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Evaluation of the impact of landfill leachate on groundwater quality in Kolkata, India

De, S.*, Maiti, S. K., Hazra, T. and Dutta, A.

Department of Civil Engineering, Jadavpur University, Kolkata 700032, India

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ABSTRACT: The present study is aimed at characterizing the landfill leachate as well as its impact on the surrounding groundwater in Kolkata, India. Landfill leachate has been seasonally characterized from 2012-2014, indicating the landfill site in methanogenic phase with high contamination of organics, nutrients, salts, and heavy metals. Sixty groundwater samples have been analyzed for twenty two physico-chemical parameters in pre-monsoon, monsoon, and post-monsoon season of 2014. Seasonal alterations of groundwater quality have been evaluated with a statistical tool, Kruskal-Wallis test, to assess the influence of leachate, showing significant changes in almost all its physico-chemical parameters with sampling time. Majority of groundwater samples were contaminated with Hg, Pb, Cd, Cr, Fe, and Mn, indicating very little effect of redox control on the occurrence and transport of heavy metals. Comparison of physico-chemical parameters with World Health Organization (WHO) and Bureau of Indian Standards (BIS) indicate that majority of groundwater samples have been inadequate to use as potable water. Therefore, this study would help in developing policies for landfill leachate treatment programs and controlling groundwater pollution at the concerned landfill site.

Keywords: groundwater quality, Kruskal-Wallis test, landfill leachate, physico-chemical parameters.

INTRODUCTION

Uncontrolled landfilling and open dumps are the prevalent methods of Municipal Solid Waste (MSW) disposal in India and the generation of leachate is one of the consequences of landfilling, hence the Ministry of Environment, Forest and Climate Change (MoEFCC) in India issued MSW landfill leachate discharge standards under Municipal Solid Waste (Management and Handling) Rules in 2000, which were reaffirmed in 2016, to ensure that the disposal of contaminants did not affect human health or degraded the ecosystem. Open dumping poses a number of threats to both natural environment and local inhabitants by polluting nearby soil, surface, and groundwater sources as an outcome of leachate plume migration (Fatta et al., 1999; Mor et al., 2006; Maiti et al., 2016). Landfill leachate is a potentially-toxic liquid effluent, produced when the rainwater infiltrates through the waste layers and interstitial water content of the disposed solid wastes undergoing biodegradation is released (De et al., 2016). MSW landfill leachate is also characterized as hazardous, owing to its constituent pollutants such as dissolved organic matter, inorganic macro-components, heavy metals, and xenobiotic organic compounds (Christensen et al.,

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* Corresponding author Email: sde@research.jdvu.ac.in, shushmitaa2010@gmail.com

1994). Thus recently, thanks to landfill leachate infiltration, groundwater contamination has become one of the most commonly encountered problems.

Groundwater is the major source of potable water for the people of Kolkata city; however, local neighbourhood of Dhapa landfill site in Kolkata is currently under acute shortage of drinking water as a result of substandard quality of groundwater. Hence, physical and chemical investigation of groundwater samples around Dhapa landfill site in Kolkata is necessary to determine the effect of landfill leachate on groundwater quality. Seasonal variation of leachate composition and its impact on groundwater quality of Kolkata have not been studied in details.

This study discusses the impact of landfill leachate on groundwater quality from an uncontrolled landfill site in Kolkata, India. Landfill leachate has been seasonally monitored to identify the characteristic alterations. Likewise, groundwater pollution has been evaluated seasonally to delineate the influence of leachate. Specifically, groundwater chemistry has been examined by ion ratios to determine the seasonal changes in groundwater quality.

MATERIALS AND METHODS

The landfill site in the present study is located in West Bengal State, India, situated on a flat plain of eastern Kolkata within East Kolkata Wetlands (EKW) at Dhapa (Fig. 1) (Hazra & Goel, 2009). The landfill site has been operating since 1981 and receives around 3000 tons of MSW per day (Chattopadhyay et al., 2009). The landfill covers approximately 21.5 ha with an alluvial soil type, having a permeability of 10^{-5} to 10^{-6} cm/s. It has been considered an uncontrolled landfill, since it is not provided with bottom liner or leachate collection system.

The climatic condition in this region is a tropical monsoonal type with an annual precipitation of 1650 mm. In India, there are three distinguished seasons: summer (pre-monsoon) from March to June, Monsoon from June to October, and winter (post-monsoon) from November to February. A confined and partially-confined aquifer system exists in this study area (Sahu & Sikdar, 2011) which consisted of clay, silty clay, sand, and sand mixed with gravels (Sahu & Sikdar, 2008). However, some places in and around the study area have no uppermost confining layer of clay, making the groundwater vulnerable to infiltration of precipitation along with the pollutants of landfill leachate (Sahu & Sikdar, 2011).

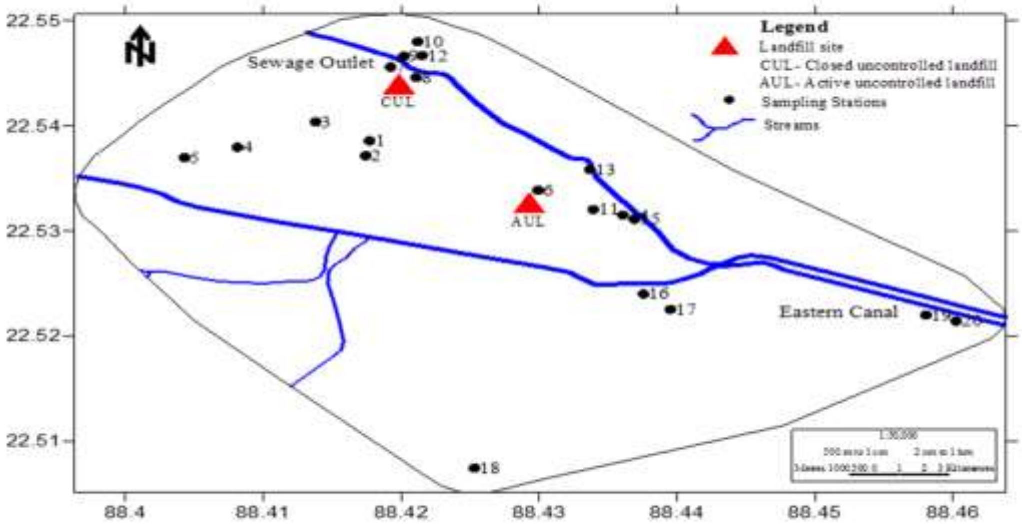

Fig. 1. The watershed, showing the landfill site and groundwater sampling stations

Composite leachate samples were collected seasonally from the landfill site for three successive years from 2012-2014. Composite samples were obtained with the assumption of equal generation of leachate to get an equivalent or representative quality. A sum of 60 (20×3) groundwater samples were collected within an area of 3.5 km of the landfill site during pre-monsoon, monsoon, and post-monsoon seasons of the year 2014. Leachate and groundwater samples were collected in a set of two pre acid-washed polypropylene bottles. To determine heavy metals, a set of samples (100 ml) was filtered with 0.45 µm Millipore membrane filter papers and preserved with 1.0 ml of concentrated HNO_3 to prevent metal precipitation. Another set (2 L in content) was used to determine all physico-chemical parameters. After collection, the samples were transported and stored in a cold room at $4^{o}C$ in the laboratory. Based on their priority, the selected parameters were subsequently analyzed within 1–3 weeks. The physico-chemical parameters, including the heavy metals, were analyzed in accordance with standard methods, internationally-accepted (APHA, 1999). Various physico-chemical parameters, determined in leachate and groundwater samples, include pH, EC, and TDS (via on-site with digital portable meter HI9813-5), TH, Ca^{2+}, Mg^{2+}, and HCO_3^{-} (via titrimetric methods), Na^{+} and K^{+} (via flame photometric method), Cl^{-} (via Argentometric method), F^{-}, NH_3-N, and NO_3^{-}-N (via Expandable ion analyzer EA940), PO_4^{3-}- P (via stannous chloride method), SO_4^{2-} (via Turbidimetric method), BOD_5 (via Azide modification of the Winkler method), COD (via closed reflux digestion method), and TKN (via Semi-Micro-Kjeldahl Method). The concentrations of As, Cd, Cr, Cu, Fe, Hg, Mn, Ni, Pb, and Zn were estimated using Perkin Elmer AAnalyst 400 Atomic Absorption Spectrometer (AAS), equipped with a graphite furnace (HGA Graphite Furnace). QA/QC measures were undertaken to evaluate the contamination, experimental accuracy and reliability of data. All the measurements were carried out in triplicate and the mean values were found to be within ±5% error limit. All the reagents were of Merck, analytical grade (AR). Analytical instruments got standardized by calibration with standard spiked solutions. Blank and standards were run after five analyses to recalibrate the instrument. All the blanks, standards, and analytical reagent solutions were prepared as per-standard method guidelines (APHA). Statistical analysis was also taken into consideration for the necessary error analysis.

Kruskal-Wallis test was selected for the groundwater samples to compare the means of the parameters' concentrations during different seasons by using Statistical Package for Social Sciences (SPSS) version 20. Kruskal-Wallis test is the non-parametric equivalence of the one-way ANOVA (Elliott et al., 2011). Non-parametric tests are used when the data deviate from ANOVA assumptions of normal distribution and small sample size, i.e. <25 sample per group (Guo et al., 2013). The independent variable was sampling time (seasons) with three levels, while the dependent one was parameters' concentration. Thus the influence of sampling time on parameters' concentration can be evaluated through this statistical analysis. Kruskal-Wallis H statistic helps identifying the differences that exist among the specific groups. The P value assesses the significance of H statistic with a confidence level of 0.05. If it is below 0.05, the independent variable has a significant effect on the dependent one.

RESULTS AND DISCUSSION

Table 1 summarizes the mean values of physico-chemical pollution parameters of leachate samples as well as their seasonal variation. They are also compared with the limits as stipulated by MoEFCC, 2016 (Table 2). Landfill leachate was in its stabilized state as long as pH stayed above 7.5 in all three seasons within the permissible limit for discharge. Chakraborty and Naresh Kumar (2016) showed a similar trend in their results, indicating mature methanogenic state of the landfill site in Ranchi, Jharkhand, India. Variation of pH in pre-monsoon (8.4), monsoon (7.9), and post-monsoon (8.2) can be attributed to biological composition of wastes or to rainfall (Demirbilek et al., 2013).

High values of EC in pre-monsoon (16190 µS/cm), monsoon (22555 µS/cm), and post-monsoon (20811 µS/cm) indicated high concentrations of soluble salts like sodium, potassium, and chloride (Kale et al., 2010). Similarly TDS values in pre-monsoon (10604 mg/L), monsoon (15489 mg/L), and post-monsoon (13476 mg/L) were much above the permissible limit, specified by the Indian standard. High concentrations of EC and TDS were found in pre-monsoon season and gradually increased during monsoon season, which reflected the dissolution of higher amounts of pollutants as a result of rain water intrusion. Fatta et al. (1999) exhibited that leachate, obtained from landfill in Attica region, Greece had a conductivity of 23,944 µS/cm and a TDS of 11747.5 mg/L which were more or less similar with the values found in the present study.

The highest mean values of Ca^{2+} (1201.10 mg/L), Mg^{2+} (1117.34 mg/L), Na^+ (3391 mg/L), K^+ (1109 mg/L), and Cl^- (6157 mg/L) were observed in monsoon season. Sorption, complexation, and precipitation reactions are minor for these inorganic elements but concentration of these pollutants decrease with time, as a result of wash out by leaching (Kjeldsen et al., 2002). In monsoon season, these elements flow out from waste mass along with the infiltrated rain water. Cl^- concentrations in all three seasons were consistently much higher than the permissible limit for discharge. In Chennai, India, Parameswari et al. (2012) presented that the leachate samples collected from Perungudi dumpsite, had a close range of concentrations of Na^+ (1400-8000 mg/L), K^+ (158-3000 mg/L), and Cl^- (900- 11,500 mg/L), similar to the present study. Alkalinity of leachate samples were mainly due to the presence of HCO_3^- ions as it was in the pH range of 7.0-8.6 which helped buffering the leachate system. Very high concentrations of HCO_3^- ions were found in monsoon (43945 mg/L) as a result of disintegration and liquefaction processes (Christensen et al., 2001).

The moderately lower values of SO_4^{2-} in pre-monsoon (488.67 mg/L), monsoon (512.44 mg/L), and post-monsoon (502.29 mg/L) can be attributed to the microbial reduction of sulfate to sulfide during the methanogenic phase (Kjeldsen et al., 2002). PO_4^{3-} - P concentrations in leachate are due to biological hydrolysis of the organic compounds, containing phospholipids and phosphoproteins (Fatta et al., 1999). The lowest mean value of phosphate concentration (4.54 mg/L) was observed in monsoon as a result of dilution effect.

High concentrations of NH_3-N prove the prevalence of reduction condition in leachate. The NH_3-N concentration increases by the hydrolysis and fermentation reactions of the organic nitrogen, present in waste mass (Yusof et al., 2009). The highest mean value of NH_3-N (3008 mg/L) was observed in pre-monsoon, indicating the reduction environment. The lowest mean value, equal to 443.37 mg/L, was observed in monsoon, since a partial aerobic condition prevailed as a result of intrusion of dissolved oxygen with rainwater. Similar trends of seasonal variation for TKN concentration were observed in leachate samples. Consequently very low concentrations of NO_3^--N were observed in leachate samples, 33.10 mg/L being the highest value in monsoon season due to partial oxidizing condition. The concentrations of both NH_3-N and TKN also much exceeded the leachate discharge standards. In Delhi, India, Mor et al. (2006), too, observed a high concentrations of NH_3-N of the leachate samples, collected from Gazipur landfill site with a mean value of 2675 mg/L.

The highest mean concentration of COD (4662 mg/L) belonged to monsoon as a result of increased hydrolysis reactions of the organic compounds. Similar trends were also observed for BOD_5. COD and BOD_5 were present in very high concentrations with reference to the discharge standards. Yusof et al. (2009) also showed similar range of concentrations for COD (4135 mg/L) and BOD_5 (666 mg/L) of the leachate samples, collected from an active uncontrolled landfill in Selangor state, Malaysia. In the present study, even though leachate samples were in the initial phase of stabilized state, BOD_5/COD ratio was 0.46 in pre-monsoon, 0.48 in monsoon, and 0.47 in post-monsoon seasons. These high values of biodegradability (BOD_5/COD) were due to the continuing process of waste deposition. However, there was no acidogenic leachate, as the proportion of old and stabilized waste mass to newly-disposed waste was high, so were bicarbonate concentrations (Demirbilek et al., 2013).

Methanogenic leachates were associated with low levels of heavy metals, as a consequence of adsorption and pollutants' settling down with inorganic groups, like sulphides, carbonates, and hydroxides (Kjeldsen et al., 2002). In the present study, however, high concentrations of heavy metals were obtained in leachate samples as a result of inadequate adsorbing of inorganic groups. Among the analyzed heavy metals, Hg, Pb, and Zn turned out to be consistent with concentrations, far above the permissible discharge standards, as reported by MoEFCC in all three seasons. The mean concentrations of Hg, Pb, and Zn for pre-monsoon were 2.28 mg/L, 0.547 mg/L, and 5.64 mg/L, which for monsoon altered to 0.190 mg/L, 0.563 mg/L, and 13.08 mg/L and for post-monsoon to 1.630 mg/L, 0.753 mg/L, and 6.07 mg/L, respectively. There was a high concentration of Cd, Cr, Fe, and Mn in leachate samples of the study area, too. In Morelos, Mexico, Vedrenne et al. (2012) perceived that the stabilized leachate exhibited a high concentration of Hg and Pb with a mean value of 33.27 mg/L and 19.59 mg/L respectively. Mor et al. (2010) also represented high concentrations of Fe (70.62 mg/L) and Pb (1.54 mg/L) in landfill leachate of Delhi, India.

Table 1 and Table 2 summarize the groundwater and drinking water quality standards (BIS, 2012; WHO, 1971, 1993, 2004, 2011), respectively.

All groundwater samples' pH stayed neutral, being within the permissible limit of the BIS and WHO standards. According to the Kruskal-Wallis test results, pH was affected by the sampling time ($H= 9.07$ and $P< 0.05$), probably indicating the effect of leachate on groundwater. EC indicates salinity of water; when it is above 2000 µS/cm in groundwater, it has laxative effects for the consumers (WHO, 2004). TDS is a major indicator of groundwater pollution as it, itself, can indicate the presence of inorganic salts of major cations and anions, along with some organic matter (WHO, 2011). High values of EC and TDS were found in GW6, GW11, GW14, and GW15, which were close to the active landfill site, showing the influence of leachate on groundwater. Likewise Indian and WHO standards, greater part of the groundwater samples surpassed the standard TDS value, making it inappropriate for drinking. There was a significant influence on EC and TDS concentrations for the sampling time ($H= 21.17$, $P< 0.05$; $H= 16.91$, $P< 0.05$), showing the impact of leachate intrusion in groundwater samples. Similarly, Nagarajan et al. (2012) studied the impact of landfill

Table 1. Physico-chemical parameters of leachate and groundwater samples collected from an uncontrolled landfill at Dhapa, Kolkata

Parameters[a]	Leachate									Groundwater		
	Pre-Monsoon			Monsoon			Post-Monsoon					
	Minimum	Maximum	Mean±SD[b]	Minimum	Maximum	Mean±SD[b]	Minimum	Maximum	Mean±SD[b]	Minimum	Maximum	Mean±SD[b]
pH	8.1	8.6	8.4±0.25	7.8	8.1	7.9±0.15	8.1	8.3	8.2±0.10	6.80	7.80	7.22±0.21
EC	12828	19980	16190±3595	17567	26000	22555±4423	19760	22428	20811±1421	863	7180	2142±1044
TDS	8980	12240	10604±1630	12465	17659	15489±2700	11820	15700	13476±2001	250	3390	974.44±524
Ca^{+2}	48.05	320.38	184.22±52	800.8	1601.6	1201.10±466	320.32	480.48	400.4±103	32.03	320.32	122.92±55
Mg^{+2}	165.17	194.32	179.75±20	874.44	1360.24	1117.34±343	291.48	1165.92	728.7±318	12.89	328.01	77.34±43
Na^{+}	292.11	1435	900.27±574	2826	4347	3391±832	869.57	1304	1092±217	59.38	1139.13	212.64±156
K^{+}	168.37	1186	638.53±513	735.29	1470	1109±367	705.88	911.76	836.56±113	0.30	5.30	2.69±1.18
Cl^{-}	3033	3493	3219±242	5675	6735	6157±536	3545	5558	4807±1099	141.80	1664	423.29±204
HCO_3^{-}	5319	7777	6398±1256	41098	46665	43945±2785	24400	26840	25673±1223	259.25	2825	975.13±627
SO_4^{2-}	343.75	601.25	488.67±131	410.34	580	512.44±89	295	690	502.29±198	0.46	65.75	18.41±13
PO_4^{3-}	12.12	45	26.04±17	1.50	7.62	4.54±3	1.20	27.06	10.65±14	0.02	0.90	0.12±0.11
NO_3^{-}-N	11.40	29	18.73±9	18.10	43	33.10±13	9.45	32.60	19.05±12	0.46	4.38	1.32±0.64
NH_3-N	1360	4210	3008±1476	290	660	443.37±192	1780	3600	2415±1027	–	–	–
TKN	2836	9139	6526±3286	3912	6897	5010±1641	3961	7946	5845±2001	–	–	–
BOD_5	525	1875	1121.67±688	1138	4493	2262±1931	960	2800	2056±969	–	–	–
COD	1200	4070	2423±1481	2300	9128	4662±3869	2400	5600	4400±1743	–	–	–
As	0.020	0.561	0.204±0 .309	0.01	0.07	0.043±0.031	0.003	0.089	0.032±0.049	ND[1]	0.071	0.009±0.003
Cd	1.20	1.893	1.57±0.347	0.006	0.028	0.016±0.011	0.023	2.11	1.41±1.19	0.001	0.02	0.01±0.007
Cr	0.104	0.311	0.209±0.104	0.640	0.930	0.763±0.149	0.840	3.43	1.80±1.42	ND[2]	0.14	0.05±0.03
Cu	0.370	0.680	0.530±0.155	0.170	0.200	0.187±0.015	0.240	0.340	0.301±0.053	0.0028	0.0370	0.01±0.009
Fe	1.02	1.55	1.27±0.267	0.950	1.20	1.06±0.128	0.800	5.13	2.38±2.39	0.02	9.57	1.27±1.58
Hg	2.06	2.650	2.28±0.322	0.160	0.220	0.190±0.030	0.450	2.50	1.63±1.06	0.02	0.48	0.19±0.09
Mn	0.680	1.380	1.13±0.393	2.14	3.90	2.87±0.919	0.850	2.24	1.63±0.711	0.09	2.93	0.86±0.89
Ni	0.490	0.650	0.557±0.083	0.200	0.230	0.213±0.015	0.290	0.770	0.463±0.266	0.01	0.08	0.03±0.02
Pb	0.390	0.640	0.547±0.137	0.540	0.580	0.563±0.021	0.390	1.14	0.753±0.376	0.005	0.96	0.20±0.26
Zn	1.95	8.42	5.64±3.37	4.42	25.14	13.08±10.77	1	8.85	6.07±4.39	0.01	20.48	4.16±5.74

[a] All concentrations are given in mg/L, except pH forand EC (µS/cm)

[b] Standard deviation

ND- Not Detected; ND[1] – the detection level was 0.0002 mg/L, ND[2] – the detection level was 0.00003 mg/L

Table 2. Leachate discharge and drinking water quality standards

Parameters[a]	Leachate discharge standards	Drinking water quality standards	
	MoEFCC standard	BIS standard	WHO standard
pH	5.5 – 9	6.5 – 8.5	7 – 8.5
TDS	2100	500	500
Ca^{+2}	–	75	75
Mg^{+2}	–	30	50
Cl^{-}	1000	250	200
HCO_3^{-}	–	200	–
SO_4^{2-}	–	200	200
NO_3^{-}-N	–	45	50
NH_3-N	50	–	–
TKN	100	–	–
BOD_5	30	–	–
COD	250	–	–
As	0.2	0.01	0.01
Cd	2.0	0.003	0.003
Cr	2.0	0.05	0.05
Cu	3.0	0.05	2.0
Fe	–	0.3	–
Hg	0.01	0.001	0.006
Mn	–	0.1	–
Ni	3.0	0.02	0.07
Pb	0.1	0.01	0.01
Zn	5.0	5.0	–

[a] All concentrations are given in mg/L, except for pH

leachate on groundwater in Erode city, Tamil Nadu, India, too, which exhibited higher concentrations of EC (1463.48 mg/L) and TDS (862.27 mg/L) in groundwater as a consequence of landfill leachate percolation in the surrounding groundwater.

With the exception of GW19 and GW20, both located farthest from the landfill site, Ca^{+2} and Mg^{+2} concentrations of all groundwater samples were above the BIS and WHO permissible limits. Carbonate-contained minerals (calcite and dolomite) are mainly responsible for the presence of calcium in groundwater (Mor et al., 2006), the abundance of which may be also due to the presence of sewage and industrial waste (Parameswari et al., 2012). Concentration of Ca^{+2} in groundwater samples was affected by the sampling time ($H= 22.40$ and $P< 0.05$), though Mg^{+2} concentration remained unaffected. Highest concentration of Na^{+} was found in GW6 (679.82 mg/L), being the nearest to the active landfill site, and Na^{+} concentration was significantly different due to the sampling time, probably as a result of the intrusion of leachate on groundwater samples ($H= 22.35$ and $P< 0.05$). K^{+} concentrations (0.30 to 5.30 mg/L) were low in all groundwater samples, being affected by the sampling time ($H= 15.85$ and $P< 0.05$). The effects of leachate on groundwater were evident as the highest concentrations of Ca^{+2}, Mg^{+2}, and Na^{+} were observed in GW6, GW11, GW13, GW14, and GW15, all in close proximity to the active landfill site. High concentrations of cations (Ca^{+2}, Mg^{+2} and Na^{+}) in groundwater, surrounding the landfill site, was also observed by Kale et al. (2010) who arrived at a Na/Ca ratio of 5.51 in pre-monsoon and 3.38 in post-monsoon, clearly demonstrating the effect of landfill leachate in groundwater.

Excessive chloride in groundwater acts as a contamination index and helps tracing groundwater pollution (Mor et al., 2006). Excepting GW18, GW19, and GW20, Cl^{-} concentrations of all other groundwater samples exceeded the permissible limit of 250 mg/L and 200 mg/L as recommended by BIS and WHO standards, respectively. The influence of leachate on groundwater was again pertinent as the highest concentrations of Cl^{-} belonged to GW6, GW11, GW13, GW14, and GW15. As the distance of the tube wells gradually increased from the landfill site, Cl^{-} concentrations declined, indicating that the Cl^{-} contaminations were mainly from the landfill leachate. Cl^{-} concentrations were not affected by the sampling time indicating that chloride is a conservative pollutant. The pH of groundwater samples was within the range of 8.3, total alkalinity as HCO_3^{-} of groundwater samples were mainly due to the presence of bicarbonates. The concentrations of HCO_3^{-} in groundwater samples were above the permissible limit of 200 mg/L in drinking water as stipulated by the BIS. High concentration of alkalinity along with high pH, TDS, and TH gave water a repulsive smell and may be harmful to human health (Kale et al., 2010). Statistical analysis indicated that there was a significant difference of HCO_3^{-} concentrations within the sampling time ($H= 47.35$ and $P< 0.05$), indicating the dissolution of landfill leachate in groundwater samples. According to Kale et al. (2010) the principal sources of SO_4^{2-} in groundwater are agricultural fertilizers and landfill leachate. SO_4^{2-} concentrations of the groundwater samples were much below the permissible limit of 200 mg/L, in accordance with BIS and WHO standards. PO_4^{3-} and NO_3^{-}-N concentrations of surrounding groundwater samples were relatively low, since much lowered concentrations of PO_4^{3-} and NO_3^{-}-N were observed in the landfill leachate. SO_4^{2-} and NO_3^{-}-N concentrations were affected by the sampling time ($H= 23.35$, $P< 0.05$; $H= 20.46$, $P< 0.05$), even though phosphate concentrations remained unaffected. Nagarajan et al. (2012) also observed elevated concentrations of Cl^{-} (201.76 mg/L), SO_4^{2-} (81.74 mg/L), and NO_3^{-}-N (7.93 mg/L) in the nearby groundwater of the landfill site, while in the present study higher concentration of Cl^- was observed, although concentrations of SO_4^{2-} and NO_3^--N were found to be lower in comparison to the above mentioned groundwater samples of the study area.

Groundwater in the studied area was highly and markedly polluted with heavy metals. Majority of groundwater samples were heavily affected by Hg, Pb, Cd, Cr, Fe, and Mn. Presence of heavy metals above the permissible limits (Figs. 2, 3, 4) in groundwater samples indicates very little effect of redox control on heavy metals' transportation. All the analyzed heavy metal concentrations were significantly influenced by the sampling time, as a result of landfill leachate, in the groundwater aquifer (Hg, $H= 20.06$ and $P< 0.05$) (Pb, $H= 44.08$ and $P< 0.05$) (Cd, $H= 50.09$ and $P< 0.05$) (Cr, $H= 19.08$ and $P< 0.05$) (Fe, $H= 15.10$ and $P< 0.05$) (Mn, $H= 40.34$ and $P< 0.05$) (Ni, $H= 7.30$ and $P< 0.05$), and (Zn, $H= 50.29$ and $P< 0.05$). Hossain et al. (2014) assessed groundwater pollution, pertaining to Rowfabad landfill in Chittagong city of Bangladesh and concluded that the groundwater samples were highly contaminated with Fe (2.94 mg/L), Cd (0.03 mg/L), and Cr (0.06 mg/L), similar to the present study. Abd EI-Salam and Abu-Zuid (2015) also observed high concentrations of Fe (0.84 mg/L) and Mn (0.31 mg/L) in groundwater, surrounding the landfill site in Alexandria, Egypt. Chakraborty and Naresh Kumar (2016) showed high concentration of Pb (0.097 mg/L), Fe (0.97 mg/L), and Mn (0.36 mg/L) during groundwater quality assessment, referring to MSW landfill site in Ranchi, Jharkhand, India. However these values of heavy metals in groundwater were lower, in comparison to the present study. Tahiri et al. (2017) detected high values of Hg higher than the Moroccan standards of 0.001 mg/L in some of the groundwater sampling stations around the landfill site of Meknes city, Morocco.

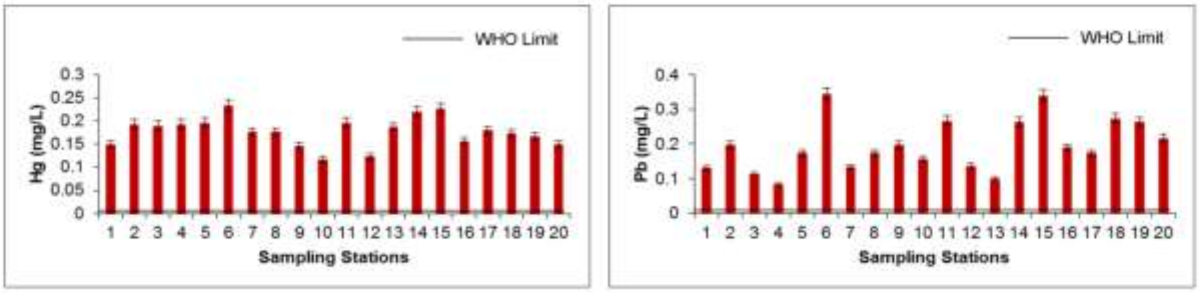

Fig. 2. Variation of Hg and Pb at different groundwater sampling stations

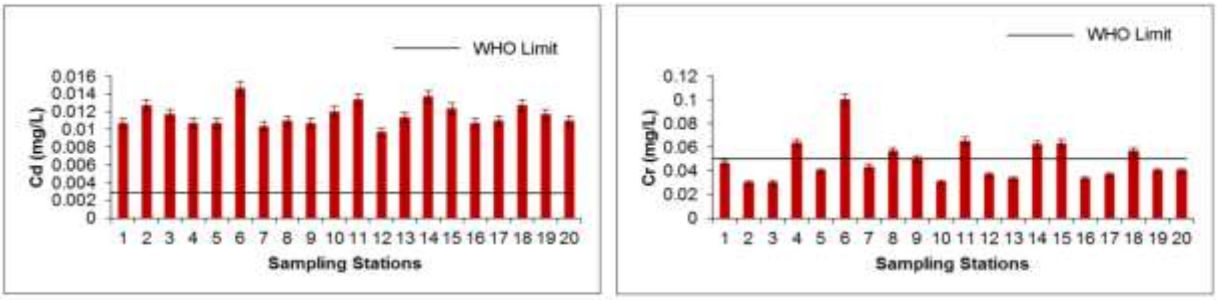

Fig. 3. Variation of Cd and Cr at different groundwater sampling stations

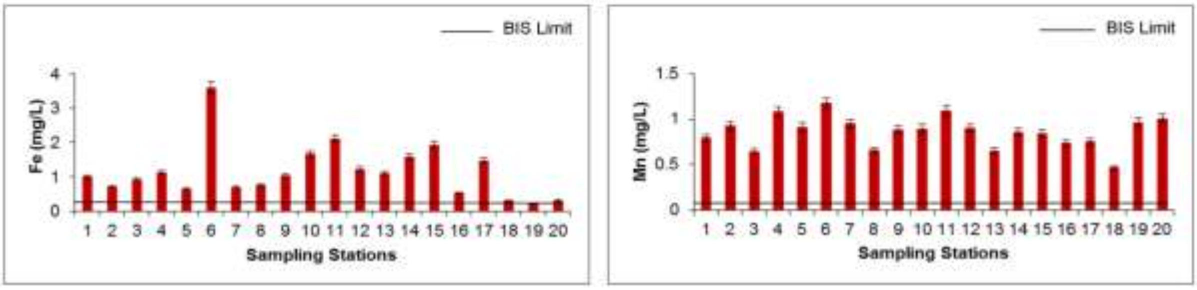

Fig. 4. Variation of Fe and Mn at different groundwater sampling stations

CONCLUSION

The results of the present study clearly indicate that leachate from the uncontrolled landfill site of Kolkata MSW was characterized by high concentrations of pollutants such as toxic heavy metals. The effect of leachate percolation and migration was also evident from the surrounding groundwater quality. For majority of the sampling stations, most of the physico-chemical parameters of the groundwater samples exceeded the BIS and WHO standards. Near the active landfill site, the concentration of major ions such as Ca^{+2}, Mg^{+2}, Na^{+}, and Cl^{-} were found to be high, indicating the influence of landfill leachate intrusion in groundwater. Among the heavy metals, Hg, Pb, Cd, Cr, Fe, and Mn were also found to possess high concentrations in majority of the sampling stations. Thus the present study urge for a proper solid waste management as a long-term policy in Kolkata Municipal Corporation (KMC) and the results indicate the need for continuous monitoring of the groundwater in and around Dhapa's uncontrolled landfill site.

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