of heavy metals measured in a leachate sample may depend strongly on the amount of colloidal matter present in the sample and the handling of the sample. No standard protocols for sampling, filtration, and storage of leachate samples exist. The content of colloidal matter in a sample depends to a large extent on the sampling technique used (Kjeldsen et al., 1993) where samples are obtained from groundwater monitoring wells. A high pumping rate will increase the colloid content of the sample significantly (Wang et al., 2000), and the heavy metal concentration may also be increased. Thus leachate samples should be filtered in the field before analysis of heavy metals, especially when the sampling is done quickly. Alternatively, samples could be withdrawn under very low pumping rates and after sufficient removal of the well. Leachate samples should be maintained under anaerobic condition until they are preserved because metal solubility varies according with their oxidation stage.

#### 2.6 Characteristics of Landfill Leachate

Generally saying, leachate from acid phase young landfill comprise of huge quantity of biodegradable organic matter (Trankler et al., 2005). Volatile fatty acid is found more than 95% in dissolved organic carbon (DOC) with little amount of high molecule weight compounds. Likewise, leachate from methanogenic phase mature landfill is highly dominated by refractory compounds and the DOC content consists of high molecular weight compounds (Wang et al., 2000). Tables 2.2, 2.3 and 2.4 below summarize the ranges of leachate composition in detail. Values of COD vary from 70,900 mg/L with leachate sample obtained from the Thessaloniki Greater Area (Greece) to 100 mg/L with sample from more than 10years old landfill near Marseille (France) (Tabet et al., 2002). With few exceptions, the pH of leachate lies in the range 5.8–8.5 as a result of the biological activity that takes inside the tip. It also shows the majority of TKN is ammonia, which can range from 0.2 to 13,000 mg/L of N. But the ratio of BOD/COD is from 0.70 to 0.04 which is in decreasing pattern in relation to the age of landfill site due to the release of the large recalcitrant organic molecules from the solid wastes. The old landfill sites produce leachate with low ratio of BOD/COD and fairly high NH<sub>3</sub>-N. Thus, the age of land fill sites is the determining factor for the production of leachate composed of diverse elements including stabilization stages of the waste evolution (Trankler et al., 2005).
Parameters	Young	Intermediate	Mature
Age	<5	5-10	>10
рН	6.5	6.5-7.5	>7.5
COD mg/L	>10,000	4,000-10,000	<4,000
BOD mg/L	>2,000	150-2,000	<150
BOD/COD	>0.3	0.1-0.3	<0.1
Organic	80% VFA	5-30% VFA+humic &	Humic & fumic
compound		fumic acid	acid
Heavy Metals	Medium	low	low
Biodegradability	Imp	Medium	Low

Table 2.1: Characteristics of leachate at different ages of landfill sites (Renoua et al., 2008)

Table 2.2: Typical concentrations in leachate comparing with sewage and groundwater (mg/L) (Mcbean et al., 1995)

Parameters	Young leachate	Old leachate	Typical sewage	Typical ground
COD	20,000-40,000	500-3,000	350	20
BOD	10,000-20,000	50-100	250	0
TOC	9,000-25,000	100-1,000	100	5
Volatile fatty acids	9,000-25,000	50-100	50	0

Table 2.3: Heavy metals composition in landfill leachate

Y-Young, MA- Medium age, O- Old; (all values except pH and BOD/COD are in mg/L)

Age	LFS	Fe	Mn	Ba	Cu	Al	Si	Ref.
Y	Italy	2.7	0.04	-	_	_	_	Lopez et al., 2004
MA	Canada	1.28-4.90	0.02-1.54	0.006-0.164	_	<0.02-0.92	3.72-10.48	Kennedy and Lentz, 2004
MA	Hong Kong	3.811	0.182	_	0.12	-	_	Li et al., 2001
MA	South Korea	76	16.4	-	0.78	_	_	IM et al., 2001
MA	Spain	7.45	0.17	-	0.26	-	_	Rivas et al., 2003
0	Brazil	5.5	0.2	-	0.08	<1	_	Silva et al., 2004
0	France	26	0.13	0.15	0.005-0.04	2	<5	Tabet et al., 2002
0	Malaysia	4.1–19.5	15.5	—	—	—	—	Aziz et al., 2004
0	South Korea	-	0.298	-	0.031	-	-	Cho et al., 2002

Age	LFS	COD	BOD	BOD:COD	pН	SS	TKN	NH <sub>3</sub> -N	Ref.
Y	Canada	1870-13800	90-9660	0.05-0.7	5.8- 6.58	_	75-212	10.0-40	Henry et al., 1987
Y	China, Hong Kong	13000- 50,000	4200- 22000	0.27-0.44	6.8–9.1	2000- 5000	3200- 13000	2260- 13000	Lo et al., 1996
Y	China, Mainland	1900–3180	3700–8890	0.36–0.51	7.4–8.5	_	-	630– 1800	Wang et al., 2000
Y	Greece	70,900	26,800	0.38	6.2	950	3,400	3,100	Tatsi et al., 2003
Y	Italy	10540- 19900	4000-4000	0.2-0.22	8-8.2	1666	-	3917- 5210	Renoua et al., 2008
Y	South Korea	24,400	10,800	0.44	7.3	2400	1,766	1,682	Im et al., 2004
Y	Turkey	10,750– 50000	6380– 25000	0.5–0.67	5;6–8.2	2630– 3930	2,370	1,946– 2,002	Ceceen et al., 2004
MA	Canada	3210–9190	_	_	6.9–9.0	_	-	_	Kennedy and Lentz, 2004
MA	Nepal	2500-4000	325-1500		6.4-7.8	-	-	-	Adhikari et al., 2014
MA	China, Hong Kong	7439	1436	0.19	8.22	784	-	-	Li et al., 2001
MA	Germany	3180-4000	800-1060	0.20.33	-	_	1,135	800-884	Baumgatten et al., 1996
MA	Greece	5350	1050	0.2	7.9		1,100	940	Tatsi et al., 2003
MA	Italy	3840-5050	1200-1270	0.25-0.31	7.9- 8.38	480	1100- 1670	940- 1330	Frascari et al., 2004
MA	Poland	1180	331	0.28	8	-	—	743	Wu et al., 2004
MA	Taiwan	6500	500	0.08	8.1	-	_	5,500	Kargi et al., 2003
MA	Turkey	9500	_	_	8.15	-	1,450	1,270	Silva et al., 2004
0	Brazil	3460	150	0.04	8.2	_	_	800	Orupold et al., 2000
0	Estonia	2170	800	0.37	11.5	_	_	_	Renoua et al., 2008
0	Finland	340–920	62-84	0.09-0.25	7.1–7.6	-	192	159–560	Tabet et al., 2002
0	France	100-1930	3-7.1	0.01-0.03	7-7.7	13– 1480	5–960	0.2-430	Gourdon et al., 1989
0	Malaysia	1533–2580	48–105	0.03-0.04	7.5–9.4	159-	_	_	Aziz et al., 2004
0	South Korea	1409	62	0.04	8.57	404	141	1,522	Cho et al., 2002
0	Nepal	100-320	80-350		7.9-8.8	-	-	-	Adhikari et al., 2014
0	Turkey	10,000	-	—	8.6	1600	1,680	1,590	Uygur et al., 2004

Table 2.4: Leachate composition at different countries (COD, BOD, BOD/COD, pH, SS, TKN, NH<sub>3</sub>-N) (all values except pH and BOD/COD are in mg/L)

### 2.7 Qualitative Study of Landfill leachate

### 2.7.1 Color and Odor

The leachate samples are of color orange brown or dark brown or black. Lechates produces malodorous smell, mainly due to the presence of organic acid, which arises because of the high concentration of organic matter when decomposed. The presence of high organic substances is responsible for the high concentration of color in landfill (Asadi, 2008). Generally, leachate produced by an old landfill with low biodegradability is classified as stabilized leachate. Such leachate contains high levels of organic substances such as humic and fluvic compounds, which can be indicated by leachate color (Chan et al., 2002). The humic substances are natural organic matter and are made up of complex structures of polymerized organic acids, carboxylic acids and carbohydrates (Adhikari et al., 2013).

### 2.7.2 pH

The pH in a landfill varies according to the age of landfills. Leachate generally is found to have pH between 4.5 and 9. The pH of young leachate is less than 6.5 while old landfill leachate has pH higher than 7.5 (Chan et al., 2002). Little variation is seen in stabilized leachates which have fairly constant pH ranging 7.5 to 9 (Tasti et al., 2003). In acid formation phase, pH levels are expected to be lower due to the production of volatile organic acids (VOAs). While in the methanogenic phase, as the intermediate acids are consumed by methanogenic bacteria the pH values increase (Tabet et al., 2002). Some other researchers; Kargi et al., (2003) and Chian et al., (1976) reported that the pH of leachate increases with the decrease of the partially ionized free volatile fatty acids. Increase in the pH suggest that a steady state has been reached between acid producing processes (e.g., cellulose and lignin degradation) and acid consuming processes (e.g., methane formation) at the landfill (San et al., 2013). Leachate exposure to the atmosphere could cause some removal of carbon dioxide from the leachate which tends to raise the pH (Robinson et al., 1983). Some studies even suggest that the higher pH levels of leachate in the leachate collection pond may be the result of carbon dioxide being utilized by algae (Christensen et al., 2002).

#### 2.7.3 Dissolved Organic Matter

It is quantified as Chemical Oxygen Demand (COD) or Total Organic Carbon (TOC), volatile fatty acids (that accumulate during the acid phase of the waste stabilization (Christensen et al., 2002), and more refractory compounds such as fulvic-like and humic-like compounds. From the leachate many researchers reported Fe (II), Mn (II), and sulfide contributed up to one-third of the COD. Poor sampling methods that expose anaerobic leachate to oxygen may cause Fe

(II) to oxidize to Fe (III) and precipitate out of the leachate. COD decreases relative where Fe (II) gets oxidized as part of the COD analysis (Aziz et al., 2004). This could be observed when the sample was maintained under anaerobic conditions until after filtration, at which point it could be acidified to reduce iron oxidation. Dissolved organic matter in leachate includes a bulk parameter covering a variety of organic degradation products ranging from small volatile acids to refractory fulvic and humic-like compounds (Chian et al., 1976). The complex properties of the high-molecular-weight component of the dissolved organic matter are the constituents through which dissolved organic matter can affect leachate composition. At the most general level, a low BOD/COD ratio suggests a leachate with low concentrations of volatile fatty acids and relatively higher amounts of humic and fulvic-like compounds (Adhikari et al., 2013). In the acid-phase leachate, more than 95% of the DOC content of 20,000 mg/L consisted of volatile fatty acids and only 1.3% of the DOC consists of high molecular-weight (MW) compounds (MW> 1000). No volatile acids, amines, or alcohols are detected, and 32% of the DOC (2100 mg/L) consisted of higher-molecular-weight compounds (MW>1000) in the methanogenic-phase leachate. According to Aziz et al., (2011) methanogenic-phase leachate, described more than 60% of the DOC content as humic-like material. While some other researches Zouboulis et al., (2004) found that only 6 to 30% of the DOC could be described as fulvic acids in leachate.

BOD, COD and BOD/COD ratio: The amount of oxygen required or consumed for the microbiological decomposition (oxidation) of organic material in water or wastewater is measured through BOD. BOD measures the biodegradable organic mass of leachate and that indicates the maturity of the landfill which typically decreases with time (Maynard et al., 2013). Due to the degradation of BOD in the leachate the waste constituents percolate down along with rainwater thus polluting groundwater nearby to MSW landfill site. The value of BOD varies according to the age of landfills. The value of BOD values for new landfills were 2000-30000 mg/L; while for mature landfills, BOD value varies from 100-200 mg/L (Lu et al., 1997). The concentration of BOD and COD appears to remain low (less than 1500 mg/L) throughout the life of the landfill, most likely due to dilution and stimulation of methanogenesis. The elevated pH in the acidogenic phase is indicated by the stimulation of methanogenesis (Aziz et al., 2011). COD represents the amount of oxygen needed to oxidize the organic waste components chemically to inorganic end products. The dilution and stimulation of methanogrnesis makes the BOD and COD concentration to appear low as the life of landfill sites increases. The pH in the acidogenic phase supports the stimulation of methanoenesis (Tatsi et al., 2013). Leachate from the shredded waste fill has significantly

higher concentration of organic pollutants than that of un-shredded waste landfills as evidenced in the high COD and BOD levels from the South Dade Shredded Landfill (Adhikari et al., 2013). In other words, leachate from shredded waste fills has significantly higher concentrations of organic pollutants than leachate from un-shredded landfills.

COD versus age of landfill: The highest concentration in leachate contains organic compounds which are volatile fatty acids (e.g. acetic, propionic, and butyric) produced during the decomposition of lipids, proteins, and carbohydrates. Similarly, in the lower concentrations Aromatic hydrocarbons, including benzene, various xylenes, and toluene, are also found frequently (Robinson et al., 1983). These compounds were considered to be components of gasoline and fuel oils. Even nicotine, caffeine, and phthalate plasticizers are found in small fraction in several leachates (Kjeldsen et al., 1983). With this observation Kjeldsen et al., (1983) concluded that leachate composition was quite site specific. The ongoing microbial and physical/chemical process within the landfill is the reason why the dominant organic class in leachate shift as the age of the landfill increases. An investigation of leachates obtained from landfills operated from one to twenty years found that the relative abundance of high molecular weight humic-like substances decreases with age, while intermediate sized fulvic materials (e.g. high density carboxyl and aromatic hydroxyl groups) showed significantly smaller decreases (Chian et al., 1976). The relative abundance of organic compounds present in leachate was observed to decrease with time in the following order: free volatile fatty acids, low molecular weight aldehydes and amino acids, carbohydrates, peptides, humic acids, phenolic compounds, and fulvic acids (Oman et al., 2008).

**BOD/COD ratio:** Different level of biodegradability characterizes the organics in leachate. Generally, the age of landfill is known through the BOD/COD ratio, which is the degree of its biodegradation. Lower range of BOD/COD ratio indicates higher concentration of non-Biodegradable organic materials which with difficulty degrades biologically (Robinson, 2007). In a landfill through BOD/COD ratio degradation of organic materials can be known. This instead can be used as an indicator to differentiate the acetogenic phase from methanogenic phase in landfills. The quality of leachate affects by microbial activity which determines the duration of waste placement in landfill (Robinson, 2007). As BOD is predominantly a biochemical parameter, it generally reflects biodegradability of organic matter in leachate thus making BOD/COD ratio the good indicator of the proportion of biochemically degradable organic matter to total organic matter (Silva et al., 2004). It is summarized that BOD/COD ratio is a best indicator for degrees of both biological and chemical decompositions that are taken place in the landfill and can also be taken as an indicator of degradation of organic matter in landfill. An eventual decline in BOD and COD concentrations is often observed as organic matter is being removed via washout and degradation (Adhikari et al., 2014).

The BOD in the leachate is measured by first order function;

BOD = UBOD  $(1 - e^{-kT})$  ..... Equation 2.2

A typical value of  $k_1$  various with the temperature and waste types ranging from 0.05 to 0.3 per day. With different parameters the rate constant of  $K_1$ ,  $K_2$  and  $K_3$  can be taken into account for the different phases like hydrolysis, acidogenesis and methanogenesis (Hunce et al., 2012)

### 2.7.4 Ammonia

A study was conducted for ammonia concentration (Kale et al., 2010) and it was concluded that ammonia concentrations between 50 and 200 mg/L have been shown to be beneficial to anaerobic processes. Ammonia concentrations between 200 and 1000 mg/L have been shown to have no adverse effects on anaerobic processes while concentrations ranging from 1500 to 3000 mg/L have been shown to have inhibitory effects at higher pH levels. Concentrations above 3000 mg/L are toxic to microorganisms. Ammonia and organic nitrogen produced by decomposition of organics are stable in an anaerobic environment, and therefore represent a high percentage of the soluble nitrogen compounds in leachate (McBean et al., 1995). Leachates of older landfills generally have lower concentrations and percentages of these constituents (Aziz et al., 2011). In leachete the ammonia generally produced from organic matter. Therefore it is expected that the BOD, COD, and ammonia concentrations would be lower in the leachate from ash fills due to the lack of organic matter in MSW incinerator ash. Many investigations report shows that of ammonia-nitrogen in the range of 500 to 2000 mg/I, and no decreasing trend in concentration with time. Ammonia came from the waste by decomposition of proteins. The only mechanism by which the ammonia concentration can decrease during refuse decomposition is leaching because there is no mechanism for its degradation under methanogenic conditions (Robinson, 2005) while in other study scientist Ehrig, (1988) reports that there is no significant change in ammonia concentrations from the acidic to methanogenic phase, and that the average value is 740 mg-N/l. Ammonia concentrations will remain high even in leachate from older landfills that is otherwise low in organic content (San et al., 2013).

#### 2.7.5 Inorganic Macro-components

The major inorganic macro components detected in landfill leachate are calcium ( $Ca^{2+}$ ), magnesium ( $Mg^{2+}$ ), sodium( $Na^+$ ), potassium ( $K^+$ ), ammonium ( $NH^{4+}$ ), ferrous ( $Fe^{2+}$ ), manganese ( $Mn^{2+}$ ), chloride ( $CI^-$ ), sulfate ( $SO_4^{2-}$ ) and hydrogen carbonate ( $HCO^{3-}$ ). Borate, sulfide, arsenate, selenate, barium, lithium, mercury, and cobalt are also found in very low concentrations and are only of secondary importance (Robinson, 2007). The concentrations of some inorganic macro-components in leachate depend on the stabilization of the landfill. The cations calcium, magnesium, iron, and manganese are lower in methanogenic phase leachate due to a higher pH (enhancing sorption and precipitation) and lower dissolved organic matter content, which may form complexes with the cations. Sulfate concentrations are also lower in the methanogenic phase due to microbial reduction of sulfate to sulfide. The effects of sorption, complexation and precipitation are minor for macro-components like chloride, sodium, and potassium (Kale et al., 2010). Concentration of these pollutants may decrease with time due to leaching, but did not observe any decrease in concentration for these parameters after up to 20 years of leaching (San et al., 2013).

### **2.7.6 Inorganic Compounds**

Major heavy metals found in leachate are Cadmium ( $Cd^{2+}$ ), chromium ( $Cr^{3+}$ ), copper ( $Cu^{2+}$ ), lead (Pb<sup>2+</sup>), nickel (Ni<sup>2+</sup>) and zinc (Zn<sup>2+</sup>). The variations in heavy metals among landfills are wide and varied. Some heavy metals found occasionally in leachate are zinc, copper, cadmium, lead, nickel, chromium, and mercury (Lu et al., 1991). Heavy metal concentrations in leachate do not appear to follow patterns of organic indicators such as COD or BOD, nutrients, or major ions (Lu et al., 1991). Heavy metal release is a function of characteristics of the leachate such as pH, flow rate, and the concentration of complexing agents. With increasing pH metal solubility's generally decrease. In addition, the hydrogen ion concentration will indirectly influence metal solubility by its impact on such processes as the dissociation of an acid to yield a precipitant anion and reduction-oxidation reactions (Hunce et al., 2012). With time, moderate to high molecular weight humic-like substances are formed from waste organic matter in a process similar to soil humification. These substances tend to form strong complexes with heavy metals. The formation of complexes between heavy metals and ligands tends to increase metal solubility although there are conditions under which the opposite may be expected (Vasanthi et al., 2008). Sulfide, however, effectively competes with most complexing agents, and consequently many heavy metals will precipitate as sulfides rather than remain in solution as complexes (Lu et al., 1991). In a study researcher Chian & Dewalle, (1976) also reported that the formation of metal sulfides under anaerobic conditions effectively eliminated the majority of heavy metals in leachate. In some instances, a remobilization of metals occurs once the organic content has been stabilized and oxic conditions begin to be re-established (Bashir et al., 2009). Adsorption is another important mechanism controlling the heavy metal concentration. Under oxidizing conditions, adsorption can regulate the concentration of metals well below the level controlled by precipitation effects (Lu et al., 1991).

Electrochemical processes can influence metal speciation and behaviour both directly by modifying the nature of the metal itself and indirectly through conversion by other species in the landfill environment. For example, the toxic non-metal, selenium, can be removed from landfills by reduction to the neutral element or conversion to the selenide ion which will be readily precipitated by ferrous ions (Cecen et al., 2004). Specific conductance is a gross indicator of the total concentration of dissolved inorganic matter or ions present in leachate. The primary metal species contributing to specific conductance are calcium, magnesium, sodium, and potassium (Kamaruddin et al., 2013).

Heavy metal attenuation and mobilization in landfills: Only 0.02% of heavy metal leaches out from the total heavy metals deposited at landfill at the period of 30 years, such low concentrations of heavy metals is seen in methanogenic leachate (Aziz et al., 2004). Waste contains soils and organic matter, which, especially at the neutral to high pH values prevailing in methanogenic leachate, has a significant sorptive capacity (Aziz et al., 2004). In addition, the solubilities of many metals with both sulfides and carbonates is low, and these anions are typical in landfills. Sulfide is formed from sulfate reduction during waste decomposition in landfills, and sulfide precipitation is often cited as an explanation for low concentrations of heavy metals (Christensen et al., 1996, Christensen, 1998). Sulfides and carbonates are capable of forming precipitates with Cd, Ni, Zn, Cu, and Pb. When carbonates are abundant in landfill leachate, the solubilities of metal carbonates are generally higher than that of metal sulfides (Adhikari et al., 2014). In general, sulfide precipitation is expected to dominate heavy metal attenuation compared with complexation agents (Reinhart & Grosh, 1999) Cr is an exception to this because it does not form an insoluble sulfide precipitate (Christensen et al., 1996). However, Cr tends to form insoluble precipitates with hydroxide (Christensen et al., 1998, Revans, 1999). Investigations of the sulfur content of landfilled waste have shown that the waste does not contain sufficient sulfur to bind all the heavy metals present in the waste. The landfill sampled by Martienssen et al., (1997) contained only enough sulfur to bind 5% of metals present. Occasionally, phosphates and hydroxides will also precipitate metals

(Christensen et al., 1998). Hydroxide precipitates form at pHs at or above neutral, which is typically the case in methanogenic leachates (Reinhart & Grosh, 1999). There are many processes including complication to inorganic and organic ligands, and sorption to colloids are capable of mobilizing heavy metals by increasing the concentration in the mobile aqueous phase. A highly varying fraction of the heavy metals was incorporated with colloidal fractions. Researchers Gounarie et al., (1993) also reported that in an American landfill a significant fraction of the Zn, Pb, and Cr were in colloidal fractions. Further, in the same study at a German landfill that the main fraction of the heavy metals was associated with the colloidal matter, primarily the 0.001 to 0.01 ztm fractions, which is dominated by humic material. In all these investigations, comparison of the distribution of organic matter and heavy metals between the size fractions indicated that the heavy metals in the colloidal fractions were not only related to organic matter, even though the colloidal humic substances are suspected to play a major role with respect to the speciation of the heavy metals. Free divalent Cd<sup>2+</sup> only made up a few percent of the total cadmium content. Most of the complexed fraction was characterized as labile complexes that easily could be redistributed to other dissolved species (Aziz et al., 2011). However, a small fraction (5 to 15%) was characterized as stable soluble complexes, defined as lack of ability to exchange with a cation exchange resin (Hunce et al., 2012). Out of three landfill leachates; in two of the investigation by Holm et al., (1995) about 20% of the total Cd content was determined to be Cd<sup>2+</sup>, while most of the Cd was identified as chloride complexes. The third leachate had high dissolved organic carbon content (3200 mg C/I) and most of the Cd in this leachate was complexed with the organic matter. In a study it was found that both low-molecular-weight compounds (<500) comparable to simple carboxylic acids and high-molecular-weight compounds (>10000) contributed significantly to cadmium complexation (Kamaruddin et al., 2013). A study was performed by Kamaruddin et al., (2013) with some speciation calculations on four leachates. Their calculations showed that 38% of Cd was present in complexes with organic ligands and 32% with inorganic ligands, while Zn and Ni were present in complexes (36% and 68%, respectively) exclusively with organic ligands. Suspended and colloidal solids presence and their types largely determine the electrical conductivity. In closed LFS many of the solids are already settled and concentration of those solid decreases with time. Intermediate age of landfill sites have greater electric conductivity than the closed landfill sites (Hunce et al., 2012). For the determination of the heavy metals and metal ions in leachate different kinetics used is:

#### For metals ions

Extended-Langmuir Isotherm Model and Langmuir-Freundlich Isotherm (Cu, Zn, Hg, Mn at constant b) is used.

 $C_e/Q_e = (C_e/Q_m) + (1/bQ_m)$  .....Equation 2.3 (Renau, 2008)

Multicomponent Isotherm, mass balance equation is used at pH 7.

 $\mathbf{Q}_{eq} = \mathbf{V}/\mathbf{M} (\mathbf{C}_0 - \mathbf{C}_{eq})$  .....Equation 2.4 (Refizul et al., 2012)

For Fe and Pb, Freundlich sorption Isotherm is used.

$$Q_e = K C_e 1/n$$
 .....Equation 2.5 (Rafizul et al., 2012)

Where Qe = adsorbent phase concentration after equilibrium

Co = initial concentration of adsorbate

Ce = final equilibrium concentration of adsorbate after absorption has occurred

V = volume of liquid in the reactor

M = mass of adsorbent

b = empirical constant, which is dependent to the concentration adsorbate

K = Freundlich capacity factor, which is dependent on pH

1/n = freundlich intensity parameter, which is dependent on pH

### 2.8 Design for Leachate Control

The bottom layer of soil may be natural existing material or it may be hauled in, placed and compacted to specifications following excavation to a suitable subgrade. In either case, the base of the landfill should act as a liner with some minimum thickness and a very low hydraulic conductivity (or permeability). Treatments may be used on the barrier soil to reduce its permeability to an acceptable level. As an added factor of safety, an impermeable synthetic membrane may be placed on the top of the barrier soil layer to form a composite liner. Immediately above the bottom composite liner is a leakage detection drainage layer to collect leakage from the primary liner, in this case, a geomembrane. Above the primary liner are a geosynthetic drainage net and a sand layer that serve as drainage layers for Leachate collection. The drain layers composed of sand are typically at least 0.30 m thick and have suitably spaced perforated or open joint drain pipe embedded below the surface of the liner. The Leachate collection drainage layer serves to collect any Leachate that may percolate through the waste layers. In this case where the liner is solely a geomembrane, drainage net may be used to rapidly drain Leachate from the liner, avoiding a significant buildup of head and limiting leakage. The liners are sloped to prevent ponding by encouraging Leachate to flow toward the drains. The net effect is that very little Leachate should percolate through the primary liner and virtually no migration of Leachate through the bottom composite liner to the natural formations below. Taken as a whole, the drainage layers, geomembrane liners, and

barrier soil liners may be referred to as the Leachate collection and removal system (drain/liner system) and more specifically a double liner system.

After the landfill is closed, the Leachate collection and removal system serves basically in a back-up capacity. However, while the landfill is open and waste is being added, these components constitute the principal defense against contamination of adjacent areas. Thus, care must be given to their design and construction. Day-to-day operation of a modern sanitary landfill calls for wastes to be placed in relatively thin lifts, compacted, and covered with soil each day. Thus, wastes should not remain exposed for more than a few hours. Although the daily soil cover serves effectively to hide the wastes and limit the access of nuisance insects and potential disease vectors, it is of limited value for preventing the formation of leachate. Thus, even though a similar procedure can be used for hazardous wastes, the drainage/liner system must function well throughout and after the active life of the landfill. When the capacity of the landfill is reached, the waste cells may be covered with a cap or final cover, typically composed of four distinct layers. At the base of the cap are a drainage layer and a liner system layer similar to that used at the base of the landfill. Again, a geomembrane liner would normally be used in conjunction with the barrier soil liner for hazardous waste landfill but has been used less frequently in municipal waste landfills. The top of the barrier soil layer is graded so that water percolating into the drainage layer will tend to move horizontally toward some removal system (drain) located at the edge of the landfill or subunit thereof. A layer of soil suitable for vegetative growth is placed at the top of final cover system to complete the landfill. A 0.60 m thick layer of soil having a loamy, silty nature serves this purpose well. The upper surface is graded so that runoff is restricted and infiltration is controlled to provide moisture for vegetation while limiting percolation through the topsoil. Runoff is promoted but controlled to prevent excessive erosion of the cap. The vegetation used should be selected for ease of establishment in a given area, promotion of evapotranspiration and year-round protection from erosion. The root system should not penetrate, disrupt or desiccate the upper liner system (Layers # 3 and # 4). Grasses are usually best for this purpose; however, local experts should be consulted to aid in selection of appropriate species. The combination of site selection, surface grading, transpiration from vegetation, soil evaporation, drainage through the sand, and the low hydraulic conductivity of the barrier soil liner serves effectively to minimize Leachate production from external water. Added effectiveness is gained by the use of geomembrane liners in the cap in conjunction with the barrier soil liner. The cap should be no more permeable than the Leachate collection and removal system so that the landfill will not gradually fill and overflow into adjacent areas

following abandonment of the landfill. This phenomenon is sometimes referred to as the "bathtub" effect.

#### 2.9 Gas Production in Landfills

Municipal solid waste (MSW) contains a significant fraction (30–50%) of organics. It can be a useful resource if this organic fraction could be used for power generation. Beside, rapid exhaustion of conventional energy sources has necessitated the search for alternate energy sources (Bhattacharya et al., 2007). Present municipal solid waste landfills generate biogas and leachate. Due the amount of waste, biogas production represents a very promising way to solve the problem of waste treatment. Furthermore, the solid residuals of fermentation might be reused as fertilizers. Landfill gas is a water saturated gas mixture containing about 40-60% methane, with the remainder being mostly carbon dioxide (CO<sub>2</sub>) (Bhattacharya et al., 2007). Landfill gas also contains varying amounts of nitrogen, oxygen, water vapor, sulfur and a hundreds of other contaminants. Inorganic contaminants like mercury are also known to be present in landfill gas (Adhikari et al., 2014). Biogas is produced during the methanegonic phase inside the landfill and the kinetics of growth of the bacteria methanogens during anaerobic digestion is

Organic matter +  $H_2O \rightarrow Biodegraded$  organic matter +  $CH_4 + CO_2$  + other gases

The produced biogas during the degradation of waste is determined by the ultimate analysis of the solid waste. The kinetics for the ultimate analysis of SW is estimated as:

$$C_{k1}H_{k2}O_{k3}N_{k4} + ((4k_1 - k_2 - 2k_3 - 3k_4)/4) H_2O \rightarrow ((4k_1 - k_2 - 2k_3 - 3k_4)/8) CH_4 + ((4k_1 - k_2 - 2k_3 - 3k_4)/8) CO_2 + k_4 NH_3 \dots Equation 2.6$$
(Yamamota, 2002)

The composition of biogas varies depending upon the origin of source for example the amount of hydrogen sulphide in the landfill gas varied from 36 to 115 ppm and in the farm biogas from 32 to 169 ppm, while hydrogen sulphide was not detected in the gas from the sewage digester (FNR, 2005). Biogas from sewage digesters usually contains from 55% to 65% methane, from 35% to 45% carbon dioxide and <1% nitrogen, biogas from organic waste digesters usually contains from 60% to 70% methane, from 30% to 40% carbon dioxide and <1% nitrogen while in landfills methane content is usually from 45% to 55%, carbon dioxide from 30% to 40% and nitrogen from 5% to 15% (Bhattacharya et al., 2007). Because of landfill gas (biogas) hazardous it is necessary to study about it to have a plan to use land fill biogas without any environmental problems. This causes to provide a qualified situation for both production and the best way using of biogas.

**Kinetics of biogas production and Gompertz equation:** Kinetics is the study of rates of processes. In biogas generation, kinetics can provide useful information such as the yield potential, duration of lag-phase, etc. With this information necessary adjustments to the contents of the digester can be made to enhance the production capability.

Several studies have been undertaken by different researchers using the Gompertz equation and its modified form to compare, analyse and determine various parameters in their work. Gil et. al., (2006) studied the inactivation behaviour under time-varying temperature conditions at the surface of a food products. The author used two heating schemes, slow heating and fast heating, to study the inactivation behaviour. Later, the data from the experiment and the simulated data were compared when they were fitted using the modified Gompertz equation. Modified Gompertz equation can be used to compare experimental and simulated values that are fitted with it.

Mu et. al., (2005) investigated the kinetics of batch anaerobic hydrogen production. The author used the modified form of Gompertz equation to determine the kinetic parameters. The modified Gompertz equation is given by,

$$P_{i} = P_{\max, i} \times \exp\left\{-\exp\left[\frac{R_{\max, i} \times e}{P_{\max, i}}(\lambda_{i} - t) + 1\right]\right\} \dots \text{Equation 2.7}$$

Biogas generation is a function of bacterial growth in batch digesters, modified Gompertz equation relates to cumulative biogas production and the time of digestion through biogas yield potential (P), the maximum biogas production rate ( $R_m$ ) and the duration of lag-phase ( $\lambda$ ). The parameters of batch growth curve were analytically quantified by fitting the modified Gompertz equation to the data obtained.

The modified Gompertz equation is given by,

$$M = P \times \exp\left\{-\exp\left[\frac{R_m \times e}{P}\left(\lambda - t\right) + 1\right]\right\} \dots \text{Equation 2.8}$$

Where,

M Cumulative biogas production, L g<sup>-1</sup> VS<sup>-1</sup> at any time t P Biogas yield potential, L g<sup>-1</sup> VS<sup>-1</sup>  $R_m$  Maximum biogas production rate, L g<sup>-1</sup> VS<sup>-1</sup> d<sup>-1</sup>  $\lambda$  Duration of lag phase, d

t Time at which cumulative methane production M is calculated, d

The biogas yield is taken as the 0.35 of total amount of volatile solids

University of Wisconsin-Madison, Solid and Hazardous Waste Education (2012) has concluded that the total gas generation depends upon the moisture content and volatile solids. The research center of same University has also stated that with time increases the production of the gas in operational landfill also increases as the rate of 1 - 4 cum. Ft per kg of MSW. The moisture content and the volatile solids can be known through the proximate analysis of the MSW. But still the researchers and the research institute are failed to explain the kinetics of the biogas production through the moisture content and volatile solids.

### 2.9.1 Biodegradation of Cellulose, Hemicelluloses and Lignin

Cellulose and hemicelluloses are the main biodegradable constituents of refuse containing 91% of the total methane potential. However, bacteria that can break cellulose down into its subunits are widely distributed in natural systems, and ruminants, such as cows, have these microorganisms in their digestive tract. Cellulose is a polysaccharide that is composed of glucose subunits. Lignin is an important structural component in plant materials and constitutes roughly 30% of wood. Significant components of lignin include coniferyl alcohol and syringyl alcohol subunits. Degradation of lignin requires the presence of moisture and oxygen and is carried out by filamentous fungi (Prescot & Harley et al., 1993). The biodegradability of lingo-cellulosic materials can be increased by an array of physical/chemical processes including pretreatment to increase surface area (size reduction), heat treatment, and treatment with acids or bases. Such treatments are useful when wood and plant materials are to be anaerobically degraded to produce methane. Three major groups of bacteria are involved in the conversion of cellulosic material to methane (Zehnder, 1978):

(1) the hydrolytic and fermentative bacteria that break down biological polymers such as cellulose and hemicelluloses to sugars that are then fermented to carboxylic acids, alcohols, carbon dioxide and hydrogen gas,

(2) the obligate hydrogen reducing acetogenic bacteria that convert carboxylic acids and alcohols to acetate and hydrogen, and

(3) the methanogenic bacteria that convert primarily acetate and hydrogen plus carbon dioxide to methane. Sulfate reducing bacteria (SRB) may also play a role in the anaerobic mineralization of cellulosic material. In the presence of sulfate, the degradation process may be directed towards sulfate reduction by SRB with the production of hydrogen sulfide and carbon dioxide (Barlaz et al., 1992).

Reactions that take place during the decomposition of the solid waste inside the landfill are explained by the equation below:

# i. <u>Hydrolysis/Liquefaction reactions</u>

 $\begin{array}{ll} \text{Lipids} \rightarrow \text{Fatty Acids} \\ \text{Polysaccharides} \rightarrow \text{Monosaccharides} \\ \text{Protein} \rightarrow \text{Amino Acids} \\ \text{Nucleic Acids} \rightarrow \text{Purines & Pyrimidines} \\ \hline \underline{\textit{ii.}} & \underline{\text{Acetogenis phase/RXN}} \\ \text{C}_6\text{H}_{12}\text{O}_6 \rightarrow 2\text{C}_2\text{H}_5\text{OH} + 2\text{CO}_2 & \dots & \text{Equation 2.9} \\ \hline \underline{\textit{iii.}} & \underline{\text{Methanegenosis phase/RXN}} \end{array}$ 

 $2C_2H_5OH + CO_2 \rightarrow CH_4 + 2CH_3COOH \dots$ Equation 2.10  $CH_3COOH \rightarrow CH_4 + CO_2 \dots$ Equation 2.11

## 2.9.2 Energy Recovery from MSW

Energy could be recovered from MSW by direct combustion in an incinerator or by anaerobic biodegradation and production of methane. Proximate analysis is used to measure moisture content, volatile matter, fixed carbon (combustible but not volatile), and ash. Proximate analysis can be used to predict ash production from incineration. The energy content is measured in a bomb calorimeter. Gas production from anaerobic digestion is typically 30% CO<sub>2</sub> and 70% CH<sub>4</sub>. The methane is a valuable fuel and has an energy content of 802.3 kJ/mol or 50 MJ/kg (Tchobanoglous, 1993). The combustion of methane produces only carbon dioxide and water. The bacterial degradation of MSW to produce methane will occur optimally at pH ranging 6.5 to 8, low ionic strength, in the absence of oxygen, nitrate and sulfate, in the presence of moisture and nutrients, and under mesophilic conditions (Gil et al., 2006).

# Chapter 3

# MATERIALS AND METHODS

# 3.1 Research Design and Approach

This research project was carried out with the leachate samples collected from Gokarna landfill, Sisdole landfill, Pokhara Municipal landfill, Dang landfill and Aletar landfill because these LFS represent the all ages/phases with the wide range of waste feeding amount. For the study of the biogas generation; Pokhara, Sisdole and Dang landfill sites were selected as these landfill sites are in operation phase.

The detail approach for the research is outlined below:



Sampling paramet	ers	
1. pH	5. Iron	13. N-NH
2. DO	6. Nickel	14. Sodium
3. COD	7. Copper	15. Magnesium
4. BOD	8. Zinc	16. Calcium
	9. Cadmium	17. Chromium
	10. Lead	18. Hydrogen Sulphide
	11. Mercury	
	12. Chloride	

Table 3.1: Physicochemical parameters of leachate study

## 3.2 Study Sites

In Nepal there are 191 municipalities out of them only six municipalities have somehow managed landfill sites. Out of them Pokhara, Dang and Sisdole/Aletar (a LFS within Sisdole) landfill sites have leachate collection pond. The following study sites were selected for the current study because these sites represent the all phases/age i.e closed and operational and also the young, intermediate and mature state of LFS with wide range of feeding amount. Aletar is closed and young age of landfill site which received 410 tons/day wastes whereas Gokarna is mature and closed dumping site. Pokhara, Dang and Sisdole are operational with intermediate age of LFS with 80 tons/day, 7.8 tons/day and 500 tons/day waste feeding amount. The detail descriptions of the sites are listed below:



Figure 3.1: Study sites

The Summary of the study sites has been listed in table 3.2 and 3.3.

Table 3.2	Summary	of the	study	sites
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LFS	Location	Leachate Treatment System	<b>Construction</b> (A.D)	<b>Operation</b> (A.D)	Current Age	Design Capacity	Current feeding rate to LFS
Gokarna	Gokarna, Kathmandu Metropolitan City 14 km from Teku TS	Leachate collection pond	1984 June	1986-2000	27 years	270 tons/day	300 tons/day
Sisdole	Okharpauwa, Nuwakot 25 Km from Teku TS	Leachate collection pond with semi aerobic recirculatory system and floating type slow speed surface aerator	1992 July	June 2005 -till date	8 years	313 tons/day	410 tons/day
Aletar	Okharpauwa, Nuwakot 25 Km from Teku TS	Leachate collection pond with semi aerobic recirculatory system and floating type slow speed surface aerator	1992 July	June 2005 - July 2009	8 years	313 tons/day	410 tons/day
Pokhara	Bachhe Buduwa- 18 PSMC 6 Km from city	Constructed wetland (CW)	1997 Dec	Jan 2004 - till date	9 Years	120 tons/day	80 tons/day
Dang	Karaute Dada-9, Dang, 1 Km away from city	Filtration with disinfection	2001 June	may 2005 - till date	8 years	10 tons/day	7.2 tons/day

**Waste Management Practices at Different Landfills:** The litter and odor problem was dominant at Sisdole LFS, while there was a slight problem at Pokhara but there was very less dominant litter and odor problem at Dang. Since relatively less waste was generated in other landfill site except Sisdole, wastes were collected and directly brought to the landfill site so they have less odors. But in case of KMC large amount of waste is produced so it is first taken to the transfer station (Teku) and then transported to the Sisdole LFS. Therefore due to long period of waste storage more odor was generated.

Pokhara and Ghorahi municipalities use the modern vehicles for collection of waste where the wastes is transferred in a special vehicle designed for waste transfer and transferred to the LFS, so odor was minimal. But KMC uses normal trucks, that covers the waste with plastics and transfer to the LFS, so more odor comes from it. Also they pour leachate in the way to the landfill site, which causes problem to the local people.

The waste management practices at these study sites are highlighted in table 4.1.

Parameters	Sisdole/Aletar	Pokhara LFS	Dang LFS	Gokarna
	LFS			
Sorting at site	No	No	Yes	No
Provision of composting	No	No(future plan)	Yes(not functional)	No
Provision of selling reusable and recyclable waste	No	No	Yes	No
Land filling type	Area	Area	Area	Area
Provision of spreading waste	Chain dozer	Chain dozer	Manually	Chain dozer
waste compaction	Yes	Yes	No	Yes
Gas collection	No	No	No	No
Soil cover	10-20 cm	10-20 cm	10-20 cm	15 cm
Littering problem	High	Slight	No	High
Odor problem	High	Slight	Slight	Slight
Industrial contamination	Yes	Yes	Yes	Yes
Medical contamination	Yes	Yes	Yes	Yes

Table 3.3: Waste management	practices at landfills (sou	rce: field observation, March 2013)
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### 3.2.1 Sisdole Landfill Site

The site was constructed as a pilot project under the financial and technical assistance of Japan International Co-operation Agency (JICA) to operate for a short-term period (2-3 yrs) to bridge the time till the development of a long-term sanitary landfill for proper management of solid waste in the cities of Kathmandu Valley.

The landfill site covers a total area of 15ha, out of which the actual landfill area cover 2 ha, site protection/ buffer zone including the forest up to the hill on the northern side of the newly constructed access road to Okharpauwa covers 12 ha, and the rest 1 ha is covered by other facilities for waste management such as administrative complex, internal service road, leachate treatment facilities etc.

The landfill consists of two basins (valleys) valley I & II. The area of first valley is 11200 square meters with a volume capacity of 166085 cum and that of second valley is 9501 square meters with a volume capacity of 108910 cum.

The length of 1st valley is 120m with 4% lateral and 1% longitudinal gradient. The drainage material consists of 50 to 150mm sized gravel (sub-angular or sub-rounded). The valley I was proposed to 2m of land filling and to be topped with clayey soil at 2 layers with 30cm thick which could reduce the landfill life by 1000 cum (Thapa et al., 2009). The Valley I was estimated to last for approx. 14-15 months at the targeted rate of 313 tons/day of incoming waste. The valley I was established with an average width of 40m stretches from south to north upwards between a level of 147m (flood level) and 174m (existing road level). But the land filling in this valley started only from a level of 153m, so that leachate treatment facilities can be safely accommodated within the level difference of 6m approx. to the flood level. The valley II was established with an average width of 60m stretches from north-west to south-east downwards between a level of 151m (flood level) and 174m (existing road level). But the land filling in this valley started only from a level of 157m to make provision for leachate treatment facilities at the downstream.

*Technical Description:* In this site liner basement was prepared by excavating the sub-soil to the depth required to attend the design level after compacting, giving a longitudinal slope of 3% and two-way cross slope of 4% to the central line of the valley. Over this compacted liner basement, bottom layer of clay liner is laid with a compacted thickness of 25 cm. Over this "bottom layer" with uniformly defined density, a second layer of clay (top layer) was placed and compacted similarly for another compacted thickness of 25 cm.

A layer of jute mat was placed over the top layer of the mineral liner to protect its top surface. The surface of jute mat was then covered with a thick layer of gravel (river bed shingles/ pebbles of grain size 30 - 50 mm) forming a drainage carpet. Additionally the facilities like natural liner system, leachate collection system, Gas vents system, leachate retention pond, leachate re-circulation and aeration system, storm water/ surface water drainage system, improvement of waste bordering dam, improvement of control room, weighbridge, and internal service road were constructed.



Figure 3.2: Sisdole and Aletar landfill sites

*Soil provision for cover material and liner basement:* For the purpose of preparing proper liner basement for the clay liner in slope, line and level, earthwork in excavation and filling was done. The excavated material was a mixture of silt clay, gravelly sand and soft rock to some extent. The hydraulic permeability of the soil is in the range of approx. 104 to 109 m/s and was therefore suitable for waste covering purposes i.e., daily, intermediate and final covering.

*Leachate Treatment System:* It has leachate collection pond with semi aerobic recirculatory system and floating type slow speed surface aerator for leachate treatment. The design leachate quantity is 45 cum/day for the retention time being 7 days. The leachate from the landfill is collected in a leachate retention pond of volume 408 cum and surface area of 334 square meters. The pond has a depth of 1.25m with the maximum leachate retention level at a depth of 1.25m below the invert level of leachate outlet pipe, so that fresh air can easily pass though the pipe opening into the waste layers. The pond is lined with 2 layers of 350 micron HDPE sheet covering all surfaces and is bordered at the top of its embankment along all four sides with stone masonry work which not only increases its retaining capacity beyond the overflow level, but also fixes the plastic sheet in position. The leachate is aerated in a pond through aerator system which is a floating type slow speed surface aerator of 15 HP (11kW approx.) and is regarded as biological aerobic system. The aerated leachate is a long portable

flexible hose pipe of 175m length and 80mm diameter. The sprinkler used for the spraying of re-circulated leachate over waste cells is a perforated PVC pipe of 80mm diameter. At present, both the aerator and recirculation pump is not in function due to lack of operation and maintenance and insufficient electricity supply in the country.

# 3.2.2 Pokhara Sanitary Landfill Site

The landfill site having total area of 10 ha is situated at *Bachhe Buduwa* in ward no: 18 of Pokhara Sub metropolitan about 8 km south of *Prithivi* Highway. The site is nearby the converging point of *Seti* river and *Phusre Khola*. It is located at an altitude of 670m above MSL and 124 m below the normal operating level of Phewa Lake. The terrain longitudinal slope along east to west is of about 2% and about 3% along north to south.

The construction of the site was started in Dec 1997 and completed on June 2003. The site was inaugurated on Jan 2004, now it has completed 9 years of operation.





# Technical Description:

*Liner Basement:* Liner basement was prepared by excavating top soil and compaction was done by road roller till full consolidation to proctor density of minimum 95%. The standard HDPE geo-membrane was laid over the prepared basement by joining the sheets with standard technology for 100% water tightness.

*Jute Mat:* The standard quality jute mat was laid over the HDPE liner for the protection of geo-membrane surface from being damaged due to vehicular movement over waste layers during landfill operation. The leachate under drain pipes laid over the jute mat, the area was covered with 30cm-thick leachate drainage layer of round river shingles.

*Waste Water/ leachate collection ditch:* It was constructed at the foot of the earthen protection dam which collects the waste water run-off from the bordering dam and leachate

coming out of the landfill area.

*Septage and Leachate treatment Plant:* Septage and leachate treatment plant was constructed for all wastewaters like municipal waste water, landfill leachate and other waste water being developed in the site.

*Reed Bed treatment System for Leachate and Septage:* Reed Bed treatment system is being used for the treatment of leachate and septage in Pokhara LFS. It uses the hybrid form of Reed Bed System with intermittent tank before both of the reeds, i.e. horizontal and vertical. The area of the HRB and VRB is  $1105 \text{ m}^2$  and  $2203 \text{ m}^2$  respectively. The designed flow of leachate is  $40\text{m}^3$ /day and that of municipal septage is  $75 \text{ m}^3$ /day, which is not in operation these days. The base of HRB has a 1% longitudinal slope and a 2% transverse slope in two ways. The base of VRB has only 1% longitudinal slope.

*Dilution of the treated effluent:* The treated leachate after reed bed treatment system is then diluted by the surface water overflow of the surface water collection basin before discharging to the Seti River.

#### **3.2.3 Dang or Karaute Danda Landfill Site**

The sanitary landfill site located at ward no. 9, *Karaute Danda*, which is situated 1km away from settlement area. The site is protected by a barbed wire fence with enough emphasis given for buffer zone. The landfill site is designed using local technologies and less engineering practice but it is considered to be one of the best managed landfill sites of Nepal (Thapa et al., 2009). The total area of landfill site is 20 ha. The land was not being used for a long time since 1970 AD, which was later used for plantation purpose. After IAP (Integration Action Plan) suggestions and suitability it was proposed for landfill site of Tribhuwan Nagar municipality (now *Ghorahi*). The positive soil test result further enhanced the plan to be implemented.

*Technical Description:* The total area of landfill site is 20 hectare. Only 1 hectare land has been utilized for waste management while rest of the land is used for fruits and tree plantation. The landfill site shall not be considered a sanitary landfill site as the landfill site is not engineered, though there is the provision of waste segregation house, composting unit and collection house of plastic and paper.

*Soil tests:* As per the Report on investigation of subsurface geologic/soil condition of the proposed waste disposal site at Karaute dada, Tribhuwan Nagar municipality, Dang, (Rimal, 1999) under Environmental geology project and department of mines and geology (DMG)

- > The permeability of the soil ranged from 1.7x10-7 to 8.8x10-8 m/s
- Clayer silt was 7m thick

## ➤ Shallow water level was 8 m below

# > The texture and CEC were found favorable for LFS

No liner basement is placed. There are certain depressions where the wastes are dumped. The valley one is filled up completely and the plantation is done. Nowadays next valley is being used for the disposal of waste.



Figure 3.4: Dang (Karaute Dada) landfill site

*Land filling Area:* The waste disposal was area method. It was observed that the waste disposal was in a slope with no liners used and no perforated pipes under the waste disposal site. The permeability of the soil was high so the leachate will not leach to the groundwater was assumed and the drainage was made at the base of the site, with no leachate leaching, the leachate was assumed to flow through the drainage to the leachate treatment plant. The 2nd site currently used for the waste disposal is also area method. The area of about 500 sq m is used for the waste disposing purpose with leachate treatment plant.

*Soil Provision for cover material:* The land is excavated from any part of the site and is used for covering. The The permeability of the soil ranged from 1.7x10-7 to 8.8x10-8 m/s at the site. The same soil is used as covering material.

*Transfer Station:* There is a house built at LF which has filtration chamber within where the vehicle unloads the waste. Vibration is not possible at the site so the waste could not be filtered.

*Leachate Treatment Plant:* Leachate Treatment Plant is constructed at the base of old valley used for the waste disposal which is full now. It has a sedimentation tank of size 10x10x2 cum. It was followed by 2 filtration chambers of size 10x3x2 cum and 10x2x2 cum respectively followed by disinfection chamber of 2x2x1.82cum which is discharged through the drain.

## 3.2.4 Gokarna Landfill Site

Gokarna Landfill site with an altitude of 1342 m, is located in the small valley northeast of Kathmandu along the road to Sakhu, at a distance of 14 km from the Teku transfer station at Kathmandu. It lies in Mulpani, V.D.C in ward number 2, 4, 5 and 8 to the North of which are Jorpati and Thali Dachhi V.D.C, to the west in Gothatar, V.D.C and Bhaktapur district on other two sides. In 1976 after an assessment of 12 possible landfill sites, Gokarna landfill site, located at the southern edge of the Gokarna Forest, was chosen. The area was seen as exemplary both aesthetically and environmentally for construction of a landfill. Before opening several investigations on the geological, hydrogeological and geotechnical conditions of the area were carried out and closeness to the Tribhuvan International Airport was the only negative aspect considered when it opened for final disposal on 9 November 1986. When the site was chosen in 1976 its volume was estimated to be 10 million m<sup>3</sup> but further examination showed just a volume of 1.1 million m<sup>3</sup> (SWRMC, 2013 Kathmandu).



# Figure 3.5: Gokarna landfill site

The construction started in 1984 and consisted of a small office building, a small guard house, a dozer garage, the foundation of the landfill, channeling of the surface water, a cross wall, a leachate pond and a boundary wall. To make compromises with the surrounding settlement the project constructed a pond for the animals, a road approaching the Mulpani Village and a water supply system. Gokarna landfill was ready for operation 1985 but before opening a

bridge across Bagmati River had to be constructed and the landfill was set in operation in late 1986.

*Closure:* Landfill was finally closed at the end of June 2000 since the site was considered full. No alternative landfill site to Gokarna landfill was available and the government did not provide the 10 ha of land that KMC had requested for a compost plant. KMC was again forced to start the dumping along Bagmati River.

## **3.3 Sample Collection**

The samples were collected bimonthly for a year. The first sampling was done on March 2013 and sixth sampling was done on January 2014. The data were compiled as seasonal variation namely; pre-monsoon, monsoon, post-monsoon and winter seasons through Principal Component Analysis (PCA) command in SPSS. The detail sample size has been shown in table 3.4.

	Tabl	e 3.4	: Sampl	le size
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	Number of	sampling point	Total samples						
		leachate							
LFS	Trenchs	collection pond	Mar, 013	May.	Jul.	Sept.	Nov.	Jan, 014	Total samples
Sisdole	4	1	25	25	25	25	25	25	150
Aletar	4	1	25	25	25	25	25	25	150
Pokhara	4	1	25	25	25	25	25	25	150
Dang	4	1	25	25	25	25	25	25	150
Gokarna	3	0	15	15	15	15	15	15	90

### 3.3.1 Leachate Sample

1 litre leachate sample from the leachate collection pond and 1 litre leachate sample from four different leachate generating trenches (15 cm below the surface of leachate) of each study landfill sites were collected on the standard sampling bottles in March, May, July, September, November of 2013 and January of 2014. Altogether 30 samples were collected from single landfill sites in study period. pH and DO were measured in field. The sample was collected using plastic bottles of 1 litre. The sampling bottles were rinsed three times before the final sample was taken. It was taken care so that no air bubbles were formed when sampling work was done. Labelling of the samples was done at the site itself as name and location of the sample, date, time of sampling, and depth of the sampling site.

![](_page_62_Picture_0.jpeg)

Figure 3.6: Sample collection

- 5ml conc.HNO<sub>3</sub> were used for the preservation of metals HNO<sub>3</sub> is added to reduce pH <2.</li>
   Below pH 2, precipitation, adsorption to container wall and microbial degradation are minimized. Secondly, sample digestion is required before AAS. Digestion converts all form of metal into a single oxidation state.
- ii. Chloride was used to preserve COD of the sample in-order to inhabit the biological activity in the sample.

Leachate samples were collected from the base of solid waste heaps (trenches) where the leachate was drained out by gravity.

Leachate samples were collected from the same locations at every sampling time to determine the effect of age and seasonal variations on leachate characteristics of MSW landfill. Various physicochemical parameters (table 3.4) were analyzed. Collected leachate were preserved and taken to the pollution control laboratory, Kathmandu University and National Environmental Scientific Services (NESS) laboratory, Babarmahal, Kathmandu for the analysis.

Parameters	Analytical Test	Instrument Specification/protocol
pH	Digital pH meter	EcoSense pH10A pen-style digital pH meters
BOD <sub>5</sub>	Winkler Azide modification (dilution and seeding)	5210 B, APHA, ISO 5815-1989
COD <sub>cr</sub>	Potassium Dichromate Reflux	5220 B, APHA
DO	Digital DO meter	Max digital dissolved oxygen cum temp. ME-981
Tot-N (mg/L)	Macro Kjeldahl Digestion,	4500-Norg B:APHA
Tot-P (mg/L)	Ascorbic Acid	4500 - PE,APHA

Table 3.5: Parameters for the leachate characterization

Fe (mg/L)	Direct Air- Acetylene	AAS, 311 B,APHA
Cd (mg/L)	Direct Air- Acetylene	AAS, 311 B,APHA
Cr (mg/L)	Direct Air- Acetylene	AAS, 311 B,APHA
Cu (mg/L)	Direct Air- Acetylene	AAS, 311 B,APHA
Hg (mg/L)	Cold vapour	AAS, 3112 B:APHA
Ni (mg/L)	Direct Air- Acetylene	AAS, 311 B,APHA
Pb (mg/L)	Direct Air- Acetylene	AAS, 311 B,APHA
Ammonia (mg/L)	Direct nesslerization	4500- NH3 C APHA
Chloride (mg/L)	Argentometric Titration	4500-Cr b, APHA
Zn (mg/L)	Direct Air- Acetylene	AAS, 311 B,APHA
Ca (mg/L)	EDTA Titrimetric	3500-Ca B & 3500-Mg B APHA
Hydrogen Sulphide (mg/L)	Iodometric Titration	3500-S2 F, APHA

Analytical methods were followed according to "Standard methods for examination of water and wastewater" specified by American Public Health Association (APHA - 2012). APHA method was used because it is well established and widely accepted method in the analysis of water and waste water samples. Moreover this method is easily accessible for testing methods and reference (Aziz et al., 2004). For the analysis of metals AAS (Trace AI 1200 serial No. 1200-AI 22/03) was used in laboratory.

Data of one year were assembled into four seasons namely pre-monsoon (March, April, May), monsoon (June, July August), post-monsoon (September, October, November) and winter seasons (December, January, February) of Nepal. A One way **ANOVA** tool was used in SPSS to analysis the data obtained from lab analysis. The landfill data were categorized separately for all the landfill sites. Dividing the data by age of landfill sites and seasonal variation was a means of regionalizing the landfills throughout the state. In order to determine whether the value of each parameter (e.g. BOD, COD, etc.) differed regionally, a single factor analysis of variance (ANOVA) was used. This method was employed because the ANOVA is used to test for differences among the means of two or more populations. Single factor means that only one type of grouping is being considered (McBean et al., 1998). In this case, seasonal variation was the classification considered. Finally the p-Value was obtained to draw the conclusion on the significance differences of parameters in accordance with the seasonal variation with the age of landfill sites.

The null hypothesis (**Ho**) tested in a single factor ANOVA is that the means of two or more populations are equal (McBean et al., 1998).

H<sub>o</sub>: 
$$\mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5$$
  
Where:  $\mu$  = sample mean

Therefore, the alternative hypothesis  $(H_1)$  is that at least one of the means differs from the others.

$$H_1: \mu_1 - \mu_2 - \mu_3 - \mu_4 - \mu_5$$

A standard level of significance of five percent (equal to 0.05) was chosen. The decision to reject or accept the null hypothesis was based on the comparison of the computed F statistic to F critical.

The F statistic is the ratio of the mean square between groups to the mean square within groups.

$$MS_{w} = \frac{SS_{w}}{N-k}$$

Where,  $MS_w =$  Mean square within group

 $SS_w = Sum of square within group$ 

N = total number data points

K = number of groups

$$MS = \frac{SS}{k-1}$$

Where,  $MS_b = Mean$  square between group

 $SS_b = Sum of square between group$ 

K = Number of groups

The numerator of the F statistic is thus influenced by the observed differences between the groups, while the denominator represents the error term since it is derived from variation within groups (Ary and Jacobs, 1976). As the difference among the groups increases, the F statistic increases. F critical is a tabulated value and represents the rejection region of the F distribution as specified by the alpha value. If the F statistic does not exceed F critical, the

null hypothesis is retained. Conversely, if the F statistic exceeds F critical one would reject the null hypothesis of equal population means.

### 3.4 Waste Sample Collection

The samples were collected bimonthly for a year. The first sampling was done on March 2013 and sixth sampling was done on January 2014. Waste sample of 100 kg from each vehicle at Dang, Pokhara and sisdole LFS was taken at each sampling time. The sampling was done taking three vehicles at Dang (300 kg waste), five vehicles at Pokhara (500 kg waste) and seven vehicles at Sisdole (700 kg waste) LFS in each sampling time. It was assumed that twenty percent sampling vehicles would represent the overall composition of the waste of the landfill sites. The samples were on the plastic mat so that no wetting effect was observed. The fractional minute particles remained after the compositions were sampled for lab analysis.

### 3.4.1 Waste Composition Study

Composition study of the waste was done using the waste reduction method. In this method, all the samples collected were thoroughly mixed. The total wastes were divided into four quarters. Diagonal wastes were taken of a side and the remaining wastes were ignored. The diagonal wastes were again mixed thoroughly and similar process was followed two more times. The wastes were segregated as organic waste, plastics, paper, glass, rubber/leather, textile, metal, construction and demolition waste and others (having less economic value). The same procedure was followed at each sampling time.

#### 3.5 Biogas Generation Study

### 3.5.1 Laboratory Analysis of Solid Waste

Proximate analysis of the solid waste was done at NESS laboratory at Babarmahal, Kathmandu and Pollution Laboratory in Kathmandu University. For moisture content, oven drying method was used. This procedure was performed in the sample that had been ovendried at 105<sup>°</sup>C for 1 hour. The method quantitatively determined the dry matter content based on the gravimetric loss of free water associated with heating. For analysis of volatile solid, gravimetry method was adopted (APHA, 2012). Total Nitrogen was calculated using Kjeldahl Digestion method (PAO, 2008). Organic matter was calculated using Walkley and Black method in which the organic matter / carbon in the sample was determined by wet oxidation method (APHA, 2012). The moisture free sample was treated with potassium dichromate in acidic condition and heated to 150°C for 30 minutes. The amount of organic carbon in the sample was determined by measuring the amount of unreacted dichromate by titrating with standard ferrous ammonium sulfate. Then the C:N ratio was calculated dividing the organic carbon to total nitrogen (APHA, 2012).

# 3.5.2 Data Compilation and Analysis of Solid Waste

Microsoft excel was used for compilation of data obtained in the field. Vehicle log sheet was observed to know the average numbers of trips done by each vehicle in landfill sites. These information were used for quantification of solid waste.

## 3.5.3 Calculation of Biogas Potential

The total waste reaching the landfill site was calculated, and percentage of organic fraction was measured at site using waste reduction method. Percentage of Total Solids was calculated from moisture content of organic fraction. Volatile solid (VS) was determined at lab. Then the methane yield was calculated assuming 0.35 cum/kg VS (AEPC, 2014), (P. Oleary, 2012). The calculation was done as:

a. Total waste that reaches to landfill or transfer station was calculated.

b. Moisture content (M%) was determined in lab by proximate analysis

c. Percentage of Total Solids was calculated from (100 - M%)

**d.** Percentage of organic waste obtained from composition analysis was used for calculation of organic fraction of solid waste.

e. Percentage of Volatile solid in solid waste was determined from laboratory test at NESS laboratory Babarmahal, Kathmandu

f. Unitary method was applied to calculate the total Volatile solid in Total solid of waste.

**g.** Similarly by using 0.35Biogas yield (cu.m/kg VS) total biogas potential (cu.m/day) and per kg yield was calculated.

### **Calculation method**

a. Total waste quantity in a day: W (tons)

b. Moisture content: M %

 $M(\%) = ((W1 - W2) / W1) \times 100$ 

Where,

W1 : Weight before ashed (Crucible + dried sample) - crucible

W2 : Weight after ashed (Crucible + dried sample) - crucible

**c.** Organic waste = O% of organic fraction of waste \* 1000 (kg)

**d.** Total Organic solid: TS= Organic waste  $\times$  (100- M)% (kg)

e. Percentage of Volatile Solids: Vs%

**f.** Volatile Solid (VS) = Vs%  $\times$  TS (kg)

**g.** Typical bio-gas (methane) yield: B ( $m^3$ ) = 0.35 ( $m^3$  / kg. of VS)

**h.** Bio-gas (methane) yield in day = VS  $\times$  B (m<sup>3</sup>)

**i.** Energy generated per cubic meter of Biogas = 6 KWh

**j.** Percentage of methane in Total Biogas production = 65%

**k.** Energy generated in MW = (methane yield in day×6×100) / ( $65 \times 1000 \times 24$ )

**I.** Using MATLAB software the biogas generation equation was derived.

*MATLAB:* Matrix Laboratory abbreviated as MATLAB, developed by Math Works, is a multi-paradigm numerical computing environment and fourth generation programming language optimized to perform engineering and scientific calculations. The MATLAB program implements fourth generation MATLAB programming language and provides a very extensive library of predefined functions to make technical computing tasks easier. MATLAB is rich programming environment with rich variety of functions; basic version of MATLAB contains more than 1000 functions, which is much richer than other technical programming languages. Problems that we tackle in real engineering world like, matrix manipulations, plotting of different functions, implementation of complex algorithms, etc. can be solved by MATLAB very easily.

### **3.6 Data Analyzation and Compilation**

One year leachate samples which were collected bimonthly were grouped into four seasons. Principle Component Analysis (PCA) was used for data compilation. PCA is the technique used to emphasis variation and bring out strong patterns in a data set. It is used to make data easy to visualize.

Finally the result obtained from above analysis and calculations were presented as:

- Closed Vs Operational landfills
- Leachate quality and seasonal variation
- Leachate quality as per the age categories
- > Potential biogas generation calculation through moisture and volatile solids

## **Chapter 4**

# **RESULTS AND DISCUSSION**

# 4.1 Waste Characteristics

# 4.1.1 Quantification of Waste

The yearly average quantity of waste in all seasons was found to be 410, 78 and 7.06 tons/day at Sisdole, Pokhara and Dang Landfill site respectively. Waste quantification was found significantly indifference seasonally in all landfill sites (p > 0.05).

LFS	Yearly average	Pre-monsoon	Monsoon	Post-monsoon	Winter	p-value
SLFS	$410 \pm 12$	410.4	408	413	409.6	0.98
DLFS	$7.8 \pm 0.24$	7.6	7.8	7.10	7.4	0.84
PLFS	80 ± 1.33	78	80	82	80	0.72

Table 4.1: Quantification of solid waste at different LFS in tons/day

### **4.1.2** Composition of Waste

Composition of solid was determined by waste reduction method. The percentage of organic content of solid waste was relatively greater in all three landfills with the least percentage of 52.5% at PLFS to 65% in DLFS and 61.6% at SLFS. The percentage composition of plastic ranged from 8-12, paper 10- 1.5, glass 3-6, rubber 2-4, textile 2-4, metal 0.4-1.5, construction demolition 4-6 and others 2-4. Glass, plastics, rubber, leather and textile were relatively higher in composition at PLFS. This may be due to the fact that larger number of tourists at the city consuming more packed foods and the living standard of the people in Pokhara is also high than that of the other area. Organic, plastic and paper content of the waste are higher at all landfill sites.

Composition	SLFS	PLFS	DLFS
Plastic	10	12	8
Paper	10	10	11.5
Glass	5	6	3
Rubber	3	4	2
Textile	3	4	2
Metals	0.4	1.5	0.5
Cons. & Dem.	4	6	6
Organic	61.6	52.5	65
Others	3	4	2

Table 4.2: Yearly average percentage composition of solid waste at different LFS

![](_page_69_Figure_0.jpeg)

The p – value for all parameters were > 0.05. So that average value was taken for the calculation.

Figure 4.1: Yearly average waste composition study at different LFS

### 4.1.3 Volatile Solids (VS)

Volatile solids also called as "organic solids" are that fraction of total solids which can be burnt (volatilized) in the muffle oven at 520°C. Only the volatile solids can be broken down by anaerobic digestion (APHA, 2012). The VS ranged from 39.63% - 44.41% in studied sites. Dang has highest value of Volatile solid and Pokhara has the lowest value. Average value of volatile solids for Sisdole, Pokhara and Dang LFS were 44.41%, 39.63%, 58.47% respectively. The highest percentage of organic waste has shown high valve of VS and vice versa. The difference was statistically insignificant (p > 0.05) in different seasons within the same LFS.

Table 4.3:Seasonal variation of VS (%) in different landfill sites	

Location	Average	Pre-monsoon	Monsoon	Post-monsoon	Winter	p-value
Pokhara	39.83	39.85	39.83	39.83	39.82	> 0.05
Dang	58.47	58.47	57	58.4	59.63	> 0.05
Sisdole	44.4	44	45	44.6	44.8	> 0.05

# 4.1.4 Moisture Content

High water contents are likely to affect the process performance by dissolving readily degradable organic matter (Thapa et al., 2009). Yearly average value of moisture content for Sisdole, Pokhara and Dang Landfill Site were 69.03%, 85%, 82% respectively and these values were seasonally significantly difference (P < 0.05) within the same LFS. The moisture

content in waste is higher in monsoon season than in other seasons The average value of moisture content in table 4.4 imply that the compaction is not done properly at Pokhara and Dang Landfill Site.

Location	Average	Pre-monsoon	Monsoon	Post-monsoon	Winter	p-value
Pokhara	85%	82%	89%	86.5%	81.5%	< 0.05
Dang	82%	78%	85%	83%	79%	< 0.05
Sisdole	69.03%	68%	71%	71%	67%	< 0.05

Table 4.4: Seasonal variation of moisture content (%) in different landfill sites

### 4.1.5 C:N Ratio

Values of C:N ratio of Sisdole, Pokhara and Dang Landfill Site were 18.82, 19.03 and 19.62 respectively. The difference was statistically insignificant (p > 0.05). These values are near to 20 which are best for anaerobic digestion of organic waste (AEPC, 2014). Microbial decomposers obtain many nutrients from the composting materials but carbon (C) and nitrogen (N) are the nutrients that affect the process the most. Microorganisms primarily use carbon compounds as an energy source and ingest nitrogen for protein (Thapa et al., 2009). If ratio is high, then low nitrogen will slow decompose and if low then excess nitrogen is lost through gas as ammonia and also produce odor problem (Adhikari et al., 2014). The C:N ratio of 20–30 may provide sufficient nitrogen for the process. AEPC, 2014 suggested that a C:N ratio between 22 and 25 seemed to be best for anaerobic digestion of fruit and vegetable waste.

Location	Average	Pre-monsoon	Monsoon	Post-monsoon	Winter	p-value
Pokhara	19.03	18.06	18.04	19.06	19.94	> 0.05
Dang	19.62	19	20	19	19.89	> 0.05
Sisdole	18.82	18.34	18.98	18.68	18.86	> 0.05

Table 4.5: Seasonal variation of C:N ratio (%) in different landfill sites

### **4.2 Physical Parameters**

# 4.2.1 pH

The pH value ranged from 6.5 to 8.7 in studied sites. Highest pH was found in GLFS and lowest at PLFS and the difference was statistically significant (p < 0.05). Except in GLFS, pH was found significantly difference seasonally in all other landfill sites. pH values were also found significantly difference in operational and closed landfill sites (p < 0.05) as well as in young, intermediate and mature landfill sites (p < 0.05). The detail value is given in table 4.2, 4.3 and 4.4. The pH value of mature LFS sites was found to be high. A similar pH was

observed in closed LFS (Aletar) which is young, closed earlier and the pH was found similar to intermediate and operational LFS. The pH varied according to the age of landfills because matured LFS complete the acetogenic phase and operates methanogenic stage but for the new LFS, acetogenic phase is dominant (Kulikowska et. al., 2008). Kulikowska et. al., (2008) reported that; as methanogenic stage developed in landfill methane gas combined with water to form methanol and thus increase the pH of the leachate. As GLFS is matured LFS, SLFS being operated for almost 9 years with large amount (410 tons/day) of waste feeding amount, hence the pH was higher than 7.5. Other two LFS's namely DLFS & PLFS are comparatively new which receive less amount of waste/day as compared to SLS and the pH was slightly acidic. The pH values remained within the permissible limit (6.0-9.0) as investigated by other researchers (Renou et al., 2008, Aziz et al., 2012, Tatsi et al., 2002). In case of Aletar LFS, the pH value is 7.9-8.0 although it is young LFS. This happens because the LFS was operated for 3 years with feeding amount of 410 tons/day waste and 2011 the LFS didn't receive any waste. At this LFS the stabilization process went very rapidly and at present this LFS is at late methanogenic phase.

By chemically adjusting the pH we can remove heavy metals and other toxic metals from water. In most runoff or wastewater, metal and other contaminants are dissolved and are not settle out. Any chemical reaction in aqueous solution always related to  $H_2O \iff 2H^+ + OH^-$ ions. As stated by Tatsi et al., (2002) and Renou et al., (2008) the biological decomposition is a complex chemical procedure that also depends on pH very much. Waste composed of huge number of organic compounds like protein, amino acids, lignin, Polysaccharides etc. of which conversion to the simpler compounds like  $CO_2$ ,  $H_2O$ ,  $CH_4$  and other nitrogen associated compound follows the chain of chemical reaction in which water is major platform.

Location	Range	Pre-monsoon	Monsoon	Post-monsoon	Winter	p-value
Pokhara	6.5-6.8	$6.5 \pm 0.089$	$6.5 \pm 0.09$	$6.6 \pm 0.08$	$6.8 \pm 0.06$	< 0.05
Dang	6.8-7.1	$6.8 \pm 0.09$	$6.9\pm0.09$	$7.0 \pm 0.07$	$7.1 \pm 0.07$	< 0.05
Sisdole	7.6-7.9	$7.6\pm0.07$	$7.7 \pm 0.05$	$7.8\pm0.03$	$7.9 \pm 0.05$	< 0.05
Aletar	7.9-8.1	$7.9 \pm 0.12$	$7.9 \pm 0.14$	$8.0 \pm 0.18$	$8.1 \pm 0.19$	< 0.05
Gokarna	8.6-8.7	$8.6\pm0.019$	$8.6\pm0.019$	8.6 ± 0.011	$8.7\pm0.010$	> 0.05

 Table 4.6: pH value at different landfill sites
Table 4.7: pH value trend at different ages of landfill sites

Age	pH range	p – value
Young	7.9 - 8.1	< 0.05
Intermediate	6.5 - 7.9	< 0.05
Mature	8.6 - 8.7	> 0.05

Table 4.8: pH value trend at different status of landfill sites

Status	pH range	p – value
Operational	6.5 - 7.9	< 0.05
Closed	7.9 - 8.7	< 0.05

### 4.2.2 BOD, COD, BOD/COD ratio

The BOD and COD value ranged from 85.2 mg/L to 1046 mg/L and 969.4 mg/L to 9153.2 respectively in studied sites. Highest BOD was found in DLFS and lowest at GLFS and the difference was statistically significant (p < 0.05). Highest COD was found in PLFS and lowest in GLFS. Except in GLFS, BOD and COD were found significantly difference seasonally in all other landfill sites. BOD and COD values were also found significantly difference in operational and closed landfill sites (p < 0.05) as well as in young, intermediate and mature landfill sites (p < 0.05). The detail value for BOD is given in table 4.5, 4.6 and 4.7 and the detail COD value found is listed in table 4.8, 4.9 and 4.10. BOD depends on the age of LFS (Aziz et al., 2010). It was recorded high in new and operating LFS and less in matured LFS. With time the solid waste material gets degraded and the waste constituents percolate down along with rainwater thus polluting groundwater nearby to MSW landfill site (Bhalla and Jha, 2013). The BOD value highly depends on organic substances that decompose in early stage. For new landfills, BOD values are up to 30000 mg/L; for mature landfills, BOD varies from 100-200 mg/L (Tatsi et al., 2002). Old LFS contains less COD as well as BOD, as the different phases of reaction are already over. BOD/COD ratio shows the degree of biodegradation and gives the information regarding the age of LFS (Renou et al., 2008). Low ratio shows the high concentration of non-biodegradable contains, as in old and closed LFS all most all organic matters are decomposed. Slightly higher BOD/COD ratio at SLS indicates the high contains of organic waste in total amount of waste. The value of BOD/COD ratio has been obtained as similar to the previous researcher (Renou et al., 2008).

For the mature landfill site such as GLS has BOD/COD less than 0.1 and for intermediate landfill sites, namely PLS, DLS and SLS the ration were in between 0.1 to 0.2 in all seasons. But in contrast to Renou et al., (2008), the value of BOD/COD ratio for the young landfill site

such as ALS is not greater than 0.3. It might be because Aleter landfill site is closed since 2011 and this landfill site has been operated for three years only. Although the age of the landfill site is 4 years i.e young landfill site, the characteristics of the landfill leachate behaves as intermediate landfill site because the amount of feeding amount to the landfill site was large (410 tons/day waste) and the landfill site was closed in 2011, May.

Location	Pre-monsoon	Monsoon	Post-monsoon	Winter	p-value
Pokhara	966.38 ± 24.71	952.12 ±36	955.48 ± 35	$934.8\pm42$	< 0.05
Dang	$1046.6 \pm 35.50$	994 ± 18	970 ± 20	940 ± 16	< 0.05
Sisdole	$355.24 \pm 23.54$	$322.8\pm24$	$345.12\pm26$	$353.96 \pm 18$	< 0.05
Aletar	$314\pm7.65$	$304.88 \pm 14$	$317.98 \pm 10$	$319.28 \pm 1.19$	< 0.05
Gokarna	$87.96 \pm 4.1$	85.2 ± 1.8	$85.3\pm0.81$	$85.4 \pm 0.8$	> 0.05

Table 4.9: Seasonal variation of BOD in different landfill sites

Table 4.10: BOD value trend at different ages of landfill sites

Age	BOD range	p – value
Young	304.88 - 319.28	< 0.05
Intermediate	322.8-1046.6	< 0.05
Mature	85.2-87.96	> 0.05

Table 4.11: BOD value trend at different status of landfill sites

Status	BOD range	p – value
Operational	322.8-1046.6	< 0.05
Closed	85.2-319.28	< 0.05

Table 4.12: Seasonal variation of COD in different landfill sites

Location	Pre-monsoon	Monsoon	Post-monsoon	Winter	p-value
Pokhara	9153.2 ± 57.11	$9038.8 \pm 84.2$	9018.6 ± 73.4	8784 ± 89.2	< 0.05
Dang	9145 ± 37.83	8999.6 ± 12.0	8540 ± 87.4	8373.6 ± 71.3	< 0.05
Sisdole	$2217 \pm 60.82$	$2098 \pm 103.4$	$2233\pm82.32$	$2229.8\pm89.4$	< 0.05
Aletar	$10745.5 \pm 286.39$	$10408 \pm 120.1$	$10745 \pm 118.9$	$10854.2 \pm 126$	< 0.05
Gokarna	$1013.2 \pm 12.06$	969.4±10.3	969.4 ± 9.32	969.4 ± 5.32	> 0.05

Table 4.13: COD value trend at different ages of landfill sites

Age	COD range	p – value
Young	10408-10854.2	< 0.05
Intermediate	2098-9153.2	< 0.05
Mature	969.4-1013.2	> 0.05

Table 4.14: COD value trend at different status of landfill sites

Status	COD range	p – value
Operational	2098-9153.2	< 0.05
Closed	969.4-10854.2	< 0.05

\* All test were done in 95% confident level i.e  $\alpha = 0.05$  & SD=Standard deviation. All units in mg/L

### 4.3 Metals and Heavy Metals

The results indicate that mature landfill site (> 10 years old LFS) has low heavy metal and metal ions concentrations than that of intermediate age landfill sites (5-10 years old LFS). The concentration of chloride was obtained highest (510 mg/L) in PLFS whereas the lowest concentration of chromium was obtained (< 0.005 mg/L) in all LFS. Average heavy metal concentrations were also significantly differing in difference seasons (p < 0.05). Concentrations of heavy metals in leachate were also found related with pH of landfill leachate, waste composition and feeding rate to the landfill sites. Cd, Cr, Hg and Ni were almost not detectable in all seasons in all LFS and minor variations in Fe, Cu, Pb and Zn was observed within the LFS in different seasons. The detail description of the individual heavy metals and other metal ions in leachate sample has been described in table 4.15.

Among different parameters examined for landfill sites only the pH value is within the range specified by WHO and Government of Nepal. This shows that leachate needs necessary treatment before releasing it to open environment. Table 4.15 'b' below shows the values of different parameters analyzed, threshold range specified by WHO and Government of Nepal.

LFS	SLS				PLS				DLS				ALS				GLS			
Feeding Amount	410 tor	ns/day			80 tons	/day			7.2 ton	s/day			410 to	ons/day			300 to	ons/day		
nonomotors	•	Б	C	D		р	C	D		D	C	П	٨	р	C	D	٨	D	C	Л
	А	D	C	D	А	D	C	D	А	D	C	D	A	D	C	D	A	D	C	D
Ca	190.3	186.2	191.3	191	454.9	428.7	419	410	212	200	198	195	147	138	141	136.2	98	96	98	94
Cd	0.005	0.005	0.003	0.006	0.01	0.009	0.009	0.009	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.003	ND	ND	ND	ND
Cl	210.6	196.4	194	194	510	501	501	480	312	310	306.6	306.6	27.3	24.2	27.2	30.12	39.4	38.5	38	38
Cr	ND	ND	4E-04	8E-04	0.05	0.05	0.05	0.05	0.03	0.028	0.028	0.028	ND	ND	ND	ND	ND	ND	ND	ND
Cu	0.034	0.015	0.022	0.02	0.24	0.22	0.15	0.15	0.016	0.014	0.011	0.01	0.04	0.03	0.04	0.032	0	ND	0	ND
Fe	5.28	4.23	4.03	3.98	3.774	3.42	3.2	3.01	1.42	1.23	1.11	1.1	3.14	2.89	2.75	2.64	0.98	0.97	0.97	0.96
Hg	0.001	ND	0.002	0.003	0.005	0.005	0.005	0.005	0.002	0.002	0.002	0.002	0.01	ND	0.01	ND	ND	ND	ND	ND
Ni	0.246	0.18	0.209	0.245	0.16	0.139	0.126	0.109	0.002	0.002	0.002	0.002	0.21	0.2	0.21	0.213	0.03	0.02	0.02	0.02
Pb	0.38	0.31	0.22	0.21	0.166	0.153	0.153	0.13	0.02	0.02	0.02	0.02	0.12	0.1	0.09	0.094	0.09	0.06	0.06	0.06
Zn	0.535	0.5	0.533	0.5	0.3	0.29	0.29	0.27	0.4	0.4	0.4	0.4	0.48	0.42	0.34	0.21	0.12	0.11	0.12	0.12

Table 4.15 a: Chemical parameters concentration at different seasons, aged and functionality LFS (mg/L)

A - pre-monsoon, B - monsoon, C - post-monsoon and D - winter

\* All test were done in 95% confident level i.e  $\alpha$  = 0.05 & ND= Not detectable. All units in mg/L

Table 4.15 b: Physicochemical parameters at different aged and functionality compared with threshold given by WHO, GoN and Researchers (mg/L except pH)

parameters	Age		Age		ionality	Conc.threshold for pollutants (WHO, 2012 )	Conc.threshold for pollutants (GoN, 2013) for waste water	Other researc 2.3 & 2.4)	chers finding (fr	om table
	Young	Intermediate	Old	Operational	Closed			Young	Intermediate	Old
рН	7.9 - 8.1	6.5 – 7.9	8.6 - 8.7	6.5 – 7.9	7.9 - 8.7	6-8	6.5 - 8.5	5.6-9.1	6.4-9	7-11.5
BOD	304-319	322-1046	85-87	322-1046	85-319	80	< 100	90-26800	325-1500	3-800
COD	10408-10854	2098-9153	969-1013	2098-9153	969-10854	100	< 100	1900-70900	1180-9500	100- 3460
Ca	136.2 - 147	186 - 454.4	94 - 98	186.2 - 454.4	94 - 147	5-15	10-25	NA	NA	NA
Cd	0.003 - 0.01	0.003 - 0.001	ND	0.003 - 0.01	0.00 - 0.01	0.1	0.1	NA	NA	NA
Cr	ND	0.028 - 0.03	ND	0.028 - 0.03	ND	0.1	0.1	NA	NA	NA
Cu	0.03 - 0.04	0.01 - 0.24	ND	0.01 - 0.24	0.00 - 0.04	1	2-5	NA	0.12-0.78	0.005- 0.08
Fe	2.64 - 3.14	1.1 - 5.28	0.96 – 0.98	1.1 - 5.28	0.96 - 2.64	1-4	1-3	2.7-10	1.28-76	4.1-26
Hg	0.002 – 0.0021	0.00 - 0.005	ND	0.00 - 0.005	0.002 - 0.002	0.01-0.1	0	NA	NA	NA
Ni	0.2 - 0.21	0.002 - 0.246	0.02 – 0.21	0.002 - 0.246	0.02 - 0.21	0.01-0.1	< 0.1	NA	NA	NA
Pb	0.09 - 0.12	0.02 - 0.38	0.06 -0.09	0.02 - 0.38	0.06 - 0.12	0.1	< 0.2	NA	NA	NA
Zn	0.21 - 0.48	0.27 - 0.535	0.11 – 0.12	0.27 - 0.535	0.11 - 0.48	0.1	< 0.1	NA	NA	NA

### 4.3.1 Iron (Fe)

The concentration of iron ranged from 0.96 - 5.28 mg/L in studied sites. Highest concentration was found in SLFS and lowest in GLFS and the difference was statistically significant (p < 0.05). Except in GLS, iron concentration was found significantly difference seasonally in all other LFS. Iron concentration ranged 1.1 - 5.28 mg/L in operational and 0.96 -3.14 mg/L in closed LFS and shows significant difference (p < 0.05). The iron concentration was also recorded as significantly difference in young, intermediate and mature LFS. The concentration of Fe was decreasing in pre-monsoon, monsoon, post-monsoon and winter in all the landfill sites as shown in table 4.11 and figure 4.1. The amount of the Fe depends on the composition of the waste and quantity of waste, which is reflected by the above data. Iron appears in landfill leachate due to the iron-base material waste from construction materials, paints, pigment colour compounds, polishing agents, and electrical appliances (Aziz et al., 2004). The seasonal variation can be describe as the release of heavy metals is the function of characteristics of leachate such as pH, flow rate and concentration of complexing agent with increasing pH metal solubility generally decrease. Generally researchers, Aziz et al., (2004) explain as the Fe concentration increase in monsoon season as the flow of seepage water is increased but they are silent about the pH in those cases. The dominant variation factor for the Fe was pH rather than the seepage flow in monsoon. This can be explained through following graph too. The low value and approximate no variation of Fe concentration in GLS is due to the age of the Landfill.

Location	Range	Pre-monsoon	Monsoon	Post-monsoon	Winter	p-value
Pokhara	3.01-3.77	3.77	3.42	3.2	3.01	< 0.05
Dang	1.1-1.23	1.42	1.23	1.11	1.1	< 0.05
Sisdole	3.98-5.28	5.28	4.23	4.03	3.98	< 0.05
Aletar	2.64-3.14	3.14	2.89	2.75	2.64	< 0.05
Gokarna	0.96-0.98	0.98	0.97	0.97	0.96	> 0.05

Table 4.16: Seasonal variation of Fe (mg/L) in different landfill sites

Table 4.17: Fe (mg/L) variation trend at different age of landfill sites

Age	Fe range	p – value
Young	2.64-3.14	< 0.05
Intermediate	1.1-5.28	< 0.05
Mature	0.96-0.98	> 0.05



Table 4.18: Fe (mg/L) variation trend at different status of landfill sites

Figure 4.2: Seasonal variation of Fe in different landfill sites

## 4.3.2 Cadmium (Cd)

The concentration of Cd ranged from 0.00 - 0.01 mg/L in studied sites. Highest concentration was found in PLFS and lowest in GLFS and the difference was statistically significant (p < 0.05). But in all studied sites Cd concentration was found significantly indifference seasonally (p > 0.05). Cd concentration ranged 0.005 - 0.01 mg/L in operational and 0.00 - 0.01 mg/L in closed LFS and shows significant difference (p < 0.05). The Cd concentration was also recorded as significantly difference in young, intermediate and mature LFS. The cadmium in the Leachate is due to the composition of waste basically presence of Lithium-Cadmium battery in waste. The amount of Cd also depends on type of soil cover. The clay minerals like Kaolinite and Monmorilonite contains the Cd during swelling in monsoon and release Cd in dry season during contraction (Aziz et al., 2004). In our research amount of Cd was found as: in SLS 0.005 mg/L, 0.005 mg/L, 0.003 mg/L and 0.006 mg/L; in PLS 0.01 mg/L; in ASL 0.005 mg/L, 0.005 mg/L, 0.003 mg/L and 0.003 mg/L respectively in pre-monsoon, monsoon, post-monsoon and winter. In our research area amount of Cd was comparatively less than other researchers like Aziz et al (2010), IM et al (2001), Kennedy et al (2000) and Cho et al

(2002). The variation also depends on the pH of the leachate but the dominant variant is not the pH in this case. The variation of Cd is as shown in figure 4.3.



Eigung 1 2. Sagar	al reminiation	of Cd in	different	londf:11	aitaa
Figure 4.5. Season	iai variation		unterent	lanum	sites

Location	Range	Pre-monsoon	Monsoon	Post-monsoon	Winter	p-value
Pokhara	0.009-0.01	0.01	0.009	0.009	0.009	> 0.05
Dang	0.01	0.01	0.01	0.01	0.01	> 0.05
Sisdole	0.003-0.006	0.005	0.005	0.003	0.006	> 0.05
Aletar	0.003-0.01	0.01	0.01	0.01	0.003	> 0.05
Gokarna	ND	ND	ND	ND	ND	> 0.05

Table 4.19: Seasonal variation of Cd in different landfill sites

Table 4.20: Cd (mg/L) variation trend at different ages of landfill sites

Age	Cd range	p – value
Young	0.003-0.01	< 0.05
Intermediate	0.003-0.01	< 0.05
Mature	ND	> 0.05

Table 4.21: Cd (mg/L) variation trend at different status of landfill sites

Status	Cd range	p – value
Operational	0.003-0.01	< 0.05
Closed	0.00-0.01	< 0.05

# 4.3.3 Copper (Cu)

The concentration of Cu ranged from 0.00 - 0.24 mg/L in studied sites. Highest concentration was found in PLFS and lowest in GLFS and the difference was statistically significant (p <

0.05). Except in GLFS, Cu concentration was found significantly difference seasonally (p < 0.05). Cu concentration ranged 0.01 - 0.034 mg/L in operational and 0.00 - 0.04 mg/L in closed LFS and shows significant difference (p < 0.05). The Cu concentration was also recorded as significantly difference in young, intermediate and mature LFS. The major sources of the copper in landfill sites are presence of copper containing materials in waste like copper wires, batteries and other medical wastes. The other source is the timber waste. Timber is seasoned by the Chromated Copper Arsenate (CCA) which leached from the waste to the leachate (Wang et al., 2002). In our case Cu presence in landfills were considerable mainly in PSL. Measurement were as: in SSL 0.034 mg/L, 0.015 mg/L, 0.022 mg/L and 0.020 mg/L; in PLS 0.024 mg/L, 0.22 mg/L, 0.15 mg/L and 0.15 mg/L; in DLS 0.016 mg/L, 0.014 mg/L, 0.011 mg/L and 0.010 mg/L respectively in pre-monsoon, monsoon, post-monsoon and winter. In ALS and in GLS not very much detected.



Figure 4.4: Seasonal variation of Cu in different landfill sites

Location	Range	Pre-monsoon	Monsoon	Post-monsoon	Winter	p-value
Pokhara	0.15-0.24	0.24	0.22	0.15	0.15	< 0.05
Dang	0.01-0.016	0.016	0.014	0.011	0.01	< 0.05
Sisdole	0.02-0.034	0.034	0.015	0.022	0.02	< 0.05
Aletar	0.03-0.04	0.04	0.03	0.04	0.032	< 0.05
Gokarna	ND	ND	ND	ND	ND	> 0.05

Table 4.22: Seasonal variation of Cu in different landfill sites

Table 4.23: Cu concentration trend at different ages of landfill sites

Age	Cu range	p - value
Young	0.03-0.04	< 0.05
Intermediate	0.01-0.24	< 0.05
Mature	ND	> 0.05

$1000 \pm 2\pm$ . Cu (mg/L) concentration trend at unrefert status of fandim sites
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Status	Cu range	p - value
Operational	0.01-0.24	< 0.05
Closed	0.00-0.04	< 0.05

### 4.3.4 Nickel (Ni)

The concentration of Ni ranged from 0.002 - 0.246 mg/L in studied sites. Highest concentration was found in SLFS and lowest in DLFS and the difference was statistically significant (p < 0.05). In DLFS, ALFS and GLFS Ni concentration was found significantly indifference seasonally (p > 0.05) whereas Ni concentration was significantly difference in SLFS and PLFS (p < 0.05). Ni concentration ranged 0.002 – 0.246 mg/L in operational and 0.02 - 0.213 mg/L in closed LFS and shows significant difference (p < 0.05). The Ni concentration was also recorded as significantly difference in young, intermediate and mature LFS. Main source of the Nickel in leachate is industrial waste. Nickle is mainly used for the formation of alloys. Quantity of Ni is more where the industrial waste is more. The seasonal variation of the Ni was not so detectable because the quantity of industrial waste to the landfill site was almost constant throughout the year. As the old landfills produces less amount of the constituents in leachate, GLS produced the less in amount. Quantity of industrial waste was less in Dang prompts the less amount of Ni. We recorded the amount of Ni as: in SLS 0.246 mg/L, 0.180 mg/L, 0.209 mg/L and 0.245 mg/L; in PLS 0.160 mg/L, 0.139 mg/L, 0.126 mg/L and 0.109 mg/L; in DLS 0.002 mg/L. 0.002 mg/L, 0.002 mg/L and 0.002 mg/L; in ALS 0.208 mg/L, 0.196 mg/L, 0.206 mg/L and 0.213 mg/L; in GLS 0.025 mg/L, 0.024 mg/L, 0.021 mg/L and 0.021 mg/L respectively in pre-monsoon, monsoon, postmonsoon and winter season.



Figure 4.5: Seasonal variation of Ni in different landfill sites

Location	Range	Pre-monsoon	Monsoon	Post-monsoon	Winter	p-value
Pokhara	0.12-0.16	0.16	0.139	0.126	0.109	< 0.05
Dang	0.002	0.002	0.002	0.002	0.002	> 0.05
Sisdole	0.18-0.246	0.246	0.18	0.209	0.245	< 0.05
Aletar	0.2-0.21	0.21	0.2	0.21	0.213	> 0.05
Gokarna	0.02-0.03	0.03	0.02	0.02	0.02	> 0.05

Table 4.25: Seasonal variation of Ni in different landfill sites

Table 4.26: Ni (mg/L) variation trend at different ages of landfill sites

Age	Ni range	p – value
Young	0.2-0.21	< 0.05
Intermediate	0.002-0.246	< 0.05
Mature	0.02-0.03	< 0.05

Table 4.27: Ni (mg/L) variation trend at different status of landfill sites

Status	Ni range	p – value
Operational	0.002-0.246	< 0.05
Closed	0.02-0.21	< 0.05

## 4.3.5 Lead (Pb)

The concentration of Pb ranged from 0.02 - 0.38 mg/L in studied sites. Highest concentration was found in SLFS and lowest in DLFS and the difference was statistically significant (p < 0.05). Except DLFS, Pb concentration was found significantly difference seasonally (p > 0.05). Pb concentration ranged 0.02 - 0.38 mg/L in operational and 0.06 - 0.12 mg/L in closed LFS and shows significant difference (p < 0.05). Amount of lead in the landfill leachate is mainly due to the electronic waste (Ahn et al., 2002). Lead is categorized as the hazardous waste. In our observations the amount of lead was high in the pre-monsoon seasons, which implies that the use of electronic appliances was more in this season. It can be correlated with more loadshieding schedule in Nepal in pre-monsoon season. But for the landfills of less developed city and passive landfills, the amount was in trace, as in DLFS and GLFS. Recorded amount of Pb was as: in SLS 0.38 mg/L, 0.31 mg/L, 0.22 mg/L and 0.21 mg/L; in PLFS 0.17 mg/L, 0.15mg/L, 0.15 mg/L and 0.13 mg/L; in DLS 0.02mg/L, 0.02mg/L, 0.02 mg/L and 0.02mg/L; in ALS 0.12 mg/L, 0.1 mg/L, 0.09 mg/L and 0.09 mg/L; in GLFS 0.09 mg/L, 0.06 mg/L, 0.06 mg/L and 0.06 mg/L respectively in pre-monsoon, monsoon, post monsoon and winter season.



Figure 4.6: Seasonal variation of Pb in different landfill sites

Location	Range	Pre-monsoon	Monsoon	Post-monsoon	Winter	p-value
Pokhara	0.13-0.16	0.166	0.153	0.153	0.13	< 0.05
Dang	0.02	0.02	0.02	0.02	0.02	> 0.05
Sisdole	0.21-0.38	0.38	0.31	0.22	0.21	< 0.05
Aletar	0.09-0.12	0.12	0.1	0.09	0.094	< 0.05
Gokarna	0.06-0.09	0.09	0.09	0.06	0.06	< 0.05

Table 4.28: Seasonal variation of Pb (mg/L) in different landfill sites

Table 4.29: Pb (mg/L) concentration variation trend at different ages of landfill sites

Age	Pb range	p – value
Young	0.09-0.12	< 0.05
Intermediate	0.02-0.38	< 0.05
Mature	0.06-0.09	< 0.05

Table 4.30: Pb (mg/L) concentration variation trend at different status of landfill sites

Status	Pb range	p – value
Operational	0.02-0.38	< 0.05
Closed	0.06-0.12	< 0.05

# 4.3.6 Calcium (Ca)

The concentration of Ca ranged from 94 – 454.9 mg/L in studied sites. Highest concentration was found in PLFS and lowest in GLFS and the difference was statistically significant (p < 0.05). Except GLFS, Ca concentration was found significantly difference seasonally (p >

0.05). Ca concentration ranged 186.2 - 454.9 mg/L in operational and 94 - 147 mg/L in closed LFS and shows significant difference (p < 0.05). Amount of Ca in leachate depends mostly on the type of soil cover. Calcium found in the soil is combined with the carbonate produced during the anaerobic decomposition to form the calcium carbonate (Jamie et al., 2010). Ca on leachate also depends on the amount of construction waste. The amount of Ca was more in Pokhara because the amount of Ca was more in the cover materials. On the other hand the amount of Ca was found more where the continuous soil cover is still in construction. As in Sisdole the amount of Ca was more whereas amount is less in ALS and GLS.



Location	Range	Pre-monsoon	Monsoon	Post-monsoon	Winter	p-value
Pokhara	419-454.4	454.4	428.8	419	410	< 0.05
Dang	195-212	212	200	198	195	< 0.05
Sisdole	186.2-191.3	190.3	186.2	191.3	191	< 0.05
Aletar	136.2-147	147	138	141	136.2	< 0.05
Gokarna	94-98	98	96	98	94	> 0.05

Table 4.31: Seasonal variation of Ca in different landfill sites

Table 4.32: Ca (mg/L) concentration variation at different ages of landfill sites

Age	Ca range	p – value
Young	136.2-147	< 0.05
Intermediate	186.2-454.4	< 0.05
Mature	94-98	< 0.05

Status	Ca range	p – value
Operational	186.2-454.4	< 0.05
Closed	94-147	< 0.05

Table 4.33: Ca (mg/L) concentration variation at different status of landfill sites

# 4.3.7 Zinc (Zn)

The concentration of Zn ranged from 0.11 - 0.535 mg/L in studied sites. Highest concentration was found in SLFS and lowest in GLFS and the difference was statistically significant (p < 0.05). Except PLFS and ALFS, Zn concentration was found significantly indifference seasonally (p < 0.05). Zn concentration ranged 0.27 - 0.535 mg/L in operational and 0.11 - 0.48 mg/L in closed LFS and shows significant difference (p < 0.05). Major sources of Zinc are the type of soil cover (Kennedy and Lentz, 2004). Furthermore the amount of leaching the Zn also depends on the electronic waste mostly batteries (Kennedy and Lentz, 2004). As the landfill ages increase, the increase in pH values causes a decrease in metal solubility. This affects the oxidation-reduction process and dissociation of acid. The heavy metals react with the hydrogen ion and precipitate in metal hydroxides. At this stage, the stabilized leachate contains less concentration of heavy metal due to the high pH value (Kulikowska and Klimiuk, 2008).



Figure 4.8: Seasonal variation of Zn in different landfill sites

Location	Range	Pre-monsoon	Monsoon	Post-monsoon	Winter	p-value
Pokhara	0.27-0.3	0.3	0.29	0.29	0.27	< 0.05
Dang	0.4	0.4	0.4	0.4	0.4	> 0.05
Sisdole	0.5-0.535	0.535	0.5	0.533	0.5	> 0.05
Aletar	0.21-0.48	0.48	0.42	0.34	0.21	< 0.05
Gokarna	0.11-0.12	0.12	0.11	0.12	0.12	> 0.05

Table 4.34: Seasonal variation of Zn in different landfill sites

Table 4.35: Zn	concentration	variation	at different	ages of	landfill	sites

Age	Zn range	p – value
Young	0.21-0.48	< 0.05
Intermediate	0.27-0.535	< 0.05
Mature	0.11-0.12	< 0.05

Table 4.36: Zn concentration variation at different status of landfill sites

Status	Zn range	p – value
Operational	0.27-0.535	< 0.05
Closed	0.11-0.48	< 0.05

## 4.3.8 Ammonia (NH<sub>3</sub>)

The yearly average amount of NH<sub>3</sub> were found to be 69.035 mg/L, 99 mg/L, 108.08 mg/L, 130 mg/L and 23.75 mg/L in ALS, DLS, PLS, SLS and GLS respectively. Highest concentration was found in PLFS and lowest in GLFS and the difference was statistically significant (p < 0.05). In all LFS, NH<sub>3</sub> concentration was found significantly indifference seasonally (p > 0.05). NH<sub>3</sub> concentration ranged 99 – 108.08 mg/L in operational and 23.75 – 69.03 mg/L in closed LFS and shows significant difference (p < 0.05) in different ages of landfill sites also.

In aqueous solution, un-ionized ammonia  $(NH_3(aq))$  exists in equilibrium with the ammonium ion  $(NH_4^+)$  according to the dissociation equation:

 $NH_4^+ + H_2O \leftrightarrow NH_3(ap) + H_3O^+$ 

Total ammonia concentration is the sum of un-ionized and ionized ammonia (Robinson, 2005). The toxic effect of total ammonia increases with increasing pH, indicating that the unionized ammonia is the main toxic form. Average amount of ammonia had been taken because the ANOVA analysis shows. Ammonia in the leachate is produced when the methanogenic reaction is started. Therefore amount of ammonia is more in the intermediate landfills rather than old or new types of landfills. The less amount of ammonia in ALS was because it is closed. GLS is old type of landfills.

Location	Average	Pre-monsoon	Monsoon	Post-monsoon	Winter	p-value
Pokhara	108.08	108.32	107	109	108	> 0.05
Dang	99	99	98	99	100	> 0.05
Sisdole	130	130	132	132	126	> 0.05
Aletar	69.035	69.04	70	68.06	69.04	> 0.05
Gokarna	23.75	24	22	25	24	> 0.05

Table 4.37: Seasonal variation of NH3 values at different LFS



Figure 4.9: Yearly average NH3 values at different LFS

Table 4.38: NH3 concentration (mg/L) trend at diff
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Age	NH3 range	p – value
Young	68.06-70	> 0.05
Intermediate	99-108.08	< 0.05
Mature	22-25	> 0.05

Table 4.39: NH3 concentration (mg/L) trend at different status of LFS

Status	NH3 range	p – value
Operational	99-108.08	< 0.05
Closed	23.75-69.035	< 0.05

# 4.3.9 Hydrogen Sulphide (H<sub>2</sub>S)

The yearly average amount of H<sub>2</sub>S were found to be 52 mg/L, 63.5 mg/L, 94 mg/L, 105.25 mg/L and 18 mg/L in ALS, DLS, PLS, SLS and GLS respectively. Highest concentration was found in SLFS and lowest in GLFS and the difference was statistically significant (p < 0.05). In all LFS, H<sub>2</sub>S concentration was found significantly indifference seasonally (p > 0.05). H<sub>2</sub>S concentration ranged 63.5 – 105.25 mg/L in operational and 18 – 52 mg/L in closed LFS and was significant difference (p < 0.05) in different ages of landfill sites also. The amount of H<sub>2</sub>S was more in new type of landfills rather than the old one. DLS had less feeding amount of organic constituents in the waste implying less amounts of H<sub>2</sub>S, in fact the total amount of waste deposited was less. Whereas the amount of H<sub>2</sub>S in SLS and PLS was high which tells the high rate of anaerobic reaction (Bashir et al., 2009). GLS is in maturation phase so the production of H<sub>2</sub>S was less there.



Figure 4.10: H<sub>2</sub>S values at different LFS

	Table 4.40: Seas	onal variation	of H <sub>2</sub> S at	different	landfill	sites
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Location	Average	Pre-monsoon	Monsoon	Post-monsoon	Winter	p-value
Pokhara	94	96	90	94	96	> 0.05
Dang	63.5	64	60	66	64	> 0.05
Sisdole	105.25	105	102	108	106	> 0.05
Aletar	52	52	52	52	52	> 0.05
Gokarna	18	18	18	18	18	> 0.05

Table 4.41: H<sub>2</sub>S concentration at different ages of landfill sites

Age	H <sub>2</sub> S range	p – value
Young	52	> 0.05
Intermediate	63.5-105.25	< 0.05
Mature	18	> 0.05

Table 4.42: H<sub>2</sub>S concentration at different status of landfill sites

Status	H <sub>2</sub> S range	p – value
Operational	63.5-105.25	< 0.05
Closed	18-52	< 0.05

# 4.3.10 Leachate Treatment Options

The leachate treatment units suggested by Cokgor et al., (2009), Kennedy & Lentz (2000), Kamaruddin et al., (2013) with major design parameters are

<u>a. Trickling Filter</u>: This is designed on the basis of BOD loading and the efficiency needed. For low rate trickling filter BOD loading should be between 80-320 kg/Day/m3 and that for High rate trickling filter 100 to 500 kg/Day/m3.

<u>b. Activated Sludge Process:</u> This type of reactor is designed according to F/M ratio, sludge volume index, and MLSS/MLVSS ratio. Generally F/M ratio is taken as 0.2 to 0.5 and MLSS/MLVSS ratio as 0.8.

<u>c. Oxidation pond:</u> This type of reactor is based on the BOD of the leachate and its hydraulic retention time. Retention time depends on BOD of leachate, which should be greater than 12 days.

Besides that heavy metal are removed basically by the chemical procedure and adsorption mechanism (Asadi, 2008). Physicochemical parameters are highly depended in designing the treatment units (Wang, 2003). The physicochemical analysis of the landfill leachate is important to understand the landfill process and leachate.

Selection of treatment facilities used depends on properties of leachate including TDS, COD,  $SO_4^{-2}$  and heavy metals. If the landfill leachate contains high concentration of TDS then it is difficult to perform biological treatment. Whereas high concentration of COD is suitable for the anaerobic treatment but high  $SO_4^{-2}$  concentration leads the production of H<sub>2</sub>S so is not suitable for the anaerobic treatment (Mojiri et al., 2014). On the other hand high concentrations of heavy metals are unfavorable for the growth of microorganism so it is not fitted for the biological treatment (Cokgor et al., 2009). Table 4.43 shows similar conclusion.

Metals	Conc.threshold of inhibitory effect	t Source of metals	
	on heterotrophic organisms		
Cd	1 mg/L	Electrodeposited and dipped coating on metals,	
		alloys, ceramic glazes, enamels	
Ca	Macro level (> 1 mg/L)	Soil covers	
Fe	0.1 mg/L	Metal based instruments, soil cover	
Pb	0.1 mg/L	Batteries, gasoline additive, cable covering,	
		piping	
Hg	0.1 mg/L	Mercury vapour lamp, mirror coating, boilers,	
		amalgams	
Zn	1 mg/L	Batteries, cables, wires	
Ni	1 mg/L	Industrial wastes, alloys	
Cu	1 mg/L	Wires, cables, timber waste, medical wastes	
Cr	1 hexavalent & 10 total chromium	Corrosion resistant plastics, inorganic pigments,	
		stainless steel	

Table 4.43: Metals concentration threshold of inhibitory effect on heterotrophic organisms (Cokgor et al., 2009)

The results that we have obtained as in table 4.15 have high concentration of the metals and metal ions as compared to the metals concentration threshold of inhibitory effect on heterotrophic organisms' growth. It can be concluded that due to the concentration of heavy metals in young, intermediate and operational landfill is not suitable for the biological treatment as primary treatment units. First municipality's authorities or plants operators need

to bring the concentration of metals as stated in table 4.43 and accordingly operators can go for the biological treatment.

All living organism required varying amount of metallic element such as iron, chromium, copper, zinc and cobalt for proper growth. Same metals can be cause adverse effect if present in high concentration (Vasanthi et al., 2008). So variety of the metal concentration should be known before treating the leachate.

For the biological treatment component like BOD, COD, ammonia, phosphate should be evaluated. The role of above components along with microorganism can be express as

 $\mu_1$  (Organic Matter) +  $\mu_2$  O<sub>2</sub> + $\mu_3$  NH<sub>3</sub> +  $\mu_4$  PO<sub>4</sub><sup>-3</sup>  $\mu_5$  (New Cell) +  $\mu_6$ CO<sub>2</sub> +  $\mu_7$  H<sub>2</sub>O ..... Equation 4.1

where  $\mu_i$  is stoichiometric coefficients (Cokgor et al., 2009)

In aeration process the necessary oxygen demand is fulfilled through oxygen transfer (Safari et al., 2007). The rate of concentration for oxygen transfer is:

$$\frac{dc}{dt} = K_{La} (C_s - C) - r_m \dots Equation 4.2 \quad (Li et al., 2001)$$

Where  $r_m$  is rate of oxygen used by the microorganism C is concentration of oxygen in solution Other carries their usual meaning.

This shows that the consumption of oxygen is due to the growth of the microorganism or production of new cell, which depends on the organic matters presence in the leachate.

On the other hand the detention time and the volume of the reactor (treatment plants) also depend on the rate utilization of soluble substrate. The kinetics for the rate utilization of soluble substrate is:

$$\mathbf{r}_{su} = \frac{kXS}{ks+S} \qquad \text{(Liu et al., 2012)}$$

where

1 110

 $r_{su}$  is rate of substrate concentration change due to utilization

k is maximum specific substrate utilization rate

X is biomass (microorganism) concentration

S is growth limiting substrate concentration

Ks is half velocity constant substrate concentration at one half the maximum specific substrate utilization rate

This shows that the biomass concentration is directly proportional to the rate of utilization of the substrate. So that biological treatment plants should be selected such that the optimal utilization rate of the substrate is achieved.

For the specific treatment plants, design considerations can be evaluated for the best fit according to the characteristics of the leachate.

Filtration plants basically used the trickling filter, is design according to the NRC equation. This shows that the volume of the reactor depends on BOD loading and the hydraulic loading and the efficiency of reactor is inversely proportional to the square root of BOD loading (Jaconi et al., 2006). The equation for this condition is stated as;

$$E_1 = \frac{100}{1 + 0.4432 \sqrt{\frac{W_1}{VF}}} \quad \dots \quad Equation \ 4.3$$

The above equation is for single stage or first unit of double stage trickling filter.

$$E_2 = \frac{100}{1 + \frac{0.4433}{1 - E_1} \sqrt{\frac{W^2}{V_2 F_2}}} \dots Equation 4.4$$

The above equation is for second stage of double stage trickling filter.

Where,

 $E_1$  and  $E_2$  are efficiencies W<sub>1</sub> and W<sub>2</sub> are BOD loadings for the first and second units of trickling filters V<sub>1</sub> and V<sub>2</sub> are volume of respective units F<sub>1</sub> and F<sub>2</sub> are recirculation factors which depends on the recirculation ratio

On the other hand, activated sludge process is designed from the food microorganism ratio (F/M) (Liu et al., 2012). Food is depending on the concentration of BOD in the leachate.

 $\frac{F}{M} = \frac{Q C}{V x}$ .....Equation 4.5

Where,

Q is discharge of the leachate

C is concentration of influent BOD

V is volume of reactor

X is amount of Biomass

Similarly, the design and size of the oxidation pond is also depends on the BOD of Leachate;

$$t = -\frac{1}{k} \log_{10} \left( \frac{UBOD - BOD5}{UBOD} \right) \dots Equation 4.6$$

where

t is retention time

k is deoxygenation constant

This reactor need about 10-15 days of the retention time, so that volume would be larger than other but the efficiencies for removing BOD and suspended solids is high. This reactor operates on the principle of Bacterial Algaeal Symbiosis (BAS), so for certain conditions like in cloudy day and in low temperature anaerobic condition may occur (Tchobanoglous et al., 2003).

There are many treatment plants for the treatment of the leachate but individual reactor may not be sufficient for treating leachate. We can choose the efficient one or the combination of reactors according to the properties of leachate. But we should be aware that the properties of the leachate is changing according to the age of LFS, seasons in the year, composition of the waste, landfill bed and cover soil properties. Based on the values obtained from this research the treatment plant operators / municipalities authorises can adjust their parameters and decide the kinds of plants suitable for the treatment.

### 4.4 Biogas Generation Study

#### 4.4.1 Estimation of Biogas Potential

The total biogas generation potential of each studied sites are presented in table 4.44.

LFS	Age	Waste	MC	Organic	Organic	Total organic	VS%	Volatile	Biogas	Estimated	Estimated	Electricity
		feeding	%	waste %	waste	solids (TS)		solids in	yield	biogas	biogas per	generation
		amount		(O%)	(tons)	Kg		organic	(cum. M /	(cum. M /	kg of total	(Wh/kg/day)
								waste (kg)	day)	day)	waste	
											(lit/kg/day)	
SLF	9	410	69	61.6	252.560	78293.6	44.41	34770.19	0.35	12169.57	29.68	178.09
PLFS	10	80	85	52.5	40.950	6142.5	39.63	2434.27	0.35	852.00	10.65	63.9
DLFS	9	7.9	82	65.0	4.589	826.02	58.47	482.97	0.35	169.04	21.67	130.03

Table 4.44: Estimation of biogas potential

Note: electricity generation is taken as 6 kWh/m<sup>3</sup> of biogas

Table 4.44 can be interpreted as, higher the moisture content of the waste lower the production of the biogas as the total organic solids decreases. But only moisture content is not the factor that affects the biogas production, volatile matters also does (FNR, 2005). Higher the volatile content then higher the production of biogas (AEPC, 2014). So the actual production of the biogas is influenced by both these factors. Figure 4.11 and 4.13 shows the comparative production of biogas due to those factors in respective landfill site. These graphs

can be used for how much moisture content and volatile solids are necessary for the production of given value of Biogas generation. For example: to produce 20 l/kg/day of Biogas we should need about 85% (from figure 4.11 & 4.13) of moisture content and about 52.5% (from figure 4.11 & 4.13) of volatile solids. The relation of Biogas Generation with moisture content (M %) and percentage of volatile Solid Content (V%) can be expressed as:

Total organic solids = Amount of organic waste \*(100 - M%)

And,

Amount of volatile solids = Total organic solids \* V%

Estimated biogas = Amount of volatile solids \* Biogas Yield

From these it gives the relation,

Biogas Generation per kg of organic waste =  $((1-(\alpha)/\beta) (\gamma)/\beta * Biogas Yield)$ 

Where  $\alpha$  = moisture %,  $\beta$  = scale coefficient (taken as 100) and  $\gamma$  = volatile solid %

This expression calculates the biogas generation from the waste with any composition of moisture content and percentage of volatile solids in total organic solids. This is Biogas Generation Calculation Equation. This equation gives that the Biogas Generation is maximum when volatile solids are maximum in organic solids having minimum moisture content. Figure 4.11 is the graph for the calculation of the biogas generation of any composition (moisture content and volatile solid content). Here the Biogas Generation Equation is divided into two part.



Figure 4.11: Comparative study of biogas generation

## Plotting the data on MATLAB

MATLAB's device-independent plotting capabilities make it very easy to plot any data at any time. Any mathematical function can be plotted by using *plot* function available in MATLAB. We can plot any data set by just creating two vectors and passing them to plot function. And we can analyze output in figure window, which was used to display MATLAB graphics. A figure can be a two or three dimensional plot of data.

MATLAB's *plot* function can be used differently. In its simplest form, *plot*, can be used as *plot* (*x*,*y*) which plots vector y versus vector x. For example to plot y = sin(x), we can follow following steps:

- 1. Creating vector x as:
  - x = -3\*pi: 0.01: 3\*pi;
- Creating vector y as:
  y = sin(x);
- 3. Applying *plot* function as:

plot(x,y);

which gives output as below



Figure 4.12: Y = Sin(x) plot

Here in step 1, x = -3 \* pi : 0.01 : 3\*pi creates vector x which has value from -3 \* pi to 3 \* pi in steps of 0.01.

For example: a = 1: 1: 5; gives, a = 12 3 4 5

In step 2, y = sin(x); creates vector y which is sine value of x vector.

And In step 3, plot(x,y); plots x versus y, x vector in x – axis and y vector in y – axis.

$$Z1 = (1 - M/100) * 10$$

Z2 = (V/100) \* 0.35 \* 1000

Using plot function available in MATLAB we had simultaneously plot two different function.

In our research M and V had same data we create vector X to represent data of M and V. Where

X = 0:10:100;

And according to value of X, it had been created vector Z1 and Z2 by applying above relations.

Where

Z1 = (1 - X/100) \* 10;

Z2 = (X/100) \* 0.35 \* 1000;

And to plot we used plot function as:

Plot (X, Z1, 'r', X, Z2, 'g');

Combining all and setting other GUI properties:

Source Code

X = 0:10:100; % creates 0 10 20 30 40 50 60 70 80

Z1 = (1-X/100)\*10; % creates Z1 vector

Z2 = (X/100) \* 0.35 \* 100; % creates Z2 vector

plot(X,Z1,'r',X,Z2,'g'); % plotting X vs Z1 and X vs Z2 and setting color red for 'X vs ZA' and green for 'X vs Z2'

axis ([0 100 0 40]); % setting horizontal axis '0 to 100' and vertical axis '0 to 40'

grid on; % Setting grid in figure window

xlabel ('Red (Z1) and Green (z2) \rightarrow'); % Setting x label, here \rightarrow gives ->

ylabel('M% and V% (Same Data) \rightarrow'); %Setting y label, here \rightarrow gives ->

# % was used for comment in MATLAB

And output obtained as;



Figure 4.13: Moisture (M%) and Volatile solids (V%) plot by MATLAB

Part 1:

Z1 = (1 - (M%)/100)\*10 .....(i)

Where 10 is scale coefficient.

Part 2:

Z2=(V%)/100 \* Biogas Yield\*100....(ii)

For above graph Biogas Yield is in m<sup>3</sup>/kg and taken as 0.35 (methane production) for this graph and 100 is scale Coefficient. Both the equations (i) and (ii) are linear and plotted using MATLAB, keeping Z1 and Z2 in ordinate and moisture content (M%) and percentage of volatile materials (V%) in abscissa. With rich variety of functions, ease of use, platform independence, graphical user interface, simulation environment and device independent plotting are most powerful features of MATLAB. In graph red line is for equation (i) and

green line is for equation (ii). Now, after finding out the M% and V% from laboratory test, Z1 is obtained from the graph, ordinate of equation (i) for given M% and Z2 is obtained from graph, ordinate of equation (ii). Then Biogas generated can be expressed as;

Biogas Generated (lit/kg/day) = Z1 \* Z2 i.e ((1-( $\alpha$ )/ $\beta$ ) ( $\gamma$ )/ $\beta$  \* Biogas Yield)

Where  $\alpha$  = moisture %,  $\beta$  = 100 (scale coefficient) and  $\gamma$  = volatile solids %

Moisture content and volatile solids were taken into account based on the - University of Wisconsin-Madison, Solid and Hazardous Waste Education (2012)

## 4.4.2 Energy Potential of Generated Biogas

Biogas has average caloric value of 21-23.5 MJ/m<sup>3</sup> and has a potential of electricity generation of 6 kwh/m<sup>3</sup> (AEPC, 2014).Total biogas contains 50% to 75% of methane (Igoni et al., 2007) produced from biodegradable matters. Here we take in average 65% methane of total biogas produced and the energy generated from the total biogas is 6 Kwh/m<sup>3</sup> (AEPC, 2014, Igoni et al., 2007). From those considerations we can generate (table 5) 4.68 MW electricity from Sisdole LFS whereas 0.33 MW and 0.7 MW from Pokhara and Dang LFS respectively. Following table represent the electricity generation potential from each LFS as energy recovery.

LFS	Estimated methane	energy generation	% of methane in	Power production / day
	(cu.m/day)	/ m3 (kWh)	overall biogas	(MW)
SLFS	12169.57	6	65	4.68
PLFS	851.99	6	65	0.33
DLFS	169.04	6	65	0.07

Table 4.45: Waste to energy conversion

Generation of electricity (resource recovery) also reduce the emission of Green House Gas (GHG). Methane has a Global Warming Potential (GWP) of 12.4 for life time 86 for 20 years span and 34 for 100 years span, as carbon dioxide is base line for GWP and taken as 1 (Myhre et al., 2013).

#### Chapter 5

## **CONCLUSIONS AND RECOMMENDATIONS**

#### **5.1 CONCLUSIONS:**

#### General:

The composition of waste coming to LFS was found to be mostly organic waste. The pH value ranged from 6.5 to 8.7 in studied sites. Highest pH was found in Gokarna and lowest at Pokhara. The BOD and COD value ranged from 85.2 mg/L to 1046 mg/L and 969.4 mg/L to 9153.2 mg/L respectively. Highest BOD was found in Dang and lowest at Gokarna. Highest COD was found in Pokhara and lowest in Gokarna. The concentration of iron ranged from 0.96 - 5.28 mg/L in studied sites. Highest concentration was found in Sisdole and lowest in Gokarna. The concentration of Cu, Pb, Ni and Zn were ranged from 0 - 0.5 mg/L in all studied sites in all seasons whereas concentration of Hg, Cr and Cd were almost not detectable. The concentration of Ca ranged from 94 - 454.9 mg/L. The yearly average amount of NH<sub>3</sub> were found to be 69.035 mg/L, 99 mg/L, 108.08 mg/L, 130 mg/L and 23.75 mg/L in Aletar, Dang, Pokhara, Sisdole and Gokarna respectively. Highest concentration was found in Pokhara and lowest in Gokarna. The yearly average amount of H<sub>2</sub>S ranged from 18 - 105.25 mg/L. Highest concentration was found in Sisdole and lowest in Gokarna. The key findings are listed below:

- Seasonally, pH was significantly difference in all sites except Gokarna which is closed and mature LFS. Gradual increase of pH from pre-monsoon to winter seasons and as per age was observed.
- 2. BOD and COD significantly decrease from pre-monsoon to winter seasons in all except in Gokarna. It could also be due to increased age of the landfill too. Concentration of BOD and COD was higher where the amount of organic waste content was higher. BOD/COD ratio was 0.02 (mature) to 0.3 (young). Low ratio reflects the lower biodegradability in landfills.
- 3. In the stable methanogenic phase, pH and BOD/COD ratio increased, reflecting the decreasing trend of degradability of the organic matter. Compared to the standard set by WHO (2012), all the physico-chemical components except pH were observed to have significantly high value in young and intermediate aged LFS. In contrast to other researchers, the concentration of leachate in young aged but closed LFS behaves likes intermediate aged leachate.

- 4. Among metals and heavy metals, concentration of Fe decreases from pre-monsoon to winter. This could be due to increased age of landfill and increased pH as seasons changes. Others metals like Ni, Pb and Zn were detected in young and intermediate aged LFS. For old aged LFS, concentration of Fe, Cu, Cr, Hg, Ni, Pb, Cd and Zn were within the threshold values recommended by WHO (2012) guidelines. These parameters were leachout earlier as this landfill is running in stabilization phase.
- 5. The null hypothesis for the functionality status, seasons and young, intermediate aged landfill sites are rejected whereas the null hypothesis for the mature aged landfill site is accepted.
- 6. The present study found biological treatment methods to be effective for freshly produced leachate under the condition that the concentration of the metals suffices for the growth of microorganism. Biological treatment in old landfills, however, is observed to be unsuccessful for the leachate treatment. In contrast, physical–chemical processes which are not favoured for fresh leachate treatment could be applied for old leachate treatment.
- H<sub>2</sub>S and NH<sub>3</sub> were high in intermediate than in young and mature aged LFS with no seasonal variation in all LFS. High H<sub>2</sub>S signifies higher anaerobic decomposition. High NH<sub>3</sub> signifies the ammonification process in LFS.
- 8. The expression " $((1-(\alpha)/\beta) (\gamma)/\beta$  \* Biogas Yield) (Where  $\alpha$  = moisture %,  $\beta$  = 100 (scale coefficient) and  $\gamma$  = volatile solids %)" calculates the biogas production at studied landfill sites (i.e. 12158 cum, 852 cum and 169 cum of biogas at Sisdole, Pokhara and Dang landfill sites respectively). This equation clearly shows that the biogas generation is dependent on moisture content and volatile solids present in total organic waste.

The outcome of this research could be used to evaluate and predict the landfill performance and also useful to study design and operation of landfills in Nepalese context and recommend the design options.

## **5.2 RECOMMENDATIONS**

- Biological treatment could be the best option for the treatment of leachate as operational LFS contained high organic waste, 900-1500 mg/L BOD and 1000-2800 mg/L COD level, but concentration of metals should be favourable for the growth of microorganism as discussed on section 4.3.10.
- 2. The influencing parameters like evaporative zone depth, precipitation, which have not been discussed in this research, are also other areas to be studied.

- Almost municipalities (except Pokhara and Kathmandu) in Nepal have open dumps. Those open dumping should be replaced or improved to controlled landfill sites and sanitary landfill sites after detail study of leachate composition.
- 4. Comparative study of landfill leachate among many landfill sites with year wise variation, cell and lift wise variation can be studied.
- 5. The current landfills produce a substantial amount of leachate and biogas. There is huge potential of energy recovery in different landfill sites of Nepal. The provision of composting and/or energy recovery can be done to minimize the atmospheric emission of biogas. Another way to reduce the GHGs emission to atmosphere is to ban the organic waste to LFS. Moreover proper gas collection and its uses address the adverse impacts of climate change.

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## APPENDICES

## Annex 1: ANOVA table for parameters analysis at different points within the same LFS

				ANOVA Table				
Parameters				Sum of Squares	Df	Mean Square	F	Sig.
Ph	Value * points	Between Groups	(Combined)	0.008	4	0.002	F Sig.   0.004 1.00   0.011 1.00   0.011 1.00   0.000 1.00   0.000 1.00   0.000 0.00   0.000 0.00   0.000 0.09   0.020 0.99   0.326 0.86	1.000
		Within Groups		415.140	745	0.557		
		Total		415.149	749			
BOD	Value * points	Between Groups	(Combined)	5,930.832	4	1,482.708	0.011	1.000
		Within Groups		101,576,310.240	745	136,344.041		
		Total		101,582,241.072	749			
COD	Value * points	Between Groups	(Combined)	19,163.467	4	4,790.867	0.000	1.000
		Within Groups		#######################################	745	15,691,281.213		
		Total		##############	749			
BOD/COD	Value * points	Between Groups	(Combined)	0.000	4	0.000	0.020	0.999
		Within Groups		1.332	745	0.002		
		Total		1.332	749			
DO	Value * points	Between Groups	(Combined)	0.114	4	0.029	0.326	0.861
		Within Groups		65.204	745	0.088		

		Total		65.318	749			
Total N	Value * points	Between Groups	(Combined)	0.000	4	0.000	0.004	1.000
		Within Groups		11.000	745	0.015		
		Total		11.000	749			
Total P	Value * points	Between Groups	(Combined)	6.417	4	1.604	0.026	0.999
		Within Groups		46,798.265	744	62.901		
		Total		46,804.682	748			
Fe	Value * points	Between Groups	(Combined)	5,560.843	4	1,390.211	1.001	0.406
		Within Groups		1,034,323.360	745	1,388.354		
		Total		1,039,884.203	749			
Cd	Value * points	Between Groups	(Combined)	0.000	4	0.000	0.150	0.963
		Within Groups		0.037	744	0.000		
		Total		0.037	748			
Cr	Value * points	Between Groups	(Combined)	0.000	4	0.000	0.007	1.000
		Within Groups		0.448	745	0.001		
		Total		0.448	749			
Cu	Value * points	Between Groups	(Combined)	0.000	4	0.000	0.017	0.999
		Within Groups		2.305	745	0.003		
		Total		2.305	749			

Hg	Value * points	Between Groups	(Combined)	0.000	4	0.000	0.333	0.856
		Within Groups		0.004	744	0.000		
		Total		0.004	748			
Ni	Value * points	Between Groups	(Combined)	0.003	4	0.001	0.097	0.983
		Within Groups		4.958	745	0.007		
		Total		4.961	749			
Pb	Value * points	Between Groups	(Combined)	0.000	4	0.000	0.004	1.000
		Within Groups		9.714	745	0.013		
		Total		9.714	749			
Ammonia	Value * points	Between Groups	(Combined)	255.184	4	63.796	0.091	0.985
		Within Groups		522,660.366	745	701.558		
		Total		522,915.550	749			
Cl	Value * points	Between Groups	(Combined)	30.207	4	7.552	0.000	1.000
		Within Groups		23,556,467.654	745	31,619.420		
		Total		23,556,497.861	749			
Zn	Value * points	Between Groups	(Combined)	0.000	4	0.000	0.005	1.000
		Within Groups		11.592	745	0.016		
		Total		11.592	749			
Ca	Value * points	Between Groups	(Combined)	10.585	4	2.646	0.000	1.000

		Within Groups		10,899,478.617	745	14,630.173		
		Total		10,899,489.202	749			
Hydrogen Sulphide	Value * points	Between Groups	(Combined)	123.771	4	30.943	0.012	1.000
•		Within Groups	I	1,986,723.937	745	2,666.744		
		Total		1,986,847.709	749			
Conductivity	Value * points	Between Groups	(Combined)	83,473.867	4	20,868.467	0.001	1.000
		Within Groups		#######################################	745	27,157,209.292		
		Total		#######################################	749			
E.coli	Value * points	Between Groups	(Combined)	5.965	4	1.491	0.000	1.000
		Within Groups	·	210,788,915.167	745	282,938.141		
		Total		210,788,921.132	749			

				ANOVA Table				
Parameters				Sum of Squares	df	Mean Square	F	Sig.
рН	Value * Months	Between Groups	(Combined)	2.223	5	0.445	0.801	0.549
		Within Groups	I	412.926	744	0.555		
		Total		415.149	749			
BOD	Value * Months	Between Groups	(Combined)	95,446.032	5	19,089.206	0.140	0.983
COD		Within Groups		101,486,795.040	744	136,406.983		
		Total		101,582,241.072	749			
COD	Value * Months	Between Groups	(Combined)	17,887,668.700	5	3,577,533.740	0.228	0.950
		Within Groups		###############	744	15,688,354.837		
		Total		#######################################	749			
BOD/COD	Value * Months	Between Groups	(Combined)	0.004	5	0.001	0.468	0.800
		Within Groups		1.328	744	0.002		
		Total		1.332	749			
DO	Value * Months	Between Groups	(Combined)	0.074	5	0.015	0.168	0.974
		Within Groups	I	65.244	744	0.088		
		Total		65.318	749			
L								

Annex 2: ANOVA table for parameters analysis according to months

Total N	Value * Months	Between Groups	(Combined)	0.009	5	0.002	0.125	0.987
		Within Groups		10.991	744	0.015		
		Total		11.000	749			
Total P	Value * Months	Between Groups	(Combined)	187.608	5	37.522	0.598	0.701
		Within Groups		46,617.074	743	62.742		
		Total		46,804.682	748			
Fe	Value * Months	Between Groups	(Combined)	6,869.337	5	1,373.867	0.989	0.423
		Within Groups		1,033,014.866	744	1,388.461		
		Total		1,039,884.203	749			
Cd	Value * Months	Between Groups	(Combined)	0.000	5	0.000	1.096	0.361
		Within Groups		0.036	743	0.000		
		Total		0.037	748			
Cr	Value * Months	Between Groups	(Combined)	0.000	5	0.000	0.007	1.000
		Within Groups		0.448	744	0.001		
		Total		0.448	749			
Cu	Value * Months	Between Groups	(Combined)	0.007	5	0.001	0.485	0.787
		Within Groups	I	2.298	744	0.003		
		Total		2.305	749			
Hg	Value * Months	Between Groups	(Combined)	0.000	5	0.000	2.715	0.019

		Within Groups		0.004	743	0.000		
		Total		0.004	748			
Ni	Value * Months	Between Groups	(Combined)	0.061	5	0.012	1.853	0.100
		Within Groups	I	4.900	744	0.007		
		Total		4.961	749			
Pb	Value * Months	Between Groups	(Combined)	0.148	5	0.030	2.297	0.044
		Within Groups		9.567	744	0.013		
		Total		9.714	749			
Ammonia	Value * Months	Between Groups	(Combined)	2,066.523	5	413.305	0.590	0.707
		Within Groups	I	520,849.027	744	700.066		
		Total		522,915.550	749			
Cl	Value * Months	Between Groups	(Combined)	5,687.646	5	1,137.529	0.036	0.999
		Within Groups		23,550,810.215	744	31,654.315		
		Total		23,556,497.861	749			
Zn	Value * Months	Between Groups	(Combined)	0.033	5	0.007	0.424	0.832
		Within Groups		11.560	744	0.016		
		Total		11.592	749			
Ca	Value * Months	Between Groups	(Combined)	426,196.448	5	85,239.290	6.055	0.000
		Within Groups	I	10,473,292.755	744	14,077.006		
						1		1

		Total		10,899,489.202	749			
Hydrogen	Value * Months	Between Groups	(Combined)	10,760.764	5	2,152.153	0.810	0.542
Sulphide								
		Within Groups		1,976,086.945	744	2,656.031		
		Total		1,986,847.709	749			
Conductivity	Value * Months	Between Groups	(Combined)	109,556,002.300	5	21,911,200.460	0.810	0.543
		Within Groups		*****	744	27,046,570.423		
		Total		*****	749			
E.coli	Value * Months	Between Groups	(Combined)	6.572	5	1.314	0.000	1.000
		Within Groups		210,788,914.560	744	283,318.434		
		Total		210,788,921.132	749			

			ANOVA Table	9				
Parameters				Sum of Squares	df	Mean Square	F	Sig.
рН	Value * Feeding_capacity	Between Groups	(Combined)	402.002	4	100.500	5,695.014	0.000
		Within Groups		13.147	745	0.018		
		Total		415.149	749			
BOD	Value * Feeding_capacity	Between Groups	(Combined)	100,974,748.525	4	25,243,687.131	30,957.659	0.000
		Within Groups		607,492.547	745	815.426		
		Total		101,582,241.072	749			
COD	Value * Feeding_capacity	Between Groups	(Combined)	#######################################	4	######################################	24,508.528	0.000
		Within Groups		88,167,099.500	745	118,345.100		
		Total		#######################################	749			
BOD/COD	Value * Feeding_capacity	Between Groups	(Combined)	1.303	4	0.326	8,433.818	0.000
		Within Groups		0.029	745	0.000		
		Total		1.332	749			
DO	Value * Feeding_capacity	Between Groups	(Combined)	60.176	4	15.044	2,179.851	0.000
		Within Groups	1	5.142	745	0.007		

Annex 3: ANOVA table for parameters analysis according to feeding amount

		Total		65.318	749			
Total N	Value * Feeding_capacity	Between Groups	(Combined)	10.876	4	2.719	16,302.778	0.000
		Within Groups	<u> </u>	0.124	745	0.000		
		Total		11.000	749			
Total P	Value * Feeding_capacity	Between Groups	(Combined)	45,318.767	4	11,329.692	5,672.793	0.000
		Within Groups	<u> </u>	1,485.916	744	1.997		
		Total		46,804.682	748			
Fe	Value * Feeding_capacity	Between Groups	(Combined)	6,411.617	4	1,602.904	1.155	0.329
		Within Groups		1,033,472.586	745	1,387.212		
		Total		1,039,884.203	749			
Cd	Value * Feeding_capacity	Between Groups	(Combined)	0.033	4	0.008	1,467.826	0.000
		Within Groups		0.004	744	0.000		
		Total		0.037	748			
Cr	Value * Feeding_capacity	Between Groups	(Combined)	0.446	4	0.111	37,720.312	0.000
		Within Groups		0.002	745	0.000		
		Total		0.448	749			
Cu	Value * Feeding_capacity	Between Groups	(Combined)	2.239	4	0.560	6,301.817	0.000
		Within Groups	<u> </u>	0.066	745	0.000		
		Total		2.305	749			

Hg	Value * Feeding_capacity	Between Groups	(Combined)	0.002	4	0.001	226.324	0.000
		Within Groups		0.002	744	0.000		
		Total		0.004	748			
		Total		0.004	740			
Ni	Value * Feeding_capacity	Between Groups	(Combined)	4.552	4	1.138	2,074.868	0.000
		Within Groups		0.409	745	0.001		
		Total		4.961	749			
Pb	Value * Feeding_capacity	Between Groups	(Combined)	8.931	4	2.233	2,122.660	0.000
		Within Groups		0.784	745	0.001		
		Total		9.714	749			
Ammonia	Value * Feeding_capacity	Between Groups	(Combined)	462,604.017	4	115,651.004	1,428.582	0.000
		Within Groups		60,311.533	745	80.955		
		Total		522,915.550	749			
Cl	Value * Feeding_capacity	Between Groups	(Combined)	23,510,652.349	4	5,877,663.087	95,513.362	0.000
		Within Groups		45,845.512	745	61.538		
		Total		23,556,497.861	749			
Zn	Value * Feeding_capacity	Between Groups	(Combined)	11.416	4	2.854	12,034.791	0.000
		Within Groups	1	0.177	745	0.000		
		Total		11.592	749			
Ca	Value * Feeding_capacity	Between Groups	(Combined)	8,770,990.514	4	2,192,747.628	767.488	0.000

		Within Groups		2,128,498.689	745	2,857.045		
		Total		10,899,489.202	749			
Hydrogen Sulphide	Value * Feeding_capacity	Between Groups	(Combined)	1,915,215.718	4	478,803.929	4,979.743	0.000
		Within Groups		71,631.991	745	96.150		
		Total		1,986,847.709	749			
Conductivity	Value * Feeding_capacity	Between Groups	(Combined)	######################################	4	#######################################	12,555.372	0.000
		Within Groups		295,743,210.833	745	396,970.753		
		Total		#######################################	749			
E.coli	Value * Feeding_capacity	Between Groups	(Combined)	210,787,771.872	4	52,696,942.968	#######################################	0.000
		Within Groups		1,149.260	745	1.543		
		Total		210,788,921.132	749			