CHARACTERIZATION OF LEACHATE OF BHALASWA LANDFILL AND ITS IMPACT ON THE GROUNDWATER QUALITY

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CERTIFICATE

This is to certify that the research work embodies in this dissertation entitled: "**CHARACTERIZATION OF LEACHATE OF BHALASWA LANDFILL AND ITS IMPACT ON THE GROUNDWATER QUALITY"** has been carried out in the Department of Environmental Engineering, Delhi Technological University, New Delhi. This work is original and has not been submitted in part or full for any other degree or diploma to any university or institute. This work is approved for submission.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

APHA	American Public Health Association
BIS	Bureau of Indian Standards
COD	Chemical Oxygen demand
CPCB	Central Pollution Control Board
EC	Electrical Conductivity
EPTRI	Environmental Protection Training & Research Institute
GSI	Geological Survey of India
GW	Groundwater Samples
IMD	Indian Meteorological Department
MSW	Municipal Solid Waste
LS	Leachate Samples
TDS	Total dissolved Solids
TP	Total Phosphate
TSS	Total suspended Solids
UNEP	United Nation Environment Programme
USEPA	United States Environmental Protection Association
USGS	United States Geological Survey
WHO	World Health Organization

ABSTRACT

Water is essential for living and is used for drinking, irrigation and other purposes. Groundwater, in general terms, is defined as water that is present beneath the underlying rocks in the earth's surface. When an unwanted contaminant changes the physical, biological and chemical properties of water, it is known as water pollution. A Landfill is the most common waste disposal practices used in many parts of the world. It is the cheapest of all waste management practices. The landfill in the present study is situated in the capital of India, New Delhi and known as Bhalaswa landfill. The Bhalaswa landfill is one of the working landfill in the capital of India; New Delhi. The other two working landfills in New Delhi are Okhla and Ghazipur.

The aim of this project is to characterize the landfill leachate and assess the groundwater quality near the vicinity of landfill to find out the impact of landfill leachate on groundwater. The samples were taken for both groundwater and the leachate to evaluate physico-chemical properties along with heavy metal assessment. The samples for leachate was collected from the outlet near the landfill site while the groundwater samples were collected from the handpumps installed in the shops, houses, temples etc in the colonies near the landfill site. All the analysis was done in the water laboratory with all the precision and methodology as prescribed in Standards Methods for the Examination of Water and Wastewater, 17^{th} edition, APHA.

The study has shown that most of the parameters found in the groundwater exceeded the permissible limits as prescribed by the Bureau of Indian Standards for drinking purposes. The water assessed was unfit for drinking, irrigation or any other purposes. Apart from the physical and chemical properties, the concentration of heavy metals was unbelievably high. The comparison of standards with both leachate and groundwater parameters is done and is represented graphically in form of bar charts and line charts respectively. The extent of pollution is analyzed along the radial distances by dividing the samples according to their distance from the landfill, the three categories were defined and the results shows that as we move towards the landfill, the water quality is degraded accordingly. The irrigation suitability for the water is also done by categorizing the water according to different theories of past along with the graphical representation through piper diagram. The overall quality of the water has shown the degraded results. Hence, the groundwater near the Bhalaswa landfill is highly polluted, non portable and is even unsuitable for irrigation purposes.

CHAPTER 1

INTRODUCTION

1.1 GENERAL

Water is vital for human survival. Water is available in various forms out of which groundwater is one of the important sources for drinking, irrigation and other purposes. Groundwater, in general terms, is defined as water that is present beneath the underlying rocks in the earth's surface. Groundwater follows the hydrological cycle i.e. it is recharged from and eventually ends in the surface. It supports wetland ecosystems but the major portion is utilized in fulfilling the basic human demands. Water quality plays a significant role in water usage. When an unwanted contaminant changes the physical, biological and chemical properties of water, it is known as water pollution. As per USEPA, both the human and the nature have contributed to pollute the groundwater but the human activities leaves the long term effects on the water bodies as compared to other natural reasons.

In various parts of world, water shortage has been reported because of the freshwater scarcity. Human activities and over utilization of the resources has depleted the available water. The management of waste and waste related environmental issues can be directly connected to increasing rate of population and their lifestyles. Groundwater has numerous sources of pollution like landfill, excess use of fertilizers, pesticides, chemicals etc., septic tanks etc. Groundwater though is considered apt for public uses without any treatment. As been underground, they are of excellent quality as they are free from odour, pathogens, colouring material, turbidity, suspended materials etc. It recharges naturally and is easily accessible. But unfortunately, the quality as well as quantity both has depleted to an alarming rate.

Solid waste generally includes paper, food, wood, cardboards, grass trimmings, rubber, leather, textiles, metals etc. Waste generation and its composition vary from country to country. This variation is due to increase in population, urbanization, affluent livelihood of a sector of society etc. Globally, millions of tons of municipal solid waste are dumped in the thousands of landfills. In 2011, Planning Commission of India has reported that India produces around 70 million tonnes of Municipal Solid waste annually but only 5% of this is processed by scientific methods. There are more than 5100 municipalities in India with average waste collection efficiency ranging between 22-60%. The waste characterization is done by the commission and showed that MSW contains 51% organic material, 17% recyclable material, 11% hazardous material and 21% inert material.

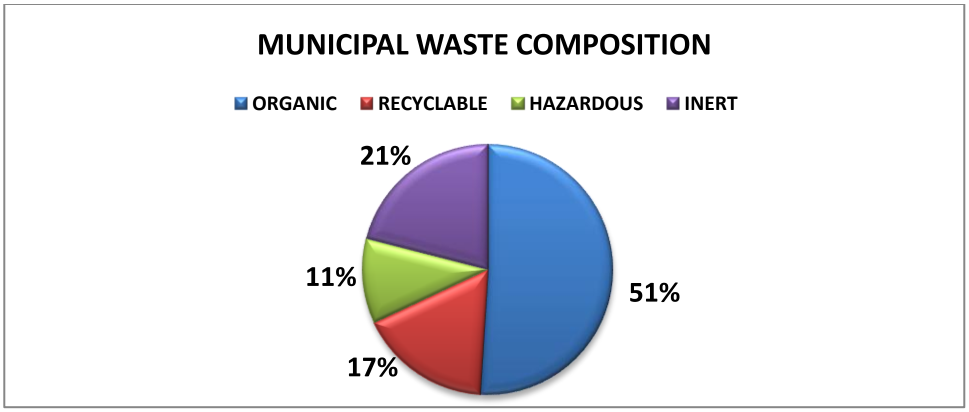

Figure 1.1: Waste Composition of MSW in India *(SOURCE: Planning Commission 2011)*

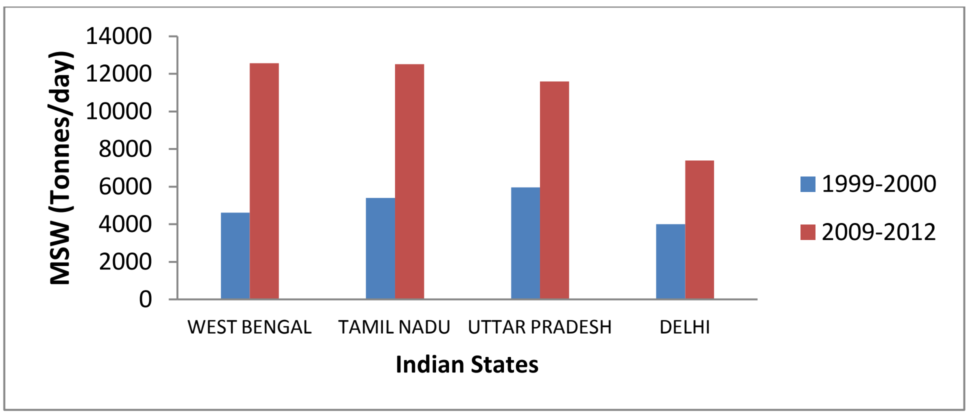

Figure 1.2: Municipal Solid Waste Generation in States of India (*Source: Central Pollution Control Board REPORT 2011-2012)*

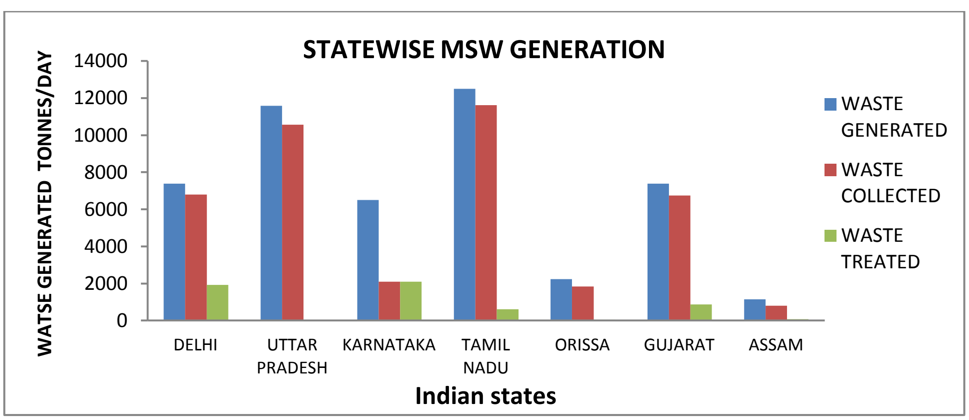

Figure 1.3: Statewise Solid Waste Generation, Collection and Treatment As On 31 July 2012 *(Source: Central Pollution Control Board REPORT 2011-2012)*

Government of India has specified certain rules for managing the generated waste and all the action plans implemented are referred with them to check whether it is in agreement with the rules or not. As per report submitted by Central Pollution Control Board (CPCB), there is hardly any city or town in India with compliance with the Municipal Solid Waste Rules, 2000. CPCB has conducted a survey through Environmental Protection Training & Research Institute (EPTRI) in 1999-2000 and State Pollution Control Boards/ Pollution Control Committees in 2009-2012 regarding the waste generated by various towns and cities in India. The overall municipal waste generation in 1999-2000 from Class-I and Class II cities was 52125 tonnes/day while 127485.107 tonnes/day in 2009-2012. West Bengal been in the lead with 12557 tonnes/day in 2009-2012 followed by Tamil Nadu, Uttar Pradesh and so on. The waste generation by Delhi was 4000Tonnes/day in 1999-2000 which has jumped to 7384 tonnes/day in 2009-12.

Central Pollution Control Board (CPCB) has conducted time to time studies to evaluate the quantity of waste generated by each state and union territories of the country. It has coordinated various State Pollution Control Boards/ Union Territory Control Committee to implement Municipal Solid Wastes (Management & Handling) Rules, 2000 by creating awareness through seminars, workshop, training etc. But annual report submitted by State Pollution Control Boards/ Union Territory Control Committee shows that most of the cities/towns are not implementing the required action plan as per Rules. Out of total waste generated, only 70% waste is been collected and 30% is remains lost in the municipal environment without collection or treatment. There is an enormous breach between the waste collections and processing as waste generated by country in year 2012 was 1, 27,486 tonnes/day, out of which 89,334 tonnes/day were collected and 15,881 tonnes/day were treated. This leaves us with 22,271 tonnes of waste per day which stays in the urban environment. On considering state wise scenario, Delhi's total waste generation was 7384 tonnes per day and collection and treatment were 6769 tonnes/day and 1927 tons/day respectively. There were few states like Uttar Pradesh, Mizoram, Nagaland, Punjab, Arunachal Pradesh etc, where none of the waste is undergoing under treatment processes. While there are some states like Assam, Manipur Sikkim, Jharkhand, where the treatment is not really done compared to generation of waste. Most of the states have municipalities in which there is no provision of scientifically disposal of the waste in the sanitary landfill and all the waste is just discarded in the dumpsite.

Landfilling is the most common waste disposal practices in many parts of the world. It is the cheapest of all waste management practices. Various processes occur within the landfill like chemical, physical or biological which aids the degradation of waste and results in leachate and harmful gases. In India, the low lying open areas are dumped with the waste and referred as dumpsites or sometimes landfills. But these areas lack the most basic elements of a sanitary landfill like use of liners or daily cover, a leachate collection or treatment unit, compaction of waste periodically, proper site designing, exhaust gases recovery systems etc. This ignorant practice of waste dumping provides a platform for the numerous health and environmental effects. The decomposition of waste dumped in any landfill site is mainly due to microbiological activities which lead to various problems like: evolution of gases from the waste, movement of landfill leachate through the underlying strata, chemical oxidation of waste materials etc (Lo, 1996). The hazard of groundwater pollution is one of the major troubles created due to landfill leachate. The waste generation has inverse effects on the climate also. As per UNEP 2010, the green house gases been generated from the waste disposal site. Methane emissions from landfill are commonly regarded as the major cause of climate impact in the waste sector.

1.2 NEED OF STUDY

India is one of the most populated countries of the world. With the population, the waste generation rate is also very high. The major concern is with the management of waste of this rapidly increasing population growth. Landfill is though the most common but the most polluted waste management technique. The inappropriate design and maintenance of the waste has lead to various environmental problems like generation of leachate, liberation of methane which thereby increases the greenhouse gases emission rate. These problems pose direct harm to humans, animals, plants and even exhaust the natural resources. The contamination of soil and the groundwater are the major setback of open waste dumping. Leachate is defined as the liquid which entered the landfill through external sources like precipitation, drainage, underground springs etc and extracts dissolved and suspended solids and is percolated through the waste (Fatta *et.al.,* 1999; Odunlami 2012).

The study of landfill leachate is required as areas near landfill sites are deeply affected by groundwater pollution (Butt & Ghaffar, 2012). The groundwater resources have a major risk of contamination by the percolation of the leachate. According to various studies (George *et.al.,* 1999; Christopher O. *et.al.,* 2012; Butt & Ghaffar 2012), it has been proved that the landfill is gradually degrading the groundwater quality and is exploiting the natural water resources. This is also one of the reasons behind the water scarcity as groundwater becomes unfit for use. The steady decay rate of the carbon stockpile present in the landfill generates emission even after ceasing of the waste disposal. This is due to the chemical and biological reactions takes time to advance and is emitted gradually over the period of years. The major emission is of methane (CH_4) and carbon dioxide (CO_2) and these greenhouse gases are major source of climate change and global warming (UNEP, 2010). As per MoEF, 2010a, India ranks fifth in cumulative in greenhouse gas emissions in the world after USA, China, the European Union and Russia.

Incidents of groundwater contamination due to landfill leachate have been widely recorded since 1975. This creates an urgent need to understand the movement of leachate generated by landfills and its ill effects on the groundwater quality. Therefore the study of the landfill leachate and the nearby groundwater is necessary as:

- If a person is living nearby the landfill area, it is vital to know whether the available groundwater is fit to use or not.
- Various health hazards, diseases or illness could spread, if there is a regular intake of contaminated water.
- The landfill authorities can get the idea of the level of contamination and can start their recovery and reclamation programs instantly by emphasizing on the control of leachate formation, or by controlling the percolation of leachate through soil routes.
- If the contamination has spread too wide and deep, that it's really hard to recover, then the resettlement of the nearby population is required, which accounts to huge economical investment.

1.3 OBJECTIVE OF THE PRESENT STUDY

The Bhalaswa landfill is one of the working landfill in the capital of India; New Delhi. The other two working landfills in New Delhi are Okhla and Ghazipur. The landfill is not scientifically lined so it is just a dump site instead of a sanitary landfill site. The landfill has already saturated and has a serious health hazards and property damage for the population living nearby. The Bhalaswa landfill leachate samples and the various groundwater samples were collected from various point sources and were analyzed. The understanding of various characteristics of landfill leachate and the nearby groundwater can help in accounting and minimizing its effects on the environment.

The research is intended to investigate the movement of leachate of Bhalaswa landfill and to determine the distribution of heavy metals and other physical and chemical parameters in leachate and leachate polluted groundwater, to study the possible influence of the landfill on the groundwater quality. The major objective of the study is outlined below:

- The characterization of the properties of the landfill leachate found nearby the study area. The parameters include physical, chemical as well as the heavy metals concentration.

- To study the spatial distribution of hydro geochemical parameters for evaluating the quality of the groundwater. The standards of WHO are used for comparison of the parameters, to check whether the parameters are within the permissible limits or not.

- To identify the tracer elements in leachate, in order to identify the impact of landfill leachate in the water samples.

1.4 DESCRIPTION OF THE CONTENT OF THE THESIS

This thesis comprises five chapters which are explained thoroughly by quoting the proper references:

- Chapter 1 brings out the general introduction regarding the solid waste, its composition, landfill practices, leachate and green house gas generation etc. This chapter mainly focuses on the objective of the present study that means it provides the idea about the whole content of the thesis.

- Chapter 2 consists of detailed review of the literature which includes the study and research work conducted by various scholars in the context of the landfill leachate generation and the adverse effects it creates on the quality of groundwater. It also includes the characterization of leachate as well as the groundwater by discussing their physical and chemical properties.

- Chapter 3 describes the research materials and methodology of the present study. It also encompasses study area which includes plan area, location, geology, climatic conditions and other factors.

- Chapter 4 deals with results obtained by the present study and a thorough discussion over the attained results.

- Chapter 5 is based on the conclusions drawn from the study and includes few recommendations on the concluded points. It also covers the future scope of the present study.

CHAPTER 2
REVIEW OF LITERATURE

2.1 GENERAL

Water is a vital need for existence of all forms of life. Water is present in the earth's surface as well as in environment in the form of river, lake, ocean, rain, fog, snow, mist, dew, ice, aquifer etc. As per UNEP, around 71% of earth's surface is water covered and out of which 96% is saline water present in the oceans. This left us with only 3% freshwater, out of which 2.5% is frozen in form of glaciers and permanent ice caps in Arctic and Antarctic regions. Thus the whole ecosystem's need is relied upon only 0.5% of the freshwater, which is unevenly distributed all around the world. Freshwater includes aquifers (in the soil); groundwater (bedrock fractures present beneath the surface of the Earth); rivers, natural lakes, streams, ponds etc (surface water); rainfall, fog, mist, dew, snow etc (atmospheric water). The percentage of water distribution as per USGS is groundwater (0.397%); surface water (0.022%) and atmosphere (0.001%). The water is used by the mankind for diverse purposes like agricultural, drinking, domestic, industrial, electricity generation, thermal power plants etc. Agriculture is the largest consumer of fresh water resources; it consumes about 42% of the total freshwater present. Electricity generation consumes approximately 39%; 11% is utilized by urban and rural areas; and remaining 8% is used in other manufacturing and mining projects and industries. The water available is not always as pure as it seems. Impurities are always present in the water, which affects the consumers severely. These contaminants are added directly or indirectly (in form of natural and manmade sources) to the water making it unfit for use. The nature of groundwater is governed by the natural geochemistry of the rocks and the minerals of the soil. The distribution of contaminated water due to natural processes is limited. But most of the freshwater contaminants are due to manmade activities.

2.2 SOURCES OF WATER POLLUTION

The various sources of water pollution are detergents (Forstmeier *et.al.,*2005; Gawad 2014), industrial outlets (Gunkel *et.al.,* 2006) domestic waste water (Yates, 1985; Krystek *et.al.,* 2014), oil spill(Goldman *et.al.,* 2014; Ng *et.al.,* 2014), leachate (Loizidou *et.al*.,1993; Christensen *et.al.,* 1994; Fatta *et.al.,* 1999; Haarstad & Borch, 2008; Zhang *et.al.,* 2013; El- Salam & Abu-Zuid, 2014;), fertilizers (Trinh *et.al.,* 2014), pesticides (Worrall & Kolpin, 2004; Ritter, 2008), herbicides (Readman *et.al.,* 1993), dye (Carnerios *et.al.,* 2010), heavy metals like Arsenic (Grassic *et.al.,* 2013), Iron (Jin *et.al.,* 2015), Cadmium (Alghasham *et.al.,* 2013), Lead (Laxen & Harrison *et.al.,* 1976; Dabrowski *et.al.,* 2004; Jeon *et.al.,*2008), Mercury (Dabrowski *et.al.,* 2004) etc.

These contaminants when crosses the certain permissible limits of discharge, contributes to the pollution. Contaminated water leads to various water borne diseases like Hepatitis A (Vogt, 1961 ; Craun, 1979), typhoid (Pfeiffer, 1973; Craun, 1979), gastroenteritis (Wellings *et.al.*,1977; Rose *et.al.*, 2001) cholera(Moore *et.al.*, 2014) , Ascariasis (Khuroo *et.al.*, 1990; Esrey *et.al.*, 1991), methemoglobinemia (Chen *et.al.*, 2012), diarrhea (Esrey *et.al.*, 1991), E.coli Infection (Khalil *et.al.*, 2014; Chan *et.al.*, 2014), Vibrio Illness (Igbinosa *et.al.*, 2011) etc. These diseases can be curbed if there is a proper management of waste. Preventing negative water quality impacts is more efficient and effective than attempting to restore the damage. One of the global concerns is efficient management of solid waste (Cointreau, 1982; Doan, 1998; Adeolu O. *et.al.,* 2011) which one of the sources of the contamination through leachate(Chain & DeWalle 1976; Loizidou *et.al.*,1993; Christensen *et.al.,* 1994; Fatta *et.al.,* 1999; Haarstad & Borch, 2008; Odunlami 2012; Zhang *et.al.,* 2013; El- Salam & Abu-Zuid, 2014).

2.3 SOLID WASTE

Solid waste is the heterogeneous collection of organic and inorganic wastes, whose characteristics are affected by various parameters like living standards, lifestyle, location etc. Composition of waste in the landfills is mainly influenced by (Harmsen, 1983; Stegman and Ehrisg, 1989; Christensen *et al.,* 2001; Rapti-Caputo & Vaccaro, 2006) by:

- climatic conditions (precipitation, groundwater interference),
- site operation and management (waste pre-treatment, compaction, vegetation cover, irrigation, re-circulation, liquid waste co-disposal and refuse decomposition),
- waste characteristics (age, permeability, particle size, density, unit weight, initial moisture content),
- internal processes (waste settlement, decomposition of organic material, gas and heat generation and transport), biodegradation processes.

Population growth is major factor responsible for increased municipal solid waste (Longe & Balogun, 2010; Odunlami 2012). Rapid development and changing lifestyles in developing nations have also transformed waste composition from mainly organic (biodegradable) to mainly plastics, paper, glass, cardboard, packaging materials (polyethene bags), e-waste (batteries, metals), hospital wastes etc, that are complex in nature and cannot be easily degraded. The waste been generated is generally disposed off in open dumps or in landfills. Landfill is generally an open area which is meant to receive the waste. Landfilling is the cheapest and cost effective method of disposal of waste (Thompson & Zandi,1975; Jhamnani & Singh, 2009; Longe & Balogon 2010; Adeolu O. *et.al.,* 2011). It is estimated that approximately

95% of the solid waste generated is disposed off in the landfill globally (Bingemer and Crutzen, 1987; Cossu, 1989; Gendebien *et al*., 1992; El-Fadel *et al*.,1997).

The composition of wastes in landfill varies as organic, inorganic, hazardous and non hazardous. As per World Bank (Hoornweg *et.al.*, 2012), world cities generate about 1.3 billion tonnes of solid waste per year. The average global solid waste is composed of 46% organic waste, 17% paper, 10% plastic, 5% glass, 4% metal, 18% others. The landfills though are cheapest form of waste disposal are considered as one of the major threats to the water resources (Christensen & Stegmann 1992; Fatta *et.al.,*1999; Longe & Balogon, 2010; Butt & Ghaffar 2012). Poorly designed landfills can create severe contamination to not only groundwater, but to soil and air also.

2.4 LEACHATE

Wastes thrown in the landfill comes in contact with the water through atmospheric precipitation and moisture. This water picks up a variety of organic and inorganic compounds and flows out of the wastes to accumulate at the bottom of the landfill known as leachate (Fatta *et.al.,*1999; Mor *et.al.,*2006; Adeolu O. *et.al.,* 2011; Odunlami 2012). Leachate may contain large amounts of contaminants such as ammonia, total Kjeldahl nitrogen TKN (Christopher O. *et.al.,* 2012; Zhao *et al.,* 2013), fluoride (Kang *et.al.,*2008), phosphate (Oketola & Akpotu*,* 2015) , sodium (Kang *et.al.,*2008; Adeolu O. *et.al.,* 2011), phenol(Mor *et.al.,*2006), organic matter(Kang *et.al.,*2008) like toluene, benzene, dichloromethane etc(Jimenez *et.al.,*2002) and heavy metals like zinc (Adeolu O. *et.al.,* 2011; Christopher O. *et.al.,*2012), iron (Fatta *et.al.,*1998;), Cadmium (Fatta *et.al.,*1998; Odunlami 2012), lead (Adeolu O. *et.al.,* 2011; Odunlami 2012)etc.

The leachate typically migrates from the landfill to pollute surface and groundwater supplies, leachate contaminants possess probable risk of affecting natural environment and health of the local residents (George *et.al.,*1999; Christopher O. *et.al.,* 2012; Butt & Ghaffar 2012). The effects of leachate on groundwater and adjacent aquifers have been a common area of interest for various studies such as those of El- Salam & Abu-Zuid (2014), who examined the impact of Borg El- Arab landfill leachate on nearby groundwater quality. Consequently, the effects of leachate in hydrological systems have been observed to extend for several hundreds of meters (Palmquist & Sendlein 1975; MacFarlane et. al, 1983; Zheng et. al. 1991; Sanchez Ledesma et. al. 1993; Flyhammar 1995; Butt & Ghaffar 2012). The refuse in landfill decomposes to produce gas. Qualitatively, landfill gas is highly dependent on the decomposition stage within the landfill *(*Rovers & Farquhar, 1973; Rees, 1980; Pohland *et al.,* 1983; Barlaz *et al.,* 1989). Studies have recognized several phases of anaerobic decomposition during which organic materials are converted to methane and carbon dioxide (Alexander, 1971; El-Fadel *et al*.1997).

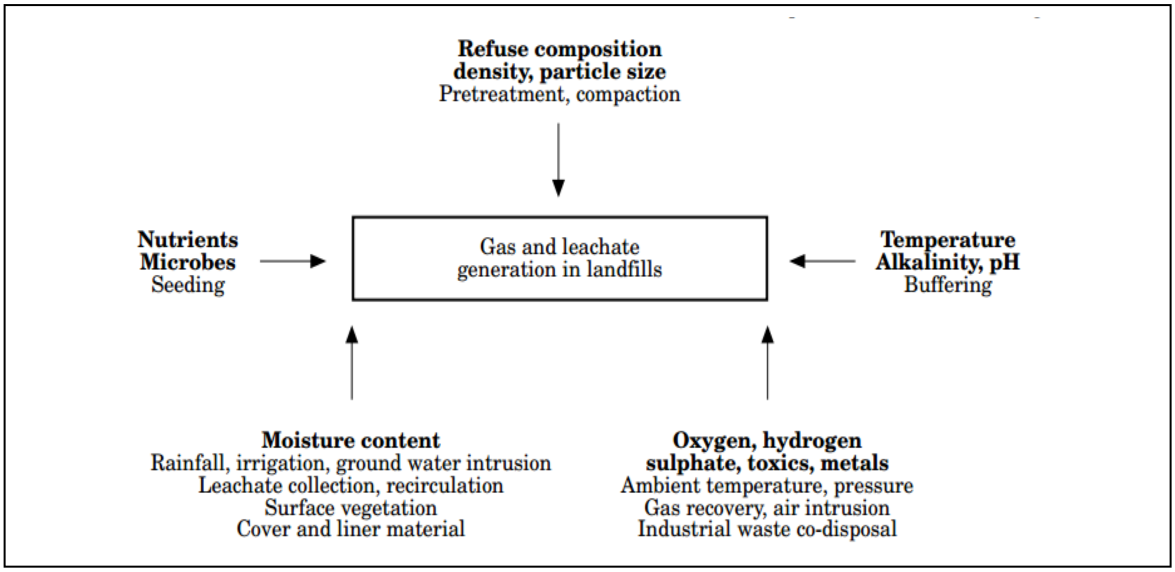

Figure 2.1: Factors Influencing Gas and Leachate Generation in Landfill, (Fadel et.al.1997)

2.5 CHARACTERIZATION OF LEACHATE AND GROUNDWATER

The physical, chemical and microbiological parameters are generally analyzed in leachate and groundwater samples from the areas adjoining to a municipal solid waste landfill site in order to assess the adverse outcome of leachate percolation on groundwater quality. Physical parameters include pH, temperature, colour, odour, Turbidity, Electrical Conductivity etc. Chemical parameters represent the chemical behaviour of the liquid. It is due to presence of some kind of chemical reactions. It consist of Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Chloride (Cl), Phosphate (PO_4), Silica (SiO_2), Nitrogen Contents - Nitrate (NO_3), Ammonia (NH_3), Total Kjeldahl Nitrogen (TKN), Calcium (Ca), Magnesium (Mg), Silica (Si), Boron (B), Sulphates (SO_4), Sulphides, Dissolved Oxygen (D.O.), Chemical Oxygen Demand (C.O.D.), Biochemical Oxygen Demand (B.O.D.), Total Organic Carbon (T.O.C.) etc. Heavy Metals are generally metals which are abundant in nature and get accumulated due to human activities and sometimes naturally. Some examples are Zinc (Zn), Iron (Fe), Copper (Cu) and Manganese (Mn), Nickel (Ni), Lead (Pb), Chromium (Cr), Arsenic (As), Cadmium (Cd) etc. Biological parameters are due to presence of microorganisms which includes bacteria (Cyanophyceae, Escherichia coli, Vibrio cholera),algae (Chlorophyceae, microcystis), fungi(Basidiobolus, Bipolaris), protozoa(giardia, entamoeba), viruses(rotavirus, poliovirus), rotifers, worms (roundworms, nematodes, planaria)etc.

2.5.1 PHYSICAL PARAMETERS

2.5.1.1 COLOR

Color is a physical identity. Presence of color in water is generally attributed to the presence of the organic matter or sometimes due to metallic complexes. Landfill leachate is a very dark colored liquid formed by the percolation of precipitation through landfill. The decomposition of organic matter may cause the water to turn yellow, brown or black (Zouboulis *et al,* 2004). A study by Fatta *et. al.* 1999 on the landfill leachate of Greece region shows the color was dark brown to black due to presence of humic compounds. Chofqi *et al.*2004 also found the color of El Jadida, landfill as black. Iron and Mn, may impart a brownish color and a bad taste (Garland & Mosher, 1975*).* As per health concern, the level of color does not directly measure the purity of water, although it may indicate the contaminated water.

2.5.1.2 ELECTRICAL CONDUCTIVITY

Electrical Conductivity is the measure of the amount of total solids dissolved in the water. It represents how conductive the water is to electric current. It is actually a good indicator of total salinity of the water. The higher value of EC has been reported in various studies (Tejero.*et.al*.1993; Loizidou *et.al*.1993; Blight,1995). Fatta *et.al*,1999 attributed the higher EC values to the high levels of anions. Rafizul & Alamgir, 2012 concluded that the salts content in leachate is harmony to the EC values and it reflects its total concentration of ionic solutes and is a measure of the solution's ability to convey an electric current. EC is found more than permissible limits can cause disturbance of salt and water balance in children, aesthetic problems like salty taste, fail to quench thrust etc., and sensitive groups could be affected. Conductivity in streams and rivers is affected primarily by the geology of the area through which the water flows. Studies of inland fresh waters indicate that streams supporting good mixed fisheries have a range between 150 and 500 µmhos/cm (US EPA). The permissible limit of EC is 1,400 µS/cm for drinking water.

EC values of different landfill leachates are 22,200–26,900 ms/cm in Athens (Fatta *et.al.,*1999), 10 to 50 mS/cm in Tunis (Yoshida *et.al.,* 2002),18.1 mS/cm for pre monsoon and 21.7 mS/cm for post monsoon in Okhla Landfill and 13.7 mS/cm for pre monsoon and 20.3 mS/cm for post monsoon in Ghazipur Landfill in New Delhi (Zafar & Alappat, 2004), 41,637 µS/cm (mean value) in Alexandria (Hassan & Ramadan, 2005), 6,230–59,000 µS/cm in TamilNadu (Parameswari *et al.,*2012), 35,260-42,857 µS/cm in Egypt (Salam & Zuid, 2014).

Similarly, electrical conductivity as observed in groundwater samples by various scholars in their respective study areas lying near landfills were 3560-4675µS/cm in Athens (Loizidou &

Kapetanios, 1993), 95-1000 µS/cm in Portugal (Matias *et.al.,*1994), 107.9 mS/cm in Tunis (Yoshida*et.al.,* 2002), 617 and 3620 µS/cm in New Delhi(Mor *et.al.,*2006), 396-3644 µS/cm in China (Han *et.al.,*2014). Loizidou & Kapetanios, 1993, Mor *et.al.,*2006 mentioned the high value of electrical conductivity in groundwater near landfill is due to the effect of landfill leachate. Fatta *et.al.,*1999 attributed higher EC values to the presence of high concentration of the different anions.

2.5.1.3 pH

pH is a measure of acidity or basicity of any aqueous liquid. It measures its hydrogen ion activity. If the value of pH is found to be 7, the sample is neutral. The value above and below 7 indicates basic and acidic nature respectively. Basicity of leachate samples were attributed in various studies like Venkataramani *et.al,* 1988 examined the landfill leachate values to be 7.5-9.0, Irene & Lo, 1996 studied the leachate characteristics of Hongkong landfills and found pH in the range7-9. Li *et.al,* 2013 found the pH as 8.58±0.12 for the leachate obtained from landfill located in China. The landfill leachate pH varies according the nature of the waste and also due to various decomposition stages of the waste. Higher pH value shows the biochemical activity in the landfill was in its concluding stage and the most of the organic load was biologically stabilized (Fatta *et.al,* 1999). Hassan & Ramadan, 2005 and Salam & Zuid, 2014 claimed in their studies that basic nature of landfill leachate is suitable for growth of methanogenic bacteria.

On the other hand, in initial stages of decomposition, pH values are quiet low due to acid formation. The evidences of acidic pH were found by Christensen *et.al,* 1994 who has studied pH of leachate sample in range 4.5-9. The acidic pH caused an extension in time required for organic fraction of waste to get stabilized since methanogenic bacteria are very sensitive to low pH (Hassan & Ramadan, 2005). Adeolu *et.al.,*2011 studied leachate pH as 8.1 in an African landfill while the groundwater samples near this landfill varied between 4-8.15.

2.5.1.4 TOTAL DISSOLVED SOLIDS

Total Dissolved Solids is the presence of inorganic salts and small amounts of organic matter present in sample. The principal constituents as per WHO in TDS are calcium, magnesium, sodium, potassium as cations and carbonate, bicarbonate, chloride, sulphates and nitrate as anions. The presence of dissolved solids in high concentration may affect the taste of water. Even the low concentration of TDS may also be unacceptable to human health, as it imparts dull taste. As per various studies, the value of leachate is found to be far more than the standards laid by WHO for discharge of effluent i.e. 500 mg/l. TDS values for leachate were found to be 8820 mg/l (Loizidou *et.al.,*1993), 11618±1638 mg/l for first trench and 11887±2916 mg/l for second trench (Fatta *.et.al.,* 1999), 2785mg/l for for pre monsoon and 3288 mg/l for post monsoon in Okhla Landfill and 2108 mg/l for pre monsoon and 3076 mg/l for post monsoon in Ghazipur Landfill in New Delhi (Zafar & Alappat, 2004),62000mg/l (Adoeolu. *et.al.,*2011), 27452±605 mg/l (El-Salam & Abu-Zaid, 2014). These values clearly indicate the level of contamination of the leachate extracted from the landfill. Similarly in case of groundwater, the values been observed were 380-500 mg/l (Nicholson *et.al.,*1983), 586-4460 mg/l (Loizidou *et.al.,*1993), 246-1981 mg/l (Fatta*.et.al.,*1999), 1072-1382mg/l in North Jordon (Abu-Rukah & Al-Kofahi, 2001), 0.39-2.38 g/l in China (Han *et.al.,*2014), 9985±93 mg/l for well1 and 8721±58 mg/l for well2 (El-Salam & Abu-Zuid, 2014).

2.5.2 CHEMICAL PARAMETERS

In order to assess, the quality of water affected by leachate, performing the experimental analysis is very time consuming and tedious job. Some studies (Loizidou & Kapetanious, 1993; Fatta*.et.al.,*1999; Hassan & Ramadan, 2005) has paid emphasis on choosing a characteristic ion or a group of ions present in leachate. These indicators are also known as tracers. The tracers vary in a wide range according to age of landfill, quality and quantity of waste, rainfall etc. Possible ions which could be used as tracer in sample analysis are Calcium (Ca), magnesium (Mg), Sodium (Na), Potassium (K) as cations and Phosphates (PO_4^{3-}), Sulphates(SO_4^{-2}), Chlorides(Cl^-), Nitrates(NO_3^-). But an ion should fulfill the following conditions to act as tracer (Loizidou & Kapetanious, 1993):

- It must be present in elevated concentration in leachate than in the water receiving the leachate.
- The concentration of tracer must be comparative to BOD_5 and Kjeldahl nitrogen(TKN) of the effluent.
- Removal should not be rapid by any removal processes like adsorption or ion exchange.
- It must not require any special storage precautions for storing.
- It must be easily measured by using simple instrumentation.
- By change in pH or by reaction with any anion or cation, it must not precipitate.

2.5.2.1 NITRATE

Nitrate is the one of the highly oxidised form of nitrogen compounds. Nitrates are generally gained from fertilizers, decomposed organic matter i.e. vegetable and animal matter, effluent from domestic drains, disposal of sludge from the sewage, industrial effluent, leachate from waste dumps etc. Unpolluted natural water contains almost null concentration of nitrate. Excessive concentration in drinking water is regarded hazardous for infants because as it causes blue baby disease known as methemoglobinaemia(WHO). In surface water, nitrate is generally present as a nutrient taken up by vegetation around the water. The permissible limit of nitrate for discharge as per CPCB standards is 10mg/l. The concentration of nitrate in leachate as studied in different parts of world were 430.2 mg/l for pre monsoon and 190 mg/l for post monsoon in Okhla Landfill, while 240 mg/l for pre monsoon and 356 mg/l for post monsoon in Ghazipur Landfill in New Delhi (Zafar & Alappat, 2004), 290 mg/l in Morocco (Chofqi *et.al.,* 2004). As per IS 10500 : 2012, drinking water standard for nitrate is 45mg/l. The nitrate concentration in groundwater samples fluctuates between 32.4 –73.5mg/ l in North Jordan (Abu-Rukah & Al-Kofahi, 2001), 1.9-166 mg/l in North Italy (Caputo & Vaccaro, 2006), 0-487 mg/l in China (Han *et.al.*, 2013).

2.5.2.2 SULPHATE

Sulphates occur naturally in plentiful minerals, including barite ($BaSO_4$), epsomite ($MgSO_4 \cdot 7H_2O$) and gypsum ($CaSO_4 \cdot 2H_2O$). Sulphates are highly valuable in the production of fertilizers, chemicals, dyes, glass, paper, soaps, textiles, fungicides, insecticides, astringents and emetics (WHO). They are also used in the mining, wood pulp, metal and plating industries, in sewage treatment and in leather processing (Greenwood & Earnshaw, 1984). The salinity is mainly determined by sulphate ions that are very mobile and constitute non-reactive tracers (Chofqi *et.al.,* 2004).

Studies shows sulphate is extracted from landfill leachate samples like 1150 mg/l in Morocco (Chofqi *et.al.,* 2004), 535 mg/l in Alexandria(Hassan & Ramadan, 2005). As per WHO 2004, sulphate intake in high concentration causes catharsis, dehydration, diarrhea etc. Permissible standard of sulphate for drinking water as per IS 10500 : 2012 is 200 mg/l. Various scholars have shown in their studies the effect of landfill leachate in the groundwater by comparing the standards with the sample values and the following values: 76.8-170.5 mg/l in North Jordon (Abu-Rukah & Al-Kofahi, 2001), 23 -1128 mg/l in North Italy (Caputo & Vaccaro, 2006), 0.02-1.20 mg/l in Africa (Adeolu.*et.al.,*2011), 46.9-515 mg/l in China (Han *et al.*, 2013), 20-1386 mg/l in Spain (Casado *et.al.*,2015).

2.5.2.3 CHLORIDE

As per WHO 2003, Chlorides exist in nature as salts of sodium (NaCl), potassium (KCl), and calcium ($CaCl_2$). The taste of the chloride anion in water is reliant on the allied cation. Sodium chloride is extensively used in the production of industrial chemicals for example caustic soda, chlorine, sodium chlorite, and sodium hypochlorite. Sodium chloride, calcium chloride, and magnesium chloride are comprehensively utilized in snow and ice control. Potassium chloride is used in the production of fertilizers. The chloride ion is highly mobile and is transported to closed basins or oceans.

Chloride ions are generally present in excess in leachate samples. Chloride being a conservative contaminant, is not affected either by the biochemical processes taking place in the dumpsite or by the natural decontamination reactions involving the leachate as it moves through the vadose zone. This property makes the chloride one of the common tracer ions (Mirecki & Parks, 1994). Since chloride migration and accumulation was higher, it degrades the aquifer of the area (Parameswari *et.al.,*2012). Hassan & Ramadan, 2005 claimed that saline water in the landfill is attributed to higher values of the chloride content in the leachate samples. An excess of chloride in water is usually taken as an index of organic pollution and considered as a tracer for groundwater contamination (Loizidou & Kapetanios,1993; Parameswari *et.al.,*2012).

Permissible Chloride concentration as per WHO is 250 mg/l for drinking water. There are several groundwater studies which have found the values of chloride near landfill vicinity to be more than that desired. Chloride values ranged as: 276-1563 mg/l in Athens (Loizidou & Kapetanious, 1993), 1600 mg/l in Morocco (Chofqi *et.al.,* 2004), 10.15-467.5 mg/l in Northern Italy (Caputo & Vaccaro, 2006), DW8 well near Pune landfill varied from 435.6 mg/l for post monsoon to 4,400 mg/l for pre-monsoon (Kale *et.al.,* 2010), groundwater samples near TamilNadu were 586 ± 365 mg/l for post monsoon and 938 ± 618 mg/l for pre monsoon(Parameswari *et.al.,*2012), 5-2100 mg/l in Spain (Casado *et.al.,* 2015). The sources of elevated chloride content in groundwater are domestic effluents, fertilizers, septic tanks, and leachates (Mor et.*al.,* 2006; Kale *et.al.,* 2010). Increase in Cl^- level is injurious to people suffering from diseases of heart or kidney (WHO 2004). Healthy individuals can tolerate the intake of large quantities of chloride provided that there is a simultaneous intake of fresh water.

2.5.2.4 PHOSPHATE

Phosphorous arises in water and in leachate samples in the form of various types of phosphates. Phosphates are generally categorized into orthophosphate and total phosphate. Orthophosphates find their way in the waste via agricultural wastes and fertilizers while organic phosphates are formed basically due to biological processes (WHO). The presence of phosphate in large quantities specifies pollution through sewage and industrial wastes. As per CPCB guidelines the permissible level of dissolved phosphate for discharge in inland surface water is 5mg/l. The values of phosphate in leachate as per different studies are 8µg/l (Loizidou & Kapetanious, 1993), 13.6±2.23 mg/l for trench 1 and 15.5±1.67 mg/l for trench 2(Fatta *et.al.,*1999), 0.33mg/l in Alexandria (Hassan & Ramadan, 2005). Water samples collected near landfills by different studies are 5.9-763 µg/l (Loizidou & Kapetanious, 1993), 76.2- 171 mg/l (Fatta *et.al.,*1999), 0.168-0.673 mg/l (Abu-Rukah & Al-Kofahi,2001).

2.5.2.5 SODIUM

Sodium is a highly dissolvable element which has no smell but could be tasted if concentration is increased by 200 mg/l (WHO, 2010). According to the British Columbia Water Association, the sources of sodium in groundwater could be erosion of salt deposits and sodium bearing rock minerals, marine water intrusion into wells and aquifers in coastal areas, irrigation and precipitation leaching through soils high in sodium, groundwater pollution by sewage effluent and infiltration of leachate from landfills or industrial sites. Sodium if present in ordinary concentration is not treacherous for health but if present in higher concentration could become problematic to people with hypertension and heart problems. K. Parameswari *et al,*2012 studied the characteristics of leachate and found the concentration of sodium to be in range of 1400-8000 mg/l. Similarly sodium concentration in leachate was examined by other studies such as 1984±690 mg/l for trench 1 and 2148 ±910 mg/l for trench2 (Fatta *et.al.,*1999), 256-778 mg/l in North Jordon (Abu-Rukah & Al-Kofahi, 2001), 470 mg/l in Ahmedabad(Singh *et.al.,*2008), 7863 mg/l (Adeolu *et.al.,* 2011), 0.451 mg/l in Nigeria (Odunlami, 2012).

Water for drinking should not exceed the sodium concentration 20 mg per litre, but in some countries levels can exceed 250 mg/litre (WHO,2003). Various scholars have analysed groundwater near landfill and gathered the following results: 50.8-448 mg/l in Athens (Fatta *et.al.,*1999), 20.4–27 mg/l in Ahmedabad (Singh *et.al.,*2008), 0.02-1.20 mg/l (Adeolu *et.al.,* 2011), 0.412-0.523 mg/l l in Nigeria (Odunlami, 2012), 230.2-872 mg/l in China (Han *et.al.,*2014), 0.07-2597 mg/l in Spain (Casado *et al.*,2015).

2.5.2.6 MAGNESIUM

Magnesium is very essential to human health. The sources of magnesium which are consumable by humans are: dairy products, vegetables, grain, fruits and nuts are vital contributors. The presence of Magnesium in the leachate is due to the disposal of construction waste along with Municipal Solid waste. Mg concentrations exhibited typical trends of constituents affected by the biological activity in the dumping site (Kanmani & Gandhimathi, 2013). The landfill site in Alexandria reported a very high amount of Mg content in its leachate samples having a mean value of 1058 mg/l(Hassan & Ramadan, 2005). As per IS 10500 : 2012, permissible value for Magnesium concentration in drinking water is 30mg/l. Few groundwater samples in different studies near landfills has shown the following results: 9.1 -195.6 mg/l in Northern Italy (Caputo & Vaccaro, 2006), 0.671 -1.022 mg/l in Nigeria(Odunlami,2012), 7.2-81.6 mg/l in Tamilnadu (Kanmani & Gandhimathi, 2013), 17.5-212.6 mg/l in China (Han *et.al.,*2014). Excess Magnesium leads to several risks. Intake of Mg from drinking water leads to the risk of cerebrovascular disease (Yang, 1998).High intake of magnesium in food supplements or medications results in diarrhea, nausea and abdominal cramping (IOM, 1997).

2.5.2.7 POTASSIUM

Potassium is an essential element and is present in all animal and plant tissues. The primary source of potassium for the general population(WHO,2009) is the diet, as potassium is found in all foods, particularly vegetables and fruits. Adverse health effects due to potassium consumption from drinking-water are chest tightness, nausea and vomiting, diarrhoea, hyperkalaemia, shortness of breath and heart failure.

Potassium ions are one of the tracers used to relate the contamination of groundwater nearby the landfill by the leachate extracted from it (Loizidou & Kapetanios, 1993). Potassium concentrations of leachate samples in Turkey were determined to be between 440- 980 mg/L (Varank *et.al.,*2011). As per guidelines of WHO, permissible level of potassium in drinking water 1-2 mg/l. Groundwater samples near the landfill has shown the following results, which clearly indicates the groundwater contamination from the landfill leachate: 10- 160 mg/l in Northern Italy (Caputo & Vaccaro, 2006), 0.256-0.351 mg/l in Nigeria(Odunlami,2012), 0.6-105 mg/l in China (Han *et.al.,*2014).

2.5.2.8 CALCIUM

Water hardness is caused primarily by the presence of cations such as calcium and magnesium and anions such as carbonate, bicarbonate, chloride and sulfate in water (Sadashivaiah *et.al.,* 2008). Calcium plays important roles in bone structure, muscle contraction, nerve impulses transmission, blood clotting and cell signaling; 99 percent of calcium is in bone and teeth and the remainder is in soft tissue. Low intake is associated with osteoporosis, rickets and hypertension. Calcium concentration resembles the hardness of water. Few landfill leachate samples in the few studies shows 181-443 mg/l in North Jordon (Abu-Rukah & Al-Kofahi, 2001), 190 mg/l in Morocco (Chofqi *et.al.,* 2004), mean value of 3000mg/l in Alexandria (Hassan & Ramadan, 2005). As per IS 10500 : 2012, permissible limit of Calcium for drinking water is 75mg/l. Loizidou &. Kapetanios, 1993 claimed that Ca could be used as the tracer ion for assessing the contamination level of groundwater due to leachate. Groundwater samples near the vicinity of the landfill were analysed as 68-98.5 mg/l in North Jordon (Abu-Rukah & Al-Kofahi, 2001), 51.8- 542mg/l in Northern Italy (Caputo & Vaccaro, 2006), 1.55-327.1 mg/l in China (Han *et.al.,*2014).

2.5.2.9 LITHIUM

Lithium is a soft, silver-white alkali metal, found in some foods and, in some places, the drinking water. Lithium is used in batteries, ceramics, air-conditioning, grease, electric cars, and in pharmaceutical products. Guidelines of drinking water by WHO is 0.05-0.30 mg/l. Studies have evaluated the value of groundwater samples nearby landfill sites to assess the contamination of landfill leachate: 67.7 mg/l for pre monsoon and 85.6 for post monsoon in Okhla Landfill and 37.6 mg/l for pre monsoon and 56 mg/l for post monsoon in Ghazipur Landfill in New Delhi (Zafar & Alappat, 2004), 0.18-0.91 mg/l in Africa (Adeolu *et.al.,* 2011), 0.110-0.156 mg/l in Nigeria(Odunlami,2012).

2.5.2.10 ZINC

Zinc is bluish white in colour. It imparts an undesirable astringent taste to water. Zinc is used in the production of corrosion-resistant alloys and brass, and for galvanizing steel and iron products (WHO,2003). The presence of Zn in the leachate shows that the landfill receives waste from batteries and fluorescent lamps and also from industrial wastes (Hassan & Ramadan, 2005; Mor. *et.al.,* 2006,). The presence of Zinc in landfill leachate as per various studies is 0.36–1.08 mg/l in Athens (Fatta *et al.,*1999), 90-261 mg/l in North Jordon (Abu-Rukah & Al-Kofahi, 2001), 0.352-0.928 mg/l in Alexandria (Hassan & Ramadan, 2005), 747.2 mg/l in Morocco (Chofqi *et.al.,* 2004), 2.21 mg/l in New Delhi (Mor. *et.al.,* 2006), 9 mg/l in Egypt(Adeolu.*et.al.,*2011), 0.861 mg/l in Nigeria(Odunlami,2012), 0.010-0.660 mg/l in lagoon 1 and 0.030-0.257 mg/l (Orescanin *et al.,* 2012).

As per IS 10500 : 2012, permissible limit of Zinc for drinking water is 5 mg/l. Water samples collected near landfills by different studies are 0- 0.8 mg/l l in New Delhi (Mor. *et.al.,* 2006), 0.003-0.015 mg/l (Adeolu.*et.al.,*2011), 0.02-3.37 mg/l in New Delhi(Jhamnani & Singh, 2009), 0.281-0.986 mg/l in Nigeria (Odunlami,2012), 0.08–0.16 mg/l in Tamilnadu (Parameswari *et.al.,* 2012).

2.5.2.11 LEAD

Lead is originate from natural deposits, and is generally used in household plumbing materials and water service lines. The greatest contact to lead is through swallowing or breathing in lead paint chips and dust (USEPA). The presence of Pb in the leachate samples indicates the disposal of Pb batteries, chemicals for photograph processing, Pb-based paints and pipes at the landfill site (Moturi et al., 2004; Mor et al., 2006).

Acidity in leachate causes lead to be released from solid waste present in the landfill (Hassan & Ramadan, 2005). According to CPCB, maximum concentration of lead is 0.1 mg/l for its disposal in inland surface water, however the leachate is collected and analyzed from different landfill sites for assessing its impact on groundwater and shown the following results: 0.24–0.57 mg/l in Athens (Fatta *et al.,*1999),0·19 - 1·50 mg/l in North Jordon (Abu-Rukah & Al-Kofahi, 2001), 0.007-0.032mg/l in Alexandria(Hassan & Ramadan, 2005), 1.54 mg/l in New Delhi (Mor *et al.,* 2006), 10.2 mg/l in Egypt(Adeolu.*et.al.,*2011), 0-0.004mg/l in (Orescanin *et al.,* 2012).

Lead in drinking water can also cause a array of adverse health effects. In babies and children, exposure to lead in drinking water above the tolerable intensity can result in hindrance in physical and mental growth, along with trivial deficits in attention span and learning aptitude. In adults, it can cause rise in blood pressure. Adults over large exposure could build up kidney problems or high blood pressure (USEPA). As per IS 10500 : 2012, permissible limit of Lead for drinking water is 0.01 mg/l. Water samples contaminated with lead were found by different studies made in the groundwater collected in the adjoining areas of landfill sites. Few such results are 0.03–1.95 mg/l in Tamilnadu (Parameswari *et.al.,* 2012).

2.5.2.12 CADMIUM

Cadmium is a soft white solid metal found in natural deposits such as ores containing other elements. There are varied uses of Cadmium such as metal plating and coating operations, including transportation gears & equipments, machinery and baking enamels, photography, and television phosphors. It is also used in nickel-cadmium solar batteries and pigments (USEPA). The estimated lethal oral dose of Cd as per WHO 2011, for humans is 350–3500 mg. Cadmium exposure can causes itai-itai disease, increase in the urinary excretion, aminoaciduria, glucosuria and phosphaturia etc.

Cadmium is present in the landfill leachate and this could be proved by these results of leachate sample being collected by landfills: (0.02–0.04 mg/l in Athens (Fatta *et al.,*1999), 0·012–0·52 mg/l in North Jordon (Abu-Rukah & Al-Kofahi, 2001), 34 mg/l in Morocco (Chofqi *et.al.,* 2004), 8.8 mg/l (Adeolu.*et.al.,*2011), although the CPCB norms for Cd discharge in inland surface water is 2mg/l. According to IS 10500 : 2012, maximum acceptable limit for Cd in drinking water is 0.003mg/l. Cadmium present in groundwater collected near landfill area is evaluated to be 0.02–0.04 mg/l(Fatta *et.al.,* 1999), 0-0.01mg/l (Kale *et.al.,* 2010).

2.5.2.13 CHROMIUM

Chromium can exist in oxidation state ranging from +2 to +6. Chromium (II) is most injurious of all forms to human health. Cr is generally used in leather industry, paints and pigments, ceramic and glass industry etc. Excess cadmium is primarily responsible for degeneration of bones, liver damage, lung insufficiency, hypertension, and renal dysfunction in human beings (Saha *et.al.,*2015). Chromium could be present in landfill leachate as analysed by scholars: 0.8–2.44 mg/l in Athens (Fatta *et al.,*1999), 156.33 mg/l in Morocco (Chofqi *et.al.,* 2004), 0.011 mg/l in Nigeria (Odunlami,2012), 0.012-2.047mg/l (Orescanin *et al.,* 2012). Water samples near the landfill has also shown the presence of Cr- 0.004- 0.1mg/l in Northern Italy (Caputo &

Vaccaro, 2006), 0.010-0.014 mg/l in Nigeria (Odunlami,2012). Although permissible level of total Cr by IS 10500 : 2012, is 0.05mg/l.

2.5.2.14 NICKEL

Nickel is a lustrous white, hard, ferromagnetic metal. It occurs naturally in five isotopic forms. The principal source of nickel in drinking-water is direct leaching from metals when they come in the contact with water through pipes and fittings. But some secondary sources also contribute to the nickel presence in groundwater for example dissolution from nickel ore-bearing rocks (WHO,2005). The main use of Nickel is in the manufacturing of stainless steels, non-ferrous alloys, and super alloys. Some other purpose served by nickel and its salts are in electroplating, as catalysts, in nickel–cadmium batteries, in coins, in welding products, and in certain pigments and electronic products. CPCB has notified in their discharge norms, the permissible value of Ni for inland surface water to be 3mg/l. Ni concentration in leachate was examined by few studies such 0.24–0.97 mg/l in Athens (Fatta *et al.,*1998),0.67±0.287 mg/l for Trench 1 and 0.67±0.135 mg/l for Trench 2 in Athens(Fatta *et.al.,* 1999), 18–70 mg/l in North Jordon (Abu-Rukah & Al-Kofahi, 2001), 133.8mg/l in Morocco (Chofqi *et.al.,* 2004), 0.073-0.081mg/l in Alexandria(Hassan & Ramadan, 2005).

According to IS 10500 : 2012, maximum acceptable limit for Ni in drinking water is 0.02mg/l. Ni in water samples collected near landfills by different studies is present in following amount: 0.02- 0.12 mg/l in Athens (Fatta *et.al.,* 1999), 0.004-0.03 mg/l in Northern Italy (Caputo & Vaccaro, 2006), 0.13 - 0.43 mg/l in New Delhi(Jhamnani & Singh, 2009), 0.05–2.40 mg/l in Tamilnadu (Parameswari *et.al.,* 2012). WHO, 2005 has mentioned the effects of Nickel in its report. The acute exposure of Ni affects kidney function, including tubular and glomerular lesions while short term exposure causes minor changes in body weight and relative weights of kidney and lung.

2.5.2.15 COPPER

Copper is a transition metal that is stable in its metallic state and forms monovalent (cuprous) and divalent (cupric) cations. Metallic copper is malleable, ductile and a good thermal and electrical conductor. It has a lot of profitable uses because of its versatility. Copper is used to make electrical wiring, pipes, valves, fittings, coins, cooking utensils and building materials. It is present in weapons, alloys (brass, bronze) and coatings. Copper compounds are used as or in fungicides, algaecides, insecticides and wood preservatives and in electroplating, azo dye manufacture, engraving, lithography, petroleum refining and pyrotechnics. Copper compounds can be added to fertilizers and animal feeds as a nutrient to support plant and animal growth (Landner & Lindestrom, 1999; ATSDR, 2002, WHO 2004). In pure water, the copper(II) ion is the more common oxidation state (US EPA, 1995) and will form complexes with hydroxide and carbonate ions(WHO 2004). Copper is found in surface water, groundwater, seawater and drinking-water. The permissible limit of Cu as prescribed by CPCB for inland surface water discharge is 3mg/l. Studies has been done to assess Cu concentrations in landfill leachate samples in different parts of world and has shown the following results: 0.16–0.31 mg/l in Athens (Fatta *et al.,*1999), 0·044–19.45 mg/ l in North Jordon (Abu-Rukah & Al-Kofahi, 2001), 157.8 mg/l in Morocco (Chofqi *et.al.,* 2004), 0.002-0.032mg/l in Alexandria(Hassan & Ramadan, 2005).

According to IS 10500 : 2012, maximum acceptable limit for Cu in drinking water is 0.05mg/l. But the following results shows the contamination of groundwater due to its nearby landfill solid waste and leachate generation: 0.02-0.3 mg/l in Northern Italy (Caputo & Vaccaro, 2006), 0.01 -0.1 mg/l in New Delhi (Jhamnani & Singh, 2009).

2.5.2.16 IRON

Iron is the second most profuse metal in the earth's crust. Elemental iron is hardly ever found in nature, as the ions of iron (Fe^{2+} and Fe^{3+}) readily combine with oxygen and sulphur containing compounds to form oxides, hydroxides, carbonates, and sulphides, but is normally found in the form of oxides. Iron is most commonly used as constructional material, pipe material and its oxides are used as pigments in paints and varnishes (WHO, 2003). Mor e*t.al.,* 2006 mentioned in their studies that incidence of Fe in the leachate samples indicates that presence of steel scraps which are been dumped in the landfill. The dark brown color of the leachate is mainly credited to the oxidation of ferrous to ferric form and the formation of ferric hydroxide colloids and complexes with fulvic/humic substance (Chu *et al.,* 1994).

Central Pollution Control Board has notified in their discharge norms, the permissible value of Fe for inland surface water to be 3mg/l and as per IS 10500:2012, permissible value for Iron concentration in drinking water is 0.5mg/l. Concentration of Fe in Leachate samples found by various scholars are 5.17–8.27 mg/l in Athens (Fatta *et al.,*1999), 24,000 mg/l in Morocco (Chofqi *et.al.,* 2004), 400 mg/L in New Delhi(Mor *et.al.,* 2006), 20 mg/L in New Delhi(Jhamnani & Singh, 2009), 0.156 mg/l in Nigeria (Odunlami, 2012). Similarly the samples were taken from adjoining areas of landfill to assess the groundwater quality and found the results to be 0.64 - 7.04 mg/l in New Delhi (Jhamnani & Singh, 2009), 1.20–19.70 mg/l in Tamilnadu (Parameswari *et.al.,* 2012).

2.6 HEALTH CONCERNS DUE TO THE CONTAMINANTS OF LANDFILL

The health effects of leachate contamination are a matter of great concern. The leachate percolates along with it numerous health hazards to the groundwater which has directly and indirectly affects the human life.

Bertoldi *et.al.,* 2012, conducted a study on mice and rat to estimate the effects of landfill leachate on their body. The animals were killed and their striatum, hippocampus and liver were dissected out to study the in vitro effects of landfill leachate on the levels of free radicals and lipid peroxidation. The result shows that the landfill leachate can induce an oxidative stress in liver and striatum on rat and mice.

Gajski *et.al.,*2012, analyzed the chemical composition and genotoxicity of a landfill in Crotia. Genotoxicity was evaluated in human lymphocytes by use of micronucleus test and comet assay test. The results of chemical analysis of the landfill leachate show the low concentration of heavy metals while organic composition exceeded the required permissible limit by almost 40 times. Comet assay test is useful in observing the DNA damage wile micronucleus test is used for indicating cellular and nuclear dysfunction caused due to exposure of toxic contaminants. The final conclusion of the study was that both the test confirms that the samples taken from the Crotian landfill did induce genetical damage to the human lymphocytes thereby indicating that contamination from landfill can induce cytotoxicity and genotoxicity in plants, animals and even in human beings, either directly or indirectly through food chain.

Eggen *et.al.,*2010, have paid emphasis on sources of emerging pollutants in the municipal landfill leachate. They have examined that the products that are used daily for household activities contains additives for improving their usage efficiency. But when these products are decomposed in the landfill, these additives are released in the environment, imparts negative effects. These products include insect repellant diethyl toluamide, personal care products such as non steroidal anti inflammatory drug ibuprofen and polycyclic musk compounds, insecticide, detergents, soaps and pharmaceutical compounds etc.

Stephen C. James 1977, collected leachate from five different landfills and concluded that leachate if comes in contact with water body directly or indirectly possess a great threat. Metals like iron coats the bottom sediments inhibiting the feeding of animals. Selenium, mercury etc. gets accumulated in the aquatic animals thereby makes them unfit for consumption by human beings.

CHAPTER 3

MATERIALS AND METHODOLOGY

3.1 STUDY AREA

The study area comes under the capital of India: New Delhi. New Delhi is one of the union territories of the India with the population of around 9 million (Census 2011). The capital covers an area of 1484 km^2 at latitudes 28°36'0"N & longitudes 77°12'0"E and falls in seismic zone IV as per Bureau of Indian Standards (BIS 1893, Part 1:2002). The urban population of India increases at the rate of 3.5% per annum and the waste generation in New Delhi increases by 1.3% per year. Municipal Corporation of Delhi operates the Municipal Solid waste operations. Since 1975, twenty landfill sites have been developed in the city, out of which 15 have already been closed and two have been suspended (NDMC). At present, there are only three active landfill sites in the city which are still in the operation: Bhalaswa, Okhla and Ghazipur.

3.1.1 LOCATION

Bhalaswa landfill is the area of the study. It is located in the North Western part of the capital. The latitudinal and longitudinal coordinates of the Bhalaswa Landfill site are 28°44’26”N and 77°9’26”E respectively. It came in operation in 1993 and covers approximately 21.06 hectares of land. The landfill area is not scientifically lined by any liner material and approximately 6 acres of land is allocated for composting plant use. Around 2200 tonnes of waste is received per day by the Bhalaswa landfill site. The waste from Civil Lines, Rohini, Karol Bagh & Najafgarh zones of North Delhi Municipal Corporation (NDMC) is generally dumped here. The dumpsite is surrounded by localities like Bhalaswa, Jahagirpuri, Rajiv Nagar, Swami Shradhanand Park, Mukundpur, Nathupura etc. The Bhalaswa landfill is located near the Bhalaswa lake, which is under maintenance of Delhi Tourism. The incoming wastes is drawn mainly from households and commercial vicinity, by conveying the waste from municipal dhalaos to landfill site but there are some wastes that are dumped to the landfill from industrial areas (Jhamnani & Singh, 2009). There is a compost treatment plant in the site, setup in 1999, run by a private developer, Nature Waste Management India Limited, having a capacity of 300 tonnes per day. The landfill site has already reached the maximum saturation limit and been used even at the huge risk of life and the property. Due to high population density, there is no apt site left for starting a new dumpsite. Hence, government is planning to implement a number of technologies to reclaim the landfill site, managing and disposing the garbage, depositing of inert material separately and also setting up the facilities to manage the e-waste which is dumped along with the municipal solid waste.

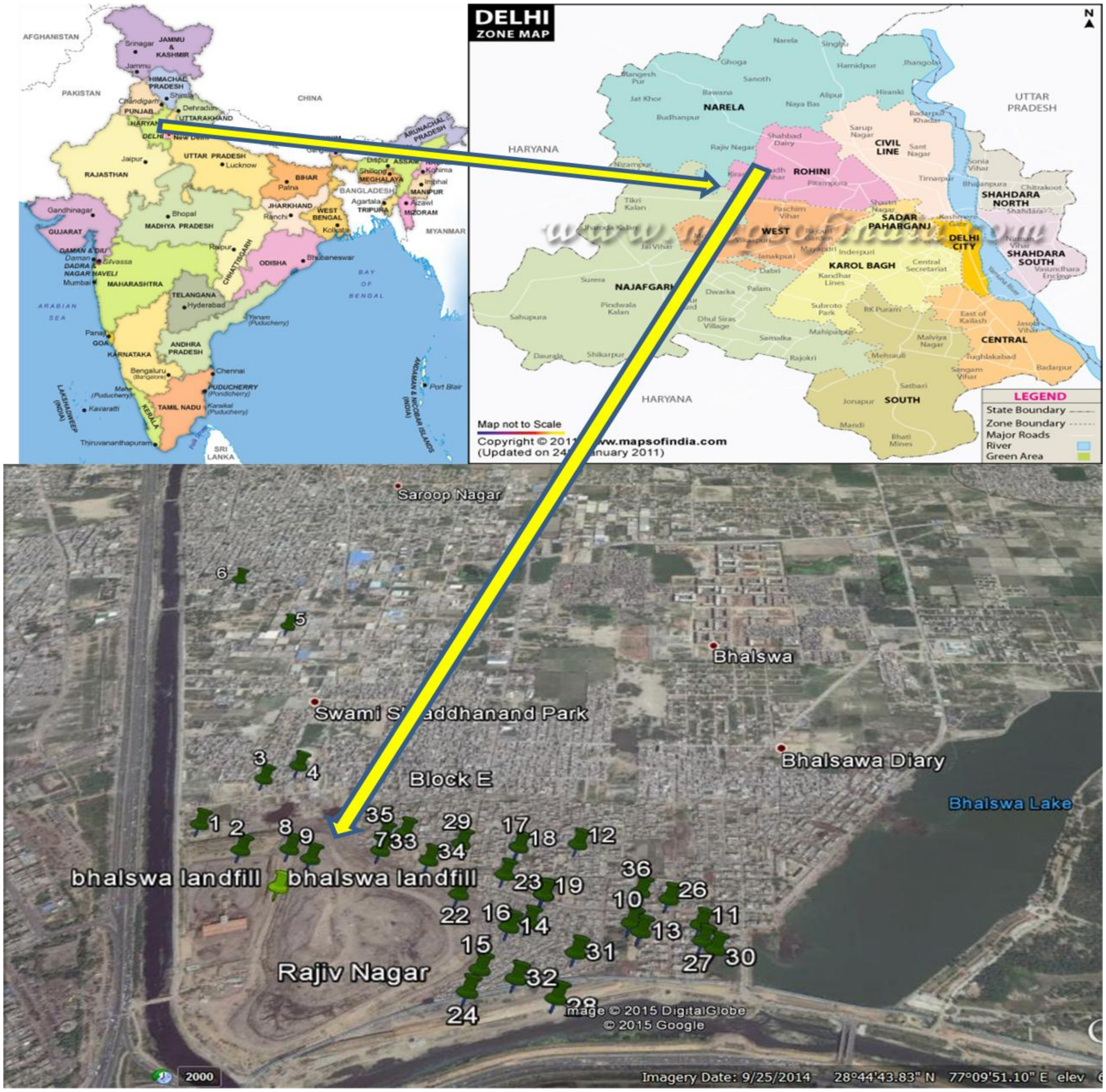

Figure 3.1: Study Area: Bhalaswa Landfill, New Delhi

3.1.2 CLIMATIC CONDITIONS

The climatic condition of the area is semi arid. There are wide seasonal variation viz. a dry and hot season between March and May, monsoon period from July to September, autumn season from September to November and lastly dry and chilling winters from December to February with average temperature between 5°C to 40°C. New Delhi receives about 87% of the total rainfall from the months of June to September every year. The normal annual rainfall in Delhi is 714mm but as per Indian Meteorological Department (2014), the average rainfall in New Delhi was 617mm in year 2014. Figure 3.2 clearly depicts that the monsoon, though started from June, exceeded the normal average rainfall curve from 16th July 2014 and fluctuates between July and August. The graph once again exceeded during the month of September far above the normal daily rainfall.

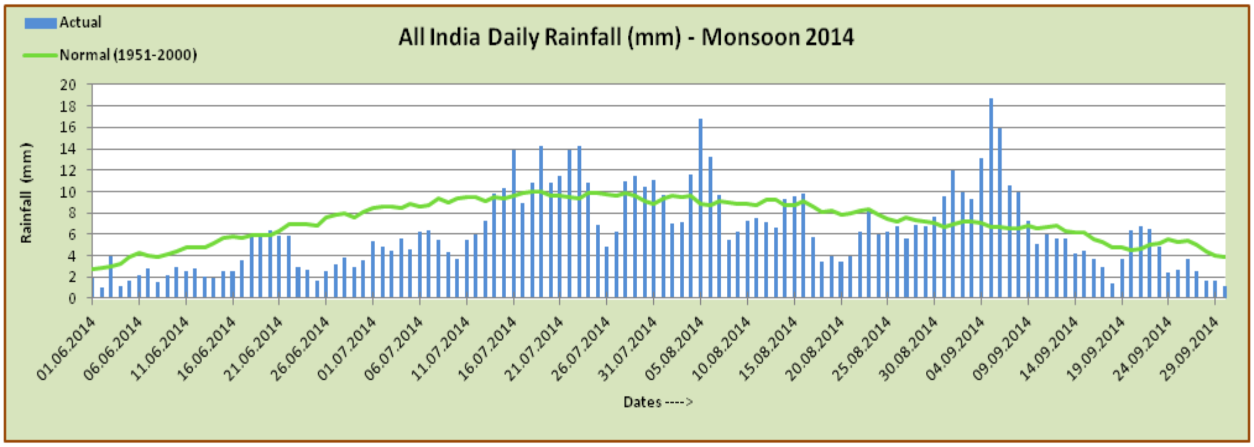

Figure 3.2: India's Daily Rainfall during Monsoon 2014 (SOURCE: IMD)

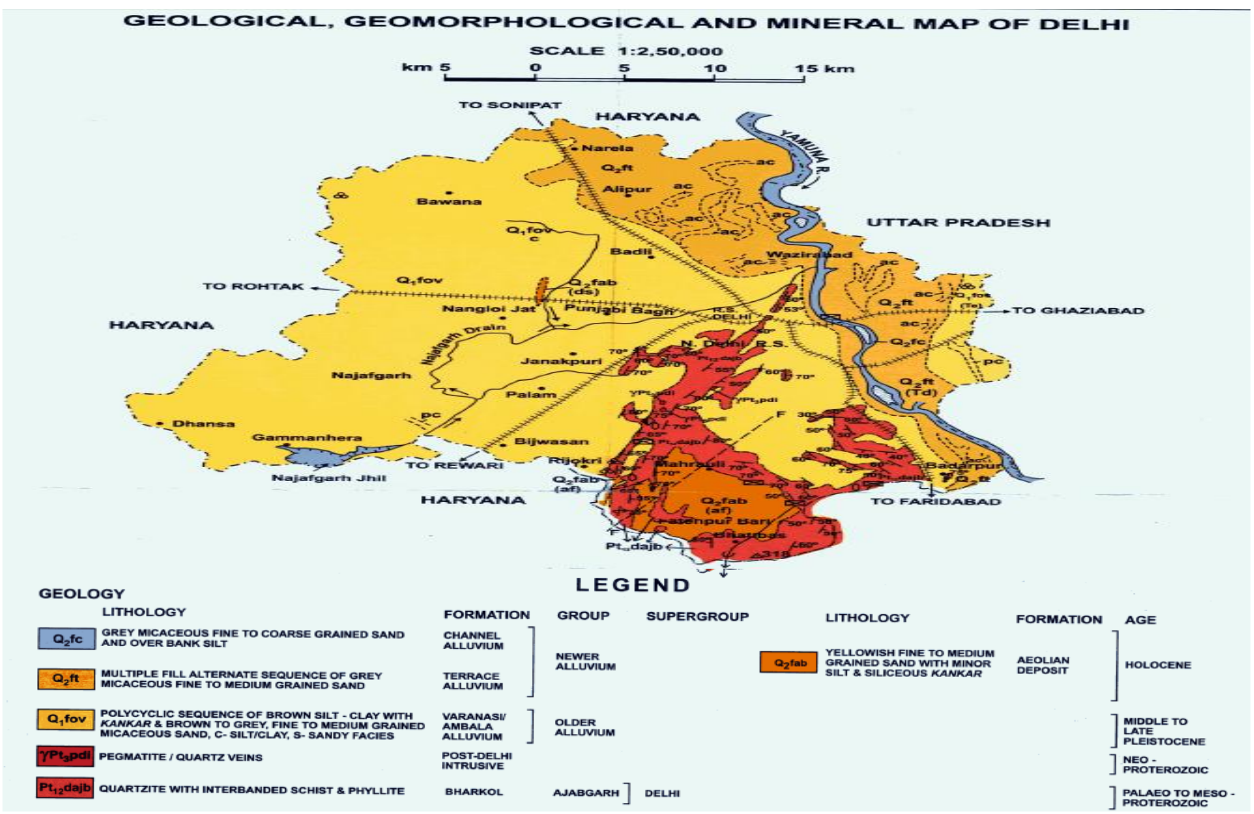

Figure 3.3: Geological Map of Location (Source: GSI)

3.1.3 GEOLOGY OF AREA

The groundwater characteristics are directly proportional to the hydrogeological properties of the area. The geology of the study area is mainly alluvium and also contains quartzite hard rocks. The Delhi ridge is positioned at the northern most wings of the great Aravali Mountains. The alluvial formation overlying the quartzite rocks have different characteristics on both side of the ridge. As per Geological Survey of India, the soil of Bhalaswa is basically polycyclic sequence of brown silt and clay with kankar and gravels. The soil type variation is accounted by change in the drainage pattern, topographical pattern and also due to presence of different type of mineralogical deposits. Groundwater is the one of the major sources of living the Delhi. People use the underground for drinking, washing, cleaning, bathing etc. In almost 90% of total geographical area of Delhi, the presence of groundwater is detected upto a depth of 60m and is in drinkable conditions. The groundwater table is nearly 7-10m below the Bhalaswa region, making it more susceptible for leaching of pollutants.

3.2 METHODOLOGY

3.2.1 SAMPLING

The samples of leachate as well as groundwater were collected in clean 1 litres plastic bottles, rinsed properly before taking the samples from the sampling points. The duration of taking leachate sample was between November 2014 to April 2015 and one sample per month was taken from the base of the landfill site. The leachate was collected from the outlet pipe which drains out the leachate from the disposal site to the nearby drainage system.

The groundwater sampling was done at 36 different stations nearby the Bhalaswa landfill area from November 2014 to April 2015 and three samples were collected from each sampling site. All the samples of groundwater were taken randomly from the handpumps installed in houses, shops, temples or the nearby localities of the landfill. The sampling was done on the basis of the distance from the study location varying from areas less than 25m from the landfill to the areas at a distance more than 1.5 km. Samples were immediately transferred to the laboratory and were stored under refrigeration. The details of the sampling sites from where the groundwater samples were collected are represented in Table 3.1.

3.2.2 ANALYSIS OF SAMPLES

The whole analysis process was carried out in Delhi Technological University's Water laboratory by implying the methods recommended by American Public Health Association (APHA 2005). All the samples of leachate as well as groundwater were analyzed for physical parameters, chemical parameters as well as for estimating the heavy metals concentration. The leachate samples were examined for pH, Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Electrical Conductivity (EC), Salinity, Total hardness, Alkalinity, Chemical Oxygen Demand (COD), Chloride (Cl), Sulphates (SO_4), Nitrate (NO_3), Total Phosphate (TP), Sodium (Na), Potassium(K), Calcium(Ca), Magnesium(Mg), Iron (Fe), Copper (Cu), Cadmium (Cd), Chromium (Cr), Zinc (Zn), Manganese (Mn), Nickel (Ni).

Figure 3.4: Leachate Samples Collected From Landfill Site

Figure 3.5: Groundwater Samples Collected From Study Area

The analysis of the groundwater samples were done for: pH, Total Dissolved Solids (TDS), Electrical Conductivity (EC), Salinity, Total hardness, Alkalinity, Chloride (Cl), Sulphates (SO_4), Nitrate (NO_3), Total Phosphate (TP), Sodium (Na), Potassium(K), Calcium(Ca), Magnesium(Mg), Iron (Fe), Copper (Cu), Cadmium (Cd), Chromium (Cr), Zinc (Zn), Manganese (Mn), Nickel (Ni).

Sampling Site	Sample type	Latitude	Longitude	Elevation
GW 1	Handpump	28°44’37.15”N	77°09’15.88”E	695 ft
GW 2	Handpump	28°44’34.55”N	77°09’20.09”E	699 ft
GW 3	Handpump	28°44’41.35”N	77°09’19.10”E	692 ft
GW 4	Handpump	28°44’44.09”N	77°09’22.05”E	695 ft
GW 5	Handpump	28°45’06.62”N	77°09’15.27”E	683 ft
GW 6	Handpump	28°45’14.89”N	77°09’08.27”E	690 ft
GW 7	Handpump	28°44’36.12”N	77°09’31.45”E	686 ft
GW 8	Handpump	28°44’34.79”N	77°09’22.70”E	696 ft
GW 9	Handpump	28°44’33.34”N	77°09’24.63”E	698 ft
GW 10	Handpump	28°44’27.14”N	77°09’49.62”E	690 ft
GW 11	Handpump	28°44’27.22”N	77°09’54.59”E	687 ft
GW 12	Handpump	28°44’35.16”N	77°09’45.17”E	686 ft
GW 13	Handpump	28°44’26.73”N	77°09’50.44”E	690 ft
GW 14	Handpump	28°44’26.77”N	77°09’40.51”E	685 ft
GW 15	Handpump	28°44’23.22”N	77°09’38.94”E	686 ft
GW 16	Handpump	28°44’27.36”N	77°09’41.99”E	686 ft
GW 17	Handpump	28°44’35.67”N	77°09’39.30”E	683 ft
GW 18	Handpump	28°44’35.31”N	77°09’41.06”E	681 ft
GW 19	Handpump	28°44’30.46”N	77°09’41.43”E	683 ft
GW 20	Handpump	28°44’28.49”N	77°09’42.93”E	686 ft
GW 21	Handpump	28°44’30.35”N	77°09’44.31”E	686 ft
GW 22	Handpump	28°44’30.34”N	77°09’36.55”E	687 ft
GW 23	Handpump	28°44’31.89”N	77°09’39.82”E	682 ft
GW 24	Handpump	28°44’21.17”N	77°09’38.28”E	688 ft
GW 25	Handpump	28°44’30.25”N	77°09’47.01”E	688 ft
GW 26	Handpump	28°44’29.56”N	77°09’52.40”E	689 ft
GW 27	Handpump	28°44’25.74”N	77°09’54.78”E	686 ft
GW 28	Handpump	28°44’20.35”N	77°09’44.44”E	687 ft
GW 29	Handpump	28°44’35.26”N	77°09’36.17”E	686 ft
GW 30	Handpump	28°44’25.00”N	77°09’55.84”E	685 ft
GW 31	Handpump	28°44’24.60”N	77°09’45.63”E	692 ft
GW 32	Handpump	28°44’22.27”N	77°09’41.53”E	691 ft
GW 33	Handpump	28°44’33.98”N	77°09’29.77”E	686 ft
GW 34	Handpump	28°44’33.72”N	77°09’33.66”E	686 ft
GW 35	Handpump	28°44’36.29”N	77°09’29.66”E	688 ft
GW 36	Handpump	28°44’30.09”N	77°09’49.93”E	690 ft

Table 3.1: Details of Location of sampling sites for groundwater near Bhalaswa landfill

The parameters analyzed along with instruments used and the methods implied to evaluate the results from the samples are categorized in the following table:

S.No.	PARAMETERS	INSTRUMENTS	METHODS
1.	pH	HANNA INSTRUMENTS PHEP POCKET SIZED PH METER	POTENTIOMETERIC
2.	TDS	THERMO ORION A329 MULTI METER	MULTI PARAMETER WATER QUALITY METER
3.	TSS	WHATMANN 40 FILTER PAPER	GRAVIMETRIC ANALYSIS
4.	EC	THERMO ORION A329 MULTI METER	MULTI PARAMETER WATER QUALITY METER
5.	SALINITY	THERMO ORION A329 MULTI METER	MULTI PARAMETER WATER QUALITY METER
6.	CHLORIDE	VOLUMETRIC TITRATION	ARGENTOMETRIC METHOD
7.	HARDNESS	VOLUMETRIC TITRATION	EDTA METHOD
8.	COD	COD DIGESTOR	OPEN REFLUX METHOD
9.	NITRATE	LABTRONICS MODEL LT 290 SPECTROMETER	SPECTROMETERY
10.	TOTAL PHOSPHATES	LABTRONICS MODEL LT 290 SPECTROMETER	SPECTROMETERY (STANNOUS CHLORIDE)
11.	SULPHATES	LABTRONICS MODEL LT 290 SPECTROMETER	SPECTROMETERY
12.	SODIUM	SYSTRONICS FLAME PHOTOMETER 128	FLAME PHOTOMETERY
13.	CALCIUM	SYSTRONICS FLAME PHOTOMETER 128	FLAME PHOTOMETERY
14.	POTASSIUM	SYSTRONICS FLAME PHOTOMETER 128	FLAME PHOTOMETERY
15.	LITHIUM	SYSTRONICS FLAME PHOTOMETER 128	FLAME PHOTOMETER
16.	IRON	NOVAA 350 ANALYTIK JENA	ATOMIC ABSORPTION SPECTROPHOTOMETER
17.	COPPER	NOVAA 350 ANALYTIK JENA	ATOMIC ABSORPTION SPECTROPHOTOMETER
18.	CADMIUM	NOVAA 350 ANALYTIK JENA	ATOMIC ABSORPTION SPECTROPHOTOMETER
19.	ZINC	NOVAA 350 ANALYTIK JENA	ATOMIC ABSORPTION SPECTROPHOTOMETER
20.	CHROMIUM	NOVAA 350 ANALYTIK JENA	ATOMIC ABSORPTION SPECTROPHOTOMETER
21.	MANGANESE	NOVAA 350 ANALYTIK JENA	ATOMIC ABSORPTION SPECTROPHOTOMETER
22.	NICKEL	NOVAA 350 ANALYTIK JENA	ATOMIC ABSORPTION SPECTROPHOTOMETER

Table 3.2: Instruments and Methods Used For Analysis

CHAPTER 4

RESULTS AND DISCUSSION

4.1 LEACHATE ANALYSIS

Physical and chemical properties of the leachate are directly related to the waste composition of the landfill and also on the precipitation. The minimum, maximum, average along with the standard deviation is evaluated for each parameter and these values are compared with the general standards for discharge of environmental pollutants in inland surface water body, by Central Pollution Control Board, New Delhi. The parameters analyzed from the experiments conducted in the laboratory have shown in the Table 4.1:

S.No	PARAMETERS	LEACHATE SAMPLES			CPCB
		MIN	MAX	MEAN ± STD DEV	
1.	Colour	Black	Black	Black	-
2.	Odour	Offensive	Offensive	Offensive	-
3.	pH- value	7.7	8.3	7.9± 0.233	5.5-9
4.	Electrical Conductivity (µS/cm)	39602	45800	42500 ± 2155	-
5.	Salinity (mg/l)	176	232	200 ± 24	-
6.	Total Suspended Solids (mg/l)	8096	9100	8660± 338	100
7.	Total Dissolved Solids (mg/l)	19165	25830	20980 ±2436	-
8.	Total hardness(mg/l)	4264	5320	4800 ± 357	-
9.	Calcium hardness (mg/l)	1353	1602	1440 ± 119	-
10.	Magnesium hardness (mg/l)	2994	3718	3360 ± 241	-
11.	Alkalinity (Bicarbonate)(mg/l)	3210	4295	3660 ± 381	-
12.	Chemical Oxygen Demand (mg/l)	7738	8240	8040 ± 168	250
13.	Chloride (mg/l)	3758	5770	4800 ± 704	-
14.	Nitrate (mg/l)	179	212	193.5± 12.9	10
15.	Total Phosphate(mg/l)	122	221	160.70 ± 35.4	5
16.	Sulphate (mg/l)	1367	1683	1488.5 ± 125	-
17.	Sodium (mg/l)	482	803	668 ± 125	-
18.	Potassium (mg/l)	302	722	500 ± 151	-
19.	Iron (mg/l)	33.9	56.12	43.026 ± 8.39	3
20.	Copper (mg/l)	1.32	2.31	1.697 ± 0.341	3
21.	Cadmium (mg/l)	1.490	1.750	1.641 ± 0.106	2
22.	Chromium (mg/l)	4.200	4.820	4.546 ± 0.246	2
23.	Zinc (mg/l)	7.554	10.982	8.816 ± 1.20	5
24.	Manganese (mg/l)	6.498	7.152	6.867 ± 0.232	2
25.	Nickel (mg/l)	0.997	2.352	1.810 ± 0.465	3

Table 4.1: Characteristics of Bhalaswa Leachate Samples

4.1.1 PHYSICAL PARAMETERS

pH: The mean value of pH is 7.9 i.e. alkaline which was expected as the Bhalaswa landfill is a matured landfill operated since 1993. The maximum & minimum pH values are 8.3 & 7.7 respectively. Fatta *et.al.,* 1999 has achieved the same results with mean pH value of 8.44 and stated that the alkaline values of pH points out that the biological activities related to the landfill has reached the concluding phase and the organic content of the landfill is now fully stabilized. On contrary, the leachate samples of few active landfill sites of Hong Kong have shown pH values to be 5.6, 6.2 and 6.8 respectively which clearly point towards the young leachate as waste disintegration was at acidic stage (Irene & Lo, 1996). The probable reason for the black colour of the leachate indicates the existence of humic compounds.

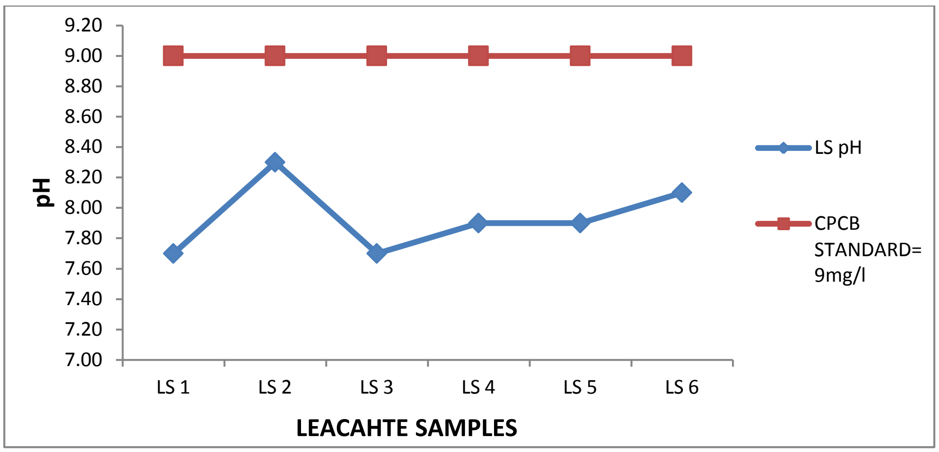

Figure 4.1: Comparison of pH of Leachate with CPCB Standard of Discharge in Surface water

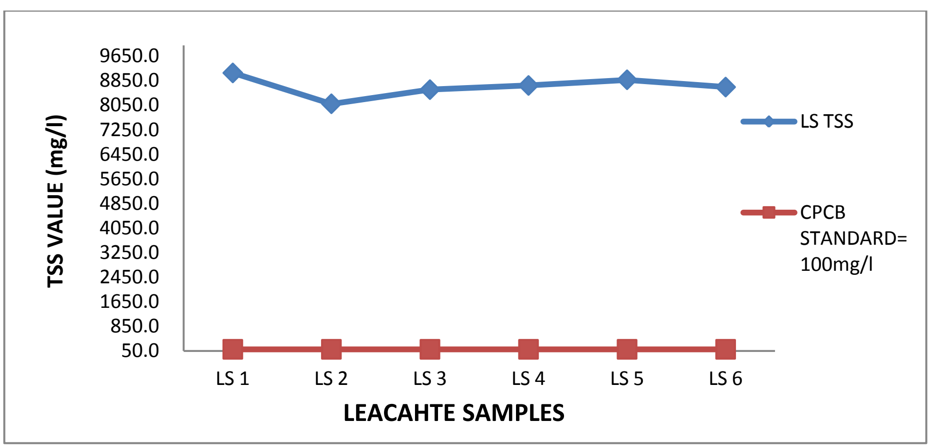

Figure 4.2: Comparison of TSS in Leachate with CPCB Standard of Discharge in Surface Water

TDS & EC: The elevated values of EC and TDS are determined in the present study which clearly indicates the occurrence of inorganic content in the leachate. The range of conductivity extended from 40,100-45100 µS/cm with mean value of 42500 µS/cm. Similarly the range of

Total dissolved solids varies as 19,452-25,830 mg/l and mean value is 20980 mg/l. The same observation were highlighted in the study conducted by Loizidou & Kapetanios, 1993, Mor *et.al.,* 2006, Adeolu *et.al.,* 2011, Nagarajan *et.al.,*2012, El-Salam & Abu-Zaid, 2013. The studies with comparable EC results are Rathod *et.al.,*2013, Zhao *et.al.,* 2013, El- Salam & Abu-Zaid, 2014, Barde *et.al.,*2014, Ramaiah *et.al.,*2014.

TSS: Total Suspended solids are the measure of all the particles which are left suspended in the leachate sample. In the present study, the value of TSS is 8660 mg/l. The discharge standard of CPCB in inland water has mentioned the maximum value of suspended solids should not exceed 100 mg/l. The observed value is almost 87 times as that required. The results of study conducted by Irene & Lo, 1996 on various active and inactive Hong Kong landfill sites concluded that the suspended solids have shown the high concentration in landfill leachate studies. Few other studies that support the result are Zhao *et.al.,* 2013, Loizidou & Kapetanios (1993).

4.1.2 CHEMICAL PARAMETERS

COD: The chemical oxygen demands accounts to the amount of pollution present in the sample taken. The COD of the leachate sample of Bhalaswa is found to be of order 7738-8250 mg/l with mean value as 8040 mg/l. Venkatramani *et.al.,* 1988 have highlighted the range of a typical landfill leachate as 23,000-30,000 mg/l. El-Salam & Abu-Zaid, 2014 have studied the leachate characteristics in an Egyptian landfill and mentioned the cause of variations in COD & other parameters which is the fluctuation in the type of waste and their characteristics and also the meteorological situation of the landfill situated area. High concentration of COD results in leachate are shown in studies of El-Salam & Abu-Zaid, 2014, Zhao *et.al.,* 2013, Orescanin *et.al.,* 2012, Kjeldson *et.al.,* 2010, Al Sabahi *et.al.,* 2009, Fatta *et.al.,*1998.

HARDNESS: On the account of hardness, the mean concentration of total hardness was 4800mg/l with Calcium and Magnesium hardness to be 1440 mg/l and 3360 mg/l respectively. The results of few other studies related to landfill leachate characterization shows Ca & Mg concentration as 190mg/l & 235 mg/l in Morocco (Chofqi *et.al.,* 2004), 69-1775 mg/l & 38-229 mg/l (Zhao *et.al.,* 2013).

CHLORIDE: The anions tested in leachate samples are Nitrate, Sulphates, Total phosphates, Chlorides and bicarbonates. Abu-Rukah & Al- Khofahi, 2001, Hem 1971 has concluded that chlorides presence are attributed to exchange of ions between the rock and the water that is infiltrated while revitalizing the groundwater. Chlorides concentration in leachate was found to be 4800 mg/l. On comparing, with a study done by Srivastava & Ramanathan, 2008 on the same landfill, Cl^- value for the leachate was 4000 mg/l which is quite comparable with the present study. Other studies have also evaluated the Cl content in the leachate sample which values varying as: 3550-3905 mg/l in Yemen (Al Sabahi *et al.,* 2009), 900-11500 mg/l in Tamil Nadu (K. Parameswari *et al.,* 2012), 5680 mg/l in Morocco (Chofqi *et.al.,* 2004),

NITRATE: Nitrate is one of the forms of nitrogen present in the waste water. It represents the final end result of aerobic decomposition of the waste. Presence of nitrate is a sign of the presence of organic content in the waste composition. It leads to nitrate poisoning also known as methaemoglobinemia. CPCB has mentioned the standards for discharge in 2001 for inland surface waters and marked the maximum limit for nitrate as 10mg/l. In the present study, nitrate content varies as 179-212 mg/l with mean value of 193.50 mg/l. Nitrate content in leachate is evident from other studies as well which are Zhao *et.al.,* 2013, Mor *et.al.,*2006, Venkatramani *et.al.,*1988 .

TP: Phosphates are generally categorized into two forms orthophosphate and total phosphate. Total phosphate level in the leachate samples of Bhalaswa landfill in this study varies as 122-221 mg/l with a mean value of 160.70 mg/l. While in 1996, Irene & Lo have concluded in their study that a typical range of phosphate in landfill leachate of Hong Kong as 630-30,000 mg/l. The presence of phosphate in the leachate is found in past in various studies of landfill leachate characterization like Christopher *et.al.,* 2012, Hassan & Ramadan,2005, Loizidou & Kapetanios, 1993.

POTASSIUM: Cations are also evaluated in the present study which includes Calcium, magnesium, Potassium, Sodium and heavy metals as well. Kjeldsen *et.al.,*2010 has mentioned in their study that the approximate range of Potassium in a landfill leachate is 50-3700 mg/l. In the present study, mean potassium concentration evaluated is 500 mg/l moreover the range of potassium is 322-702mg/l. Clark & Piskin, (1977), has found the value of K in Illinois landfill to be 270mg/l. Abu-Rukah & Al-Kofahi,2001 studies the leachate characteristics of El Akader landfill and took the samples from six locations and found the value in the range of 61.6-1371 mg/l. The results of Varank *et.al.,*2011 are 440-980 mg/l in Turkey. A worth noting result was obtained by a study conducted by Fatta *et.al.,*1999, in Athens, where the Potassium concentration in Trench 1 varies as 1499-2094 mg/l and in Trench 2 as 1287-2927 mg/l.

SODIUM: The presence of sodium in the leachate samples of Bhalaswa landfill is detected by carrying out analysis using spectrophotometer. The minimum value of sodium is 482mg/l while the maximum value is 804mg/l. The presence of sodium in the leachate is very high which results in high salinity and could probably results in high TDS and EC values. CPCB has not laid their standards for permissible limit of sodium so the comparison analysis cannot be done.

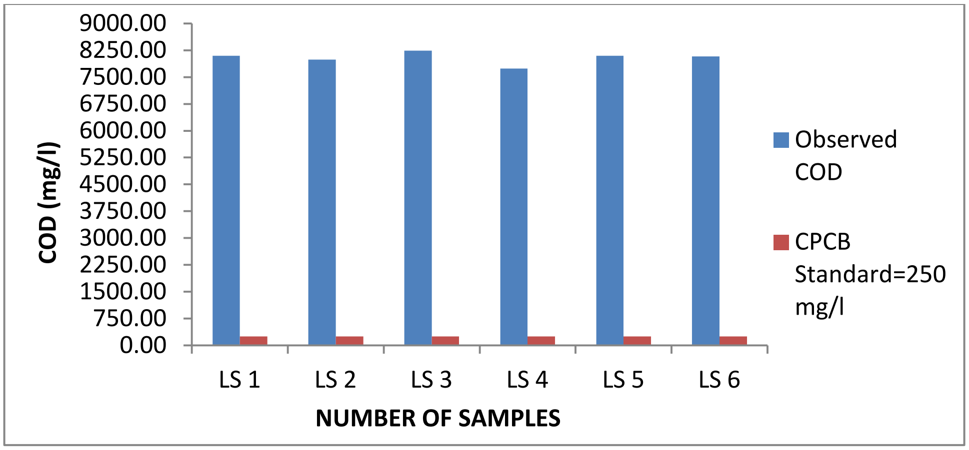

Figure 4.3: Comparison of Leachate COD with CPCB Standard of Discharge in Surface Water

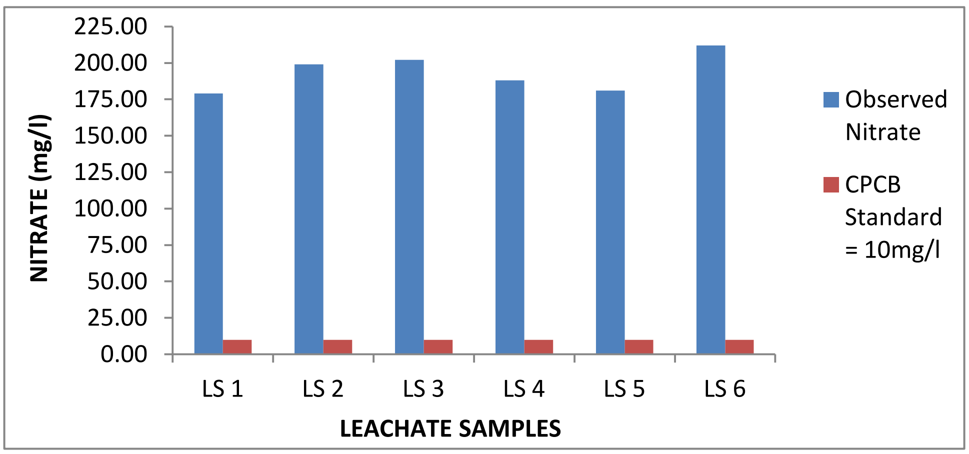

Figure 4.4: Comparison of Nitrate of Leachate with CPCB Standards of Surface Water

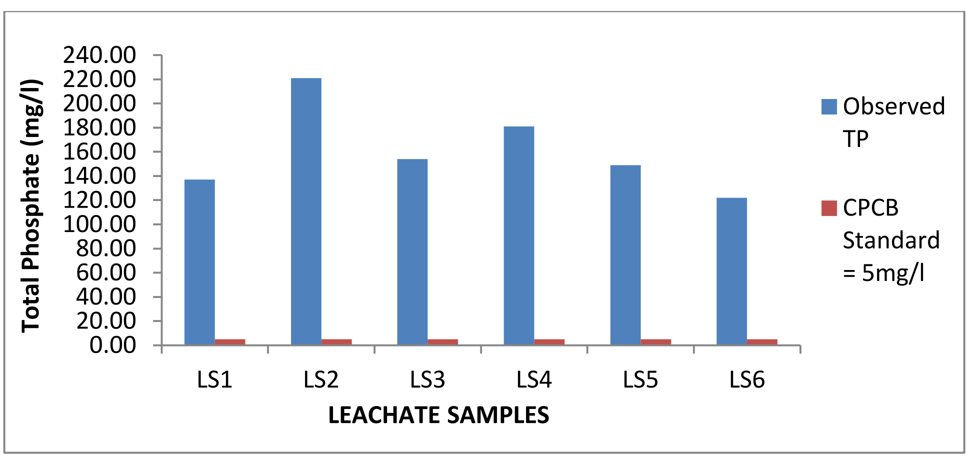

Figure 4.5: Comparison of Total Phosphate in Leachate with CPCB Standards of Surface Water

4.1.3 HEAVY METAL CONCENTRATION

The heavy metal concentration evaluated for characterization of landfill leachate was: Cadmium, Chromium, Copper, Iron, Zinc, Manganese, and Nickel. Baumann *et.al.,* 2006 studies the characteristics of leachate from three landfill sites viz. Augsburg disposal site, Munich disposal site and Gallenbach disposal site. The concentration of Cadmium in leachate in Augsburg, Munich & Gallenbach was found to be 5mg/l, 11 mg/l & 7 mg/l respectively. Srivastava & Ramanathan, 2008 has also studied the characteristics of Bhalaswa landfill and found cadmium concentration to be 0.2mg/l (2004) & 0.25 mg/l (2005) respectively. In the present study, the mean Cadmium concentration is 1.68 mg/l which is quite more than earlier results of 2004 & 2005.

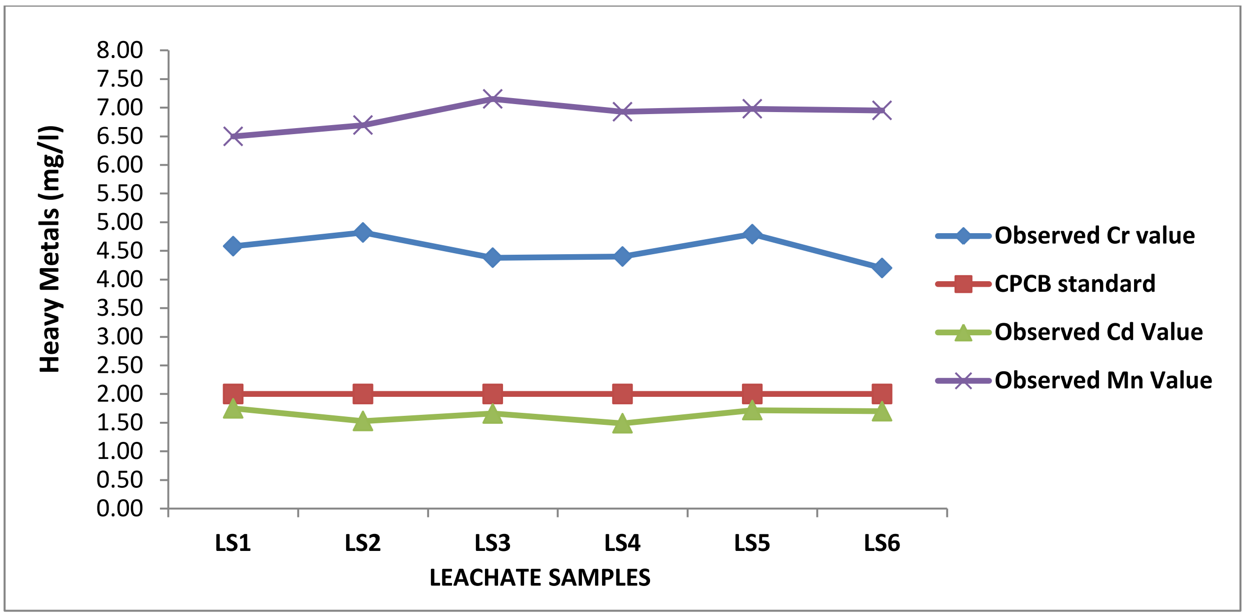

Figure 4.6: Comparison between Observed Value of Cr, Cd, Mn and CPCB Standards for Discharge

Manganese could be present in the environment in a suspended form caused due to industrial emissions, volcanic emissions, burning of petrol etc (WHO, 2003). The mean concentration of Manganese in the present study is 6.869 mg/l with range varies as 6.498-7.142 mg/l. Baumann *et.al.,* 2006 found the value of Mn in Augsburg, Munich & Gallenbach to be 134 mg/l, 166 mg/l & 171 mg/l respectively. Similarly Chofqi *et.al.,* 2004 studied characteristics of Morocco landfills and found Mn in the range 400-4922 mg/l. Zinc concentration usually ranges as 0.03-1000 mg/l in landfill leachate samples (Kjeldsen *et.al.,*2010). The mean value of Zn in present study is 8.817 mg/l. Jhamnani & Singh, 2009 has conducted the study on same Bhalaswa landfill and found Zinc concentrations in sample were <10 mg/l. Similarly some results of other studies includes 5.4-11.1 mg/l (Christopher *et.al.,* 2012), 9mg/l in African landfill (Adeolu *et.al.,* 2011), 0.1-0.5 mg/l in Italy (Caputo & Vaccaro, 2006), 6.76 mg/l in Athens (Fatta *et.al.,*1999), 180- 1200 mg/l in Finland (Assmuth,1992).

The mean Copper concentration in the present study is experimentally analyzed in Atomic Absorption Spectrophotometer and found to be 1.697mg/l. Clark & Piskin, (1977), has found the value of Cu in Illinois landfill to be 25.2 mg/l. Similarly the results from other studies were 0.044-19.45 mg/l in Northern Jordon, (Abu-Rukah & Al-Kofahi, 2001), 217-342 mg/l in Germany (Baumann *et.al.,* 2006) and 0.93mg/l in New Delhi (Mor *et.al.,* 2006), 1.5-30 mg/l in Finland (Assmuth,1992). Iron in the leachate of Bhalaswa landfill site is found in significant concentration of 43.026 mg/l. The similar result was found in Yemen, where Fe content in leachate was in a range of 45.7-46mg/l (Al Sabahi *et al.,* 2009). While the result of study conducted by Srivastava & Ramanathan, 2008 and Jhamnani & Singh, 2009 was 22mg/l and 20mg/l respectively for Bhalaswa landfill. Mor *et.al.,* 2006 studied Ghazipur landfill in New Delhi and Zn concentration in their study was 70.62 mg/l. High concentration of Iron is evident from the study of a HongKong active landfill site in which Fe was found to be 280mg/l.

Nickel was examined in the present study and value for leachate was 0.997-2.352 mg/l with mean as 1.810 mg/l. The Nickel concentration varies widely as 0.015-13 mg/l in a typical landfill site (Kjeldsen *et.al.,* 2010). But the value of Ni in various studies contradict this statement as 18–70 mg/l in North Jordon (Abu-Rukah & Al-Kofahi, 2001) & 133.8mg/l in Morocco (Chofqi *et.al.,* 2004). However some results of Ni evaluation were 0.1-0.25 mg/l in active HongKong landfill sites (M-C Lo,1996), 0.01-0.152 mg/l in Egypt (El-Salam & Abu-Zaid, 2014). Chromium metal concentration in the present study is 4.546 mg/l. El-Salam & Abu-Zaid, 2014 has shown the varying concentration of Cr as 0.029-0.094mg/l. Results of other studies are: 0.011 mg/l in Nigeria (Odunlami, 2012), 0.13-0.36mg/l in Italy (Caputo & Vaccaro, 2006), 36-810 mg/l in Finland (Assmuth,1992), 0.58mg/l in Illinois (Clark & Piskin, 1977).

4.2 GROUNDWATER ANALYSIS

The groundwater of the studied area is utilized for washing, cleaning and other domestic purposes except drinking. All the water samples are collected from the handpumps near the landfill locality. The samples collected were analyzed for its physico-chemical characteristics along with heavy metal concentrations. The following table shows the results of the laboratory analysis of groundwater samples. The mean, maximum, minimum and standard deviation for each water quality parameter analyzed for all the thirty six samples are shown in (Table 4.2)

4.2.1 PHYSICAL PARAMETERS

pH: The pH of groundwater samples range being 6.8-7.3 with the mean pH as 7.02. These values are indication of neutral nature of the samples. The values are well within the permissible range of BIS & WHO standards. Butt & Ghaffar, 2012 have studied the water samples near Mehmood Boti landfill of Pakistan and the results were quite similar to the present study with value varying as 7.27-8.16. Other studies conducted on the groundwater samples near landfills which supports the present study are Rahim *et.al.,* 2010, Islam & Shamsad, 2009, Srivastava & Ramanathan, 2008, Mor *et.al.,*2006, Loizidou & Kapetanios,1993.

S.No.	PARAMETERS	GROUNDWATER SAMPLES			STANDARDS	
		MIN	MAX	MEAN	BIS (2012)	WHO
1.	pH	6.8	7.3	7.02±0.12	6.5-8.5	6.5-8.5
2.	TDS (mg/l)	736	2918	1308.67±447	500	1000
3.	EC (µS/cm)	1936	5230	2830.55±705	-	1400
4.	Salinity(mg/l)	1.108	3.218	1.883±0.513	-	-
5.	Chloride(mg/l)	142	1180	419.11±168	250	250
6.	Total Alkalinity(mg/l)	185	1695	541.52±304	200	200
7.	Total Hardness(mg/l)	167.5	522.5	303.33±71	200	500
8.	Calcium(mg/l)	72.5	292.5	139.28±44	75	200
9.	Magnesium(mg/l)	88.6	268.9	164.04±36	30	50
10.	Sulphate(mg/l)	76.582	170.17	132.55±23	200	250
11.	Nitrate(mg/l)	4.27	33.60	15.16±7.06	45	50
12.	Total Phosphate(mg/l)	0.018	0.513	0.222±0.117	-	-
13.	Sodium(mg/l)	123.8	874.1	341.55±149	-	200
14.	Potassium(mg/l)	107.5	420.5	187.50±71	-	200
15.	Iron(mg/l)	0.117	0.502	0.257±0.07	0.3	0.05-0.3
16.	Copper(mg/l)	0.152	0.315	0.228±0.04	0.05	2
17.	Zinc(mg/l)	0.001	0.586	0.110±0.11	5	5
18.	Manganese(mg/l)	0.052	1.637	0.637±0.436	0.1	0.5
19.	Nickel(mg/l)	0.010	0.254	0.118±0.066	0.02	-
20.	Cadmium(mg/l)	0.228	0.585	0.422±0.104	0.003	0.003
21.	Chromium(mg/l)	0.104	0.390	0.268±0.091	0.05	0.05

Table 4.2: Physical & Chemical Characteristics of Groundwater Samples

EC & TDS: TDS accounts for inorganic salts as well as organic matter that get dissolved in the water. EC and TDS values are complementary and are usually proportional to each other. The range of EC in studied area is 1936-5230 µS/cm with a mean of 2830.55 µS/cm. In 2008, Srivastava & Ramanathan have studied the effects of Bhalaswa landfill in groundwater and found the values fluctuating as 789-2673 µS/cm. Many researchers have identified high value of EC in the groundwater samples near landfill as Casado *et.al.,* 2015, Rafizul & Alamgir, 2012, Kale *et.al.,* 2010, Al Sabahi et.al.,2009, Mor *et.al.,* 2006, Hassan & Ramadan, 2005, Fatta *et.al.,* 1999. According to BIS 2012, the maximum permissible limit of TDS is 2000 ppm and desirable is 500 ppm. TDS in water if exceeds 500mg/l, can cause gastrointestinal irritation. In the present study, the value of TDS is found out to be in a range of 736-2918 mg/l with a mean of 1308.67 mg/l. Mor *et.al.,* 2006 have conducted the study on Ghazipur landfill site in New Delhi and found comparable values of TDS varying as 302-2208mg/l. Many other studies have also conducted test in groundwater samples near landfill and have shown a very high TDS values as Han *et.al.,* 2014, Rafizul & Alamgir, 2012, Al Sabahi *et.al.,*2009, Abu-Rukah & Al- Kofahi, 2001, Hassan & Ramadan, 2005, Fatta *et.al.,* 1999 , Mirecki & Parks, 1994.

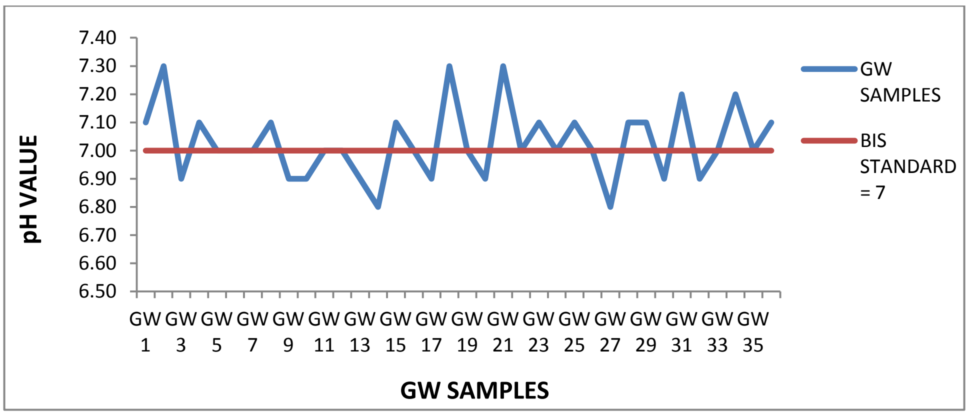

Figure 4.7: Comparison of pH value of groundwater samples with BIS standard

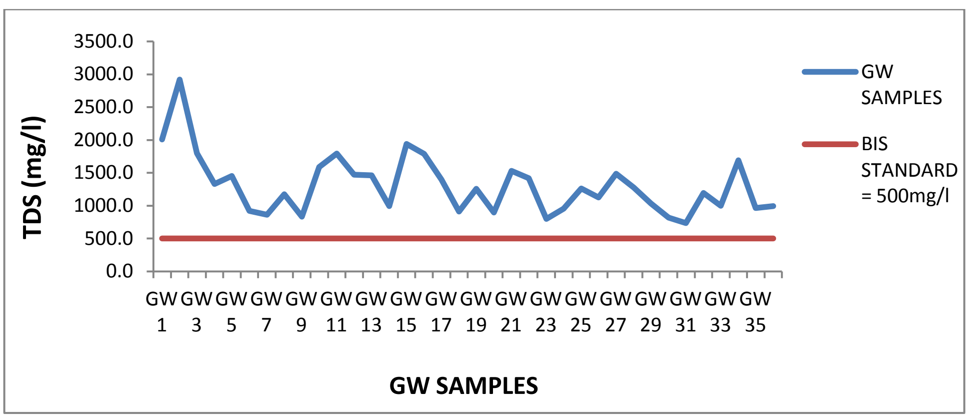

Figure 4.8: Comparison of TDS values of groundwater samples with BIS standard

4.2.2 CHEMICAL PARAMETERS

Chloride: BIS standard for chloride content in water is 250mg/l as maximum desirable value & 1000 mg/l as maximum desirable value. In the present study, the value of chloride in water samples was in the range of 142-1180 mg/l with a mean of 419.11 mg/l. The samples with high values of chloride are from sampling sites 1, 2, 12, 27. Nearly every sampling site values have exceeded the mark of 250mg/l which shows the presence of high concentration of chloride ions in the groundwater samples near Bhalaswa landfill. The study conducted by Jhamanani & Singh, 2008 in the same landfill area has pointed that the value of Chloride varies with the distance from landfill and the range of Cl was 135.56- 1174.2 mg/l. The other studies with high values of Chloride are Han *et.al.,* 2014, Rahim *et.al.,* 2010, Al Sabahi *et.al.,*2009.

Total Hardness: Multivalent cations mainly Ca & Mg are generally present at considerable concentration in natural water. They get effortlessly precipitated and react with soap and make removal of scum really difficult. Hardness is expressed as the summation of total calcium & magnesium ions equivalent as $CaCO_3$. The maximum permissible limit of total hardness in water as per BIS (2012) is 600mg/l while the maximum desirable limit is 200mg/l. In the present study the value of total hardness is in the range of 1.675-522.5 mg/l with a mean value of 303.33 mg/l. Similarly the value of Ca & Mg is 72.5-253.6 mg/l & 88.6-268.9 mg/l respectively. BIS standards for Ca & Mg for maximum permissible value are 200mg/l & 100mg/l. There are various studies conducted on landfill where groundwater analysis is done to assess the contamination due to landfill leachate. The studies with high total hardness in the water samples are 234-1521(Han *et.al.,* 2014,), 109-996 mg/l (Kale *et.al.,* 2010). Ca & Mg are also present in excess of the desirable permissible limit in studies as Han *et.al.,* 2014, Rahim *et.al.,* 2010, Kale *et.al.,* 2010, Al Sabahi *et.al.,*2009, Hassan & Ramadan, 2005, Nicholson *et.al.,*1983.

Total Alkalinity: Total alkalinity has the maximum desirable value of 200mg/l as per Bureau of Indian Standards. In the present study, the value of total alkalinity is due to presence of only bicarbonates. The value of HCO_3^- in the present study is found out to be in range of 185-1695 mg/l. the mean value is 541.52 mg/l. The value of bicarbonate ion clearly exceeds the desirable limits. Other studies which has shown the similar results are Han *et.al.,* 2014, Lopes *et.al.,* 2012, Kale *et.al.,* 2010.

Nitrate: The major sources of nitrate in the groundwater are domestic sewage, runoff from agricultural fields & leachate from landfill sites (Srivastava & Ramanathan, 2008). In the present study, the value of nitrate nearby Bhalaswa landfill is in the range 4.27-33.60mg/l. BIS(2012), has given the maximum desirable value of nitrate in water to be 45mg/l. Hence the nitrate concentration is well below the standard. There are other studies where nitrate values are below standard as Al Sabahi *et.al.,*2009, Hassan & Ramadan, 2005, Fatta *et.al.,*1999. While there are some studies where nitrate values have exceeded the desirable limit as Abu- Rukah & Al-Kofahi, 2001.

Sulphate: In the present study, the maximum & minimum values of sulphate are 76.582mg/l & 170.17 mg/l respectively with mean value of 132.55 mg/l. Samples with high value of sulphates were Sample 1, 7, 35, 36. The maximum permissible limit of sulphate for drinking water as per IS 10500 : 2012 as well as WHO is 200 mg/l. Srivastava & Ramanthan, 2008 has shown their results of groundwater samples near Bhalsawa landfill of 2004 & 2005. In 2008, the value ranges between 56.12-551.47 mg/l and in 2009, the value ranges as 58.45-612.48mg/l. Various scholars have shown in their studies the effect of landfill leachate in the groundwater by comparing the standards with the sample values and the following values: 76.8-170.5 mg/l in North Jordon (Abu-Rukah & Al-Kofahi, 2001), 23 -1128 mg/l in North Italy (Caputo & Vaccaro, 2006), 0.02-1.20 mg/l in Africa (Adeolu.*et.al.,*2011), 46.9-515 mg/l in China (Han *et al.*, 2013), 20-1386 mg/l in Spain (Casado *et.al.*,2015).

Total Phosphate: Phosphate concentrations assessed in this study from the groundwater samples were quite less as compared to other parameters. The values obtained were least as compared to all other parameters. The minimum value total phosphate was for sample 1 which was 0.0184 mg/l and maximum was 0.5135 mg/l for sample 22. There are no standard values laid by Indian government for total phosphate content in the drinking water standards. From past studies of Loizidou & Kapetanios in 1993, the values obtained in their studies were quite comparable to the present studies. They have evaluated phosphate values for seven sampling sites and found the values to be: Site 1: 0.496-0.763 mg/l , Site 2: 0.126-0.209 mg/l, Site 3: 0.211-0.346 mg/l, Site 4: 0.211-0.346 mg/l, Site5: 0.031-0.053 mg/l, Site6: 0.057-0.108 mg/l, Site7: 0.007-0.013 mg/l.

Sodium: Sodium is a highly dissolvable element which has no smell and is most commonly present in the water samples. In the present study, the maximum and minimum values of Na are 123.8mg/l & 874.1 mg/l. WHO(2010) have laid the standards for maximum desirable value of Na in water as 200mg/l. Srivastava & Ramanthan, 2008 have conducted a study near the Bhalaswa landfill and found the values of sodium in range 45.46-735.97mg/l in 2004 & 67.79-783.49mg/l in 2005. The studies with presence of Na in water samples as obtained near landfill are Han *et.al.,*2014, Rahim *et.al.,* 2010, Al Sabahi *et.al.,*2009, Mirecki & Parks , 1994.

Potassium: Potassium concentration is usually evaluated in most of the studies related to landfill leachate contamination. Many scholars (Fatta *et.al.,* 1998; Loizidou & Kapetanios, 1993) claimed that potassium can be taken as a trace element to evaluate the effect of leachate in the groundwater bodies as potassium is one of the elements that travel along with the landfill leachate. The standard limit of potassium to be present in the drinking water is not mentioned in the drinking standards laid by Indian Government. But in the reports of WHO, 200mg/l is assumed to be the prescribed limit of the presence of potassium in the drinking water. So the comparison of the assessed values of potassium is done with respect to the WHO standards. The minimum value of Potassium is 107.5mg/l for sampling site 35 while the maximum value recorded was 420.5mg/l for sampling site 2. The mean value was found out to be 187.50 mg/l which is less than the WHO standards but the areas with high values were sampling sites 2,9,10,11,12,13. A study of Rahim *et.al.,* 2010 is evident that the presence of potassium is limited to values of 1.5-2.6 mg/l in groundwater samples in west Malaysia, this indicates that the potassium concentration in groundwater near Bhalaswa landfill is highly contaminated by the presence of high concentration of potassium.

4.2.3 HEAVY METALS

Zinc: The permissible value of zinc as laid by Bureau of Indian standards is 5mg/l in IS 10500 (2012). In the present study the value of Zinc, were evaluated in all the sampling sites and the minimum value was found out be 0.001 mg/l from sampling site 1 while the highest was 0.5863mg/l from sampling site 7. The values evaluated from all 36 sampling sites are well below the prescribed limit and indicates that the Zinc concentration is not affecting the quality of groundwater. But there are few studies in which the concentration of Zinc is so high that it has exceeded the prescribed limit and has contaminated the water making it unfit for drinking purposes like studies conducted by Odunlami, 2012, Lopes *et.al.,* 2012, Rahim *et.al.,* 2010, Kale *et.al.,* 2010, Al Sabahi *et.al.,*2009, Jhamanani & Singh, 2008 , Mirecki & Parks, 1994.

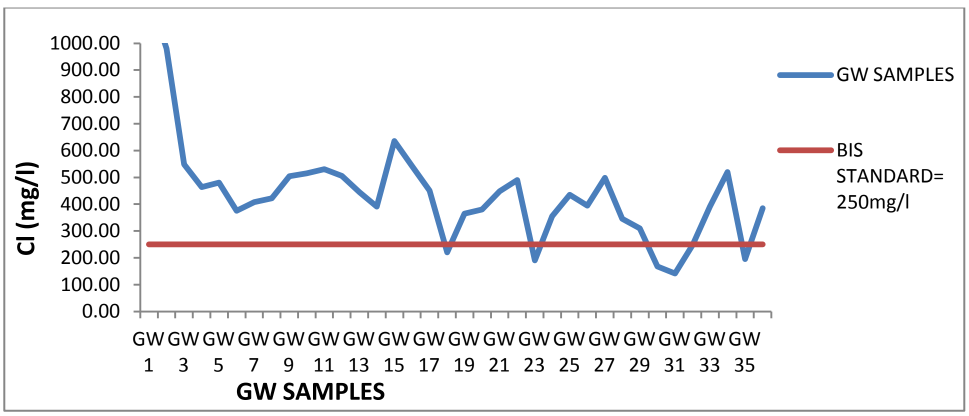

Figure 4.9 Comparison of Chloride values of groundwater samples with BIS standard

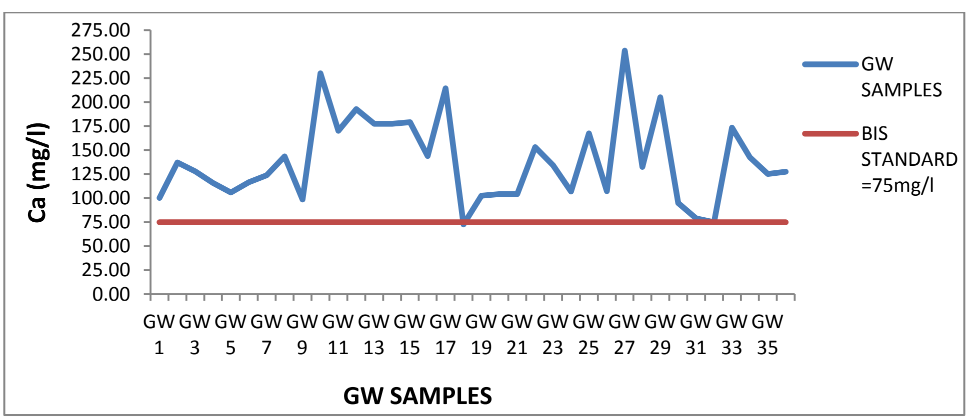

Figure 4.10 Comparison of Calcium values of groundwater samples with BIS standard

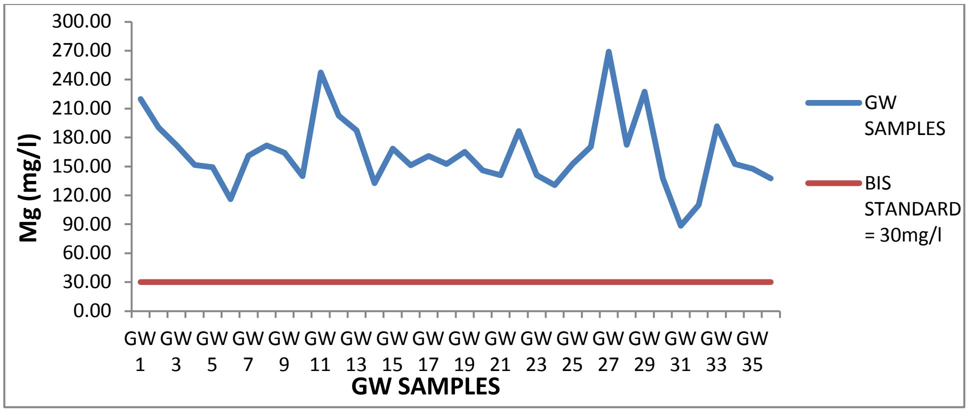

Figure 4.11: Comparison of Magnesium values of groundwater samples with BIS standard

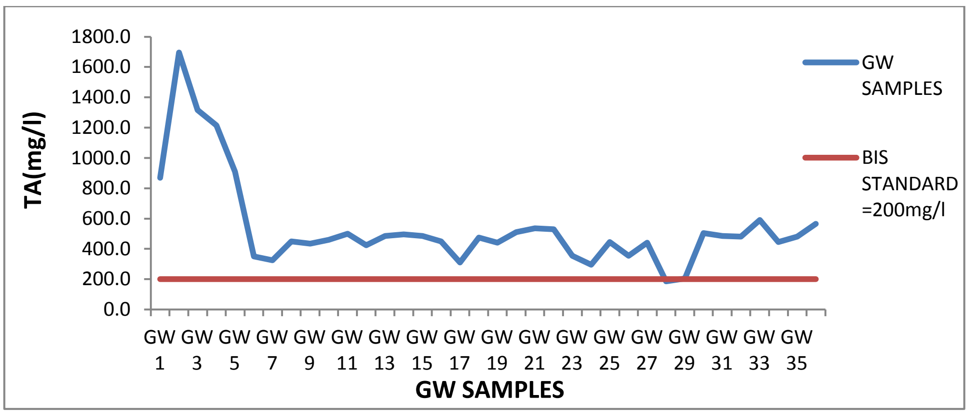

Figure 4.12: Comparison of Total Alkalinity values of groundwater samples with BIS standard

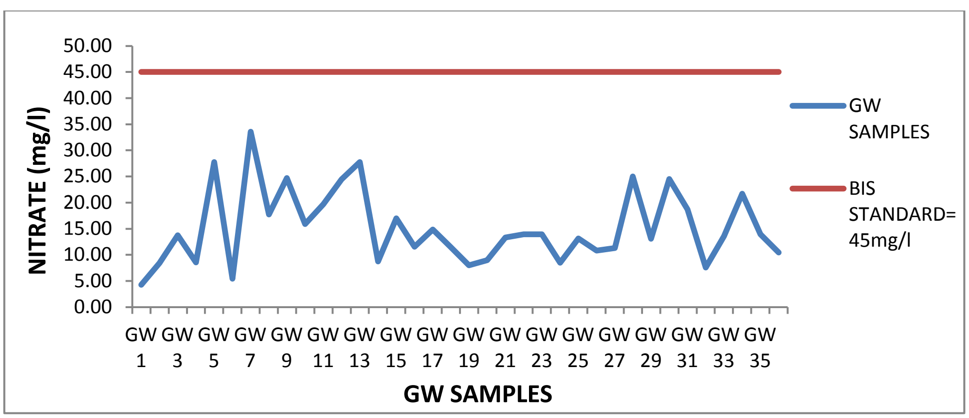

Figure 4.13: Comparison of Nitrate values of groundwater samples with BIS standard

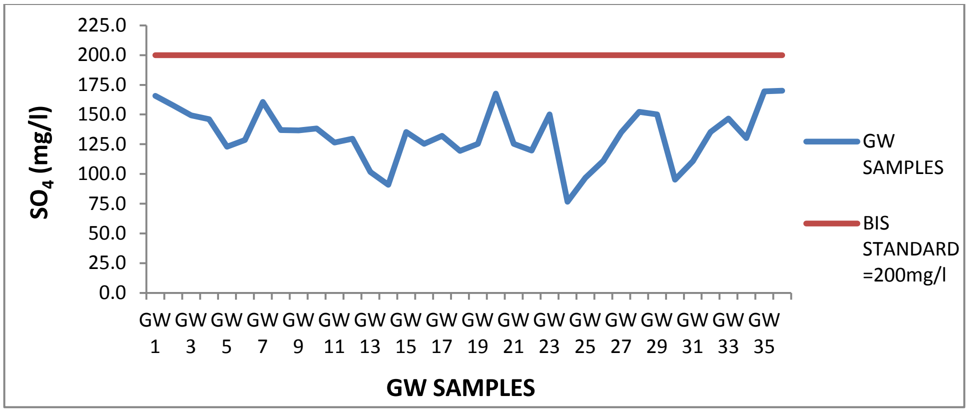

Figure 4.14: Comparison of Sulphate values of groundwater samples with BIS standard

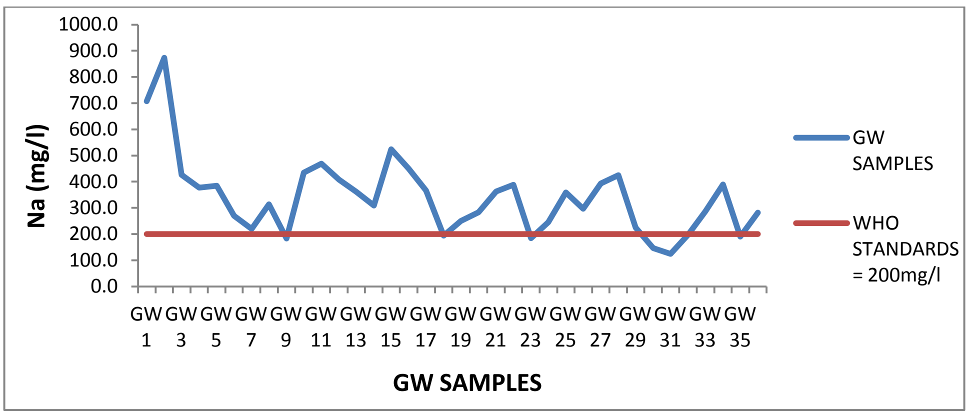

Figure 4.15: Comparison of Sodium values of groundwater samples with WHO standards

Nickel: Nickel concentration was found out in the groundwater samples near the Bhalaswa landfill site. The values of Ni as laid by the India Standards IS: 10500 (2012) is 0.02 mg/l. The maximum value of Ni was found to be 0.2544 mg/l in sampling site 8 which is nearly 10 times as permitted. This indicates the high contaminated state of groundwater quality near the study area. The minimum value of Ni was found out to be 0.01 mg/l in sampling site 21. The sampling sites with high concentration of Ni are 1, 8, 9, 22, 32. Some studies with similar results for Ni presence in groundwater nearby the landfill sites are Lopes *et.al.,* 2012, Odunlami 2012, Rahim *et.al.,* 2010, Al Sabahi *et.al.,*2009,Jhamanani & Singh, 2008, Hassan & Ramadan, 2005.

Copper: The presence of Copper in the groundwater samples near the landfill sites are evident from studies of Lopes *et.al.,* 2012, Odunlami, 2012, Kale *et.al.,* 2010, Al Sabahi *et.al.,*2009, Jhamanani & Singh, 2008. In the present study, the mean value of copper for the samples was found to be 0.228mg/l. The BIS of copper in drinking water is 0.05 mg/l which means the value above this is not permitted for drinking purposes. The samples in the present studies have shown 100% samples were above the permissible value. This indicates the severe contamination of the groundwater nearby the Bhalaswa landfill site. The sampling site shows the maximum value among all the samples viz. 0.3152mg/l while the minimum value of 0.1527 mg/l is found out in sampling site location 30.

Iron: The groundwater samples were also analyzed for the presence of one of the most undesirable heavy metals viz. Fe. Its presence is highly disagreeable for drinking water consumption. The BIS standard of Fe for purpose of drinking is 0.3 mg/l which is similar to the standard laid by WHO. In the present study, the samples of the groundwater have shown huge variation in their values. The sampling sites 23, 26, 30, 35 have exceeded the desirable limits while sampling sites 1, 4, 17, 24 are well below the standard limit. The mean value of Fe in the groundwater is 0.2579 mg/l. The maximum value is 0.5021 mg/l collected from sampling site 23 and the minimum value is 0.1174 mg/l collected from the sampling site 9. Few scholars have also evaluated the similar results which are Han *et.al.,* 2014, Odunlami,2012, Rahim *et.al.,* 2010, Al Sabahi *et.al.,*2009, Jhamanani & Singh, 2008.

Manganese: In the present study Mn concentration varies as 0.052-1.637 mg/l with the mean value of 0.637 mg/l. The prescribed limit of Mn as per Bureau of Indian Standards is 0.10 mg/l for drinking purposes. The result shows that all the samples except sampling site 14 lies above the limit desired. Sampling site 11 shows the maximum departure from the prescribed limit and sampling sites 8, 11, 12, 15, 18, 20, 21, 25 are also well above the mark of 0.10 mg/l. Studies like Han *et.al.,* 2014, Odunlami, 2012, Rahim *et.al.,* 2010, Hassan & Ramadan, 2005 has also work in the field of evaluation of Mn from the groundwater near the landfill site.

Chromium: The value of chromium is evaluated in various studies related to the contamination of groundwater quality near the landfill site. The permissible value of Cr as per Bureau of Indian standards is 0.05mg/l. In the present study, the value of chromium is found out in the all the water samples collected from thirty six sampling sites. The maximum value is found out be 0.3905 mg/l in sampling site 31. The other sites with high values of Cr are 22,26,27,33, 34. While the minimum value of chromium as indicated by the results was 0.1045 mg/l and is obtained from the sampling site 3. The chromium in the groundwater samples as collected near Bhalaswa landfill site have shown that 100% samples were above the permissible values. It implicates the extent of contamination of Chromium and its adverse effects on the quality of drinking water. The results of present study are justified by the study of Rahim *et.al.,* 2010.

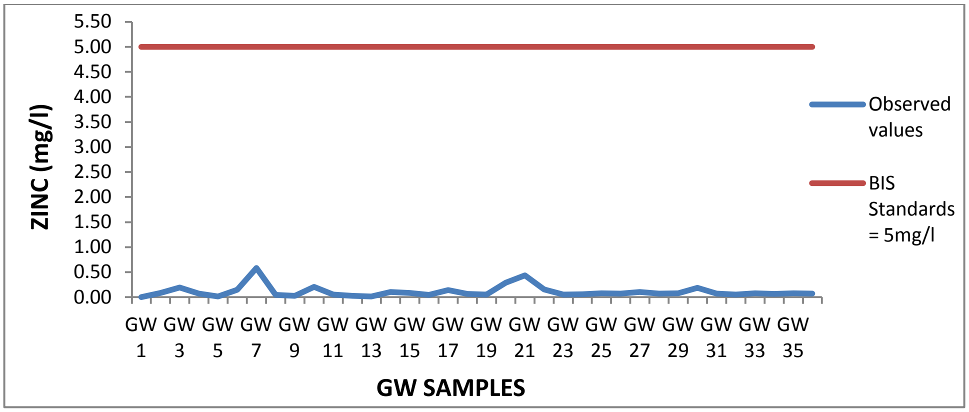

Figure 4.16: Comparison of Zinc values of groundwater samples with BIS standard

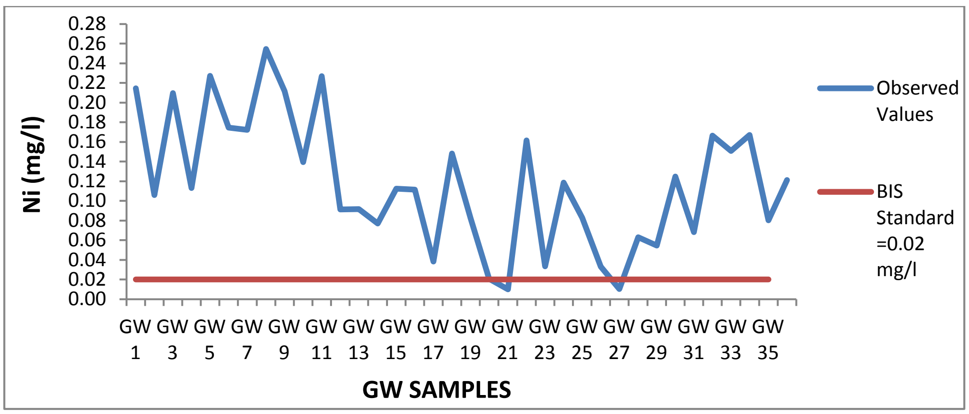

Figure 4.17: Comparison of Nickel values of groundwater samples with BIS standard

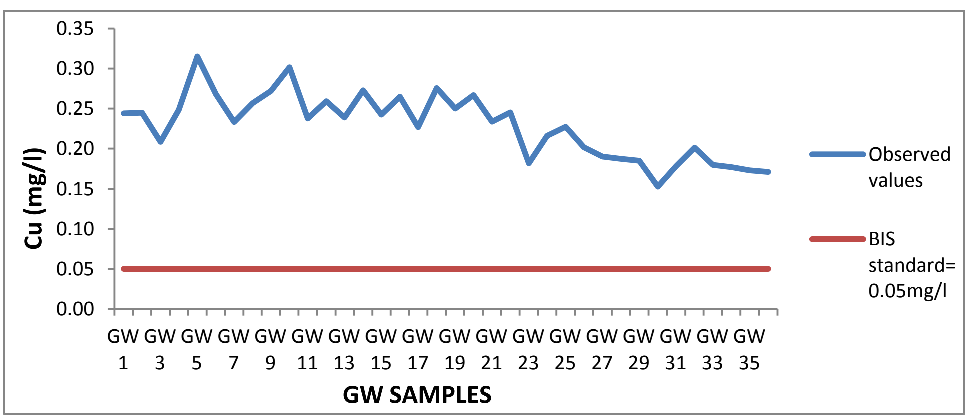

Figure 4.18: Comparison of Cu values of groundwater samples with BIS standard

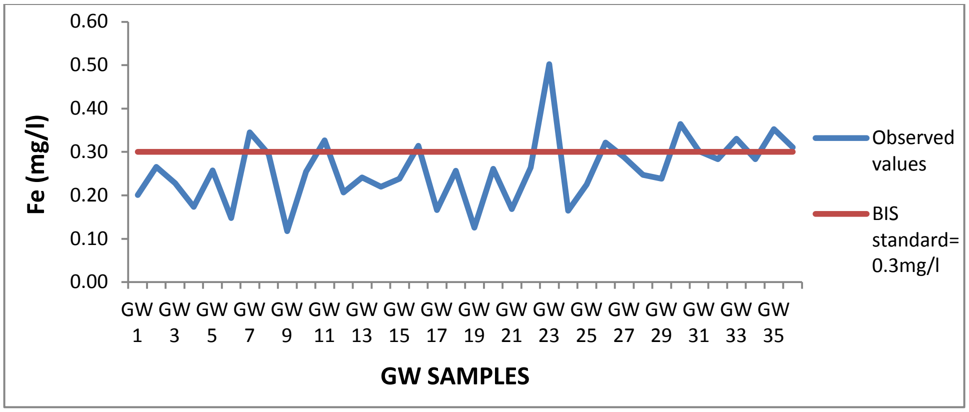

Figure 4.19: Comparison of Iron values of groundwater samples with BIS standard

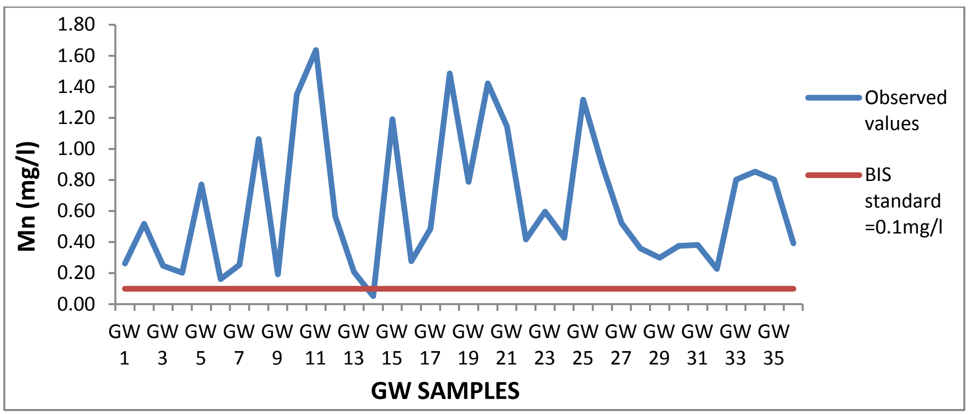

Figure 4.20: Comparison of Mn values of groundwater samples with BIS standard

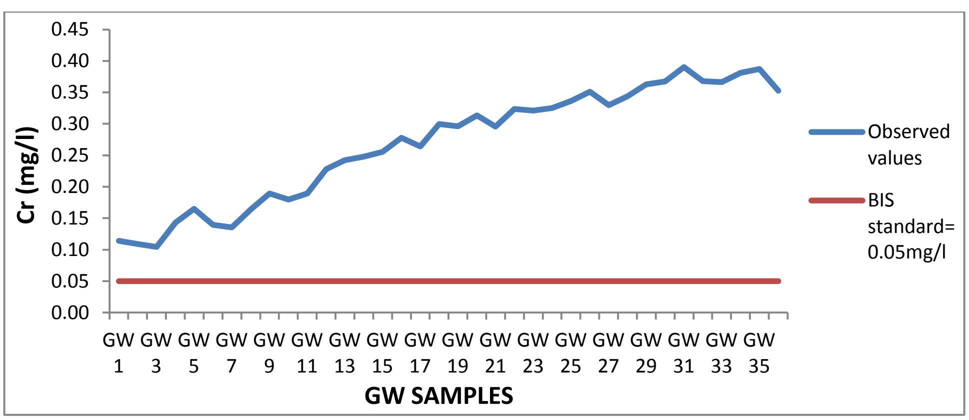

Figure 4.21: Comparison of Cr values of groundwater samples with BIS standard

4.3 DATA PRESENTATION

The data signifies that the landfill acts as a key source for all the contaminants present in the groundwater because the groundwater flow is outward away from the present landfill site and the concentration of contaminants reduces as we move radially from the landfill along the groundwater flow. The flow of groundwater enhances the process of dispersion and diffusion of the pollutants that are percolated in the groundwater aquifer system. The data represented in the present study is further distributed with the distance of the sampling site with the landfill so that a clear picture of the pollution due to landfill can be drawn from the analysis of groundwater. The parameters analyzed are divided into three groups according to their distance viz. samples within a radius of 0.25 km from the landfill, samples taken from the sites which vary radially between 0.25 km to 0.5 km and the samples taken from the site beyond the 0.5km radius of the landfill site. The data is well expressed in the form of Table 4.3, in which the maximum and minimum values of each parameter analyzed is represented along the radius in three categories.

PARAMETERS		DIST<0.25km		0.25km< DIST<0. 5km		DIST >0.5km	
		MIN	MAX	MIN	MAX	MIN	MAX
1.	pH	6.8	7.3	6.8	7.3	6.8	7.1
2.	TDS (mg/l)	800	2918	736	2010	820	1794
3.	EC (µS/cm)	2038	5230	1936	4190	2003	3507
4.	Salinity(ppt)	1.25	3.218	1.266	2.558	1.108	2.491
5.	Cl (mg/l)	190	1180	142	804	168	530
6.	TH (mg/l)	262.5	522.5	232.5	432.5	167.5	395
7.	Ca (mg/l)	98.44	292.2	88.6	270	72.5	243.8
8.	Mg (mg/l)	52.5	258.9	40.85	202.5	30.3	197.5
9.	Alkalinity (mg/l)	295	1695	205	1315	185	910
10.	SO_4 (mg/l)	95.227	170.17	76.582	165.7	89.73	156.32
11.	NO_3 (mg/l)	8.3986	33.597	5.4126	27.764	4.2769	24.483
12.	TP (mg/l)	0.0902	0.5135	0.0184	0.4173	0.0858	0.3735
13.	Na (mg/l)	182.84	874.1	123.8	707.6	146.2	468.85
14.	K (mg/l)	117.8	420.5	110.65	368.55	107.5	352.2
15.	Fe (mg/l)	0.1478	0.5021	0.1252	0.3141	0.1174	0.3645
16.	Cu (mg/l)	0.173	0.3152	0.1783	0.3016	0.1527	0.2726
17.	Cr (mg/l)	0.109	0.3871	0.1045	0.3905	0.1395	0.3673
18.	Zn (mg/l)	0.0257	0.5863	0.001	0.4349	0.0136	0.1845
19.	Mn (mg/l)	0.1618	1.637	0.1931	1.486	0.052	1.191
20.	Ni (mg/l)	0.0335	0.2544	0.01	0.2146	0.0102	0.227
21	Cd (mg/l)	0.2572	0.5851	0.2286	0.5677	0.2895	0.5506

Table 4.3: Cation, Anion & Heavy metal concentration of groundwater at radial distance from landfill

The presence of the all the major ions(Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-} , NO_3^- , HCO_3^-, PO_4^{3-}) in the all the samples represents maximum concentrations of available dissolved ions in the freshwater (Ramanathan 2006). The distribution of all these ions present in the groundwater near the Bhalaswa landfill follows a trend which can be summarized for Cations as: $Na^+ > K^+ > Ca^{2+} > Mg^{2+}$ and for anions as $HCO_3^- > Cl^- > SO_4^{2-} > NO_3^- > PO_4^{3-}$.

4.3.1 CROSS PLOTS BETWEEN IONS

Cross plot is a basically a scatter plot diagram which is used to compare multi parameters measured at same time or location along its axes. The points are plotted based on time or location and a relationship is set up by drawing a best fit line through the points. The less

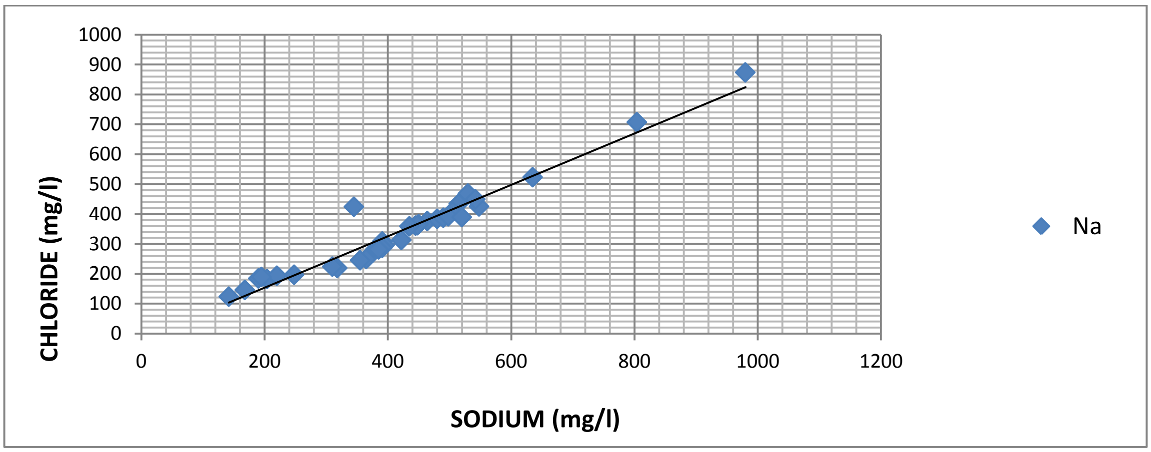

Figure 4.22: Cross plot between Sodium and Chloride analyzed from groundwater samples

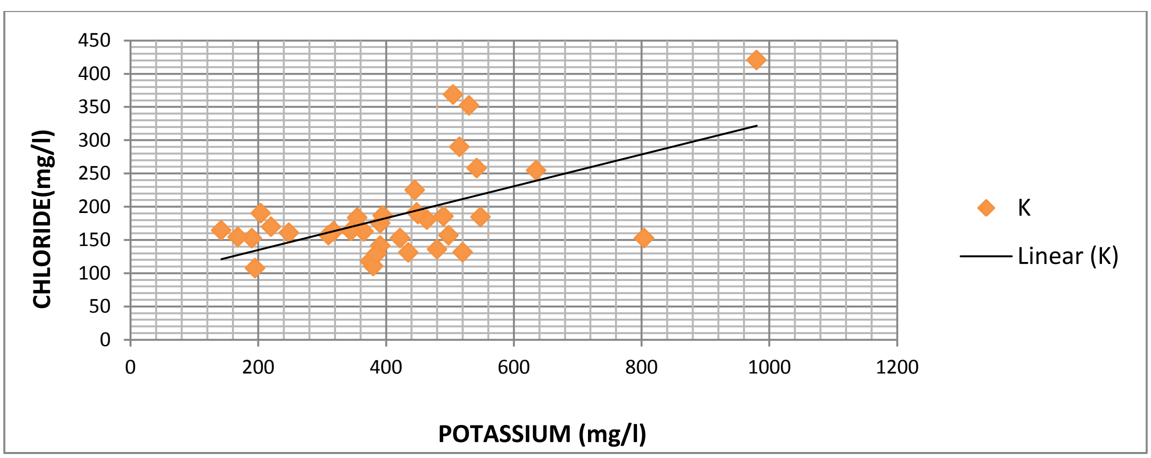

Figure 4.23: Cross plot between Potassium and Chloride analyzed from groundwater samples

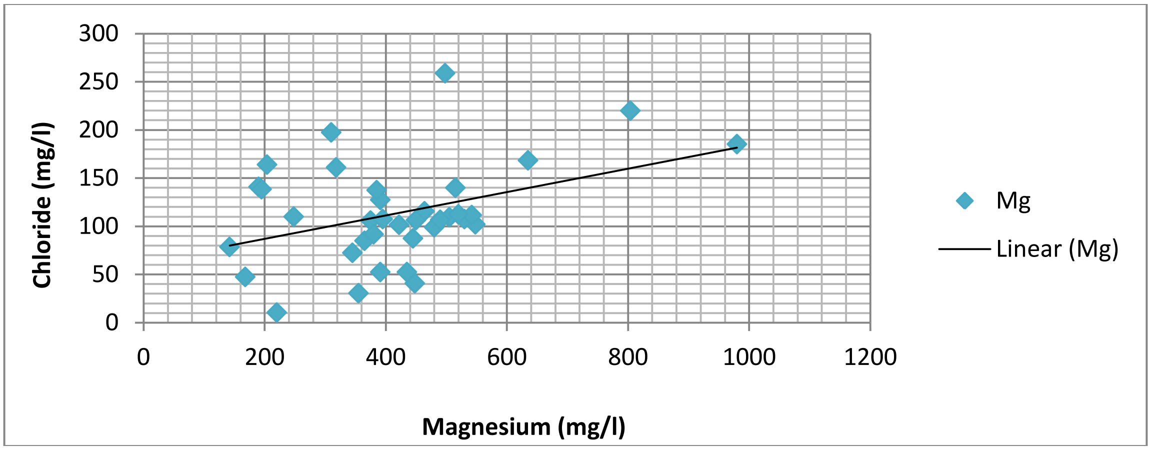

Figure 4.24: Cross plot between Magnesium and Chloride analyzed from groundwater

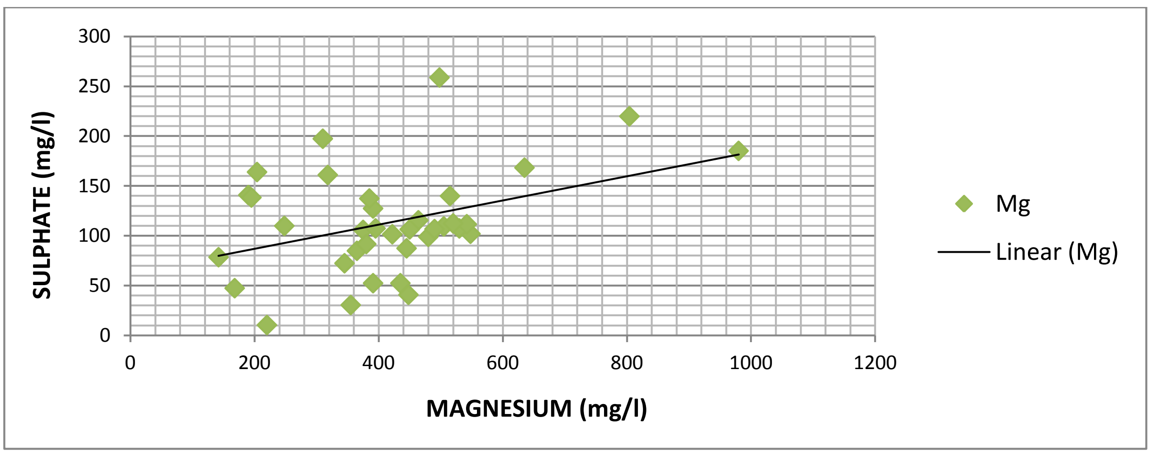

Figure 4.25: Cross plot between Magnesium and Sulphate analyzed from groundwater

scattering of points indicates the more confidence that means the points lies almost near the best fit curve. The cross plots of are drawn among all the ions but only few has shown the less scattering around the best fit curve viz. the plot diagram between Sodium & Chloride. The plot between Magnesium & sulphate and between Potassium & Chloride have shown an average scattering result but the rest other relationships were not as comparable to the above mentioned and there correlation was not enough to plot their interrelationship.

4.3.2 CORRELATION ANALYSIS FOR WATER QUALITY PARAMETERS

Correlation is a technique to assess the degree of interrelation and alliance between two variables. A correlation value of +1 indicates a perfect positive relation between two variables while -1 indicates the inverse relationship of the variables. A value of 0 shows no relationship between the variables (Kanmani & Gandhimathi, 2013). The value from 0.5 to +1 shows the moderate relationship between the respective parameters. Table 4.5 represents the Pearson correlation coefficient matrix among the physical and chemical parameters evaluated from the groundwater samples near the Bhalaswa landfill site. A fairly good correlation was observed between TDS & EC, TDS & Cl^-, EC & Cl^-, Na^+ & Cl^- , Na^+ & EC, Mg^{+2} & Ca^{+2}, showing all of them have similar source. Few parameters show moderate relationship like K & TDS, K^+ & EC, Ca^{+2} & Mg^{+2}, Na^+ & Mg^{+2}, Mg^{+2} & SO_4^{-2}, and Na^+ & K^+. Many parameters show good correlation with conductivity because conductivity increases with dissolution of metals through ion exchange or oxidation-reduction reaction in a groundwater aquifer system (Subba Rao 2002).

	TDS	*EC*	*Cl⁻*	*Mg^{+2}*	*Ca^{+2}*	*SO_4^{-2}*	*NO_3^-*	*TP*	*Na^+*	*K^+*
TDS	1									
EC	0.990767	1								
Cl^-	0.927759	0.953984	1							
Mg^{+2}	0.43306	0.452004	0.463588	1						
Ca^{+2}	0.275395	0.280074	0.321824	0.857605	1					
SO_4^{-2}	0.17373	0.176115	0.197736	0.725428	0.750554	1				
NO_3^-	-0.11929	-0.14765	-0.2166	0.074895	0.097202	-0.07678	1			
TP	0.101828	0.104404	0.02134	-0.04965	0.099693	-0.1313	-0.08335	1		
Na^+	0.941374	0.957121	0.970627	0.464059	0.290694	0.237118	-0.16699	0.03719	1	
K^+	0.667901	0.645345	0.568199	0.340243	0.320903	-0.05629	0.115491	0.151866	0.605704	1

Table 4.4: Pearson Correlation coefficient matrix for water quality parameters of groundwater

Sodium showed a very good correlation with chloride (0.97), indicating anthropogenic input in groundwater, and good correlation with TDS (0.94) and EC (0.95) indicating these two are also directly related to existence of the sodium ion. Chloride showed good relationship with EC (0.95) & TDS (0.92) and a moderate correlation with K (0.56), Mg^{+2} (0.46). Calcium showed quite good correlation with total hardness (0.90), indicating that a major source of calcium in groundwater while both calcium and magnesium showed moderate correlation with sodium and potassium, indicating a possible ion-exchange process in the groundwater aquifer system (Drever 1997; Mahlknecht 2003). EC and TDS (0.99) showed a first-class correlation in samples because conductivity increases as the concentration of all dissolved constituents/ions. The presence of all kind of ions has strengthened the relationship between these two parameters. The parameters with average correlation indicate anthropogenic input into the groundwater system, such parameters with average association are Mg^{+2} & SO_4^{-2} (0.72), K^+ & TDS (0.66), K & EC (0.64), Na^+ & K^+ (0.60), Mg^{+2} & Cl^- (0.46), Mg^{+2} & EC(0.45), Mg^{+2} & TDS (0.43).

The Pearson correlation coefficient matrix for heavy metals found in groundwater analysis of Bhalaswa landfill area is presented in Table 4.6. The relationship between the heavy metals studied offer remarkable information on the sources and pathway of the heavy metals. The metals have shown that there is hardly any relativity between each others as values were neither near -1 or +1. However Cadmium and chromium has shown direct relation (r=0.982625) which means they are directly proportional to each other.

	Fe	*Cu*	*Zn*	*Mn*	*Ni*	*Cd*	*Cr*
Fe	1						
Cu	-0.47458	1					
Zn	0.046404	0.029785	1				
Mn	0.139825	0.20955	0.082639	1			
Ni	-0.06582	0.31973	-0.14888	-0.02488	1		
Cd	0.354052	-0.68944	-0.09291	0.09811	-0.5606	1	
Cr	0.327909	-0.65008	-0.13871	0.115076	-0.53621	0.982625	1

Table 4.5: Pearson Correlation coefficient matrix for heavy metals of groundwater samples

4.4 CLASSIFICATION OF WATER TYPES FOR IRRIGATION PURPOSES

There are various classifications which were given in the past to analyse water type which have different criteria to judge the water quality. These classifications are done to evaluate the fitness of water for the irrigation purpose. The groundwater extracted from the present study area could also be used by the farmers for the irrigation purposes. To assess the quality of water near the Bhalaswa landfill site, the water is classifies as:

Wilcox (1955) has divided the water samples into five divisions taking the percentage of Na and the EC value as its base. Taking on account the percentage of sodium, all the sample values for sodium of groundwater were above the prescribed standards, that means the groundwater quality is highly unsuitable for consumption. While when EC value was taken as its base, 19.44% samples were found to be within the permissible limits. But 77.78% of samples were found in the doubtful state leaving 2.78% of samples unsuitable for its use. Richard (1954) has classified the quality of water on the basis of sodium absorption ratio (SAR). SAR is defined by U.S. Salinity Laboratory (1954) where the ion concentrations are expressed in mill equivalents per liter. It predicts the state at which water tends to enter into cation exchange reaction in the soil that means higher value of SAR implies the tendency of sodium ions to replace calcium and Magnesium ions in the water. The formula for SAR calculation is given as:

$$SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

All the parameters in the above formula are taken in mill equivalent per litre.

CLASSIFICATION SCHEME	CATEGORIES	RANGES	PERCENT OF SAMPLES
EC (WILCOX 1995)	Excellent	<250	0
	Good	250-750	0
	Permissible	750-2250	19.44
	Doubtful	2250-5000	77.78
	Unsuitable	>5000	2.78
Na% (Wilcox 1995)	Excellent	0-20	0
	Good	20-40	0
	Permissible	40-60	0
	Doubtful	60-80	0
	Unsuitable	>80	100
Na% (Eaton 1950)	Safe	<60	0
	Unsafe	>60	100
TDS Classification (USSL 1954)		<200	0
		200-500	0
		500-1500	25%
		1500-3000	75%
Cl classification (Stuyfzand 1989)	Extremely fresh	<0.14	0
	Very Fresh	0.14-0.85	0
	Fresh	0.85-4.23	0
	Fresh brackish	4.23-8.46	0
	Brackish	8.46-28.21	0
	Brackish Salt	28.21-282.06	33.33%
	Salt	282.06-564.13	61.12%
	Hypersaline	>564.13	5.55%
SAR (Richard 1954)	Excellent	0-10	0
	Good	10-18	0
	Fair	18-26	50%
	Poor	>26	50%

Table 4.6: Water Classification based on various classification schemes (Source: Srivastava & Ramanathan, 2008)

Based on the Richard's classification, the groundwater samples in the present study, 50% samples were in poor condition as SAR lies between 18-26 and rest 50% were in fair condition with SAR values more than 26. Stuyfzand classification is solely based on the concentration of chloride ions. The water samples are categorized into eight categories viz. extremely fresh, very fresh, fresh, fresh brackish, brackish, brackish salt, salt & hypersaline. In the present study, 33.33% of samples were brackish salt, 61.12% were salt and 5.55% were hypersaline.

SAMPLE	SAR
GW1	55.94
GW2	68.30
GW3	34.75
GW 4	32.58
GW 5	34.03
GW 6	25.05
GW 7	18.39
GW 8	24.97
GW 9	15.95
GW 10	31.97
GW 11	32.45
GW 12	29.06
GW 13	26.76
GW 14	24.77
GW 15	39.71
GW 16	37.02
GW 17	26.75
GW 18	18.27
GW 19	21.59
GW 20	25.28
GW 21	32.77
GW 22	29.74
GW 23	15.74
GW 24	22.52
GW 25	28.40
GW 26	25.16
GW 27	24.29
GW 28	34.37
GW 29	15.25
GW 30	13.55
GW 31	13.52
GW 32	20.48
GW 33	21.26
GW 34	32.10
GW 35	16.25
GW 36	24.48

Table 4.7: Sodium Adsorption ratio of the groundwater samples

Another classification is given in 1954 and is based on the concentration of total dissolved solid (TDS). It is known as USSL classification. In the present study, this classification categorize water as 25% of samples showed TDS values in the range of 500-1500mg/l and the rest 75% in the range 1500-3000mg/l. In 1954, Eaton also gave a water quality classification which was based on the percentage of sodium in the water. The results of this study show that 100% samples are unsafe for use in irrigation.

4.4.1 PIPER DIAGRAM

Piper diagram is most commonly used graphical representation to assess the water quality. The main purpose of graphical representation of the water quality data is to gain better insight into the processes. In most natural freshwater, the presence of ions accounts to about 95-100%. The diagram basically comprises three components: two triangular plot and one combined diamond plot. The cation plot consists of Calcium, Magnesium, sodium and potassium while the anion plot consists of sulphate, chloride, carbonate and hydrogen carbonate. A triangular is placed at bottom left corner representing the cations present in the sample while a triangular plot at bottom right represents anions. These two ions plot are pointed towards a bigger diamond shaped plot which is combination of both plots. The diamond shaped diagram shows the overall quality of the water samples. It shows the relative interrelationship between both cation and ion. The axes of triangular and diamond shaped plots read in varying directions as the plot of cation reads the increasing percentage in the clockwise directions each leg varies between 0%-100% with Ca ion on the bottom axis, Magnesium on the left leg and the combination of sodium and potassium on the right leg. However the anionic plot reads in anticlockwise direction with Chloride is represented by the bottom leg, sulphate by the right leg and bicarbonate ion along the left leg of the triangular plot.The location of each sample in the respective triangular plot is ultimately projected towards the diamond shaped plot where the two projections each from cation and anion plot are intersected. The diamond shaped plot doesn’t follow any specific order of reading the values. The upper left hand side goes in clockwise direction representing Sulphate and Chloride ions while the upper right reads Calcium and magnesium ions in anti clockwise direction.

Hence each sample plotted in the Piper diagram is represented by a cation and an anion in each triangular plot and their relationship in the diamond shaped plot. The concentration in mg/l is converted into percentage and then plotted in the diagram which shows the relative percentage of all the ions present. However piper diagram doesn’t provides absolute information regarding the concentration of each ion. In the present study, the piper diagram is drawn with the help of AqQA software version 1.1.1[1.1.5.1] manufactured by Rockware. This software is advantageous over Ms Excel as it can create eleven types of diagram related to water chemistry viz. Series, Piper diagram, Stiff diagram, Durov diagram, Ternary diagram, Time Series, Cross plots, Schoeller diagram, Ion Balance, Pie Chart and Radial Plot.

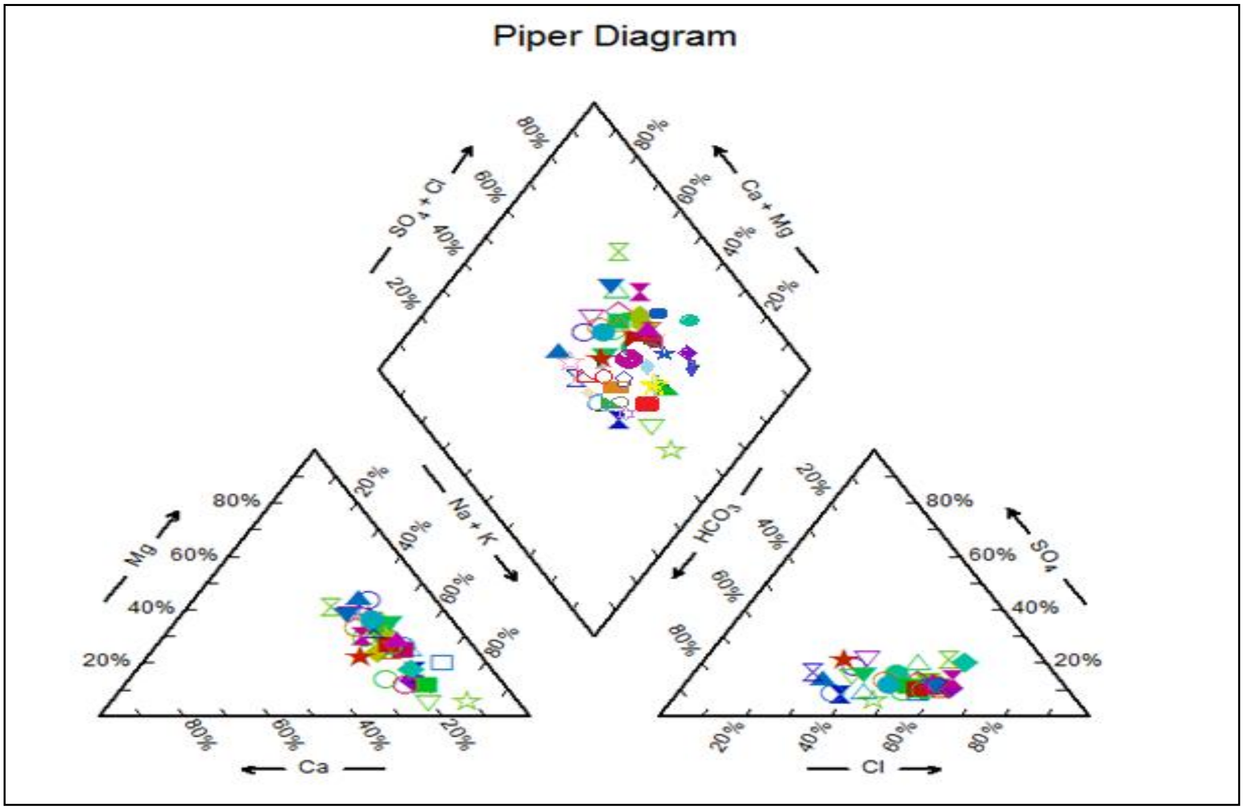

Figure 4.26: Piper diagram for groundwater samples collected near Bhalaswa landfill

The plot in the present study indicates the supremacy of ions Na^+, K^+, Cl^-, while the other ions like Calcium, Magnesium, Bicarbonate and sulphates were less characterized by the the piper diagram. The presence of Sodium and potassium as seen from the cationic plot is 40% and above while the calcium presence is between 20%-40%. On reading the anionic plot, the chloride ion concentration is maximum ranging between 40%-80% while sulpahte shows a dull result with values ranging between 20%-40%.

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The population of the NCT of Delhi is going beyond the accommodation limit which has created the high demand of the basic amenities; clean drinking water is one of them. The environmental balance is shattered as the increasing population creates the pollution in every possible ways. The major challenge related to the present study for the governmental bodies is to keep a check on the solid waste generation and its disposal techniques. General practice for the disposal of solid waste these days is to dump the waste in dumpsite without implementing the scientific methods to make the site fit for the disposal purposes. This study was carried out keeping its focal point on the generation of the landfill leachate and its harmful effects on the groundwater quality of the nearby areas. There are various conclusions which can be drawn from the present study:

- The disposal of solid waste is made in a rampant way in the Bhalaswa landfill site of Delhi is major problem identified in the present study. In November 2002, the Bhalaswa relocation outpost was created for about eleven clusters on the excuse of beautification of the city near the present disposal site due to which waste generated by these colonies was dumped in a chaotic ill mannered way.

- The next greatest menace due to the Bhalaswa landfill site is the generation of considerable quantity of leachate, which is been generated when the waste thrown in the landfill makes contact with the water through atmospheric precipitation and moisture.

- The third troublemaker in the present study is the percolation of the landfill leachate through the soil to the underground water bodies. This is basically one of the major loopholes in the landfill operation & management system. The Bhalaswa landfill area was formerly employed for sugarcane plantation and hence is not technically setup for waste disposal.

- The gases are also emitting continuously from the landfill site affecting the local as well as global environment. The green house gases emissions are major point of concern here as methane is emitted by the anaerobic decomposition of the waste present in the landfill.

5.2 RECOMMENDATIONS

India; which is still a developing country, the designing of an engineered landfill is still in its initial phase of improvement. An engineered landfill is actually a site which is designed to accommodate the solid waste generated and have minimum adverse effects on the surrounding area. Apart from its capacity, the landfills are designed by experts to provide complete isolation from the environment and avoid damage to life and property. The isolation here is basically hydrogeological, the base of the landfill is properly lined by a material called liner. The material of the liner may be natural or synthetic, provides security against tipping of leachate down to the base of the landfill and avoids its contact from groundwater and the soil. Leachate collection & treatment facilities are also included in an engineered landfill design system. A team of skilled and trained staffs are appointed to supervise the landfill activities. The waste collected is not thrown randomly over the landfill site, while it is deposited and later spread in layers and are compacted properly. The soil or some impermeable material is often used to divide the layers to avoid the interference between the layers. A gas collection and management system is also installed to collect the gas generated due to decomposition of the waste in the landfill.

Indian Government has taken a step forward and now some places where the engineered landfill are working includes Puttur (Karnataka), AUDA (Gujarat), Karwar (Karnataka), Surat (Gujarat), Pune (Maharashtra), Vizianagaram (Andhra Pradesh), Ankola (Karnataka), Ambad (Maharashtra) etc. But in the present Indian circumstances, where the capital itself lacks the engineered landfill facility, the rural areas are clearly out of the picture. So it's necessary to find an alternative to manage without the adequate resources like using the natural liners instead of the synthetic ones. Compacted clay is the one of the best liner that can be used for small villages or even towns because of its impervious nature. It is easily compacted, cheap, readily available, requires no expertise supervision etc. There are few recommendations that can bring some positive changes in the present conditions:

- The waste disposal in not followed in a systematic way even it is not even divided by the layers of soil to keep away the intervention between the different layers. The reason is probably the ignorance of the operating bodies that have turned the blind eye towards the exaggerated situation. Due to this reason the height of the landfill is still increasing, and has reached about 25m of height quiet above the permissible as per the regulations. The landfill was supposed to be closed in November 2009 and it's still operating.

- The leachate generated by landfill picks up a variety of organic and inorganic compounds; is hazardous itself and if discharged untreated to any water body, can pollute it by raising its parameters above the permissible values regulated by the pollution control authorities. This situation could be avoided if a leachate collection operation is performed efficiently at the outlet of the discharging body and the collected leachate is directly sent to the treatment units.

- The continuous leaching of the contaminants and affecting the water and soil properties could be avoided if a suitable liner is provided with proper scientific measures according to the waste properties and the foundation requirements. This can avoid the leakage and the contamination of the underground water.

- But the major need is to reclaim the existing landfill sites in the country and set up recycling plants at every landfill. Few technologies like waste to energy, compost plant etc should be installed with proper working conditions and maintenance. There is also an urgent requirement to set up amenities to suitably handle e-wastes that are sometimes being dumped at the landfills and causes severe damage the environmental resources.

- A gas collection system could also be installed to collect the emitting gases and utilize it where they are required preventing the major air pollution issues. The proper facility of venting can also be provided to maintain balance with the environment.

5.3 FUTURE SCOPE OF STUDY

The research in any area can never be accomplished completely as there is always an opportunity of upgradation and improvement. In this study also there are various scopes for future work:

- A model can be developed by taking into account the solute transport equations in two as well as three dimensional variables.

- The study of landfill contamination in the ground water can be extended radially as well as vertically, to get a clear picture of actual contamination of the groundwater in the vicinity.

- The sampling time can be extended on the basis of season like pre monsoon and post monsoon; it can also be extended on yearly or monthly basis which will provide a clear idea of exact contamination roots.

- The liners can also be designed to control the seepage of the landfill leachate which reaches the underground water bodies. A detailed study of the composition, material, permeability and a proper design can also be incorporated so that an ideal lining can be installed in other landfills also.

- A study on generation of greenhouse gas emissions can be conducted on the Bhalaswa landfill area as its one of the major global issues that is need to be keep under vigilance. Apart from the generation, its control measure could also be designed so that emissions don’t contribute to air pollution.

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