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## ASSESSMENT OF GROUNDWATER QUALITY IN LANDFILL AREA OF NAGPUR CITY, CENTRAL INDIA

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*The explosive growth in population and sustained drive for economic progress and development over the last couple of decades has resulted in remarkable increase in quantity of municipal solid wastes generation in Nagpur. Land filling is the most popular way for municipal solid waste disposal. Leachate generated from landfills is becoming a great threat to the regional aquifers as it contains high concentration of toxic substances. This study aimed to assess the quality of groundwater resources serving the communities situated in the vicinity of Bhandewadi landfill of Nagpur city. Groundwater samples were collected, analyzed and characterized. Analytical results showed a measurable impact of the landfill on groundwater quality. Elevated levels of  $\text{Na}^+$ ,  $\text{NO}_3^-$ ,  $\text{Cl}^-$  and heavy metals, such as Mn and Fe, were detected at measurable levels in groundwater. The ionic ratio plots suggest that the silicate weathering and anthropogenic activities are dominant factors that determine the major ionic composition in the study area. The Na–Cl water type is associated with high nitrate pollution. Majority of the samples are not suitable for domestic purposes and far elevated compared to drinking water standards. Continuous water quality monitoring is suggested to effectively study the impact of landfill sites on the environment and human health. Adequate buffer zone between the landfill site and the adjacent property line should be maintained, before locating a new landfill site.*

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## **INTRODUCTION**

The fast population growth, uncontrolled urbanization and industrialization, poor sanitation situation and uncontrolled waste disposal are the causes of serious quality degradation of surface and groundwater throughout the world and specifically in developing countries. The urbanization rate in India is rapid. It has increased from 10.84% in 1901 to 28.5% in 2001. Unregulated growth of urban areas, particularly over the last two decades, without necessary infrastructures services for proper collection, transportation, treatment and disposal of domestic solid waste led to increased pollution and health hazards.

The municipal solid waste disposal methods followed in most of the cities and towns of India are unsystematic and non-scientific. This landfill may just be a piece of open land that has been fenced off, old excavations, mining areas, or isolated ravines and valleys. Most of the landfill sites in India are only uncontrolled dumps where a mixture of domestic, commercial and industrial wastes are dumped together. Site selection is generally based on geographical rather than geological and hydrogeological considerations, i.e. the closer the site to the source of the waste the better in terms of logistics. It is not uncommon, therefore to find waste disposal sites within municipal boundaries and surrounded by residential areas.

Although landfills are an indispensable part of everyday living, they may present long-term threats to surface water and also groundwater that are hydrologically connected. Groundwater contamination is a major concern in landfill operations because of the impact of landfill leachates and its potential health risks (Yanful et al., 1988; Fatta et al., 1999; Mor et al., 2006). Leachate is a fluid that has passed through or emerged from the waste in a landfill, picking up a variety of suspended and dissolved compounds along the way. Once leachate is formed and is released to the groundwater environment, it will migrate downward through the unsaturated zone until it eventually reaches the saturated zone. Leachate then will follow the hydraulic gradient of the groundwater system. The realization of the polluting effects of landfill leachates on the environment has prompted a number of studies. These include studies on domestic wastes (Sridhar et al., 1985; Mor et al., 2006), leachate quality (Fatta et al., 1999; Ostman et al., 2006), as well as underground water quality (Loizidou and Kapetanios, 1993) and heavy metals in groundwater (Yanful et al., 1988). The main objective of this study is to investigate the level of groundwater contamination in the vicinity of the landfill as groundwater is the major source for drinking and domestic purposes.

## **STUDY AREA**

### **Location and Climate**

The Bhandewadi landfill (latitude 21°08' and 21°09' N and longitudes 79°07' and 79°08' E), that is the focus of the current study is situated in south east corner of the city (Figure 1). Nagpur city generates about 875 MT of waste per day; 350-400 grams per capita per day. About 30% of this waste is organic compostable material. The remaining 70% consists of paper (11.9%); rubber, leather and synthetics (3.02%); glass (0.98%); metals (0.33%) and other inert materials (53%). The landfill accepts officially, non-hazardous solid wastes of domestic, commercial, industrial and institutional origins, but in practice all type of wastes are co-disposed.

The climate of Nagpur is semi-arid with minimum temperature of 10 °C in winter and maximum temperature of 48 °C in summer. The average rainfall is 1200 mm and major part of which (70%) occurs during the south-east monsoon (June to September).

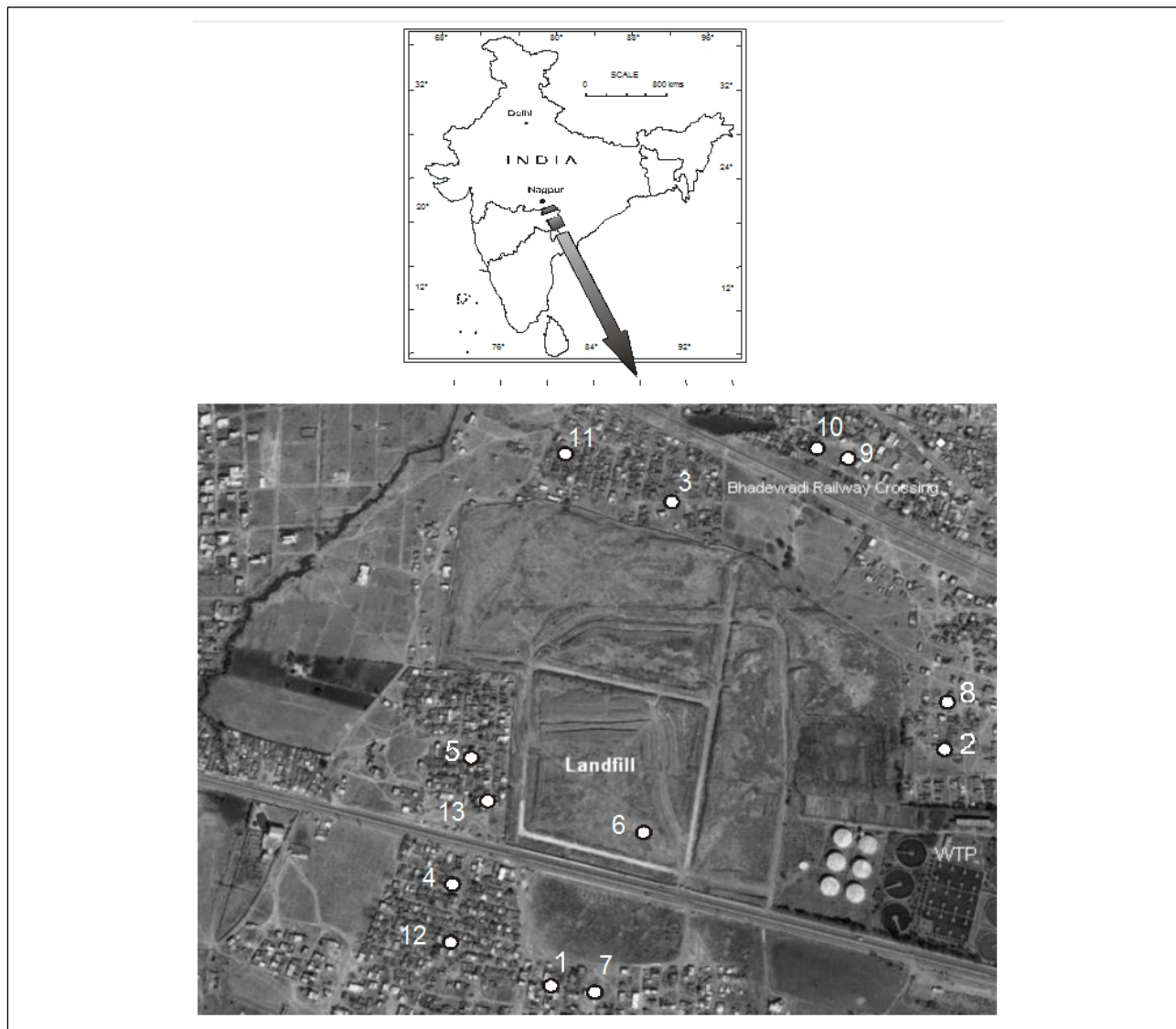


Figure1. Location map of study area showing sampling points (WTP - Water treatment plant).

### Geology and Hydrogeology

Geologically major part of study area is covered by unclassified gneisses of Archaean age. The granitic gneisses are represented by pink coloured coarse grained rocks consisting of plagioclase and quartz with minor amount of microcline, biotite and hornblende.

In the study area occurrence of groundwater is mostly controlled by the degree of weathering and the thickness of weathered zone is in the range of 1 to 10m. Groundwater in the weathered zone is under unconfined conditions. General gradient of the area is towards the stream situated along the northwest corner of the area.

### METHODOLOGY

In the present study, prior to data collection, a selection criterion was established to aid in the identification of appropriate sampling sites for the groundwater quality assessment around the landfill area. The landfill is located at elevated portion of land and the samples were collected along the hydraulic gradient to measure the extent of groundwater pollution. The dugwells and borewells were selected for sampling which were in continuous use.

Table1. Analytical data for the groundwater samples in the study area.

S.No <sup>a</sup>	pH	EC	TDS	TH	TA	Na <sup>+</sup>	K <sup>+</sup>	Ca <sup>2+</sup>	Mg <sup>2+</sup>	Cu	Fe	Mn	Zn	HCO <sub>3</sub> <sup>-</sup>	Cl <sup>-</sup>	SO <sub>4</sub> <sup>2-</sup>	NO <sub>3</sub> <sup>-</sup>
1	7.8	2590	1426	410	345	388	68	58	64.4	BDL	BDL	0.024	0.039	420.9	415.3	8.35	213.9
2	7.7	2080	1241	350	530	356	81	64	46.2	BDL	0.607	1.077	0.175	646.6	333.7	11.51	25.4
3	7.6	2600	1687	350	455	379	203	36	63.2	BDL	BDL	BDL	0.038	555.1	404.7	12.5	311.6
4	7.6	1835	993	490	120	169	4	84	68	BDL	0.056	BDL	0.102	146.4	429.5	0.6	164.6
5	6.4	3260	1769	700	390	411	99	60	133	0.012	0.025	2.436	0.069	475.8	713.5	25.3	88.45
6	7.1	3750	2927	1490	140	413	101	260	204	0.023	0.71	0.942	0.343	170.8	1562	34.8	266.5
7	8.4	1442	1077	55	465	389	89	8	8.5	0.11	6.949	0.277	8.52	567	223.6	3.95	71.76
8	7.6	1835	1023	255	390	246	78	28	45	BDL	0.64	0.033	0.293	475.8	166.8	8.4	213.2
9	7.5	1766	1204	320	460	345	75	18	66.8	BDL	0.192	BDL	0.066	564.2	291.1	6.78	121
10	8	1823	1251	270	420	375	81	40	41.3	BDL	BDL	BDL	0.038	512.4	411.8	3.2	42.5
11	7.6	1502	996	340	270	232	63	76	36.4	BDL	0.916	BDL	0.097	329.4	273.3	4.69	145.4
12	7.4	1615	1105	190	360	323	81	18	35.2	BDL	0.937	BDL	0.143	439.2	241.4	10.2	176.4
13	7.3	2760	1713	670	480	383	98	74	117	BDL	0.463	0.518	0.226	585.6	539.6	2.8	205
Min.	6.4	1422	981	55	120	169	4	8	8.5	BDL	BDL	BDL	BDL	146.4	166.8	0.6	25.4
Max.	8.4	3750	2927	1490	530	413	203	260	204	0.11	6.95	2.44	8.52	646.6	1562	34.8	311.5
Avg	7.5	2220	1416	453	371	339	86.2	63.4	71.6	---	---	---	---	452.8	462	10.2	157.3
WHO	7-9.2	--	500-1500	100-500	--	200	--	75-200	50-150	1	.3	0.1	5	--	200-600	200-400	45

Dugwell and borewell groundwater samples were collected in plastic containers, which were previously cleaned with distilled water. As a part of the quality control measures, containers were rinsed with sampled groundwater before filling. Samples for the heavy metals analyses were collected in one liter polyethylene bottles, and preserved using 2 ml concentrated HNO<sub>3</sub>. Separate samples were collected for major cation and anion analyses. All samples were preserved at 25°C and transported to the laboratory for analysis. Physicochemical parameters of the samples were analyzed following standard analytical procedure (APHA, 1995). On site measurement of pH and electrical conductivity (EC) were carried out using pH and electrical conductivity meters. Calcium (Ca<sup>2+</sup>) and magnesium (Mg<sup>2+</sup>) were determined titrimetrically using standard EDTA solution. Chloride (Cl<sup>-</sup>) was determined by standard AgNO<sub>3</sub> titration. Carbonate (CO<sub>3</sub><sup>2-</sup>) and bicarbonate (HCO<sub>3</sub><sup>-</sup>) were determined by titration with HCl. Sodium (Na<sup>+</sup>) and potassium (K<sup>+</sup>) were measured by flame photometry. Sulphate (SO<sub>4</sub><sup>2-</sup>) and nitrate (NO<sub>3</sub><sup>-</sup>) were determined by using UV-Visible spectrophotometer. Levels of heavy metals such as copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn) were measured using Atomic Absorption Spectrometer. Figure 1. Location map of study area showing sampling points (WTP - Water treatment plant)

## RESULTS AND DISCUSSION

### Hydrochemical Parameters and Groundwater Quality

The result of the chemical analyses of representative groundwater samples of study area and their comparison with the WHO guidelines is given in Table 1. The groundwater is alkaline with pH varying between 6.4 and 8.4. EC and total dissolved solids (TDS) signify the inorganic load of any water body. The TDS value of groundwater samples from the study area varies from 981 to 2927 mg/l. As the distance of sampling sites from landfill increases,

TDS content decreases. Based on the classification suggested by Freeze and Cherry (1979), majority of the groundwater samples of the study area comes under brackish water category. The

study shows that no sample is below 500 mg/l of TDS which can be used for drinking without any risk. EC values ranges from 1422- 3750  $\mu\text{S}/\text{cm}$ . Such a high EC can be attributed to high salinity and effect of landfill site on groundwater regime (Fatta et al., 1999).

The total alkalinity (TA), as  $\text{CaCO}_3$  in groundwater of study area ranges from 120 to 530 mg / l. The high alkalinity imparts water with unpleasant taste, and may be harmful to human health. The total hardness (TH) of groundwater varies from 55 to 1490 mg/l. The maximum allowable limit of TH for drinking purpose is 500 mg/l and the most desirable limit is 100 mg/l (WHO, 2002). Based on TH, Durfor and Becker (1964) classified water as 0–60, soft; 61–120, moderately hard; 121–180, hard; and >180 very hard. Groundwater exceeding the limit of 300 mg/l is considered to be very hard (Sawyer and McMcarty, 1967). Very hard groundwater is dominant in the aquifers of study area, which may raise the risk of calcification of arteries, urinary concretions, diseases of kidney or bladder or stomach disorder (Hopps, 1972). The high value of TH in supply water may cause corrosion of pipes.

The relative concentrations of the ions occurs in the order of  $\text{Na}^+ > \text{K}^+ > \text{Mg}^{2+} > \text{Ca}^{2+}$ , and  $\text{Cl}^- > \text{HCO}_3^- > \text{NO}_3^- > \text{SO}_4^{2-}$  along the gradient from landfill site. In groundwater of study area, the concentration of  $\text{Na}^+$  ions ranges from 169 to 413 mg/l and most of the samples exceeded the maximum permissible limit (200 mg/l). The higher concentration of  $\text{Na}^+$  may pose a risk to the persons suffering from cardiac, renal and circulatory diseases (Mor et al., 2006). The concentration of  $\text{K}^+$  ions varies from 4 to 203 mg/l.  $\text{K}^+$  is an essential nutrient but if ingested in excess may behave as a laxative.  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  are important ions for total hardness.  $\text{Ca}^{2+}$  content in the groundwater varies between 8.0 and 260.0 mg/l. In most of samples concentration of  $\text{Ca}^{2+}$  is within desirable limit (Table 1; WHO, 2002). The concentration of  $\text{Mg}^{2+}$  ions varies from 8.5 to 204 mg/l. Except the sample situated over the landfill area, all the studied samples are within the maximum permissible limit of 150 mg/l recommended by WHO (2002).  $\text{Mg}^{2+}$  ions are essential as an activator of many enzyme systems, but its salts are cathartic and diuretic. Their high concentration may cause laxative effect, while their deficiency may cause structural and functional changes (Hopps, 1972).

The  $\text{HCO}_3^-$  ion concentration in groundwater varies from 146.4 to 646.2 mg/l. The high concentration of  $\text{Cl}^-$  in water usually taken as an index of pollution and considered as tracer for groundwater contamination (Loizidou and Kapetanios, 1993).  $\text{Cl}^-$  is a good measure of the extent of the dispersion of leachates in groundwater. The  $\text{Cl}^-$  content in groundwater samples from study area ranges from 166.8 to 1562.0 mg/l. Almost all samples contain higher concentration of  $\text{Cl}^-$  ion than desirable limit of 200 mg/l (WHO, 2002). The higher consumption of  $\text{Cl}^-$  may be crucial for the development of hypertension, risk for stroke, left ventricular hypertrophy, osteoporosis, renal stones and asthma (Hopps, 1972). In the groundwater samples of the study area  $\text{SO}_4^{2-}$  concentration ranges from 0.6 to 34.8 mg/l. The concentration of  $\text{SO}_4^{2-}$  in most of the samples is below the desirable limit of 200 mg/l accepted for drinking water (WHO, 2002). Drinking water containing more than 45 mg/l of  $\text{NO}_3^-$  can cause blue baby or methamoglobinemia in infants and gastric carcinomas (Hopps, 1972; Jalali, 2005). About 77 % of samples from study area have  $\text{NO}_3^-$  content above 45 mg/l, which show high level of pollution.

## **Heavy Metals**

Heavy metals are normally associated with igneous and metamorphic rocks, and in particular, with ore bodies. Weathering of these rocks, including oxidation and leaching, may give rise to elevated trace metal levels in groundwater (Hopps, 1972; Loizidou and Kapetanios, 1993).

However, trace metals may also be brought into the groundwater system by human activities. Elevated concentrations of trace metals in groundwater may locally make this resource unfit for human consumption or affect the natural ecosystem. The trace metals rarely occur in groundwater at concentrations large enough to comprise a significant percentage of the total dissolved solids (Loizidou and Kapetanios, 1993).

In the present study, Fe, Cu, Mn and Zn content are analysed in the groundwater samples (Table 1). Measured values of Fe in groundwater ranges from 0.025 to 6.949 mg/l. About 53.8% of samples show concentration of Fe above the guideline value of 0.3 mg/l (WHO, 2002). The ingestion of large quantities of Fe results in haemochromatosis, a condition in which normal regulatory mechanisms do not operate effectively leading to tissue damage as a result of accumulation of Fe (Hopps, 1972). In most of the samples Cu is below detectable limit. Measured value of Cu in groundwater ranges from 0.01 to 0.11 mg/l. Mn concentration varies between 0.02 and 2.44 mg/l. Concentrations of Mn in excess of 0.2 mg/l makes water distasteful to drink with no specific toxic effects. About 38% of samples show Mn concentration above guideline value of 0.1 mg/l (WHO, 2002). Measured value of Zn ranges from 0.04 to 8.52 mg/l and only one sample shows high concentration of Zn above the guideline value of 5.0 mg/l specified for potable water. The study area is underlain by granitic gneisses which contain very less concentration of heavy metals. All these metals are normally present in sewage sludge and industrial wastes, and have limited mobility in soils (Loizidou and Kapetanios, 1993). The concentrations of heavy metals in the groundwaters of study area are not high as the landfill site mainly receives domestic waste.

## **Origin of Solutes**

### *Water/Rock interaction*

Various processes such as silicate weathering, mineral dissolution, leaching, ion exchange, evaporation, and other processes related to anthropogenic activities, controlled the groundwater chemistry (Subba Rao and Surya Rao, 2009). The origin of solutes and the process that generated the observed water compositions can be predicated by inter ionic relationship between ions present in the groundwater. A great part of  $\text{HCO}_3^-$  originated from dissolution of carbonate rocks in the aquifer through the action of percolating waters enriched in  $\text{CO}_2$  after being in contact with the atmosphere (Appelo and Postma, 1996). Thus, the dissolution of carbonate releases  $\text{Ca}^{2+}$ , yielding Ca– $\text{HCO}_3$  type water. Presence of  $\text{Ca}^{2+}$  in water generally varies according to the proximity of natural sources. Evaluation of the slopes of  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$  and  $\text{Na}^+$  with  $\text{HCO}_3^-$  gives valuable information about the stoichiometry of the process (Edmunds et al., 1987). There is strong negative relation between  $\text{Ca}^{2+}$  and  $\text{HCO}_3^-$  ( $r = -0.6$ ), indicating that calcite may not be the source of  $\text{Ca}^{2+}$ . In study area,  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  presented a strong positive correlation ( $r = 0.83$ ) (Figure 2a), indicating a common source, possibly weathering of rocks. To know the major functional sources of dissolved solids in the groundwater, the chemical data of the groundwater samples of the study area is plotted on  $\text{Ca}^{2+} + \text{Mg}^{2+}$  versus  $\text{HCO}_3^- + \text{SO}_4^{2-}$  diagram (Figure 2b). The sampling points fall below the equiline (1:1) which suggests that calcite, dolomite and gypsum, are not the source of  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{HCO}_3^-$  and  $\text{SO}_4^{2-}$  in the study area (Jalali, 2009). When this  $\text{HCO}_3^-$  has been balanced by  $\text{Na}^+$  support the role of silicate weathering as it is the prime mechanism to release the  $\text{Na}^+$  and  $\text{HCO}_3^-$  ions into the groundwater system (Subba Rao and Surya Rao, 2009).

The  $\text{Na}^+$ - $\text{Cl}^-$  relationship has been also used to identify the mechanisms responsible for the origin of solutes (Magaritz et al., 1981). A poor correlation ( $r = 0.42$ ) between  $\text{Na}^+$  and  $\text{Cl}^-$  in groundwater samples of study area suggest non halite source for  $\text{Na}^+$ . The groundwater samples

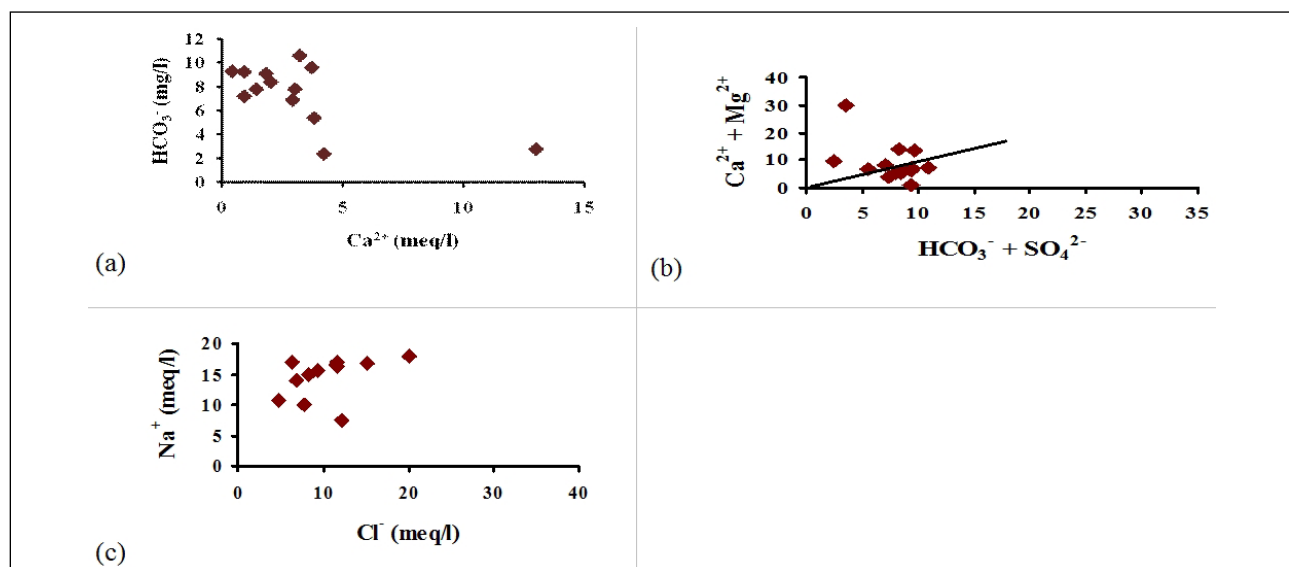


Figure 2. Interionic relationship among cations and anions.

of the study area are plotted on  $\text{Na}^+$  versus  $\text{Cl}^-$  diagram (Figure 2c), where most groundwater samples lie above the theoretical line (1:1). This infers that the groundwater has an excess concentration of  $\text{Na}^+$ , which is derived from the silicate weathering (Meyback, 1987). If it is so, the groundwater would have  $\text{HCO}_3^-$  as the most dominant anion (Rogers, 1989), as observed in the study area (Table 1). The molar ratio of  $\text{Na}^+/\text{Cl}^-$  for groundwater samples of the study area ranges from 0.41 to 2.7 with an average of 1.47. Majority samples from the study area have ratio more than 1 also supports the silicate weathering as the possible source of  $\text{Na}^+$  (Subba Rao and Surya Rao, 2009). The cation exchange between  $\text{Ca}^{2+}$  or  $\text{Mg}^{2+}$  and  $\text{Na}^+$  may also explain the high  $\text{Na}^+$  concentration (Stimson et al., 2001). Those samples with a value of  $\text{Na}^+/\text{Cl}^-$  ratio higher than 1 also show a deficit in  $\text{Ca}^{2+} + \text{Mg}^{2+}$ , and this is consistent with the  $\text{Ca}^{2+} - \text{Na}^+$  cation exchange process which leads to a softening of the water (Hidalgo and Cruz-Sanjulian, 2001).  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  can exchange  $\text{Na}^+$  sorbed on the exchangeable sites of the clay minerals, resulting in the decrease of  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  and the increase of  $\text{Na}^+$  in groundwaters.

### **Anthropogenic Input**

Variation in TDS in groundwater may be related to land use and other anthropogenic sources (Jalai, 2009). As  $\text{Cl}^-$ ,  $\text{SO}_4^{2-}$ ,  $\text{NO}_3^-$  and  $\text{Na}^+$  ions are mostly derived from agricultural fertilizers, animal wastes and industrial and municipal sewage (Jalai, 2009). Thus correlation of these ions with TDS can be used to indicate the influence of human activities on the water chemistry (Han and Liu, 2004). The relationship between various anions and cations with TDS is illustrated in Figure 3. There is strong correlation between TDS and  $\text{Na}^+$  ( $r = 0.58$ ),  $\text{Ca}^{2+}$  ( $r = 0.84$ ),  $\text{Mg}^{2+}$  ( $r = 0.92$ ),  $\text{Cl}^-$  ( $r = 0.96$ ),  $\text{SO}_4^{2-}$  ( $r = 0.44$ ) and  $\text{NO}_3^-$  ( $r = 0.86$ ), suggesting the influence of human activities on the water chemistry (Jalai, 2009). The  $\text{Na}^+$  concentrations show an increasing trend with increasing TDS (Figure 3a) and may be related to the anthropogenic sources such as sewage, household waste, engineering work effluents, deicing road salt, etc (Choi et al., 2005) in addition to the weathering of silicate minerals. The high concentration of  $\text{Na}^+$  around landfill site of present area also indicates impact of landfill on the groundwater regime. Increase of  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  concentrations with increasing TDS (Figure 3b, c) support the anthropogenic input, mainly domestic and industrial waste (Jalali, 2009).  $\text{Cl}^-$  and  $\text{NO}_3^-$  show a good trend of increasing concentration with increasing TDS (Figure 3d, e), suggesting same source and can be used as pollution indicators (Jalali, 2009). The  $\text{SO}_4^{2-}$  appears to show a good trend of increasing

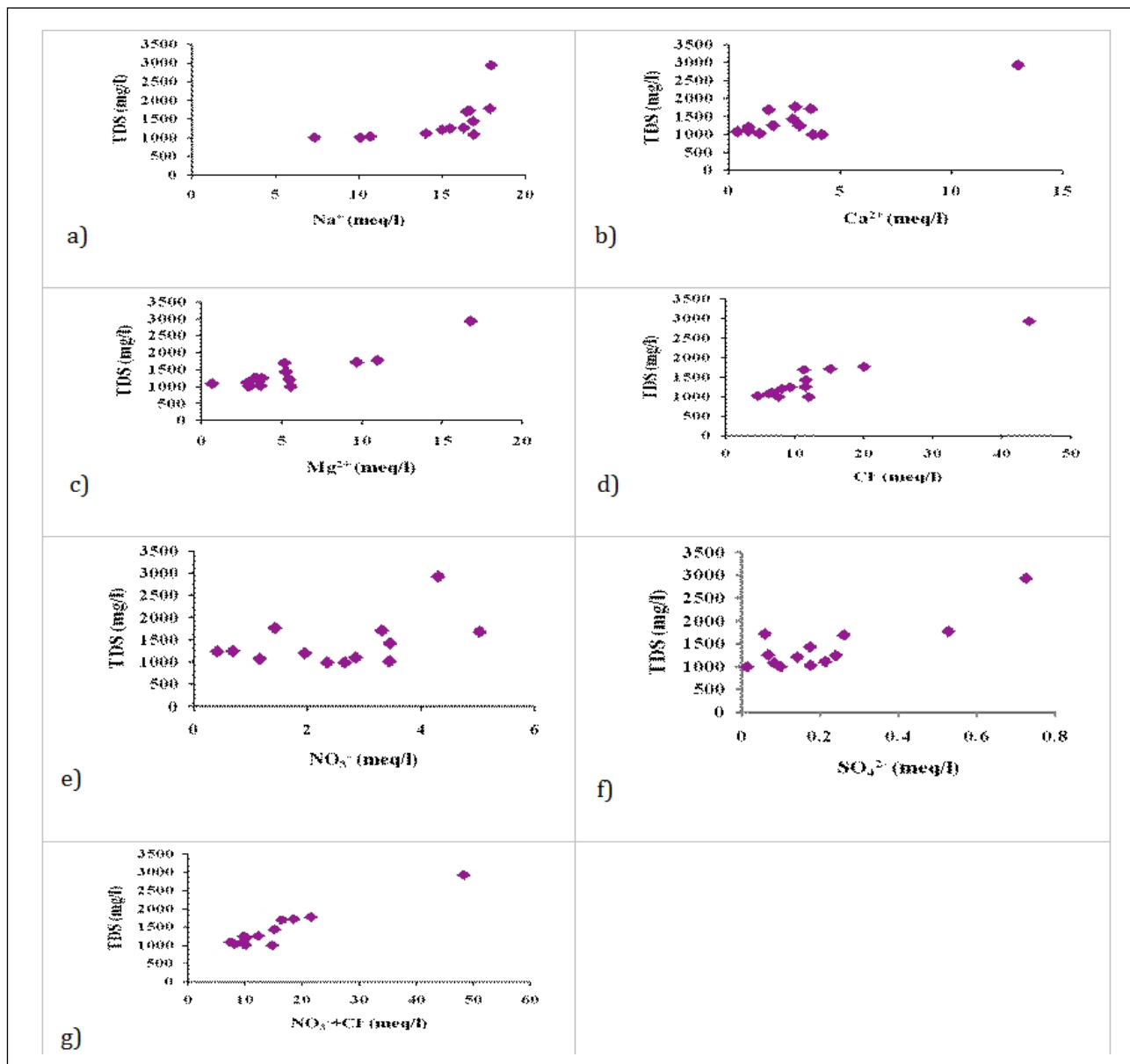


Figure 3. Relationship between TDS and cations/ anions in groundwater of the study area.

concentration with increasing TDS (Figure 3f). A positive correlation between TDS with  $(NO_3^- + Cl^-) / Na^+$  (Figure 3g) molar ratios also supports the role of anthropogenic inputs.

In absence of geological source, the possible source of  $SO_4^{2-}$  in study area is mainly agricultural activities, industrial effluents and domestic sewage (Choi et al., 2005). A poor correlation between  $NO_3^-$  and  $SO_4^{2-}$  ( $r=0.24$ ) is observed suggesting different source of both ions as no agricultural activity is observed in the study area (Figure 4a). The correlation between  $Cl^-$  and  $NO_3^-$  above 0.35, indicate common source and input from anthropogenic activities (Pacheco and Cabrera, 1997). In the study area the correlation between  $Cl^-$  and  $NO_3^-$  is 0.36 indicating the common source for both these ions (Figure 4b). A positive correlation between  $Ca^{2+}$  and  $NO_3^-$  (Figure 4c) suggests the common source.

### Geochemical Classification of Groundwater

Classification of groundwater is based on the concentration of various predominant cations and anions or on the interrelationships of ions. A Piper trilinear diagram is useful in bringing out the



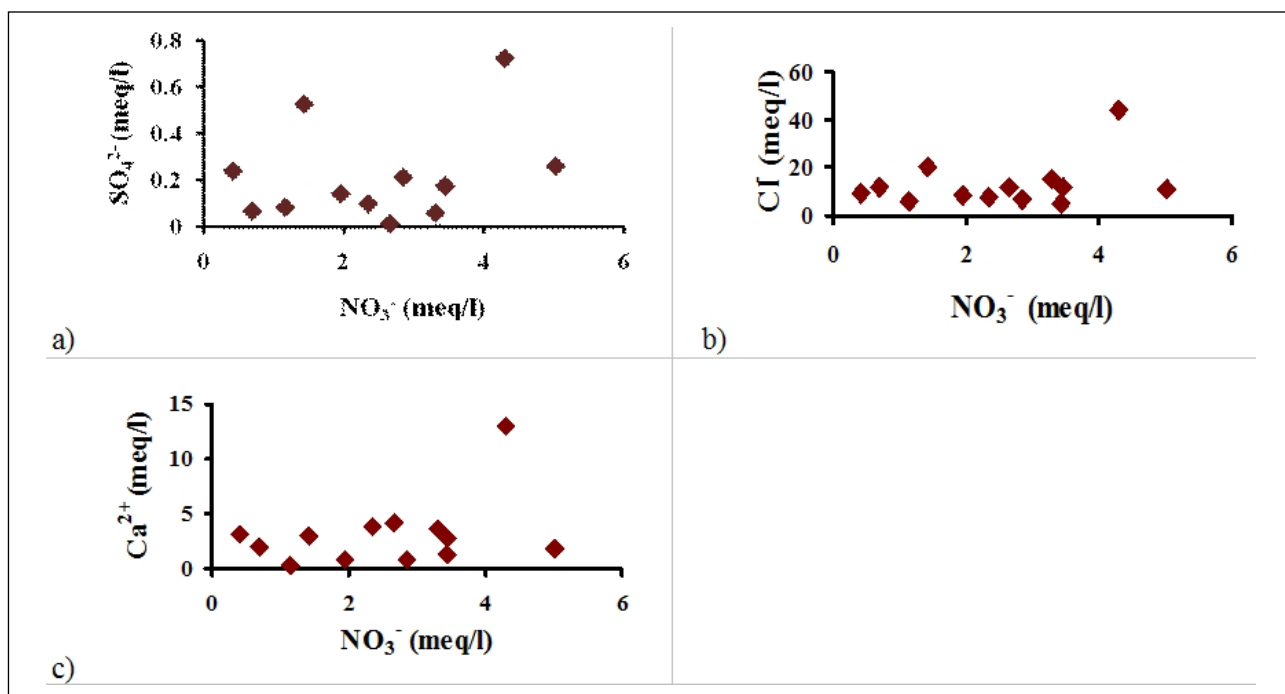


Figure 4. Interrelationship among nitrate and other ions.

chemical relationships and classification of groundwater in definite terms (Piper, 1944). The chemical data of the study areas has been plotted on Piper trilinear diagram (Figure 5). Two triangular fields, plotted separately from the percentage meq/l values of the cations  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  (alkaline earths) and  $\text{Na}^+$  and  $\text{K}^+$  (alkali), and the anions  $\text{HCO}_3^-$  (weak acid) and  $\text{SO}_4^{2-}$  and  $\text{Cl}^-$  (strong acid). Included are projections of these points in the triangular fields to a central diamond shaped field representing the general characteristics of the water (Figure 5). Groundwater in the study area is significantly dominated by alkalis ( $\text{Na}^+$  and  $\text{K}^+$ ) over the alkaline earths ( $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$ ). The strong acids ( $\text{Cl}^-$  and  $\text{SO}_4^{2-}$ ) exceed the weak acid ( $\text{HCO}_3^-$ ). Strong acids are dominated in about 77% of samples.

### Irrigation Suitability

The US Salinity Laboratory's diagram (USSL, 1954) is used widely for rating the irrigation waters. On the US Salinity diagram (Figure 6), the plot of groundwater samples from study area mostly fall within  $\text{C}_3\text{S}_1$  (High Salinity-Low  $\text{Na}^+$ ) region, while remaining in  $\text{C}_4\text{S}_1$  (Very high Salinity-Low  $\text{Na}^+$ ) region, indicating high saline low sodium type water. These waters are suitable for irrigation purposes.

## CONCLUSIONS

Analyses of groundwater from both deep (BW) and shallow (DW) aquifer along the gradient from Bhandewadi landfill show strong evidence of groundwater contamination. The aquifers located along the gradient from landfill site have higher concentration of  $\text{Na}^+$ ,  $\text{Cl}^-$  and  $\text{NO}_3^-$ , illustrating the contribution of landfill towards groundwater pollution. There is a risk of increase in groundwater pollution around the landfill site considering the current levels of  $\text{Na}^+$ ,  $\text{Cl}^-$  and  $\text{NO}_3^-$  found in the groundwater. About 77% of groundwater samples have  $\text{NO}_3^-$  higher than 45 mg/l and are unsuitable for drinking. The current observed  $\text{Cl}^-$  concentration in groundwater samples is very high making water unfit for drinking. In 38.5 % of samples, Mn is found above the guideline value and in almost half of the samples studied, Fe concentration is found above the guideline value

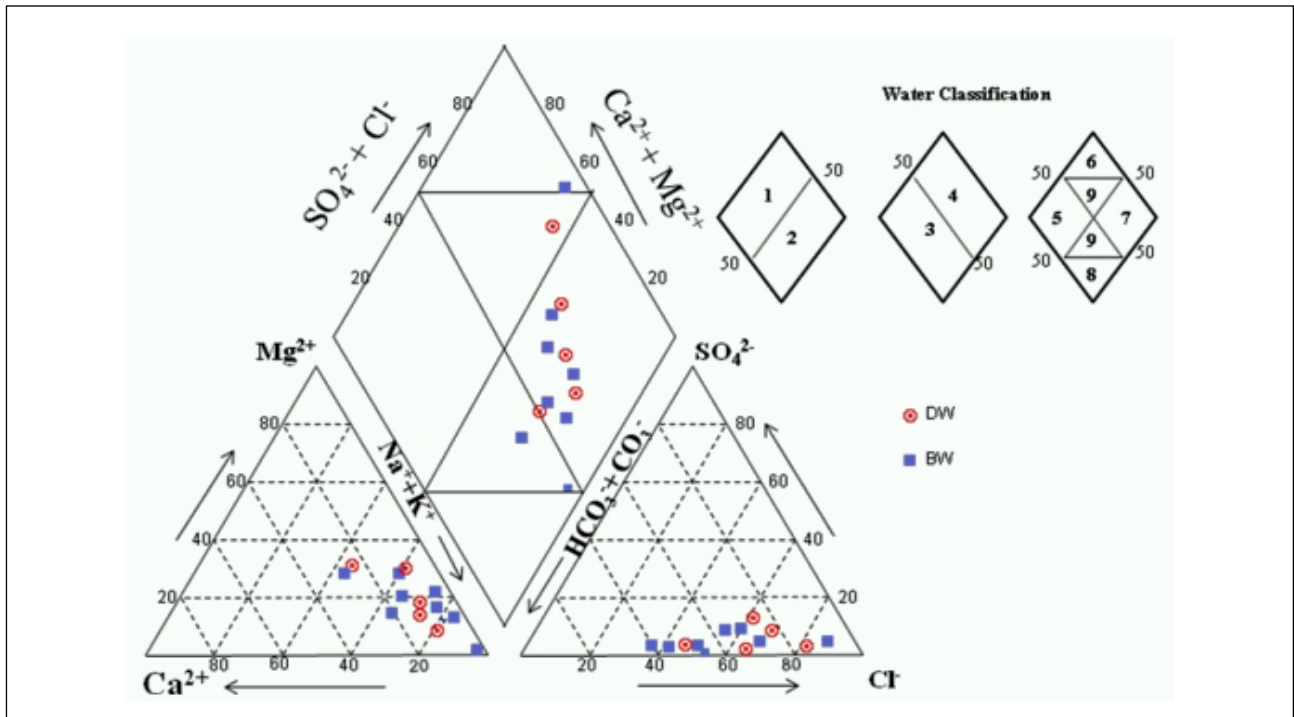


Figure 5. Trilinear plots for groundwater samples from study area.

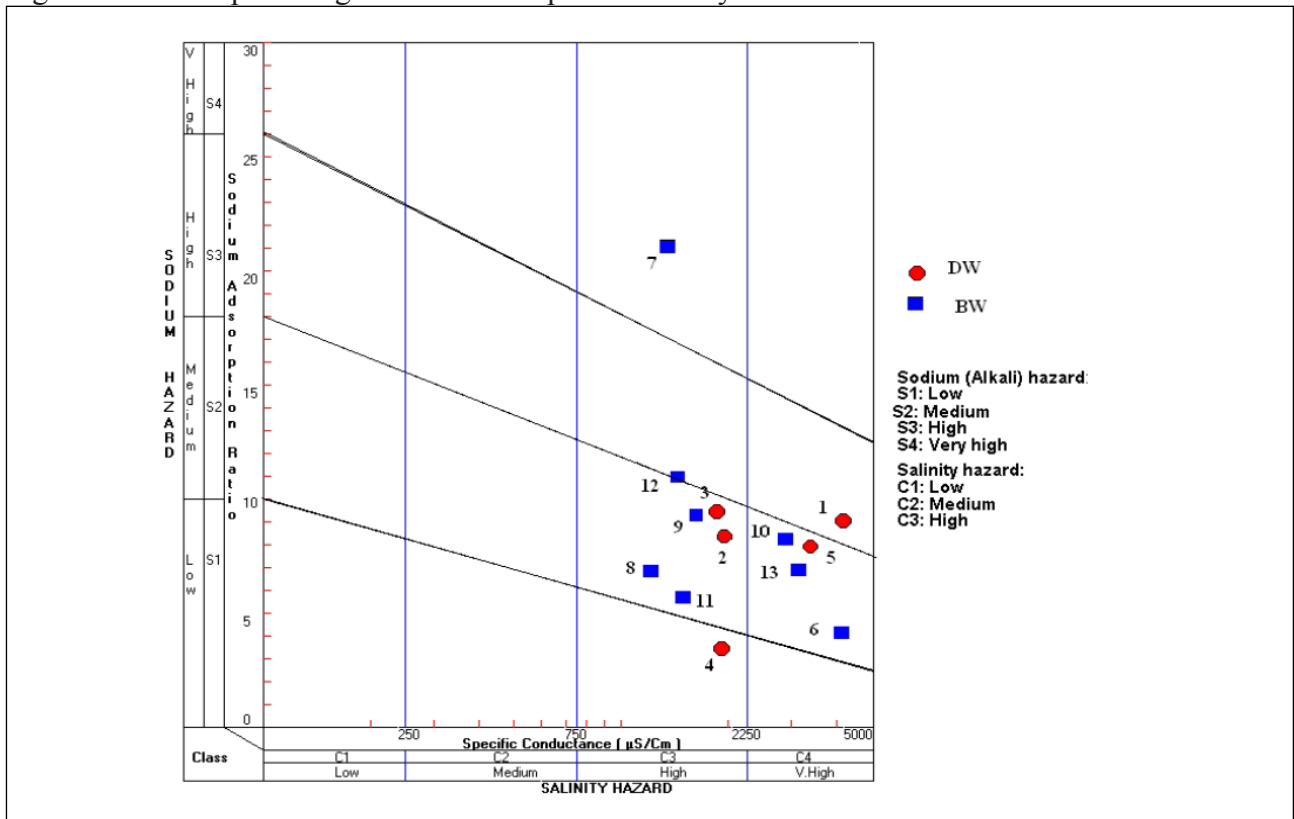


Figure 6. US Salinity Diagram for irrigation water classification with data from Bhandewadi landfill area.

suggested by WHO. Very high concentration of heavy metals are not found in the groundwaters of the study area, as the landfill site receives mainly domestic waste which have less amount of heavy metals. This study adds to our understanding of the impact of landfill on major groundwater resources. Chemical properties of groundwater near landfill are controlled both by natural geochemical processes such as silicate weathering and anthropogenic activities.

Graphical representation shows high salinity - Medium Na<sup>+</sup> to very high salinity- Medium Na<sup>+</sup> type groundwater, which need adequate drainage to overcome salinity problems for irrigational purpose and could be used for irrigation purpose. Overall analyses indicate increasing risk for sustainability of groundwater resource.

The 3-R principle (reduces, reuse and recycle) is an appropriate methodology for solid waste management and also for abatement of leachate induced groundwater pollution. In order to protect the groundwater quality of study area, monitoring programme for groundwater quality status around the vicinity of landfill is suggested. Before setting a new landfill site, an adequate buffer zone between the landfill and the property line of the adjacent property should be maintained to minimize the effect of pollution. A buffer zone of two to three miles in the direction of groundwater flow is most appropriate.

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