Leachate Generation and Characterization from Solid Waste Dumps of Islamabad and Rawalpindi

By

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DECLARATION

I hereby declare that this dissertation is the outcome of my own efforts and has not been published anywhere else before. The matter quoted in the text has been properly referred and acknowledged.

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APPROVAL SHEET

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To

My Beloved Parents

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List of Abbreviations

APHA	:	American Public Health Association
ASTM	:	American Standard of Testing Materials
BC	:	Bhatta Chowk
BOD	:	Biological oxygen demand
COD	:	Chemical oxygen demand
Cr^{+6}	:	Hexavalent Chromium ion
Fc	:	Field capacity
Fe^{+3}	:	Trivalent Iron ion
g/L	:	Grams per liter
INSIDOC	:	Indian National Network for Social Science Information and Documentation Centers
Kg	:	Kilograms
L	:	Liters/ Cubic decimeters
m^3	:	Cubic meter
mg/L	:	Milligrams per Liter
mm	:	Millimeters
ms/cm	:	Millsiemens per Centimeters
MSW	:	Municipal Solid Waste
NTU	:	Nephelometric Turbidity Units
P	:	Rain Fall/ Precipitation
Q	:	Leachate generated
$Q_{(BC)}$	:	Leachate Generated by BC Column
$Q_{(H-10)}$	:	Leachate Generated by H – 10 Column
$Q_{(H-12)}$	:	Leachate Generated by H – 12 Column
St Dev	:	Standard Deviation
SWM	:	Solid Waste Management
%	:	Percentage

ABSTRACT

This study was aimed to determine leachate generation potential and its chemical characterization from three main dumps of Islamabad and Rawalpindi using column cell approach. Compositions and density of the waste of sector H-10, Bhatta Chowk and sector H-12 dumps were studied to maintain the percentage of their components in their respective column cells, constructed and operated as leachate generating units. Percentage of organic waste in Bhatta Chowk dump is found to be higher than H-10 dump. Density of waste in H-12 dump has found to be greater than Bhatta Chowk dump which is greater than H-10 dump. The equations developed for determining leachate generation of three dumps for any rain fall are: $Q_{(H\text{-}10)} = 0.800(P) - 2.155$, $Q_{(BC)} = 0.797(P) - 2.304$ and $Q_{(H-12)} = 0.684(P) - 1.847$. Leachate generated for the dumps at an average depth of one, two and three meters was determined using the column cell results. Chemical characteristics of various samples of leachate sampled from the columns were determined as; COD 3390 - 8320mg/L, Sulphates 35 – 180 mg/L, Chlorides 325 – 1535 mg/L, Nitrites 5.1 – 56.33 mg/L, TDS 3.20 – 8.05 g/L, Turbidity 69 – 240 NTU, pH 6.0 – 8.0, Trivalent metal Iron 0.5 – 1.7 and Trivalent chromium 0.41 to 1.5 mg/L. Characterization study reveals that concentration of all parameters exceeded the NEQ safe limits for inland waters. Thus Phytocapping remediation at sector H-12 dump, MRF with compost facility at Bhatta Chowk dump and increasing the frequency of clay lining at sector H-10 dumps is recommended as preventive measure against leachate contamination.

Chapter 1

INTRODUCTION

1.1 BACKGROUND

Since the advent of civilization, many community-based environmental issues have been evolving. Solid waste management is one of the most emerging environmental issues both for the rural and urban communities due to increase in population and development. High income countries in Asia (e.g. Japan and Singapore) generate solid waste 1.5-2.0 kg/capita/day, middle income countries (e.g. Indonesia, Malaysia, Thailand etc.) generate solid waste 0.75-1.0 kg/capita/day; and low income countries (e.g. India, Philippines, etc.) generate 0.4-0.6 kg/capita/day. By 2025, several countries in this region, e.g. Bangladesh, Myanmar, Nepal and Vietnam are predicted to have their urban waste quantities to increase by about four to six times of the current amount (World Bank, 1999).

In most of the developing countries, municipal solid waste (MSW) is finally disposed off in open dumps. In Thailand and India for example, 70-90% of final disposal sites are open dumps (Visvanathanan *et al*., 2003). The rate of waste generation/person in Pakistan is 0.283 to 0.613 kg/capita/day (Khan, 1998). Many open dump sites are being improved by, at least, compacting MSW, provide soil cover intermittently for reducing nuisance, and final cover when the dump areas are full. Yet a number of other dumps in many Afro-Asian countries are left open and are a constant source of intense environmental hazards (Ashford *et al*., 2000).

Solid waste dumps, though not very safe for the environment, are and shall remain, in practice for long times to come for the ultimate disposal of all types of solid waste in most of the developing and under developed areas of the world (Kumar and Alappat, 2005).

Water when passes through the waste in dumps, absorbs all the exchangeable and dissolvable ingredients/chemicals from the solid waste, thus it gets highly contaminated and is known as leachate. Landfill leachates contain a large number of compounds, some of which can be expected to create a threat to public health and environment (Oman and Junested. 2007). The risk of groundwater pollution is probably the most severe environmental impact from landfills which were made without liners or leachate collection systems (kJeldson *et al*., 2002). Thus the assessment of quality and quantity of leachate is very important for the solid waste dumps.

There are many open dumps in Islamabad and Rawalpindi, but three main dumps were selected for the estimation of their leachate generation and its chemical characterization. Two of the dumps are currently being used for the disposal of MSW while the third one has been abandoned. The dumps are named after their locations and are: a) sector H-10 dump, b) Bhatta Chowk (BC) dump, and c) sector H-12 dump (abandoned). The average quantity of waste coming to sector H-12 dump, Islamabad was 320 tons per day, the total quantity of waste in sector H-12 dump Islamabad is 0.143 million tons (Baig and Elahi, 2003). According to PEPA (2008), the average quantity of waste disposed in Islamabad was 387.6 tons/day. The waste disposed at Rawalpindi dump was 600 tons/day (World Bank 2007). The locations of these dumps have been shown on Fig. 1.1.

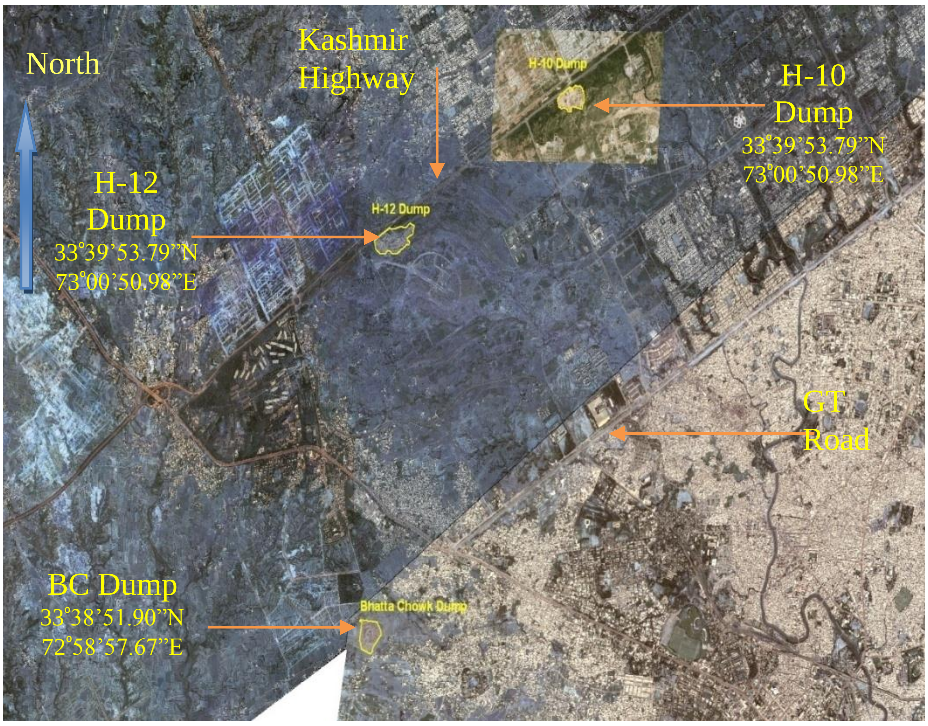

Fig 1.1: Location plan: Islamabad – Rawalpindi open solid waste dump sites

1.2 OBJECTIVES OF STUDY

The major objectives of the study are:

1- Estimation of leachate generated at different depth of the solid waste in the selected dumps using open cell column approach
2- Characterization of leachate produced from dumps of Islamabad and Rawalpindi

1.3 SCOPE OF STUDY

The scope of the study comprises the following:

1- Determination of composition, density and moisture content of solid waste of the selected dumps.

2- Preparation of columns of the dumps using solid waste material from the respective dumps, while keeping the densities and composition of solid waste as found in situ.
3- Artificial showering of various rainfall amounts onto the filled in columns for quantification of leachate generation.
4- Applying the column cell leachate generation results to the dumps for the estimation of leachate in each of the three dumps at different depths of solid waste material.
5- Characterization of leachate samples through laboratory analyses.

1.4 BENEFITS OF STUDY

1- The determination of leachate quantity and quality provide a basic parameter for the designing of a leachate treatment system for any landfill constructed for the disposal of municipal solid waste.
2- Leachate pollution indices for the three dumps of Islamabad and Rawalpindi could be determined.

Chapter 2

REVIEW OF LITERATURE

2.1 GENERAL

Leachate is formed when water through any source enters the solid waste and exceeds the moisture absorption limit of the material. According to El Fedal *et al* (2002), leachate is formed when water entering the dump exceeds its field capacity. Thus leachate carries all the dissolvable and exchangeable ingredients of solid waste.

2.2 LEACHATE - A THREAT TO GROUND WATER AND PUBLIC HEALTH

Leachate released from dumps is capable of contaminating the ground water and its properties depend upon the composition of solid waste. According to Klink and Stuart (1999), medical waste like surgical dressings and disposed syringes, diapers, burning of solid waste in the dumps, sludge from the sewerage treatment plants, biodegradation of organic matter (food waste etc) are mainly responsible for the bacterial and microbial contamination of aquifers, causing water born diseases like Typhoid, Cholera, Diarrhea, and Hepatitis.

2.3 FACTORS EFFECTING LEACHATE GENERATION IN DUMPS

Trankler *et al*., (2001) reported that the composition of landfill leachate varies from site to site depending on solid waste composition, rainfall over of the landfill, climate, and hydrology of landfill site, age of the landfill, temperature and pH. A combination of physical (moisture content, field capacity, compression, porosity etc.), chemical (aerobic, anaerobic reactions, synthesis, precipitation, phytocatalysis etc.), and microbial (biological degradation/decomposition) processes, transfer pollutants from the waste material to the percolating water (Christensen and Kjeldsen, 1989).

2.3.1 Water Infiltration

According to the mass balance explained by Vesilind *et al.*, (2004), no leachate shall be generated without infiltrating water. According to the mass balance,

$$C = P\,(1-R) - S - E,$$

Where, C = Leachate/Infiltration, P = Precipitation, R = Runoff coefficient,

S = Storage within the waste, E = Evapotranspiration.

2.3.2 Composition of Solid Waste

Composition of solid waste has a large impact on leachate generation and characterization. According to (World Bank 1999), the major portion of MSW generated in Asia is mainly composed of easily biodegradable organic material with high moisture content. The composition of biodegradable waste in various Asian countries is as: Bangladesh: 84%, Myanmar: 80 %, Sri Lanka: 76 %, Indonesia: 70% and Thailand: 49 %. Solid waste in Pakistan has three main categories i.e. biodegradables including food waste, animal waste, leaves, grass and wood; non biodegradables such as plastic, rubber, textile waste, stones; and recyclables such as paper, cardboard, rags, bones and metals (Mahar *et al* 2007). Initial moisture content, density, field capacity all depend upon the composition of solid waste which has an impact on leachate generation from waste (Tatsi and Zoubolis, 2002).

2.3.3 Density of Solid Waste

According to Tatsi and Zoubolis (2002), leachate production is increased when solid waste has less density. According to Demirekler *et al*., (1999) highly compacted waste has less hydraulic conductivity. Leachate production is generally greater whenever; the waste is less compacted, since compaction reduces the filtration rate (Lema *et al*., 1988).

2.3.4 Moisture Content of Waste

Leachate generation is directly proportional to the volumetric water content of solid waste. The moisture flux coming out of each refuse layer changes with depth and time. According to Rovers *et al* (1973), if the wet density of solid waste is 314.43 Kg/m^3, its moisture content is 14.86 mm/m.

2.3.5 Field Capacity (Fc)

According to Vesiland *et al*., (2004) field capacity is the maximum moisture in a material that can be retained without a continuous downward percolation due to gravity. According to Tatsi and Zouboulis (2002), quantity of leachate produced is proportional to the quantity of water entering the solid waste. According to El-Fadel *et al*., (2001) leachate is produced when water percolating the waste exceeds its field capacity. According to Rover *et al* (1973), if the wet density of solid waste is 314.43 Kg/m^3, its field capacity is 28.03 mm/m.

2.4 LEACAHTE GENERATION

Various methods have been used by researchers to determine the leachate generation from solid waste. Various approaches used for leachate generation studies are as follows:

2.4.1 Lysimeters as an Approach to Estimate Leachate Generation

Kranchanawong and Yongpisalpop, (2009) used four lysimeters for leacahte generation and characterization study. The composition of waste in all the four lysimeters was same. The waste comprised of 11% papers, 15.1 % plastic, 9.6% glass, 2.1% metals, 0.9% rubbish and leather, 2.6% cloth, 1.2% garden waste, 2.1% stones and ceramics; and 1.4% miscellaneous. Soil covers were used in three of the lysimeters while fourth one was not covered with any soil. Cumulative amount of rain fall added to the 4^{th} lysimeter was 10.7 liters. The leachate generation from this lysimeter was 11.8 liters. The author attributed this phenomenon to the high initial moisture content which was calculated to be 55.3 percent where leachate quantity exceeded the amount of rainfall.

Wisitirakul, (2006) used lysimeters to evaluate sustainable landfill rainfall event by combining open cell and water management strategies. Their studies were aimed to investigate the open cell rainfall event studies by combining it with water management. The authors regarded the water management as storage, evaporation and recirculation of leachate as they carried out the study during a rainfall season (four months) and then dry season (three months) event for a continuous period of seven months. The researchers used four landfill lysimeters and operated in different conditions - open cell landfill, open cell landfill combined with leachate recirculation, open cell landfill of pre-sorted waste combine with leachate recirculation and conventional landfill. Of these, the first one representing the open cell landfill corresponds to this study where leachate generation, leachate characteristics and settlement variation of MSW were monitored. The water balance evaluated by HELP model agreed with experimental results of open cell landfill lysimeters. Fig. 2.1 presents the relationship between rainfall and cumulative leachate generation from landfill lysimeters since July 2005 to February 2006.

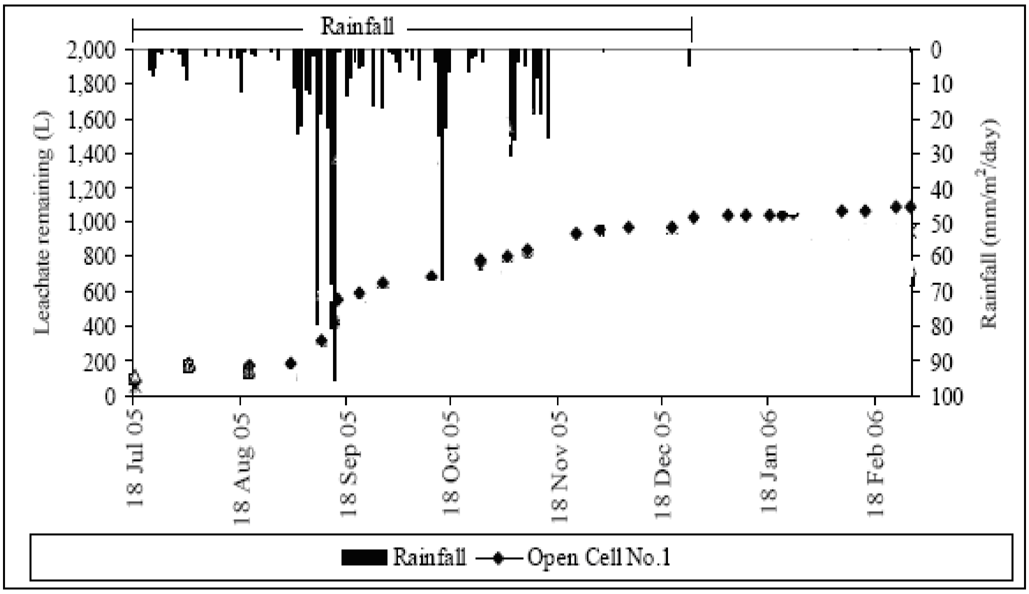

Fig 2.1: Relationship between rainfall and cumulative leachate generation from landfill lysimeters (Wisitertakul, 2006)

First period of the rainfall event was rainy season which started from July to mid-November 2005. High amount of leachate was generated which was mainly due to initial moisture content of MSW, decomposition of solid waste and precipitation in this period. The leachate generation was significantly increased in September 2005 which had high and intense rainfalls with long durations.

The second period was dry wherein there was very less or no rainfall. Thus, in this period, the leachate was produced in small amounts. The cumulative leachate generation from open cell landfill was slowly increased.

The above studies conclude that the leachate quantity will increase if, because of its own weight, the waste released pore water when squeezed. Unsaturated waste continues to absorb water until it reaches field capacity (a water saturation state).

However, it must be noted that in actuality, channeling causes water to flow through the waste without leaching chemicals or being absorbed by the waste.

Qasim and Chiang (1994), used lysimeters to study and monitor the leachate quality and quantity of solid waste. They used large lysimeters (15-16 m x 6-9 m x 2.5-3 m), constructed outdoor and exposed to natural climatic conditions. They conducted long term experiments for predicting the quantity and quality of leachate of various non-hazardous wastes.

2.4.2 Leachate Generation using Columns

Bilgili *et al*. (2006) performed column studies for the quantity of leachate produced by waste in aerobic and anaerobic conditions. They filled the columns with specific composition and densities of waste as found in the landfills and performed leachate gener4ation and recirculation experiments.

2.4.3 Computer Models as a Tool for Determining Leachate Generation

Various computer models are also in frequent use to determine the leachate quantity for known physical parameters of waste, climatic data and landfill design criteria. The experimental and theoretical concentrations of leachate constituents were fairly close (Straub and Lynch 1982). Hydrologic Evaluation of Landfill Performance (HELP) model established by US Army Corps of Engineers uses a Quasi-2 Hydrologic model for leachate generation (Schroeder *et al*., 1994). Fenn *et al*, (1975) provided a detailed method for conducting water balance calculations. Dass *et al,* (1977) showed moisture balance calculations where after Pfeffer (1992), gave a simplified moisture based method for leachate generation estimations.

Tchobanoglous *et al*. (1993) gave leachate quality estimation based upon water budget method. Lutton *et al*, (1979) adopted a model "US Department of Agriculture Hydrograph Laboratory model (USDAHL)" and applied this model to calculate landfill conditions. Perrier and Gibson (1980) developed a model "Hydrologic Simulation on Solid Waste Disposal Site (HSSWDS)". USEPA (1992), developed a multimedia Assessment model (MULTIMED) that simulates the transportation of contamination released from the waste diposal facility into the multimedia environment.

2.4.4 Leachate Quantity in Various Landfills

In the Landfill near Madrid (Spain), the leachate production was 7 mm/year, near Pavia (Italy) 82 mm/year, near Athens (Greece) 40-60 mm/year against annual rainfall of 387 mm. El-Fadel *et al*., (2001) determined that equivalent average leachate generation, from a landfill in Beirut City of Kuwait during 1998 to 2000 was 150 liter/ton of the refuse which is high for presorted waste. Presorting is done to remove organic and bulky items leaving dry compacted refuse with a high moisture retention capacity. The high leachate is attributed to high percentage of organic waste and high rainfall which is about 760 mm/year in the area.

2.5 LEACHATE CHARACTERIZATION

More than 100 compounds have been identified in landfill leachates (O'man and Hynning, 1993). According to O'man and Junested (2008), more than 90 organic and metal organic compounds and 50 inorganic elements have been detected, some of which seem to have not been detected before. Compounds detected include halogenated aliphatic compounds, benzene and alkylated benzenes, phenol and alkylated phenols, ethoxylates, polycyclic aromatic compounds, phthalic esters, chlorinated benzenes, chlorinated phenols, PCB, chlorinated dioxins and chlorinated furans, bromated flame-retardants, pesticides, organic tin, methyl mercury and heavy metals.

According to kJeldson *et al* (2002), the dissolved organic matter and inorganic macrocomponents are 1000 to 5000 times higher in leachate than concentrations found in groundwater; several parameter change dramatically as the landfill stabilizes and during the acid phase; the leachate may show low pH values and high concentrations of many compounds i.e. volatile fatty acids etc. In the later stable methanogenic phase, the pH increases reflecting the degradability of the organic carbon (Ehrig, 1988). Seasonal variations in leachate composition have been observed in several cases. According to (Kulikowska and Klimiuk 2008), chemical composition of leachate and concentration of contaminants depend upon the quantity of water entering the solid waste. Akesson and Nilsson (1997) observed lower leachate concentrations in the wet season in a Swedish landfill test cell. Similar observations were found by Chu et al. (1994) in a Hong Kong landfill. Several researchers have investigated the behavior of heavy metals in the landfills. According to Flyhammer *et al*. (1998), approximately 30% of the metals in MSW were available in reactive solid form.

2.5.1 Characteristics of Leachate from Column/Lysimeters Study

Solid waste in a dump if exposed to the air, remains aerobic. When there are many layers of waste accumulated over the older waste, the older waste layer becomes anaerobic. Therefore solid waste in a dump is sometimes aerobic and sometimes anaerobic. The characteristics of aerobic waste as determined by Bilgilli (2008), providing aerobic conditions to the column generating the leachate were as: pH 4.4 – 9.1, TDS 10.9 – 27.7 g/L, Conductivity 16.4 – 38.6 ms/cm, COD 5120 - 68515 mg/L, Chlorides (Cl^{-1}): 2080 – 6600 mg/L. The characteristics of leachate while providing anaerobic conditions to the columns were: pH 4.4 – 7.7, TDS 2.7 to 16.6 g/L, conductivity 4-24.8 ms/cm, chlorides (Cl^{-1}) 2250- 5280 mg/L, and COD 1600-94800 mg/L. Visvanathan *et al*., (2007) determined the chemical characteristics of leachate collected from lysimeters. The results of characterization showed, COD: 940 – 32790 mg/L., TDS 3,670-14,445 mg/L and pH 5.75- 8.36.

2.5.2 Characteristics of Leachate, Collected from an Upgraded Dump

Oyoh and Evbuomwan (2008) determined chemical characteristics of leachate samples collected from Port Harcourt landfill which had a dump site since 1990. The dump was upgraded to a landfill by the establishment of leachate collection pipes in 1999. Landfill covers 9 hectare of solid waste which is deposited to an estimated average depth of 2.5 meters. To determine the leachate, integrated samples were collected from randomly selected leachate drains at the site. TDS (4093.75 mg/L) and pH (8.17) were determined by glass electrode method. Concentrated tertrasulphate solution was used to determine the COD (2914.5 mg/L). Scott *et al*., (2005) compared the pollution parameters of leachate determined from landfills/dumps of various countries and recorded the range of various pollutants as; COD: 0-152000 mg/L, Conductivity: 470-72500μS/cm, Chlorides: 34-11375 and Sulphates: 0-7750.

Alsabahi *et al*., (2009), characterized leacahte samples from Ibb city (Yemen) landfill which has an open dump located in Al School area over 0.8 Km^2. The dump has been converted into three separate but contiguous landfills. Three leachate samples were determined to assess the ground water contamination capacity of the landfills. Results of their characterization were as: pH: 8.24, Electrical Conductivity: 6923.5 - 6887 μS/cm, TDS: 4476 - 4524 mg/L, COD: 1540 - 1540 mg/L, Chlorides: 4245 - 4317 mg/L and Chromium 0.131-0.1331mg/L.

2.5.3 Characteristics of Leachate in an upgraded Dump of Arabian Peninsula

Alsabahi *et al*., (2009), characterized leacahte samples from Ibb city (Yemen) landfill which has an open dump located in Al School area over 0.8 Km^2. The dump has been converted into three separate but contiguous landfills. Three leachate samples were determined to assess the ground water contamination capacity of the landfills. Results of their characterization were as: pH: 8.24, Electrical Conductivity: 6923.5 - 6887 μS/cm, TDS: 4476 - 4524 mg/L, COD: 1540 - 1540 mg/L, Chlorides: 4245 - 4317 mg/L and Chromium 0.131-0.1331mg/L.

Based upon the above discussion, it is concluded that leachate generation depends upon rainfall, composition, density, initial moisture content, and field capacity of solid waste. Chemical characteristics of leachate depend upon the composition, density and the infiltration rater of water through the solid waste.

Chapter 3

MATERIALS AND METHODS

Three dumps of Islamabad and Rawalpindi cities were selected for leachate generation and characterization study. The details of these dumps are as follows (Table 3.1) and shown previously in fig 1.1.

Table 3.1: Selected dumps of Islamabad and Rawalpindi

Dump	Site Location	Coordinates	Current Status
H-10	Sector H-10, Islamabad, Pakistan	33°39’53.79”N 73°00’50.98”E	Functional
BC	BC, Near Haji Camp, Rawalpindi, Pakistan	33°39’53.79”N 73°00’50.98”E	Functional
H-12	Sector H-12, Islamabad, Pakistan	33°38’51.90”N 72°58’57.67”E	Abandoned

3.1 SOLID WASTE SAMPLING & COMPOSITION ANALYSIS

Ten samples of solid waste, weighing ten Kg each, were collected randomly from ten different points of each dump. The collection process continued for seven days. ASTM D- 5956-(2001) was used as sampling methodology for each of the three dumps.

3.1.1 Moisture Content Analysis

Various components of waste were collected and carried to the laboratory for moisture content determination. The wet weights of these components were measured on electrical balance and were dried in an electric oven at 104^o C for determining their dry weight. The drying process was continued separately for each component until there was no further reduction in weight. Following formula by Vesilind *et al*., (2004) was used to determine the percentage moisture content by weight of each component of solid waste.

$$\text{Moisture Content} = \{(\text{Wet Weight} - \text{Dry Weight})/\text{Wet Weight}\}*100$$

3.1.2 Determination of Solid Waste Density

Density of the solid waste of each of the three dumps was determined at five random locations situated sparingly throughout the area of each dump. Pits of 0.028 m^3 (1 ft^3) were made in the dump and the waste within this volume was weighed to determine the density. The equation used for the determination of density is as follows:

$$\text{Density} = \text{Mass (Kg)} / \text{V} (m^3)$$

3.2 INSTRUMENTAL SETUP FOR LEACHATE GENERATION

Three open cell columns were prepared using water tank (double ply), having a volume of 200 gallons ($0.757 m^3$), for leachate generation observations; each considered representing the solid waste in a unit area of a specific dump. The diagram showing all components of the columns used for leachate generation set ups are shown in Fig 3.1.

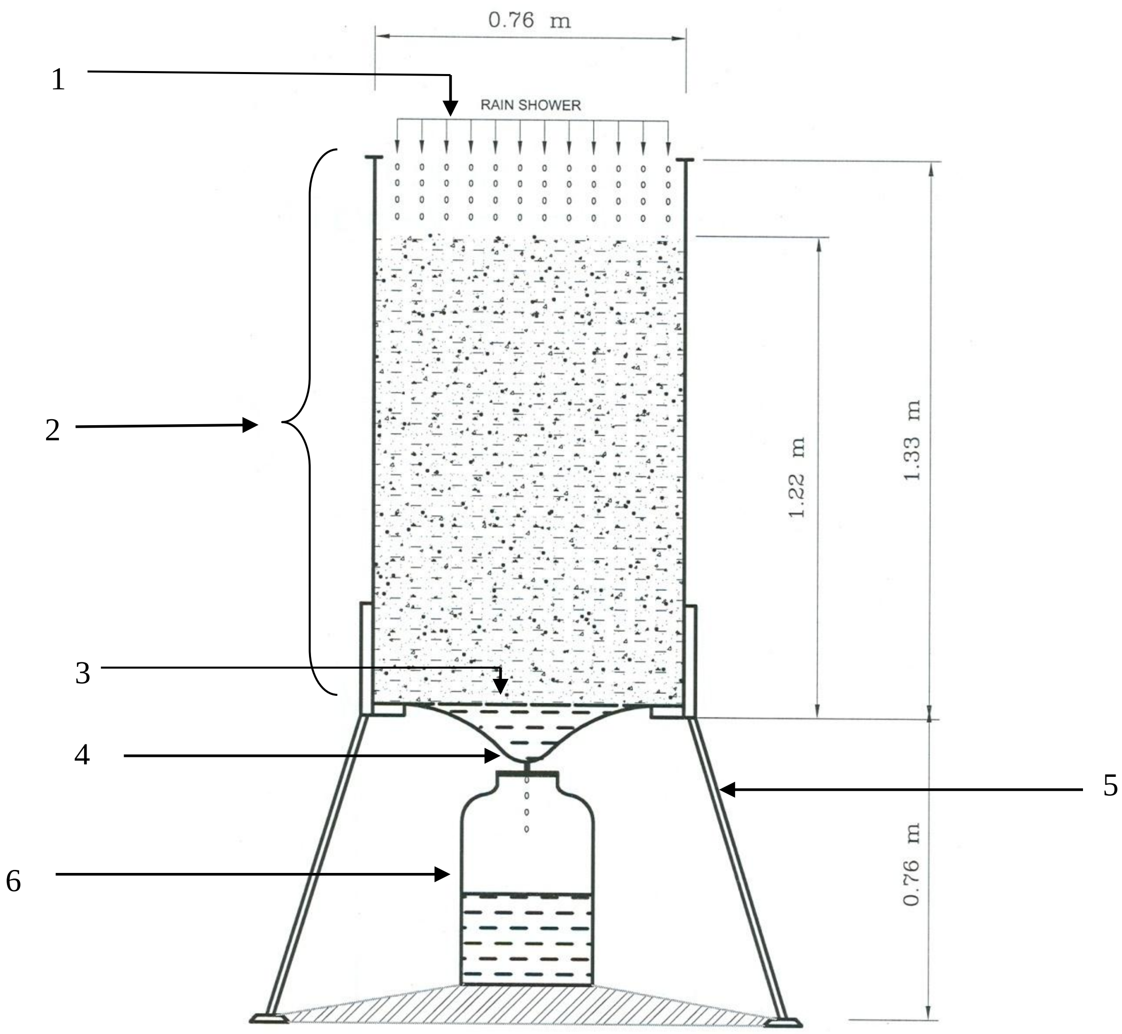

Fig 3.1 Laboratory Setup for Leachate Generation & Observation

(Detail of Various Components Given Below)

1- *Rainfall receiving open area.*
2- *Cylindrical column tank containing MSW, height 1.33 m, dia 0.76 m.*
3- *Perforated double ply tray for separating leachate from MSW.*
4- *Leachate collection chamber having a small pore.*
5- *Metallic stand 0.76 meter high, holding the column.*
6- *Leachate collection container for the collection, measurement and calibration of leachate quantity.*

3.3 FILLING THE COLUMN WITH DUMP REPRESENTATIVE MATERIAL

The columns were filled with the solid waste taken from the dumps having the in-situ physical characteristics (composition and density) as found in the dumps. The estimated quantities of mass of solid waste for each column are as given in Table 3.2.

Table 3.2: Density, and mass of solid waste in each column cell

Dump Site	Density, Kg/m^3	Mass of Waste in each Column, Kg
H – 10	450	**249.3**
BC	500	**277**
H – 12	550	**304.7**

3.4 RAINFALL INPUT FOR COLUMN CELLS

3.4.1 Rainfall Events

Rain fall events ranging from 2 mm to 55 mm (0.91 liter-24.91 liter) were shed on the columns according to the schedule as presented in Table 3.3. The intensity of rainfall was kept 33 mm/hr. The selection of the range of rainfall has been based upon the maxima and minima of the historical hydrometeorology occurrences in the area where the dumps are located.

Table 3.3: Rainfall input used in the column cells for leachate generation

Dates (2009)	**Precipitation, mm**	**Precipitation, liter**
20 - Jan	9.93	4.50
21 – Jan	9.93	4.50
22 – Jan	11.04	5.00
2 – Feb	19.52	8.84
5 – Feb	3.00	1.35
6 – Feb	21.83	9.89
8 – Feb	20.36	9.22
9 – Feb	10.45	4.73
11 – Feb	3.00	1.36
12 - Feb	8.38	3.80
17 – Feb	16.43	7.44
21 – Feb	43.66	19.78
2 – Mar	55.00	24.91
4 – Mar	2.00	0.91
6 – Mar	23.49	10.64
10 – Mar	30.91	14.00
12 – Mar	50.77	23.00
14 – Mar	35.32	16
17 – Mar	8.60	3.90
22 – Mar	48.57	22.00
31 – Mar	15.59	7.06

3.4.2 Conversion of Rain fall Depth to Rainfall Volume

It has been estimated that one millimeter rainfall over the receiving area (0.456 m^2) of each column cell would be equivalent to 0.453 liters by volume. The calculation for conversion is presented in the following example:

Example:

Suppose Rain fall = 21.83 mm = 0.0218 m

Area of column = $\pi (D/2)^2$

$= (3.14)(0.762/2)^2$

$= 0.455\ m^2$

Volume = Area of column X Depth of waste in the column

$= 0.455\ m^2 X\ 0.0218\ m$

$= 0.0099\ m^3$

$0.0099\ m^3 = 9.9\ dm^3$

Therefore, 21.83 mm rain fall = 9.9 dm^3

1mm of rainfall = 9.9/21.83 = 0.453 dm^3 or liters

3.5 LEACHATE GENERATION SIMULATION FOR THE DUMPS

Column cells provided the result of leachate generation upto a depth of 1.22 meter. Since the depth of solid waste varies in the dumps, leachate generation at 1, 2 and 3 meter depth of MSW has been estimated. The system losses (absorption etc) of moisture in the dump at 1.22, 1, 2 and 3 meter depths have been calculated by using column cell results and then leachate at these depths is calculated by using mass balance equation. Q = P-A, where Q is leachate, P is rainfall and A indicates the accumulated system losses.

3.6 LEACHATE CHARACTERIZATION – LABORTORY ANALYSES

Twenty four samples of leachate, 8 from each column were preserved and shifted to IESE analytical laboratory for determination of eleven chemical characteristics. The following paragraphs summarize the analytical techniques / instruments used for leachate characterization.

3.6.1 Determination of pH, Turbidity, and TDS

Table 3.4 presents the instruments and their types used for the detection of pH, turbidity and TDS.

Table 3.4: Instruments used for characterization of pH, turbidity and TDS

Parameter	**Analytical Instrument**
pH	Sens Ion 1
Turbidity	2100 N Turbidimeter
TDS	Sens Ion 5

3.6.2 Determination of COD

COD was measured by closed reflux method by using following formulae. The method is given by (Pitwell *et al*, 1996).

COD, mg/L = (A-B) (M) (8000) (Dilution Factor)/ ml of Sample

Where, A = ml of FAS used for Blank

B = ml of FAS used for Sample

M = Molarity of ferrous ammonium sulphate (FAS)

8000 = Milli equivalent weight of Oxygen × 1000 ml/L

3.6.3 Determination of Other Constituents:

Determination of Sulphates SO_4^{-2}, Nitrites NO_2^{-1}, Chlorides Cl^{-1}, Hexavalent Chromium Cr^{+6}, and Trivalent Iron Fe^{+3} was measured by HACH DR/ 2010 Spectrophotometer. Sabahi *et al*, (2009) also used HACH DR 4000, 48000 and 48100 spectrophotometers for the determination of sulphates (SO_4^{-2}) and Nitrites (NO_2^{-1}). A list of chemical reagents and wave-length usd for the analysis of these characteristics is presented in Table 3.5.

Table 3.5: Chemical reagents and wave lengths used for detection of pollutants in HACH DR/2010.

Parameters	Reagents	Wave Length
SO_4^{-2}	Sulfaver Reagent	450
NO_2^{-1}	Nitraver 2 Nitrite Reagent	585
Cl^{-1}	Mercuric Thyocyante Solution	455
Cr^{+6}	Chromaver 3 Reagent	540
Fe^{+3}	Ferrozine Iron Reagent	562

3.6.4 Statistical Analysis of Pollutant Concentrations

For varying concentrations of all the pollutants, average, median and standard deviations were calculated.

Chapter 4

RESULTS AND DISCUSSION

4.1 GENERAL

This chapter presents the results of the field investigations, leachate generation through column cell approach, laboratory analyses, and the relevant analytical exercises carried out during the research work. The results presented herein have been discussed for their scientific interpretation and to draw rational/valid inferences. This seriatim presentation is in the sequence of activities carried out for this study.

4.2 SOLID WASTE COMPOSITION

The composition of solid waste of the dumps was studied in order to maintain it in the column cells used for leachate generation. The results of the study showed that the components and the percentage of solid waste of sector H-10 dump and BC dump were quite comparable. However, the composition of the abandoned dump of sector H-12 was different from that of the other two dumps. Table 4.1, Table 4.2 and Table 4.3 present percentage composition by weight of solid waste of Sector H – 10 dump, BC dump and Sector H – 12 dump respectively.

Table 4.1: Percent composition by weight of solid waste of sector H-10 dump

Components	**Composition by Weight (%)**
Organics (Food and Yard Waste)	62.71
Paper	8.44
Cardboard	6.49
Plastic Bags, Packs	4.67
Rags	4.07
Glass	2.61
Plastic Bottles	2.43
Construction and Demolition	2.26
Metals	2.24
Medical Waste	1.67
Leather and Rexene	0.61
Bones	0.33
Wood	0.23
Others (Dirt and Ash)	1.23

Table 4.2: Percentage composition by weight of solid waste for BC dump

Components	Composition by Weight (%)
Organics (Decayed mate)	67.00
Paper	9.10
Cardboard	5.40
Plastic Bags, Packs	3.50
Rags	3.30
Plastic Bottles	3.20
Medical Waste	2.00
Metals	1.50
Glass	1.50
Construction and Demolition	1.20
Leather and Rexene	0.80
Bones	0.50
Wood	0.50
Others (Dirt and Ash)	0.50

Table 4.3: Percentage composition by weight of solid waste for sector H – 12 Dump

Components	Composition by Weight (%)
Remaining (Degraded organics etc.)	68.33
Plastic	24.14
Rags	4.76
Wood	2.76

4.2.1 Composition of H-10 and BC Dumps

Sector H-10 dump contains the waste carried from the municipal jurisdictions of Islamabad city. The composition of solid waste is largely influenced by the living style and cultural practices of the community generating the solid waste. Economic condition of a community is the factor that has a major impact on the nature and composition of solid waste. The large quantity of yard waste makes the percentage of organic waste high in MSW of the city. Metals are quite less because of scavenging or recycling before the primary collection and immediately after dumping. Same is the case with paper waste. Most of the paper waste is recycled before primary collection could occur. MSW of the two dumps comprises the highest percentage of organic waste. The second largest quantity is of the waste paper and card board which comprises the waste newspaper, wrappers, and cartons of packages of commercial materials. Plastics aggregate ranges from 7.6 - 7.9 percent due to bottled items and shopper bags produced for commercial purposes. Rags and glass are next to the plastics. Medical waste is also carried to the dumps from some of the hospitals.

According to Visvanathan *et al*., (2007), the Srilankan waste contains Paper/Cardboard 12.3%, Plastic 6.8%, Metals 3.7%, Glass 3%, Wood 10.2% and Biowaste 64.7%. The percentage composition of organic waste estimated by both the studies has a considerable similarity. Cheema (1998), determined the composition of solid waste of Rawalpindi city as: Food Waste 64%, Plastic 10%, Cardboard/Paper 7%, Wood5%, Glass/Metal 6%, Rags/Textile 5% and others 3%.

4.2.2 Composition of Waste from Sector H – 12 Dump

Sector H-12 dump is an abandoned dump in Islamabad City. All types of organic waste and paper have been degraded within the dump except plastics, some wood and rags. The organic materials in the dump have been converted into humus and are completely mixed with soil and dirt, so it has been titled as "Others". Plastics are the 2nd largest part of the composition in the solid waste. The plastics comprise 24.14% of the entire material of the dump, rags 4.76%, wood 2.76% and the "remaining" comprise 68.33% including dirt and the entire decomposed material.

4.3 DENSITY OF WASTE IN THE DUMPS

The density of the MSW of the dumps of Islamabad and Rawalpindi exhibits a systematic increasing trend. The results of the measurement of density have been presented in Fig. 4.1. Accordingly, sector H-12 dump has the maximum density (550 kg/m^3) because of the settlement of waste material taken place since the dump has been abandoned. The BC dump material has high density (500 Kg/m^3) because of accumulation of large layers of waste which have made high compaction within the functional dump. In sector H-10 dump of Islamabad, compaction of waste is done intermittently using heavy machines and a soil cover.

The density of MSW in various Indian Cities's dumps (Bhide and Sundaresan, 1983) is as: Baroda: 457 Kg/m^3, Dehli: 422 Kg/m^3 and Jaipur: 537 Kg/m^3. The density of solid waste in Indian dumps nearly matches with those of the dumps of Islamabad and Rawalpindi (Pakistan).

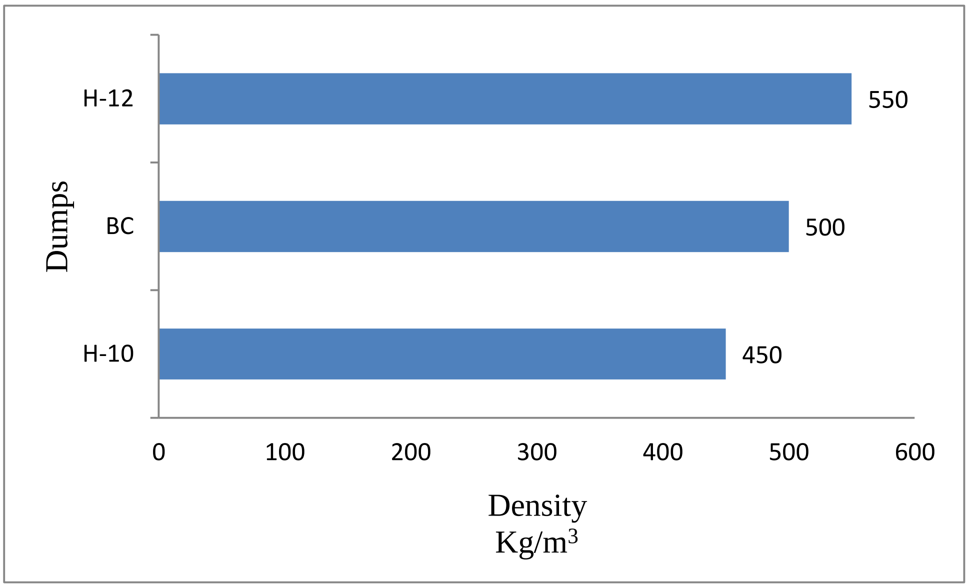

Fig 4.1: Densities of the solid waste of the dumps

4.4 MOISTURE CONTENTS OF MSW COMPONENTS

The moisture contents of solid waste components of the dumps, as determined in the IESE laboratory during this study, have been presented in Table 4.4. Composition of the results has been presented against the results of the Vasilind *et al*., (1994). The comparison shows that the results of both the studies are quite comparable to each other.

Table 4.4: Moisture contents of various solid waste components

S. No.	Components	Moisture % by Weight (This Study)	Vesilind *et al*., (1994)
1	Food Waste	82.00	30-80
2	Yard Waste	75.00	-
3	Rags	24.00	-
4	Wood	12.00	4-8
5	Card Board	10.00	4-10
6	Newspaper	9.00	-
7	Plastic Bags	2.00	1-4
8	Bones	1.00	-

4.5 LEACHATE GENERATION

The column cell observations aimed at the generation and estimation of leachate in a unit area and 1.22 m depth of each of the three dumps. The amount of leachate thus estimated was used to estimate leachate at 1m, 2, and 3m depth of the respective dump. The unit area of a dump is assumed to be equivalent to the area of a column cell.

The column cell application on all the three columns were started on 20th January 2009 and carried out continuously before terminating on 31st March 2009. Rainfall events, 21 in number, ranging from 2 mm through 55 mm were shed on each column. A proper record of input (rainfall) and output (leachate) was maintained. However, no record was preserved for such small inputs, where no leachate production was observed except those of the natural rainfall. Table 4.5 through Table 4.7 present a summary of the results of leachate generation observations of the three columns.

Table 4.5: Leachate generation from column representing H-10 dump

Rainfall Event No.	Dates (2009)	Rainfall Input, mm	Leachate Generation, mm	Leachate, %	Remarks
1	20-Jan	9.93	3.13	31.52	Low leachate due to high absorption of water in MSW.
2	21-Jan	9.93	5.74	57.80	Percentage leachate generation increased as moisture of MSW increased.
3	22-Jan	11.04	8.34	75.54	Percentage increased due to high rainfall input and moisture in the column.
4	2-Feb	19.52	14.83	75.97	High percentage of leachate due to high rainfall and some existing moisture.
5	5-Feb	3.00	-	-	No leachate generation due to small amount of rainfall.
6	6-Feb	21.83	16.83	77.1	High percentage of leachate generation due to high rainfall and moisture contents.
7	8-Feb	20.36	14.52	71.32	Percentage declined due to high temperature (sunshine).
8	9-Feb	10.45	5.92	56.65	Low percentage of leachate generation due to low rainfall.
9	11-Feb	3.00	-	-	No leachate generation.
10	12-Feb	8.38	2.98	35.56	Low leachate generation due to low rainfall.
11	17-Feb	16.43	12.23	74.44	Leachate generation percentage increased due to high rainfall and moisture.
12	21-Feb	43.66	31.37	71.85	Leachate generation declined a little because of some reduction in moisture.
13	2-Mar	55.00	46.21	84.02	High leachate generation due to high rainfall.
14	4-Mar	2.00	-	-	No leachate generated at trace rainfall.
15	6-Mar	23.49	15.13	64.41	Leachate generation increased due to increased moisture.
16	10-Mar	31.91	21.24	68.72	Leachate generation increased due to high rainfall.
17	12-Mar	50.77	36.89	72.66	High leachate generation due to high rainfall.
18	14-Mar	35.32	25.76	73.00	Leachate generation due to high moisture.
19	17-Mar	8.60	5.85	68.20	Lechate generation declined due to low rainfall and moisture.
20	22-Mar	48.57	34.68	71.40	High leachate generation due to high rainfall.
21	31-Mar	15.59	11.31	72.50	High leachate generation due to high rainfall.

Table 4.6: Leachate generation from column representing BC dump

Rainfall Event No.	Dates (2009)	Rainfall Input mm	Leachate Generation mm	Leachate %	Remarks
1	20-Jan	9.93	2.98	30.00	Low leachate due to high absorption of water in MSW.
2	21-Jan	9.93	4.94	50.00	Percentage leachate generation increased as moisture of MSW increased.
3	22-Jan	11.04	8.02	72.6	Percentage increased due to high rainfall input and moisture in the column.
4	2-Feb	19.52	14.64	75.00	High percentage of leachate due to high rainfall and some existing moisture.
5	5-Feb	3.00	-	-	No leachate generation due to small amount of rainfall.
6	6-Feb	21.83	16.81	77.00	High percentage of leachate generation due to high rainfall and moisture contents.
7	8-Feb	20.36	14.45	71.00	Percentage declined due to high temperature (sunshine).
8	9-Feb	10.45	5.85	56.00	Low percentage of leachate generation due to low rainfall.
9	11-Feb	3.00	-	-	No leachate generation.
10	12-Feb	8.38	2.74	32.70	Low leachate generation due to low rainfall.
11	17-Feb	16.43	11.96	72.80	Leachate generation percentage increased due to high rainfall and moisture.
12	21-Feb	43.66	31.19	71.40	Leachate generation declined a little because of some reduction in moisture.
13	2-Mar	55.00	46.00	83.60	High leachate generation due to high rainfall.
14	4-Mar	2.00	-	-	No leachate generated at trace rainfall.
15	6-Mar	23.49	15.00	64.03	Leachate generation increased due to increased moisture.
16	10-Mar	31.91	20.97	68.00	Leachate generation increased due to high rainfall.
17	12-Mar	50.77	36.56	71.60	High leachate generation due to high rainfall.
18	14-Mar	35.32	28.00	71.60	Leachate generation due to high moisture.
19	17-Mar	8.6	5.85	68.00	Lechate generation declined due to low rainfall and moisture.
20	22-Mar	48.57	34.50	71.00	High leachate generation due to high rainfall.
21	31-Mar	15.59	11.01	71.00	High leachate generation due to high rainfall.

Table 4.7: Leachate generation from column representing H-12 dump

Rainfall Event No.	Dates (2009)	Input, mm	Output, mm	Leachate, %	Remarks
1	20-Jan	9.93	2.60	26.70	Low leachate due to high absorption of water in MSW.
2	21-Jan	9.93	4.37	44.00	Percentage leachate generation increased as moisture of MSW increased.
3	22-Jan	11.04	6.89	62.40	Percentage increased due to high rainfall input and moisture in the column.
4	2-Feb	19.52	13.04	67.00	High percentage of leachate due to high rainfall and some existing moisture.
5	5-Feb	3.00	-	-	No leachate generation due to small amount of rainfall.
6	6-Feb	21.83	15.04	69.00	High percentage of leachate generation due to high rainfall and moisture contents.
7	8-Feb	20.36	14.18	69.60	Percentage declined due to high temperature (sunshine).
8	9-Feb	10.45	4.37	41.80	Low percentage of leachate generation due to low rainfall.
9	11-Feb	3.00	-	-	No leachate generation.
10	12-Feb	8.38	3.20	38.20	Low leachate generation due to low rainfall.
11	17-Feb	16.43	9.76	59.40	Leachate generation percentage increased due to high rainfall and moisture.
12	21-Feb	43.66	24.90	57.03	Leachate generation declined a little because of some reduction in moisture.
13	2-Mar	55.00	41.24	75.00	High leachate generation due to high rainfall.
14	4-Mar	2.00	-	-	No leachate generated at trace rainfall.
15	6-Mar	23.49	13.62	64.03	Leachate generation increased due to increased moisture.
16	10-Mar	31.91	17.92	58.00	Leachate generation increased due to high rainfall.
17	12-Mar	50.77	31.50	63.00	High leachate generation due to high rainfall.
18	14-Mar	35.32	21.43	60.60	Leachate generation due to high moisture.
19	17-Mar	8.60	5.07	59.00	Lechate generation declined due to low rainfall and moisture.
20	22-Mar	48.57	29.16	60.00	High leachate generation due to high rainfall.
21	31-Mar	15.59	9.31	60.00	High leachate generation due to high rainfall.

4.5.1 Column Observations

As already mentioned, Table 4.5 presents the details of column cell observations carried out on the column representing sector H-10, BC and H-12 dumps. The table also includes different amounts of rainfall input and the corresponding quantities of leachate generated there from. A short discussion regarding sector H-10 column observations is presented below:

Rainfall Events 1-3

Prior to start of rainfall input, there was no moisture in the column. Therefore, the first rainfall event (9.93mm) was mostly absorbed and generated about 31.52% leachate whereas the next day rainfall event generated about 57.81% leachate with same amount of rainfall. Similarly, the 3rd consecutive day rainfall generated 75.54% leachate which was 17.70% higher than that of last rainfall event with only 1.11% of increase in the input rainfall; as the 2nd and the 3rd rainfall amounts were 9.93 mm and 11.04 mm. Leachate generation for BC column for three rain fall events was 30%, 50% and 72.6% respectively. H-12 column showed least leachate generation i.e. 26.7%, 44% and 62.4% respectively.

Rainfall Events 4-8

The second series of column observations was carried out after a gap of 10 days so as to let the column cell materials dry. This comprised three sets of rainfall events in the following sequence:

- Rainfall event-4, with an artificial rainfall of 19.52 mm, yielded 14.83 mm (76%) of leachate for H-10, 14.64 mm (75%) for BC and 13.04 mm (67%) for H-12 columns.

- After a gap of two days, natural rainfall of total 3mm rainfall over the day took place. No leachate generation was noted in any of the three columns. This rainfall, however, increased the moisture contents of the solid waste in the any of the columns. This natural rainfall stood at the 5^{th} place in the series of rainfall events.

- The 6^{th} column rainfall event was again carried out on the day following the 5^{th} rainfall event. The artificial rainfall of about 21.83 mm, yielded nearly 16.83 mm (77.1%) leachate for H-10 column, 16.81mm (77%) for BC column and 15.04mm (69%) for H-12 column. The output clearly indicates a combined effect of drying and then wetting of solid waste prior to this rainfall event.

- With a gap of one day, the 7^{th} rainfall event was carried out with an artificial rainfall of 20.36 mm which again yielded 71.3% (14.52 mm) leachate for H-10 column, 14.45 mm (71%) for BC column and 14.18% (69.60%) for H-12 column. The comparison of 6^{th} and 7^{th} rainfall events also highlights the significance of antecedent moisture conditions in the solid waste of leachate generation columns.

- 8^{th} rainfall event was initiated with 10.45 mm of artificial rainfall. Much of the rainfall was utilized in recouping the saturation of the solid waste; where after the leachate generated was 5.92 mm (56.65%) for H-10 column, 5.85 mm (56) for BC column and 4.37mm (41.8%) in case of H-12 column.

Rainfall Events 9-10

Rainfall event of 3 mm occurred yielding no leachate. Rainfall event of 8.38 mm occurred yielding leachate of 3.20 mm (38.2%) for H-10 column, 2.74mm (32.7%) for BC and 3.2mm (38.2%) in case of H-12 column.

Rainfall Events 11-13

Rainfall event-11 with artificial rainfall of 16.4 mm started after four days of the end of last rainfall event. This yielded a leachate of 12.2 mm (74.4%) for H-10 column, 31.19 mm (20.97%) for BC column and 31.50 mm (63%) for H-12 column. Similarly, rainfall event-12 performed with the same gap (4 days) after rainfall event-11, generated 71.85% of leachate for H-10 column, 72.80% in case of BC column and 59.40% in case of H-12 column. Both the rainfall events performed under similar antecedent moisture conditions of solid waste, yield quite comparable results.

Rainfall event-13 was performed after a bit longer gap but with the maximum possible amount of rainfall (55 mm) which corresponded to the maximum average monthly historical natural event of the area. This correspondingly yielded the highest amount of leachate 46.21 mm (84.02%) in case of H-10 column, 46 mm (83.60%) in case of BC column and 41.24 mm (75%) in case of H-12 column. This rainfall event essentially inferred to the fact that the amount of leachate generated in a system of solid waste, is directly proportional to the quantity of input precipitation and amount of moisture existing in MSW prior to a particular rainfall event.

Rainfall Event 14-15

One day after the end of rainfall event-13, a small shower of natural rainfall (2.0 mm) was again observed which was regarded as rainfall event-14. Correspondingly, no leachate generation was observed in any column due to this rainfall. With a gap of another 24 hours, rainfall event-15 was started with an input precipitation of 23.5 mm. The amount of leachate generated was recorded as 15.13 mm (64.4%) for H-10 column, 15mm (64.03%) in case of BC column and 13.62 mm (64.03%) in case of H-12 column.

Rainfall Events 16-21

The duration of these rainfall events were almost a wet period. Most of the times, it remained cloudy. Fractional amounts of rainfall had been falling sparingly. Rainfall events 16, 17 and 20 were due to considerable storms of natural precipitation of 31.9 mm, 50.77 mm and 48.57 mm. Rainfall event 18-19 and rainfall event-21 were performed with artificial rainfall amounts of 35.3 mm, 8.6 mm and 15.60 mm respectively. Although the rainfall of event-19 was quite low (8.60 mm) as compared to others of this series, the leachate generation remained high in case H-10, BC and H-12 columns due to the wet weather during the period, due to which the solid waste of the column maintained its high moisture contents.

4.5.2 Comparison of Leachate Output from the Three Columns

For the purpose of comparison of leachate generated by the three columns, the date-wise data was transposed in the order of ascending input rainfall sequence i.e. the lowest rainfall at the top and the highest at the end with their corresponding leachate outputs. This kind of data has been plotted on Fig. 4.2 for sector H-10 column, BC column and sector H-12 column.

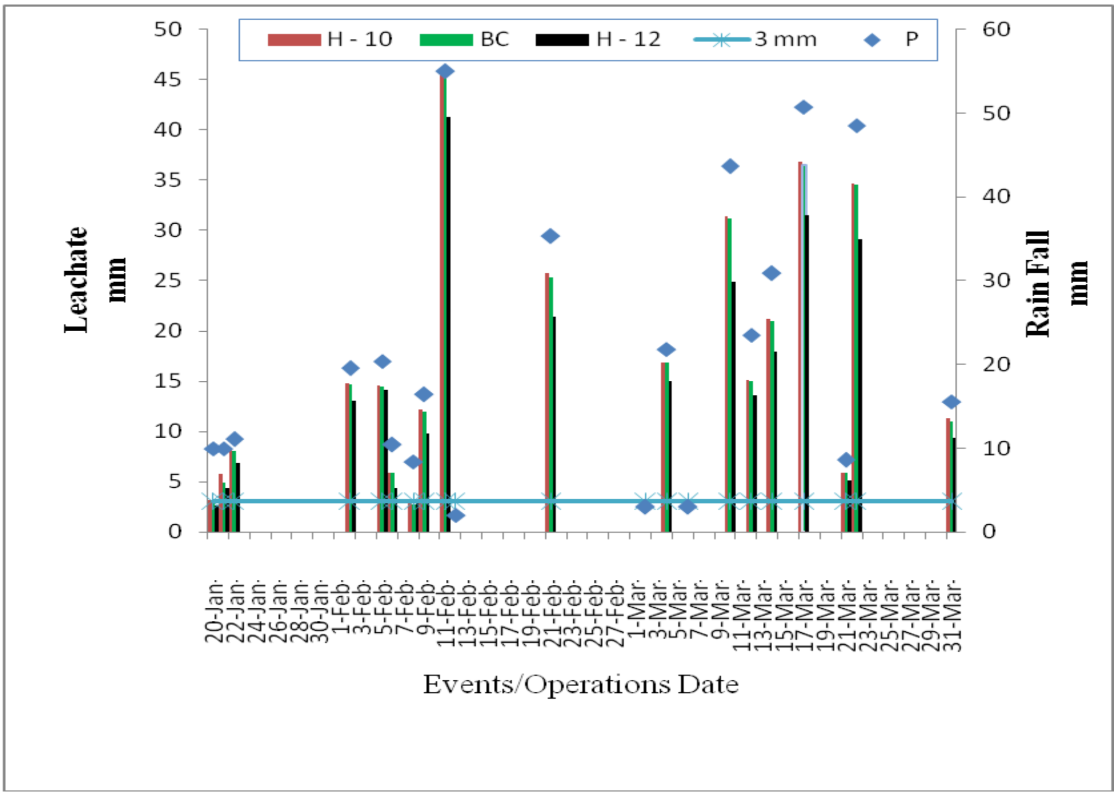

Fig 4.2: Leachate generation from column cells

A careful review of Fig. 4.2 reveals that:

i- Grossly, the leachate generation of all the three columns follows the pattern of input rainfall.

ii- The leachate generation of sector H-10 column and BC column, not only follow the same pattern but also the magnitudes of their quantities possess a little deviation. The little differences in the magnitudes of their leachate generation correspond to the minor difference in the in-situ densities and composition of the solid waste of their respective dumps.

iii- According to Tatsi and Zoubolis (2002), following factors play a basic role in the leachate generation of a dump:

a. **Antecedent Moisture Conditions:**

Antecedent moisture conditions of solid waste play an important role in the leachate generation of solid waste. The higher the antecedent moisture of solid waste, the higher the leachate generation and vice-a-versa. Quantity of leachate produced is proportional to the quantity of water entering the solid waste.

b. **Water Holding Capacity:**

Some researchers regard this property of the solid waste as the field capacity. This depends upon the composition of the solid waste and its various sources. The higher the water holding capacity of MSW, the lower the leachate generation.

c. **The density of solid waste:**

If the density of solid waste is heavier due to the presence of finer particles with finer voids, they would possess the greater water holding capacity, whereby the leachate generation is reduced. On the other hand, if the density of solid waste is heavier due to heavy components e.g. metals etc which absorb less or no water, the leachate generation is increased.

d. Composition of solid waste:

If the solid waste is composed of easily decomposable, compressible and squeezable materials, it would produce more leachate and vice-a-versa. Density, moisture content and absorption capacity of waste depend upon the composition of MSW.

4.5.3 Comparison of Results with other Studies

Most of the researchers have used lysimeters for their research. This study has used the column cell technique to estimate the leachate from the dumps. So the results have to be compared with those of the lysimeters. This comparison presents an overall range of results based upon the leachate generation in terms of percentage of the input precipitation. Following are the results of some other studies (Table 4.8):

Table 4.8: Comparison of Leachate generation of dumps under study with other landfills

S. No.	Reference	Result		
		Input (Rainfall)	**Output Leachate**	**%age Output**
1	Tatsi *et al.*, (2002)	400 mm	107 mm	26.75
2	This Study (H-10 Dump Islamabad)	448 mm	254 mm	56.83
3	This Study (BC Dump Islamabad)	448 mm	129 mm	28.71
4	This Study (H-12 Dump Islamabad)	448 mm	35 mm	7.81

4.5.4 Leachate Generation from Dumps upto Depth of 1.22 Meters

The assessment of leachate generation from dumps has been undertaken by the application of column cell results to the dumps. The input-output data of the column rainfall events has been plotted separately for each representing H-10, BC and H-12 columns in Fig. 4.3, Fig. 4.4 and Fig. 4.5. Since the depth of solid waste in the columns was kept as 1.22 meter, this data simulates the leachate from dumps only upto a depth of 1.22 meters. The equations, as derived from the x, y scatter graphs (Fig. 4.3 – Fig. 4.5) of the input - output of the columns is:

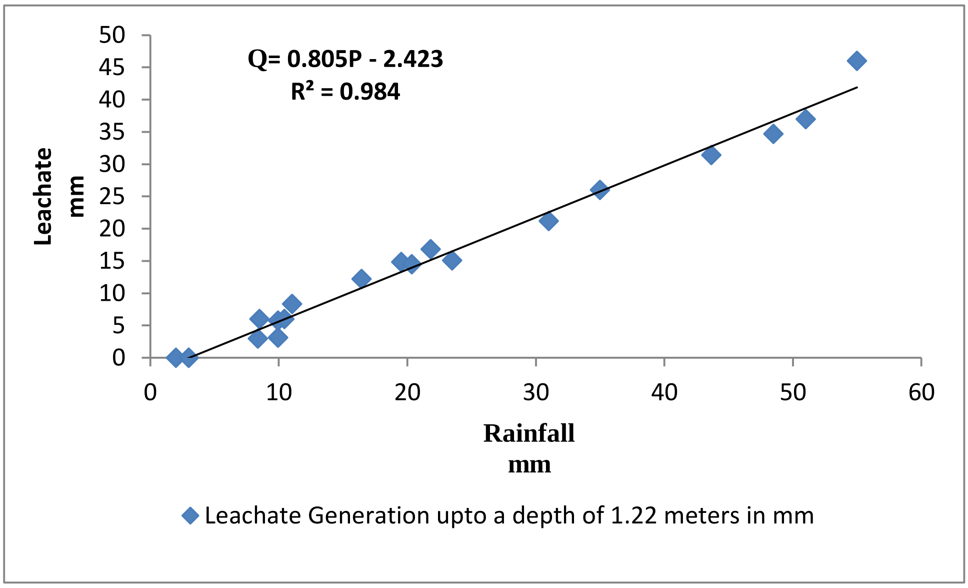

Fig 4.3: Leachate generation trend - sector H - 10 Column

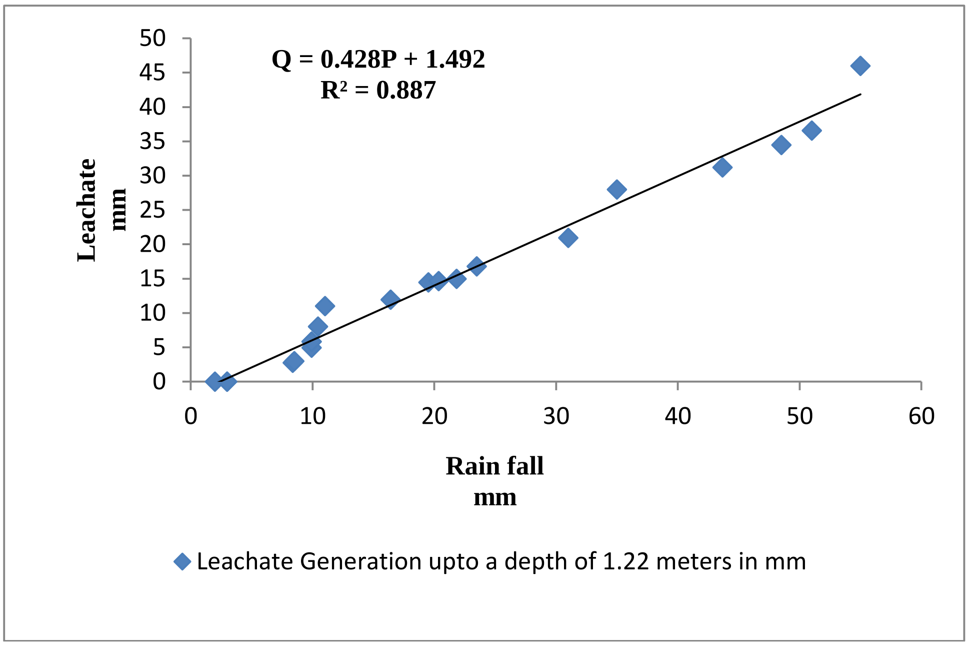

Fig 4.4: Leachate generation trend - BC column

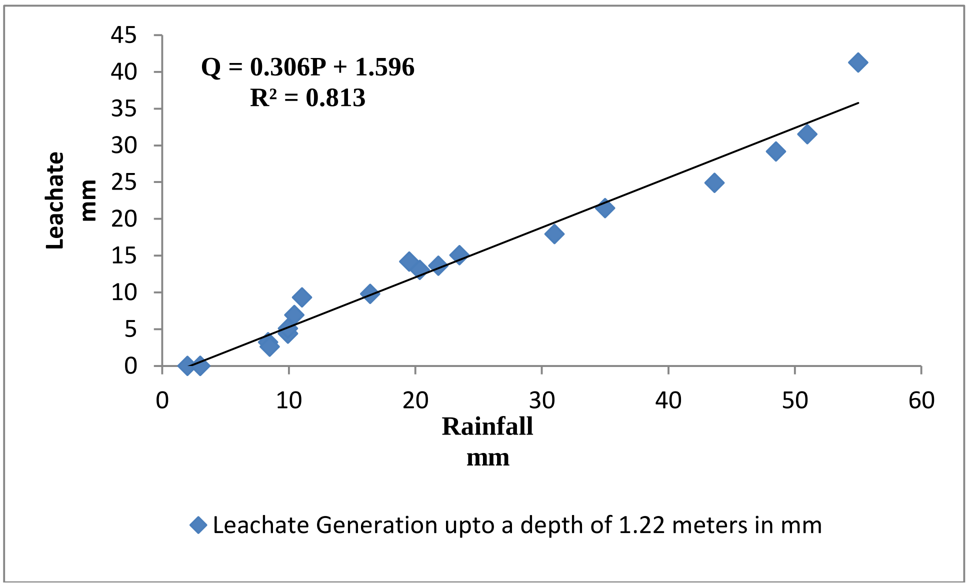

Fig. 4.5: Leachate generation trend – sector H – 12 column

$$Q_{(H\text{-}10)} = 0.805P - 2.423 \text{ --------------- } (1)$$

$$Q_{(B.C)} = 0.428P + 1.492 \text{ ----------------- } (2)$$

$$Q_{(H\text{-}12} = Q = 0.306P + 1.596 \text{----------- } (3)$$

Equation 1, 2 and 3 explain the mathematical relations for leachate generation of unit cells in sector H-10 dump, BC dump and sector H-12 dump respectively. The regression coefficient (R^2) for these equations are 0.984, 0.887 and 0.813 wherein P denotes the input (rainfall) and Q stands for the quantity of output (lachate), taken both in mm. The statistical parameter R^2 provides considerable confidence for the application of these equations to their respective dumps.

4.6 Application of Results on Actual Dumps

The leachate quantities derived from the column observations have been used for the estimation of leachate per unit area of the respective dump for a depth of one, two and three meters. The mass balance technique used for the estimation of leachate generation was as follows:

1- Column study gave the leachate generation up to a depth of 1.22 meters as shown in Fig 4.3 to Fig 4.5. Leachate absorption was calculated by subtracting leachate generation from the respective rainfall for a depth of 1.22 meters. Leachate absorption at a depth of 1 meter was interpolated. On the basis of leachate absorption estimated at a depth of 1 meter, leachate absorption at two meter and three meter was also calculated.

2- Subtracting leachate absorption at one, two and three meters depth from respective rainfalls, leachate generation was calculated for all the three dumps for the respective depths.

3- These results have been plotted using x-y scatter technique in order to establish leachate generation trends (equations) for 1, 2 and 3 meter depth of the respective dumps. The regression coefficients of these relations are well within the reasonable range acceptability.

4- The input (rainfall) and output (leachate) units for these equations are millimeters. The multiplication of the area of the respective dump with the output would provide the leachate yield from the dump against a given rainfall input.

The leachate generation estimation curves of the three dumps for 1 m, 2 m and 3 m depths of solid waste have been presented in Fig. 4.6 through Fig. 4.8.

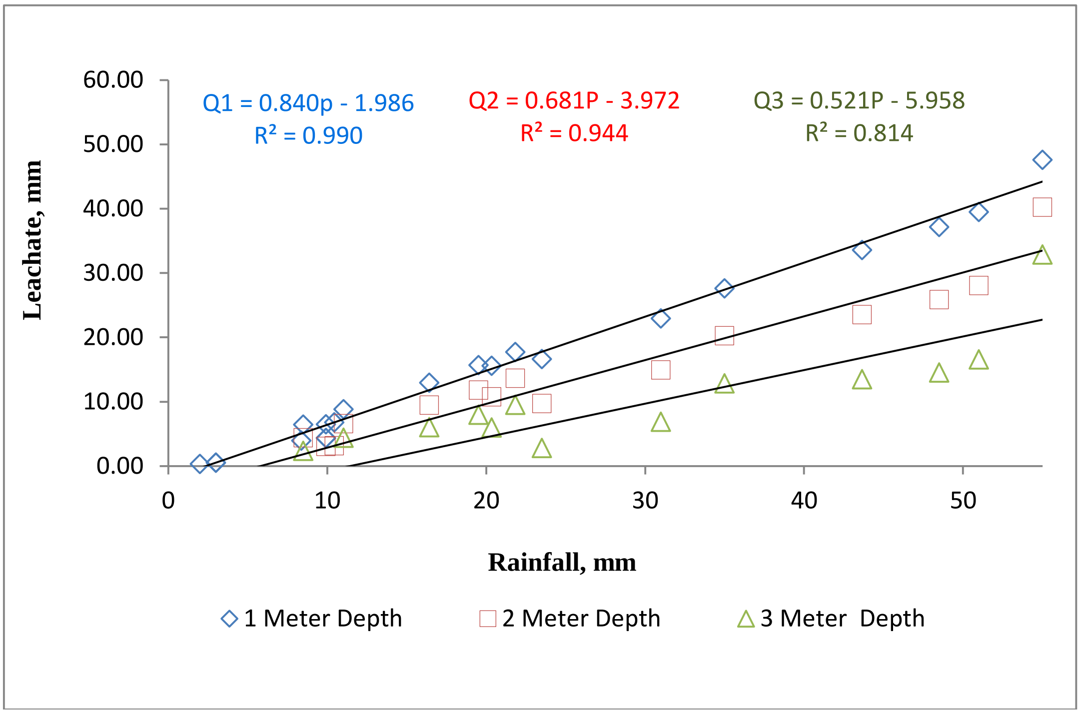

Fig 4.6: Leachate generation at various depth of MSW in Sector H-10 Dump

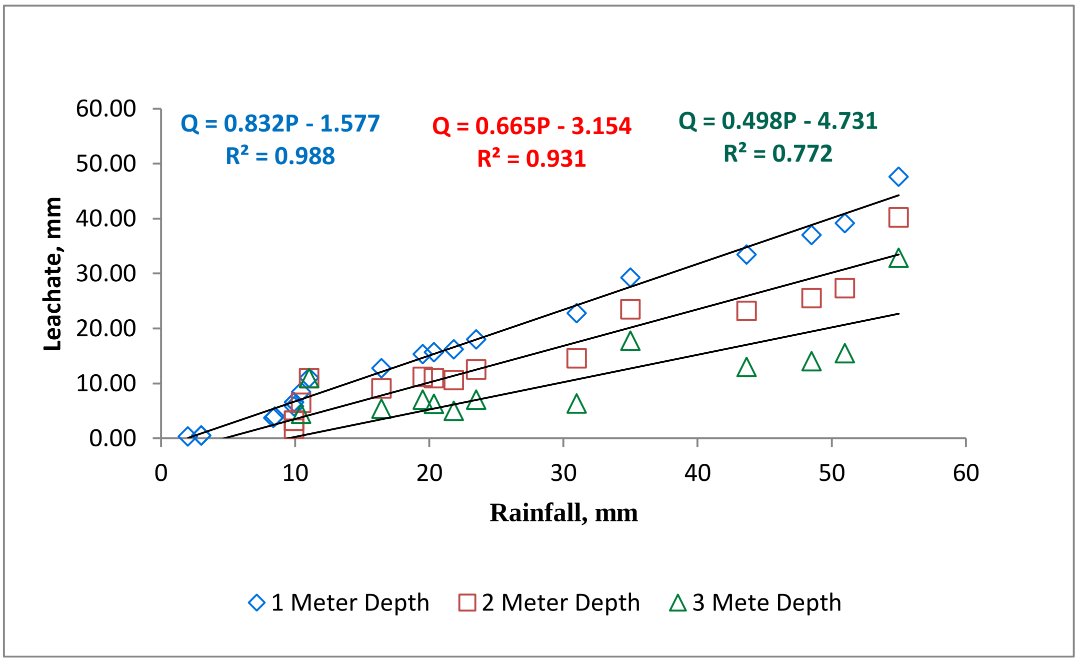

Fig 4.7: Leachate generation at various depth of MSW in BC Dump

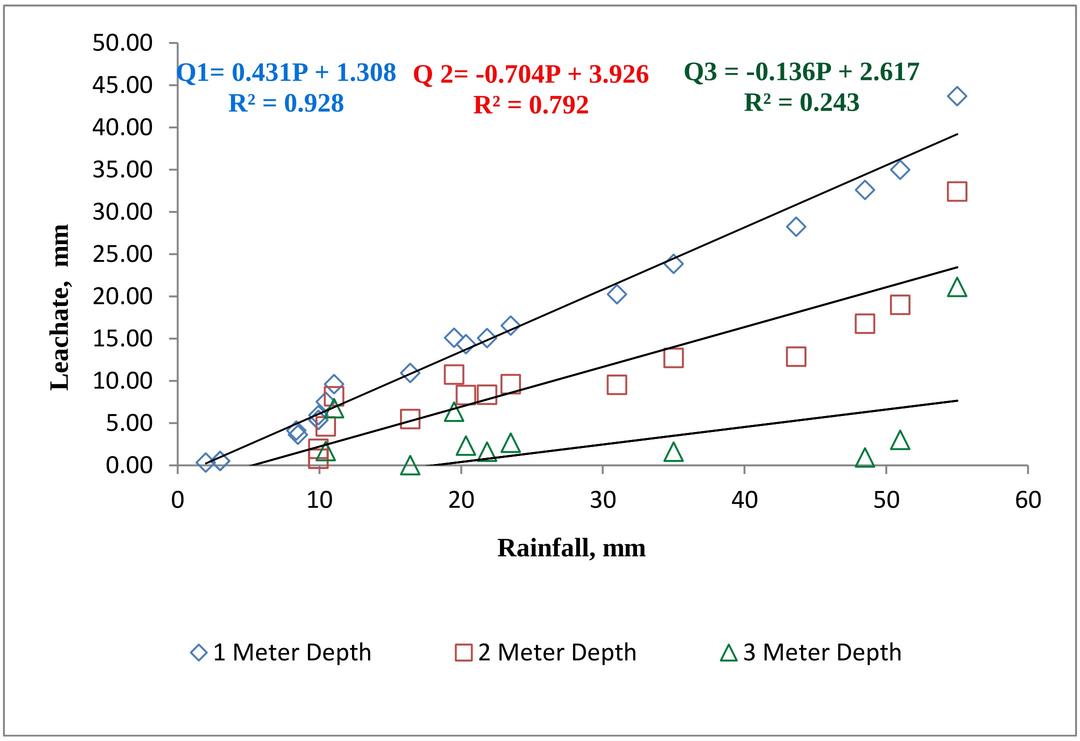

Fig 4.8: Leachate generation at various depths of MSW in sector H-12 Dump

4.7 LEACHATE CHARACTERIZATION

4.7.1 General

Leachates, migrate vertically and laterally into the environment by direct discharge into the land surface. Leachate is responsible for the deterioration of groundwater quality (Aluko *et al.*, 2000). At MSW disposal areas, leachate has resulted in low farm production, obnoxious gasses into the environment, and contamination of the domestic water sources (Tairu, 1998).

This study therefore, has identified compositions of the solid waste in dumps, the leacahte produced by them and their chemical characteristics which can be utilized for estimating their polluting effects and to designing a sustainable, cost effective and environment friendly system of treatment.

4.7.2 Chemical Oxygen Demand (COD)

Table 4.9 and Fig. 4.9 present the results and graph for COD concentrations of the three dumps against various quantities of rainfall. The graphic and tabular presentations indicate that the highest values of COD were found in leachate of BC column. Results reveal that leachate of BC column contain higher COD than that of the sector H-10 column. This is because of larger percentage of organic waste in BC column than that of the sector H-10 column. Sector H-12 column contains largest quantity of organic waste indicated as "Remaining" than the other two columns, but the nature and composition of organic waste is such that it didn't contribute to COD as much as the other columns did. The quantity of rainfall has also been found to have an impact on COD concentrations of all the three columns. It has been critically observed that the larger the quantity of rainfall, the lower the concentration of COD and vice-a-versa. The gap between two consecutive rainfalls has also an impact on the concentration of COD. In case of very close consecutive rainfall events, the COD is considerably reduced. This is due to the fact that the consecutive rainfall events wash away, the leachable contaminants quickly and the time available to microorganisms for decomposition of solid waste is not sufficient. Maximum rainfall event of 55mm has been encountered on 2nd March, as a result of excessive rainfall. Due to this event, COD concentrations of all the columns have been found to be minimum. Among the three columns, COD of BC column has shown the highest result i.e. 4290 mg/L Sector H-10 column has shown COD 3840 mg/L and that of Sector H-12 column 3390 mg/L. The closest consecutive rainfall events were found on 8th Feb and 12th Feb having the rainfalls of 20.36 mm and 8.83 mm respectively. The concentration of COD for BC column was found to be 5761 mg/l on 8th Feb and 5318 mg/L on 12th Feb. Thus the decline in the COD value is noted because of a close rainfall event of 12th Feb. The COD results of other two columns are also similar. The average of all the COD values reveals that COD of BC column is the highest than the other two columns.

Table 4.9: Result of leachate analysis for COD

COD (mg/L)					
Sr. No.	Dates	Rain Fall mm	Column/Dump		
			Sector H - 10	BC	Sector H - 12
1	20-Jan	9.93	7680	8320	7040
2	2-Feb	19.52	7460	7231	7010
3	8-Feb	20.36	5261	5761	4771
4	12-Feb	8.83	4793	5318	4358
5	2-Mar	55	3840	4290	3390
6	10-Mar	31	4235	4655	3805
7	17-Mar	8.5	4553	5153	4263
8	1-Apr	15.6	6537	6987	6207
Average			5545	5964	5106
Median			5027	5540	4565
St Dev			1486	1406	1444

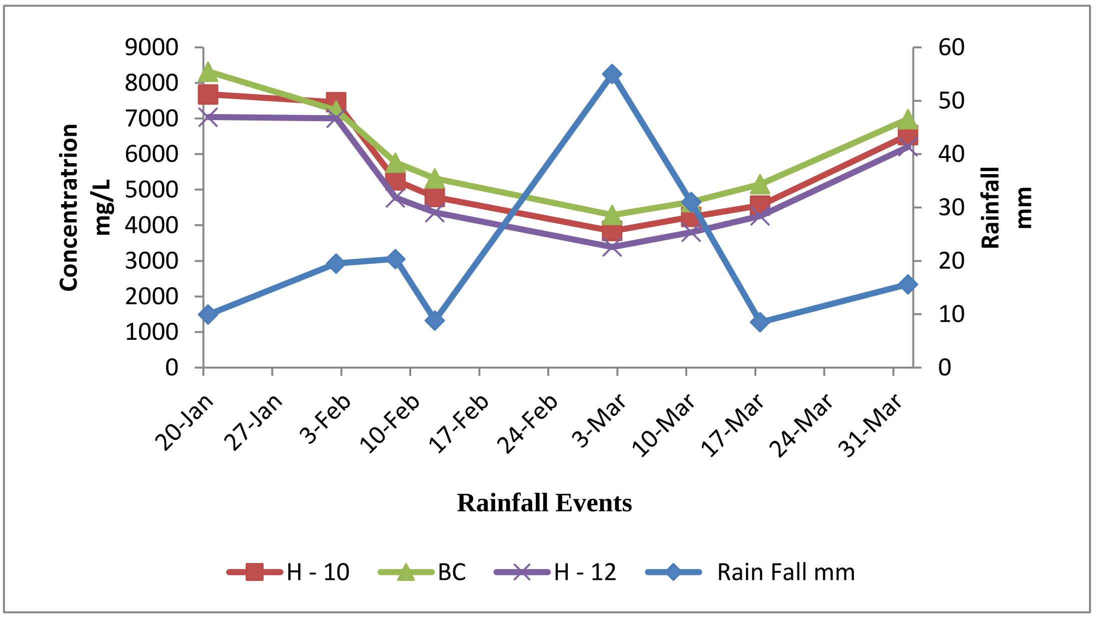

Fig 4.9: Result of leachate analysis for COD

4.7.3 Sulphates (SO_4^{-2})

Average of SO_4^{-2} concentration for all the samples reveal that leachate of Sector H-12 column contains largest concentration. BC column and Sector H-10 column have shown leachate concentrations close to each other but far less than that of Sector H-12 column. This is due to the fact that all of the organic waste in Sector H-12 column has been degraded. Thus by the action of bacteria, the organic content has started to convert into inorganic forms having chemicals like SO_4^{-2}. Table 4.10 and Fig. 4.10 present the leachate analysis for SO_4^{-2}.

Table 4.10: Results of leachate analysis for SO_4^{-2}

SO_4^{-2} (mg/L)					
Sr. No.	Dates	Rain Fall mm	Column/Dump		
			Sector H - 10	BC	Sector H - 12
1	20-Jan	9.93	80	70	180
2	2-Feb	19.52	70	59	161
3	8-Feb	20.36	55	48	138
4	12-Feb	8.83	62	55	150
5	2-Mar	55	44	35	115
6	10-Mar	31	53	45	127
7	17-Mar	8.5	48	41	124
8	1-Apr	15.6	50	39	120
Average			58	49	139
Median			54	47	133
St Dev			12	12	23

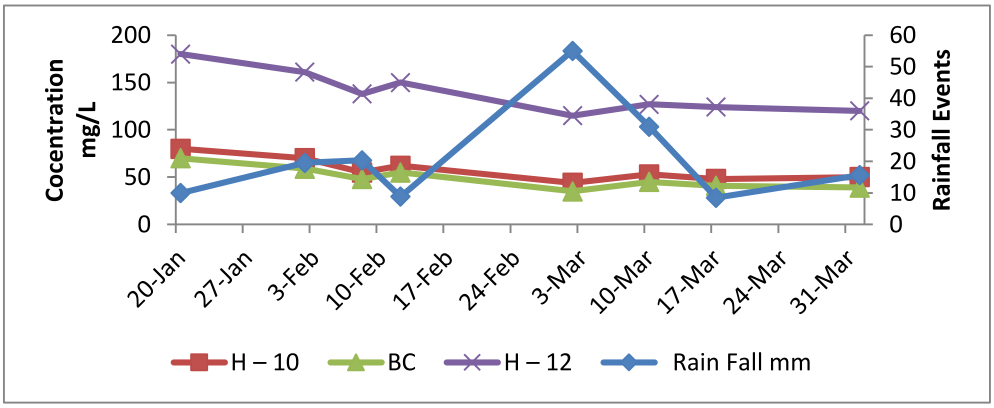

Fig. 4.10: Results of leachate analysis for – SO_4^{-2}

4.7.4 Nitrites (NO_2^{-1})

As compared to the SO_4^{-2}, the value of NO_2^{-1} has been found to be very low in leachate of all the three columns. Especially Sector H-12 column has least concentration of NO^{-1}, where the concentrations of SO_4^{-2} are very high. This is because of the fact that nitrogenous compounds encounter an enormous action of bacteria in the soil and undergo nitrogen cycle. Organic compounds are, in turn, converted to ammonia, molecular nitrogen, nitrites and nitrates. The conversion of nitrites into nitrates is a reversible reaction. The nature of waste in Sector H-12 dump is in decomposition phase due to the action of nitrifying bacteria. Table 4.11 and Fig. 4.11 present the results of leachate analysis for NO_2^{-1}.

Table 4.11: Results of Leachate analysis for NO_2^{-1}

NO_2^{-1} (mg/L)					
Sr. No.	Dates	Rain Fall mm	Column/Dump		
			Sector H - 10	BC	Sector H - 12
1	20-Jan	9.93	33.8	56.33	8.33
2	2-Feb	19.52	29	49.2	8
3	8-Feb	20.36	22	43	7.3
4	12-Feb	8.83	25	46	8.1
5	2-Mar	55	10	30	5.1
6	10-Mar	31	16	36	6.2
7	17-Mar	8.5	23.2	45.2	7
8	1-Apr	15.6	30.2	51.2	7.5
Average			23.7	44.6	7.2
Median			24	46	7
St Dev			8	8	1

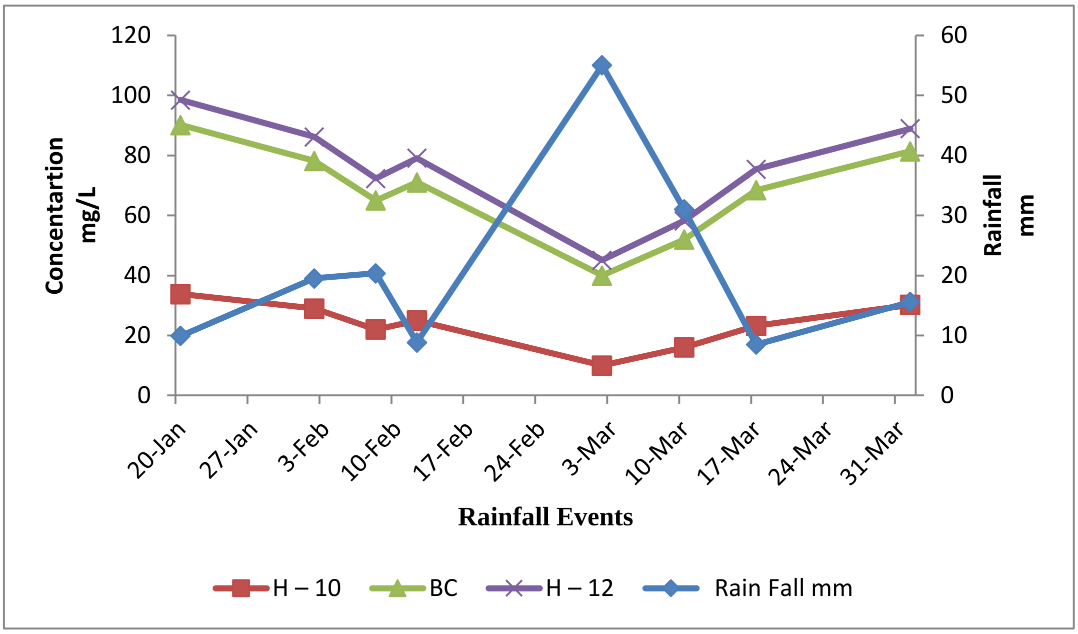

Fig 4.11: Results of leachate analysis for NO_2^{-1}

4.7.5 Chlorides (Cl^{-1})

Food waste contains salts mostly in the form of Sodium Chloride (NaCl). In aqueous form, NaCl is converted into its ionic form Na^+ as a cation and Cl^{-1} as anion. Since BC column and Sector H-10 column contain food waste as considerable part of their composition, chloride is present in good amounts in their leachate. Sector H-12 column contains least concentration of chlorides as because most of it has been leached down. The average concentration of chlorides found in Sector H-10 column, BC column and Sector H-12 column is 956.9, 1223.8 and 347.9 mg/L respectively. Table 4.12 and Fig. 4.12 present the results of leachate analysis for Cl^{-1}.

Table 4.12: Results of leachate analysis for Cl^{-1}

Cl^{-1} (mg/L)					
Sr. No.	Dates	RainFall mm	Column/Dump		
			Sector H - 10	BC	Sector H - 12
1	20-Jan	9.93	1240	1535	390
2	2-Feb	19.52	1019	1320	357
3	8-Feb	20.36	820	1073	330
4	12-Feb	8.83	957	1182	350
5	2-Mar	55	710	973	325
6	10-Mar	31	795	1060	335
7	17-Mar	8.5	993	1256	346
8	1-Apr	15.6	1121	1391	350
Average			956.9	1223.8	347.9
Median			975	1219	348
St Dev			177	189	20

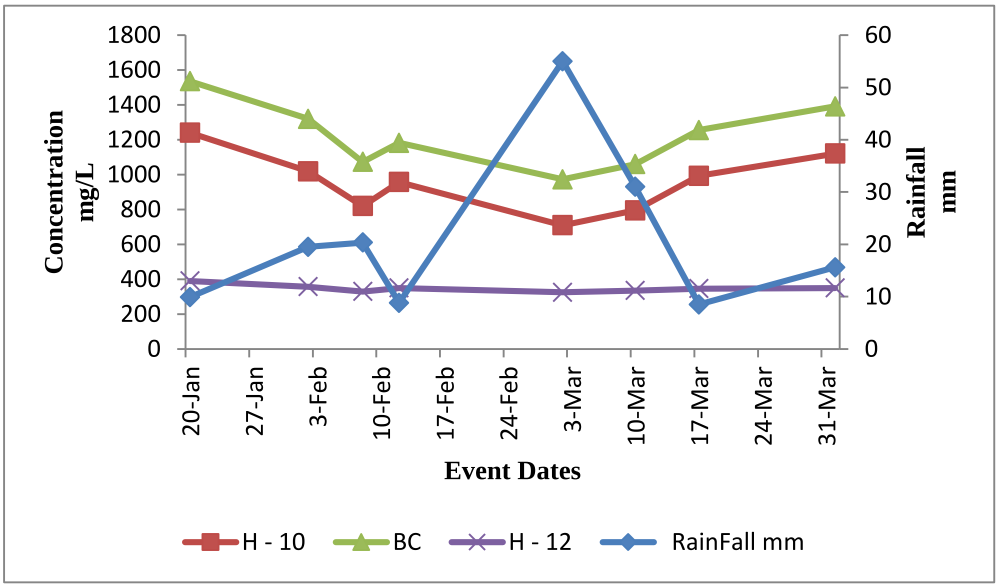

Table 4.12: Results of leachate analysis for Cl^{-1}

4.7.6 Total Dissolve Solids (TDS)

Total Dissolved Salts (TDS) is a measure of the combined content of all inorganic and organic substances contained in a leachate/liquid. Average of TDS of each of columns reveals that Sector H-12 has minimum TDS concentration due to excessive leaching. The TDS concentrations of sector H-10 column and BC column are quite close to each other with the a little difference as of their densities. Table 4.13 and Fig. 4.13 present the results of leachate analysis for TDS.

Table 4.13: Results of leachate analysis for TDS

TDS (g/L)					
Sr. No.	Dates	Rain Fall mm	Column/Dump		
			Sector H - 10	BC	Sector H - 12
1	20-Jan	9.93	8.05	7.8	3.8
2	2-Feb	19.52	7.5	7.3	3.5
3	8-Feb	20.36	7	6.6	3.2
4	12-Feb	8.83	7.3	7.1	3.5
5	2-Mar	55	6.8	6.85	3.3
6	10-Mar	31	7.1	6.9	3.32
7	17-Mar	8.5	7.7	7.6	3.45
8	1-Apr	15.6	7.5	7.2	3.41
Average			7.4	7.2	3.4
Median			7.4	7.15	3.43
St Dev			0.40	0.40	0.18

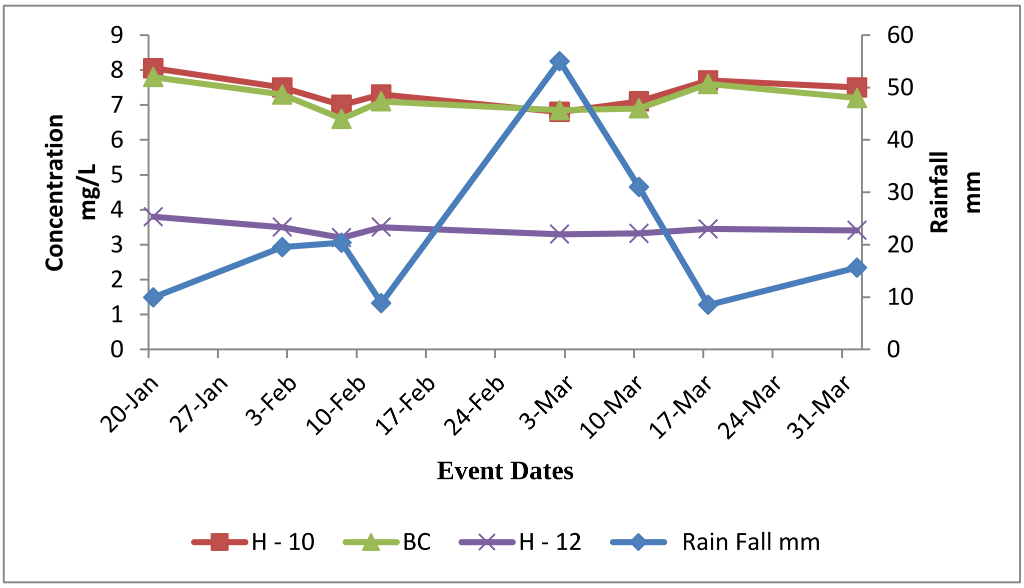

Fig. 4.13: Results of leachate analysis for TDS

4.7.7 Turbidity

Turbidity is the cloudiness or haziness of a fluid caused by individual particles (suspended solids) that are generally invisible to the naked eye, similar to smoke in air. The measurement of turbidity is a key test of water quality. Average of all the results reveals that turbidity of BC column leachate sample is the highest as compared to that of sector H-10 column and sector H-12 column leachate sample.

The reasons for this are the same as already stated in previous parts of this section. Table 4.14 and Fig. 4.14 present the results of leachate analysis for turbidity.

Table 4.14: Results of leachate analysis for Turbidity

Turbidity (NTU)					
Sr. No.	Dates	Rain Fall mm	Column/Dump		
			Sector H - 10	BC	Sector H - 12
1	20-Jan	9.93	232	240	80
2	2-Feb	19.52	200	223	72
3	8-Feb	20.36	222	245	73
4	12-Feb	8.83	183	203	69
5	2-Mar	55	220	250	70
6	10-Mar	31	225	233	72
7	17-Mar	8.5	181	245	70
8	1-Apr	15.6	203	225	73
Average			208.3	233	72.4
Median			212	237	72
St Dev			19	16	3

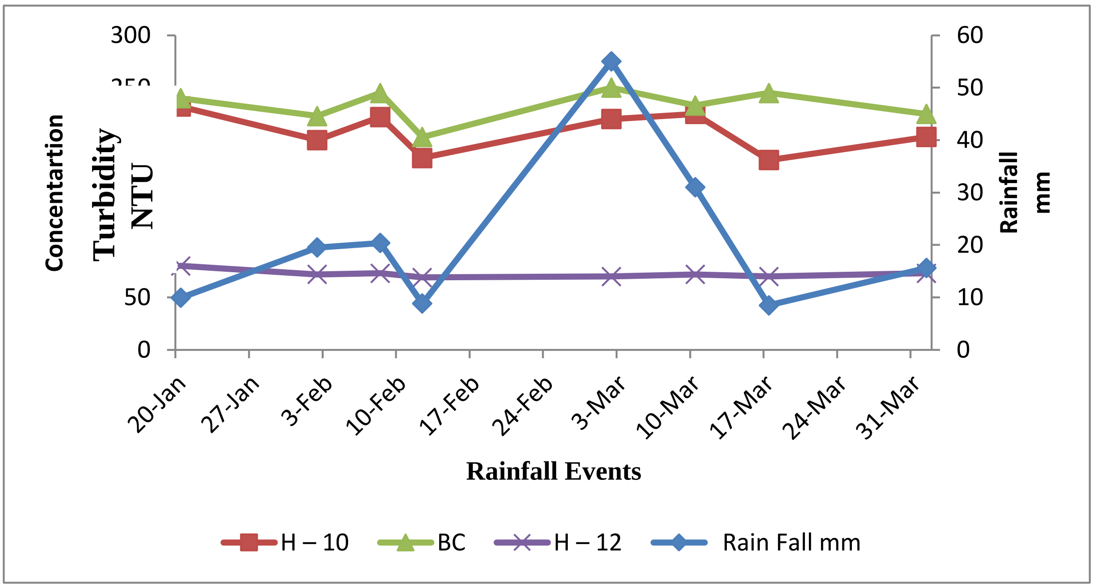

Fig 4.14: Results of leachate analysis for Turbidity

4.7.8 pH, Cr^{+6} and Fe^{+3} Concentrations

Heavy metals and pH are inter related phenomena. Heavy metals usually precipitate at high pH values. Thus their results are combined to provide a good picture of heavy metals and pH in the leachate samples of columns/dumps. The analysis reveals that maximum concentration of heavy metals has been detected on 20th

January where a rainfall of 9.93 mm was showered on the column at lowest pH of 6.0. The concentration of chromium and iron for Sector H-10 column was found to be 1.5 mg/l and 1.7 mg/l respectively. This column samples showed an average concentration of 0.8 mg/L and 1.2 mg/L for Cr^{+6} and Fe^{+3}. Table 4.15 and Fig. 4.15 present pH and the concentrations of heavy metals (Cr^{+6}, Fe^{+3}) in the leacahte samples of Sector H-10 column/dump.

Table 4.15: pH and concentrations of heavy metals for sector H-10 column/dump

Sr. No.	Dates	Rainfall mm	pH	mg/L	
				Cr^{+6}	Fe^{+3}
1	20-Jan	9.93	6.0	1.5	1.7
2	2-Feb	19.52	6.2	1.2	1.5
3	8-Feb	20.36	6.3	0.8	1.3
4	12-Feb	8.83	6.5	0.7	1.2
5	2-Mar	55.00	6.6	0.75	1.1
6	10-Mar	31.00	6.7	0.6	0.9
7	17-Mar	8.50	6.9	0.65	0.8
8	1-Apr	15.60	7.0	0.5	0.7
Average			6.5	0.8	1.2
Median			6.6	0.7	1.2
St Dev			0.3	0.3	0.3

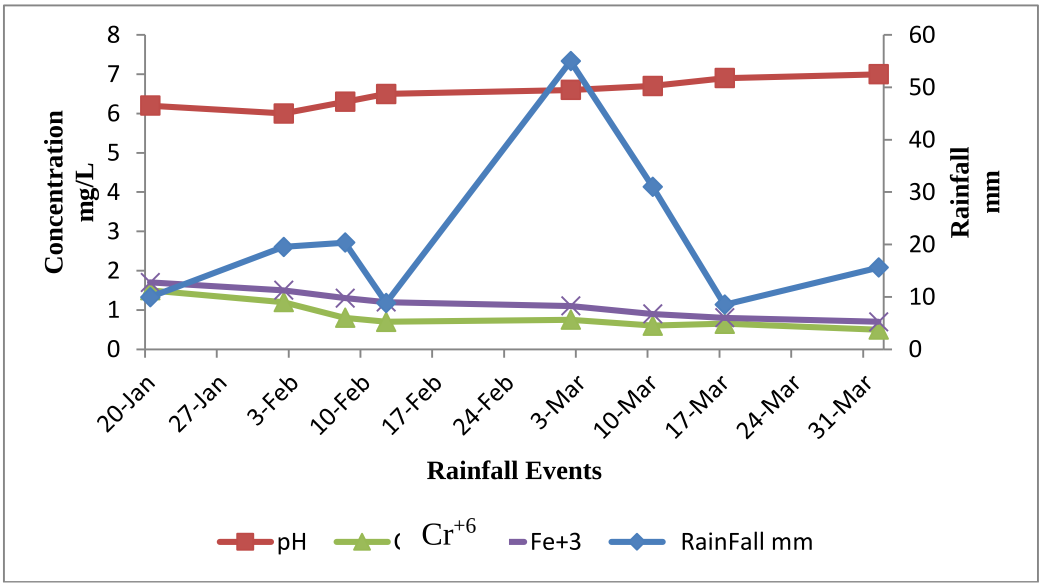

Fig 4.15: Comparison of pH and heavy metals for sector H - 10 column

BC column had maximum chromium and iron concentration of 0.45 mg/l and 0.55 mg/l respectively at lowest pH of 7.0. The average concentrations of chromium and iron were found to be 0.4 mg/l and 0.5 mg/l respectively. Table 4.16 and Fig. 4.16 present concentrations of pH and heavy metals in BC column/dump.

Table 4.16: pH and concentration of heavy metals for BC column

Sr. No.	Dates	Rain Fall mm		mg/L	
			pH	Cr^{+6}	Fe^{+3}
1	20-Jan	9.93	7.0	0.45	0.55
2	2-Feb	19.52	7.1	0.44	0.55
3	8-Feb	20.36	7.2	0.44	0.54
4	12-Feb	8.83	7.5	0.43	0.53
5	2-Mar	55	7.6	0.43	0.53
6	10-Mar	31	7.7	0.42	0.52
7	17-Mar	8.5	7.9	0.41	0.51
8	1-Apr	15.6	8.0	0.41	0.5
Average			7.5	0.4	0.5
Median			7.55	0.43	0.53
St Dev			0.37	0.01	0.02

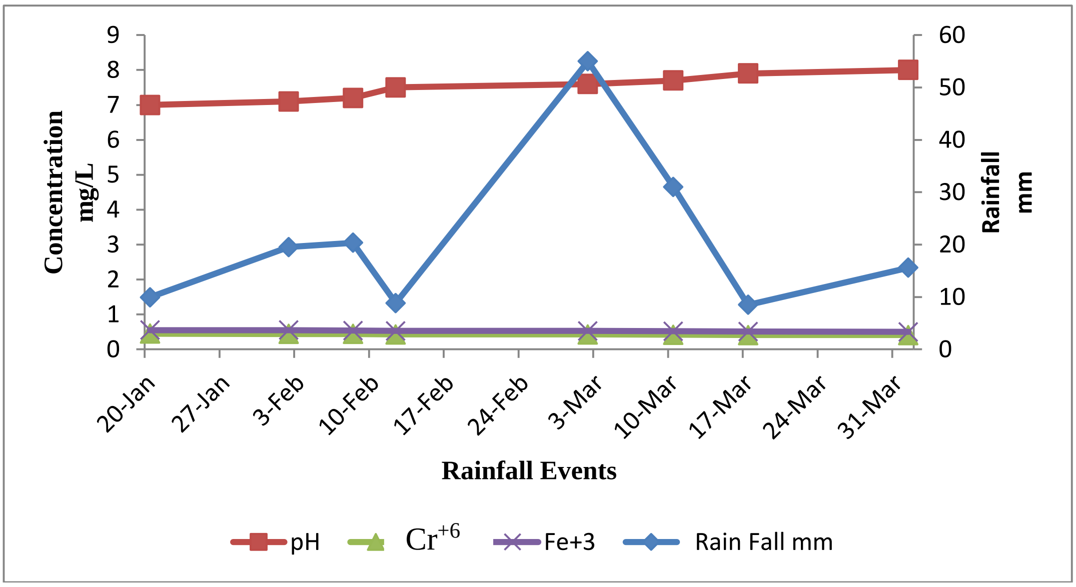

Fig 4.16: Comparison of pH and heavy metals for BC column

Sector H-12 column leachate had a range of pH between 7 and 8. Consequently the concentration of contaminants was also less at comparatively high value of pH. The average concentration of chromium and iron was found to be 0.4 mg/l and 0.5 mg/l. Table 4.17 and Fig. 4.17 show the concentration of pH and heavy metals.

Table 4.17: Comparison of pH and concentration of heavy metals for H - 12 column

Sr. No.	Dates	Rain Fall mm	pH	mg/L	
				Cr^{+6}	Fe^{+3}
1	20-Jan	9.93	7.0	0.45	0.55
2	2-Feb	19.52	7.1	0.44	0.55
3	8-Feb	20.36	7.2	0.44	0.54
4	12-Feb	8.83	7.5	0.43	0.53
5	2-Mar	55.00	7.6	0.43	0.53
6	10-Mar	31.00	7.7	0.42	0.52
7	17-Mar	8.50	7.9	0.41	0.51
8	1-Apr	15.60	8.0	0.41	0.5
Average			7.5	0.4	0.5
Median			7.6	0.4	0.5
St Dev			7.6	0.0	0.0

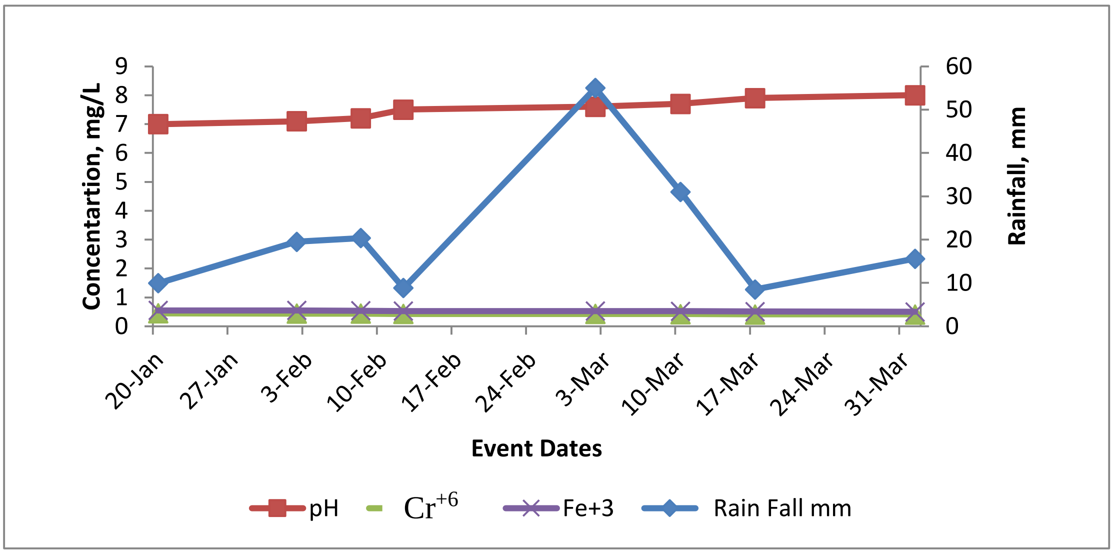

Fig 4.17: Comparison of pH and heavy metals for H-12 column

4.8 Overall View of Characterization

The characteristics of leachate, as determined by the laboratory analyses of the samples have been presented in Table 4.8 through Table 4.16; and Fig. 4.8 through Fig. 4.16. Each table and Fig presents the data regarding the columns/ dumps so as to have a view of the results with regard to the leachate composition of solid waste of the columns against the rainfall amounts, their sequence and intervals of precipitation events. Three inferences have been drawn from all the leachate characterisation results.

1- The quantity of waste has the greatest influence on concentration of contaminants in leachate. Generally greater the quantity of waste in the column, greater would be the concentration of contaminant.

2- Higher the quantity of rain fall over the columns, lower would be the concentration of contaminants.

3- Greater the duration of two consecutive rainfall events, higher would be the concentration of contaminants in the resulting leachate.

4.9 Comparison of Results with Other Studies

The results of this study have been compared with the findings of other researchers in order to establish a viable level of authenticity. Table 4.18 presents a comparison of the results of this study with the recent work of other researchers.

Table 4.18: Leachate characterization - comparison of results with other studies

S. No.	Leachate Characteristics	Name of Study/Author	Author's study, Range of Values	This Study
1	COD, mg/L	Visvanathan *et al.*,(2007)	940-32,790	3,390-8,320
2	Sulphates(SO_4^{-2}), mg/L	Ehring (1998)	10-1,200	35-180

S. No.	Leachate Characteristics	Name of Study/Author	Author's study, Range of Values	This Study
3	Chlorides (Cl^{-1}), mg/L	Ehring (1998)	30-4,000	325-1535
4	Nitrite (NO_2^{-1}), mg/L	Bahaa (2005)	5.12-32.0	5.1-1,535
5	TDS g/L	Visvanathan *et al* (2007)	3.67-14.45	3.20-8.05
6	Turbidity, NTU	Visvanathan *et al* (2007)	-	69.0-250
7	pH	Visvanathan *et al* (2007)	5.75-8.36	6.0-8.0
8	Iron (Fe^{+3}), mg/L	Baha (2005)	0.67-10.60	0.5-1.7
9	Chromium(Cr^{+6}), mg/L	Christensen (1992)	0.2-1.5	0.41-1.5

The comparison presented herein above indicates that the results of this study are well within the usual range of values.

4.10 Comparison of Results with NEQS

Table 4.19 presents a comparison of the results of this study with (NEQs 2000). In case of NO_2^{-1} and turbidity, the NEQs are not available. As a result of the comparison, following inferences can be drawn regarding the leachate characteristics of the columns/dumps:

- The leachate of sector H-10 and BC dumps contain high concentrations of chemicals which are quite injurious for environment and human/animal health.
- The leachate concentrations of sector H-12 dump have been reduced to a large extent due to considerable decomposition. However COD, NO^{-1}_2 and turbidity of sector H-12 dump exceed the NEQs to a large extent.
- The SO^{-2}_4, pH, Fe^{+3} and Cr^{+6} ion concentrations are seemingly within the range of NEQs. However, Fe^{+3} and Cr^{+6} ions may exceed the permissible concentrations in the leachates produced after long pause of rainfall.

Table 4.19: Leachate characterization - comparison of results with NEQs

S. No.	Leachate Characteristics	Units	This Study (Values)	NEQs
1	COD	mg/L	3,390-8,320	400
2	SO_4^{-2}	mg/L	35-180	600
3	Cl^{-1}	mg/L	325-1535	1000
4	NO_2^{-1}	mg/L	5.1-1,535	-
5	Turbidity	NTU	3.20-8.05	-
6	TDS	g/L	69.0-250	3.5
7	pH	-	6.0-8.0	6.0-9.0
8	Fe^{+3}	mg/L	0.5-1.7	8.0
9	Cr^{+6}	mg/L	0.41-1.5	1.0

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSION

1- The percentage of different components of solid waste of sector H-10 dump and BC dump is quite comparable except the organic waste (Food and Yard waste). The BC dump waste contains higher percentage of organic matter due to which the leachate generation in BC dump exhibits higher COD than that of the sector H-10 dump.

2- Organic matter in sector H-12 dump has been decayed due to bacterial activity after the closure of the dump. Thus the largest percentage of waste material of the dump contains soil, dirt and degraded organic matter and second largest component comprises plastics.

3- The quantity of leachate generated in sector H-10 dump is a little higher than that of the BC dump. However, the quantity of leachate produced in sector H-12 dump is considerably less than other two dumps due to the high density and absorption capacity of its material.

4- Leachate produced in all the three dumps is highly toxic and their COD exceeds the NEQ limits.

5.2 RECOMMENDATIONS

1- Phytocapping technique can be applied to sector H-12 dump for leachate reduction.

2- The frequency of soil cover on the MSW of sector H-10 dump may be increased in order to reduce leachate generation.

3- Material recovery facility (MRF) and composting plant can appropriately be established for waste reduction at BC dump which would lead to decrease the leachate generation.

4- This study has developed a methodology for the qualitative as well as qualitative estimation of the leachate generation in an open dump. This can form the basis for the design of leachate treatment/management facilities for the future dumps.

5- Leachate pollution indices (LPI) of all the three dumps should be determined to estimate the extent and nature of pollution caused by the three dumps. The leachate generation and characterization results drawn in this study can be used for the determination of LPIs of the three dumps.

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