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Full Length Research Paper

Assessment of groundwater contamination by leachate near a municipal solid waste landfill

Aderemi Adeolu O.[1]*, Oriaku Ada V.[2], Adewumi Gbenga A.[2] and Otitoloju Adebayo A.[1]

[1]Ecotoxicology Laboratory, Department of Zoology, Faculty of Science, University of Lagos, Akoka, Lagos, Nigeria.
[2]Department of Botany and Microbiology, Faculty of Science, University of Lagos, Akoka, Lagos, Nigeria.

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Physico-chemical and microbiological parameters were analyzed in leachate and groundwater samples obtained at different locations adjacent to a municipal solid waste landfill in order to assess the impact of leachate percolation on groundwater quality. Total dissolved solids (TDS), electrical conductivity (EC), and Na^+ exceeded the World Health Organization (WHO) tolerance levels for drinking water in 62.5, 100, and 37.5% of the groundwater samples, respectively with pH and Fe exceeding WHO limits in 75% of the samples. Significant negative correlations of -0.839, -0.590, and -0.590 were shown by Na^+, TDS, and EC respectively to distance from landfill. A high population of *Enterobacteriaceae* ranging from 4.0 $\times 10^3 \pm 0$ to $1.0575 \times 10^6 \pm 162,705$ CFU/ml was also detected in the groundwater samples, indicating contamination. The results show that the leachate from the landfill has a minimal impact on the groundwater resource and this can be attributed to the existing soil stratigraphy at the site consisting of clay which is deduced to have a significant influence on the natural attenuation of leachate into groundwater.

Key words: Groundwater, correlation, percolation, landfill, leachate, municipal solid waste, natural attenuation, Enterobacteriaceae.

INTRODUCTION

Municipal solid waste (MSW) disposal is a global concern, most especially in developing countries across the world, as poverty, population growth and high urbanization rates combine with ineffectual and under-funded governments to prevent efficient management of wastes (Cointreau, 1982; Doan, 1998). Landfilling is the simplest, cheapest and most cost effective method of disposing of waste in both developed and developing nations of the world (Barrett and Lawlor, 1995). However, in most developed nations there has been a reduction in the number of landfills as well as the amount of MSW landfilled over the years. According to USEPA (2008), the total amount of MSW going to landfills in the United States dropped by about 5 million tons, from 142.3 million tons in 1990 to 137.2 million tons in 2007. The number of landfills in the United States also declined steadily from 7,924 in 1988 to 1,754 in 2007 (USEPA, 2008).

Wastes placed in landfills are subject to either groundwater underflow or infiltration from precipitation and as water percolates through the waste, it picks up a variety of inorganic and organic compounds, flowing out of the wastes to accumulate at the bottom of the landfill. The resulting contaminated water is termed 'leachate' and can percolate through the soil (Mor et al*.,* 2006). Municipal landfill leachate are highly concentrated complex effluents which contain dissolved organic matters; inorganic compounds such as ammonium, calcium, magnesium, sodium, potassium, iron, sulphates, chlorides and heavy metals such as cadmium, chromium, copper, lead, zinc, nickel; and xenobiotic organic substances (Lee and Jones-Lee, 1993; Christensen et al., 2001).

Leachate varies widely in composition depending on many interacting factors such as the composition and depth of waste, availability of moisture and oxygen, landfill design, operation and age (Reinhart and Grosh, 1998). Leachate composition is primarily a function of the

*Corresponding author. E-mail: bodeoludunks@yahoo.com. Tel: +2348052215218.

age of the landfill and the degree of waste stabilization. The stabilization of waste is suggested to proceed in five sequential or distinct phases (Pohland and Harper, 1985) and the rate of progress through these stages is dependent on the physical (availability of free oxygen), chemical and microbiological conditions developed within the landfill with time (Pohland et al*.,* 1985).

Improper solid waste management (SWM) is a major environmental problem in the Lagos metropolis due to the absence of modern engineered landfills, therefore posing serious contamination risk to both groundwater and surface water. Landfills are considered one of the major threats to groundwater (USEPA, 1984; Fatta et al*.,* 1999). The scale of this threat depends on the concentration and toxicity of contaminants in leachate, type and permeability of geologic strata, depth of water table and the direction of groundwater flow (Al-khaldi, 2006). Modern Sanitary landfills have also been reported to leak leachate and pollute groundwater (Lee and Jones-Lee, 2004). Failure of liners and/or leakage of the leachate collection systems are the primary causes of such leachate seepage and infiltration into groundwater (Lee and Jones-lee, 1994).

Groundwater is the major source of potable water supply in the study area and Lagos in general (Longe et al*.,* 1987; Yusuf, 2007) and its contamination is a major environmental and health concern. This study was therefore undertaken with the objective of assessing the possible impact of leachate percolation on groundwater quality in the vicinity of an unlined MSW landfill at Igando New Town in the Lagos metropolis.

MATERIALS AND METHODS

Description of the study area

The landfill is located at the extreme east-west area of metropolitan Lagos, operated by Lagos Waste Management Authority (LAWMA) and referred to as Soluos. The site (Figure 2) spreads over an area of 7.8 hectares with an average life span of 5 years. The hydrogeological condition of the landfill site is consistent with the regional hydrogeological setting of Lagos area as depicted by Longe et al. (1987). The sub-surface geology of the landfill consists of clay intercalated with lateritic clay which is capable of protecting underlying confined aquifers but not water table aquifers from leachate contamination (Longe et al., 1987).

Waste disposal practices

The site was originally a borrow pit for lateritic soil. The landfill started operation in 2008 and on an average about 2,250 m^3/day of waste is dumped on the site with the waste filling heights varying from 12 to 15 m. The wastes dumped on this site are largely from domestic and commercial sources. Additional wastes from the poultry farm bordering it and adjacent slaughterhouse are also dumped. The site is a non-engineered open pit bordered by residential houses in Igando new town. Waste brought here by PSP (Private Sector Partnership) collection trucks from different parts of the city are dumped haphazardly without segregation. The site is characterized by landfill fires mostly due to spontaneous combustion which are prevalent in the dry season. There is a well water bore at this site used for the washing of the garbage collection vehicles and maintenance of heavy earth moving equipment.

Sampling of leachate and groundwater

In an effort to study the extent of groundwater contamination, eight (8) sampling points were selected within 0.55 km radius of the landfill site from where the groundwater samples were taken (Figure 1). Details of the sampling points are presented in Table 1. The samples were collected in clean 500 ml plastic bottles after the extraction of water either from a hand pump or a tube well at the beginning of the wet season in April, 2009. 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 (Mor et al., 2006). Since the landfill was not equipped with a leachate collection system, the leachate accumulating at the base of the landfill was sampled randomly from three different locations within the landfill and was mixed prior to analysis. The samples for microbiological analysis were aseptically taken in 50ml sterile universal containers.

Physico-chemical analysis of leachate and groundwater

The leachate and groundwater samples were immediately transported to the laboratory, stored at 4°C and analyzed the same day. All the samples were analyzed for relevant physico-chemical parameters according to internationally accepted procedures and standard methods (APHA, 1994). The parameters analyzed in the groundwater and leachate samples include pH, electrical conductivity (EC), total dissolved solids (TDS), chemical oxygen demand (COD), total hardness (TH), sodium (Na^+), sulphate (SO_4^{2-}), ammonium (NH_4^+), iron (Fe), zinc (Zn), cadmium (Cd), and lead (Pb). The concentrations of heavy metals were determined using an atomic absorption spectrophotometer.

Microbial enumeration

Serial dilutions were carried out on the groundwater and leachate samples collected. Appropriate dilutions were plated on MacConkey agar (Oxoid CM3 Basingstoke, Hampshire, England, UK) using the spread plate technique (Harrigan and MaCance, 1976), for the enumeration of Enterobacteriaceae. After the period of incubation, the total viable counts were expressed as means of three determinants.

Statistical analysis

The results of the microbial counts were presented as mean ± SE. The level of statistical significance was estimated at $P<0.05$ using the t-test. A correlation matrix was also set up and Pearson correlation coefficients calculated for the various parameters obtained in the groundwater samples using SPSS statistics 17.0 software.

RESULTS

Physico-chemical characteristics of leachate and groundwater samples

The results of the physico-chemical analysis of the

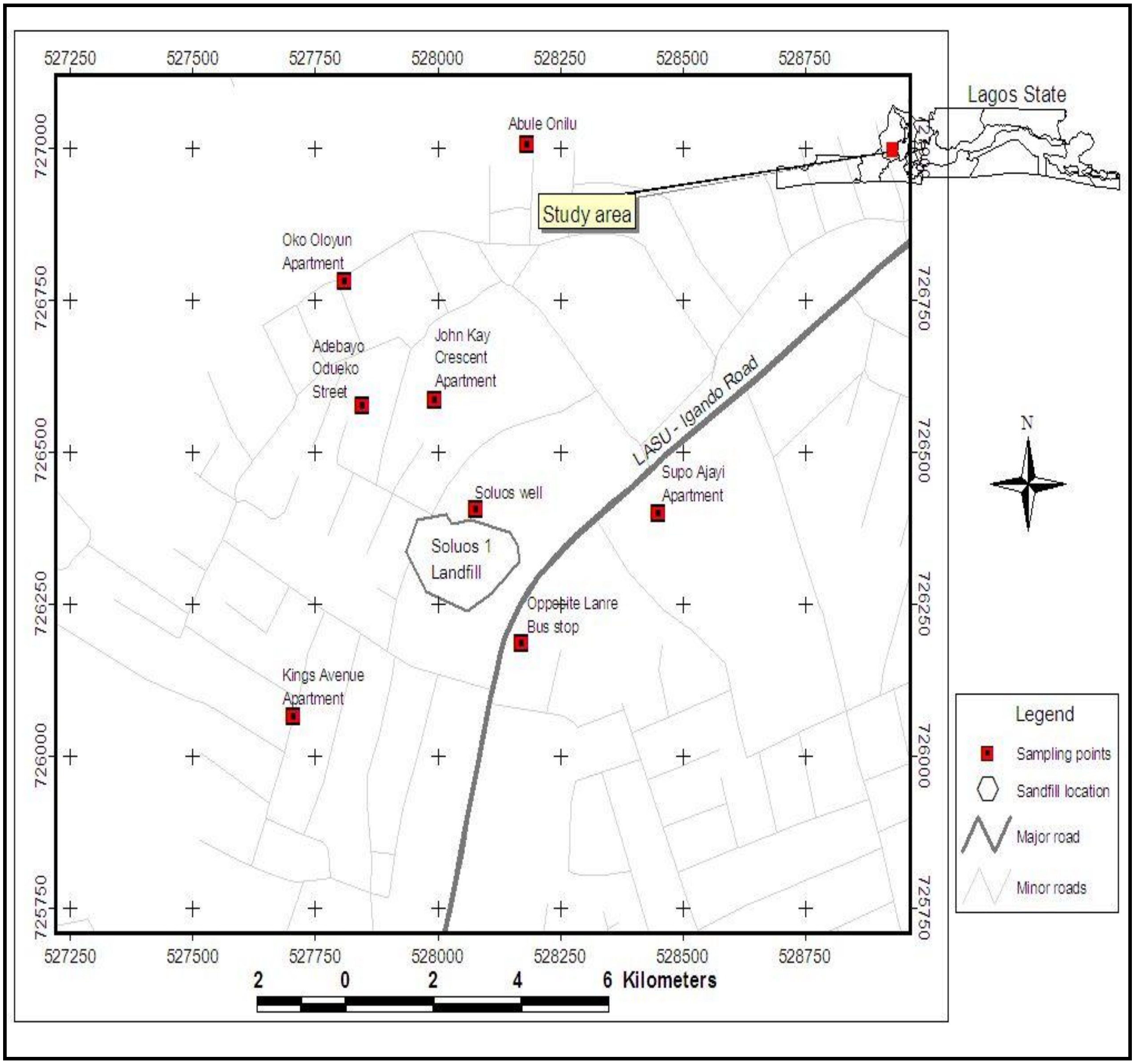

Figure 1. Location of landfill and the sampling sites for groundwater analysis.

leachate and groundwater samples are presented in Table 2. Table 3 shows the maximum permissible limits for drinking water as recommended by the Federal Environmental Protection Agency (FEPA) in Nigeria and the World Health Organization (WHO). The pH of groundwater in the study area ranged from 4.0 to 8.15 while the leachate was alkaline. The mean pH value of 4.2 recorded for the groundwater in this study is below the WHO permissible limits of 6.5 to 9.2 for potable water. Water from GW8 at 0 km away from the landfill has the lowest pH of 4.0, hence the most acidic in this study. TDS values ranging from 160 to 5310mg/l were observed in the water samples exceeding the permissible limit for potable water in 62.5% of the samples while a very high TDS value of 62000 mg/l was obtained in the leachate. The highest TDS value was recorded in well GW4, 0.08 km away from the site. High values of EC followed the same pattern in both leachate and water samples exceeding the WHO allowable limit for drinking water in all the groundwater samples.

The COD levels varied from 8.5 to 33.6 mg/L in the water samples while a value of 160 mg/l was obtained in the leachate. The Na^+ value was very high in the leachate (7863 mg/L) and varied from 13.25 to 325 mg/L in the water samples exceeding WHO drinking water standard of 200 mg/L in the three wells closest to the site. The highest concentrations of Na^+ were observed at GW8 (325 mg/L), GW4 (250.9 mg/L) and GW7 (225.5 mg/L), which are 0 km, 0.08 km, and 0.1 km away from the landfill respectively. For the heavy metals, the

Figure 2. A view of the landfill site, 2009 showing buried waste.

concentration of Fe in groundwater samples varied from 0.18 to 0.91 mg/L and found well above the WHO tolerance levels in 75% of the samples. Zn was observed in the water samples with concentration ranging from ND to 0.02mg/L far below the WHO tolerance value of 5.0mg/l while Pb and Cd were not detected in any of the groundwater samples. However, high levels of these metals were observed in the leachate.

Microbial analysis of leachate and groundwater samples

Table 4 summarizes the results of the microbial analysis of the leachate and groundwater samples from the study area. This shows the presence of *Enterobacteriaceae* in the leachate and the groundwater samples. The total viable count of the *Enterobacteriaceae* in the leachate was $1.26 \times 10^5 \pm 37,264$ CFU/ml while the total viable count of *Enterobacteriaceae* in the groundwater samples ranged from $4.0 \times 10^3 \pm 352$ to $1.0575 \times 10^6 \pm 162,705$ CFU/ml. The highest count was recorded in well GW8, the closest to the landfill and the lowest count at GW1, the farthest from the site.

Influence of distance from landfill on groundwater quality

Correlation matrix between various parameters is shown

Table 1. Site specification for groundwater samples. km = kilometers, GPS = latitude and longitude positions.

Sample	Sampling location	Type	Distance from landfill (km) boundary	Location (GPS)
GW 1	Abule Onilu Street	TW[a]	0.55	N06°34.625’ E003°15.217’
GW 2	Supo Ajayi Apartment	TW[a]	0.37	N06°34.296’ E003°15.362’
GW 3	Okooloyun Street	MO[b]	0.28	N06°34.503’ E003°15.014’
GW 4	John Kay Crescent	MO[b]	0.08	N06°34.398’ E003°15.114’
GW 5	Kings Avenue Street	TW[a]	0.26	N06°34.155’ E003°14.975’
GW 6	Opposite Lanre bus stop	TW[a]	0.24	N06°34.180’ E003°15.210’
GW 7	Adebayo Odueko Street	MO[b]	0.1	N06°34.392’ E003°15.034’
GW 8	Soluos Landfill well	MO[b]	0	N06°34.300’ E003°15.160’

[a] Tube well, [b] Motor operated.

Table 2. Physico-chemical characteristics of Leachate and groundwater samples.

Samples	pH	EC	TDS	TH	COD	Na^+	SO_4^{2-}	NH_4^+	Fe	Zn	Pb	Cd
Leachate	8.1	124000	62000	9300	160	7863	1.21	4.5	6.5	9.0	10.2	8.8
GW1	4.56	925	462.5	60	13	15.73	0.32	ND	0.18	0.004	ND	ND
GW2	5.92	1034	517	ND	15	19.66	0.79	ND	0.62	0.015	ND	ND
GW3	5.5	3660	1830	100	16	43.25	1.20	ND	0.72	0.003	ND	ND
GW4	8.15	10620	5310	50	14	250.9	0.78	ND	0.8	0.007	ND	ND
GW5	5.68	320	160	20	18	7.68	0.35	ND	0.46	0.005	ND	ND
GW6	5.85	950	475	ND	12	13.25	0.6	ND	0.91	0.003	ND	ND
GW7	6.8	5800	2900	21	8.5	225.5	0.02	ND	0.68	0.02	ND	ND
GW8	4.0	3060	1530	40	33.6	325	0.08	ND	0.18	ND	ND	ND

All values in (mg/L) except EC (µS/cm) and pH; ND = not detected.

in Table 5. TDS had a positive correlation with a number of parameters like EC (1.0), pH (0.735), and Na^+ (0.688). Fe was found to have a moderately positive correlation with SO_4^{2-} (0.543). Table 6 shows the Pearson’s correlation matrix between the various parameters and their distance from the landfill site. A strong negative correlation (-0.839) was obtained between the concentrations of Na^+ and their distance from the landfill site. Moderately indirect correlations (-0.590) were also shown by EC and TDS.

DISCUSSION

The low COD and the alkaline pH observed in the leachate can be attributed to the methane fermentation phase of the landfill. In this phase, alkaline pH supports the growth of methanogens which convert much of the organic contaminants in leachate to gas (Mcbean et al., 1995). An environmental consequence of this phase is the landfill fires that occur frequently on the landfill site in the dry season due to spontaneous combustion. The

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

*Parameter	FEPA[a] Standards	WHO[b] standards
pH	6-9	6.5-9.2
Total hardness	-	300
Total dissolved solid	2000	500
Electrical conductivity	-	300[c]
Total coliform count (100 ml)	0	0
Sulphate	20	200
Sodium	-	200
Ammonium	0.01	1.5
Zinc	5.0	5.0
Iron	0.05	0.3
Lead	0.01	0.05
Cadmium	0.05	0.01

*All values in mg/L, except pH, EC (µS/cm) and Total coliform count (CFU/ml); [a] FEPA (1991), [b] WHO (1997), [c] WHO (2003).

Table 4. Microbiological enumeration of leachate and groundwater samples CFU/ml = colony forming units per milliliters in mean ± standard error of mean (s.e.m).

Sample	Total viable count of *Enterobacteriaceae* (CFU/ml)
Leachate	$1.26 \times 10^5 \pm 37264$
GW 1	$4 \times 10^3 \pm 0$
GW 2	$1.055 \times 10^5 \pm 16879$
GW 3	$8.85 \times 10^4 \pm 11500$
GW 4	$1.60 \times 10^4 \pm 3055$
GW 5	$1.66 \times 10^4 \pm 11680$
GW 6	$1.0 \times 10^4 \pm 5033$
GW 7	$2.17 \times 10^4 \pm 3842$
GW 8	$1.0575 \times 10^6 \pm 162705$

Table 5. Correlation coefficient for different physicochemical parameters in groundwater.

Physicochemical parameters	pH	EC	TDS	TH	COD	Na^+	SO_4^{2-}	Fe
pH	1							
EC	0.735*	1						
TDS	0.735*	1.0	1					
TH	-0.156	0.036	0.036	1				
COD	-0.603	-0.134	-0.134	-0.029	1			
Na^+	0.164	0.688*	0.688*	-0.311	0.459	1		
SO_4^{2-}	0.280	0.121	0.121	0.825	-0.229	-0.427	1	
Fe	0.748*	0.367	0.367	-0.172	-0.596	-0.152	0.543*	1

*correlation is significant from 0.5 to 1.0

acidic nature of Lagos groundwater is characteristic of the coastal groundwater whose pH is primarily controlled by its hydrogeological setting (Longe et al., 1987). However the observation of the most acidic water from the well closest to the site is an indication that the impact of leachate cannot be ruled out. One major implication of this is the corrosion of plumbing materials.

The presence of high levels of heavy metals in the leachate suggests their origin could be from the various wastes dumped in the landfill. The presence of high

Table 6. Pearson's correlation coefficients between distance of sampling wells from landfill and physicochemical parameters in groundwater.

Parameter	pH	EC	TDS	TH	COD	Na^+	SO_4^{2-}	Fe
Distance	-0.296	-0.590*	-0.590*	0.363	-0.414	-0.839*	0.265	-0.205

*correlation is significant from -0.50 to -1.00.

concentration of Fe in the leachate indicates that Fe scraps are likely dumped in the landfill. Elevated levels of Pb in leachate had also been observed by Moturi et al. (2004) and this may be attributed largely to the disposal of batteries, lead-based paints and lead pipes found at the site. The high value of Zn may be attributed to the presence of fluorescent tubes, batteries, and a variety of food wastes as well as the burning tyres at the site. The discarding of dry cell batteries and paint cans are possible sources of cadmium.

The presence of Pb and Cd in the landfill leachate and their absence in all the groundwater samples can be attributed to the sub-surface geology of the site which consists of clay. These metals have the affinity to be absorbed by clayey soil (Mor et al., 2006; Longe and Enekwehi, 2007). The high Fe level recorded in the well samples is a characteristic of groundwater in Lagos environs which is due to local geology (Longe et al., 1987). Concentration of Fe above the permissible limit in water results in aesthetic problems relating to taste, odour and colour.

The TDS is a valuable indicator of the total dissolved salt content of water. The very high EC and TDS observed in the groundwater suggest a downward transfer of leachate into groundwater as reported earlier by Mor et al. (2006), Al-khaldi (2006) and Longe and Enekwechi (2007). High concentrations of TDS decrease the palatability of water and may also cause gastro-intestinal irritation in humans and laxative effects particularly upon transits (WHO, 1997).

The *Enterobacteriaceae* are normal flora of the intestinal tract of many animals and their presence in the leachate and groundwater is likely influenced by the nearby abattoir and poultry farm as well as the waste pickers who defaecate at the site. Their presence in groundwater precludes its use for potable water purposes and therefore poses potential health risks to the users.

The occurrence of Na^+ above the WHO tolerance levels in wells closest to the landfill is an indication of possible leachate flow into groundwater and agrees with previous report by Loizidou and Kapetanios (1993). This a great health concern for those suffering from high blood pressure, certain heart conditions, circulatory or kidney diseases and cirrhosis of the liver who are normally placed on a salt restricted diet (UME/USEPA, 2007). It is recommended by USEPA that sodium levels in drinking water should not exceed 20 mg/L for individuals on no salt diets (UME/USEPA, 2007).

The direct correlation between Fe and SO_4^{2-} is an indication that the metal is most likely present in form of the sulphate salt at the site. The significant indirect correlations between Na^+, EC, TDS with distance from the dumpsite shows that the concentrations of contaminants in groundwater normally decreases with increase in distance from the pollution source. These parameters could therefore be used as indicators of inorganic groundwater pollution. Further studies on the geology and the hydrogeology of the study area need to be carried out in order to corroborate these findings and confirm leachate contamination of groundwater in the study area.

Conclusion

The results obtained in this study shows that the leachate generated from the landfill site has a minimal impact on the groundwater quality in the locality. The soil stratigraphy of the site, being predominantly clay and lateritic clay, seems to have significantly influenced the low levels or absence of contaminants especially heavy metals in the groundwater samples. The observation of elevated levels of Pb, Cd and Zn in leachate and the presence of some conventional contaminants above the WHO permissible limits in some of the groundwater samples is an indication that in the absence of a leachate collection system, the uncontrolled accumulation of leachates over time at the landfill base will represent a significant threat to the groundwater quality. The findings obtained from this assessment have shown that groundwater of the study area is unreliable for drinking water supply purposes and therefore puts emphasis on the need to improve on waste management practices and construct properly engineered sanitary landfill sites to curtail the pollution of groundwater.

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