Leachate Characterization and assessment of groundwater pollution near municipal solid waste landfill site

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Abstract

Leachate and groundwater samples were collected from Gazipur landfill-site and its adjacent area to study the possible impact of leachate percolation on groundwater quality. Concentration of various physico-chemical parameters including heavy metal (Cd, Cr, Cu, Fe Ni, Pb and Zn) concentration and microbiological parameters {total coliform (TC) and faecal coliform (FC)} were determined in groundwater and leachate samples. The moderately high concentrations of Cl^-, NO_3^-, SO_4^{2-}, NH_4^+, Phenol, Fe, Zn and COD in groundwater, likely indicate that groundwater quality is being significantly affected by leachate percolation. Further they proved to be as tracers for groundwater contamination. The effect of depth and distance of the well from the pollution source was also investigated. The presence of TC and FC in groundwater warns for the groundwater quality and thus renders the associated aquifer unreliable for domestic water supply and other uses. Although some remedial measures are suggested to reduce further groundwater contamination via leachate percolation, the present study demand for the proper management of waste in Delhi.

Keywords*: Solid waste; landfill; leachate; groundwater contamination; health risk; tracer; remedial measure.*

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Introduction

Landfills have been identified as one of the major threats to groundwater resources (Fatta et al., 1999; USEPA, 1984;). Waste placed in landfills or open dumps are subjected to either groundwater underflow or infiltration from precipitation. The dumped solid wastes gradually release its initial interstitial water and some of its decomposition by-products get into water moving through the waste deposit. Such liquid containing innumerable organic and inorganic compounds is called 'leachate'. This leachate accumulates at the bottom of the landfill and percolates through the soil.

Areas near landfills have a greater possibility of groundwater contamination because of the potential pollution source of leachate originating from the nearby site. Such contamination of groundwater resource poses a substantial risk to local resource user and to the natural environment The impact of landfill leachate on the surface and groundwater has given rise to a number of studies in recent years (Saarela, 2003; Abu-Rukah and Kofahi, 2001; Looser et al., 1999; Christensen.et al., 1998; De Rosa et al., 1996; Flyhammar, 1995). Many approaches have been used to assess the contamination of underground water. It can be assessed either by the experimental determination of the impurities or their estimation through mathematical modeling (Moo-Young et al., 2004; Hudak, 1998; Stoline et al., 1993; and Butwa et al., 1989).

In the present study, the impact of leachate percolation on groundwater quality was estimated from an unlined landfill site at Gazipur, Delhi. Various physico-chemical parameters including heavy metals and quality indicator microbes were analyzed in leachate and in groundwater samples to understand the possible link of groundwater contamination. The effect of depth and distance of landfill from groundwater sources

were also studied and some remedial measures were discussed to reduce further contamination of groundwater.

Site specification

Delhi is the capital of India and sprawls over 1483 km^2 at latitudes 28^o35'N and longitude77^o12'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 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 tones 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. 1). 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 waste. Furthermore no environmental impact assessment had been carried out prior to selection of these sites.

Gazipur Landfill Site

The Gazipur landfill started in the year 1984 and still in use. It spreads over an area of approximately 3 x 10^5 m^2 and 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.

Experimental

Sampling of leachate and groundwater

In an effort to study the extent of the groundwater contamination 12 sampling sites were selected within 1.5 km of landfill site from where the samples were taken (Fig. 2). Details of the sampling points are presented in Table 1. The samples were collected

after the extraction of water either from hand pump or from tube well in September 2003. The water was left to run from the source for about 4 min to equate the minimum number of well volume and to stabilize the electrical conductivity (EC). Since the landfill site was not equipped with a leachate collector, the leachate collected at the base of the landfill was sampled randomly from three different locations and were mixed prior to its analysis.

Analytical methods

After the sampling, the samples were immediately transferred to the lab and were store in cold room (4 ^{o}C). The analysis was started without delay in lab based on the priority to analyze parameters as prescribed by APHA (1994) methods. All the samples were analyzed for selected relevant physico-chemical parameters, heavy metals and total coliform (TC) and faecal coliform (FC) according to internationally accepted procedures and standard methods (APHA, 1994) Various physico-chemical parameters examined in groundwater samples includes, pH, electrical conductivity (EC), total dissolved solids (TDS), total dissolved volatile solids (TDVS), fixed dissolved solids (FDS), chemical oxygen demand (COD), biological oxygen demand (BOD), total alkalinity (TA), total hardness (TH), calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}), potassium (K^{+}), ammonia (NH_4^{+}), chloride (Cl^{-}), fluoride (F^{-}), sulphate (SO_4^{2-}), nitrate (NO_3^{-}), nitrite (NO_2^{-}), phosphate (PO_4^{3-}), boron (B), silica (Si) and phenol. EC and pH were recorded using a Systronics conductivity meter, mode 306 and µ pH system 361(Systronics). TDVS and FDS were estimated by using oven-drying method. Estimation of COD was done by reflux titrimetry, while BOD was calculated by oxygen determination by Winkler titration. TA, TH, Ca^{2+}, Mg^{2+} and Cl^{-} were estimated by titrimetry, Na^{+} and K^{+} by flame photometry (Systronic-128). Estimation of F^{-} by SPADNS, PO_4^{3-} by molybdenum–blue complex formation using spectrophotometer (Systronic 20D+), while

SO_4^{2-}, NO_3^-, NH_4^+, NO_2^-, B, Si and phenol were also determined by using either the same spectrophotometer or by Perkin-Elmer UV/VIS Lambda 2 spectrophotometer. The concentrations of cadmium (Cd), copper (Cu), chromium (Cr), iron (Fe), nickel (Ni), lead (Pb) and zinc (Zn) were determined using a SpectrAA-20 (Varian) atomic absorption spectrometer. The limit of detection (LOD) of these elements were 0.02, 0.03, 0.06, 0.03, 0.1, 0.1, and 0.01 mg l^{-1}, respectively. Samples for TC and FC were aseptically taken from the wells and their estimation was done by membrane filtration technique.

All the experiments were carried out in triplicate and the results were found reproducible within ± 3% error. The data were statistically analyzed by setting up and calculating a correlation matrix for the various parameters using Statistical Package for Social Sciences (SPSS) software package (Norusis and SPSS Inc, 1997).

Results and Discussion

Leachate

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 Gazipur landfill site has been presented in Table 2. The pH value of the collected sample was found to be 6.9. The relatively high values of EC (24500 µScm^{-1}) and TDS (27956 mg l^{-1}) indicate the presence of inorganic material in the samples. The presence of high BOD (19000 mg l^{-1}) and COD (27200 mg l^{-1}) indicates the high organic strength. Among the nitrogenous compound, ammonia nitrogen (2675 mg l^{-1}) was present in high concentration, this is probably due to the deamination of amino acids during the decomposition of organic compounds (Crawford and Smith, 1985; Tatsi and Zouboulis, 2002). High concentrations of NO_3^- (380 mg l^{-1}) and Si (326 mg l^{-1}) were also observed in the leachate samples.

The high level of Fe (70.62 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 (2.21 mg l^{-1}) in the leachate shows that the landfill receives waste from batteries and fluorescent lamps. The presence of Pb (1.54 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 (0.29 mg l^{-1}), Cu (0.93 mg l^{-1}) and Ni (0.41 mg l^{-1}) were also present in the leachate samples. A variety of waste is dumped at Gazipur 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.

Groundwater

Physico-chemical Characteristics

The underground water of the studied area is used for domestic and other purposes. Table 3 shows the desirable and maximum permissible limit recommended by Bureau of Indian Standard (BIS, 1991) and World Health Organization (WHO, 1997). The pH of all the groundwater samples was about neutral, the range being 7.02 to 7.85 (Fig. 3). The EC is a valuable indicator of the amount of material dissolved in water. The EC in the studied area range between 617 and 3620 µS cm^{-1} and was found to be high, especially at sites 1, 3, 8, 9, 10, 12 (Fig. 3). 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 302 and 2208 mg l^{-1} (Fig. 3). The TDS concentration was found to be

remarkably high at sites 1,8,9,10 and 12. As per the classification of Rabinove et al., (1958) based on TDS, seven samples were non-saline and five samples were slightly saline (Table 3). 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). TDVS in the water samples ranged from 36 to 268 mg l^{-1} and the concentration of FDS in the samples varied from 264 to 2008 mg l^{-1} (Fig. 3). COD is a measure of oxygen equivalent to the organic matter content of the water susceptible to oxidation by a strong chemical oxidant and thus is an index of organic pollution. The COD level in the groundwater samples varied from 2 to17 mg l^{-1}, indicating the presence of organic contaminants in the water (Fig. 3) and can be used as organic indicators to assess the groundwater pollution caused by landfill.

The concentration of TA as $CaCO_3$ in groundwater ranges from 230 to 734 mg l^{-1} (Fig. 3). Water within the approximate pH range of 4.3 to 8.3 contain bicarbonate alkalinity and weak acids such as carbonic acid (carbon dioxide in solution) can also exist. Natural processes such as the dissolution of carbonate minerals and dissolution of CO_2 gas from the atmosphere and soils could be a mechanism, which supply HCO_3^- into the groundwater:

$$CaCO_3+CO_2+H_2O \leftrightarrow Ca^{2+}+2HCO_3 \quad (1)$$

$$CO_2+H_2O \leftrightarrow H^++HCO_3^- \quad (2)$$

In addition, anthropogenic CO_2 gas should be considered as a potential source of bicarbonate in groundwater. Potential sources of CO_2 gas are (a) CO_2 gas originating

from municipal wastes within unlined landfill sites, (b) CO_2 gas due to the oxidation of organic materials leaked from old latrines and sewage systems in the downtown area, and (c) HCO_3^- from sulfate reduction of organic materials in the aquifer (Clark and Fritz, 1997).

$$CH_2O+O_2 \leftrightarrow CO_2+H_2O \quad (3)$$

$$2CH_2O + SO_4^{2-} \leftrightarrow H_2S+2HCO_3^- \quad (4)$$

The high alkalinity imparts water with unpleasant taste, and may be deleterious to human health with high pH, TDS and TH.

Multivalent cations, particularly Mg^{2+} and Ca^{2+} are often present at a significant concentration in natural waters. These ions are easily precipitated and in particular react with soap to make it difficult to remove scum. TH is normally expressed as the total concentration of Ca^{2+} and Mg^{2+} in mg l^{-1}, equivalent $CaCO_3$. TH ranged from 296 to 1388 mg l^{-1} (Fig. 4). According to the classification of Durfor and Becker (1964) for TH a very hard groundwater dominantly distributed in the studied area (Table 5). Ca^{2+} and Mg^{2+} are the important parameters for total hardness. Ca^{2+} concentration in groundwater ranged from 43 to 477 mg l^{-1} (Fig. 4). Ca^{2+} often comes from carbonate-based minerals, such as calcite and dolomite. Ca^{2+} and SiO_2 may also come from the dissolution of concrete in streets and the side walks. The concentration of Ca^{2+} found to be very high in samples from site 1 and 3. The excess of Ca^{2+} causes concretions in the body such as kidney or bladder stones and irritation in urinary passages. The concentration of Mg^{2+} ions varied from non-detectable (nd) to 220 mg l^{-1} (Fig. 4). Mg^{2+} salts are cathartic and diuretic and high concentration may cause laxative effect, while deficiency may cause structural and functional changes. It is essential as an activator of many enzyme systems (WHO, 1997). The concentration of Na^+ in water samples varied from 22 to 313 mg l^{-1}

(Fig. 4). The high concentration of Na^+ may pose a risk to persons suffering from cardiac, renal and circulatory disease. K^+ has been reported to be an indication of the leachate effect (Ellis, 1980). The concentration of K^+ in the water samples varied from 6 to 56 mg l^{-1} and was found to be well within the permissible limit at Gazipur (Fig. 4). The NH_4^+ concentration in the samples ranged from nd to 4.3 mg l^{-1} (Fig. 4) and likely indicate its origin from leachate.

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 groundwater samples ranged between 28 mg l^{-1} to 737 mg l^{-1}. At sites 8 and 10, the chloride concentration was found to be comparatively high (Fig. 5). 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 concentration of F^- in the studied water samples ranged from 0.37 to 1.13 mg l^{-1} and found to be slightly high in sample at site 10 (Fig. 5). F^- at low concentration (~1 mg l^{-1}) in drinking water has been considered beneficial but high concentration may causes dental fluorosis (tooth mottling) and more seriously skeletal fluorosis (Ravindra and Garg, 2005). The concentration of NO_3^- in water sample varied from nd to 56 mg l^{-1} (Fig. 5). Although only one sample (site 9) exceeds the permissible limit but it shows a moderately high concentration. Jawad et al. (1998), have also reported increase in NO_3^- concentration in groundwater due to wastewater dumped at the disposal site and likely indicate the impact of leachate. The concentration of NO_2^- varied from nd to 0.56 mg l^{-1}. PO_4^{3-} in the water sample was well below the permissible limit and the concentration

varied from nd to 0.06 mg l^{-1} (Fig. 5). Concentration of SO_4^{2-} in water sample ranged from 12 to 1096 mg l^{-1} and was significantly high at sites 1, 8 and 10 (Fig. 5).

Concentration of B varied from 0.2 to 2.4 mg l^{-1} (Fig. 6). The presence of Si in water sample varied from 19.6 to 42.4 mg l^{-1} (Fig. 6). A very low concentration of phenol was also observed in water samples and its concentration varied from nd to 0.1 mg l^{-1}, which further support that groundwater near landfill site is being significantly affected by leachate percolation.

Heavy Metals

The groundwater samples were analyzed for heavy metal such as Cu, Fe and Zn, which are characterized as undesirable metals in drinking water. WHO (1997) has proposed their permissible value of 1, 0.3 and 5 mg l^{-1} respectively in drinking water. Only Fe and Zn showed their presence in groundwater samples above the LOD of the present analytical method. Fe concentration in the water samples varied from 0.04 to 2.48 mg l^{-1} (Fig. 6) and found well above the WHO permissible limit in many samples. Presence of Fe in water can lead to change of color of groundwater (Rowe et al., 1995). The concentration of Zn varied from nd to 0.8 mg l^{-1} (Fig. 6). The metals Pb, Cd, Cr and Ni are characterized as toxic one for drinking water. The concentration of these metal was found to be below detection limit in groundwater samples. This likely indicates that these metal may be adsorbed by the soil strata or by the organic matter in soil.

Heavy metals remain in the waste or at the waste–rock interface as a result of redox controlled precipitation reactions (Yanful et al., 1988). Further the metal mobility is also controlled by physical sorptive mechanisms and landfills have an inherent *in situ* capacity for minimizing the mobility of toxic heavy metals (Pohland et al., 1993). This

fixing of heavy metals reduces the risk of direct toxic effects due to ingestion of leachate contaminated groundwater.

However, once the leachate leaves the site the situation changes. The leachate is generally a strongly reducing liquid formed under methanogenic conditions and on coming into contact with aquifer materials has the ability to reduce sorbed heavy metals in the aquifer matrix. The most important reactions are the reduction of Fe and Mn to more soluble species. Hence the concentration of these components increases under favorable conditions close to a landfill and may lead to a serious toxic risk.

Microbial contamination

The difficulty of detecting low concentration of pathogenic bacteria and viruses, coliform bacteria are used to determine the faecal contamination. The concept of coliforms as bacterial indicator of microbial water quality is based on the premise that coliforms are present in high numbers in the faeces of humans and other warm-blooded animals. If faecel pollution has enters in groundwater; it is likely that these bacteria will be present, even after significant dilution. Table 6 shows the presence of TC and FC in most samples, indicating the contamination of groundwater possibly due to leachate percolation in groundwater. The presence of faecal contamination is an indicator that a potential health risk exists for individual exposed to this water.

The coliform bacteria can multiply where leachate enters an oxygenated system. Klink and Stuart, 1999 found that when leachate was diluted with the bacteria-free groundwater there was an increase in the number of thermotolerant coliform and the bacteria were able to survive for up to two weeks under laboratory conditions.

Correlation analysis

Correlation analysis is a preliminary descriptive technique to estimate the degree of association among the variables involved. The purpose of the correlation analysis is to measure the intensity of association observed between two variables. Such association is likely to lead to reasoning about causal relationship between the variables. Correlation matrix between various parameters is shown in table 7.

Most of the parameters were found to bear statistically significant correlation with each other indicating close association of these parameter with each other. TDS had a strong correlation with a number of parameters like TH, Mg^{2+}, Cl^{-}, SO_4^{2-}, Na^{+}, and K^{+} indicates the high mobility of these ions. Thus the single parameter of TDS can give a reasonable good indication of a number of parameters (Ravindra et al., 2003).

Total hardness was found to be positively correlated with Ca^{2+}, Mg^{2+}, Cl^{-}, SO_4^{2-}, Na^{+} and K^{+}. Mg^{2+} found to be negatively correlated with B, but positively correlated with SO_4^{2-}, Na^{+} and K^{+}. An excellent correlation value of Na^{+} with Cl^{-} and SO_4^{2-} indicate that the main water type in the sample is Na-Cl and Na-SO_4.

Effect of depth and distance

The extent of contamination of groundwater quality due to leachate percolation depends upon a number of factors like leachate composition, rainfall, depth and distance of the well from the pollution source, the landfill site in the present case. Water samples collected from different depths and distances were analyzed for this study. Fig. 7 shows that the concentrations of various species in the groundwater samples for equal distance of 1.5 km from the landfill site boundary at varying depth. Interestingly the water contamination drops fast with depth up to 30 m and further percolation of leachate

becomes gentler. However, this aspect needs further investigations by drilling more wells of varying depths for having a proper correlation between time and percolation depth.

Similarly when the water quality of the wells situated at different distances from the landfill site but having the same depth was compared (Table 8, see site 1 and 12). Water sampled from the well situated close to the landfill site was found to be more contaminated than that of the well situated farther away. It obviously follows from the fact that the gravitational movement of the viscous fluid, leachate is hindered due to the mass of the solid soil matter. With increasing time the viscous fluid penetrates deeper and spread all over a longer distance. A combined effect of distance and depth can also be assessed from Table 8 (site 1 and 5), which again confirms the above discussion. Although increased levels of few pollutants in groundwater may also be contributed by some near by activity such as cattle and poultry farming around the landfill.

Strictly speaking one should avoid using groundwater drawn from the wells located in proximity of the waste dumping sites. If this is unavoidable, deeper drilling and frequent analysis of water samples are desirable. Efforts should be made to supply clean water through pipelines from distant sources.

Remedial Measures for the Groundwater Pollution

From the groundwater monitoring it is clearly evident that the leachate generated from the landfill site is affecting the groundwater quality in the adjacent areas through percolation in the subsoil. Therefore, some remedial measures are required to prevent further contamination. This can be achieved by the management of the leachate generated within the landfill. Leachate management can be achieved through effective control of leachate generation, its treatment and subsequent recycling throughout the waste.

Engineered landfill sites are generally provided with impermeable liner and drainage system at the base of the landfill, which will not allow leachate to percolate into subsoil. All the leachate accumulated at the base of the landfill can be collected for recycling or treatment. This collected leachate can be distributed throughout the waste by means of spraying the leachate across the landfill surface. Some of the water may be lost through evaporation and therefore leading to reduction in the volume of the leachate for ultimate treatment.

Techno economic feasibility studies should be carried out for choosing the options for a landfill site. Retrofitting techniques for the existing, old sites, like Gazipur, would be cumbersome and expensive. At and around this site water supply drawn from safe, distant sources should be the first option. Gazipur site will soon be closed for MSW disposal since it has already received waste beyond its capacity. Remedial measures should be considered by taking this into account.

Gazipur landfill site is non-engineered landfill. It is neither having any bottom liner nor any leachate collection and treatment system. Therefore, all the leachate generated finds its paths into the surrounding environment. In such conditions only feasible options that could be followed are:

(i) Limiting the infiltration of the water through the landfill cover by providing impermeable clay cover. Due to this less water will enter and subsequently less leachate will be generated, thereby reducing the amount of leachate reaching the landfill base.

(ii) Extraction of the leachate collected at the base can be done and it can be recycled, so that less amount will enter the aquifer lying below.

(iii) Increasing the evapo-transpiration rate by providing vegetation cover over the landfill can also reduce leachate production.

Conclusions

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. Further, the presence of Cl^-, NO_3^-, NH_4^+, Phenol and COD can be used as tracer with relation to leachate percolation. The samples were also found to be bacteriological unsafe. 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 Gazipur landfill site. The groundwater quality improves with the increase in depth and distance of the well from the pollution source. Although, the concentrations of few contaminants do not exceed drinking water standard even then the ground water quality represent a significant threat to public health. Some remedial measures are also recommended to stop further groundwater contamination.

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Table 1: Site specification for groundwater samples

Sample No	Sampling locations	Type	Depth (m)	Distance (km)*
GW.1	Dairy Farm, 3rd Street	TW[a]	46	0.2
GW.2	Dairy farm, Govt. Veterinary Hospital	MO[b]-HP[c]	24	0.4
GW.3	Delhi Electricity Board, Gazipur	MO-HP	21	0.5
GW.4	Adjacent to Hindon Canal	HP	9	0.7
GW.5	Delhi Jal Board; Rajveer Colony	TW	85	1.5
GW.6	Sangam Park, Khoda	HP	12	1
GW.7	Poultry Market	TW	37	0.8
GW.8	Gazipur Village, Street No.130/52	HP	9	1
GW.9	TELCO, Gazipure	TW	24	1.5
GW.10	Simant Vihar Apartment	TW	31	1.5
GW.11	Solid Waste Landfill Site	TW	-	0
GW.12	Park in front of SBI, Gazipur	TW	46	1

*From the landfill site; [a]Tube Well; [b]Motor Operated; [c]Hand Pump.

Table 2: Physical- chemical characteristics of the leachate

Parameter	Concentrations*
pH	6.9
EC	24500
TDS	27956
TDVS	14992
FDS	12964
COD	27200
BOD	19000
Na^+	545
K^+	1590
NH_4^+	2675
NO_2^-	Nil
NO_3^-	380
Si	326
Phenol	0.02
Cd	0.06
Cr	0.29
Cu	0.93
Fe	70.62
Ni	0.41
Pb	1.54
Zn	2.21

*All in mg l^{-1} except pH and EC ($\mu S\ cm^{-1}$)

Table 3: Drinking water quality standards as recommended by BIS and WHO.

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}

Table 4: Classification of groundwater samples on the basis of TDS Concentration.

Type of groundwater	**TDS (mg l^{-1})**	**Samples**
Non- saline	<1000	07
Slightly Saline	1000-3000	05
Moderately saline	3000-10,000	Nil
Very saline	>10,000	Nil

Table 5: Classification of groundwater samples on the basis of Total Hardness.

Hardness	Descriptions	Samples
0-60	Soft	Nil
61-120	Moderately Hard	Nil
121-180	Hard	Nil
>180	Very Hard	12

Table 6: Microbiological analysis of water

Site No.	Total coliforms Nos/100 ml	Faecal coliforms Nos/100 ml
1	<1	<1
2	3600	350
3	1500	380
4	<1	<1
5	3500	12
6	<1	<1
7	3600	<1
8	9800	104
9	8100	<1
10	14800	22
11	1500	48
12	900	4

Table 7: Correlation matrix for different water quality parameters

	pH	EC	TDS	TDVS	FDS	TA	TH	COD	Ca^{2+}	Mg^{2+}	Cl^{-}	F^{-}	SO_4^{2-}	PO_4^{3-}	B	Na^{+}	K^{+}	NO_2^{--}	NO_3^{-}	NH_4^{+}	Fe	Zn
pH	1.000																					
EC	-0.099	1.000																				
TDS	-0.120	**0.994**	1.000																			
TDVS	-0.274	**0.851**	**0.888**	1.000																		
FDS	-0.101	**0.996**	**0.999**	0.863	1.000																	
TA	-0.377	0.265	0.285	0.358	0.273	1.000																
TH	-0.348	**0.918**	**0.941**	**0.961**	**0.926**	0.392	1.000															
COD	-0.181	0.090	0.078	0.021	0.084	0.027	0.075	1.000														
Ca^{2+}	-0.173	0.413	0.460	0.717	0.426	0.427	**0.619**	0.198	1.000													
Mg^{2+}	-0.246	**0.697**	**0.676**	0.437	**0.693**	0.036	**0.585**	-0.115	-0.274	1.000												
Cl^{-}	0.006	**0.986**	**0.976**	**0.827**	**0.979**	0.230	**0.886**	0.058	0.459	**0.609**	1.000											
F^{-}	0.278	0.513	0.485	0.303	0.499	-0.028	0.273	-0.444	-0.068	0.407	0.548	1.000										
SO_4^{2-}	0.015	**0.912**	**0.931**	**0.760**	**0.937**	0.176	**0.815**	-0.073	0.275	**0.715**	**0.892**	0.572	1.000									
PO_4^{3-}	-0.034	0.124	0.108	-0.079	0.127	-0.264	0.053	0.168	-0.245	0.311	0.111	-0.134	0.138	1.000								
B	-0.095	-0.368	-0.326	-0.125	-0.344	**0.711**	-0.187	0.042	0.351	**-0.595**	-0.359	-0.420	-0.364	-0.398	1.000							
Na^{+}	0.015	**0.986**	**0.966**	**0.773**	**0.974**	0.202	**0.846**	0.070	0.340	**0.683**	**0.989**	**0.591**	**0.892**	0.162	-0.423	1.000						
K^{+}	-0.364	**0.652**	**0.681**	**0.604**	**0.680**	0.284	**0.663**	-0.101	-0.023	**0.834**	0.538	0.261	**0.733**	0.044	-0.222	0.572	1.000					
NO_2^{--}	0.161	-0.160	-0.140	-0.206	-0.131	**0.691**	-0.172	-0.170	-0.001	-0.213	-0.148	-0.037	-0.024	-0.194	**0.777**	-0.160	-0.007	1.000				
NO_3^{-}	-0.307	0.184	0.133	-0.051	0.151	-0.004	0.094	0.067	-0.334	0.454	0.146	0.147	0.062	**0.711**	-0.415	0.237	0.095	-0.214	1.000			
NH_4^{+}	0.363	-0.075	-0.075	-0.058	-0.075	-0.238	-0.067	-0.009	-0.108	0.024	-0.066	-0.397	-0.092	-0.004	-0.042	-0.076	0.061	-0.108	-0.217	1.000		
Fe	-0.172	-0.225	-0.235	-0.434	-0.211	0.048	-0.283	0.013	-0.399	0.063	-0.234	-0.046	-0.086	0.353	0.009	-0.193	-0.115	0.284	0.503	-0.194	1.000	
Zn	-0.115	-0.449	-0.447	-0.402	-0.445	-0.005	-0.361	0.458	-0.102	-0.322	-0.478	-0.508	-0.441	-0.239	0.227	-0.485	-0.357	0.082	-0.202	-0.088	0.213	1.000

Table 8: Comparison of various parameter levels in groundwater at different distance and Depth.

Parameters	Concentrations (mg l^{-1})		
	Site 1 (At 0.2 km*, depth 46 m)	**Site 12** (At 1.0 km*, depth 46 m)	**Site 5** (At 1.5 km*, depth 85 m)
EC	3490	2060	700
TA	546	518	230
TH	1388	836	380
COD	6	2	4
Ca^{2+}	477	46	21
K^{+}	16.9	37	7.8
Na^{+}	291	155	32
NH_4^{+}	0.6	1.6	Nil
Cl^{-}	737	286	58
SO_4^{2-}	665	221	58
F^{-}	0.85	0.8	0.67
NO_3^{-}	Nil	24.5	Nil
Zn	0.03	Nil	Nil
Fe	0.04	0.17	0.12

***Distance from landfill site**

Fig. 1: Location of Gazipur and other landfill sites in Delhi.

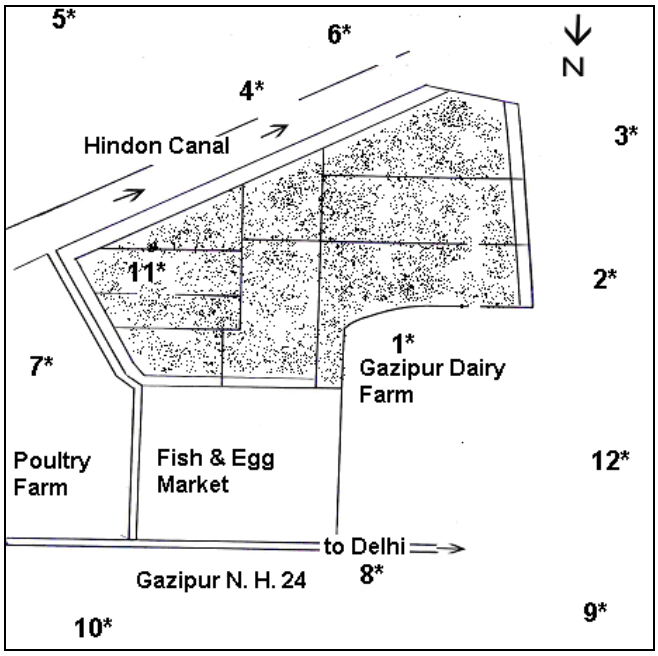

Fig. 2: Sketch map of sampling sites near and around Gazipur landfill site. (* distance not on scale)

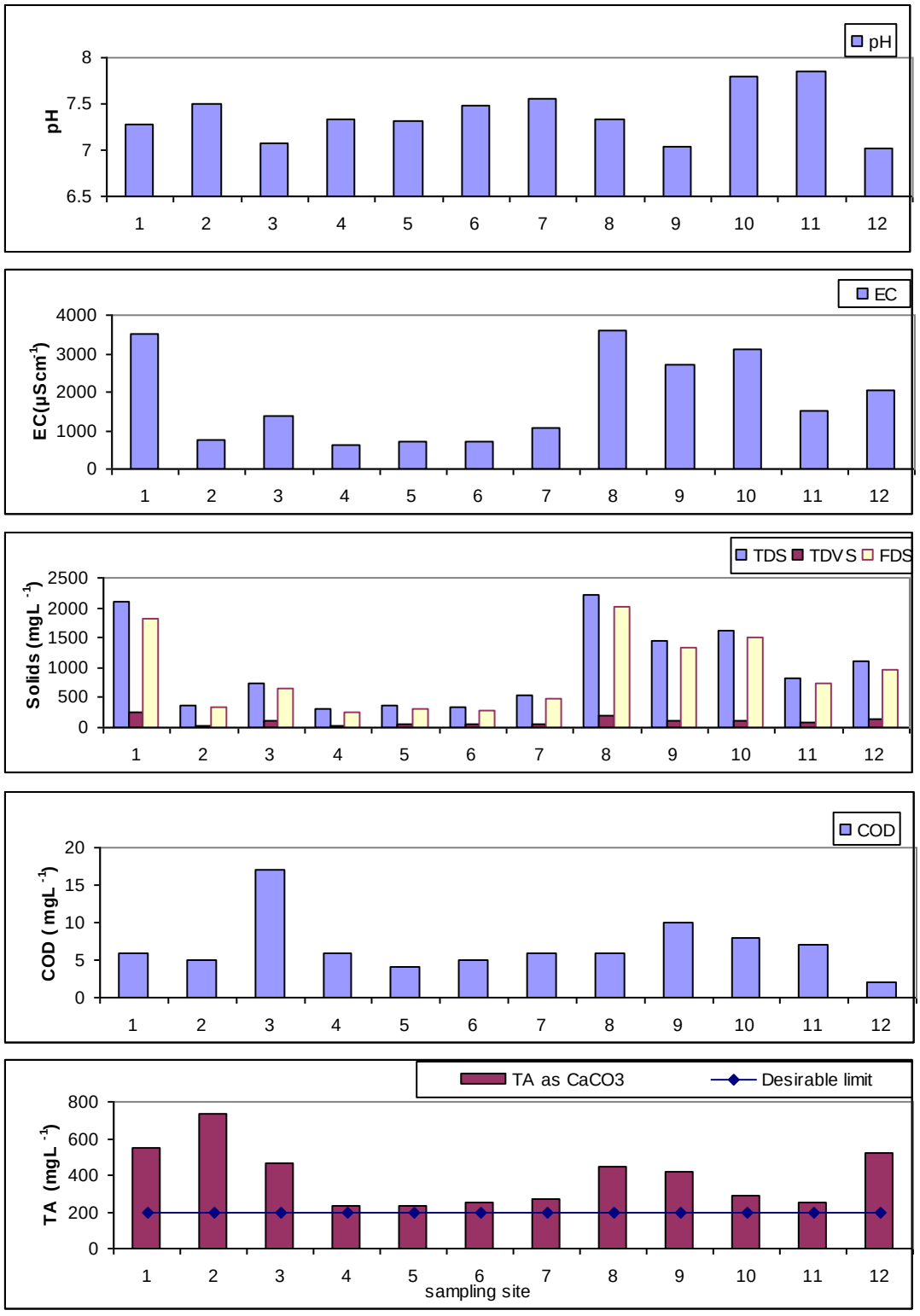

Fig. 3: Concentrations of pH, EC, TDS, TDVS, FDS, COD and TA in groundwater samples.

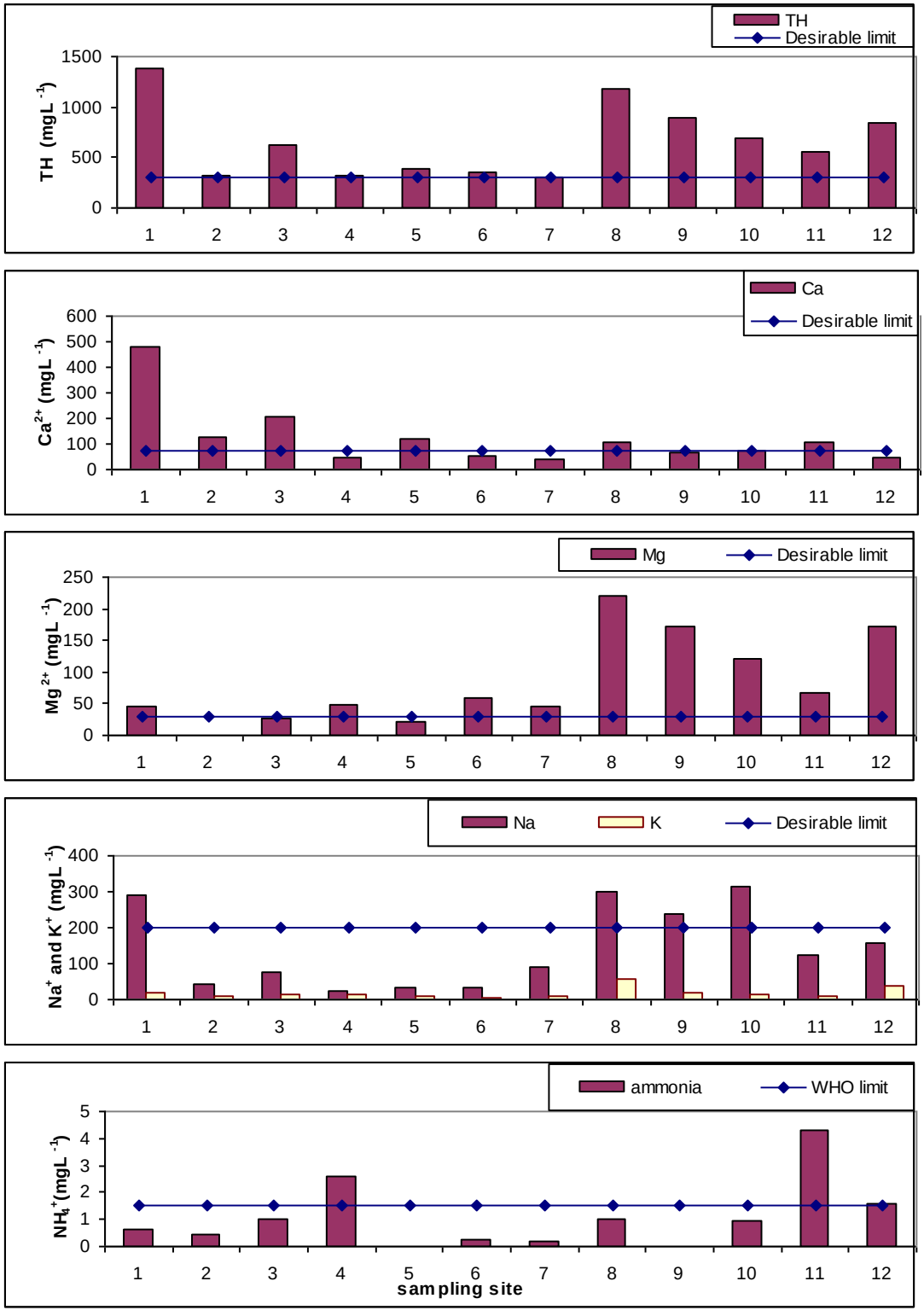

Fig. 4: Concentration of TH, Ca^{2+}, Mg^{2+}, Na^{+}, K^{+} and NH_4^{+} in groundwater samples

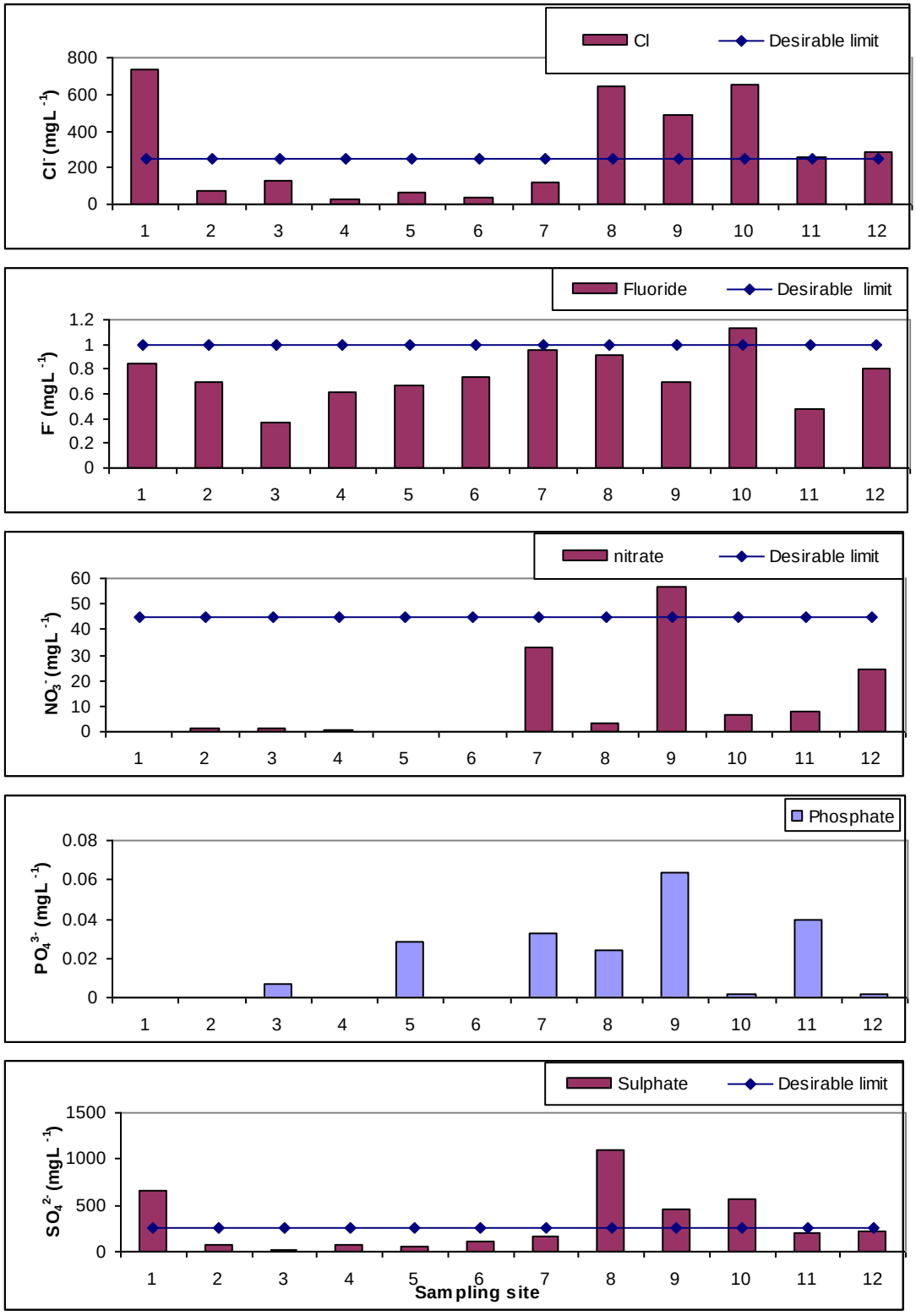

Fig. 5: Concentration of Cl^-, F^-, NO_3^-, PO_4^{3-} and SO_4^{2-} in groundwater samples.

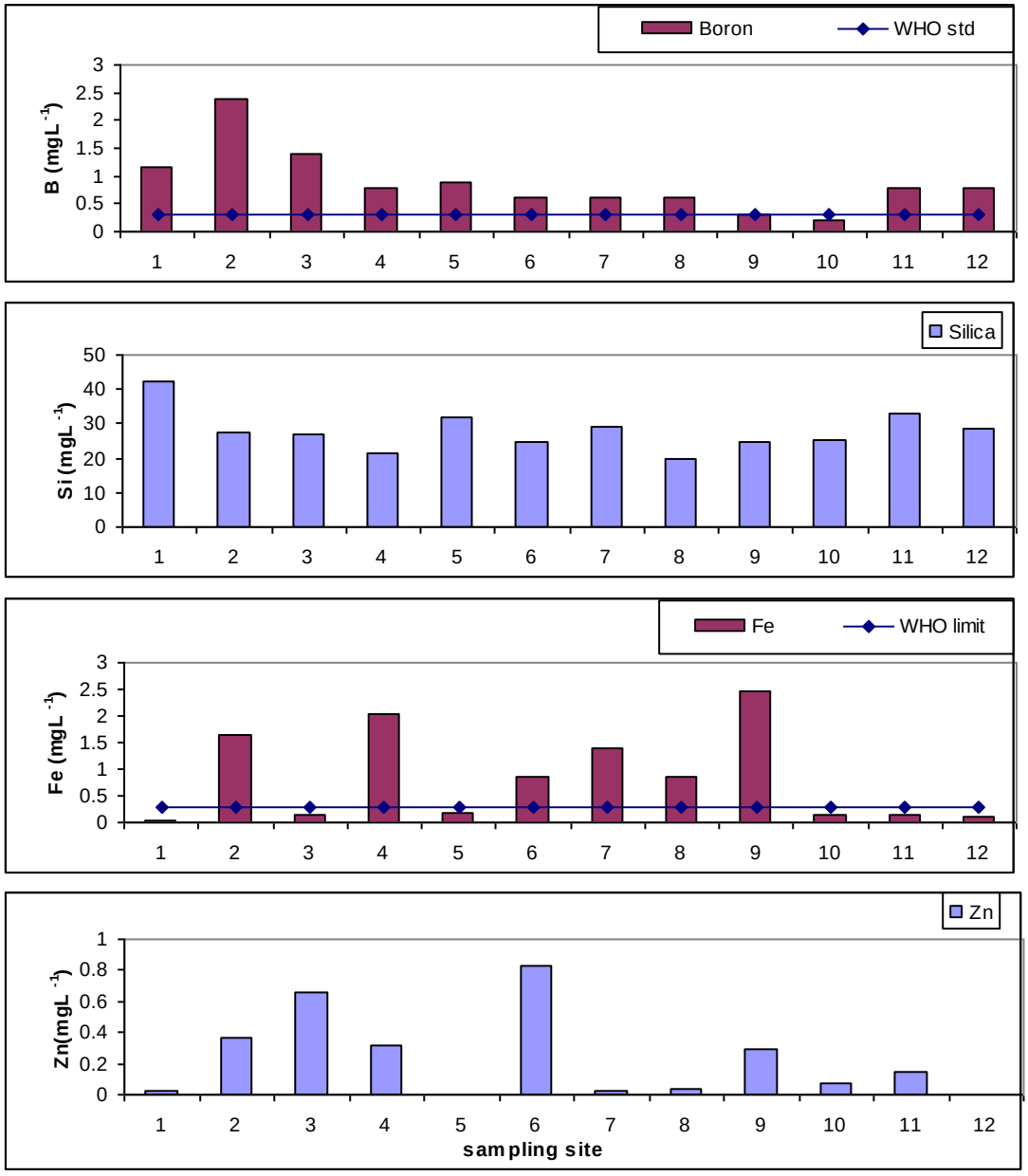

Fig. 6: Concentration of B, Si, Fe and Zn in groundwater samples.

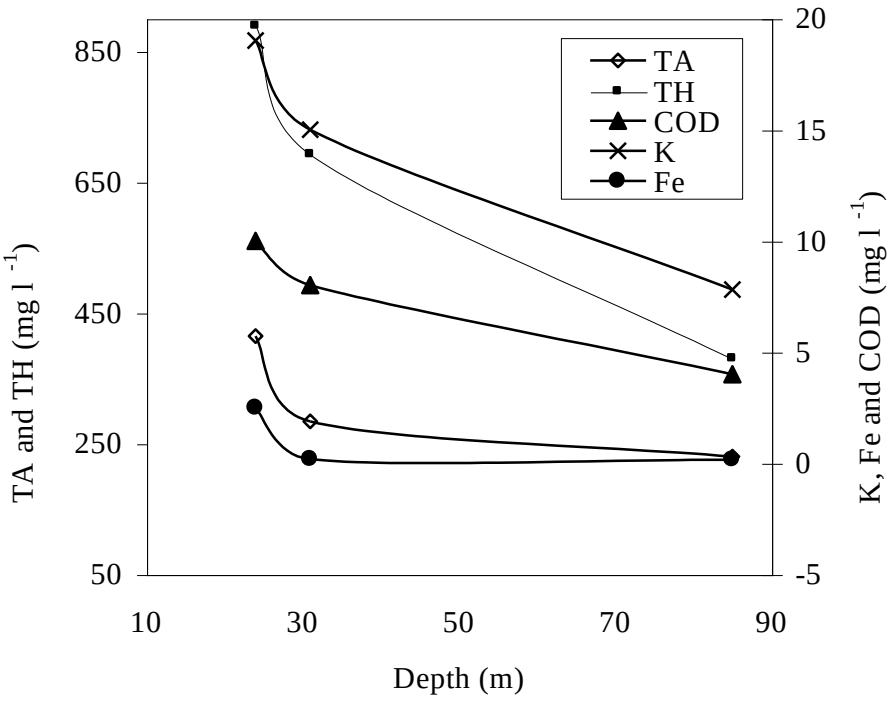

Fig. 7: Variation in the concentration of different species for varying depths at 1.5 km distance from the landfill boundary.