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3. Title of the scheme:

"Study of Groundwater Contamination through Landfill Site, NCT Delhi"

(Ministries sanction letter no: No. 23/41/2005-R& D /905 dated July 6th 2006).

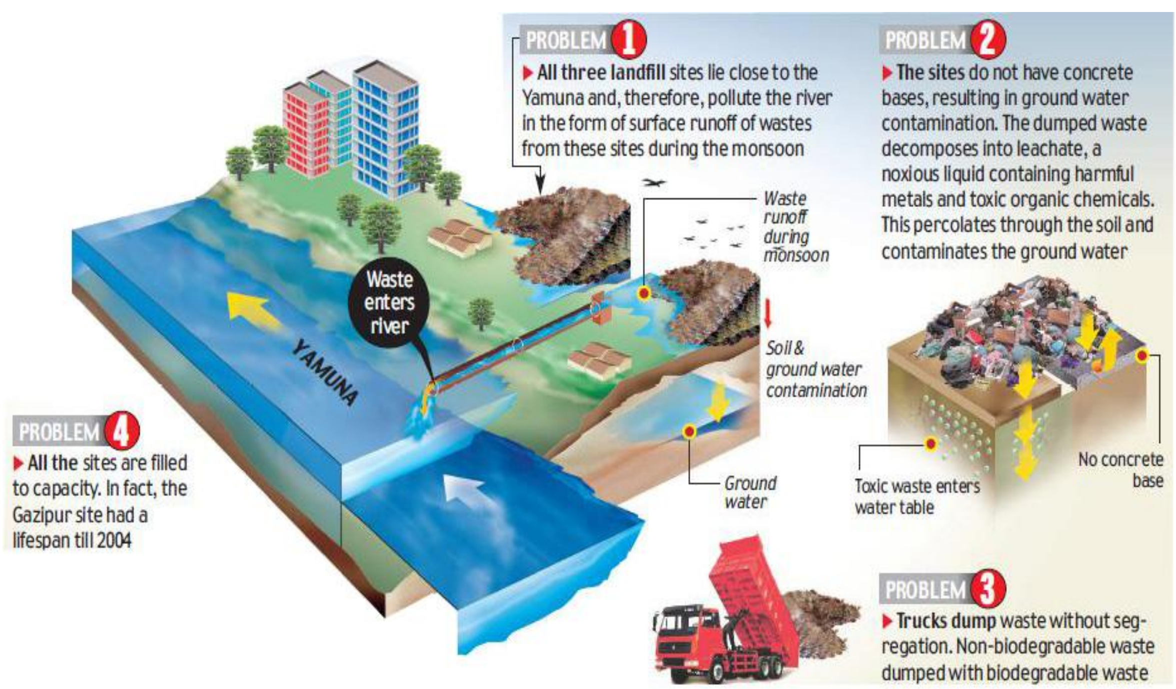
4. Financial details:

Sanctioned Cost	Amount Released	Expenditure	Unspent Balance	Return of Unspent Balance
Rs 16,16,580	Rs 10,97,000	Rs 11,74,737	Rs 4,41,849	Nil

1. INTRODUCTION

Solid waste landfills are a necessity in modern-day society, because the collection and disposal of waste materials into centralized locations helps in minimizing risks to public health and safety. Solid waste landfills, which are regulated differently than hazardous waste landfills, may accept a variety of solid, semi-solid, and small quantities of liquid wastes. Landfills generally remain open for decades before undergoing closure and post closure phases, during which steps are taken to minimize the risk of environmental contamination.

Municipal solid waste (MSW) landfills accept non-hazardous wastes from a variety of sources, such as households, businesses, restaurants, medical facilities, and schools. Many MSW landfills can also accept contaminated soils from gasoline spills, conditionally exempted hazardous waste from businesses, small quantities of hazardous waste from households, and other toxic wastes. Industrial facilities may utilize their own captive landfill (i.e., a solid waste landfill for their exclusive use) for the dsiposal of non-hazardous waste from their processes, such as sludge from paper mills and wood waste from wood processing facilities.



Reference: ***Mail Today,*** *New Delhi, Monday, March 28, 2011*

1.1. *The Concern over Landfill Impacts*

Although landfills are an indispensable part of everyday living, they may pose long-term threats to groundwater as well as surface waters that are hydrologically connected. In the United States, federal standards to protect groundwater quality were implemented in 1991 and this required some landfills to use plastic liners which could collect and treat leachates. However, many disposal sites were either exempted from these rules or grandfathered (excused from the rules owing to previous usage).

The quantity and quality of municipal solid waste (MSW) depends upon various factors such as population, life style, food habit, standard of living, the extent of industrial and commercial activities in the area, cultural tradition of inhabitants and climate. As per future the predictions, the amount of wastes generated around the world which stands at 12.7 billion tons in 2000 will be increased to approximately 19 billion tons by 2025 and to approximately 27 billion tons by 2050 (Report of Ministry of Environment, Japan, 2006). Asia, in particular, will see a dramatic increase in the amount of waste generated. Furthermore, the MSW generation amount in India, which was 0.46 kg per person per day in 1995 is expected to grow to 0.70 kg per person per day by 2025 (Source: Secretariat of the Basal Convention). The amount of MSW generation rate both in terms of per day and per capita basis for the seven most important metros are shown in Fig.1 (Singh et al., 2008; Yedla and Parikh 2001; CPCB, 2000, 2004). Moreover, the collection, transportation and disposal of MSW are unscientific and chaotic in India (Gupta et al, 1998). Nearly all the Indian cities dispose off their wastes simply by dumping whereas the environment friendly ways of disposal like composting, incineration constitutes only about 9% (Nath, 1984, EPTRI, 1995).

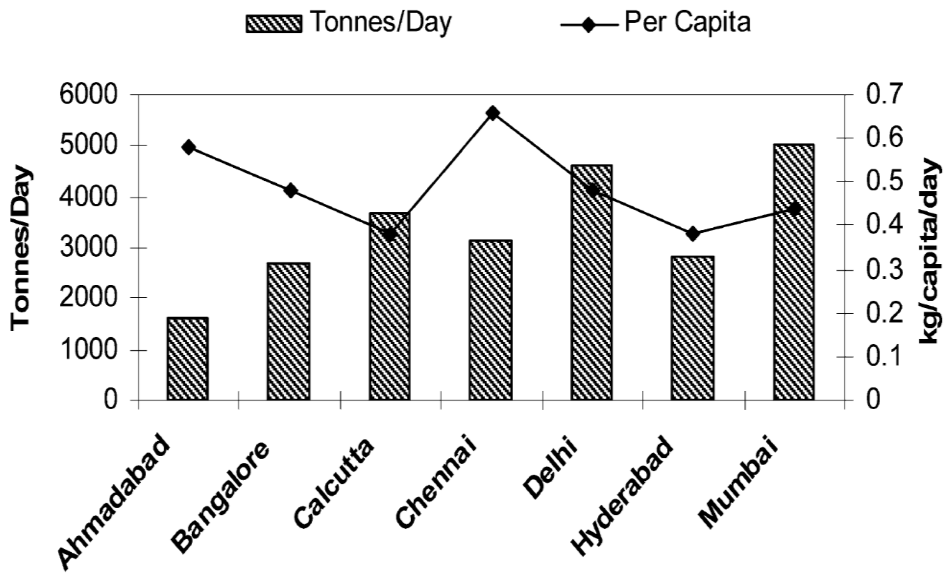


Fig. 1 MSW generation rates both in terms of per day and per capita basis for the seven most densely populated metro city of India (CPCB, 2004)

If such a big amount of MSW will not be managed properly, it will have a severe impact on the environment. The waste management policies and strategies are still struggling with the conflicts arising between developmental and environmental goals. The draft of the National Environmental Policy of 2005, which incorporates the concept of the 3Rs, is currently under consideration (MoEF, 2006 India). The ever increasing demand for larger space for the disposal of domestic and industrial wastes generated from urban areas makes landfill sites a necessary component of the urban life cycle. These low-lying disposal sites, being devoid of a leachate collection system, landfill gas monitoring and collection equipment, can hardly be called sanitary landfills and are a potential threat to the water resources, especially groundwater. The pollution threat becomes more important in regions where fractures or weak zones are present either just beneath the landfill or in its surrounding area.

Although the rules marked a significant improvement in the management of solid wastes, some think that these rules do not go far enough. There is an increasing belief among solid waste experts that unless further steps are taken to detoxify land filled materials, today's society will be placing a burden on the upcoming generations to address future landfill impacts. Much of the concern revolves around leachates, the watery solution which results after water passes through a landfill.

In recent decades, groundwater resources have become increasingly threatened by the leaching of contaminants from uncontrolled landfills, containing industrial and/or household wastes. Infiltration of pesticides and fertilizers from agricultural areas and leakage of a wide range of organic pollutants from petrol stations, refineries, pipelines etc. are some of the most severe problems for groundwater quality. Solid wastes may potentially contain any solid material found in nature and in addition many manmade materials they constitute the most heterogeneous collection of substances possible. (Calvo et.al. 2005) studied about the environmental diagnosis methodology for municipal solid waste landfill. **(**Themistoklis and Kontos 2005) studied the municipal solid wastes and reported high contaminations of ground water quality in MSW. (Pradeep, et.al., 2004) studied the heavy metal content in soil reclaimed from municipal solid waste landfill and reported high contamination consisting of fine and intermediate fractions) outside of the landfill. A more detailed site-specific study to evaluate the risk associated with the land application of the residual soil reclaimed from an MSW landfill would be beneficial.

Increasing demand for groundwater due to ever-increasing population has initiated the need for effective management of available groundwater resources. Groundwater modelling is a powerful management tool, which can serve multiple purposes such as providing a framework for organizing hydrological data, quantifying the properties and behaviour of the system and allowing quantitative prediction of the response of those systems to externally applied stresses (Anderson, et.al., 2002). Industrialization in all cities and dumping of their effluents in an unplanned way has caused a great concern to the environment. Hence, it is essential to understand the contaminant transport in groundwater through simulation of groundwater flow and contaminant transport. Dispersion and advection play a major role in spreading of leachate plumes (Freeze and Cherry, 1979). The adverse impacts of landfill leachate on adjacent surface water and groundwater have prompted a number of studies; these include research on the constituent of leachates as well as on the groundwater quality (Kjeldsen et al., 1993). Leachates are generated as a result of water or the liquid passing through the wastes (Kumar and Alappat, 2005). The uncontrolled infiltration of leachates into an unsaturated zone is considered as the worst environmental impact of the landfill (Tajero et al., 1993). The origin of these contaminated liquids can be attributed to many facts, including the water produced during the decomposition of the waste. Research has shown that the compositions of landfill leachates from the same source, as well as from different sources, are extremely variable (Chian and DeWalle, 1976).

Several researchers have solved the groundwater flow problem both analytically and numerically from the stochastic point of view by using a three dimensional model of variable saturated flow on hill slopes (Serrano, 1993; Gutjahr et.al., 1993; Nachabe et.al. 1995; Govindaraju et.al. 1994). Binely, et.al, 1989 investigated the effect of random hydraulic conductivity on surface -subsurface run-off and found them to be highly dependent on the variance and spatial dependence of the random field. Unplanned dumping of municipal and industrial wastes in residential areas of a metropolitan city like Delhi (~ 15 million population) is of great concern to the environment. Delhi, the capital city of India has been affected with fluoride contamination since a long time. No major research work has been carried out to locate point or non point source of fluoride in Delhi, having only a few researchers like Sujatha (2003) who tried to work in neighbouring state of Delhi. Kumar and Alappat (2005) worked in a few landfill sites in Delhi, which are one of the major sources of toxic heavy metals in Delhi groundwater aquifer.

As per an estimate of the Central Pollution Control Board (CPCB), the landfills of the National Capital Territory (NCT), Delhi, cumulatively generate a significant amount of leachates annually, which is alarming in terms of groundwater (CPCB 2001). In many parts of India, especially in the arid and semiarid regions, due to the vagaries of monsoons and scarcity of surface water, dependence on the groundwater resource has increased tremendously in recent years. Viewed from the international standard, availability of water "<1,700 m^3/person/year" qualifies as water-stressed and "1,000 m^3/person/year" as water-scarce, India is water-stressed today and is likely to face severe water scarcity by 2050 (CPCB 2001). Delhi, as the rapidly growing capital city of Asia, is facing problems both in terms of the groundwater quality and quantity.

The geology of the study area, an older and younger alluvium, makes it more susceptible to leaching. Hence, more attention is needed to understand the processes happening in and around this specific landfill site. A vast amount of literature is available on the presence of heavy metals in the solid wastes (Terao et al. 1993; Tisdell and Breslin 1995; Shivhare and Pandey 1996; Singh et al., 2008) and on the acidity of the soil solution and solubility of metals that are closely related (Taylor et al. 1987). According to Taylor et al. (1987), the acidity of soil increases by three- to five-fold with an increase in metal concentration. This causes heavy leaching of hazardous metals (Blais et al. 1993). Solid waste that contains metals at low pH has a high pollution potential to contaminate groundwater (Olaniya et al. 1991). In the study area, there has been no documented scientific study on the impact of the Bhalswa landfill leachate on groundwater. Although there are some unpublished reports on fluorosis and major ions by CPCB (2001), no published information with systematic data presentation is available to indicate the impact on the population that is exposed to contaminated groundwater in the surrounding area of the Bhalswa landfill.

The climate of study area is semi-arid due to marked diurnal difference of temperature, high saturation deficit and low–moderate rainfall. The climate is markedly periodic and is characterized by a dry and gradually increasing hot season between March and June, a dry and cold winter from October to February and the warm, monsoon period from July to September. The average rainfall is 721 mm and the annual evaporation is about 2,565 mm (Indian Meteorological Department (IMD) (1990–2005). The mean minimum and maximum temperatures are 18.7 ^{0}C and 30.5 ^{0}C, respectively, with daily maximum temperatures during the hottest months commonly exceeding 42.2 ^{0}C.

Hence, in this project a systematic study was carried out for the first time with the objective of studying the impact of landfill on groundwater quality, identifying the hydrogeochemical processes related to groundwater quality, conducting a hydrochemical evaluation of the aquifer system and delineating the various factors controlling the water chemistry and general suitability of the groundwater for domestic and drinking purposes in the vicinity of landfill sites. In this study an attempt has also been made to study of the movement of heavy metal transport in groundwater aquifer system. For simulation of solute transport a very small area of around 298.17 km2 in south Delhi was selected. It covers 60 % of City Block and 40 % of Mehrauli Block of NCT Delhi (Survey of India, 2001). The study area is surrounded in the west, north-west and south by Aravali ridge, while Yamuna River borders east and north-eastern side of the study area (Geological Society of India, 2001). Since the study area is triangular in shape and surrounded by natural boundaries only a small area is bounded by flux boundary. The study area is mainly overlain by alluvium which is underlain by quartzite patches and ridge of Arravali hillocks (Geological Society of India, 2001). This study has been attempted in Central-South Delhi, a region in between the river Yamuna and Aravali ridge covering an area of about 298.17 km^2 (Survey of India, 2000).

Delhi and the National Capital Territory of Delhi (NCT Delhi) has a specific status in the Indian political federalism. This territory has a pseudo-state status and is under the mixed control of the central government, and of a local government similar to other state's government. The National Capital Territory spreads over a total area of 1483 km^2, of which more than 60% is now urban (Census of Government of India 2001). This political situation has a direct impact on the city's access to water resources since in the Indian constitution, the management of water resources is primarily under the responsibility of the states. The National Capital Territory of Delhi, with a population around 15 million people (census 2001), has therefore very few resources under its direct control. Thus it is very essential to protect our groundwater resource (main source of drinking water in Delhi), from being contaminated by leaching of pollutants.

2. OBJECTIVES OF THE STUDY

Detailed characterization of Hydrogeological frame work of the study area through analysis of available information and detailed field inventory.

- Assessment of ambient status of contamination around landfills in space and time and identification of potential sources and path ways of migration of pollutants.
- Periodic groundwater regime monitoring in terms of quality and quantity in select observation wells in and around the land fill sites in respects of the constituents as per BIS -10500, and utilization of data so generated in ground water modeling studies to identify the geochemical behaviour and migration pathways of contaminants in ground water as well as its futuristic predictions.
- It is also proposed to incorporate integrated hydrogeological and geophysical study for identification of potential contamination sites as well as selecting suitable sites for the future landfills.

3. STUDY AREA

Delhi is the capital of India and sprawls over 1483 km^2 at latitudes 28^{o}35'N and longitude77 ^{o} 12'E located at an altitude of 218 m above the mean sea level. The Gangetic Plain and the Aravalli Ridge converge at Delhi and they give a mixed geological character with alluvial plains as well as quartzite bedrocks. The climatic regime of Delhi belongs to the semi arid type and is characterized by extreme dry conditions associated with hot summers and cold winters. The temperature ranges between 18.7 ^{o}C (mean minimum) and 40.3 ^{o}C (mean maximum). It also experiences heavy rains primarily during the periods of monsoon with an average rainfall of 714.6 mm. The groundwater level in Delhi city varies between 15 to 20 meter depth. Delhi, with a population approaching to 14 million is estimated to generate about 7000 metric tonnes of garbage daily. The per capita generation of solid waste in Delhi ranging from 150 gms to 600 gms a day depending upon the economic status of the community involved and it mainly includes waste from household, industries and medical establishments.

The earliest landfill was started in Delhi in 1975 near Ring road. In 1978 two other landfills were started at Timarpur and Kailash Nagar. Till date 17 landfill sites have been filled and closed. At present there are three large functioning landfill sites at Ghazipur, Okhla and Bhalswa (Fig 2). These sites are spread over an area of about 1.5 x 10^6 m^2. None of their bases is lined, which may result in continuous groundwater contamination. These sites had not been designed systematically before being used for disposal /dumping of wastes. Furthermore no environmental impact assessment had been carried out prior to selection of these sites.

I) Ghazipur Landfill Site

The Ghazipur landfill was started in the year 1984 and is still in use. It spreads over an area of approximately 3 x 10^5 m^2 and is situated near National Highway 24. On an average 2200 MT/day of waste is dumped and the waste fill height varies from 12 m to 20 m. It is located at the close proximity of the Hindon Canal. The waste dumped at this site includes domestic waste, e.g. kitchen waste; paper, plastic, glass, cardboard, cloths. Construction and demolition waste consisting of sand, bricks and concrete block are also dumped. Further waste from the adjacent poultry market, fish market, slaughterhouse, dairy farm and non-infectious hospital waste is also dumped. The site is non-engineered low lying open dump, looks like a huge heap of waste up to a height of 12-20 m. Trucks from different parts of the city collect and bring waste to this site and dump the waste in irregular fashion. The waste is dumped as such without segregation, except the rag pickers who rummage through the garbage and help in segregating it. They generally collect glass material, plastic and metals and sell this to the recycling units (Aggarwal et al., 2005). At this landfill site two water bore wells are operational, which are used for washing of refuse removal vehicles and maintenance of heavy earth moving equipments.

II) Bhalswa Landfill Site

The Bhalswa landfill is located in one of the most urbanized area in north-west Delhi between 28°42'30" to 28°45' latitudes and 77°7'30" to 77°11'54" longitudes, with an area of about 5 hectares used for dumping of the municipals solid wastes and industrial wastes. One side of this landfill is aligned by the River Yamuna.

The geology of Bhalswa landfill is mainly alluvium (98 %), while unconfined shallow aquifer (water table around 7 - 10 m) of this region is making it more susceptible for leaching of pollutants. The area of landfill is about 5 hectares and its life span is more than 5 years (source-CGWB Annual Report 1995). The Bhalswa region shows high population density as reported by census of India (Census 2001), which causes high load on groundwater resource (source-CGWB Annual Report). In general, peoples around landfill use groundwater only for domestic washing purpose, but most of sweets shopkeepers are still using it very frequently for cooking purposes also. Some people from Bhalswa Dairy village reported stomach pain if they used it anyhow for drinking. Generally few specific hand pumps show very high conductivity and pollution load. Sampling was done for complete two years in about 28 sq. kms around the landfill.

III) Okhla Landfill

The Okhla landfill Phase II is located in south Delhi near Tugalakabad fort at the top of Aravalli ridge, near the bank of the river Yamuna.

The geology of Okhla landfill is alluvium (25 %) with patches of quartzite (75 %). The Central Ground Water Authority (2000) reported this area as notified because of the shortage of groundwater resource. According to rule not a single boring is permitted without prior special permission of CGWA. But practically so many government as well private hand pumps are present in almost all the houses as well in streets of Prahlad Pur both East and West because of political reasons. In comparison to Bhalswa, here population density was very less (Census 2001). Area of this specific landfill is about 5 hectare and lifespan is more than 5 years (source- CGWB Annual Report 1995).

A deep aquifer was reported by CGWB, water table was obtained at the depth of 60-80 m from ground surface. Most of people in this region are using this groundwater for domestic purposes but Delhi Jal Board has maintained constant supply. Delhi Jal Board workers have not proper instructions about how much chlorine they should use one-gallon of water instead they generally dumped it without any scientific knowledge. Most of time, chlorinated water caused a very bad smell; sometimes it becomes self-toxic for our health.

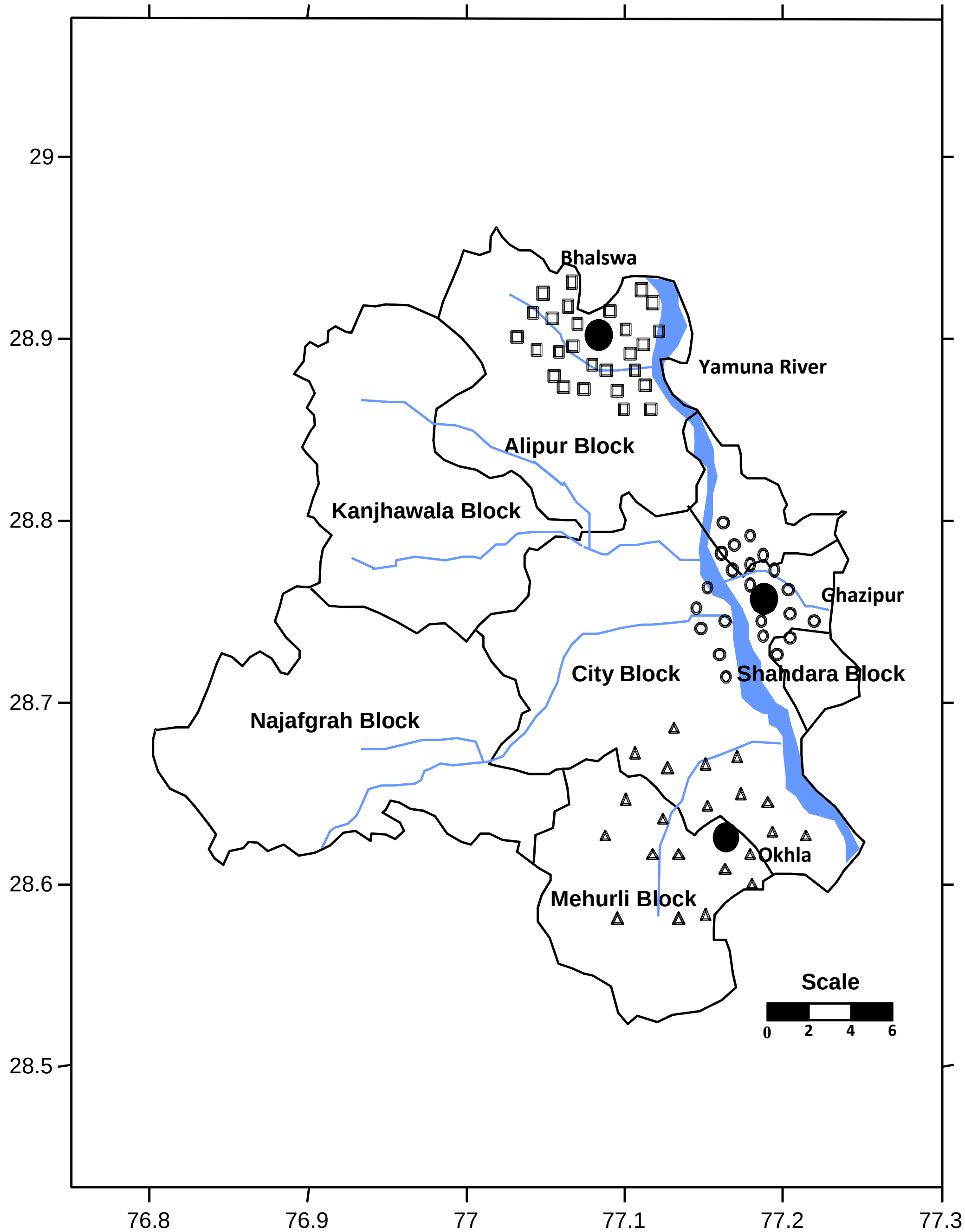


Fig 2 Study area and Sample location map

3.1. Geology of the Area

The groundwater availability in the territory is controlled by the hydro geological situation characterized by occurrence of alluvial formation and quartzite hard rocks. The hydro-geological set up of groundwater and the following distinct physiographic units further influence the groundwater occurrence (Fig 3).

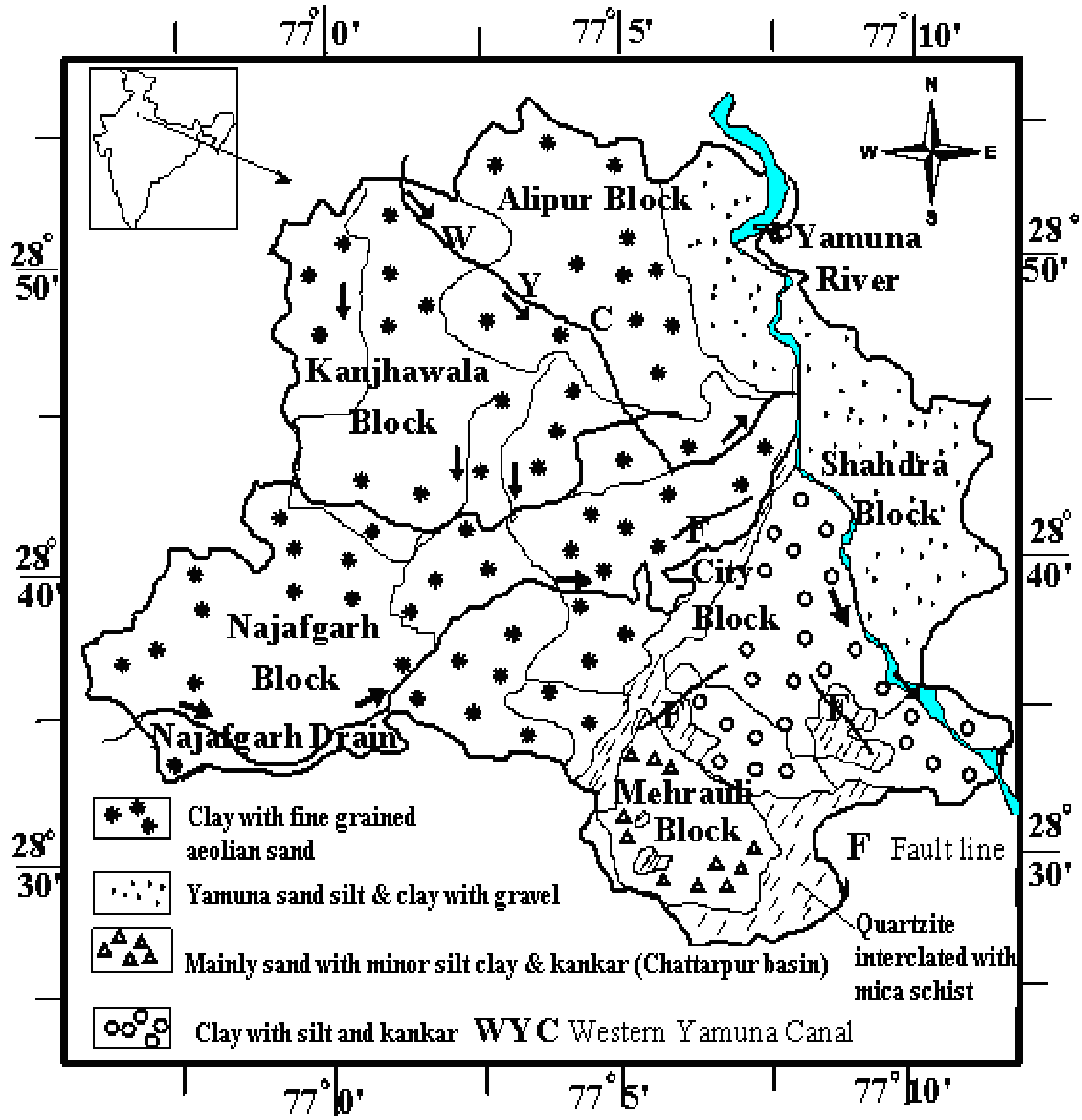
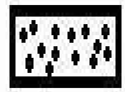
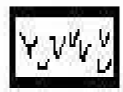
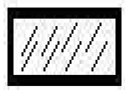
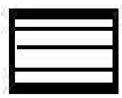
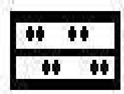


Fig. 3 Geology of the study area

Table 1 General stratigraphic sequence of the rock formation in Delhi and NCR

	Age Group	Lithology		Hydrological Condition	Groundwater potential
Unconsolidated Formation	Newer Alluvium (Quarternary)	Yamuna sand, slit and clay with gravel		30-40 m thick unconfined to semiconfined aqifers	Very large field 100-280 m^3/hr
	Older Alluvium (Tertiary)	Predominantly clay associated with fined grained aeolian deposits		Fairly thick regional extensive, semi-confined aquifers	Large field prospects 30-100 m^3/hr
		Predominantly clay with slit and kankar		Local, limited thick semi-confined aquifers	Moderate field prospects 23-100 m^3/hr
Consolidated Formation	Delhi super group (PreCambrian)	Mainly sand with minor silt, clay & kankar (chattarpur basin)		Fairly thick regionally extensive aquifers	Low field prospects 10-30 m^3/hr
		Quartzite interclated with mica schist, intruded by pegmatites & quartz veins		Weathered fractured quarzite, highly jointed	Limited field prospects 0-10 m^3/hr

1) Alluvial plain on eastern and western sides of the ridge.

2) Yamuna flood plain deposits.

3) Isolated and nearly closed Chattarpur alluvial basin.

4) NNE-SSW trending Quartzite Ridge

The Delhi ridge, which is the northernmost extension of Aravalli Mountain, consists of quartzite rocks and extended from southern part of the territory to western Bank of the river Yamuna for about 35 Km.

The alluvial formations overlying the quartzite bedrock have different nature on either side of the ridge. The Yamuna flood plain contains a distinct river sediment deposits. The closed Chattarpur alluvial basin occupies an area of about 48 sq. km, occupied by alluvium derived from the adjacent quartzite ridge. The general stratigraphic sequence of the rock formation in the territory is as follows:

3.1.1 Alluvial Deposits

The alluvial deposits of the Quaternary age are mainly composed of unconsolidated clay silt and sand with varying proportions of gravel and kankar etc. The alluvial formation is further divided into-

(i) New alluvium belonging to recent age and refers to the sediment deposited in the flood plains of the Yamuna River, also along watercourse of major streams flowing from the hills. These sediments range in texture from clay / silt mixed gravel etc. Newer alluvium in general, is characterized by absence of permanent vegetation (due to periodic flooding) and lack of Kankar.

(ii) Older alluviums are the sediments deposited as a result of past cycles of sedimentation of Pliestocene age and occur extensively in the alluvium plains of the territory. This is comprised of inter-bedded, lenticular and inter fingering deposits and sometimes as hard/compact pans. Older alluvium is predominantly clayey in nature, in major parts of territory except the nearly closed alluvium basin of Chattarpur where the alluvial formation is derived from the weathered quartzite rocks.

3.1.2 Hard Rock formation

The Alwar quartzites of Delhi System exposed in the area belong to Pre-Cambrian age. The quartzites are pinkish to gray in colour, hard, compact, highly jointed/ fractured and weathered. These occur with inter-beds of mica schist and are intruded locally by pegmatite and quartz veins. The strike of these rocks varies northeast to southwest (NE-SW) with steep dips towards SW and East except for some local variation due to folding. The prominent joint sets are strike joints and bedding joints. Quartzites are ferruginous and gritty types and weathering and subsequent disintegration give rise to coarse sand (Badarpur sands). The chemical weathering of deeper horizons is also common in Delhi.

3.1.3. Sub-Surface Configuration

The exploratory drilling undertaken has brought out the subsurface configuration of rock formations and depth to bedrock in different parts of NCT of Delhi. The nature of bedrock topography is rendered uneven due to existence of subsurface ridge.

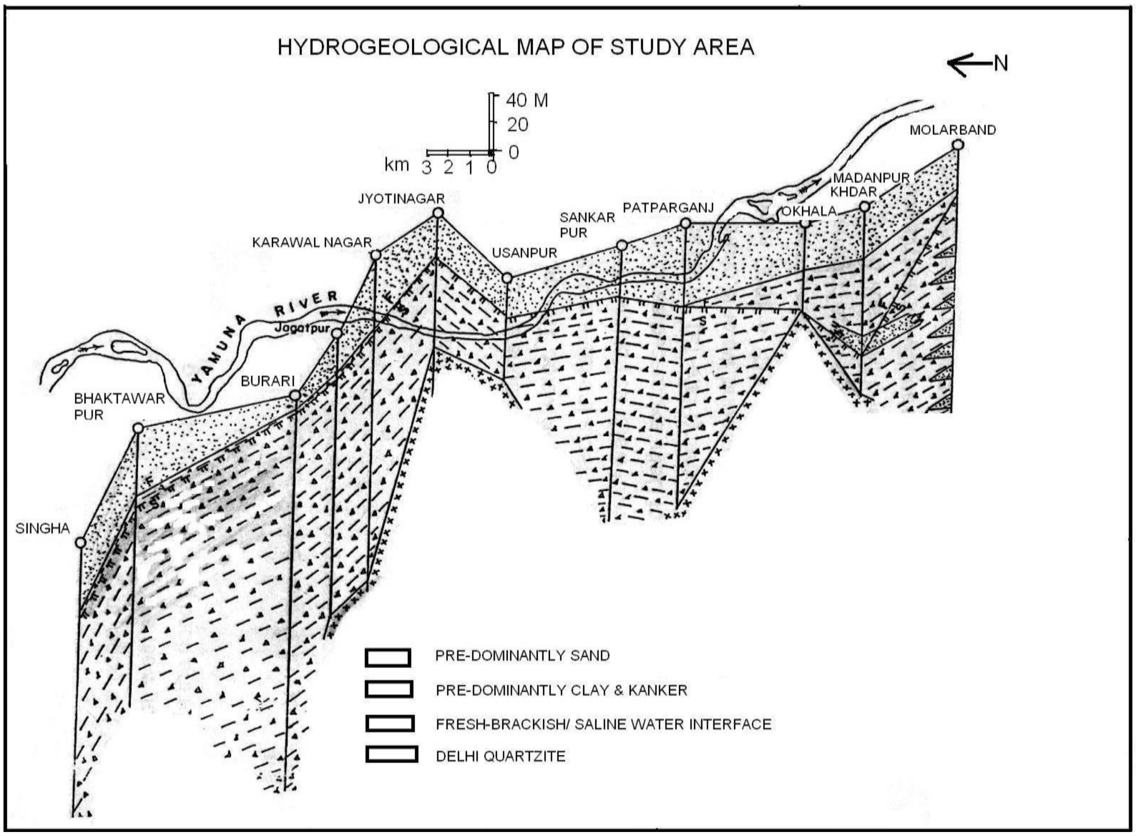


Fig 4 Hydro-Geological Map of Study Area

The thickness of alluvium overlying the quartzite increases away from the outcrops. While the thickness of alluvium is 300 m or more in most parts of Najafgarh, Kanjhawala and Alipur blocks while, in the south-eastern parts of Alipur block, it varies from 100 m to 300m. In the eastern parts of Najafgarh Block, the thickness range is from 50m to 300m. In city block (West of the Ridge), the alluvium thickness away from the ridge is 300m or more. The east of the ridge, in the area up to the river Yamuna, the alluvium thickness is comparatively less to about 165m. While the east of the river Yamuna covering parts of city and Shahdara blocks, thickness ranges from 48 m to 240 m. In the Chattarpur basin of Mehrauli block, the alluvial thickness varies from a few meters near the periphery to 115 m around Satbaribund.

The exploratory borehole data exhibits subsurface geology of the study area (Fig 4), west of the ridge and in north-northwest Delhi. These areas exhibit a predominantly clayey nature of alluvial formations generally beyond shallow depths. The top horizons in the depth range of 10 - 50 m are generally sandy in nature.

3.1.4. Soil Characteristics

The soils of the study area are mostly alluvial in origin. The precipitation and flood plain deposits influence the weathering process of soil in the study area. There are wide variations in the soil types and it is due to its mineralogical composition, topography, drainage pattern and geo-hydrological conditions. The soils of the present study are light grey in color and texturally sandy loam, silt loam and clay loam in around Bhalswa landfill, Ghazipur Landfill and sandy loam in Okhla landfill. These soils are generally highly alkaline and calcareous in nature.

3.2.1. Surface Water Resource

The river Yamuna is the main source of surface water in the capital territory, which emerges from the hills near Tajewala and flows from north to south in the territory. It enters Delhi near Wazirabad and after flowing through the Capital Territory for about Territory and flows through Dhansa Bund more or less as sheet flows. It first discharges into Nazafgarh Jheel and then flows into the river Yamuna through Nazafgarh drain. Besides, the rainwater generates run off which flows during monsoon through streams, nalas and drains. The streams have their well-defined watersheds mostly in hard rocks in the Delhi ridge areas and Chattarpur basin.

3.2.2. Groundwater Situation in Delhi

The NCT of Delhi, despite its limited aerial extent has a diversified geological and topographic set up giving rise to divergent GW situation in different parts. The prevalent rock formations ranging in age from Pre-Cambrian to recent, which control occurrence and movement of groundwater, are widely varied in composition and structure. The variations of landforms are like ridge areas traversing across the territory. The alluvial plain of western Delhi, closed Chattarpur basins and flood plains of the river Yamuna are quite significant to control the occurrence and movement of groundwater (CGWB, 1995).

The relatively high relief areas of the Delhi ridge with steeper topographic slopes and characteristic quartzite formation offer high runoff and less scope for rainwater infiltration. The inherent in homogeneity and low permeability of these hard rock formations further create a complex situation for occurrence and movement of groundwater. This in turn makes the groundwater development site specific, which needs to be decided through scientific surveys and exploration. The groundwater occurs in weathered and fractured / jointed parts of these rocks. The shallow aquifers mainly consist of weathered residuum, where as the joints and fractures constitute deeper aquifers.

The alluvial tract occupying large parts constitutes the potential groundwater reservoir in the territory. The characteristics and potential of groundwater reservoir, groundwater movement and occurrence show a distinct variation even in the alluvial aquifers due to their manner of deposition. The aquifer in western alluvial plains of the territory is distinct from the aquifers of the Chattarpur basin and those occurring in the Yamuna flood plains. The hydrological parameters and the potential of these aquifers are varied. The variation of quality of groundwater in space as well as depth adds another dimension to the complex groundwater situation in the territory. The presence of saline water aquifers at shallow depths varying from 20 m to 50 m below ground level in many parts presents a typical groundwater scenario. The groundwater occurs under phreatic condition in the shallow aquifer zone where as semi confined to confined conditions of groundwater are quite common in deep aquifers. In Yamuna flood plains and the Chattarpur basin, shallow fresh water aquifers within depth range of 40-50 m behave as a single unconfined aquifer system. In western part of the territory in Najafgarh block semi confined and confined aquifers occur at such depths.

3.3. CLIMATE

3.3.1. Rainfall

The records of every day rainfall data in the NCT are available from 13 stations viz. Chandrawal, New Delhi (Safdarjang), Delhi University, New Delhi (Palam), Okhla, Mehrauli, Delhi Sadar, Nangloi, Shadra, Najafgarh, Badli, Alipur and Narela. The normal annual rainfall in the territory is 611.8 mm. The rainfall increases from the southwest (SW) to northeast (NE) (source-IMD, Delhi). About 80 % of annual rainfall is received during monsoon in months of July, August and September (Table 3.1). The rest of annual rainfall is received as winter rain and as thunderstorm rain in the Pre- and Post- monsoon months. All these monthly rainfall data for 15 years (1990-2004) was collected from Indian Meteorological Department, New Delhi, India. These rainfall data were used in study of temporal variation of groundwater quality in the vicinity of selected landfill because rainfall is the major source of recharge of groundwater in the study area. Rainfall data were also used in simulation of solute transport in vicinity of the landfill because it helps in calculation of recharge in the given study area.

Table 2: The month wise break up of rainfall for NCT Delhi is as follows

	Jan.	Feb.	March	Apr.	May	Jun	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Normal Rainfall	14.5	13.2	9.9	5.5	9.2	38.8	191.6	197.4	105.3	19.3	2.8	4.3	611.8
Avg. No. of Rainy days	1.2	1.0	0.8	0.5	0.8	2.1	7.4	7.9	4.0	0.8	0.1	0.4	-

As the rainfall data indicates, most of rainfall occurs in the months of July to August and in the rest of the months, rainfall is very nominal. Hence it indicates most of recharge will takes place during the monsoon period. Hence major groundwater quality study is carried out in pre soon and post-monsoon, while a winter study is also carried out in order to link the gap between pre-monsoon and post-monsoon.

The precipitation over NCT of Delhi generates surface water runoff through streams, drains and as sheet flow. Considering a runoff, coefficient of 30 % in urban areas and 12 % in other areas, the total surface runoff works out to be 162 mm. The major part-of this runoff generally contributes to Yamuna flow in the mid and downstream part of the river.

The three-dimensional bar diagram of rainfall of the study area is shown in (Fig 6). While average number of days of rainfall in each month is shown in (Fig 7), the bar diagram shows that the most of the rainfall in the study area is by summer monsoon in the month of July and August, while winter monsoon shows very less rainfall. In the month of July 190 mm , August 198 mm and September 105 mm reported (Source: IMD, New Delhi). Average numbers of rainfall days in each month also indicates, most of the rainfalls occur by summer monsoon. On average 7 to 8 days rainfall takes in month of August and July while, minimum rainfalls occur in February and March month. (Source: IMD, New Delhi).

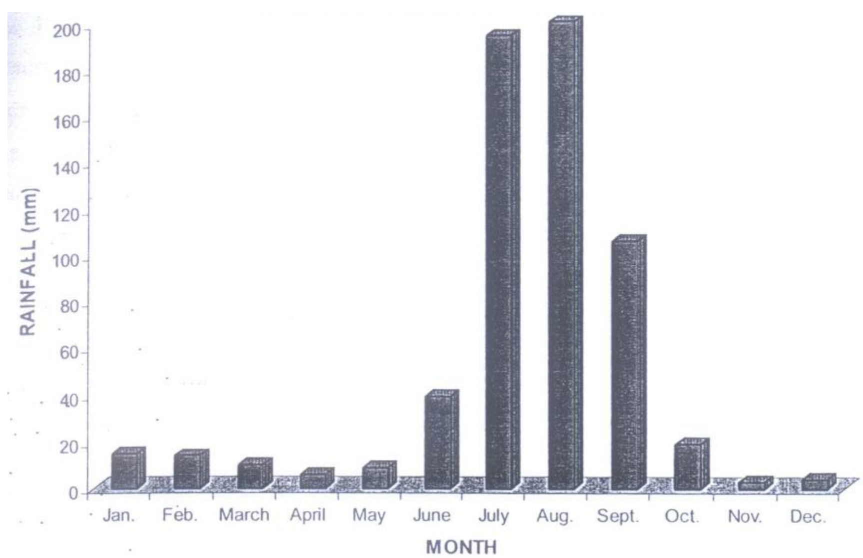


Fig. 6 The three-dimensional bar diagram of rainfall of the study area

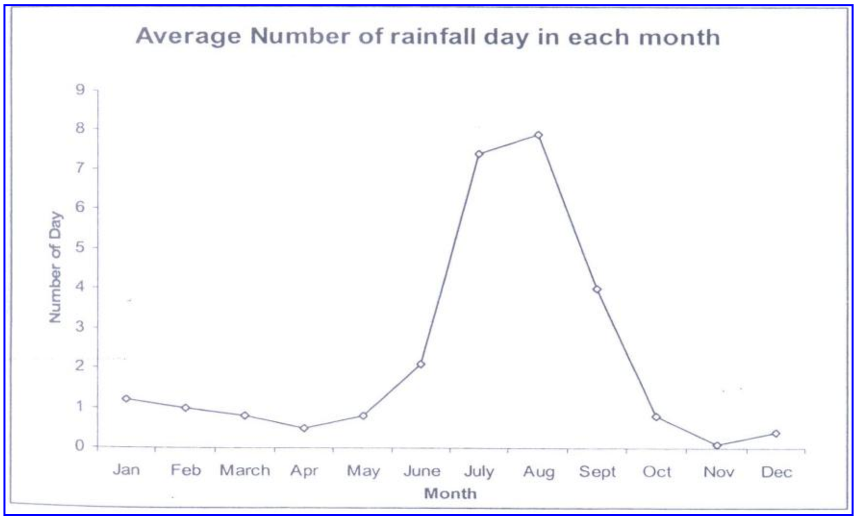


Fig. 7 The average number of day of rainfall in each month

3.3.2. Temperature

Daily temeperature data for 15 years from 1990 to 2004 was collected from Indian Meteorological Department, New Delhi, India to study climate change and its impact on hydro geochemistry of groundwater in the vicinity of selected landfill. Since, India is a tropical country, temperature causes impact on number of hydrological parameters like evapo-transpiration, humidity, discharge, infiltration and recharge etc. These data was also used in simulation of solute transport in the vicinity of the landfill. The summer of the study area is very hot and winter is very cold. The temperature range varies from 45 °C in summer to 4 °C in winter.

3.3.3. Humidity

The humidity data (from 1990-2004) is also collected from the Indian Meteorological Department, New Delhi, India. For study of groundwater quality, it is very essential to know humidity of the study area. High humidity is recorded during the month of July-August, while in the other months humidity is very normal as in a tropical country.

3.3.4. Evapotransparation

The evapotransparation is very important parameter for study of spatial and temporal variation of groundwater quality and simulation of solute transport. Evapotransparation daily data (from 1990-2004) were collected from Indian Meteorological Department, New Delhi, India. The Pan method was used for collection of evapotransparation data.

The evapotranparation data indicate that maximum evaporation takes place in month of June-July because of high temperature and high humidity. These evapotransparation data were quite useful for simulation of solute transport and study of groundwater quality in vicinity of the landfill in Delhi.

4. LITERATURE REVIEW

The study on landfills shows that the solid waste disposals and the leachate generated will affect the ground water and pollute the nearby surface water bodies. It is estimated that there is some role of complexion in determining the fate of metals in sanitary landfills. The leachate formation depends upon several factors whose importance had not yet been adequately investigated or reported in the available literature (Bloomfield and Pruden, 1975). Some Scholar like Poland reported that enhanced degradation of land fill wastes, degrade or immobilze harmful compounds within the waste mass and store excesses leachates (Pohland, 1975; Suiling Wang et.al.2005) reported occurrence of arsenic contamination in groundwater in Canada and their spatial distribution in aquifer system by analyzing the bioremediation of contaminant in aquifer system. The hydrochemical study shows that ground waters in the vicinity of the landfill are characterized by high contents of organic and inorganic chemicals: more than 4.5 mS cm^{-1} electric conductivity, 1600 mg l^{-1} chloride, 1000 mg l^{-1} sulphate, 15–25 μg l^{-1} cadmium and 60–100 μg l^{-1} chromium (Amina Chofqi et. al. 2005). The main pollution source is linked to the infiltration of leachate that conveys a strong polluting load and to the direct contact of the leachate with waters of the aquifer in the landfill carriers. Groundwater pollution and its distribution in the unsaturated zone are favored by: low depth of water table, high soil permeability, absence of drainage systems of the leachate, direct contact of groundwater with leachate at the bottom of landfill carriers, semi-arid climate (Amina Chofqi, 2005).

4.1. Groundwater contamination

Olaniya and Saxena (1977) had conducted studies for groundwater contamination for the period of two years (1969-1971) at Jaipur in Rajasthan, India. The results indicated higher concentration of TDS, COD, chloride, and Fe salts found to the depth of 450 meters. Whereas, the contamination of some toxic heavy metals like Cr, Cu, Fe, Mn, Cd, Pb in ground water around industrial and sewage waste of Parwanoo district, Himachal Pradesh, India was reported by Singh et al. (1976). The fate of heavy metals in solid waste leachates leaking into the groundwater or fed to a wastewater treatment plant not only depends on its bulk concentration but also on the actual speciation of heavy metal. Hegde et al. (1992) had found that open wells and bore wells, located in the vicinity of sewage courses found with Ca, Cl and Na ions at Hubli city, Hyderabad. Similarly Shivkumar and Biksham (1995) in their work mentioned that the elements like Cu, As, Se, Fe and F are five to ten times higher in surface soil and subsurface soil and in ground water around Medak district, Hyderabad. The industrial activities such as sugar mills, dying, bleaching and allied units release effluents without treatment, which may percolate down to the aquifer and foul it. The parameters analyzed in this water had pH 7.4- 8.0, EC 1940-21000 μmhos/cm, heavy metals Cu 1.04 –7.24, Cr 1.52-2.68, Cd ND-0.60, Zn 8.92-44.04 mg/L, in the order of Zn>Cr>Cu>Cd. Leachate will flow along the path of least resistance and in low hydraulic conductivity areas. The waste near flow channel was preferentially wetted compared to more distant waste, which suggests that channelling may decrease opportunity for leachates storage and enhancement of the biological activity.

Contamination of ground water is common in the areas surrounding the city refuse dumping sites. This is more so where dumping is done in low-lying areas and the rate of percolation through the soil is high. The composition of leachates and the presence of heavy metals in the leachates from wastes had been reported by number of workers. The rate and extent to which metals attenuate in the soil depends on the soluble complexes formed, the heavy metals speciation and pH of wastes (Bloomfield and Pruden, 1975; Glauser et al. 1988 and Blais et al. 1993). They had also reported high percentages of metals in the leachates of the size less than 500 molecular weight fraction. Das et al. (1989) studied the leaching behaviour of granular solid wastes in Netherlands. Whereas, Knox and Jones (1997) in Southern Ontario (Canada) found, that leachates were capable of forming complex with Cd. They also reported that the formation of complex is associated with molecular weight of the compound. Their behaviour suggested that complex might be formed between phenol's hydroxyl groups and Cd.

Lin et al. (1996) reported that the soluble organic matter of leachates from municipal and industrial wastes influence the heavy metals movement. The researcher from Kuwait, analyzed leachates from Al-Sulaibiyah solid waste disposal site in Kuwait and found high concentration of Ni and V in the leachates samples, which indicated the presence of petroleum related wastes at the site.

5. MATERIALS AND METHOD

With an increase in the population of Delhi city, quantity of waste materials also increases every day. All of them are located near the bank of the Yamuna River. The sampling locations are selected in such a way, that it truly represents length and breadth and the nature of dumping taking place in different parts to get the homogeneous picture of study area. The sampling has been carried out in pre-monsoon, post-monsoon in each year, during the period from 2004 to 2007 in and around these landfill-sites. A total of about seventy samples of ground water were collected in every season. The sampling locations had been selected in order to get maximum representation of the probable variations in groundwater quality and land use pattern with due consideration to its hydro-geological setup.

5.1. Field method

Groundwater samples were collected in 500-ml clean bottles and capped airtight. The parameters [pH, oxidation-reduction potential (ORP), dissolved oxygen (DO), electrical conductivity (EC), total dissolved solids (TDS) and temperature] were analyzed or measured in the field at the time of sampling by using a water-analyzer kit and crosschecked in laboratory. For cations, 100-ml samples were filtered using 0.45µm filter paper and preserved on site with ultra pure nitric acid (boric acid was used as a preservative for nitrate), and stored at $4^{o}C$ to avoid any major chemical alteration (APHA 1995). Sodium and potassium were analyzed by an AIMIC, PE I Flame photometer following the standard method (APHA 1995). An atomic absorption spectrophotometer (AAS-900) was used for the analysis of heavy metals (Mn, Fe, Cu, Ni and Zn) and alkaline earth metals (Mg and Ca). Anions (SO_4^{2-}, NO_3^{-}, F^{-} and silicate) were analyzed by using a JENWAY 6505 using the standard method as given in APHA (1995), UV/Vis spectrophotometer was used for analysis of HCO_3^{-} and Cl^{-} by titration method.HCO_3^{-} and Cl^{-} were analyzed by titration method using the standard procedure as given in APHA (1995). The landfill leachates were collected according to standard procedure as explained by Kumar and Alappat (2005) and Christensen et al. (2001) and were analyzed in the School of Environmental Sciences, Jawaharlal Nehru University, India.

5.2. Geochemical Studies

Chemistry of groundwater, collection of samples and the methods adopted including standard procedures for the sampling techniques are discussed by various authors (Schoeller 1967; Palm Quist 1973; Pickens et al. 1979).The analytical techniques and the sample collection are important in order to obtain a good result and therefore interpretation (APHA 1985, Ramanathan et al. 1993, 1996; Ramesh and Anbu 1996).

Parameters	**Methods**
pH, EC, TDS, DO and ORP	Electrode
Bicarbonate	Titration method
Sodium and Potassium	Flame photometer
Magnesium, Chlorine	Titration method
Silicate, Sulphate, Phosphate and Calcium	Spectrophotometer
Nitrate, Fluoride	Ion Selective Electrode
Heavy metals	AAS

5.3. Modeling

Groundwater models describe the groundwater flow and transport processes using mathematical equations based on certain simplifying assumptions. These assumptions typically involve the direction of flow, geometry of the aquifer, the heterogeneity or anisotropy of sediments or bedrock within the aquifer, the contaminant transport mechanisms and chemical reactions. Because of the simplifying assumptions embedded in the mathematical equations and the many uncertainties in the values of data required by the model, a model must be viewed as an approximation and not an exact duplication of field conditions. The models are important to understand general aspects of both groundwater flow and transport models so that application or evaluation of these models may be performed correctly. The following programs were used for groundwater modeling.

SPSS- This Statistical program is mainly used in correlation and factor analysis and other statistical analysis.

Aquachem: Geochemistry

6. RESULT AND DISCUSSION

6.1. Bhalswa Landfill

The distribution pattern of major cations and anions in groundwater in the vicinity of the landfill in all seasons was as follows: $Na^{+} >> Ca^{2+} > Mg^{2+} > K^{+}$ and $Cl^{-} >> SO_4^{2-} > HCO_3^{-} > F^{-}$. The analytical precision of the data was measured using the normalized inorganic charge balance (Huh et al. 1998), which is defined as $[(\sum+ - \sum-)/ (\sum+ + \sum-)]$ and represents the fractional difference between the total cations and total anions (Edmond et al. 1995).

Most of the groundwater samples showed good charge balance with ±5.0% error, which is generally considered acceptable because it is very difficult to analyze all cations and anions (Berner-Kay and Berner 1987; Edmond et al. 1995; Huh et al. 1998). The analysis of major ions (Na^{+}, K^{+}, Ca_2^{+}, Mg_2^{+}, Cl^{-}, SO_4^{2-} , NO_3 – , HCO_3^{-}) is generally enough to give a charge balance because it represents maximum concentrations of available dissolved ions in freshwater. Most of the water samples showed a charge balance mainly with positive-charge excess except for a few samples with some negative-charge deficit. Positive-charge excess greater than 5% observed earlier agrees with the database on the dissolved load near the Yamuna River (Sharma et al. 2004). The negative-charge deficit could be related to the fact that no analysis was made for organic matter.

6.1.1. Water chemistry and leachates composition

The average, maximum, minimum and standard deviation for each water quality parameter analyzed for both pre-monsoon and post-monsoon samples for years 2004,2005,2006 and 2007 are shown in (Table 3). The data indicates the landfill as the point source for all the contaminants because groundwater flow is outward away from the landfill site and the concentration of pollutants decreases radially as we move away from the landfill along the groundwater flow. Groundwater flow helps in dispersion and diffusion of leached contaminants in the groundwater aquifer system, but there is variation at different depths of water samples because leachate movements in groundwater vary with hydraulic gradient.

Groundwater pH around the landfill site is slightly alkaline due to the influx of HCO_3^- ions in subsurface water with rainwater through various ion-exchange processes in the aquifer system. (Fig. 6.1a1) indicates an unexpected rise in DO over a short period of observation due to the high inorganic activity/content in the water, which is believed to inhibit the consumption of oxygen by microorganisms (Srivastava and Ramanathan, 2006).

Table 3 Hydro-geochemistry of Groundwater around Bhalswa landfill (Ave, Min, Max value are in mg/l except PH and EC (µS/cm) in 2004, 2005, 2006, and 2007)

Pre-monsoon					Post-monsoon				
	Min	**Max**	**Avg**	**Std dev**		**Min**	**Max**	**Avg**	**Std dev**
Ca	60.49	215.49	107.39	40.13	**Ca**	59.4	210.84	101.21	39.78
Mg	12.29	50.07	24.86	9.35	**Mg**	11.79	43.48	23.33	8.96
Na	52.49	683.47	296.44	164.18	**Na**	50.19	678.94	294.07	163.73
K	3.79	46.84	22.66	9.74	***K***	3.66	40.05	18.02	10.08
Cl^-	138.79	1023.45	434.89	225.56	**Cl^-**	133.49	1027.46	444.05	224.50
HCO_3	62.56	284.27	147.81	52.86	**HCO_3**	62.05	284.16	139.87	53.46
SO_4	60.12	556.18	238.49	128.60	**SO_4**	60.12	562.48	236.83	128.19
NO_3^-	7.89	44.57	19.92	9.62	**NO_3^-**	7.01	45.16	22.73	9.97
F^-	2.01	10.01	5.74	2.25	**F^-**	1.98	9.95	6.21	2.17
H_4SiO_4	16.07	119.75	22.58	1.83	**H_4SiO_4**	17.12	29.12	23.47	1.63
pH	4	8.02	7.32	0.63	**pH**	6.29	8.49	7.18	0.36
Cond.	684	3256	1721.16	744.90	**Cond.**	648	2974	1661.21	724.34
TDS	474	2041	1166.82	505.79	**TDS**	464	2064	1183.79	506.82

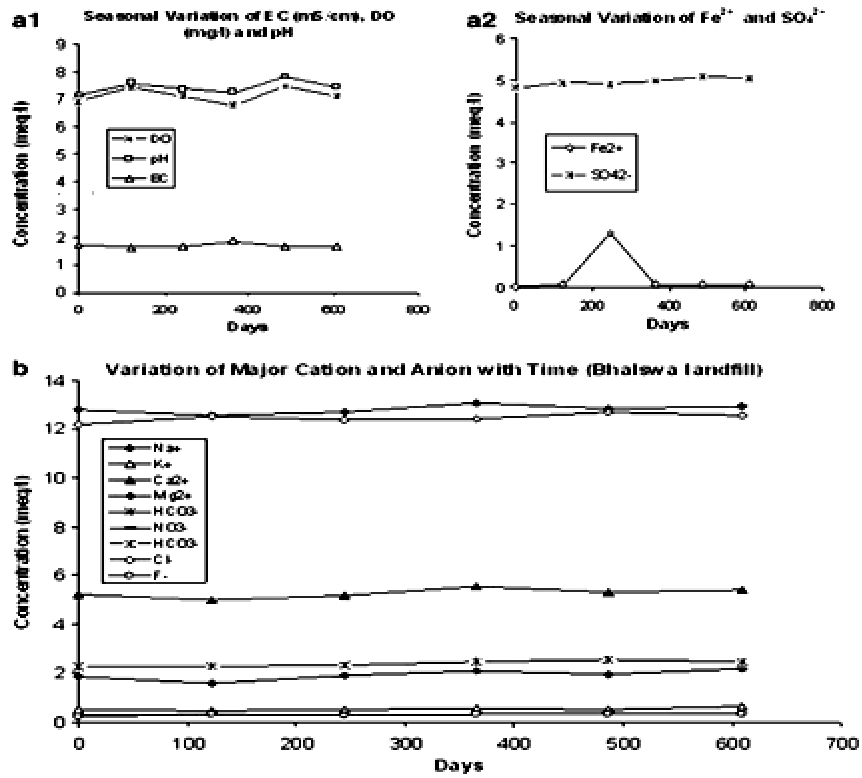
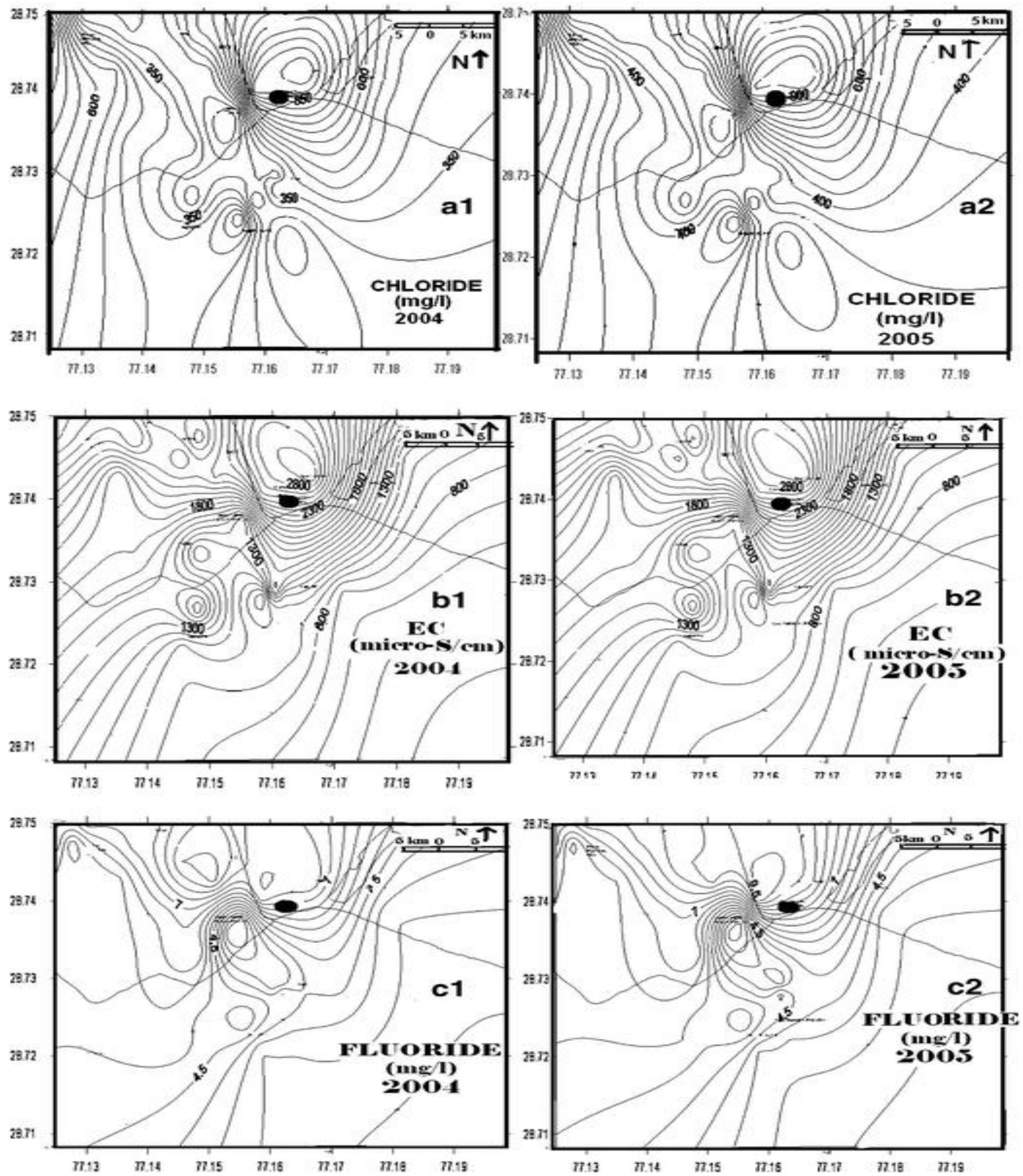


Fig. 8 Temporal variation in EC, DO, pH, Fe^{2+}, $SO_4{}^{2-}$ and other cations and anions in groundwater around landfill

The variation occurs due to spatial and temporal changes in the migration of contaminants from landfill leachates, indicated by the clustering of contour lines in and around the landfill. A few samples in Bhalswa Dairy village, which is located close to the landfill where the landfill leachates quickly seep into the groundwater, showed exceptionally high EC, i.e. 2,800 μS/cm. In general, Bhalswa Dairy village, and other areas, including Shalimar Village, J. J. Colony, Badali and Ramgarh, showed comparatively high EC values in their groundwater samples. Chloride and sulphate concentrations were also highest in this region, i.e., around 1,000 and 550 mg/l, respectively. The contour lines indicate high concentrations around Bhalswa Lake because it is acting as a pond to receive leachates from the landfill.


a1
CHLORIDE
(mg/l)
2004
a2
CHLORIDE
(mg/l)
2005
b1
EC
(micro-S/cm)
2004
b2
EC
(micro-S/cm)
2005
c1
FLUORIDE
(mg/l)
2004
c2
FLUORIDE
(mg/l)
2005
N
5 0 5 km
29.75
29.74
29.73
29.72
29.71
77.13
77.14
77.15
77.16
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77.18
77.19

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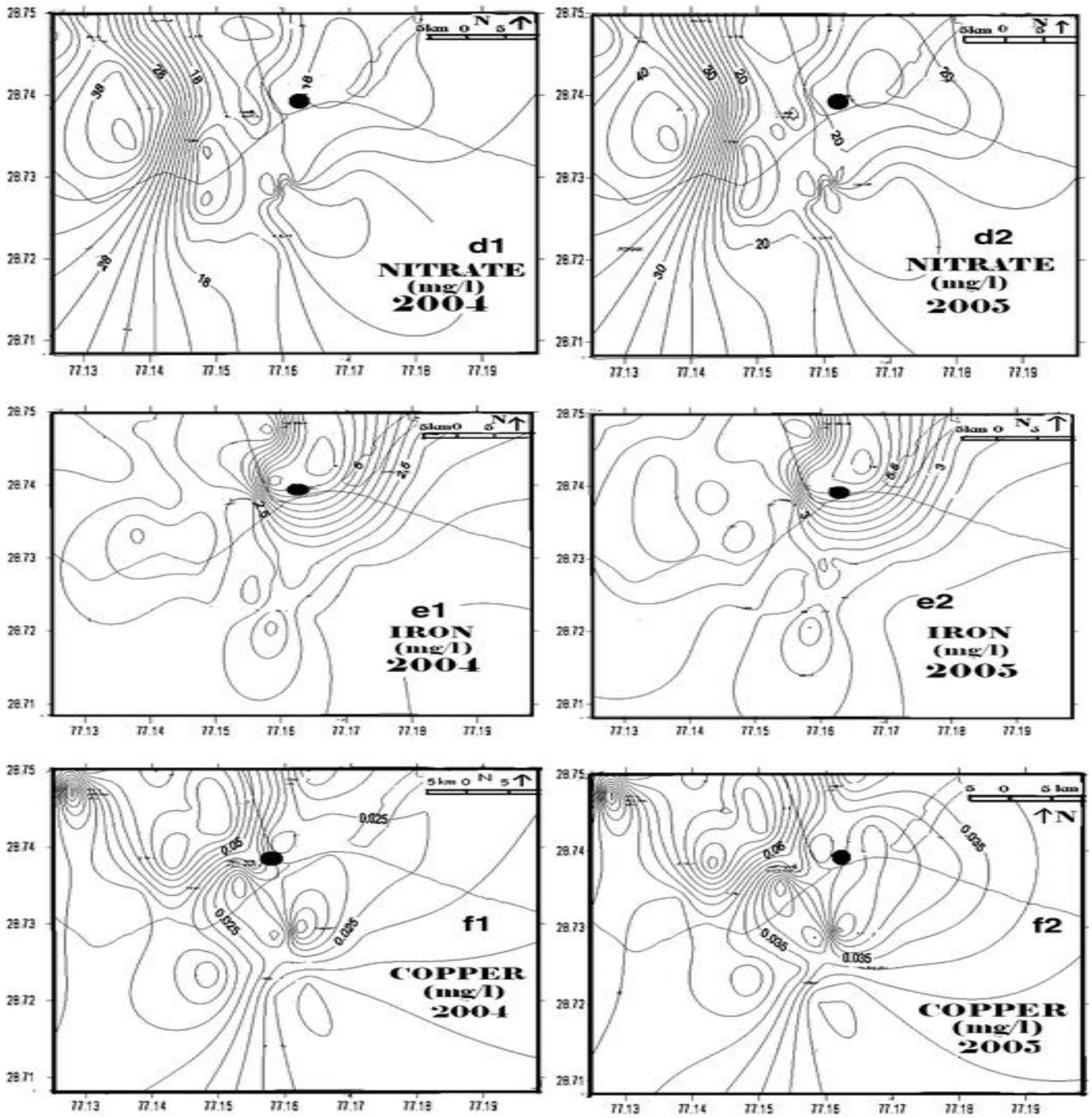


Fig. 9 Spatial distribution of different anions and heavy metals in groundwater around landfill

The average values for chloride and other anions (SO_4^{2-}, NO_3^-, F^-) are higher during post-monsoon than pre-monsoon perhaps due to the rise in the water table in post-monsoon, which allows salts coated in soil to dissolve in rainwater (Ramesam 1982; Ballukray and Ravi

1999; Jalali 2005). The other source of these anions is leachate that seeps along with the rainwater, a hypothesis that is supported by the variation in the different parameters with distance. The high-concentration contour lines for the anions around the landfill indicate possible anthropogenic input of these contaminants, i.e. leaching of these anions from the landfill. (Fig 9) The landfill leachates contain high concentrations of Cl^- (~4,000 mg/l), NO_3^- (~30 mg/l), F^- (~50 mg/l) and PO_4^{3-} (~4 mg/l), values that are higher than the values recommended by the Central Pollution Control Board (CPCB 2001), Delhi, India. The Bhalswa Dairy Village, Ramgarh and Yadva Nagar show comparatively high concentrations, perhaps due to migration of contaminant plume with groundwater flow.

Generally the major sources for nitrate in groundwater include domestic sewage, runoff from agricultural fields, and leachates from landfill sites (Lee et al. 2003; Jalali 2005). The groundwater samples collected around the landfill show that the nitrate concentration in the groundwater is very close to the concentration observed in leachate. This indicates that the vertical soil profile of the landfill is highly saturated with nitrate, which enables a large quantity of nitrate to seep out from the landfill to the groundwater. The hypothesis that the landfill serves as a point source for nitrate is also justified by the study of nitrate levels with distance from the landfill; statistical analysis supports this view. In general, Bawana and J. J. Colony show very high concentrations of nitrate, indicating anthropogenic input in the groundwater aquifer system (Jalali 2005). The spatial and temporal variations in nitrate concentration around the landfill indicate possible leaching of contaminants from the landfill because the landfill is the only known point source in this area.

Chemical analyses were used to identify the geochemical processes and mechanisms in the groundwater aquifer system. Most of the samples have a Na/Cl ratio around or above 1 during pre-monsoon and less than 1 during post-monsoon, indicating that an ion exchange process is prevalent in the study area.

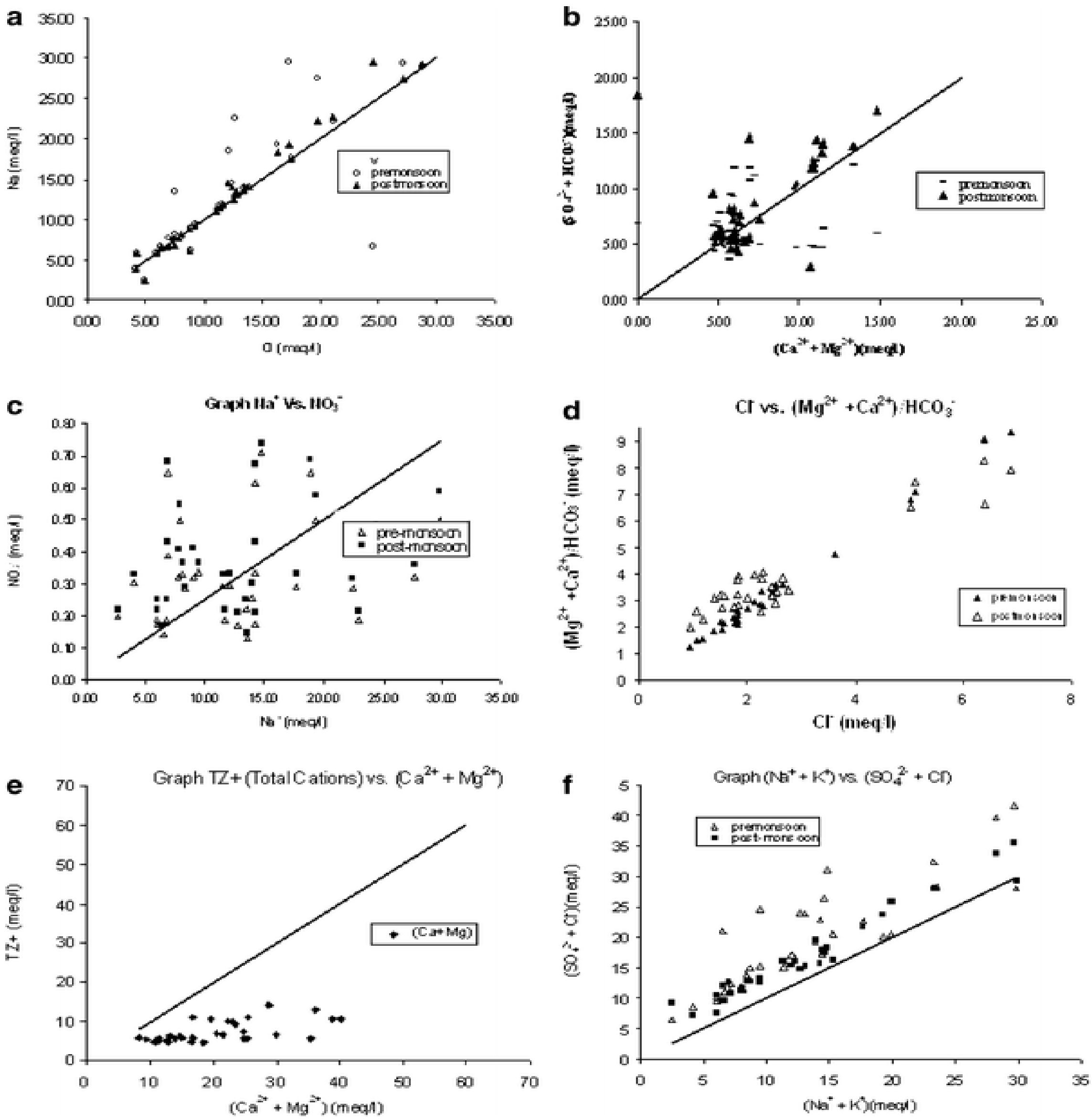


Fig. 10 Graphs of different parameters

The graph of $Ca^{2+} + Mg^{2+}$ versus $SO_4^{2-} + HCO_3^{-}$ will feature a nearly 1:1 line if dissolutions of calcite, dolomite and gypsum are the dominant reactions in the system. Ion exchange tends to shift the points towards right because of the excess of $SO_4^{2-} + HCO_3^{-}$ ions, which may be due to anthropogenic input in the groundwater system (Cerling et al. 1989; Fisher and Mulican 1997). The graph of $Ca^{2+} + Mg^{2+}$ versus $SO_4^{2-} + HCO_3^{-}$ shows most of samples fall above the 1:1 ratio line except for a few post-monsoon samples, indicating the predominance of the ion-exchange process in the groundwater system, which indicates possible leaching of these anions from the landfill. The graph of Na^{+} versus NO_3^{-} shows most of the groundwater samples scattered and falling above the equiline 1:1, which suggests anthropogenic input into the groundwater system because nitrate is released in groundwater mainly from anthropogenic sources (Lee et al. 2003; Subba Rao 2002). Since a major source of pollutants in this area is the Bhalswa landfill, an assumption of possible leaching of nitrate from the landfill is justified by the nitrate contour lines around the landfill. (Fig 9 d1&d2) The source of Ca and Mg in the groundwater can be deduced from the m $(Ca^{2+} + Mg^{2+})$/m (HCO_3^{-}) ratio. If calcium and magnesium originate solely from dissolution of carbonate in the aquifer from the weathering of accessory pyroxenes and amphibole minerals, the ratio would be about 0.5 (Sami 1992). The fact that this ratio increases with salinity shows that Ca and Mg are released into the groundwater aquifer faster than bicarbonate, indicating some anthropogenic input in the aquifer system.

The graph of TZ^{+} (total cation) versus $Ca^{2+} + Mg^{2+}$ shows most of the samples far below the theoretical line (1:1) (Fig 10 e), indicating an increasing contribution of alkalis to the major ions, which indicates anthropogenic input in the groundwater (Subba Rao and Devadas 2003). The increase in alkalis with a simultaneous increase in $Cl^{-} + SO_4^{2-}$ suggests a common source of these ions, as well as the presence of Na_2SO_4 and K_2SO_4 in the soils, indicates leaching of these ions from landfill leachates (Datta et al. 1996). The dominance of Na^{+}, an index of weathering, suggests that the ions result from dissolution of soil salts and/or derived from landfill leachates, which also suggests that the higher concentration of alkalis is from sources other than precipitation (Singh and Hasnain 1999).

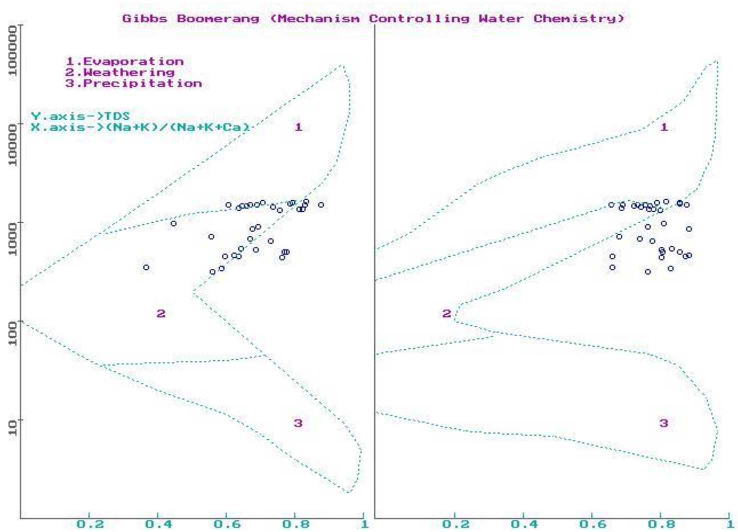


Fig. 11 Gibbs Diagram

All this indicates a significant effect of landfill leachates on the hydrogeochemical process occurring in groundwater aquifer systems in the vicinity of landfill. Most of the samples fall in the rock weathering zone (Fig 11).

Heavy metals in leachates and groundwater

Heavy-metal concentrations in groundwater and landfill leachates show spatial and temporal variation in the groundwater around the landfill .The contour lines around the landfill show a high concentration of heavy metals around Bhalswa Lake because it works like a leachate pond for the landfill, while the temporal variation indicates a consistent increase in heavy metals in groundwater. The spatial distribution shows some areas are highly contaminated, including the Badali Industrial Area, Rajasthan Industrial Area, and Bhalswa Dairy village, because all these areas are located very close to the landfill, which acts as a point source for these heavy metals because landfill leachates contain high concentrations of heavy metals (Fig 9). The hypothesis that the heavy metals originate from the landfill is also justified because there is no known natural source of these heavy metals in the study area. High concentration of heavy metals (Mn, Ni, Cu, Zn, Pb) was observed, which is hazardous for health.

Statistical analysis

The correlation matrix for groundwater samples collected around the Bhalswa landfill is shown in (Table 4). Numerical analysis of hydro geochemical data has been attempted to determine the geochemical parameters of groundwater (Lawrence and Upchurch 1982). Correlation and factor analysis are widely used in statistical or numerical concepts for parametric classification of modelling studies (Balasubramanian et al. 1985). Statistical data generally provide a better representation than graphical data because (a) there are a finite number of variables that can be considered, (b) variables are generally limited by convention to major ions, and (c) superior relationships may be deduced by use of certain procedures.

Table 4 Correlation Matrix of Bhalswa Landfill

	ORP	EC	TDS	Na+	K^+	Mg^{2+}	Ca^{2+}	Mn^{2+}	Fe^{2+}	Zn^{2+}	Cu^{2+}	Ni^{2+}	F^-	Cl^-	SO_4^{2-}	NO_3^-	HCO_3^-	PO_4^{3}
ORP	1																	
EC	−0.91	1																
TDS	−0.92	0.99	1															
Na+	−0.45	0.52	0.50	1														
K^+	−0.39	0.51	0.48	0.48	1													
Mg^{2+}	0.02	0.02	0.01	0.38	0.28	1												
Ca^{2+}	0.06	−0.07	−0.07	0.37	0.24	0.96	1											
Mn^{2+}	0.02	0.16	0.12	0.26	0.10	0.37	0.34	1										
Fe^{2+}	−0.42	0.58	0.47	0.55	0.33	0.51	0.48	0.53	1									
Zn^{2+}	−0.63	0.75	0.69	0.78	0.57	0.29	0.25	0.38	0.68	1								
Cu^{2+}	−0.36	0.48	0.39	0.02	0.11	−0.38	−0.39	−0.37	−0.16	−0.01	1							
Ni^{2+}	0.08	−0.11	−0.12	0.29	−0.11	0.01	−0.09	0.30	0.11	0.09	−0.36	1						
F^-	−0.72	0.78	0.79	0.56	0.52	0.02	0.01	0.11	0.47	0.53	0.48	−0.27	1					
Cl^-	−0.45	0.51	0.48	0.99	0.44	0.46	0.41	0.25	0.61	0.79	0.01	0.29	0.49	1				
SO_4^{2-}	0.13	−0.10	−0.10	0.28	0.30	0.91	0.92	0.24	0.54	0.19	−0.36	−0.12	−0.01	0.35	1			
NO_3^-	−0.33	0.39	0.37	0.22	0.31	−0.29	−0.32	−0.26	−0.03	0.18	0.44	0.18	0.22	0.15	−0.29	1		
HCO_3^-	−0.58	0.71	0.70	0.54	0.65	−0.01	−0.06	0.14	0.39	0.76	0.20	−0.03	0.58	0.54	−0.12	0.56	1	
PO_4^{3-}	0.57	−0.48	−0.49	−0.35	−0.03	0.27	0.22	−0.02	−0.29	−0.33	−0.31	−0.11	−0.58	−0.35	0.28	−0.16	−0.29	1

Good correlation was observed between TDS and EC, F− and EC, Na^+ and EC, K^+ and EC, HCO_3^- and EC, Zn and EC, Ca^{2+} and Cl^-, Ca^{2+} and Mg^{2+}, Ca^{2+} and Na^+, Ca^{2+} and SO_4^{2-} , Ca^{2+} and K^+, Na^+ and Mg^{2+}, Mg^{2+} and Cl^-, Mg^{2+} and SO_4^{2-} , Ca^{2+} and F^-, Na^+ and Cl^-, Na^+ and F^-, Na^+ and SO_4^{2-} , and Na^+ and K^+, indicating that all of them have the same origin (Chidambaram and Ramanathan 2000). Almost all analyzed metals showed 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). Sodium showed good correlation with chloride (0.99),(Table 4) indicating anthropogenic input in groundwater, and moderate correlation with fluoride (0.56), zinc (0.78) and iron (0.55), indicating input of heavy metals and fluoride in groundwater through leaching of landfill (Kumar and Alappat 2005). In general, highly polluted groundwater samples have low oxidation-reduction potential because of the reducing atmosphere. Most of the samples in the vicinity of the Bhalswa landfill show low oxidation-reduction potential, which indicates a reducing atmosphere in the groundwater in the vicinity of the landfill.

Factor analysis

Factor analysis is one of most important statistical methods for interpretation of hydrochemistry of groundwater (Subba Rao 2002). Mahlknecht (2003) presented molar relationships to elucidate factors controlling geochemical reactions in the groundwater aquifer. In our study, factor analyses were used as an alternative tool for corroboration of the concept obtained from molar calculation. Factor analyses allow determination of basic independent dimensions of variables (Chidambaram and Ramanathan 2000). The factor analysis in this study was carried out using SPSS. The software provides a numerical value resulting from different variants as components and initial eigen values for each species (Table 5). With the help of linear combinations, an originally large number of variables can be reduced to a few factors. These factors can be interpreted in terms of new variables. There exist numerous solution methods and variations for determination of factors (Mahlknecht et al. 2004).

Factor analysis as applied to widely differing sets of groundwater hydro geochemical data appears to be moderately successful as a statistical tool for revealing hydro chemical and hydro geological features (Mahlknecht et al. 2004). The aim of the factor analysis of the hydro geochemical data is to explain the observed relationship in simple terms expressed as a new set of variables called factors. In general, the factor will be related to the largest eigen value and will explain the greatest amount of variance in the data set. The factor analysis of groundwater data around the Bhalswa landfill is shown in Table 5.

Factor I of the principal component factor matrix of groundwater around the Bhalswa landfill is characterized by the strong loading of Fe, Na^+, K^+, Cl^-, F^-, HCO_3^-, EC and TDS and accounts for 35.74% of the variance in pre-monsoon and 38.80% of the total variance in post-monsoon because of dissolution of various ions with rainwater. Strong loading of Na^+ and K^+ indicates natural weathering of rock minerals and various ion-exchange processes in the groundwater system in the vicinity of the landfill (Drever 1997). There were no known natural sources of fluoride in Bhalswa landfills; the hypothesis of anthropogenic input is also justified by the spatial distribution of F– ions around the landfill.

Factor II of the principal component factor matrix of groundwater around the Bhalswa landfill is characterized by the strong loading of Ca^{2+}, Mg^{2+} and SO_4^{2-} ions, which accounts for 22.29% of the variance in pre-monsoon samples and 19.72% of total variance in post-monsoon samples. The strong loading of Ca^{2+} and SO_4^{2-} indicates weathering of gypsum, which is believed to be available in the geology of Delhi.

Factor III is characterized by strong loading of Ni, which accounts for 8.77% of total variance in pre-monsoon samples and 13.20% post-monsoon. The strong loading of Ni indicates an anthropogenic input in groundwater system because there are no known natural sources of Ni in the geology of the study area.

Factor IV is characterized by the strong loading of NO_3^- ions, indicating an anthropogenic input in the groundwater system due to leaching of fertilizer from agriculture land (Mahlknecht et al. 2004) or leaching from the municipal landfill (Kumar and Alappat 2005), while spatial distribution of NO_3^- around the landfill indicates possible leaching of NO_3^- from the landfill.

Factor V indicates groundwater chemistry is controlled by the pH variation in the aquifer system.

Table 5 Principal component matrix for each parameter analyzed for groundwater.

	Pre-monsoon							Post-monsoon					
	1	2	3	4	5	Initial	Extraction	1	2	3	4	Initial	Extraction
pH	−0.39	0.14	0.33	0.35	0.69	1	0.88	−0.64	0.10	0.36	0.31	1	0.67
ORP	−0.71	0.49	0.09	0.02	−0.32	1	0.84	−0.82	0.32	0.01	0.11	1	0.75
EC	0.78	−0.48	−0.07	−0.09	0.29	1	0.94	0.88	−0.33	−0.001	−0.11	1	0.84
TDS	0.79	−0.49	−0.10	−0.12	0.25	1	0.95	0.88	−0.33	−0.003	−0.1	1	0.81
Na	0.83	0.09	0.25	0.18	−0.09	1	0.80	0.74	0.35	0.25	0.28	1	0.66
K	0.73	−0.06	0.21	0.21	−0.27	1	0.70	0.79	−0.04	−0.06	0.11	1	0.82
Mg	0.46	0.81	−0.11	0.13	0.19	1	0.94	0.25	0.52	−0.65	0.23	1	0.87
Ca	0.37	0.84	−0.24	0.15	0.16	1	0.95	0.31	0.77	−0.34	0.26	1	0.82
Mn	0.38	0.47	0.23	−0.39	0.04	1	0.58	0.31	0.47	0.57	−0.42	1	0.77
Fe	0.69	0.35	0.01	−0.31	0.15	1	0.72	0.70	0.43	0.13	−0.26	1	0.83
Zn	0.92	−0.02	0.09	−0.15	−0.12	1	0.89	0.87	0.18	0.19	−0.06	1	0.67
Cu	0.02	−0.7	−0.36	−0.03	0.23	1	0.67	0.27	−0.69	−0.34	0.02	1	0.81
Ni	0.11	0.1	0.91	−0.01	−0.09	1	0.85	0.02	0.17	0.87	0.19	1	0.83
Fluoride	−0.19	−0.07	0.24	−0.57	0.29	1	0.50	0.81	−0.29	−0.24	−0.17	1	0.82
Chloride	0.84	0.16	0.23	0.13	−0.07	1	0.80	0.78	0.38	0.18	0.18	1	0.90
Sulphates	0.32	0.84	−0.3	0.12	0.13	1	0.92	0.17	0.84	−0.39	−0.03	1	0.83
Nitrate	0.27	−0.48	0.26	0.62	0.09	1	0.76	0.31	−0.48	0.12	0.70	1	0.67
Bicarbonate	0.77	−0.32	0.03	−0.01	−0.27	1	0.77	0.77	−0.23	0.11	0.10	1	0.67
Total	6.43	4.01	1.58	1.26	1.16			6.60	3.35	2.24	1.18		
% of variance	35.74	22.29	8.77	6.98	6.43			38.80	19.72	13.20	6.92		
Cumulative %	35.74	58.03	66.80	73.78	80.21			38.80	58.52	71.72	78.64		

Classification of water types

Based on the Na %, about 42.42% of our groundwater samples were within permissible limits, 48.48% were doubtful, 3.03% were unsuitable and 6.06% were good. On the basis of EC, 63.64% of our groundwater samples were permissible, 30.30% were doubtful and 6.06% were good. Seasonal variations in groundwater quality were also seen but were very small. Richard (1954) classified water quality on the basis of sodium absorption ratio (SAR) as shown in (Table 5). According to Richard's classification, 81.81% of our groundwater samples were excellent and 18.19% were good. Stuyfzand (1989) classified water on the basis of Cl^{-} ion concentration into eight divisions as shown in Table 6.4. According to Stuyfzand, 63.64% of our groundwater samples were brackish, 27.27% were fresh-brackish, 6.06% were fresh and 3.03% were brackish-salt on the basis of Cl^{-} concentration. USSL (1954) classification is based on the concentration of total dissolved solids as shown in Table 6. According to USSL classification, 60.60% of our groundwater samples showed total dissolved solids concentrations in the range of 500–1,500 mg/l, 36.36% were in the range of 1,500–3,000 mg/l and 3.03% were in the range of

200–500 mg/l. Eaton also classified water quality on the basis of percentage of Na in water. According to the Eaton Classification (Eaton 1954), 48.48% of our groundwater samples were safe, while 51.52% were unsafe for use. Most of the samples show decreasing order of cation facies order with Na+ > Ca2+ > Mg2+ > K+, while a few samples show a different trend, indicating some localized changes in quality. This is possible only in cases of anthropogenic input in the groundwater system (Guler et al. 2002). The other possible hydrochemical facies based on major cation concentrations in the groundwater aquifer system in the vicinity of Bhalswa landfill are as follows: $Na^{+} > Ca^{2+} > Mg^{2+} > K^{+}$(73.45%), $Na^{+} > Mg^{2+} > Ca^{2+} > K^{+}$ (13.45%), and $Ca^{2+} > Na^{+} > Mg^{2+} > K^{+}$ (13.10%).

Table 6 Water classifications

Classification scheme	Categories	Ranges	Percent of samples
EC (Wilcox 1955)	Excellent	<250	0
	Good	250–750	6.06
	Permissible	750–2,250	63.64
	Doubtful	2,250–5,000	30.30
	Unsuitable	>5,000	0
RSC (Richard 1954)	Good	<1.25	100
	Medium	1.25–2.5	0
	Bad	>2.5	0
Na% (Wilcox 1955)	Excellent	0–20	0
	Good	20–40	6.06
	Permissible	40–60	42.42
	Doubtful	60–80	48.48
	Unsuitable	>80	3.03
Na% (Eaton 1950)	Safe	<60	48.48
	Unsafe	>60	51.52
TDS classification (USSL 1954)		< 200	0
		200–500	3.03
		500–1,500	60.60
		1,500–3,000	36.36
Cl^{-} classification (Stuyfzand 1989)	Extremely fresh	<0.14	0
	Very fresh	0.14–0.85	0
	Fresh	0.85–4.23	6.06
	Fresh brackish	4.23–8.46	27.27
	Brackish	8.46–28.21	63.64
	Brackish-salt	28.21–282.06	3.30
	Salt	282.06–564.13	0
	Hypersaline	>564.13	0
SAR (Richard 1954)	Excellent	0–10	81.81
	Good	10–18	18.18
	Fair	18–26	0
	Poor	>26	0

Most samples showed decreasing order of anions in groundwater samples as $Cl^{-} > SO_4^{2-} > HCO_3^{-}$, while a few samples showed different trends, indicating some localized changes in quality. The other possible hydrochemical facies based on major anion concentrations in the groundwater aquifer system in the vicinity of the Bhalswa landfill are as follows: $Cl^{-} > SO_4^{2-} > HCO_3^{-}$ (73.45%), $Cl^{-} > HCO_3^{-} > SO_4^{2-}$ (23.45%), $SO_4^{2-} > Cl^{-} > HCO_3^{-}$ (3.10%).

The Piper and Durov diagrams indicate most of the samples were classified as Ca–Na type of cation facies and Cl^{-} type of anion hydrochemical facies, while samples BH11, BH15 and BH24 showed Cl^{-}– SO_4^{2-} –HCO_3^{-} type of anion hydrochemical facies (Fig 12 a1, a2, b1, b2) (Table 7). The Piper and Durov diagram shows temporal variation of these ions, indicating an increase in concentration of chloride ions because of anthropogenic input from the landfill, since there is no known natural source of chloride in the study area. A total of 90.91% of groundwater samples collected around the landfill showed Ca–Na type cation hydrochemical facies and Cl^{-} type of anion hydrochemical facies in pre-monsoon, whereas 9.09% of groundwater samples showed Ca–Na type cation hydrochemical facies and Cl^{-}– SO_4^{2-} –HCO_3^{-} type of anion hydrochemical facies in pre-monsoon.

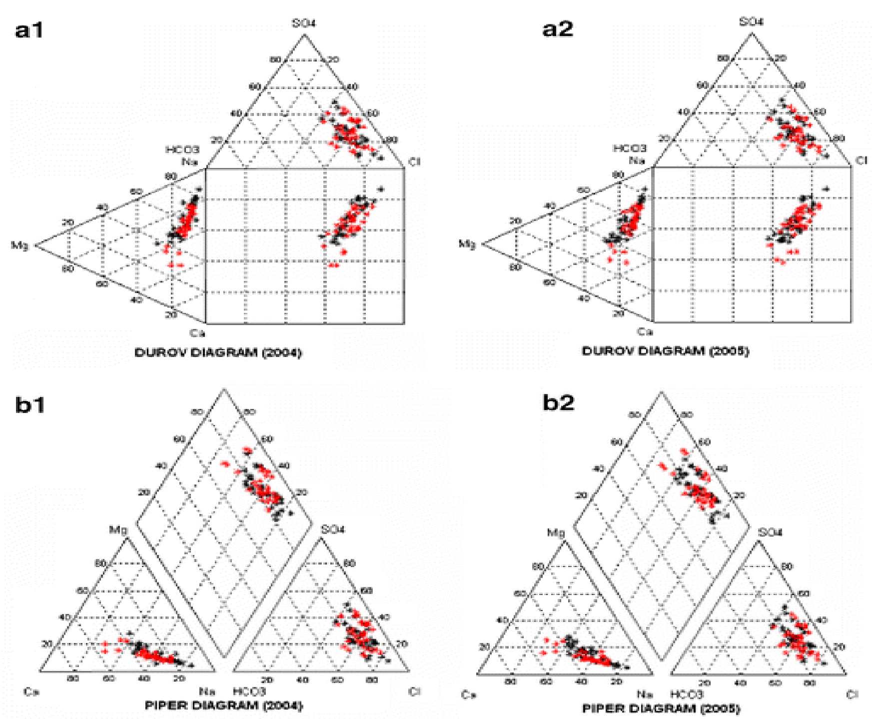


Fig. 12 Durov, Piper and Schoeller diagrams (red pre-monsoon, black post-monsoon)

Table 7 Hydro geochemical facies type

Sample no.	Hydrochemical facies type
Pre-monsoon	
BH1, BH2, BH3, BH4, BH4, BH5, BH6, BH7, BH8, BH9, BH10, BH12, BH13, BH14, BH16, BH17, BH18, BH19, BH20, BH21, BH22, BH23, BH25, BH26, BH27, BH28, BH29, BH30, BH31, BH32, BH32, BH33	Cation facies: calcium–sodium facies Anion facies: chloride facies
BH11, BH15, BH24	Cation facies: calcium–sodium facies Anion facies: chloride-sulfate-bicarbonate facies
Post-monsoon	
BH1, BH2, BH3, BH4, BH4, BH5, BH6, BH7, BH8, BH9, BH10, BH12, BH13, BH14, BH16, BH17, BH18, BH19, BH20, BH21, BH22, BH23, BH25, BH26, BH27, BH29, BH30, BH31, BH32, BH32, BH33	Cation facies: calcium–sodium facies Anion facies: chloride facies
BH11, BH15, BH24, BH28	Cation facies: calcium–sodium facies Anion facies: chloride-sulfate-bicarbonate facies

The situation is changed post-monsoon due to the addition of various ions from rainwater and further dilutions in various proportions (Rajamohan and Elango 2004). Post-monsoon only 87.88% samples showed Ca–Na type of cation hydrochemical facies and Cl^- type of anion hydrochemical facies, and 12.12% groundwater samples showed Ca–Na type cation hydrochemical facies and Cl^- – SO_4^{2-} – HCO_3^- type of anion hydrochemical facies (Chidambaram and Ramanathan 2000). The results indicate that groundwater samples collected from Rajasthan Industrial Area (BH11), Haidur Pur (BH15) and J. J. Colony (BH24) showed Cl^- – SO_4^{2-} – HCO_3^- type hydrochemical facies in pre-monsoon period (Table 7). This indicates a change in water quality because of localized anthropogenic inputs in this area along with input of contaminants from the landfill.

6.2. Okhla Landfill

Ground Water Quality in Vicinity of Okhla Landfill

Okhla landfill site is a small landfill with an area of about 5 hectares, generally used for municipal dumping but industrial waste product dumping is also very common in this area (CPCB, 1995-2004). The geology of this area makes it more susceptible as a source for groundwater contamination (Dinesh Kumar et.al. 2005). In 1998, on the recommendation of Central Pollution Control Board, Government of India ordered to close down the cement factory very close to this landfill, because Central Pollution Control Board reported arsenic problem in some container of the industry (CPCB, 1998). But still municipal solid waste and other industrial waste dumping continues. As reported of different organizations, landfill dumping is over flooded and Central Ground Water Authority (CGWA, 1995) has declared as notified area which makes more important for the study of groundwater quality .in this area. As geology of the study area makes it more susceptible for leaching. Central Pollution Control Board (1995-2004) reported indication of pollution due to leaching of pollutants. Hence, it needs vast study on this specific landfill.

The studies of hydrochemistry give an indication of environment around the study area. It helps to understand the changes in water quality due to rock-water interaction as well as anthropogenic influences i.e. by the leaching of pollutant from landfill (Kimmel and Braids 1974). The geochemical properties of groundwater also depend on the chemistry of water in the recharge area as well as the different geochemical processes that are occurring in the subsurface water. The contaminant moves all along the three dimensions of aquifer system as simulation for contaminant transport has been done by (Annamaria et.al. 2006).

The graph between total cation and total anion shows that most of the samples fall very close to 1:1 line indicate concentration of anion is less, because it is difficult to analyse all the organic anions.(Fig 13) The measured major ions (Na^+, Ca^{2-}\$Mg^{2+}$, K^+,Cr,$S0_4^{2-}$\$NO_3^-$\ HCO_3^-) are generally enough to give a charge balance.

Most of the water samples showed a charge balance mainly in favor of positive charge excess, but some negative charge deficit also (Guller et.al. 2002). Positive charge excess higher than 5% agrees with the database of the dissolved load. Most of groundwater samples show charge balance in range of +5.0%.

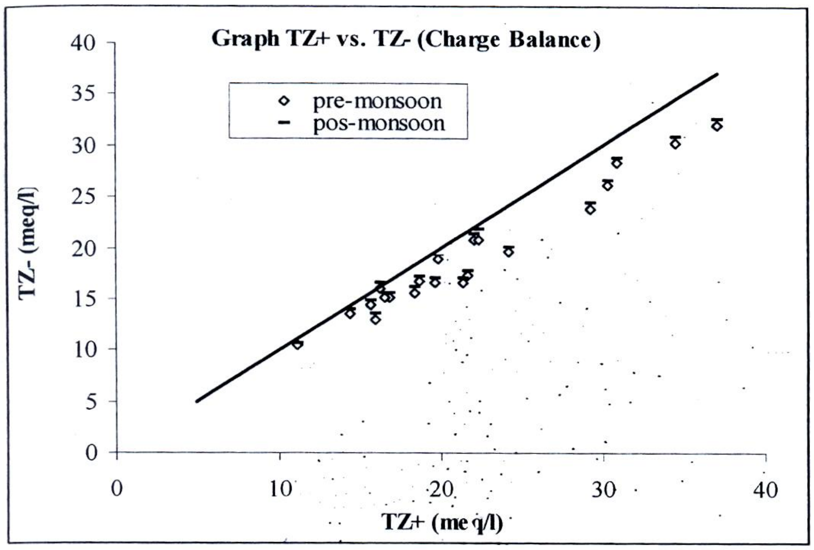


Fig. 13 Charge balance of major cation and anions in ground water Okhla landfill site

Hydro-Geochemistry of Groundwater

The general trend of pH ranges from 6.90 to 8.21 (pre-monsoon), 7.01 to 8.42 (pos-monsoon) (Table 8). The Okhla landfill leachate pH is 4 (CPCB, 2001). The seasonal variation of pH occurs due to leaching of pollutants (Slack et.al. 2004) and dilution of groundwater in different proportion with rainwater (Rajamohan et.al. 2004). The high pH is observed because of alluvium soil in the study area (CPCB, 2001). Low pH reported in 1 km radii around landfill, may be because of leaching of pollutant from the landfill. In general, conductivity ranges from 500 µS/cm to 1648 µS/cm (pre-monsoon), 480 µS/cm to 1532 µS/cm (post-monsoon) the conductivity graph was shown in (Fig 14b) indicate consistent rise in conductivity, it may be due to leaching of pollutant from landfill with time. The groundwater samples collected around landfill shows high concentration indicating leaching of pollutant from the landfill. The high value of TDS observed in post-monsoon period in comparison to pre-monsoon, because of leaching of salt from surface to subsurface with rainwater in post-monsoon period.

Dissolved oxygen in general, is ranged from 6.23 mg/1 to 6.95 mg/1 (pre-monsoon), 6.48 to 7.49 (post-monsoon). The Fig. 14a indicates unexpected rise of DO in short period of observation of 600 days. It may be due to high inorganic content in water, which inhibit the consumption of oxygen by microorganism (Srivastava et. al. 2005), indicate leaching of heavy metals in groundwater with time. High dissolved oxygen was observed in post-monsoon period than winter and least was observed in pre-monsoon, because during rainy season. Sulphate concentration ranges from 163.49 mg/1 to 521.56 mg/1 (pre-monsoon), 162.09 mg/1 to 531.71 mg/1 (post-monsoon). In general, post monsoon show higher concentration in comparison to winter and pre-monsoon because of leaching of salt with rainwater from surface to subsurface water (Rajmohan et.al. 2004 and Subba Rao, 2002). The spatial distribution of sulphate ion concentration gives an indication about the anthropogenic input in groundwater. The natural source of chloride are sand dunes (1075-2562 µg/g), alluvium (31-282 µg/g), and quartzite (61-156 µg/g) (Manju et.al.2000).The chloride concentration were found to be higher in the area covered with sand dunes, especially western and northern part of the study area which are mainly covered with the sand dunes forms, due to weathering of ridge-material (Wadia, 1978). In these sand dune regions rainwater may react with the evaporite minerals to enhance the topsoil with Cl^-, HCO_3^- and Na^+ (Subramanian et.al. 1983).

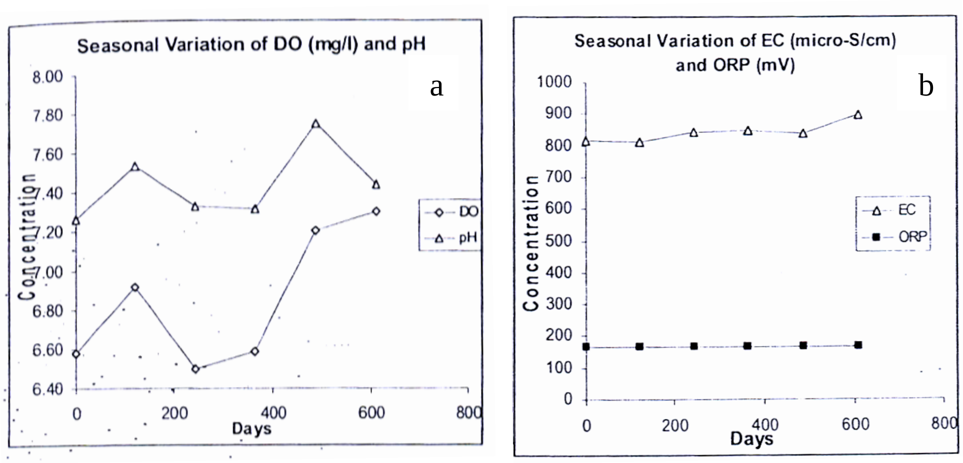


Fig. 14 (a) The seasonal variation of DO (mg/l)), (b) pH, EC (µS/cm) and ORP (mV) with time in ground water (Okhla Landfill site)

Table 8 Hydro-geochemistry of Groundwater around Okhla landfill (Ave, Min, Max in 2004, 2005, 2006, and 2007)

Pre-monsoon					Post-monsoon				
	Min	**Max**	**Avg**	**Std dev**		**Min**	**Max**	**Avg**	**Std dev**
Ca	72.22	246.7	160.54	51.44	**Ca**	60.13	222.49	146.61	50.15
Mg	17.12	62.19	38.24	13.23	**Mg**	14.19	51.79	33.60	12.34
Na	77.56	516.78	236.01	117.03	**Na**	66.48	501.84	222.70	115.54
K	6.08	21.45	12.35	3.71	***K***	5.55	19.48	10.52	3.21
Cl^-	109.49	749.89	361.77	166.87	**Cl^-**	109.37	749.37	361.59	166.70
HCO_3	54.25	103.45	83.80	13.26	**HCO_3**	56.48	103.45	85.99	13.47
SO_4	163.49	521.56	361.75	123.23	**SO_4**	162.09	523.71	361.96	123.56
NO_3^-	3.02	27.49	13.34	6.66	**NO_3^-**	3.48	28.46	14.21	6.79
F^-	0.46	2.35	1.16	0.58	**F^-**	0.39	2.32	1.13	0.58
H_4SiO_4	5	7.46	6.25	0.71	**H_4SiO_4**	5.29	7.61	6.47	0.70
pH	6.9	8.21	7.31	0.29	**pH**	7.01	8.42	7.54	0.30
Cond.	500	1648	849.14	260.27	**Cond.**	480	1532	795.52	248.43
TDS	356	1084	584.29	169.52	**TDS**	349	1124	579.14	171.00

The graphs between Na^+ vs. Cl indicate that most of the samples in pre-monsoon lie above the 1:1 ratio line (Fig 15) It shows that there are other possible sources of these ions in groundwater (Rajamohan et.al. 2004); it may be due to leaching of contaminants in groundwater aquifer system (Dinesh Kumar et.al. 2005). Okhla landfill leachate contains chloride concentration around 4000 mg/1. The high chloride concentration indicate anthropogenic source of contamination i.e. by leaching of landfill (Dinesh Kumar et.al. 2004). In general chloride concentration ranges from 109.49 mg/1 to 749.89 mg/1 (pre-monsoon), 109.37 mg/1 to 749.37 mg/1.

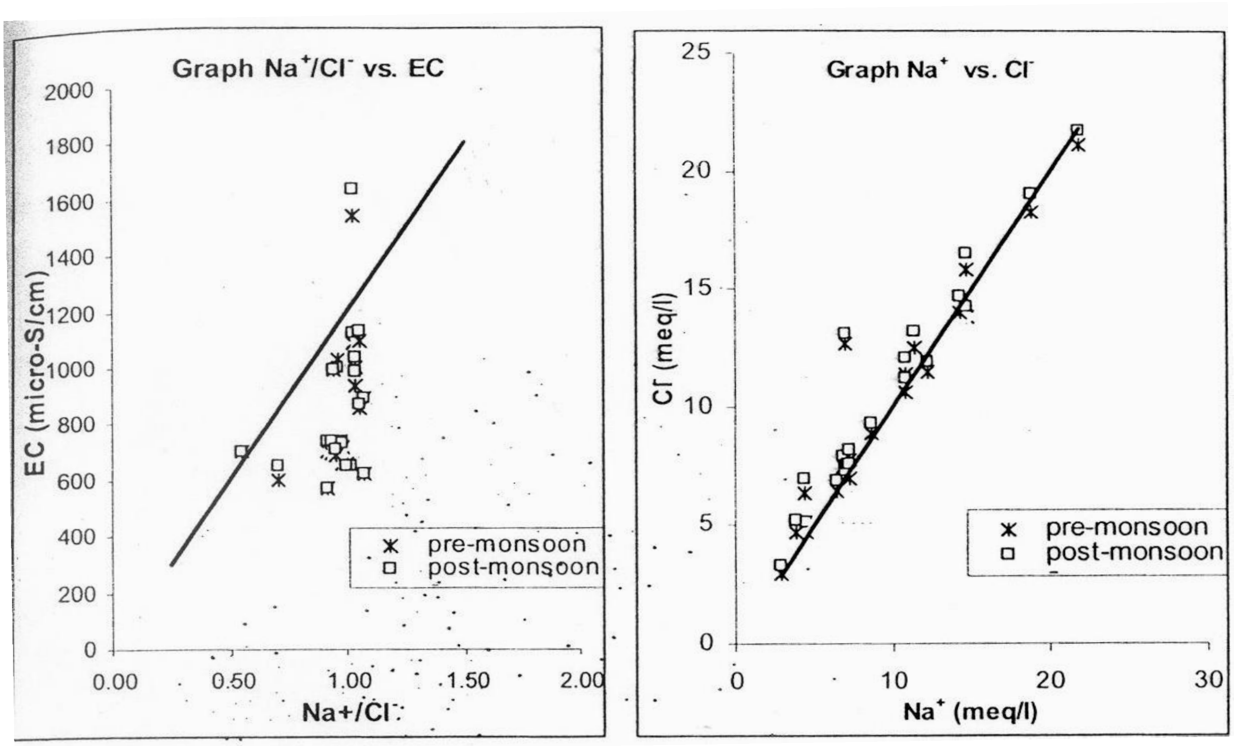


Fig 15: Graph between different parameters in Pre monsoon and Post monsoon

Heavy Metals

The simulation of movement of iron in groundwater in south-central Delhi has been carried out by using Okhla landfill. This simulation shows similar results like other contaminants Cu, Pb, Zn, Ni, Mn, nitrate, fluoride and chloride. The rate of transport varied in south Delhi from central Delhi due to variation in hydraulic gradient, aquifer parameters and topography of this area. The heavy metals can be released in groundwater by natural sources by various ion-exchange process, oxidation-reduction reaction or weathering rock/ minerals (Drever, 1997).

Heavy metals are defined as metals with density > .5 g / cm^3 ((Lee, 2000 and Christensen et. al., 2001). These metals form oxide and sulphide, which are very hard to dissolve and they tend to bound in stable complexes with organic and inorganic particles. In India, industrial effluents are generally dumped into landfill without prior treatment or processing. These effluents contain high quantity of heavy metal, which may pass into groundwater by leaching from landfill. Out of so many heavy metals present in groundwater few are analyzed based on their biological importance as well as concentration availability (Fig.16). The study of heavy metals in groundwater is very important because of their toxic effect as well as an indicator of anthropogenic input in groundwater.

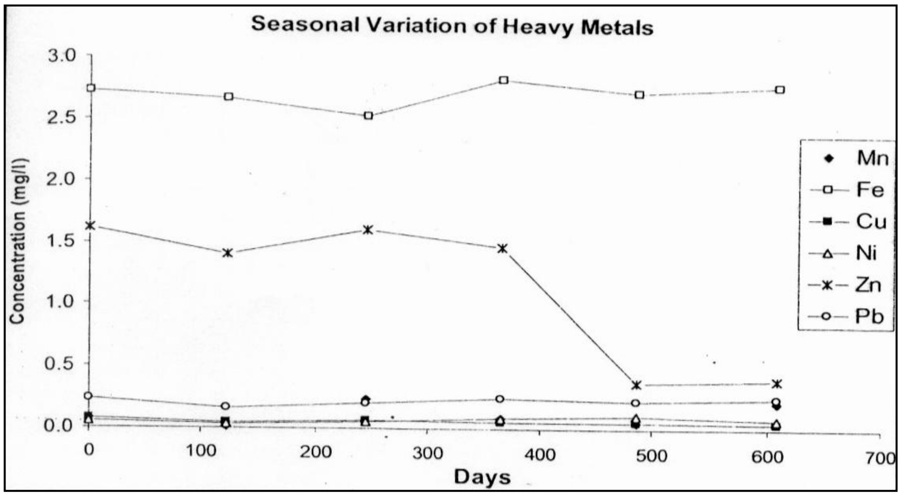


Fig.16 Seasonal variation of Heavy metals

The samples analyzed in heavy metals concentrations were much higher than the standard USPH and WHO maximum permissible limits for drinking water. All these high concentrations show contamination of groundwater in vicinity of the landfill by anthropogenic activity and leaching of pollutant from the landfill. Pre-monsoon period shows high input in groundwater system (Guller et. al. 2002). The other possible hydro chemical facies based on major anions concentration in groundwater aquifer system in vicinity of Okhla landfill.

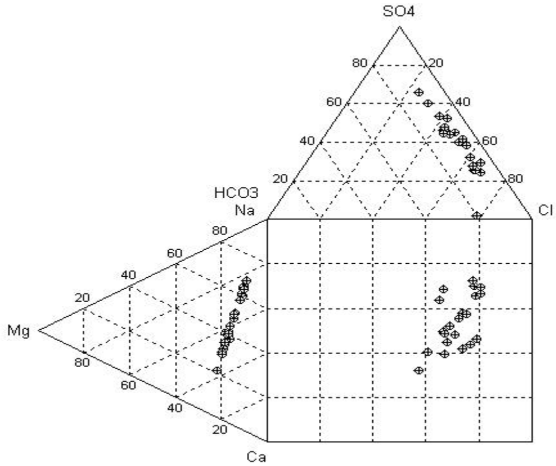
Graphical Representation of Water Quality Data

The main purpose of graphical of representation of the water quality data is to gain better insight into the processes. Some of the methods employed for this purpose are described below.

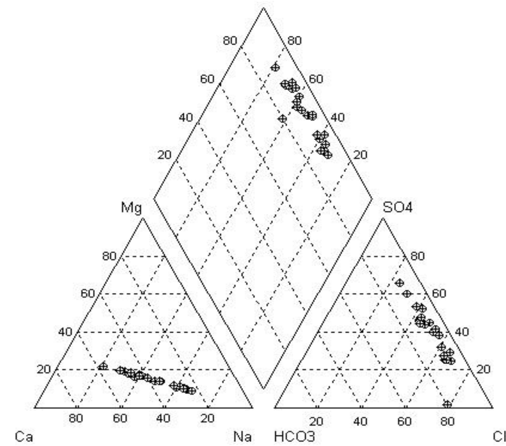
In this study, Piper (1944) tri-linear diagram has been used to decipher the geochemical evolution of ground waters. The diagram consists of two triangular fields and a central diamond shaped field. In the two triangular fields, percentage epm values of major cations and anions are plotted separately and then projected on to the central field for the representation of overall characteristics of water (Guller et.al, 2002). The cation, anion triangles and central diamond-shaped areas in these diagrams (Fig.6.9) can be divided into several designated sub areas, each of which is assigned on area number codes which represent water of certain geochemical character.

The Piper and Durov diagram (Fig.17) of groundwater around Okhla landfill shows dominance of mainly sulphates, chloride, sodium and calcium, some other source of these ions other than weathering of rock minerals (Cetidang, 2003). It indicates some anthropogenic inputs in groundwater system in vicinity of the Okhla Landfill. Concentrations of all these parameters increased from 2004 to 2007; which indicate an increase in pollution with time period. Dominance of sodium and chloride in piper diagram indicate saline nature of groundwater, it may be due to leaching of pollutant from Okhla landfill site.

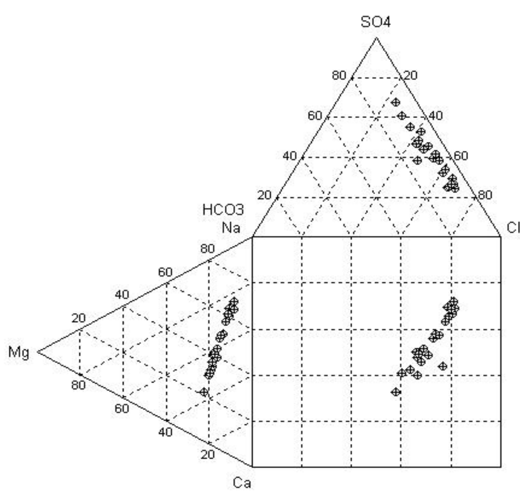
DUROV OF OKHLA LANDFILL (POST)



PIPER OF OKHLA LANDFILL (POST)



DUROV OF OKHLA LANDFILL (PRE)



PIPER OF OKHLA LANDFILL (PRE)

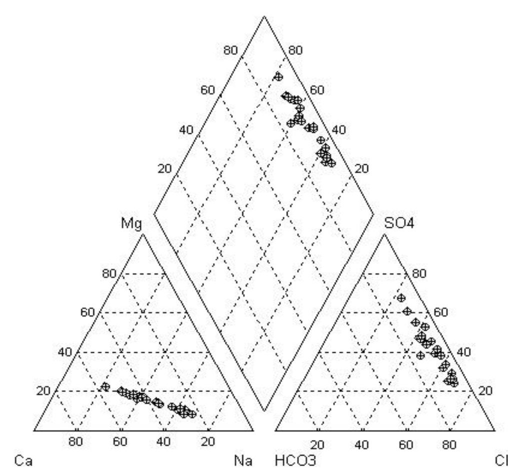


Fig. 17 The piper and Durov diagram of groundwater around Okhla landfill

Statistical analysis

The numerical analysis of hydro-geochemical data has been attempted to determine the geochemical parameters of groundwater (Lawrence and Upchurch 1982). Correlation and factor analysis are widely used in statistical or numerical concepts for parametric classification of modeling studies (Balasubramanian, et.al.1989). Statistical data generally have better representation than graphical representation because (a) there are a finite number of variables that can be considered (b) variables are generally limited by convention to major ions and (c) superior relationship may be introduced by use of certain procedure.

In view of limitation of the existing graphical methods and increasing number of chemical parameters now being measured in groundwater chemistry studies, there is need for wide range of statistical analysis of data. Delineating the relationship between the geochemical water types is difficult, while it is almost impossible to visualize the impact of both the physical and chemical variables on the water chemistry (Mellout and Collin 1992). Statistical methods, especially factor analysis and correlation analysis are often used to achieve the above objectives.

Correlation Matrix

The results of the correlation analysis were considered in the subsequent interpretation. A high correlation coefficient (near 1 or -1) means a good relationship between two variables and a correlation coefficient around zero means no relationship (Mahlknecht et.al. 2004). The correlation matrix for groundwater samples collected from Okhla landfill is shown in table 5.6. Good correlation observed between TDS-EC; F-EC; Na-EC, K-EC; HCO_3^- EC; Zn-EC; Ca-Cl^-; Ca-Mg; Ca-Na; Ca-SO_4^{2-}; Ca-K; Na-Mg; Mg-CT; Mg-SO_4^{2-}; Ca-F; Na-Cl; Na-F; Na- SO_4^{2-}; Na-K etc shows all of them have same origin source (Chidambaram et. al, 2000; Kumar et al., 2006). While minus correlation shown between ORP-TDS; EC-ORP, shows they are negatively correlated to each other (Table 15), indicates oxidation-reduction potential reduced with a rise in conductivity. In almost all seasons, groundwater samples show similar correlation. In general highly polluted groundwater samples have low oxidation-reduction potential because of reducing atmosphere (Kumar et.al, 2007). Most of the samples in vicinity of Okhla landfill show comparatively low oxidation-reduction potential, it indicates reducing atmosphere in groundwater in vicinity of the Okhla landfill.

Conductivity shows good correlation with total dissolved solid, because all these are dependent on the concentration of dissolved ions. EC shows good correlation with heavy metals also like Zn (0.68), Pb (0.52) and Ni (0.44), indicate possible anthropogenic input in groundwater system, it may be from landfill because landfill contains reportedly high concentration of Zn and Ni (CPCB, 2001 and Kumar ct.al. 2005).

Na^{+} shows good correlation with CI^{-} (0.96), shows same source of origin indicate anthropogenic input in groundwater system; it may be due to leaching of these salts from landfill. Ca^{-} ion shows good correlation with SO_4 (0.93) and $HC0_3^{-}$ (0.51), indicate major source of Ca^{2+} ion in groundwater is natural weathering; it may be from gypsum or some carbonate minerals present in geology of study area (Drever, 1997). Mg^{2+} ion shows good correlations with $S0_4^{2-}$ (0.91) and $HC0_3^{-}$ (0.52) indicate major source of these ions is natural weathering while seasonal variation occurs due to dilution of groundwater in various proportion with rainwater (Rajmohan et.al, 2004).

Table 9 Correlation matrix for different water quality parameters

	Cond	TDS	ORP	Cl	SO_4	H_2SO_4	HCO_3	NO_3	PO_4	F^-	Na^+	K^+	Ca^+	Mg^+	Mn^+	Fe^-	Cu	Ni	Zn
Cond	1																		
TDS	0.98	1																	
ORP	-0.17	-0.21	1																
Cl	-0.56	-0.53	0.17	1															
SO_4	0.43	0.34	0.12	-0.06	1														
H_2SO_4	0.4	-0.42	0.17	0.2	-0.25	1													
HCO_3	-0.29	-0.24	0.11	-0.08	-0.36	0.21													
NO_3	0.19	0.16	0.19	0.17	0.34	-0.27	-0.28	1											
PO_4	-0.05	-0.05	0.22	-0.05	-0.2	0.59	0.28	-0.37	1										
F^-	0.49	0.49	-0.21	-0.35	-0.09	-0.07	-0.21	0.23	-0.21	1									
Na^+	-0.59	-0.57	0.23	0.96	0.03	0.22	-0.14	0.21	-0.03	-0.38	1								
K^+	-0.46	-0.44	0.62	0.45	-0.51	0.15	0.37	-0.1	0.26	-0.16	0.42	1							
Ca^+	0.29	0.19	0.36	-0.03	0.75	-0.06	0.23	0.22	0.10	0.08	0.06	-0.16	1						
Mg^+	0.4	0.31	0.22	-0.28	0.66	0	-0.23	0.24	0.35	0.02	-0.18	-0.31	0.87	1					
Mn^+	-0.01	0.04	-0.05	-0.34	-0.2	-0.01	0.36	-0.23	-0.09	0.04	-0.35	-0.07	0.02	-0.14	1				
Fe	-0.51	-0.51	0.51	0.34	-0.46	0.35	0.37	-0.16	0.37	-0.11	0.32	0.75	0.09	0.02	-0.01	1			
Cu	-0.11	-0.23	0.16	0.00	0.6	-0.05	-0.1	0.12	-0.20	-0.39	0.12	-0.26	0.34	0.29	-0.2	-0.23	1		
Ni	-0.26	-0.28	0.5	0.1	0.37	0.34	0.12	0.02	0.29	-0.09	0.19	0.07	0.61	0.52	0.04	0.29	0.19	1	
Zn	-0.15	-0.11	-0.05	-0.17	-0.09	0.14	0.23	0.29	0.02	0.13	-0.14	-0.17	0.14	0.11	0.78	-0.04	-0.01	0.31	1
Pb	0.53	0.63	-0.25	-0.37	-0.08	-0.45	0.14	0.13	-0.08	0.18	-0.4	-0.25	-0.14	0.06	0.38	-0.28	-0.31	-0.29	0.19

F^- Shows good correlation with heavy metals like Mn (0.45), Zn (0.32) and Pb (0.44), Indicate possible source may be industrial effluent containing high concentration of heavy metals fluoride because; the landfill leachate contains high concentration of heavy metals and fluoride.

Cu shows quite good correlation with Mn (0.82), indicate anthropogenic input in groundwater system because there are no known common source of copper and manganese in geology of Okhla landfill site.

Factor Analysis

In this study, the factor analyses were used as an alternative tool for corroboration of the concept obtained from molar calculation. Factor analyses serves for determination of basic independent dimensions of variables (Chidambaram, 2000). Factor analysis as applied to widely differing sets of groundwater hydro-geochemical data, appears to be moderately successful as statistical tool for revealing hydro-chemical and hydro-geological feature (Mahlknecht et.al. 2004).

The aim of the factor analysis of the hydro-geochemical data is to explain the observed relationship in simple terms expressed as new set of varieties called factors (Cetindag, 2003). Factor analysis model is assumed to represent an overall variance of the data set and structure expressed in this pattern of variance and covariance between the variables and similarities between the observations (Davis 1986). Contribution of a factor is said to be significant when the corresponding eigen value is greater than unity (Briz Kishore and Murali 1992).

The principle component analyses (PCA), which aims to load most of the total variance onto one factor, is used in the present case. The factors were extracted through the principle extraction method (Mahlknecht et.al. 2004). In general the factor will be related to the largest eigen value and will explain the greatest amount of variance in the groundwater of around Okhla landfill (Table 10).

Factor I of Principle component factor matrix of groundwater around the Okhla landfill is characterized by strong loading of Na^+, K^+, Mg^{2+}, Ca^{2+}, chloride and sulphates indicate natural weathering may be one of the source of alkali and alkaline earth metals because geology of landfill contain gypsum (Mahlknecht et.al. 2004) and factor analysis indicate high loading of Ca^{2+} (0.892) and Mg^{2+} (0.876) ; While presences of chloride (0.56) indicate some anthropogenic input in groundwater I system, it may be due to leaching of these pollutants from Okhla landfill and account for 40.63 % of the variance (Kumar et.al. 2005). The seasonal variations are occurs due to dilution of groundwater in various proportions with rainwater (Rajmohan et.al, 2004; Kumar et al., 2011).

Factor II of Principal component factor matrix of groundwater around Okhla landfill is characterized by strong loading of Na^+ (0.78) and Chloride (0.77), indicate anthropogenic input in groundwater system in vicinity of Okhla Landfill and account for 18.81 % of the variance (Mahlknecht et.al. 2004). The major anthropogenic source of contaminant in this area is Okhla landfill (CPCB, 1995-2004), while landfill leachates contain high concentration of chloride (4000 mg/1). The spatial distributions also indicate leaching of contaminant from landfill. The seasonal variations are due to dilution of groundwater in various proportions with rainwater (Rajmohan et.al, 2004).

Table 10: Principal Component Analysis.

Pre Monsoon

	Component		
	1	2	3
EC	.444	.265	-.512
Na+	.459	-.758	.252
K+	.337	.570	-.211
Mg2+	.863	.256	.349
Ca2+	.904	.201	.257
Fluoride	-.507	.447	.618
Chloride	.673	-.643	.194
Sulphate	.841	.310	.370
Nitrate	.402	-.119	-.674
Bicarbonate	.651	.127	-.320

Extraction Method: Principal Component Analysis.
a. 3 components extracted.

Post Monsoon

	Component			
	1	2	3	4
EC	.213	.287	.509	.671
Na+	.505	.819	.160	-2.51E-03
K+	.428	-.450	-.122	.575
Mg2+	.882	-.295	.207	-.248
Ca2+	.892	-.255	.234	-.253
F-	-.504	-.272	.769	8.148E-02
Cl-	.540	.797	8.707E-02	-5.17E-02
Sulphate	.839	-.318	.356	-.111
Nitrate	.431	3.209E-02	-.633	.138
Bicarbonate	.613	-.177	-.348	.261

Extraction Method: Principal Component Analysis.
a. 4 components extracted.

Factor III shows strong loading of F (0.70), EC (0.62) and Na^+ (0.25) with account of 15.22 % of the variance, indicate some anthropogenic source of fluoride in groundwater aquifer system. The landfill leachates of Bhalswa landfill contain high concentration of fluoride (Dinesh Kumar et.al, 2005). The spatial distributions indicate high concentration of fluoride in nearby area of landfill, shows landfill leachate impact on groundwater quality in vicinity of Okhla Landfill (Kumar et.al, 2005). The seasonal variations are due to dilution of groundwater in various proportions with rainwater (Rajmohan et.al, 2004).

Delineating the relationship between the geochemical water types is difficult, while it is almost impossible to visualize the impact of both the physical and chemical variables on the water chemistry (Mellout and collin 1992).

6.3. Ghazipur Landfill

Groundwater contamination is the degradation of the natural quality of GW due to anthropogenic activity. The adverse impacts of landfill leachates on adjacent surface water and GW have prompted a great number of studies. These include research on the constituent of leachates (Kjeldsen et al., 1993) as well as on the groundwater quality. Leachates are generated as a result of water or the liquid passing through wastes. The uncontrolled infiltration of leachates into an unsaturated zone is considered as the worst environmental impact of the landfill (Tajero et al., 1993). The origin of these contaminated liquids can be attributed to many facts, including the water produced during the decomposition of the waste. Research has shown that the composition of landfill leachates from the same source, as well as from different sources is extremely variable (Chian and DeWalle, 1976).

Advection and dispersion are the two major transport processes that determine the maximum extent of the leachates plume spread and the geometric character of the concentration distribution. Advection is mass transport due simply to the flow of water in which the mass is dissolved. The direction and rate of transport coincide with the groundwater. Dispersion is a process of fluid mixing that causes a zone of mixing to develop between fluids of one composition that is adjacent to a fluid with a different composition.

Physico-chemical characteristics of the leachate depend primarily upon the waste composition and water content in total waste. The characteristics of the leachate samples collected from the Ghazipur landfill site. The pH value of the collected sample was found to be 7.2. The relatively high values of EC (21289 μScm^{-1}) and TDS (23498 mg l^{-1}) indicate the presence of inorganic material in the samples. Among the nitrogenous compound, ammonia nitrogen (2744 mg l^{-1}) was present in high concentration this is probably due to the domination of amino acids during the decomposition of organic compounds (Crawford and Smith, 1985;

Tatsi and Zouboulis, 2002). High concentrations of NO_3^- (281 mg l^{-1}) and Si (329 mg l^{-1}) were also observed in the leachate samples.

The high level of Fe (45.23 mg l^{-1}) in the leachate sample indicates that Fe and steel scrap are also dumped in the landfill. The dark brown color of the leachate is mainly attributed 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). The presence of Zn (2.51 mg l^{-1}) in the leachate shows that the landfill receives waste from batteries and fluorescent lamps. The presence of Pb (2.94 mg l^{-1}) 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., 2005). Cr (0.41 mg l^{-1}), Cu (1.38 mg l^{-1}) and Ni (0.39 mg l^{-1}) were also present in the leachate samples. A variety of waste is dumped at Ghazipur landfill site, which likely indicate the origin of Zn, Pb, Cr, Cu and Ni in leachate (Moturi et al., 2004; Mor et. al. 2005). Christensen et al., 1994 have also reported the presence of these compounds in leachate.

Physico-chemical Characteristics

The underground water of the studied area is used for domestic and other purposes. (Table.11) shows the desirable and maximum permissible limit recommended by Bureau of Indian Standard (BIS, 1991) and World Health Organization (WHO, 1997).

Table. 11 Drinking water quality standards as recommended by BIS (1991) and WHO (1997)

Parameter*	**BIS Standards**		**WHO standards**
	Desirable	***Max. Permissible***	
Color	5	25	-
Odor	Unobjectionable	Unobjectionable	-
Taste	Agreeable	Agreeable	-
pH	6.5-8.5	6.5-8.5	6.5-9.2
TH	300	600	300
TA	200	600	
TDS	300	1500	500
Cl^-	250	1000	250
SO_4^{2-}	250	400	200
NO_3^-	45	45	50
F^-	1.0	1.5	0.5
Ca^{2+}	75	200	100
Mg^{2+}	30	100	150
K^+	-	-	200
Na^+	-	-	200
NH_4^+	-		1.5
Phenol	-		0.0
B	-		0.3
Fe	-		0.3

*Except pH and color (hazen unit) all unit are in mg l^{-1}

The pH of all the groundwater samples was about neutral, the range being 6.59 to 7.95 and post monsoon 6.7 to 8.01. The EC is a valuable indicator of the amount of material dissolved in water (Table.6.10). The EC in the studied area ranged between pre-monsoon 378 to 1480 and post-monsoon 370 to 1510 $\mu S\ cm^{-1}$ and was found to be high, these high conductivity values obtained for the underground water near the landfill is an indication of its effect on the water quality. TDS indicates the general nature of water quality or salinity. The range of TDS at all sites falls in between 83 to1130 and 240 to 1120 mg l^{-1} .This high value of TDS may be due to the leaching of various pollutants into the groundwater. Olaniya and Saxena (1977) also reported the groundwater pollution from refuse in the vicinity of the dumping sites detectable through increased TDS concentration of water. The high concentrations of TDS decrease the palatability and may cause gastro-intestinal irritation in human and may also have laxative effect particularly upon transits (WHO, 1997).

An excess of Cl- in water is usually taken as an index of pollution and considered as tracer for groundwater contamination (Loizidou and Kapetanios, 1993). The concentration of Cl^- the pre monsoon groundwater samples ranged between 100.12 to 526.48 mg l^{-1}. And a post monsoon range between 105.47 to 522.17 mg l^{-1}.The chloride concentrations was found to be comparatively high. High Cl^- content of groundwater is likely to originate from pollution sources such as domestic effluents, fertilizers, and septic tanks, and from natural sources such as rainfall, the dissolution of fluid inclusions. Increase in Cl^- level is injurious to people suffering from diseases of heart or kidney (WHO, 1997).

The moderately high concentration of EC, TDS, Cl^-, SO_4^{2}-, NO_3^-, Na^+ and Fe etc. in groundwater near landfill deteriorates its quality for drinking and other domestic purposes. As there is no natural or other possible reason for high concentration of these pollutants, it can be concluded that leachate has significant impact on groundwater quality near the area of Ghazipur landfill site.

Table 12 Hydro-geochemistry of Groundwater around Ghazipur landfill (Ave, Min, Max in 2004, 2005, 2006, and 2007)

Pre-monsoon					Post-monsoon				
	Min	**Max**	**Avg**	**Std dev**		**Min**	**Max**	**Avg**	**Std dev**
Ca	38.47	93.49	66.49	12.51	**Ca**	34.37	98.1	71.76	12.77
Mg	10.12	24.27	16.57	3.32	**Mg**	9.45	26.49	18.89	3.13
Na	51.09	354.16	149.47	67.87	**Na**	50.48	357.44	150.47	68.04
K	20.45	64.67	43.05	13.31	***K***	20.49	66.34	44.06	13.41
Cl^-	100.12	526.48	241.02	96.40	**Cl^-**	105.47	522.17	234.21	96.22
HCO_3	35.48	96.45	66.16	15.88	**HCO_3**	36.89	92.45	68.18	17.79
SO_4	55.47	349.48	161.72	58.08	**SO_4**	56.18	348.7	168.92	72.78
NO_3	1.02	21.85	11.89	6.14	**NO_3**	1.08	21.23	11.93	6.51
F	1.48	7.05	3.65	1.51	**F**	1.36	6.78	3.55	1.62
H_4SiO_4	12.48	17.78	14.09	0.81	**H_4SiO_4**	12.94	17.46	14.29	1.12
pH	6.59	7.95	7.60	0.21	**pH**	6.7	8.01	7.21	0.27
Cond.	378	1480	881.12	408.53	**Cond.**	370	1510	932.40	422.45
TDS	83	1130	612.56	289.68	**TDS**	240	1120	642.40	307.18

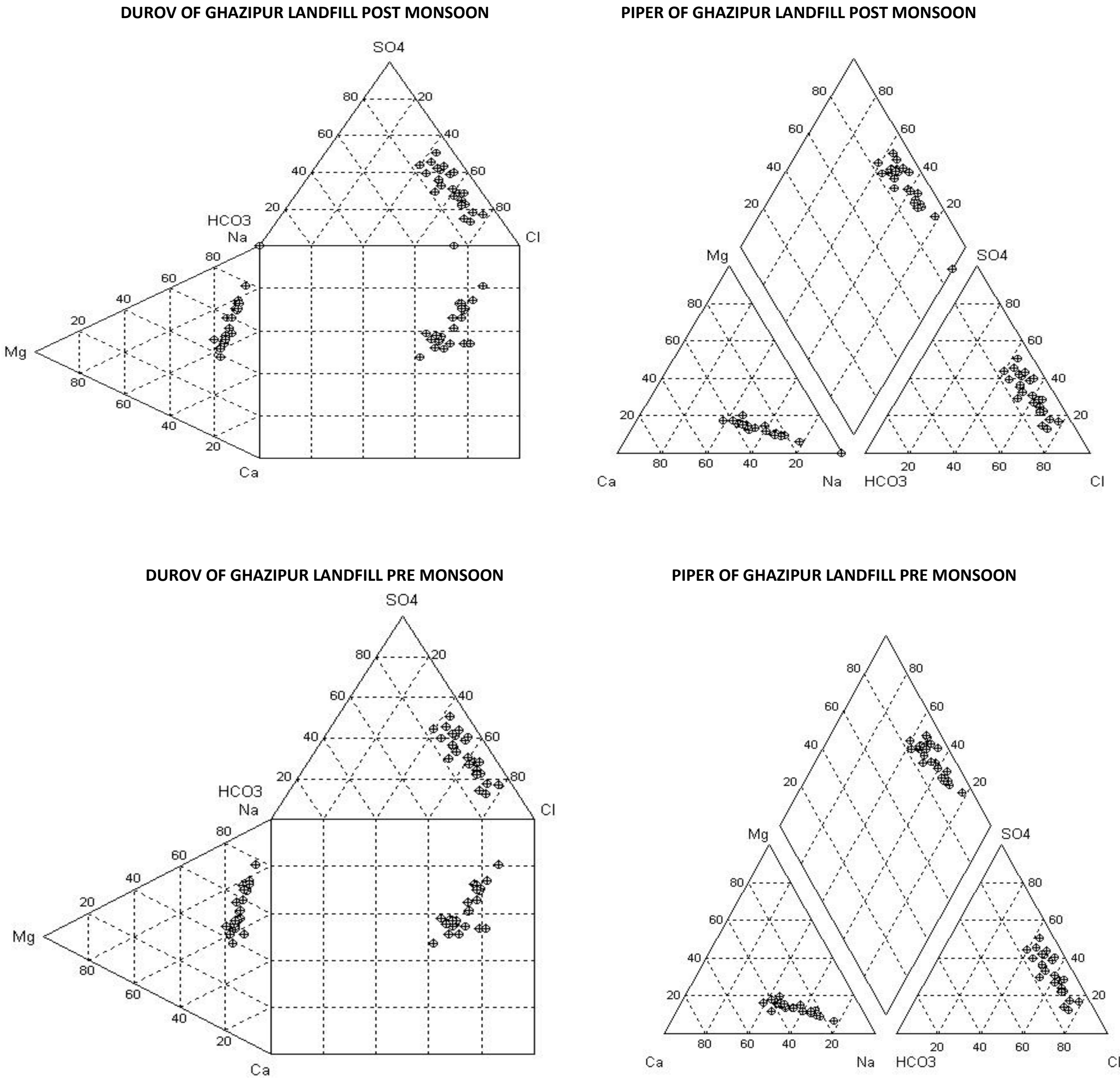


Fig. 18 Durov diagram and piper diagram of Ghazipur landfill area

The piper diagrams of ground water around Ghazipur landfill (Fig 18) shows dominance of mainly sulphates and chloride, sodium and calcium, indicate pollution due to anthropogenic source. Concentrations of all these parameters are increases from 2004 to 2007 indicate increase in pollution with time period. Dominance of Na and Cl in piper diagram indicate saline nature of ground water it may be due to leaching of pollutant from landfill site (Kumar et.al. 2002; Singh et al., 2008; Kumar et al., 2009)

Correlation Matrix

The correlation analysis was applied to describe the degree of relation between two hydro chemical parameters (Chidambaram et.al. 2000). The results of the correlation analysis are considered in the subsequent interpretation. A high correlation coefficient (near 1 or -1) means a good relationship between two variables and a correlation coefficient around zero means no relationship. The correlation matrix for groundwater samples collected from Ghazipur landfill is shown in (Table. 13). Good correlation observed between EC-TDS (1.00), EC-$S0_4^{2+}$ (0.95), EC-NO_3^- (1.00), EC-F^- (0.96), EC-PO_4^{3-} (0.80), EC-Mn^{2+} (1.00), EC-Pb^{2+} (0.95),Silicate -Chloride, Na^+-Cl^- (0.98), $S0_4^{2+}$-$N0_3^-$ (0.94), Cu^{2+}-Cl^- (0.85), Ni^{2+}-Cl^- (0.99), Zn^{2+}- Cl^- (0.96), Pb^{2+}- Cl^- (0.70), Pb^{2+}-SO_4^{2-}(0.80) etc shows all of them have same origin source (Table 13).

Manganese shows good correlation with $P0_4^{3-}$ (0.85), $S0_4^{2-}$ (0.92), F^- (0.93) and $N0_3^-$ (1.00) indicate manganese is leached in groundwater through anthropogenic source like Ghazipur landfill. Because there are no such natural sources of manganese, it shows moderate correlation with Ca^{2+} (0.51) and Mg^{2+} (0.52), it is due to ion-exchange process in groundwater aquifer system (Drever, 1997). While it shows -ve correlation with Na^+ and CI^- indicate it helps in precipitation of these salts. Seasonal variation occurs due to dilution of groundwater in various proportions with rainwater during monsoon period.

Nickel shows good con-elation with CI^- (0.99), Na^+ (1.00) and Cu^{2+} (0.92), indicate sample source of origin. Ni^{2+} shows good correlation with Cu" due to ion-exchange process in groundwater system. While good correlation with Cl^- and Na^+, may be -due to anthropogenic input in groundwater system. Lead shows good correlation with SO_4^{2-} (0.80), NO_3^- (0.96), PO_4^{3-} (0.95) and F^-(0.81), indicate these ions are released from industrial effluent dumped in landfill at the time of working stage. While good correlation with Ca^{2+} (0.70) and Mn^{2+} (0.97), indicate ion-exchange process in groundwater aquifer in vicinity of Ghazipur landfill.

Table. 13 Correlation matrix for different water quality parameters

	Cond	TDS	ORP	Cl	SO_4	H_2SO_4	HCO_3	NO_3	PO_4	F^-	Na^+	K^+	Ca^+	Mg^+	Mn^+	Fe	Cu	Ni	Zn	Pb
Cond	1																			
TDS	0.47	1																		
ORP	-0.54	-0.62	1																	
Cl	0.02	0.07	-0.04	1																
SO_4	0.19	0.25	-0.08	0.22	1															
H_2SO_4	0.08	0.18	-0.08	-0.09	-0.15	1														
HCO_3	0.44	0.41	-0.41	0.18	0.43	-0.29	1													
NO_3	0.36	0.31	-0.39	0.14	0.14	0.18	0.16	1												
PO_4	0.06	0.09	0.1	0.14	0.07	0.03	-0.03	-0.14	1											
F^-	-0.27	-0.28	0.54	-0.4	-0.08	-0.03	-0.5	-0.63	0.17	1										
Na^+	-0.11	-0.04	-0.04	0.96	0.24	-0.09	0.12	0.1	0.08	-0.34	1									
K^+	0.21	0.15	-0.21	-0.09	0.37	-0.32	0.36	0.2	-0.22	-0.03	-0.13	1								
Ca^+	0.35	0.4	-0.07	0.31	0.91	-0.15	0.44	0.23	0.1	-0.23	0.26	0.24	1							
Mg^+	0.27	0.31	-0.03	0.24	0.94	-0.2	0.4	0.15	0.03	-0.15	0.23	0.26	0.96	1						
Mn^+	-0.23	-0.21	-0.02	0.04	-0.14	-0.25	-0.02	0.05	-0.04	-0.16	0.12	-0.46	0	0.02	1					
Fe	0.11	0.07	0.02	0.16	0.03	0.05	-0.25	0.29	0.04	0.16	0.28	-0.25	-0.05	0.01	0.12	1				
Cu	0.3	0.35	-0.28	0.35	0.6	-0.22	0.45	0.12	0.01	-0.3	0.3	0.27	0.68	0.66	-0.07	-0.3	1			
Ni	0.34	0.35	0.05	0.08	0.31	0.03	-0.12	0.24	0.38	0.19	0.09	-0.22	0.37	0.35	0.06	0.67	0.11	1		
Zn	-0.15	-0.08	-0.13	-0.39	0.29	0.19	-0.01	-0.09	0.12	0.37	-0.36	0.29	0.05	0.08	-0.14	-0.1	-0.01	0.01	1	
Pb	0.23	0.2	0.02	0.09	0.22	-0.16	0.02	0.2	0.09	0.22	0.06	0.2	0.23	0.2	0.05	0.37	0.17	0.41	0.37	1

Conductivity shows good correlation with almost all anions and heavy metal but negative correlation with alkali metals, indicate anthropogenic input in groundwater system. Since alkali and alkaline earth metals are mainly released in groundwater through weathering process. it also indicates ion-exchange process in groundwater system in vicinity of Ghazipur landfill while it shows good correlation with TDS indicate conductivity is dependent on the concentration of dissolved species in water.

Conductivity shows moderate correlations with ORP indicate oxidation -reduction reaction in groundwater system (Drever, 1997 and Roger, 1996). ORP shows good correlation with few alkali metals and heavy metals indicate oxidation-reduction reaction and ion-exchange reaction in groundwater system. In general, highly polluted groundwater samples have low oxidation-reduction potential because of reducing atmosphere (Dinesh Kumar et.al, 2005).

Most of the samples in vicinity of Ghazipur landfill show a comparatively low oxidation-reduction potential, it indicates reducing atmosphere in groundwater in the vicinity of Ghazipur landfill.

Factor Analysis

Factor analysis as applied to widely differing sets of groundwater hydro-chemical data, appears to be moderately successful as a statistical tool for revealing hydro chemical and hydro geological feature (Mahlknecht et.al. 2004). The aim of the factor analysis of the hydro-geochemical data is to explain the observed relationship in simple terms expressed as new set of varieties called factors. Factor analysis model is assumed to represent an overall variance of the data set and structure expressed in this pattern of variance and covariance between the variables and similarities between the observations (Davis 1986). Contribution of a factor is said to be significant when the corresponding eigen value is greater than unity (Briz Kishore and Murali 1992). In general the factor will be related to the largest eigen value and will explain the greatest amount of variance in the data set (Mahlknecht et.al. 2004).

The factor analysis in this study has been earned out by SPSS (Table 14). The software provides some numerical value as result for different variant as component and initial eigen value for each species. With the help of linear combinations, an originally large number of variable are reduced to a few factors. These factors can be interpreted in terms of new variables. There exist numerous solution methods and variants for determination of factors (Mahlknecht et.al. 2004 and Chidambaram, 2000). Seasonal variation occurs due to dilution of groundwater in various proportions with rainwater during monsoon period (Rajmohan et.al, 2004).

Factor I of Principal component factor matrix of groundwater around Ghazipur landfill is characterized by strong loading of Ca^{2+} (0.88), Mg^{2+} (0.84), Sulphates (0.82) and Nitrate (0.57) and account for 28.65 % of the variance, indicate possible weathering of rock minerals in groundwater system because geology of study area is dominating with gypsum (CGWB, 1995) while, strong loading of nitrate with Ca+ and Mg2+ indicate possible anthropogenic input in groundwater system (Dinesh Kumar et.al, 2005). Ghazipur landfill is the only landfill out of three landfill showing dominance of nitrate, which comes from anthropogenic source, since there are no residential areas except a few slums like Nangala Machi, Kali Mata Colony etc around this landfill. This shows that the landfill is the only source of high loading of nitrate in groundwater (Mohsen Jalil, 2003). The spatial distribution of nitrate around the landfill also indicates this landfill as point source for contamination of groundwater.

Factor II of Principal component factor matrix of groundwater around Ghazipur is characterized by strong loading of Na^{+} (0.80), K^{4} (0.66), Chloride (0.76) and bicarbonate (0.41) and account for 22.56 % of variance. It indicates anthropogenic input in groundwater system may be due to leaching of contaminant from landfill because there is no known natural source of chloride in geology of Ghazipur et.al, 2005). While spatial distributions of chloride around the landfill indicates the landfill as a point source for this contaminant.

Factor III is characterized by strong loading of K^{+} (0.50) and fluoride (0.75) with account 17.90 % of the variance. It indicates release of fluoride from mica may be due to weathering or ion-exchange process in groundwater system (Drever, 1997). Fluoride can be released with ion-exchange process with other rock minerals in groundwater system (Drever, 1997). Seasonal variation observed due to dilution of groundwater in various proportions with rainwater (Rajmohan et.al, 2004).

$$K\,(Fe, Mg)_3\,AISi_3Oio\,(F, OH)_2 \leftrightarrow K^{+} + F^{-} + X \text{ (other species)}$$

Factor IV is characterized by strong loading of Ca^{2+} (0.42), Mg^{2+} (0.23) and bicarbonate (0.65) with account of 10.25 % of the variance. It indicates carbonate weathering to be one of the factors responsible for the release of Ca^{2+}, Mg^{2+} and HCO^{3-} in groundwater system in the vicinity of Ghazipur landfill.

Table 14: Principal component matrix for each parameter analyzed for groundwater

Pre Monsoon

	Component		
	1	2	3
EC	.457	-.355	-.434
Na+	-3.29E-02	.858	-.478
K+	.182	.592	.601
Mg2+	.876	-5.84E-03	-4.22E-02
Ca2+	.858	.102	-1.05E-02
Fluoride	.301	.180	.789
Chloride	-.147	.815	-.521
Sulphate	.793	-2.41E-02	-.186
Nitrate	.643	.322	.105
Bicarbonate	-.311	.393	.370

Extraction Method: Principal Component Analysis.
a. 3 components extracted.

Post Monsoon

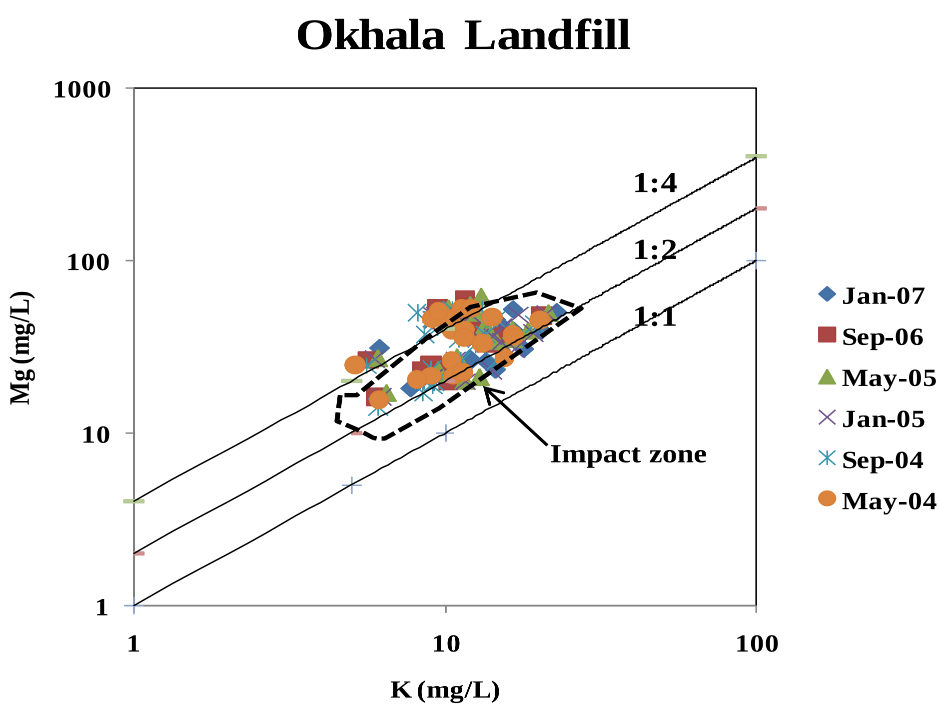
	Component			
	1	2	3	4
EC	.406	-.454	-.527	.285
Na+	.232	.862	-.417	-2.08E-02
K+	.264	.449	.589	-.420
Mg2+	.772	.121	.210	.272
Ca2+	.817	-7.33E-02	.153	1.742E-02
Fluoride	.413	-.192	9.478E-02	.495
Chloride	.128	.863	-.457	.114
Sulphate	.787	-.237	-.137	-.218
Nitrate	.692	8.213E-02	.114	-.240
Bicarbonate	-.164	.414	.512	.648

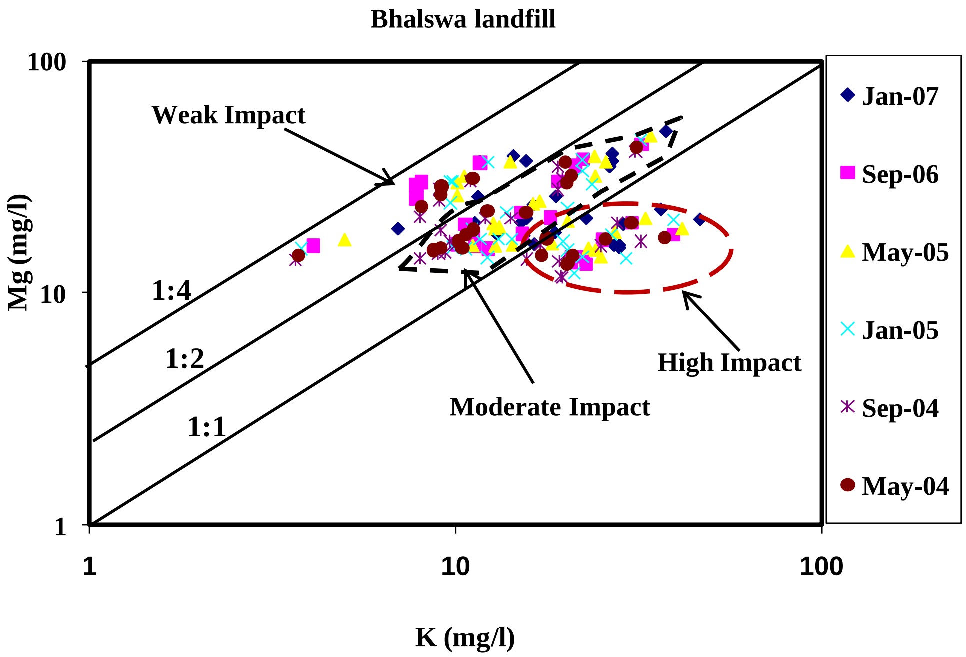
Extraction Method: Principal Component Analysis.
a. 4 components extracted.

6. 4. Comparative Assessment of Pollution Status

An effort was made to carry a comparative assessment of pollution status of the three landfill sites in question. Alternatively, it gave an idea of different threat levels to fix the priority for management need. In order to do so, a series of arbitrary tests was established. This was based on the comparison of "background" groundwater chemistry with leachate. The following observations were made:- (1) leachate is intermediate in total inorganic load; (2) Mg^{2+} dominates Ca^{2+} in leachate, Ca^{2+} dominates Mg^{2+} in background waters and leachate has the highest K^+/Mg^{2+} ratio (3) leachate has the highest EC value.

Based on these observations, Mg^{2+} Vs K^+ cross plot was plotted which reveals three levels of impacted groundwater samples (Fig 19). In the vicinity of Okhala landfill site weak to moderate level of impact was observed while for Bhalswa landfill moderate to high impact was noticed. This plot suggests that Gazipur landfill site has the most impact on groundwater quality as all samples falls below 1:1 line and belongs to high impact zone. This is quite understandable considering the lithology of the area. The comparatively least impact was observed for Okhala landfill might be due to its location on quartzite belt where clay is the major constituent of soil. It is a well known fact that clay has high sorption capacity and partitioning coefficient thus the retardation coefficient. That is why contaminant flow through the unsaturated zone is being retarded in this case. However, there is a limit of sorption capacity and once that is saturated soil itself will start releasing the contaminant with infiltrating water. Thus even if the situation is much better comparatively, it is very likely that in future it will detoriate with time and impact will shift towards moderate to high impact.





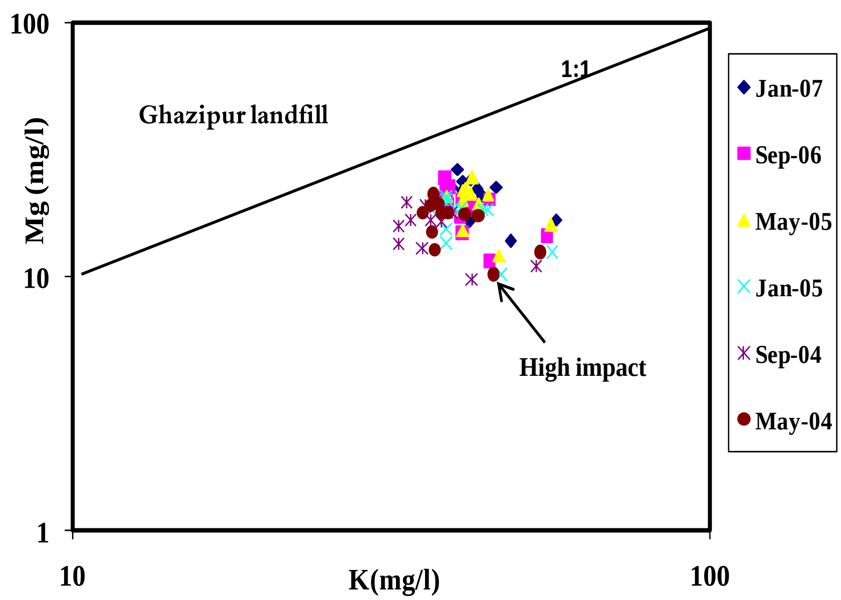
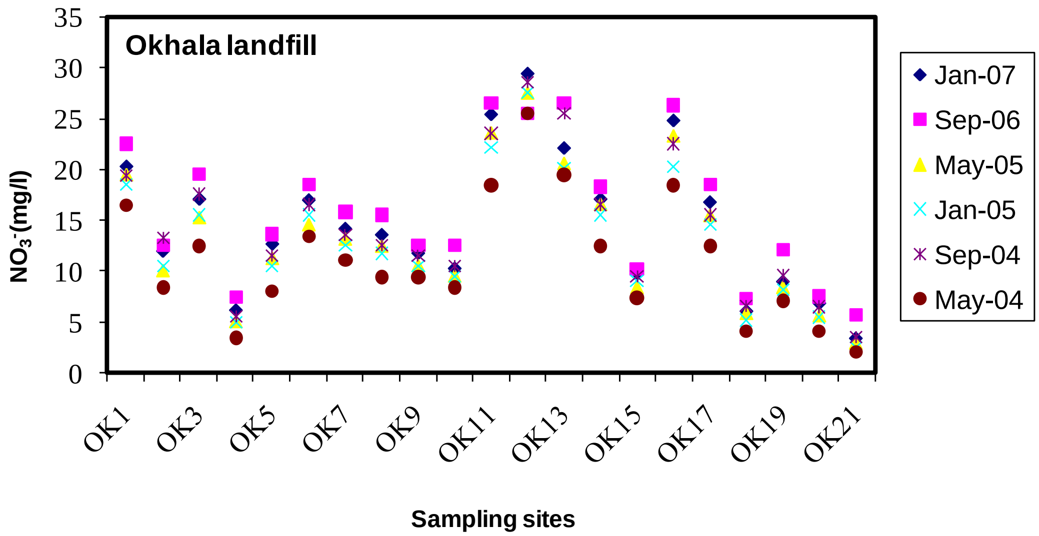
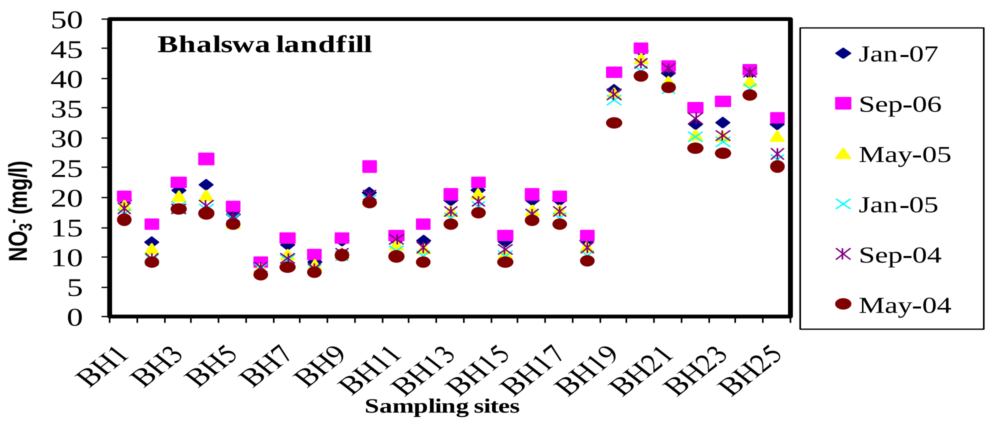


Fig. 19 A scatter plot of Mg vs K to observe the impact on groundwater samples

Gazipur landfill is located on the newer alluvium which is a flood plain of the Yamuna river with high sand content that is why groundwater in the vicinity of this landfill showed the highest impact of landfill. Kumar et al., (2009) suggested that there is a strong interaction between groundwater and the Yamuna River, these facts makes this site more vulnerable and needs proper management.

On the other hand Bhalswa landfill showed all levels of impact ranging from weak to high impact. This landfill site is surrounded my sandy Yamuna flood plain in its eastern boundary while in its western side there is older alluvium with high clay. This may be the reason of having all different levels of impact. However, situation is more critical concerning the drinking water supply, which draws groundwater in the upper Yamuna flood plain. Therefore the impact from this site is likely to affect the Delhi people more severely. It is highly recommended that an immediate management action must be taken for this landfill on priority basis.





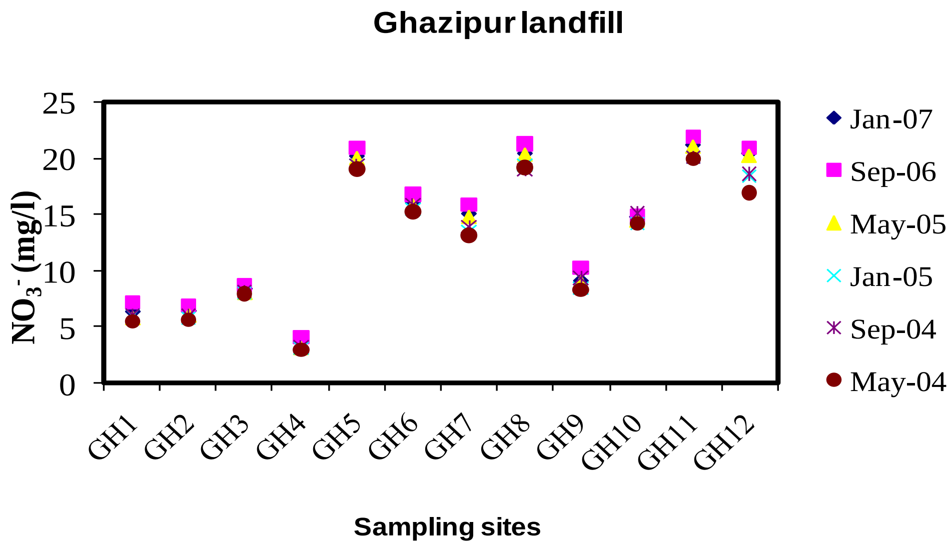


Fig. 20 A plot of temporal variation of nitrate concentration in the groundwater

The common sources of nitrate in water are the leachates from the landfill sites whether in use or abandoned, local agricultural fields, domestic sewage etc. However, because of laminar flow condition and due to difference in specific gravity and viscosity between nitrate slugs and the natural freshwater, some diffusion is bound to occur. But no such natural sources are reported to exist in the area for NO_3^- (Handa, 1988). Therefore a graph was plotted for different landfill site to visualize the temporal variation of nitrate concentration in the groundwater of different landfill sites (Fig 20).

Results suggest that there is no definite trend in nitrate concentration, a certain difference between May 2004 samples and September 2006 samples can be easily observed where September 2006 samples occupy the highest place and that of May 2004 samples occupied the lowest. As far as the magnitude of temporal variation is concerned Okhala landfill vicinity showed highest difference followed by Bhalsawa and Gazipur. This is a very likely result, as discussed above as well that Okhala landfill site is in its initial phase where the movement of contaminants are being retarded by the presence of clay which will weaken as time progresses. Similarly, Gazipur due to its location on flood plain already has high impact thus temporal variation is less. However, the contamination level is highest in the case of Bhalswa followed by Okhala and Gazipur. Comparatively less nitrate level in the vicinity of Gazipur landfill is probably due to the dilution effect caused by surface water-groundwater interactions (as suggested by Kumar et al., 2009), which is minimum in the case of other two landfill sites.

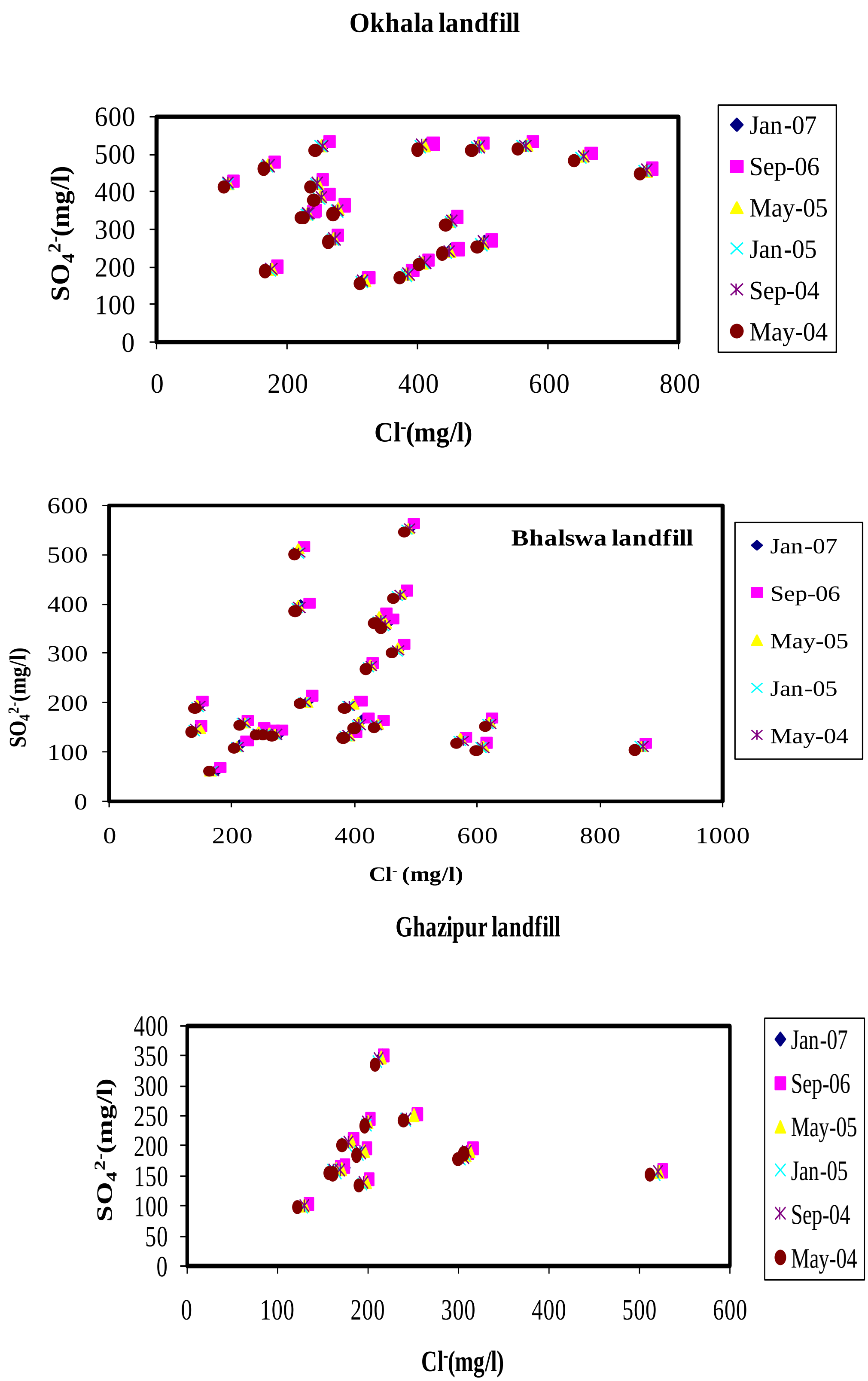


Fig. 21 A scatter plot of sulphate Vs Cl in the groundwater samples

Sulfate and chloride are two major anions found in the groundwater, which is somewhat antagonistic in nature as they fight for the same absorptive site and cations to be paired with. A high sulphate water oftenly comes with low Cl level, as in nature common source for both anions are not common. However in the case of landfill site where external wastes of different nature and contents are disposed it is very likely that high sulphate coincides with high Cl content of the water. Therefore a scattered graph was plotted for different landfill site to visualize the landfill impact (Fig 21).

Results suggest that there is a strong correlation between high Chloride and high sulphate concentrations, which is most evident for all the range in case of Okhala landfill. In case of the groundwater sample collected from the vicinity of Okhala landfill, high chloride concentration of more than 500 mg/L is also coincide with high sulphate concentration (>400mg/L). This is a strong indication that there are samples that are having their impact. In the case of Bhalswa landfill chloride ranging from 250 to 450 mg/L coincides with high sulphate (300 to 600 mg/L). This is the range where landfill impacts are more visible. Otherwise there are samples that have either low Cl or low sulphate indicating a normal situation. Again in the case of Gazipur landfill almost all samples shows very good positive correlation with these two anions expressing the strength of leachate impact.

6.5 Geophysical Survey Of Landfill Site In Delhi Area

Geophysical survey was conducted in three Municipal Solid waste sites of Delhi region, i.e. two locations in Bhalswa site, two in Okhla site and one from Ghazipur site. Sites were selected in such a way that, on site was on the landfill and the other near the Landfill, along the water table. The maximum, minimum and average value of this ρ_a values are given in the (Tables 15) and (Fig 22) below.

Table 15 The maximum, minimum and average value of this ρ_a values

	OK-1	OK-2	GZ-1	BL-1	BL-2
Min	3.3493	2.1273	1.1183	1.0355	3.1542
Max	4.5255	24.7632	9.8153	13.991	9.9627
Avg	3.716	6.658	3.2681	3.342	5.82275

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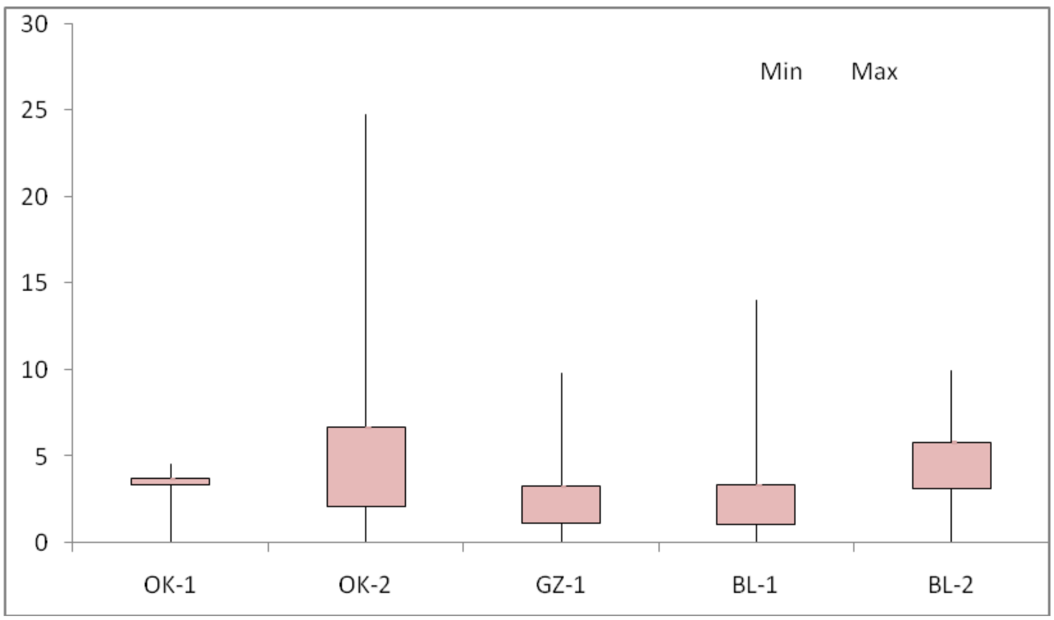

Fig. 22 The maximum, minimum and average value of this ρ_a values

I) Bhalswa landfill

Two main curve types were identified in the Bhalswa region as Q type (Fig 23) and H type (Fig 24). Q type is noted in the observation above landfill indicates the increasing of conductivity with depth, the region of the ρ_a values show clear impact of contamination. The H type curve shows the increase of conductivity in the middle aquifer and at the deeper aquifer it's comparatively less contaminated.

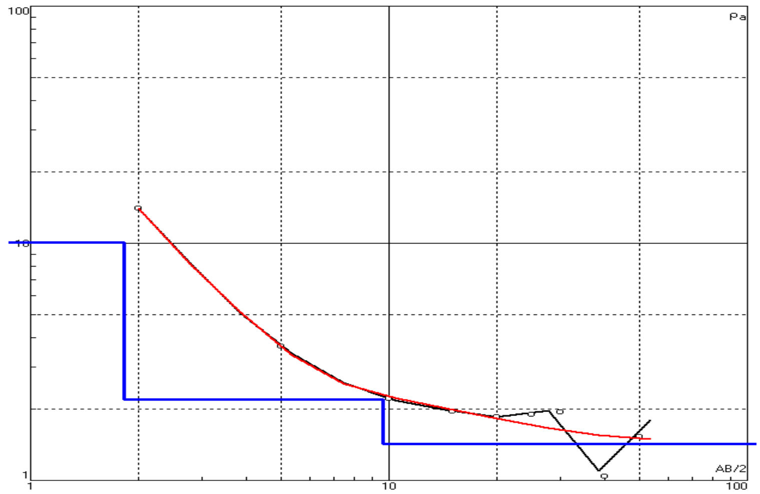

Fig. 23 Q type curve of Bhalswa landfill site in top area

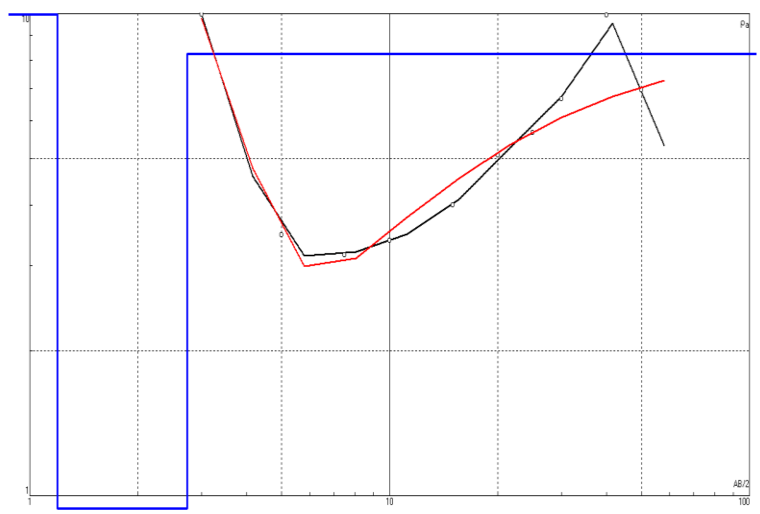

Fig. 24 H type curve of Bhalswa landfill site in ground area

The observed maximum value in site-I is 13.991, minimum value is 1.0355, average value is 3.3422 and in site-II the maximum is 9.962 and minimum is 3.154 and average value is 5.822.

The Geophysical apparent resistivity value (Fig 25) indicates that the value is lesser at the landfill site since it is falling in the sedimentary formation and the ρa values are lesser than 5 Ωm which indicates pollution or leaching of landfill substance into the groundwater. The first 5 meters represents the water table where the spread was done in 5 m interval and the change in ρ_a at this depth is attributed to the water table, in both the sites. The Bhalswa site shows less value throughout the depth, at site II there is an increase till 40m and then it decreases further. This scenario states that the ground water throughout the depth is contaminated at site I and site II. The degree of contamination decreases with depth, the decrease in the ρ_a value beyond 40m may be due to the presence of clay lens.

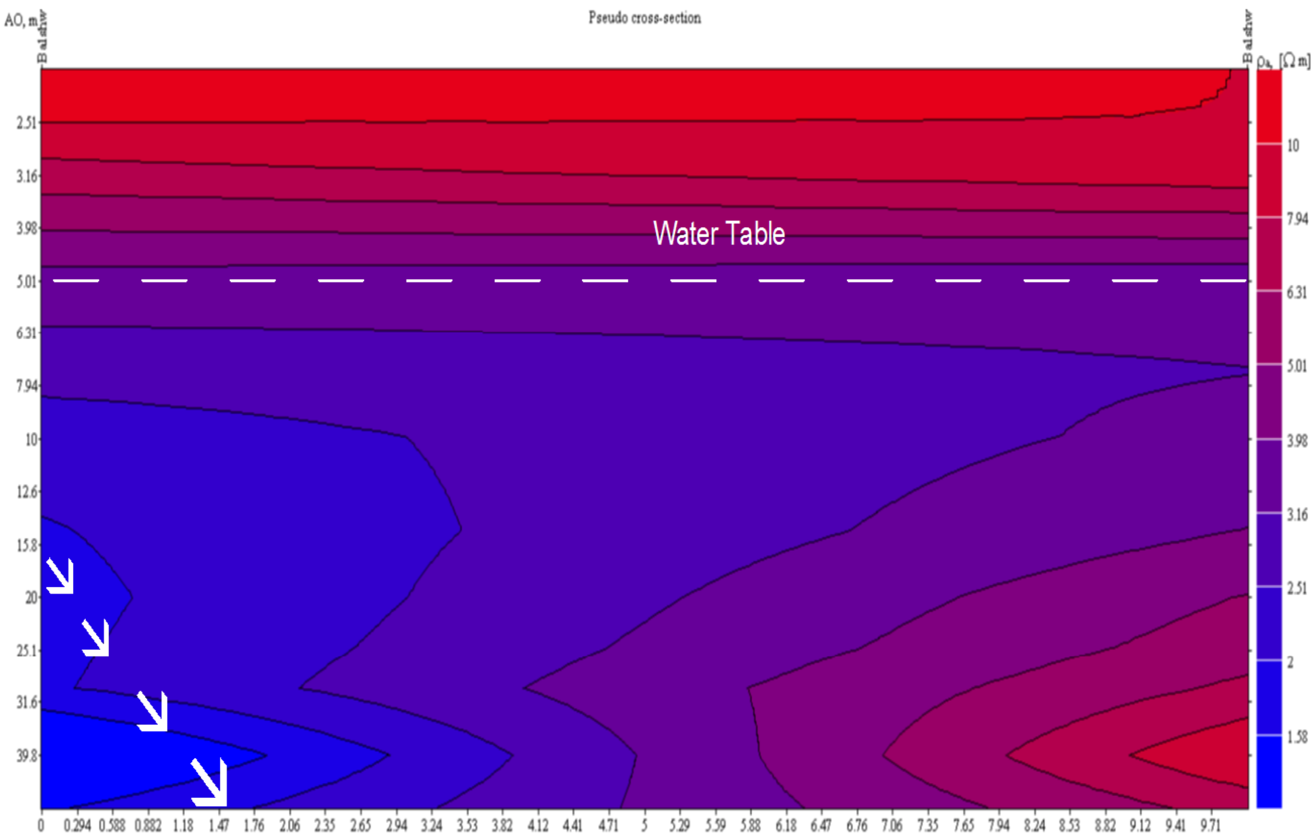

Fig. 25 Cross section of Bhalswa landfill site

II) Okhla landfill site

Similarly, two sites were selected for study, one above the landfill, which shows almost an uniformity less ρ_a value with depth (Fig 26) & shows a 'H' type curve and the other near the landfill (Fig.27) which shows a 'Q' type curve indicating contamination at depth, than at the shallow aquifer.

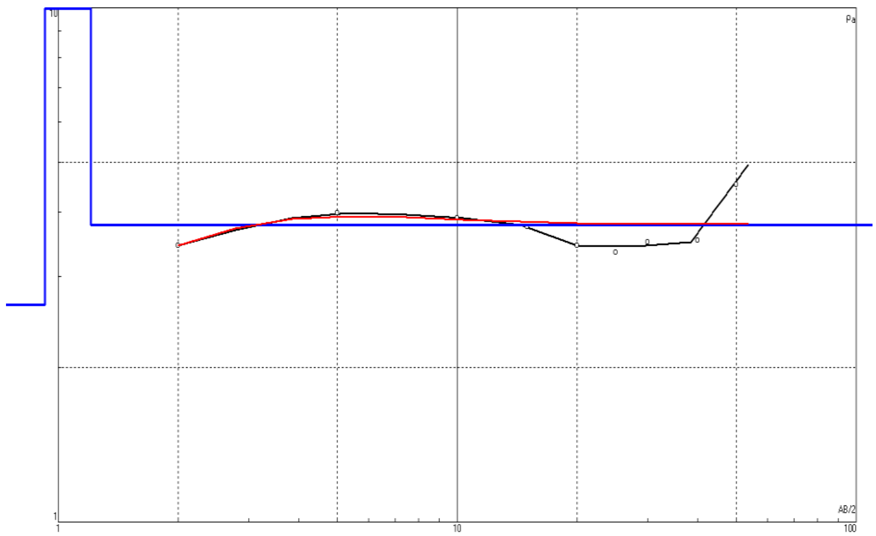

Fig. 26 H type curve of Okhla landfill site in top area

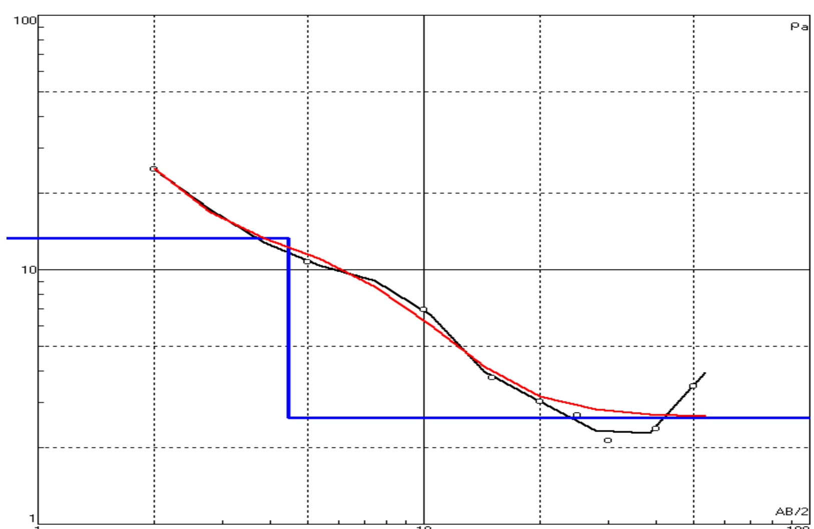

Fig. 27 Q type curve of Okhla landfill site in ground area

The maximum value of site-I is 4.525 and minimum is 3.349, average value of the ρa value is 3.716 and in Site-II, maximum value is 24.763 and minimum 2.127. Average value is 6.658.

Similar to Bhalswa site, the Okhla site was selected one over the landfill and another nearby. It's interesting to note that the ρa value is also lesser here and no definite variation was observed . ρ_a values remains almost constant with depth with less ρ_a indicating pollution but at Okhla site II (Fig 28) the shallow waters are comparatively less contaminated but the deeper water is contaminated due to the flow of polluted water along the groundwater flow direction as the shallow aquifer has higher value than the deeper groundwater.

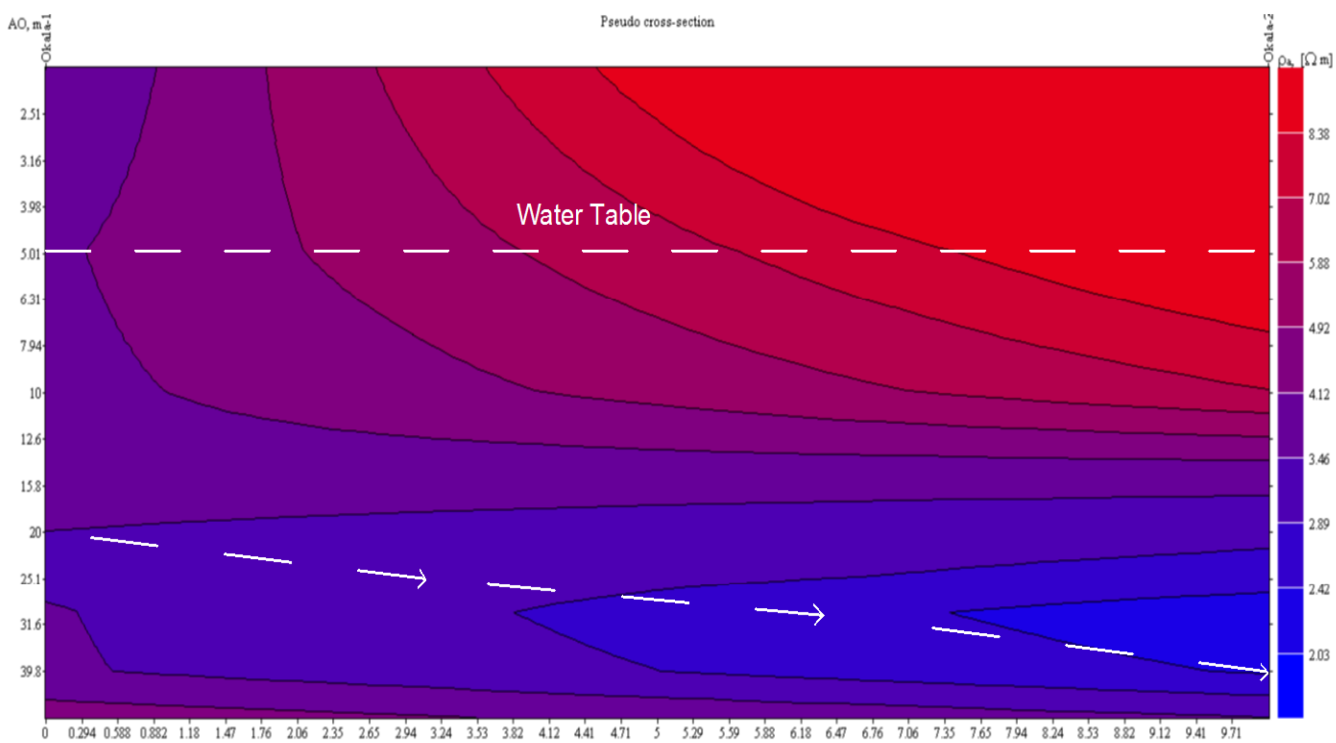

Fig. 28 Cross section of Okhla landfill site

III) Ghazipur landfill

Survey was conducted in only one site near the landfill due to non availability of spreading space .The (Fig 29) shows curve Q type, which shows increase in contaminant with depth. The maximum value of 9.815 and minimum 1.118, the average value of the area is 3.268

The depth profile of the Ghazipur region indicates similar pattern to that of Okhla site II where the shallow groundwater has comparatively higher value than that of the deeper aquifer indicating more contamination of leachates at deeper region.

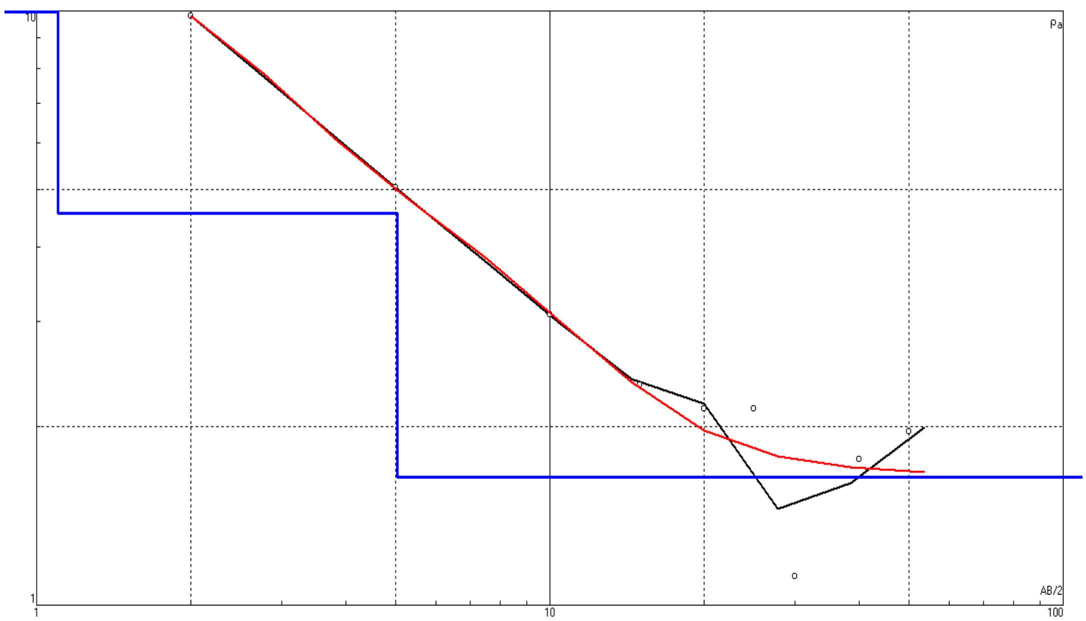

Fig. 29 Q type curve of Ghazipur landfill site area

Studying all the depth profiles, it is evident that the water level stays below 5m and there are two main horizons above and below 40m in all the depth profiles except at Bhalswa site II which shows a decreasing zone I trend below 5m and increasing trend above 40m. This (Fig 30) shows the higher contamination which is reflected in the geophysical survey is 40m and below this the degree of contamination is lesser comparatively. In general from the geophysical survey its evident that the landfill is contaminated due to the leachates. This is also evident from the lesser value of ρ_a and Q type curves in almost all the survey locations.

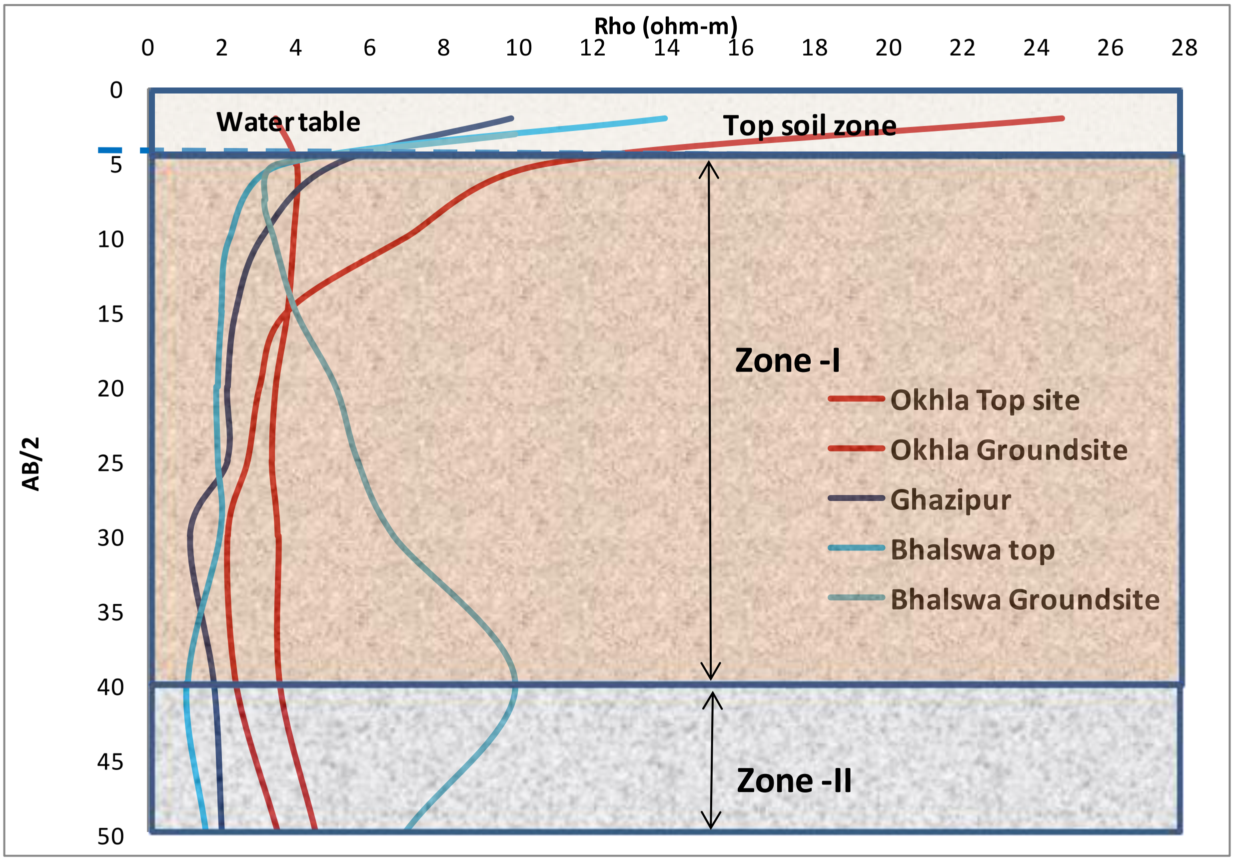

Fig 30 Depth profile of land fill site

7. CONCLUSION

Systematic sampling and analysis of groundwater have been carried out in all three major seasons in Delhi for complete 4 years from 2004 to 2007, around all the three landfills (Bhalswa, Okhla and Ghazipur) covering area of about 28 sq. km. each, to infer the influence of municipal/industrial waste dumping landfill and anthropogenic sources on the groundwater quality of Delhi.

Most of groundwater samples around all the three landfills are colorless, odorless and alkaline in nature, but colour of the groundwater samples are light yellowish with salty taste e.g. in Bhalswa Dairy Village. These few groundwater samples around Bhalswa landfill show high value of TDS (2041 mg/1) and EC up to 3256 µS/cm $^{-1}$. Most of samples around all three landfill shows slightly near neutral to basic in nature (pH > 6.0), but few groundwater samples collected around Bhalswa landfill shows slightly acidic nature (pH< 6.0) because of high concentration of heavy metals in groundwater through leaching of contaminants from landfill. Seasonal variations occur due to dilution of groundwater in various proportions during monsoon period with rainwater.

The statistical analysis and charge balance of most of the samples shows + 5.0 % error which is in the acceptable range (Guller et.al. 2002). This also indicates the precession of sample analysis for the major and minor ions. High concentration of Chloride, Fluoride, Nitrate, and Sulphate observed in almost all groundwater samples, with some exception in groundwater samples collected from Narendra Dev College, Govind Puri, Nehru Place etc. because all these areas are far away from Okhla landfill sites. Most of anions show high concentration in post monsoon due to addition of these ions by precipitation and resultant leaching with rainwater in monsoon period. The spatial distribution of fluoride, nitrate, chloride and phosphate indicate the migration of leachates from landfill site to groundwater system.

The high concentration of heavy metals and other cations are observed around all the three landfills. Bhalswa landfill shows more contamination than Okhla and Ghazipur, due to variation in geology, soil and depth of water table around all these landfills. The landfill leachates contain Fe (>20 mg/1), Ni (< 3 mg/1), Mn (< 20 mg/1), Cu (<10 mg/1), Zn (< 10 mg/1) and Pb (< 2 mg/1), which is much higher than the values recommended by Central Pollution Control Board and other world organizations. The groundwater samples around all these landfills contain higher concentration of heavy metals and other cations than recommended by USPH and WHO standard for drinking water. The spatial, distributions of all these heavy metals indicate possible leaching of contaminant from landfill. The simulations of contaminant transport in groundwater aquifer indicate the landfill as one of the major point source of contamination of Delhi groundwater.

The comparative studies of these landfills indicate that groundwater quality in vicinity of Bhalswa landfill is very poor while other landfills like Okhla and Ghazipur are comparatively better. All these variations are due to difference between quality/quantity of dumping material. The results indicate that both the working landfills are over used. The spatial variations of heavy metals indicate that landfills are the major point source of contaminant in that area.

The contour lines of heavy metal and other anion concentration (mg/1) around the landfill show the impact of landfill leachates on groundwater quality. High concentrations of chloride in groundwater indicate impact of anthropogenic input on groundwater quality. In Swami Shridhdhanad Park, Badali industrial area, J.J. Colony, Bhalswa Dairy Gaon etc, groundwater samples shows high concentration of nitrate because of landfill leachate impact along with the fertilizer leaching used in agriculture practices. Kalimata Colony, Chiriya Ghar etc groundwater samples shows high value of nitrate concentration in groundwater due to human as well animal wastage along with fly ash dumping in Bhalswa landfill. The groundwater samples around Okhla landfill show less contamination because of geology of this area showing domination of quartzite as well water table is quite below than in comparison to other regions of Delhi.

The calibration of model has been carried out with Correlation coefficient with 0.83 (1.19 Days), 0.98 (244 days), 0.94 (365 days) and 1.0 (487 days) and 0.99 (609 days) at 95 % confidence. The Normalized RMS value is about 2.67 with 95% confidence interval for period of 609 days. The simulation of heavy metal and other ions like fluoride, chloride, phosphate and nitrate migrations in south-central Delhi has also been carried out in this study.

The fluoride spread up to Lodhi garden, AIIMS and HauzKhas within a short period of 90 days from Ghazipur landfill, and it spread to all south eastern and central Delhi within 365 days. The iron, nitrate, phosphate and other heavy metals also shows similar results. Heavy metal shows different movements in groundwater aquifer system, which is due to solvation (solvent activity or adsorption/desorption process etc.) of heavy metal in various proportions with other contaminant in groundwater aquifer system of Delhi. The geophysical aspects of Okhla and Bhalsawa landfill area show high contamination up to 20 meter of aquifer the landfill leachate influence is inferred. Above 20 m it is moderately affected indicating the influence of Yamuna river surface water.

8. SUMMARY OF THE PROJECT TECHNICAL WORK DONE SO FAR

The study area selected were suspected to be influenced by landfill dumping; the area has almost the same lithology and aquifer systems, and extends in an approximately few kilometer radius from the two landfill site. Sampling sites in the vicinity of the landfill were chosen in such a way as to indicate possible influences from the past, present and future. The landfills are located in one of the most urbanized areas of Delhi, and its influences on the huge population are inevitable in the capital city of India, because it is unplanned, lying in the flood plain of the Yamuna River, and its alluvial lithology makes it more susceptible to contamination by leaching of pollutants. Most of the samples reported had high conductivity, high heavy-metal concentration, chloride, nitrate and other cations and anions, indicating anthropogenic input, i.e. leaching of pollutants from the landfill. The pollutant concentrations seems to be decreasing in the direction of the groundwater flow along the radius as we move away from landfill, indicating that the landfill acts as a point source of contamination. Various graphical plots and statistical analysis have been applied to the chemical data based on the ionic constituents, water types, and hydrochemical facies to deduce the impact of the landfill on groundwater quality. The statistical analysis and spatial and temporal variations indicate leaching of contaminants from the landfill into the groundwater aquifer system. The concentrations of heavy metals in the leachates were higher than the standards.

A comparative study based on Mg^{2+} Vs K^{+} cross plot suggested that Gazipur landfill site has the most impact on groundwater quality followed by Bhalswa and Okhala. Least impact was observed for Okhala landfill which is may be due to its location on quartzite belt where clay is the major constituent of soil which has high sorption capacity and partitioning coefficient thus the retardation coefficient. That is why contaminant flow through the unsaturated zone is being retarded in this case. However, there is limit of sorption capacity after which the saturated soil will start releasing the contaminant with infiltrating water. Thus even if the situation is much better comparatively, it is very likely that in future it will deteroriate with time and impact will shift toward moderate to high impact.

Gazipur landfill is located on the newer alluvium which is a flood plain of the Yamuna River with high sand content that is why groundwater in the vicinity of this landfill showed the highest impact of landfill. Kumar et al., (2009) suggested that there is a strong interaction between groundwater and the Yamuna River, these facts makes this site more vulnerable and need proper management. On the other hand, Bhalswa landfill showed all levels of impact ranging from weak to high impact. This landfill site is surrounded my sandy Yamuna flood plain in its eastern boundary while in its western side there is older alluvium with high clay. This may be the reason of having all different levels of impact. However, situation is more critical concerning the drinking water supply, which draws groundwater in the upper Yamuna flood plain. Therefore the impact from this site is likely to affect the Delhi people more severely. It is highly recommended that an immediate management action must be taken for this landfill on priority basis.

As the common sources of nitrate in water are the leachates from the landfill sites whether in used or abandoned, local agricultural fields, domestic sewage etc a graph was plotted for different landfill site to visualize the temporal variation of nitrate concentration in the groundwater of different landfill sites. Results suggested that there is no definite trend in nitrate concentration, a certain difference between May 2004 samples and September 2006 samples can be easily observed where September 2006 samples occupy the highest place and that of May 2004 samples occupied the lowest.

As far as the magnitude of temporal variation is concerned Okhala landfill vicinity showed highest difference followed by Bhalsawa and Gazipur. This is a very likely result, as discussed above as well that Okhala landfill site is in its initial phase where the movement of contaminants are being retarded by the presence of clay which will weaken as time progresses. Similarly, Gazipur due to its location on flood plain already has high impact thus temporal variation is less. However, the contamination level is highest in the case of Bhalswa followed by Okhala and Gazipur. Comparatively less nitrate level in the vicinity of Gazipur landfill is probably due to the dilution effect occurring due to the surface water-groundwater interactions (as suggested by Kumar et al., 2009), which is minimum in the case of other two landfill sites. Such results was further substantiated by the scattered graph between Chloride and sulphate, which showed that there is a strong correlation between high Chloride and high sulphate concentration.

9. SUGGESTION

Study of ground water quality carried out by us for three years in the vicinity of selected landfill in Delhi helped us to suggest some positive approach so that possible damage can be minimized up to a certain limit and possible precaution to be taken for future planning of landfill.

-Both working landfills may be closed as soon as possible so that further source of contaminant can be reduced.

-Proper management should be undertaken to sort out or remove hazardous solid wastes before dumping so that leachates from Bhalswa and Okhala landfill can be reduced and will not contaminate ground water

-Guidelines must be stricter and a Resource Conservation and Recovery Act should be brought in to provide new restrictions and standards for land disposal facilities as per USEPA, 1986B. This act will enforce:

- Banning liquids from landfills.
- Banning any drinking use from the water well located within 1 to 4 miles from the site.
- Requiring more stringent structural and design conditions for the landfills and surface impoundments, including two or more liners, leachate collection system above and between the liners, and continuous groundwater monitoring.
- Requiring cleanup or corrective action if hazardous waste leaks from a facility.
- Requiring information from disposal facilities on pathways of potential human exposure to hazardous substances.
- Requiring location standards that are protective of human health and the environment: for example, allowing disposal facilities to be constructed only in suitable hydrogeological settings.
- Study of vertical movement of contaminate through aquifers should be undertaken in all three landfills in order to delineate more accurately the movement of pollutant from the surface to the subsurface zone.
- People living around the landfill should be educated about possible consequences of using contaminated water.
- Delhi government and Delhi Jal board should be more cautious in supplying ground water to public from their drinking water needs and should take all necessary precautions.
- Proper lined sanitary landfill sites along with segregation of wastes and incinerators using plasma techniques need to be developed which are effective in keeping the surface and ground water free from leachates enriched with pollutants.

10. FURTHER INVESTIGATION REQUIRED

Considering the limitation of the study we have identified following topics to be investigated further:

1. Leachate movement simulation using Lysimeters network should be immediately carried out to protect the water resource. This study will help to identify the place of leachate collection and also to build some lining structure in leachate plume direction.
2. As our study was limited to chemical parameters we felt an immediate need of biological parameter analysis for landfill leachate contaminant concentrations. This is a critical point as chemical and biological reaction changes with age of the landfill.
3. Field and laboratory testing for estimating Permeability and Hydraulic conductivity of soil and bed rock is also required for actual estimation of recharge rate that takes contaminants to the groundwater.
4. Estimation of various saturated and unsaturated soil parameters like partitioning coefficient will give quantitative estimation of retardation factor as well infiltration rate. In this context infiltrometers can be used to estimation of Infiltration and lateral drainage.
5. Resistivity imaging surveys and geo-morphological study can also add a new dimension.
6. Application of water balance method to estimate the percolation of quantity of leachate periodically.
7. Application HELP and CHRONO for assessment of landfill performance.
8. Mathematical modelling of flow and contaminant transport.
9. Application of Soil erosion models.

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Plate 1. Collection of Leachate Samples and Geophysical Method.