ORIGINAL PAPER

Geochemical investigation of groundwater contamination in Perungudi dumpsite, South India

K. Parameswari · B. V. Mudgal

Abstract Unscientific disposal of municipal solid waste causes groundwater contamination. The migration of leachate from the solid waste dumpsite to the aquifer varies according to the geohydrological profile of the dumpsite. A detailed study of the mechanism of leachate percolation to the groundwater helps to design a proper groundwater remediation technique. Multilevel boreholes were drilled in the periphery of the Perungudi dumpsite, Chennai, India. The major lithological layers and the geochemical analysis of the contaminant migrated from the dumpsite to the underlying aquifer has been studied. The distribution of heavy metals such as Pb, Fe, Zn, Cr, and Cd follows a similar trend in the pollutant source, groundwater samples around the dumpsite, and at various litho units beneath the dumpsite. The analysis thus helps to find an appropriate groundwater remediation technique to remove the specific contaminant and thereby provide a safe drinking water for the surrounding community.

Keywords Municipal solid waste · Multilevel borehole · Lithology · Leachate · Groundwater contamination

Introduction

Due to rapid urbanization and population growth, generation and disposal of solid waste is unavoidable. Open dumps are the oldest and most common way of disposing solid wastes. A scientific method of disposal is needed to prevent the environmental issues due to leachate generated from municipal solid waste (MSW) dumping. The most important impact of

landfill leachate is the surface and groundwater contamination which has given rise to a number of studies in the last two decades (Flyhammar 1995; De Rosa et al. 1996; Christensen et al. 1998; Looser et al. 1999; Abu-Rukah and Al-Kofahi 2001; Saarela 2003; Mor et al. 2006; Jaskelevicius and Lynikiene 2009; Bhalla et al. 2011; Sholichin 2012). A detailed study of the leachate chemistry and hydrogeology is of utmost importance to formulate a proper and scientific method of leachate removal without contaminating the aquifer. Also, assessing the groundwater quality and developing strategies to protect aquifers from contamination are necessary for proper planning and designing water resources.

The contribution of lithological variability on the propagation process of the contaminant elements within the aquifer system and the importance of the position of the monitoring network in the identification of the contamination process are to be considered to identify the environmental risks associated with the leachate flowing into the groundwater resources (Dimitra and Caputo 2006). Predicting the quantity and quality of groundwater flowing in an aquifer requires accurate information about the geometry and hydraulic properties of the aquifer. This information is commonly obtained by drilling, logging and analyzing the sediments obtained as cores or cuttings from the boreholes (Radhey and Sharma 2006; Frederick and Ronad 2000). Differences in groundwater chemistry are also related to the depth of the sampled aquifer zone (Katz et al. 2011). Peter et al. (2006) stated that contaminant dilution can occur at a saturated zone, and it is difficult to identify contamination migration pathways with any degree of certainty. These issues can be overcome by the use of multilevel sampling systems (Beck 2003). The use of long-screened monitoring boreholes can significantly mask hydraulic and chemical variations that occur naturally over short vertical distances. Hydraulic and chemical conditions within longer screened monitoring boreholes can become averaged or biased toward the dominant condition (Martin-Hayden and

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Robbins 1997; Martin-Hayden 2000a, b; Gibs et al. 2000; Sevee et al. 2000). Multilevel boreholes can be used to analyze the changes of water quality in various lithological units.

The previous studies pertaining the chemical quality of leachate and groundwater in and around the Perungudi dumpsite in Chennai Metropolitan Area have been reported (Vasanthi et al. 2008; Mohan and Gandhimathi 2009; IWS 2003), but no attempt has been made on micro-level aquifer characterization to study the vertical migration mechanism of leachate to the groundwater beneath the dumpsite to arrive at an appropriate solution for groundwater remediation. The present study aimed at lithological stratification, leachate characterization, and groundwater quality analysis around the municipal solid waste dumpsite at Perungudi, Chennai, India, to evaluate the contribution of lithological variability on propagation process of the contaminant elements within the aquifer system.

The major factors governing the contamination of groundwater by the disposal of waste are the waste deposited in landfills or in refuse dumps, which immediately becomes part of the prevailing hydrological system. The risk posed to groundwater-fed drinking-water sources by waste disposal in landfills or dumps can be considered in terms of three controls. They are solid waste loading and composition; leachate production; and leachate migration, attenuation, and dilution. The conceptual model for the pollution transport mechanism is shown in Fig. 1.

Study area

Chennai city, the capital of Tamil Nadu, has a population of about 4.68 million (Census 2011). Due to urbanization,
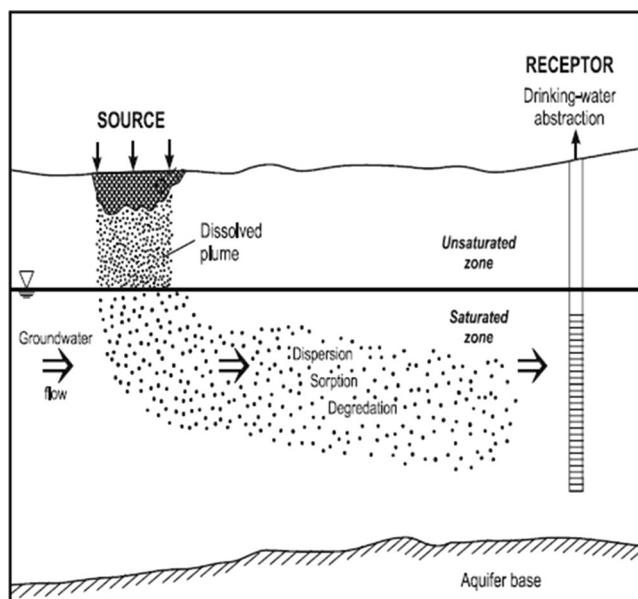
increase in population, and consumption pattern, the problem of solid waste management in Chennai has been rapidly increasing. The solid waste generated is dumped on Perungudi dumpsite, Kancheepuram district in Tamil Nadu, India. The dumping yard located at Perungudi on the southern part of Chennai city is in operation since 1987. It lies between 12° 56′ 59.14″ N to 12° 57′ 27.61″ N latitude and 80° 13′ 06.75″ E to 80° 14′ 06.34″ E longitudes with an aerial extent of 78 ha as shown in Fig. 2. Open dumping and leveling by bulldozer is the method of waste disposal. The dumpsite lies at 1.5 to 2.0 km from the western side of Buckingham canal and 3 km west of Bay of Bengal coastline. It is situated within a low-lying Pallikaranai marsh which extends for a length of approximately 10 km from north to south and for a width of 3 to 4 km from west to east that makes the dumpsite always surrounded by stagnant and moving water. The physical analysis of the waste from the Perungudi dumpsite is food waste 8 %, green waste 32.20 %, timber 6.99 %, consumable plastic 5.86 %, industrial plastic 1.80 %, steel and allied material 0.13 %, rags and textiles 3.14 %, paper 6.45 %, inert material 33.98 %, and rubber and leather 1.45 % (Vasanthi et al. 2008). Since un-segregated waste is being dumped in the dumping yard, it imposes a serious threat by introducing the heavy metals in the subsurface environment. Hence, groundwater contamination poses environmental, socio-economic, and health problems (Akoteyon et al. 2011).

The rock of Mio–Pliocene age termed as Cuddalore formation are noticed along the eastern coastal part of the study area, overlying the charnockite and consists of a pebbly bed below and coarse gravel friable sand and clay with reddish clayey sandstone above. The uppermost silty clays and sandy clays with a combined thickness of 6.0 to 8.0 m were found in the marshy area. The annual rainfall of the area is 1,200 mm and the major part of the rain occurs during northeast monsoon spanning from October to December. The dumpsite is without lining at the bottom and sides that makes the leachate generated to percolate deep to join the groundwater.

Materials and methods

The leachate samples from the Perungudi dumpsite were collected randomly from three locations and analyzed for heavy metals such as Pb, Fe, Cr, Zn, and Cd to understand the quality of leachate under the existing conditions. Following the leachate samples, 30 shallow wells around the dumpsite were chosen, water level was measured, and the water samples were collected and analyzed for Cd, Cr, Pb, Fe, and Zn. The measured water levels were used to plot the water level contour to identify the groundwater flow direction. The groundwater was found to enter the study area from north and west and flows towards the east and
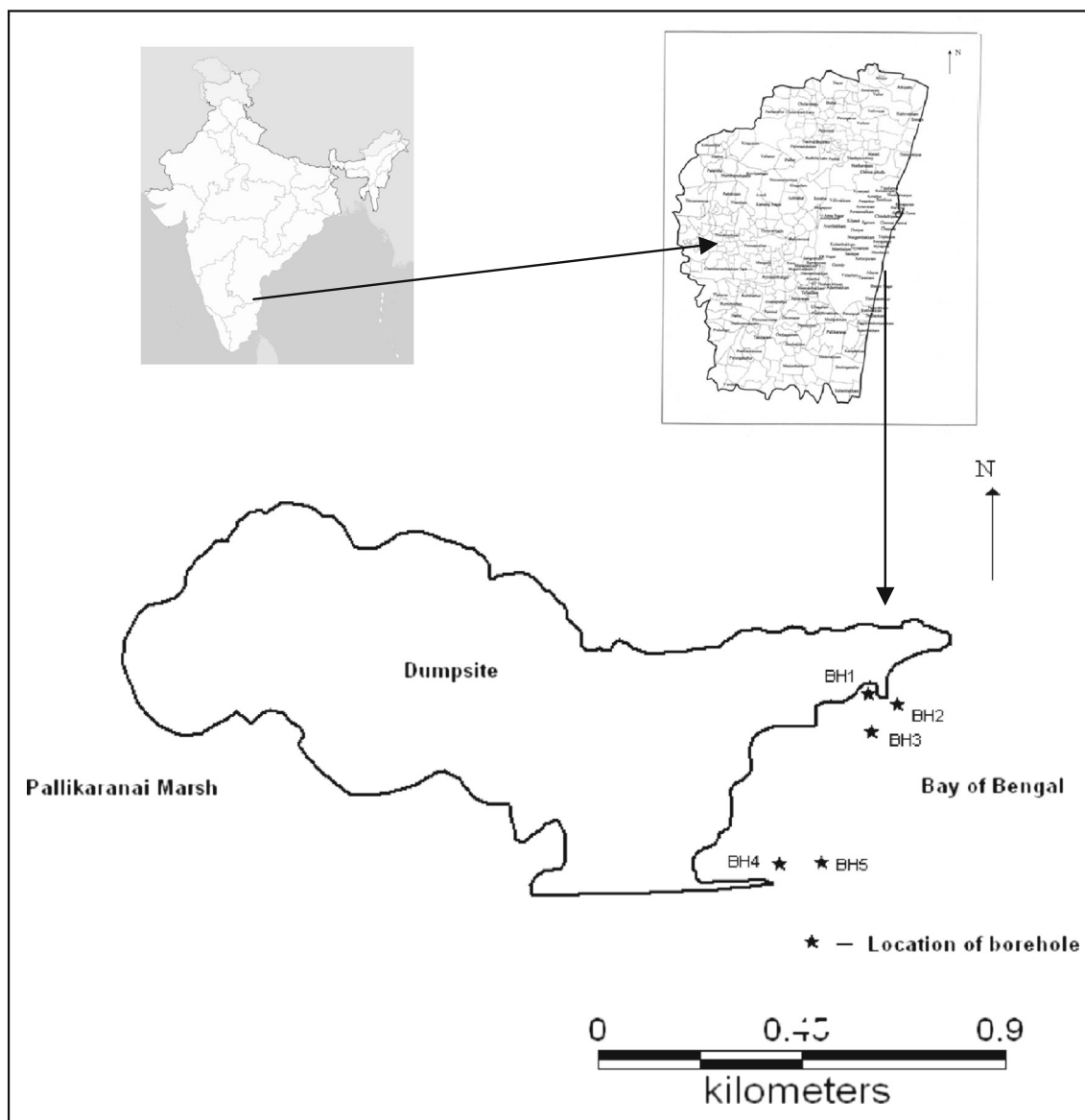

Fig. 1 Conceptual model for pollution transport

Fig. 2 Borehole locations at the eastern direction of the dumpsite

south directions. It was assumed that the leachate also follows the groundwater flow direction.

Based on the preliminary analysis, bore holes were drilled to understand the subsurface lithology along with leachate and groundwater quality variations at varied depths along the eastern part of the dumpsite. Five boreholes BH1, BH2, BH3, BH4, and BH5 were drilled at the eastern part of the study area at 2.0, 4.0, 5.5, 9.0, and 14.0 m depths, respectively, as shown in Fig. 2. The samples from boreholes BH1, BH2, and BH3 were used for leachate characterization studies, while from BH4 and BH5 were used to study the degree of contamination in the unconfined and semi-confined aquifers, respectively.

The hand auger drilling method was followed, as it is inexpensive, easy to operate, permits collection of undisturbed samples, and hence is more suitable for unconsolidated formations. A steel casing was erected at the time of drilling to prevent the mixing of water from different layers, and a 10-cm-diameter polyvinyl chloride pipe (PVC) was inserted inside the steel casing. The plain PVC pipe was joined with a 0.6-m-long slotted PVC pipe at the bottom to allow the lateral flow to the bore holes. The bottom end of the pipe was closed by an end cap to arrest the flow in the upward direction. The annular space between the steel casing and slotted PVC pipe was filled with pebbles, and the portion above was filled with clay slurry and clay packing.

A screened borehole was purged and emptied for at least two borehole volumes prior to sampling. Regarding multilevel systems, a thorough purging of each multilevel channel was necessary to reduce diffusion biases, which could

occur through the thin polyethylene walls. Following purging, the samples were collected at a low pumping rate to ensure a laminar flow. The samples were collected in clean polyethylene bottles, transported by placing in cooled ice box, and refrigerated until analysis at 4 °C.

Initially, a borehole (BH5) of 14 m depth was excavated to collect water and soil samples at every 0.9 m depth to understand the groundwater chemistry and to differentiate various lithological units. Fourteen samples from BH5 were collected and analyzed for pH, total dissolved solids (TDS), and electrical conductivity (EC) at the time of drilling. After borehole construction, water samples were collected on a monthly basis from all the boreholes for the period February 2010 to January 2011 and analyzed for various physico-chemical parameters. The parameters considered for the study include pH, TDS, EC, chloride (Cl), calcium (Ca), magnesium (Mg), sulfate (SO_4), sodium (Na), potassium (K), and heavy metals like cadmium (Cd), chromium (Cr), lead (Pb), iron (Fe), zinc (Zn), and nickel (Ni). The analysis was performed at the Wet Chemistry Laboratory, Centre for Water Resources, Anna University, based on standard methods prescribed by the American Public Health Association (APHA 1998).

Results and discussion

Leachate characterization

The heavy metal analysis of the leachate is shown in Fig. 3. The concentrations of Pb are observed to be highest of all heavy metals, with values ranging from 2.5 to 3.3 mg/L which are above the standards (0.1 mg/L) as specified by MoEF (2000). The presence of Pb in the leachate samples indicates the disposal of Pb batteries, chemicals for photograph processing, Pb-based paints, and pipes at the dumpsite (Moturi et al. 2004; Mor et al. 2007).

Concentrations of Cd in the leachates were very low with 0.01 and 0.02 mg/L (Fig. 3), which are well below the standards (2 mg/L). Fe concentrations ranged from 0.25 to 0.62 mg/L and the Zn concentrations remained between
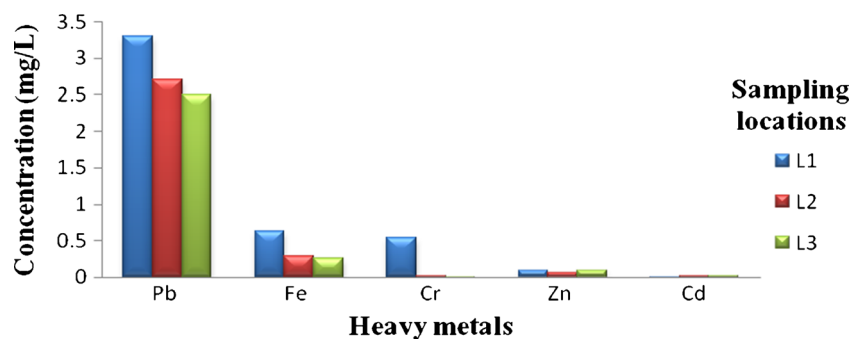
Table 1 Heavy metal analysis for the groundwater samples

Sampling well no.	Cd	Cr	Pb	Fe	Zn
1	BDL	BDL	0.055	0.060	0.0896
2	BDL	BDL	0.078	0.065	0.0527
3	BDL	BDL	0.091	0.119	0.6655
4	BDL	BDL	0.042	0.063	0.1653
5	BDL	BDL	0.161	1.304	0.6445
6	BDL	BDL	0.054	0.160	0.109
7	BDL	BDL	0.062	0.029	0.1266
8	BDL	BDL	0.073	0.043	0.2252
9	BDL	BDL	0.051	0.054	0.1932
10	BDL	BDL	0.027	0.106	0.1075
11	BDL	BDL	0.114	0.144	0.2313
12	BDL	BDL	0.120	0.108	0.2206
13	BDL	BDL	0.025	0.039	0.089
14	BDL	BDL	0.049	2.076	0.0153
15	BDL	BDL	0.040	0.084	0.0677
16	BDL	BDL	0.120	BDL	BDL
17	BDL	BDL	0.197	BDL	BDL
18	BDL	1.014	0.703	0.105	1.5675
19	BDL	1.016	0.480	0.070	0.1005
20	BDL	1.021	0.240	BDL	BDL
21	BDL	0.682	0.057	BDL	BDL
22	BDL	BDL	0.018	BDL	BDL
23	BDL	BDL	BDL	BDL	BDL
24	BDL	BDL	0.017	BDL	BDL
25	BDL	BDL	0.006	BDL	BDL
26	BDL	BDL	0.026	BDL	BDL
27	BDL	BDL	0.010	BDL	BDL
28	BDL	BDL	0.142	BDL	BDL
29	0.025	BDL	0.119	BDL	BDL
30	0.1095	BDL	0.832	0.958	10.375

BDL below detection limits

0.06 and 0.09 mg/L for the sampling locations. The high level of Fe in the leachate sample indicates that Fe and steel scrap are also disposed in the dumpsite. The presence of Zn in the leachate shows that the dumpsite receives waste from batteries and fluorescent lamps.

Fig. 3 Heavy metals in the leachate

Groundwater analysis

The groundwater samples analyzed for heavy metals such as Cd, Cr, Pb, Zn, and Fe are shown in Table 1. Cd and Cr were observed in few locations, and the leachate analysis clearly shows that very minimal concentrations were oozing out when compared to lead and iron. Lead ranges from 0.01 to 0.97 mg/L along the eastern and south eastern direction of the dumpsite, which is in line with the groundwater flow direction. It clearly indicates the influence of the leachate in the aquifer. Lead is toxic for drinking water. In most of the samples, Pb values were higher than the desirable limit of 0.1 mg/L as specified by bureau of indian standards (BIS). Lead can cause several unwanted effects such as disruption of the biosynthesis of hemoglobin and anemia, disruption of the nervous system, and brain damage (Low et al. 2000; Bulut and Bayasal 2006).

The distribution of Zn in the sampling wells is similar to that of lead and it ranges from 0.01 to 10.35 mg/L. For the determined heavy metals, only the Zn values were found to comply with the stipulated standards along the eastern and southern direction. Iron ranges from 0.05 to 2.08 mg/L. Most of the samples were below or nearer to the desirable level (0.3 mg/L) as specified by BIS. The presence of Fe may be due to the geogenic influence in addition to the anthropogenic activities. The concentration of iron may increase under favorable conditions close to a landfill and may lead to serious toxic risk. Fe changes the color and taste of the groundwater. Also, ingestion of large quantities of iron results in hemochromatosis, a condition in which normal regulatory mechanisms do not operate effectively. This leads to tissue damage, as a result of the accumulation of iron (Hopps 1972).

Lithology characterization

The marshy area in the northern, southern, and western part of the dumpsite is characterized by a sandy clay layer overlain by a clay layer. Figure 4 shows the location of the boreholes with subsurface lithological profile from north to south of the study area. The elevation of the profiles shows that the upstream side of the dumpsite is at an elevated position of 5 m above mean sea level (MSL), whereas the downstream side of the dumping yard is at MSL. BH1 is constructed at an elevation of 2 m above MSL to understand the leachate quality before it migrated to the subsurface environment. BH2 is constructed to analyze the leachate quality in the top clayey sand layer and BH3 in the subsequent sandy clay layer.

The lithological profile showed that the clayey sand exists for a depth of 2 m (0–2 m below MSL) followed by sandy clay layer for a depth of 6 m (2–8 m below MSL). A greenish clayey layer with calcareous orange streaks is observed underneath for a depth of 3 m (8–11 m below
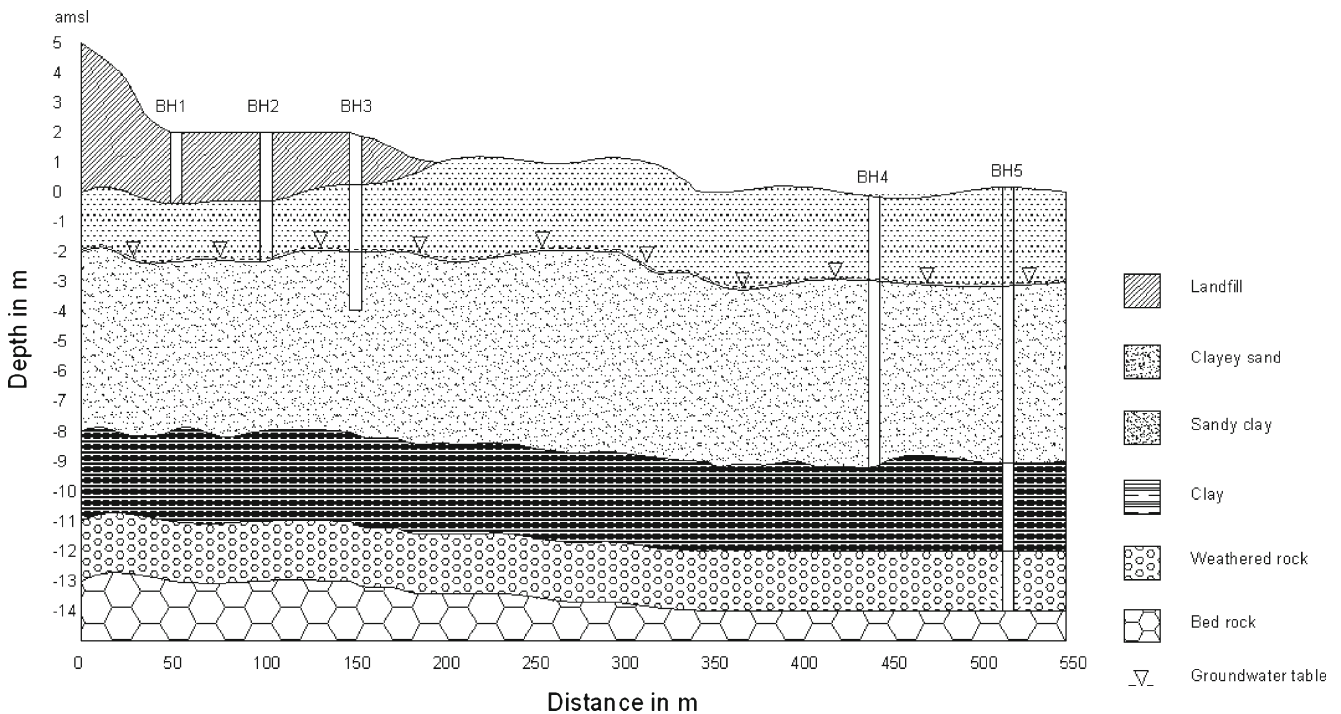

Fig. 4 Location of boreholes with geological profile from north to south direction

Table 2 Statistical analysis of leachate variation in the boreholes BH1, BH2, and BH3

Parameter	BH1		BH2		BH3	
	Range	Ave±SD	Range	Ave±SD	Range	Ave±SD
pH	6.91–7.98	7.54±0.35	6.98–8.09	7.23±0.35	6.6–7.11	6.81±0.16
TDS	640–5,500	3,409±2,000	2,020–6,790	4,780±1,589	2,540–6,370	4,775±1,469
EC	1,067–9,250	5,771±3,384	3,367–11,300	7,965±2,646	4,233–10,600	7,956±2,446
Cl^-	180–1,750	849±515	620–3,000	1,375±710	590–2,350	1,400±659
SO_4^{2-}	16–31	24±7	554–1,070	811±260	306–580	470±119
Na^+	220–1,814	1,035±558	688–3,198	1,592±826	536–2,590	1,615±738
K^+	110–940	564±297	119–712	306±190	37–404	131±102
Ca^{++}	35–110	70±31	40–290	126±112	35–300	121±122
Mg^{++}	590–1,025	713±209	660–1,055	794±177	800–1,300	1,119±219

All values are in milligrams per liter except pH and EC (μS/cm)

MSL) followed by highly decomposed rocky stratum (weathered rock) for a depth of 2 m (11–13 m below MSL) and encountered hard rock strata at 13 m below MSL.

The presence of sandy clay layer below the dumpsite causes the water-holding capacity of the area to be high with less permeability, while the clay layer beneath characterized by low permeability reduces the permeability of the whole stratigraphic unit. The occurrence of alternate sandy and clayey layers facilitates the propagation of contaminants as very little space is available to store the leachate. The generated leachate thus has to move out of the dumpsite, with a lateral movement beyond the dumpsite. The marshy land surrounding the dumpsite which acts as flood carrier during monsoon and as recharge zone during non-monsoon also aids the migration of contaminants to the nearby aquifers.

Geochemical analysis

Leachate variation at BH1, BH2, and BH3

The leachate samples collected for the period February 2010–January 2011 from BH1, BH2, and BH3 were

analyzed for physicochemical parameters. The statistical analysis of the leachate variation in the boreholes is given in Table 2.

In BH1, the TDS varies from 640 mg/l to 5,500 mg/l. A high TDS of 6,790 mg/l is measured in BH2 and decreases to 6,370 mg/l in BH3. As the EC and TDS have a linear relationship, a similar trend has been observed for the EC variation in the boreholes. The concentration of the leachate depends on the depth of borehole and litho units. A plot of temporal variation of TDS and rainfall indicate that the dilution during monsoon plays a major role as the concentration values get reduced to half as shown in Fig. 5.

In BH1, chloride ranges from 180 mg/l to 1,750 mg/l and in BH3, it varies from 590 to 2,350 mg/l. A high chloride of 3,000 mg/l is measured in BH2 as shown in Table 4. A higher concentration chloride and sulfate is found in BH2 (clayey sand) when compared to the BH1 (garbage) and BH3 (sandy clay). The high calcium concentration of 300 mg/l is measured in BH3. Magnesium concentrations also increase with increasing depth. Among all the cations, sodium showed higher concentrations with BH2 at a higher concentration. The analysis clearly shows that the high TDS is mainly due to sodium and chloride concentration. The

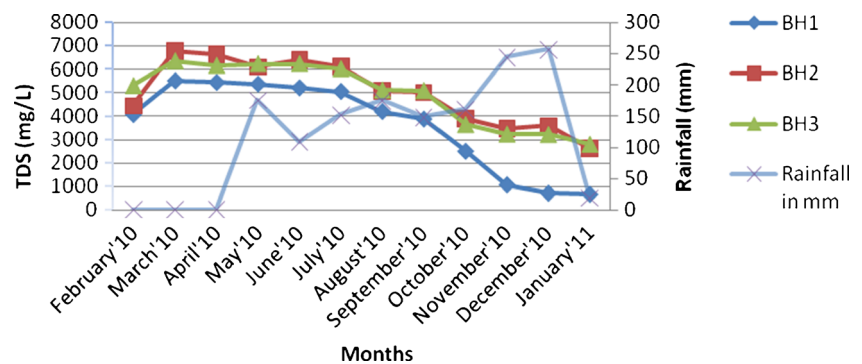**Fig. 5** Temporal variation of total dissolved solids versus rainfall

Table 3 Statistical analysis of water quality variation in BH4 and BH5

Parameter	BH4		BH5	
	Range	Ave±SD	Range	Ave±SD
pH	6.6–7.35	6.97±0.21	6.8–7.3	7±0.17
TDS	20,400–48,450	36,496±8,510	22,700–55,600	43,868±11,314
EC	34,000–80,750	60,766±14,198	37,833–93,000	73,166±18,880
Cl^-	15,500–26,841	21,978±3,726	20,250–44,020	33,495±6,899
SO_4^{2-}	420–1,942	1,157±766	530–1,970	1,223±727
Na^+	11,923–21,008	18,154±2,927	17,000–46,337	31,464±7,940
K^+	199–378	290±65	273–713	468±129
Ca^{++}	1,540–2,760	2,233±627	1,900–2,960	2,560±576
Mg^{++}	14,600–19,740	16,567±2,774	15,680–32,740	21,540±9,703

All values are in milligrams per liter except pH and EC (µS/cm)

contribution of solid waste disposal plays a major role, in addition to the geological contribution, in the increased concentration of TDS in the groundwater.

As the top layer of 2 m is the dumped garbage, the result of BH1 shows the chemicals leached out from the solid waste. The leachate analysis in the BH2 and BH3 shows the variation of the leached chemicals when they pass through clayey sand and sandy clay layers. The parameters analyzed in the uppermost clayey sand generally show higher values than the lower sandy clay layer. The major reason behind the changes in the contamination is that the clayey sand's ability to filter the contaminants is limited. The contaminant attenuation in the soil depends on the water moving through the layers of soil at a rate that ensures the maximum contact between the percolating water that contains contaminants and the soil particles. Since the water enters the clayey sand layer, it drains downwards by gravity. Also, the deep, medium, and fine-textured soils are the best, whereas coarse-textured materials are poor in terms of contaminant removal. In coarse materials like sand and clayey sand, water moves through rapidly, reducing the contact between the water and soil particles which may be the reason for the higher concentration in the clayey sand layer.

Groundwater analysis at BH4 and BH5

The groundwater samples collected for the period February 2010–January 2011 from BH4 and BH5 were analyzed for physicochemical parameters. The statistical analysis of the water quality variation in the boreholes is given in Table 3.

The TDS in BH4 ranges from 20,400 to 48,450 mg/l, and it rises rapidly in BH5 to 55,600 mg/l. The TDS are found to increase with an increase in the depth. This may be due to lack of aeration, sunlight, low flow, and less physicochemical reaction with the soil matrix and represents the cumulative effect. The study showed that also in the groundwater, the major concentration of TDS is due to chloride and sodium, which is in line with the samples collected from BH1, BH2, and BH3. A similar trend is observed for the other anions and cations analyzed in the groundwater. The major reason for the very high concentration of the TDS and other parameters is the influence of marshy area in addition to the dumpsite.

When the water quality of unconfined aquifer (BH4) is compared with that of the semi-confined aquifer (BH5), it is found that the parameters have lower concentration in the unconfined aquifer due to the dilution during the monsoon at a faster rate. This is also substantiated by the plot of temporal variation of TDS versus rainfall as shown in

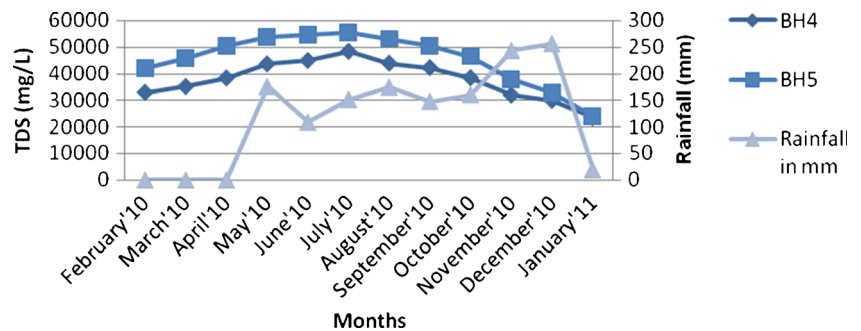**Fig. 6** Temporal variation of total dissolved solids in BH4 and BH5

Table 4 Heavy metal analysis for February 2010 and February 2011 in the leachate

Parameters	Sampling locations (February 2010)			Sampling locations (February 2011)		
	BH1	BH2	BH3	BH1	BH2	BH3
Pb	0.0378	0.0681	0.7066	2.166	2.318	0.1276
Fe	0.302	0.5789	0.6169	0.22	0.32	0.54
Zn	2.336	2.034	0.0805	0.02	0.04	0.5
Cr	0.0124	0.0409	0.0565	0.002	0.001	–
Cd	BDL	BDL	BDL	BDL	BDL	BDL
Ni	0.001	0.002	BDL	BDL	BDL	BDL

BDL below detection limits

Fig. 6. Also, most of the wells in the locality are shallow; the pumping of water favors the groundwater flow which may reduce the contamination level when compared to the semi-confined aquifer.

The heavy metal analyses were carried out for the water samples from all the boreholes. The presence of heavy metals such as Zn, Fe, Pb, Cr, Cd, and Ni given in Tables 4 and 5 clearly indicates the influence of the municipal solid waste on the groundwater. The higher concentration of heavy metals may not be attributed to the lithological variation of the aquifer. The BH1 and BH2 showed a higher concentration when compared to BH3 which may be based on the mobile nature of the metals in different soils. Among the analyzed heavy metals, lead shows a higher concentration when compared to chromium, iron, and zinc. Of all the trace metals, Pb is retained by soil and soil constituents to the greater extent. Puls et al. (1991) have verified the decreased sorption of Pb in the presence of complexing ligands and competing cations. The presence of Pb, Zn, and Cr in BH4 and BH5 shows the migration of leachate to the aquifers.

Conclusion

In the present study, leachate characterization at the source and the groundwater samples around the dumpsite has been carried out. Based on the analysis, boreholes were drilled along the periphery of the dumpsite to understand the lithological stratification, leachate characterization, and groundwater quality at various layers. The multi-level boreholes drilled at five different locations showed the variation of concentration in leachate and groundwater samples at different layers. The order reported for the analyzed heavy metals in the leachate at the source level is as follows: Pb>Fe>Cr>Zn>Cd. The distribution of heavy metals in the groundwater samples is as follows: Pb>Fe>Zn>Cr>Cd which is similar to that of the leachate samples. The differences in the vertical migration of the leachate may be due to the lithological variations beneath the dumpsite. The leachate variation in the shallow boreholes showed lower concentration at BH1, while a comparatively higher concentration was observed in BH3 and a still higher concentration in BH2. The study showed that deep, medium, and fine-textured soils are the best, whereas coarse-textured materials are poor in terms of contaminant removal. In coarse materials like sand and clayey sand, water moves through rapidly, reducing the contact between the water and soil particles which may be the reason for a higher concentration in the clayey sand layer. Similarly, the higher concentration of heavy metals shows the intensity of migration of leachate to the aquifers which also follows the same trend as that in the source and groundwater samples. The detailed study of the contaminant on the pollutant source, migration at different layers, and in the surrounding shallow wells thus helps to design a practical and feasible solution for a proper groundwater remediation technique.

Table 5 Heavy metal analysis for February 2010 and February 2011 in the groundwater

Parameters	Sampling locations (February 2010)		Sampling locations (February 2011)	
	BH4	BH5	BH4	BH5
Zn	0.0322	ND	0.244	0.3288
Fe	0.402	ND	0.38	0.45
Pb	0.174	ND	0.03	0.07
Cr	0.0278	ND	–	–
Cd	BDL	ND	BDL	BDL
Ni	BDL	ND	BDL	BDL

BDL below detection limits, *ND* not done

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