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Groundwater Quality Assessment near a Municipal Landfill, Lagos, Nigeria

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Abstract: The current research examined the level of groundwater contamination near a municipal landfill site in Alimosho Local Government Area of Lagos State, Nigeria. Water quality parameters (physico-chemical and heavy metals) of leachate and groundwater samples were analyzed. The mean concentrations of all measured parameters except NO_3^-, PO_4^+ and Cr^- conform to the stipulated World Health Organization potable water standards and the Nigerian Standard for Drinking Water Quality. Mean concentration values for TDS, DO, NH_4^+, SO_4^+, PO_4^+, NO_3^- and Cl^- are 9.17 mg L^{-1}, 3.19 mg L^{-1}, 0.22 mg L^{-1}, 1.60 mg L^{-1}, 10.73 mg L^{-1}, 38.5 mg L^{-1} and 7.80 mg L^{-1} respectively. The mean concentration values for Fe, Mn, Zn and Cr^- in groundwater samples are 0.07mg L^{-1}, 0.08mg L^{-1}, 0.08mg L^{-1} and 0.44mg L^{-1} respectively. The current results show insignificant impact of the landfill operations on the groundwater resource. The existing soil stratigraphy at the landfill site consisting of clay and silty clay is deduced to have significantly influenced natural attenuation of leachate into the groundwater resource. It is however observed that in the absence of a properly designed leachate collection system, uncontrolled accumulation of leachates at the base of the landfill pose potential contamination risk to groundwater resource in the very near future. The research recommends an upgrade of the solous landfill to a standard that would guarantee adequate protection of both the surface and the groundwater resources in the locality.

Key words: Contamination, groundwater, leachate, municipal, quality and stratigraphy.

INTRODUCTION

The intensity of man's activities has led to increasing volume of solid waste worldwide despite the current level of technological advancement and industrialization. Explosive population growth is one other major factor responsible for increased municipal solid waste (MSW). Land filling of municipal solid waste is a common waste management practice and one of the cheapest methods for organized waste management in many parts of the world (El-Fadel *et al*., 1997; Dsakalopoulous *et al*., 1998, Jhamnani *et al*., 2009). In most low to medium income developing nations, almost 100 per cent of MSW generated goes to landfills. Landfill operations are most feasible in these countries as land is vastly available and moderately inexpensive. Even in many developed countries where land is scarce and where policies of reduction, reuse and diversion from landfills are strongly promoted, great percentage of their generated MSW are still land filled. For instance, in 2006, out of the 251 million tons of MSW generated in the United States of America, 138.2 million tons representing 55% was disposed of in landfills (USEPA, 2007). In England, out of the 29.1million tons of municipal solid waste generated between 2003 and 2004, 72% was land filled (DEFRA, 2005). The scenario is similar in Northern Ireland and Scotland where82.9% and 85.4% of their generated MSW were land filled in 2005 and 2007 respectively (EHS, 2005; SEPA, 2007). Today, however, there is a progressive decrease in the volume of MSW being land filled in these developed countries on a yearly basis as great efforts in solid waste management are today directed towards waste reduction and recycling programmes which is a real giant step in environmental improvements (USEPA, 2007, 2008).

Landfills may however pose serious threat to the quality of the environment if incorrectly secured and improperly operated. The threat to surface and ground waters could be deleterious. The scale of this threat depends on the composition and quantity of leachate and the distance of a landfill from water sources (Slomczynska and Slomczynski, 2004). 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, nickel, zinc; and xenobiotic organic substances (Lee and Jones-Lee, 1993; Christensen *et al*., 2001; Tengrui *et al*., 2007; Ogundiran and Afolabi, 2008). The rate and characteristics of leachate production depends on a number of factors such as solid waste composition, particle size, degree of compaction, hydrology of site, age of landfill, moisture and temperature conditions, and

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available oxygen. During the course of stabilization of landfilled wastes, non-conservative constituents of leachate (primarily organic in nature) tend to decompose and stabilize with time, whereas conservative constituents remain long after waste stabilization occurs (Jhamnani and Singh, 2009). Such conservative constituents include various heavy metals, chlorides and sulphides. The age of a landfill also significantly affects the quantity of leachate formed. The ageing of a landfill is accompanied by increased quantity of leachate. Leachates generated in the initial period of waste deposition (up to 5 years) in landfills have pH- value range of 3.7 to 6.5 indicating the presence of carboxylic acids and bicarbonate ions. With time, pH of leachate becomes neutral or weakly alkaline ranging between 7.0 and 7.6. Landfills exploited for long period of time give rise to alkaline leachate with pH range of 8.0 to 8.5 (Słomczyńska and Słomczyński, 2004).

Inadequate solid waste management (SWM) is a major environmental problem in Lagos metropolis. The contributing factors range from technical problems to financial and institutional constraints. There is an absence of any properly designed solid waste disposal facilities in the state therefore posing contamination risk to both ground and surface waters. Groundwater is known as major source of water supply in the project area and in Lagos state in general (Longe *et al.*, 1987), and its contamination is a major environmental and health concern. Past studies had shown impairments of groundwater quality through leachates outflow and infiltration from landfill operations in Lagos state (Longe and Kehinde, 2005; Longe and Enekwechi, 2007). Longe and Enekwechi (2007) described leachates outflow and infiltration as the most critical source of groundwater contamination from the existing solid waste management practices in Lagos State and thus constituted potential public health and environmental problems.

The current study therefore aimed at assessing the level of groundwater contamination through leachate percolation from beneath the unlined Solous landfill in Alimosho Local Government Area of Lagos State, Nigeria.

MATERIALS AND METHODS

Study Area: The Solous landfill is situated at Igando in Alimosho Local Government Area of Lagos State, Nigeria. It started operations in the year 1996 with a projected lifespan of between 5 and 6 years. The landfill initially covered an area of about three hectares (Plate 1), and surrounded by residential, commercial and industrial set-ups. The landfill site has since witnessed rehabilitation which consisted of reclamation of land, construction of accessible road for ease of tipping, spreading and compaction of waste since inception. The expansion work was ongoing during the course of this study. Tipping at the landfill on a daily basis is averaged at 1000 tonnes of waste. Solous receives waste from entire Lagos

Plate 1: A view of the Landfill in Igando, Lagos, Nigeria

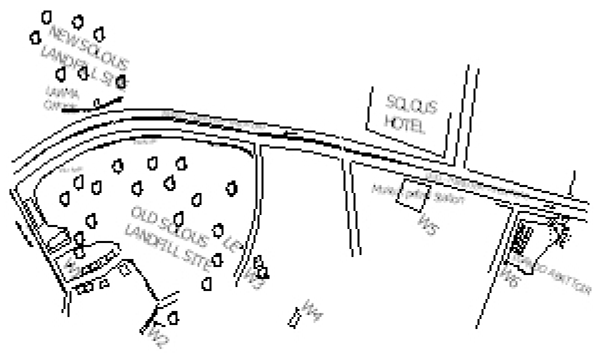

Fig 1: Schematic diagram showing the study area with sampling points

metropolis. In its quarterly report, the Lagos State Waste Management Authority (LAWMA) reported that a total of 469,202.50 tonnes of MSW was land filled in 2007 alone (LAWMA, 2009). Wastes are of different types, ranging from organic to inorganic, hazardous and non-hazardous. Like in all other existing landfills in the state, the waste stream is made up of domestic, market, commercial, industrial and institutional origins. Even though the state government micro water works supply piped borne water to the people of the study area, the populace still depends on wells (shallow and deep) for their domestic water supply.

Field Sampling and Laboratory Analysis: In an effort to investigate the extent of groundwater contamination, six sampling points designated W_1 to W_6 were selected between 10 and 375 m down-gradient of the landfill site while the leachate sample was designated LE (Fig. 1).

Field sampling was done at the end of the wet season in November, 2008. Details of the sampling points are presented in Table 1.

Water samples were collected in 1litre plastic containers and prior to collection as part of our quality control measures all the bottles were washed with non-ionic detergent and rinsed with de-ionized water prior to usage. Before the final water sampling was done, the bottles were rinsed three times with well water at the

Table 1: Sampling Location and well characteristics

Sample	Distance From Landfill Site (m)	Depth To Water Level in Wells (m)
LE	0	
W_1	10	14.0
W_2	20	16.8
W_3	40	15.4
W_4	107	16.2
W_5	260	15.8
W_6	375	4.8

point of collection. Each bottle was labeled according to sampling location while all the samples were preserved at 4ºC and transported to the laboratory.

Analytical methods: All the samples were analyzed for the following physico-chemical parameters and heavy metals; pH, total dissolved solids (TDS), dissolved oxygen (DO), nitrate (NO_3^-), sulphate(SO_4^+), phosphate (PO_4^+), ammonia (NH_4^+), chloride (Cl^-), copper (Cu), lead (Pb), chromium (Cr^{3+}), iron (Fe), manganese (Mn) and zinc (Zn). The physico-chemical analyses of both the water and the leachate samples were carried out in accordance to standard analytical methods (APHA, 1992). Results of laboratory analyses were subjected to data evaluation by use of standard statistical methods (Kottegoda and Rosso, 1997; Gupta, 2009)

RESULTS AND DISCUSSION

Groundwater Hydrology: The soil stratigraphy of Solous landfill consists of clay intercalated with lateritic clay. This lithology is capable of protecting the underlying confined aquifer from leachate contamination. This assertion could not be true of the water table aquifer which has high contamination risk potential (Longe *et al.*, 1987). The sub-surface geology of Solous landfill site is similar to that of Olushosun landfill and thus suitable for an attenuation landfill if properly planned, designed and constructed (Longe and Enekwechi, 2007).

Groundwater Quality: Analytical results of physico-chemical characteristics of leachate and groundwater samples from wells are presented in Table 2 and 3. The leachate has a pH value of 6.84, while the pH values of groundwater samples range between 5.30 and 7.07. The results indicate anaerobic or methanogenic fermentation stage of the leachate. This stage is usually characterized with production of volatile fatty acids (VFAs) and high partial pressures of carbon dioxide with a pH range of 6 to 8 (Kjeldsen *et al.*, 2002).

The groundwater samples are generally acidic with a mean pH value of 6.13 which is below the World Health Organization (WHO) and the Nigerian Standard for Drinking Water Quality (NSDWQ) guidelines for potable water. Past studies had equally revealed the acidic nature of Lagos groundwater (Longe *et al.*, 1987; Longe and Kehinde 2005; Longe and Enekwechi, 2007; Yusuf, 2007). The acidic nature of Lagos groundwater is characteristic of the coastal groundwater whose pH is primarily controlled by its hydrogeological setting (Longe *et al.*, 1987).

The dissolved oxygen concentration in the leachate sample is 1.40mg L^{-1} while the values in groundwater samples range from 2.91 to 3.94 mg L^{-1} with a mean concentration in water of 3.19 mg L^{-1}. Water samples from W_2 and W_5 wells have lowest levels of DO (2.91 mg L^{-1} and 3.00 mg L^{-1}) respectively. These values indicate a fairly high level of dissolved oxygen in groundwater samples above the leachate value of 1.40mg L^{-1}. It could be inferred from these results that there is little or no direct contamination of the aquifer by the leachate outflow. Concentrations of TDS, NH_4^+ and SO_4^+ in groundwater samples are low and found within the specified WHO and NSDQW standards for drinking water quality (Table 2). These results clearly show the influence of the young age of the rehabilated landfill on its low contamination potential. The concentrations of NH_4^+ in groundwater samples range between 0.12 and 0.30 mg L^{-1} while its value in the leachate sample is 3.22 mg L^{-1}, the highest concentration of NH_4^+ occurred in W_1 and W_6. The mean value of 0.22 mg L^{-1} obtained is within the tolerance level of 0.5 mg L^{-1} stipulated by the WHO for potable water. The mean value is equally well below the acceptable value of 5.0 mg L^{-1} stipulated by the Nigerian Standard for Drinking Water Quality. Sulphate is only detected in W_2 and W_6 and at very low concentrations of 1.2 mg L^{-1} and 2.0 mg L^{-1} respectively, while its concentration in the leachate stands at 1.0 mg L^{-1}. High levels of sulphates could lead to dehydration and diarrhea and children are more sensitive to it than adults. Phosphate levels are in the range of 7.07 and 10 mg L^{-1}, exceeding the WHO stipulated tolerance level of 5.0 mg L^{-1} for potable water. Even though phosphate is not detected in leachate sample, the localized presence of phosphate in groundwater at W_1, W_2 and W_5 could still be linked to the landfill operations as no specific and organized tipping of waste is practiced. Composition of leachate could vary from one part of a landfill to another and thus have different pollutional effects on the environment (Tricys, 2002). The pollutional levels therefore depend on its sources (sewage, detergents, industrial effluents and agricultural drainage) and volume. Traces of PO_4^- even at 0.1mg L^{-1} in water has deleterious effect on water quality by promoting the development of slimes and algal growth (Adekunle *et al.*, 2007). Higher concentration is detrimental to food preparation because of its buffering effect.

The concentration of NO_3^- in the leachate is 62.8 mg L^{-1}, while in groundwater samples its levels range between 20.4 mg L^{-1} and 60.5 mg L^{-1}, W_5 recording the highest level. All obtained values are above the WHO

Table 2: Physico-chemical characteristics of the leachate and groundwater

Sample	Distance (m)	pH	TDS (mg/l)	DO (mg/l)	NH_4^+ (mg/l)	NO_3^- (mg/l)	PO_4^- (mg/l)	SO_4^+ (mg/l)	Cl^- (mg/l)
NSDWQ		6.5-8.5	500	NS	5.0	50	NS	100	250
WHO		6.5-8.5	500	NS	0.5	50	NS	100	250
LE	0	6.84	30.0	1.40	3.22	62.80	ND	1.00	7.09
W_1	10	7.07	23.0	3.94	0.30	ND	7.07	ND	3.55
W_2	20	6.78	5.00	2.91	0.12	48.50	ND	1.20	2.84
W_3	40	5.30	3.00	3.10	0.24	45.70	15.12	ND	13.47
W_4	107	5.80	13.0	3.01	0.19	20.40	ND	ND	11.34
W_5	260	5.76	4.00	3.00	0.17	60.50	10.00	ND	12.76
W_6	375	6.09	7.00	3.18	0.30	17.40	ND	2.00	2.84

NS: Not specified; ND: Not Detected

Table 3: Descriptive Statistics for Physico-chemical characteristics of groundwater

Parameter (mgL^{-1})	Min.	Max.	Mean	SD	Variance	Range	Std. Error	Std. Dev
pH	5.30	7.07	6.13	0.67	0.45	1.77	0.27	0.67
TDS	3.00	23.00	9.17	7.65	58.57	20.00	3.12	7.65
DO	2.91	3.94	3.19	0.38	0.14	1.03	0.15	0.38
NH^+_4	0.12	0.30	0.22	0.07	0.01	0.18	0.03	0.07
SO_4	1.20	2.00	1.60	0.57	0.32	0.80	0.40	0.57
PO_4^-	7.07	15.12	10.73	4.07	16.60	8.05	2.35	4.07
NO_3	17.40	60.50	38.50	18.77	352.17	43.10	8.39	18.77
Cl^-	2.84	13.47	7.80	5.23	27.31	10.63	2.13	5.23

stipulated tolerance level of 10 mg L^{-1} for potable water. However, the level of nitrate at designated well W_5 is above the NSDWQ maximum permissible level of 50mg L^{-1}. Problems associated with high nitrate concentrations in groundwater have become increasingly prevalent in recent years. Natural levels of nitrate in groundwater may be enhanced by municipal and industrial wastewaters including leachate from waste disposal sites and sanitary landfills. High nitrate concentrations thus have detrimental effects on infants less than three to six months of age. Nitrate reduces to nitrite which can oxidize haemoglobin (Hb) to methaemoglobin (metHb), thereby inhibiting the transportation of oxygen around the body (Chapman, 1992, Lee and Jones-Lee, 1993; Alsabahi *et al*., 2009). Chloride concentrations in well water range from 2.84 mg L^{-1} to 13.47 mg L^{-1}, hence satisfying WHO and NSDWQ limits of 250 mg L^{-1} for potable water.

Heavy metals: Measured values and descriptive statistics of heavy metals in landfill leachate and groundwater samples are presented in Table 4 and 5. The WHO and NSDWQ permissible level of iron (0.3 mg L^{-1}) is not exceeded in all wells. Iron levels range from 0.02 to 0.15mg L^{-1} in the sampled wells. For Manganese, the range is from 0.06 to 0.16 mg/l therefore exceeding WHO acceptable level of 0.05mg/l but within the national water drinking water quality standard of 0.2mg/l. High iron level noticed in well water is characteristic of groundwater in Lagos environs which is due to the local geology (Longe *et al.*, 1987). Excessive dissolved iron and manganese concentrations result in taste and precipitation problems.

The concentrations of all other heavy metals in groundwater are negligible or undetected. However, appreciable concentrations of chromium are found in W_1, W_3 and W_6 (0.20, 0.43 and 0.71mg/l) respectively. All values are above the WHO and NSDWQ stipulated value of 0.05mg/l of chromium in drinking water quality. The highest level of 0.71 mg L^{-1} obtained in W6 is likely to be influenced by a nearby abattoir. Omole and Longe (2008) described abattoir as a potential source of contamination to water sources.

Heavy doses of chromium salts even though are rapidly eliminated from human body, could corrode the intestinal tract (WHO, 2004). Heavy metals such as lead, cadmium, chromium, arsenic and copper have also been reported at excessive levels in groundwater due to landfill operations (Lee *et al.*, 1986, Ogundiran and Afolabi, 2008).

Results obtained in this study reveal that the quality of the groundwater resource underlying Solous landfill site has been moderately impacted. The results of analysis of the following specific water quality parameters NO_3^-, PO_4^+ and Cr^- are above the highest permissible levels allowed by Nigerian Standards for Drinking Water Quality and the WHO permissible limits (NSDWQ, 2007; WHO, 2004). Observation reveals that with time the accumulation of leachate at the base of the sanitary landfill can breakthrough into the groundwater while gas emission also poses potential environmental and health risk. The soil stratigraphy of Lagos metropolis or the existing sequence of soil types occurring in the metropolis makes land filling operation very risky especially when one consider the prevalent high water table in Lagos. However, the soil stratigraphy at Solous landfill site consisting of clay and silty clay appears to have significantly influenced the low levels of contaminants found in groundwater samples. The age of the landfill and the volume of operation are equally contending favourable factors. This assertion needs further confirmation through geotechnical investigation with

Table 4: Heavy metals concentrations in leachate and groundwater

Samples	Distance (m)	Fe (mg/l)	Mn (mg/l)	Cu (mg/l)	Zn (mg/l)	Pb (mg/l)	Cr^{-}_{3} (mg/l)
NSDWQ	-	0.3	0.2	1.0	3.0	0.01	0.05
WHO	-	0.3	0.05	2.0	NS	0.01	0.05
LE	0	0.15	0.09	ND	0.26	ND	0.45
W_1	10	0.05	0.16	ND	0.07	ND	0.20
W_2	20	0.03	0.08	ND	0.04	ND	ND
W_3	40	0.15	ND	ND	0.08	ND	0.43
W_4	107	0.12	0.06	ND	0.05	ND	ND
W_5	260	0.02	0.07	ND	0.00	ND	ND
W_6	375	0.09	0.10	ND	0.23	ND	0.71

ND: Not Detected, NS: Not Specified

Table 5: Descriptive Statistics for Heavy Metals in Groundwater

Parameter (mg L^{-1})	Min.	Max.	Mean	SD	Variance	Range	Std.Error	Std. Dev.
Fe	0.02	0.15	0.08	0.05	0.003	0.13	0.02	0.05
Mn	0.06	0.16	0.09	0.04	0.002	0.10	0.02	0.04
Zn	0.00	0.23	0.08	0.08	0.006	0.23	0.03	0.08
Cr^{-}_{3}	0.20	0.71	0.45	0.26	0.065	0.51	0.15	0.26

appropriate planning and design. The existing low permeability clay and lateritic clay strata on which tipping is currently down even though has limited potential for groundwater contamination could as well favour leachate ponding and outflow into both surface and groundwater. Hence, upgrading of Solous landfill is highly recommended so as to guarantee the integrity of the groundwater quality in the vicinity.

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