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Flow system, physical properties and heavy metals concentration of groundwater: A case study of an area within a municipal landfill site

Adebisi, N. O.[1], Oluwafemi, O. S.[2], Songca, S. P.[3]* and Haruna, I.[4]

[1]Department of Earth Sciences, Faculty of Science, Olabisi Onabanjo University, Ago Iwoye, Ogun State, Nigeria.
[2]Department of Chemistry, Cape-Peninsula University of Technology, P.O.Box 652, Capetown, 8000, Western Cape, South Africa.
[3]Department of Chemistry, Walter Sisulu University, Private Bag X1, Mthatha, 5117, South Africa.
[4]Ikorodu Local Government, Ikorodu, Lagos State, Nigeria.

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Groundwater within the Olusosun landfill site in Lagos Metropolis was evaluated. Previous research on quality parameters of groundwater in the area made use of equipment of low detection capacity for heavy metals concentrations in water. Also, subsurface flow and significant attenuation of leachate due to horizontal distance between wells and landfill site are yet to be technically elucidated. In the present investigation, priority was given to heavy metals as small quantities may build up in human systems to become a significant health hazard. Then analysis was done with Inductively Coupled Plasma Mass Spectrometry (ICP-MS), while Geographical Information Systems (GIS) technique was used for spatial data analysis and management to illustrate localised flow of groundwater. Digital subsurface model of data from 20 drinking-water wells showed that flow directions are north-south, north-west and south-east. The two extremes of the pH for the groundwater are 4.04 and 8.05, indicating slightly acidic to weakly basic water. Total Dissolved Solids (TDS) are positively-strongly correlated with electrical conductivity (EC) in a line of fit TDS = 29.71 EC - 47.9. From the ICP-MS results, Fe concentrations at locations 1, 3 and 4, and Pb concentrations at locations 1, 5, 7, 8, 14 and 16 did not conform to international human-health benchmarks. Generally, the longer the horizontal distance between a well and the landfill site, the lesser its potential for groundwater contamination. This study better clarifies heavy metals concentrations in water, with GIS for satisfactorily display of positional and attribute for groundwater flow in the area.

Key words: Heavy metals, groundwater, landfill, Geographical Information Systems (GIS), Inductively Coupled Plasma Mass Spectrometry (ICP-MS).

INTRODUCTION

Heavy metals occur naturally and artificially in a groundwater system with large variations in concentration. Landfill is a common and the cheapest method for organized solid waste management in many parts of the world. However, heavy metal contamination of groundwater does arise from landfill source. In very small amounts, heavy metals such as Cobalt (Co), Copper (Cu), Chromium (Cr), Manganese (Mn) and Nickel (Ni) are required by man to support life, while in larger amounts, Mercury (Hg), Cadmium (Cd), Lead (Pb) and Chromium (Cr) are toxic. They may build up in human systems if consumed in contaminated water to

become a significant health hazard. In this category are Manganese, Mercury, Lead and Arsenic which are carcinogenic, affecting among others, the central nervous system. Hg, Pb, Cd and Cu affect the kidneys or liver, while Ni, Cd, Cu and Cr affect skin, bones, or teeth.

The Ojota area of Lagos has the largest municipal landfill situated at Olusosun, while groundwater is the major source of water supply for people living at Oregun, Ikosi-Ketu, Ojota garage and Ojota-Ogudu, around the landfill site. Lagos metropolis is highly industrialized with rapidity in urban population. For this reason, probable contamination of groundwater from both domestic and industrial wastes in the area has been of major concern to researchers in environmental and health. Previous work revealed that the Olusosun landfill shows a measurable impact of leachate outflows on groundwater quality at elevated levels of anions (NO_3^-, Cl^- and SO_4^{2-}) in the groundwater body and heavy metals (Cr^{3+}, Cd and Cu) attenuation following no definite pattern (Longe and Enekwechi, 2007).

From other parts of Lagos, Longe and Balogun (2009) examined the level of groundwater contamination near a municipal landfill site at Alimosho where the mean concentrations of NO^{3-}, SO_4^{2-} and Cr^{3+} did not conform to the stipulated World Health Organisation (WHO) potable water standards and the Nigerian Standard for Drinking Water Quality (NSDWQ). Momodu and Anyakora (2010) assessed heavy metal contamination of groundwater in middle class neighbourhood of Lagos. None of the samples analysed contained Al^{3+} in concentrations above the WHO and NSDWQ maximum contamination level, with the exception of [Cd] and [Pb^{2+}], which are above the tolerable contamination level. This population is prone to a significant risk due to the toxicity of these metals and the fact that for many, hand dug wells and bore holes are the only sources of their water supply.

The impact of leachate percolation on ground water quality in the vicinity of an unlined municipal solid waste landfill site at Igando area of Lagos metropolis has been studied by Aderemi et al. (2011). From the study, total dissolved solids (TDS), electrical conductivity and [Na^+] exceeding the WHO's tolerance limits for drinking water with 75% of the samples exceeding WHO's limits for pH and ΣFe. In addition, high population of *Enterobacteria-ceae* ranging from $4.0 \times 10^3 \pm 0$ to $1.0575 \times 10^6 \pm 162,705$ cfu/ml was also measured in the groundwater samples.

The objective of this paper is to develop a subsurface flow model, and analyze the horizontal distance influence of landfill site from wells on heavy metals concentration in the groundwater in the shallow aquifer overlying active the landfill. Even though, the vulnerability of groundwater to landfill operations in Lagos has been revealed, no previous work has employed a GIS to describe the subsurface flow below the active Olusosun landfill. Also, the most common instrumental method used to determine heavy metals concentrations in groundwater is mainly atomic absorption spectrometry (AAS). Compared to AAS technique, Inductively Coupled Plasma Mass Spectrometry (ICP-MS) method is characteristic of high sensitivity and accuracy (Vladimir et al., 2007). ICP-MS is a type of mass spectrometry which is capable of detecting metals and several non-metals at concentrations as low as one part in 10^{12} (part per trillion). This is achieved by ionizing the sample with inductively coupled plasma and then using a mass spectrometer to separate and quantify those ions. This database technology will go a long way to explain subsurface flow and significant contamination or otherwise of the heavy metals chemistry taking cognisance of drinking water quality standards as recommended by FEPA (1991) and WHO (2003).

Study area

The Olusosun landfill is situated exactly on a geographical cross wire at latitude N6° 35' 40.4"and longitude E3° 22' 44.3" as shown in Figure 1, 48 m above sea level. It covers about 42.7 ha of land with estimated residual life span of 20 years. Figure 2 is a photograph of part of the landfill site showing areas of refuse dump and leachate release. LAWMA report (2007) indicates that the dump site receives approximately 40% of the total waste deposits from Lagos metropolis and has been active since Friday 19th November, 1992.

In various discussions which pertain to the physical setting of Lagos, vegetation and soil types have been implicated to influence the spatial pattern of the landform. Abegunde (1976) showed how the relief and drainage patterns of Lagos generally reflect the coastal location. The coastal lowlands which dominate the Lagos landscape form part of a wider stretch of the coastal zone of southern Nigeria (Figure 3). The mode of landform evaluation in Lagos has been largely influenced physico-tropical climatic characteristics, which include; rainfall amount, intensity and distribution character of vegetation. All of which have been implicated in the dynamics of coastal landform processes in the area.

Geologically, Lagos area is within the Dahomey Miogeosynclinal Basin, Southwestern Nigeria. It is underlain by sedimentary deposits comprising silt, clay, peat or coal and sands of various sizes, and composition with a high degree of lithologic variability (Figure 4). From hydrogra-phical study, Onwuka (1990) identified two broad geological formations in Lagos area. These are Ilaro Formation and Coastal Plain Sands in the seacoast of Lagos. The Quarternary Formation of the Coastal Plain Sands is more wide spread over the study area.

MATERIALS AND METHODS

Field materials, measurements and sampling

Well depth and water level measurements were obtained using

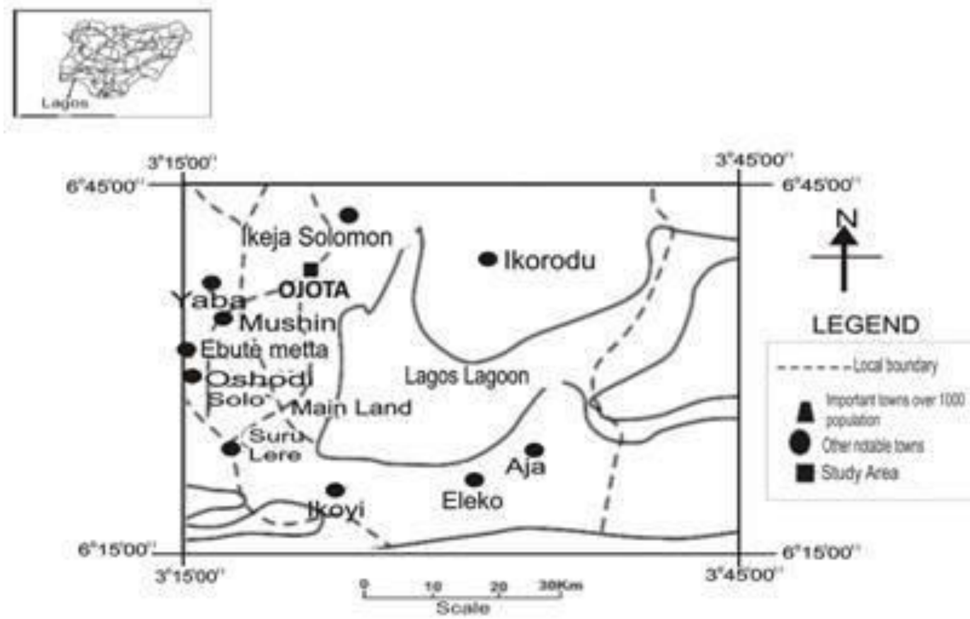

Figure 1. Map of Lagos metropolis showing location of the study area.

Figure 2. Photograph of part of the Olusosun landfill site showing areas of refuse dump and leachate release.

string, beaker, hook and sinker with measuring tape. Geographical locations of wells and elevation were captured on the field using Global Positioning System (GPS). During the reconnaissance survey, twenty wells comprising 11 tube wells (boreholes) and 9 large diameter wells (hand dug wells) were earmarked for sampling and designated L1 to L20. Wells numbers 15 and 16 were earmarked for control sampling because of the distance from the land fill site. The wells were between less than 200 and above 3000 m within and around the landfill site. The leachate sample was designated SLE. Two of the wells at 3010.2 m and 2963.2 m were also earmarked for control sampling.

Twenty raw water samples were collected from the wellhead in 20, 500 ml laboratory certified polyethylene, which has been earlier rinsed 3 times with the well water to be sampled and acidified. Maximum holding periods were designated for each physical parameter, while the samples were preserved by keeping it cool in order to slow chemical and biochemical reactions. The leachate accumulating at the base of the landfill was sampled from one location within the landfill site.

Vector mapping of water flow

A vector map was created from information in a-two-grid vector using *Surfer 8*. The vector was drawn at each grid node based on static water level and elevation information. This was with a view to emphasize on the groundwater flow direction within the study area where arrow symbols will indicate the "downhill" direction and their lengths will be indicative of the magnitude, or steepness, of the slope enhancing the flow direction of groundwater and groundwater potential zones (Figure 5).

Analytical methodology

Equipments employed to measure physical parameters are pH meter (For measuring hydrogen ion concentration) and Horiba U-10 multiprobe meter (For Total Dissolved Solids (TDS), Electrical Conductivity, EC) and Salinity. The concentrations of trace elements were determined using an Inductively Coupled Plasma Atomic Absorption Mass Spectrophotometer (ICP-MS). The internal standard of the ICP-MS also serves as the diluent consists primarily of deionized water, with nitric or hydrochloric acid, and Indium. 5 ml of the internal standard was added to a test tube along with 10 to 500 µl of the water sample. This mixture was then vortexed before it was pipetted and analyzed.

PRESENTATION OF RESULTS

The consistency of groundwater datasets helped in the explanation of subsurface flow analysis model in the study area. Figure 3 shows a steady state flow, where well head is independent of depth. This is important in order to generate a raster for groundwater flow vector. The standard output raster generated represents the groundwater volume balance residual, which measures the difference between the flow of water into and out of every cell within the 3 km radius of the Olusosun landfill site. Since the flow calculations are performed through each of the cell walls independently (flow is governed by the differences between adjacent cells), it is possible that more (or less) water may flow into a location than out of it, resulting in a positive (or negative) volume balance residual.

Unlike surface water which flows from areas of high to low elevation on the terrain, groundwater flows from a point of higher pressure gradient to a point of lower pressure gradient. The magnitude of pressure gradient in the subsurface is indicated by the length of the arrow, whereby areas of higher pressure gradients have longer arrows than areas of lower pressure gradients. The flow directions are north-south, north-west and south-east. Areas of high groundwater potentials are where the gradient is enhancing the flow direction of groundwater.

Results of physical properties of the investigated groundwater are summarized in Table 1 compared with the Federal Environmental Protection Agency (FEPA, 1991) and World Health Organisation (WHO, 2003) standards. The decimal logarithm of the reciprocal of the hydrogen ion activity of a water sample is defined as its pH. The pH value varies with temperature. Electrical conductivity (EC) in this context measures the ability of groundwater to conduct an electric current. This measurement is indispensable as it strongly relates to the Total Dissolved Solids (TDS) in the water, which in turn reflects groundwater catchment geology as it finds application in water classification (Ela, 2007).

Figure 6 is a regression model for the line of best fit TDS = 29.71 EC - 47.9 in which the values for slope, TDS-intercept and EC of the groundwater are defined. Strong positive correlation (r = 0.85) exists between TDS and EC of the groundwater with high coefficient of determination (r^2 = 0.72). The studied water samples at locations 5, 8 and 19 have elevated SL values in areas of shallow water tables, though still lower than the amount that could adversely affect human health.

Table 2 shows values of heavy metals concentration compared with drinking water standards of FEPA (1991) and WHO (2003), which provides the suitability picture of the groundwater for domestic and other purposes in the study area. Zinc (Zn) is one of the important trace elements that play a vital role in the physiological and metabolic process of man. Nevertheless, at higher concentration, zinc can be toxic to the man. Copper (Cu) is also an essential element for human beings, excess of which can be toxic, causing hypertension, pathological changes in brain tissues and specific diseases of the bone (Iyengar et al., 1988). In this study, the maximum concentration of Cu recorded is 0.02 mg/l which is within the recommended limits of drinking water.

The most common source of Iron (Fe) and Manganese (Mn) in the local groundwater around the study area is the leachate from the municipal landfill site. Fe in groundwater occurs mainly in form of ferric hydroxide. It is found in significant concentration in some sample of the studied groundwater only at locations 1, 3 and 4. The shortage of Fe causes anemia, while its prolonged consumption in water may lead to a liver disease called haermosiderosis (Iyengar et al., 1988). The main source of Cd in groundwater is industrial activities such as electroplating, pigments, plastic, stabilizes and battery manufacturing. Small quantities of Cd can cause adverse changes in the arteries of human kidney (Iyengar et al., 1988). It replaces zinc biochemically and causes high blood pressures, kidney damage and etc. It interferes with enzymes and causes a painful disease called Itai-itai. Cd concentrations in groundwater of the study area are mostly below the detectable level, except at location 14 where a concentration of 0.01 mg/l is recorded.

Lead (Pb) is an undesirable trace metal and a serious cumulative body poison, which can inhibit several key enzymes involved in the overall process of haemo-synthesis whereby metabolic intermediate accumulates. Pb concentrations above the safe limit were measured in groundwater samples at locations 1, 5, 7, 8, 14 and 16. Measured values of heavy metals in groundwater are presented in Table 2.

From the descriptive statistics (Table 3) Pb has the maximum average concentration of 0.07 mg/l compared to other heavy metals, while Cd has the minimum standard deviation of 0.003. C_U is the most variable heavy metal, while Fe is the least variable trace element

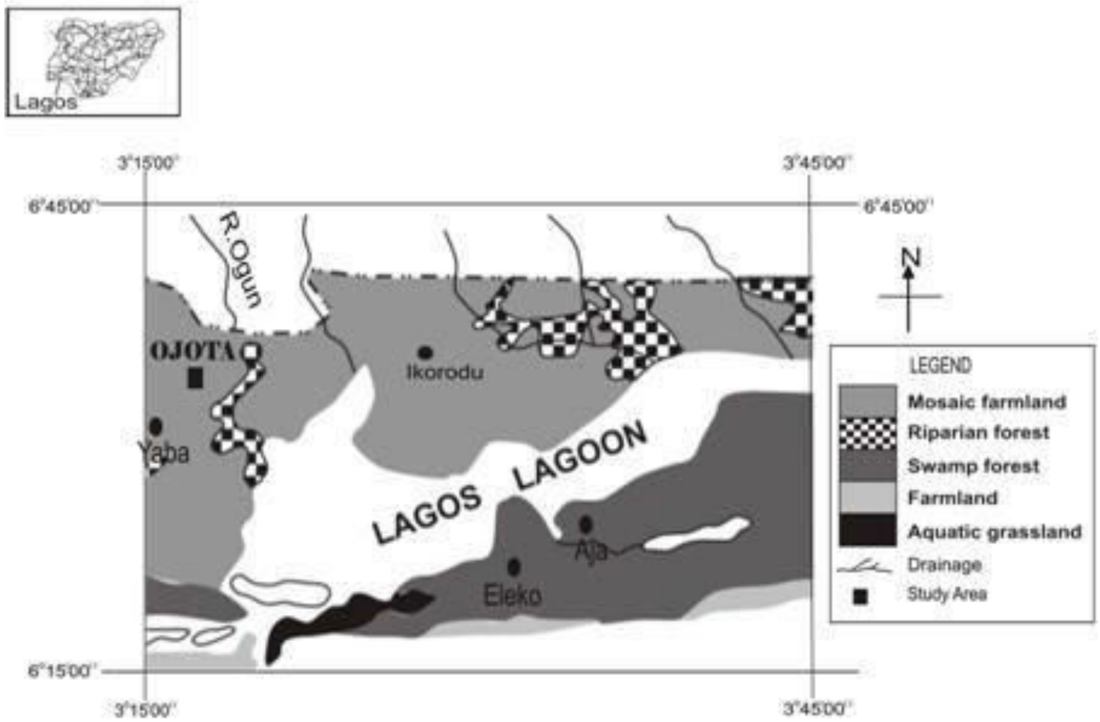

Figure 3. Map showing the major rivers and vegetation of Lagos.

Table 1. Physical properties of the studied groundwater.

Sample S/N	pH	E.C. (µS/cm)	TDS (mg/l)	Salinity (mg/l)
FEPA (1991)	**6 – 9**	**1.00**	**200**	**250**
WHO (2003)	**6.5 - 9.2**	**1.00**	**500**	**250**
LE	8.05	13.2	464	40
L1	5.87	1.28	10	10
L2	5.36	0.75	11	2
L3	5.61	0.94	17	6
L4	6.8	5.70	17	253
L5	6.58	4.80	0	180
L6	5.25	1.25	0	34
L7	5.96	1.72	6	30
L8	6.76	4.64	0	165
L9	5.73	1.98	4	90
L10	5.15	0.18	1	50
L11	7.25	2.40	17	10
L12	6.48	1.80	4	63
L13	4.04	1.66	16	47
L14	5.96	1.01	0	32
L15(CTR)	4.16	1.71	6	52
L16(CTR)	4.48	0.95	6	32
L17	4.25	2.03	4	59
L18	6.57	4.06	0	169
L19	4.44	0.81	0	16
L20	4.83	0.81	5	33

NS: Not specified; CTR: control; LE: leachate.

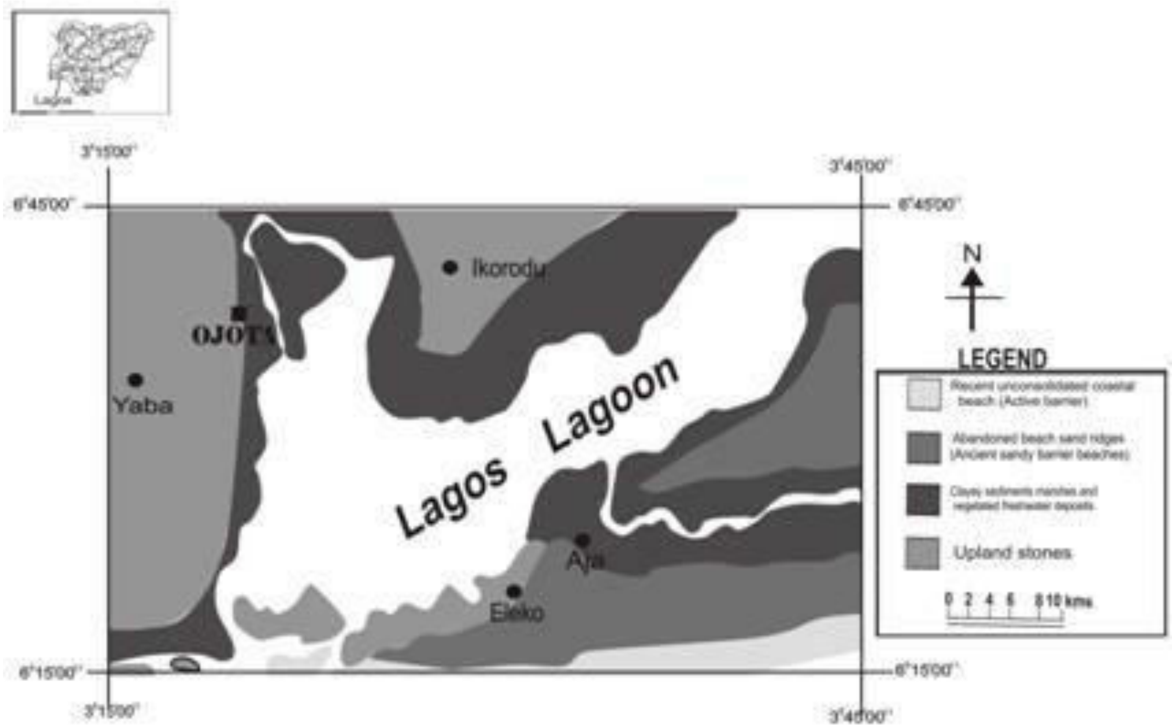

Figure 4. Map showing the surface geology of Lagos.

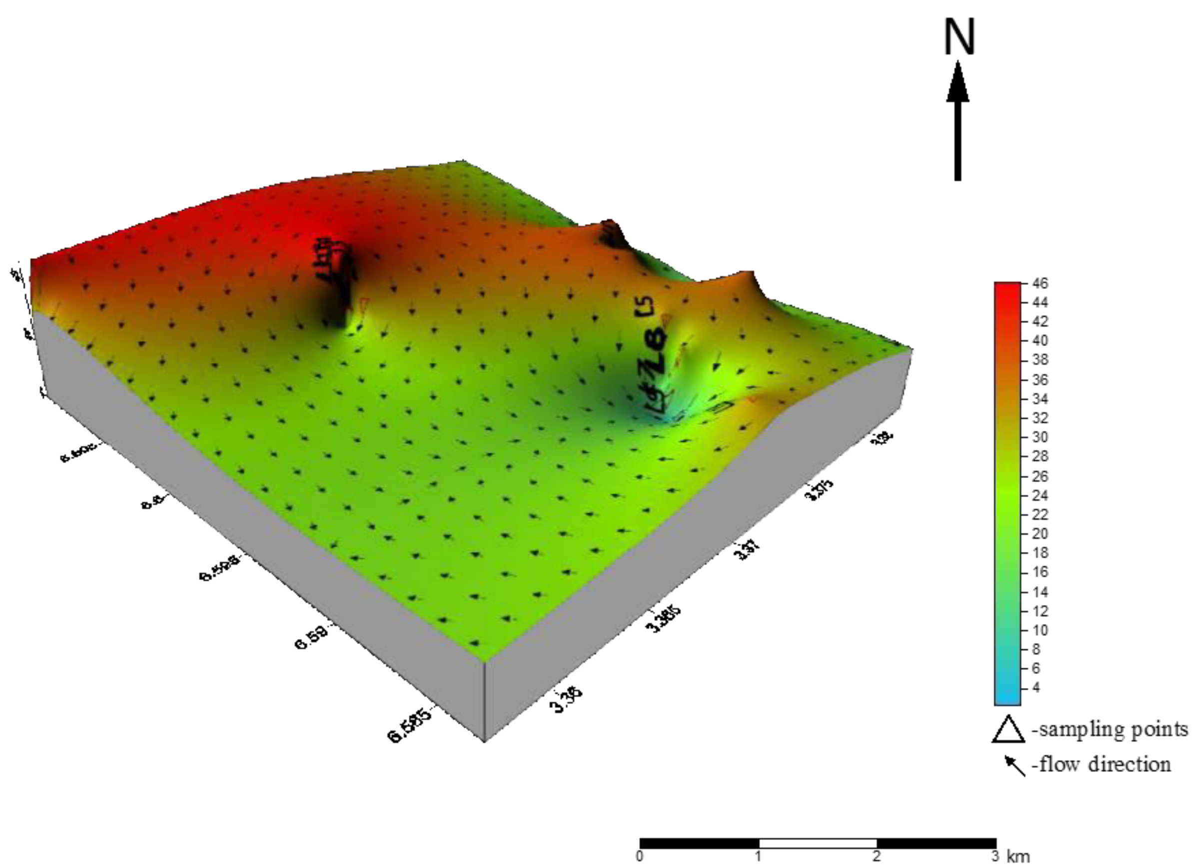

Figure 5. Digital terrain model of the study area and groundwater flow direction.

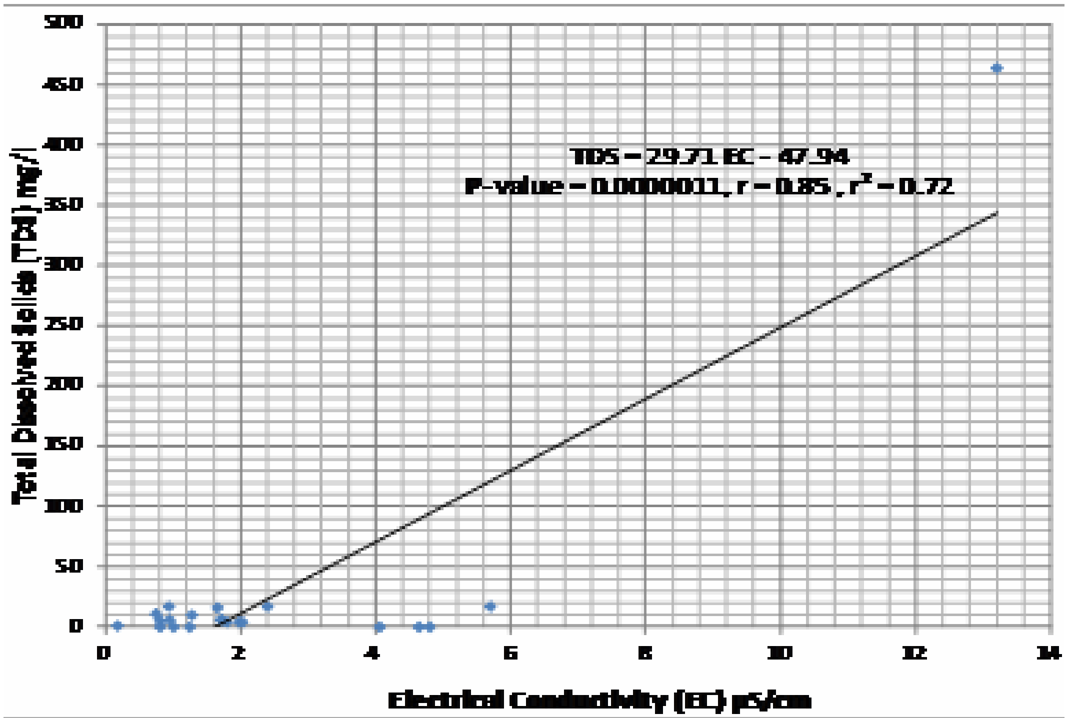

Figure 6. Regression plot of Total Dissolved Solids against electrical conductivity of groundwater.

Table 2. Heavy metals concentration of the studied groundwater.

Sample S/N	Distance (m)	Zn (mg/l)	Cu (mg/l)	Mn (mg/l)	Fe (mg/l)	Cd (mg/l)	Pb (mg/l)	Cr (mg/l)
FEPA	--	3.0	1.00	0.20	0.30	NS	0.01	0.1
WHO	--	1.5	0.50	0.50	0.03	0.002	0.01	0.1
LE	0.	0.0	0.01	0.00	0.06	0.01	*0.20*	0.0
L1	269.2	0.0	0.01	0.01	0.05	0.00	*0.09*	0.0
L2	414.4	0.0	0.00	0.01	0.02	0.00	0.01	0.0
L3	145.0	0.0	0.00	0.00	*0.36*	0.00	0.01	0.0
L4	121.0	0.0	0.00	0.00	*0.64*	0.01	*0.20*	0.0
L5	735.6	0.0	0.00	0.01	0.00	0.00	*0.92*	0.0
L6	900.8	0.0	0.00	0.00	0.00	0.00	0.00	0.0
L7	977.0	0.0	0.00	0.00	0.00	0 .00	*0.06*	0.0
L8	888.8	0.0	0.00	0.01	0.00	0.00	*0.04*	0.0
L9	1061.0	0.0	0.00	0.01	0.00	0.00	0.00	0.0
L10	687.63	0.0	0.01	0.00	0.00	0.00	0.00	0.0
L11	737.6	0.0	0.01	0.04	0.01	0.00	0.00	0.0
L12	1539.6	0.0	0.01	0.02	0.01	0.00	0.00	0.0
L13	1609.6	0.0	0.01	0.02	0.00	0.00	0.00	0.0
L14	1603.6	0.0	0.01	0.00	0.00	0.01	*0.02*	0.0
L15(CTR)	3010.2	0.0	0.01	0.01	0.01	0.00	0.01	0.0
L16(CTR)	2963.2	0.0	0.01	0.00	0.00	0.00	*0.04*	0.0
L17	1446.4	0.0	0.01	0.02	0.00	0.00	0.00	0.0
L18	1471.4	0.0	0.01	0.02	0.00	0.00	0.00	0.0
L19	643.6	0.0	0.02	0.00	0.00	0.00	0.00	0.0
L20	740.8	0.0	0.01	0.00	0.00	0.00	0.00	0.0

NS: Not specified; CTR: control; LE: leachate.

Figure 7 shows line plots of groundwater heavy metals concentration and well horizontal distances from the Olusosun landfill site. Among the measured heavy metals, only Pb and Fe show elevated concentration of 0.6 and 0.9 mg/l respectively, at a distance less than 1000 m. It follows that wells need be located at least 1500 m away from the landfill site.

DISCUSSION

Aquifer flow system

The well head raster generated so far is reasonable with respect to transmissivity, porosity, and aquifer thickness. Considering the elevation information, the directions at which arrows are pointing are in the direction of pressure release where wells are concentrated. The hydrogeological condition of the landfill site is consistent with the regional hydrogeological setting of Lagos (Longe et al., 1987). The subsurface geology of the landfill area comprises a lateritic cover of variable thickness averaging 4 m, which overlies an alternating sequence of sand and clay deposit. The water-bearing zone consisting of loose, medium to coarse sand with an average thickness of 10.4 m is directly below it.

Physical properties

The physical properties of groundwater are significant factors for the occurrence of many trace elements. For instance, pH below 7 is a significant factor in the occurrence of many cationic metals, such as Al, Fe, Mn, and Ni; these metals, as well as Cu, Pb, and Zn, adsorb more strongly to aquifer materials as pH increases (Ayotte et al., 2011). Chemically, water dissociates according to the equilibrium

$2H_2O \rightleftharpoons H_3O^+(aq) + OH^-(aq)$-------------------- Equation 1

with a dissociation constant, K_w defined as

$K_w = [H^+][OH^-]$------------------------------------ Equation 2

Where $[H^+]$ is the concentration of the aquated hydronium ion, and $[OH^-]$ represents the concentration of the hydroxide ion. K_w has a value of about 10^{-14} at 25°C.

The two extremes that describe the pH of studied water samples are 4.04 and 8.05, indicating slightly acidic to weakly basic groundwater. Tested samples of groundwater in the study area have TDS values which placed them in the class of fresh waters. Raw water samples from wells in the study area have TDS values ranging from 0 to 17 mg/l, which is far below the recommended limits of FEPA (1991) and WHO (2003).

The trend of specific electrical conductance with dissolved solids is such that as the number of charged ions in the water (TDS) increase so does the EC. Also about 72% in the variation of the TDS was associated with the EC of the groundwater. On the basis of the p-value which is far less than the predetermined significance level α (which is often 0.05 or 0.01), it can be concluded that the TDS is highly dependent on the EC of the studied groundwater. Therefore, it is possible to estimate TDS of the water measured values of EC.

Salinity (SL) is a major water quality limitation on the environmental values of groundwater. Human action such as waste disposal among others has been implicated to cause excessive salinity in groundwater. Salinity has limited the use of groundwater sources as they are too salty for human consumption.

Heavy metals concentration and quality standards

In addition to landfill site contribution, the geologic composition of aquifers and aquifer geochemistry are among the major factors affecting trace-element occurrence (Katz et al., 2007). Zn concentration in the groundwater is below the detectable level. This can be due to its restricted mobility from geological formation which underlies the dump site. At concentrations found in most of the sampled groundwaters, Fe and Mn are at concentrations below the aesthetic objective, and therefore, not considered a health risk. This study reveals that the concentration of Pb is below the detectable level in most of the groundwater samples.

Variation in heavy metals concentration

Trace metals that occur in the studied groundwater are not of concentrations large enough to constitute a significant health impact. However, the order of decrease in concentration is Cu > Mn > Cd > Pb > Fe.

Landfill site and well distance

Locating a well in a safe place takes careful planning and consideration of factors such as horizontal distance from pollution source. The horizontal distance between a well and landfill site is one of the most crucial safety factors to consider when studying groundwater contamination. The minimum distance between a well and the landfill site can lead to contamination, but longer distances would better protect the well. For wells located at a distance less than 1000 m, the landfill site can have a major impact on them.

CONCLUSIONS AND RECOMMENDATIONS

The Olusoun landfill was considered a critical site for groundwater pollution as it comprises heavy domestic

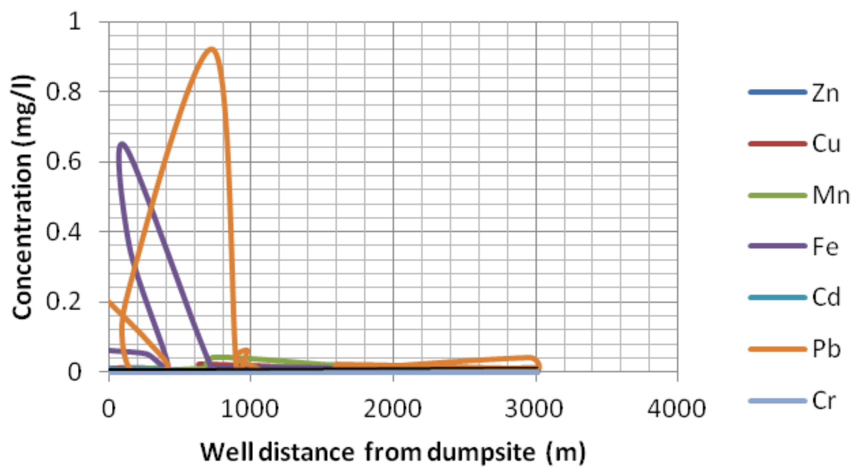

Figure 7. Well distances and heavy metals concentration of groundwater.

and industrial wastes. Groundwater flows from points of higher pressure gradient to a point of lower pressure gradient. The flow directions are north-south, north-west and south-east. Areas of high groundwater potentials are where the gradient is enhancing the flow direction of groundwater. The two extremes that describe the pH of studied water samples are 4.04 and 8.05, indicating slightly acidic to weakly basic groundwater. The regression model for the line of best fit TDS = 29.71 EC - 47.9 shows that it is possible to estimate TDS of the water measured values of EC, and about 72% in the variation of the TDS was associated with The EC of the groundwater.

There exist a moderate number of heavy metal pollutants exceeding the guideline level for water supply. Significant concentration of Fe in water samples are only at locations 1, 3 and 4. Cd concentrations in groundwater of the study area are mostly below the detectable level, except at location 14 where a concentration of 0.01 mg/l is recorded. Pb concentrations above the safe limit were measured in groundwater samples at locations 1, 5, 7, 8, 14 and 16. Among the measured heavy metals, only Pb and Fe show elevated concentration of 0.6 and 0.9 mg/l respectively, at a distance less than 1000 m.

This study concludes that wells for domestic needs be located at least, 1500 m away from the landfill site. For wells located at a distance less than 1000 m, the landfill site can have a major impact on the waters from them. In order to authenticate these findings, more detailed study on groundwater quality in and around the landfill site will be necessary. In addition groundwater pollution monitoring programme for quality status in the vicinity of the landfill is suggested.