DOI: https://dx.doi.org/10.4314/gjpas.v30i4.6

GLOBAL JOURNAL OF PURE AND APPLIED SCIENCES VOL. 30, 2024: 471-487
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AN APPRAISAL OF THE IMPACT OF LEACHATES FROM A WASTE DUMPSITE ON COASTAL SOILS AND GROUNDWATER SYSTEM OF THE METROPOLITAN AREA OF LAGOS, SOUTHWESTERN NIGERIA

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(Received 22 August 2024; Revision Accepted 2 September 2024)

ABSTRACT

Open dump being the common waste disposal practice in most of the urban centres has posed serious challenges to groundwater quality especially within its vicinity. This study assessed the impact of solid waste disposal on the quality of groundwater and soils in Oke-Odo area of Metropolitan Lagos, Nigeria. Field physicochemical parameters such as pH, electrical conductivity (EC), total dissolved solids (TDS) and temperature were measured using PC Testre Model 35. A total of 36 water samples, two leachate samples and 15 soil samples were analyzed for their major ions and trace metal components using titration and Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) methods. Results revealed a decrease in concentrations of trace and major elements with respect to their distance from the waste dumpsite. A decrease in concentrations of Fe was observed with distances from the dumpsite with values ranging from 12.6 to 0.03mg/l and 4.3 to 0.03mg/l for samples within 500 m and 500-1,500 m, respectively. With exception of a few locations having higher concentrations of Fe, Al, Br, Cu, Mn and Pb, the groundwater sources in the study area are chemically potable with respect to their chemical compositions and generally conform to the World Health Organization and the Nigerian Standard for drinking Water Quality standards for drinking water; and thus, fit for domestic purposes. Sodium adsorption ratio ranges between 0.82 and 5.80 %, indicating low sodium and medium to high salinity hazards. This implies suitability of the water for irrigation purpose. The leachate from the active part of the waste dumpsite showed high concentrations of heavy metals such as Pb (4 mg/l), Cd (0.7 mg/l), Zn (6.54 mg/l) and Cu (3.57 mg/l), which indicates a potential environmental risk. The absence of these metals in the groundwater can be attributed to the attenuating role of the soil above the water table as confirmed by higher concentration of the measured trace metals in comparison to the control sites, with values ranging from 280 to 636 mg/l for Pb, 2 to 9.9 mg/l for Cd, 1041 to 10,000 mg/l for Zn and 102 to 1,307 mg/l for Cu. A total of 66.6 % of soil samples havevery high degree of contamination while 33.3% is considerably contaminated. Hydrochemical characterization of the water revealed predominant Na-K-Cl end-member water type and Ca-Mg-Cl water type which could be attributed to the influence of leachate from the waste dumpsite and possible contribution of seawater from the adjoining lagoons and cation exchange process. This study has revealed that soils and groundwater quality within the vicinity of Oke-Odo dumpsite has been impacted minimally.

KEYWORDS: Groundwater, dumpsite, leachate, soils, quality, hydrochemistry.

INTRODUCTION

The quest for improvement in the standard of living especially in the developing nations have led to infrastructure development, increased social amenities and improved healthcare delivery system. These have contributed to increased human population (Nyong, 2024). One of the negative effects of population explosion and economic development is the generation of copious wastes of varied kinds from households, agricultural activities, industries, health facilities and even military installations, etc.

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The management of these wastes have posed great concern as poor funding amongst other factors have resulted to improper design and poor waste management techniques (Ugbaja et al., 2021). Recognizing the link between human actions and pollution and understanding the importance of safeguarding human health have led to early water quality regulations and monitoring techniques (USEPA, 2007, Ehimentan et al., 2024).

Safe and potable water is an essential prerequisite for human survival. However, fresh water quality and availability remains a very critical environmental issue. Of all sources of freshwater on earth, groundwater constitutes over 90 % of the world's readily available freshwater resources (Boswinkel, 2000), with the remaining 10 % in lakes, reservoirs, rivers and wetlands. This therefore makes groundwater an important valuable natural resource for reliable and economic provision of potable water supply in both the urban and rural environments. It thus plays a fundamental role in domestic, industrial and agricultural water demand. Furthermore, groundwater has an edge over surface water because of the susceptibility of the latter to contamination due to its location. In spite of all its advantages, the contamination of groundwater through various means such as anthropogenic and natural processes including salt water intrusion, seepage from underground storage tanks, oil wells and septic tanks still remains a highly topical issue.

Threats to groundwater from unlined and uncontrolled landfills exist in many parts of the world, particularly in the low income countries where agricultural and industrial wastes are co-disposed with municipal waste and no provision of properly engineered landfill exists.he fast expansion of urban, agricultural and industrial activities spurred by rapid population growth and the change in consumer habits have produced vast amounts of solid wastes. Irrespective of the type of solid wastes, most urban wastes are degradable which aid the rate of leachate formation and migration compared to non-biodegradable wastes that can last for many years without any sign of decomposition. Leachate production is aided by the release of the initial water contained in the dumped waste and rainwater infiltrating through the waste deposit which decomposes some elements in the waste. This liquid containing innumerable organic and inorganic compounds (leachate) accumulates at the bottom of the landfill and infiltrates through the soil. Since soil is the primary recipient of these solid wastes of various sources and composition, the contamination of soils is also an important factor for consideration. In the literatures, it is well explained that municipal wastes increase the nitrogen, pH, cation exchange capacity, percentage base saturation and organic matter of the receiving soils as well as heavy metal concentrations in the soil which may have harmful effects on the soils, crop and human health (Smith *et al*., 1996; Nyle and Ray, 1999; Okoronkwo *et al*., 2006). Also, the direct use of dumpsites for cultivating vegetables and the on-farm use of compost sourced from the dumpsites are potentially harmful to the health and well-being of the populace. Areas near landfills have a greater possibility of groundwater and soil contamination because of the potential pollution source of leachate originating from the nearby site. The rate of groundwater contamination depends on the hydraulic gradient and transmissivity of the aquifer, the porosity and permeability of the soil, as well as the type and concentration of the pollutants in the source area.

With emphasis on the above background, the assessment presented in this study was tailored towards an appraisal of the possible impacts of Oke-Odo dumpsite on the groundwater and soil within the vicinity and to examine the concentrations and spatial variation of physico-chemical parameters, major ions and heavy metals as well as the suitability of the groundwater for domestic and industrial purposes.

Location, site characteristics and geological setting of the study area

The area under consideration is in Oke-Odo Agbado Local Council Development Area (LCDA), Alimosho Local Government Area of Lagos State, Southwestern Nigeria. The studied dumpsite is situated in the north-western part of Lagos metropolis; along the Lagos-Abeokuta expressway (Fig. 1) between Ile-Epo and Abule-Egba. The area lies between longitudes 3°17′E and 3°19′E and latitudes 6°37′N and 6°39′N.

The studied dumpsite has been in existence since 1983. It covers an approximate area of 10.5 hectares. This dumpsite is a non-engineered open pit which was originally a lateritic borrow-pit. It is fenced round to avoid waste encroachment into the Lagos-Abeokuta expressway and nearby residential buildings. The dumpsite can best be categorized into two groups: the active site and the inactive site (Fig. 2). Although the Oke-Odo dumpsite is no longer operational by the Lagos State Waste Management Authority (LAWMA) but a fraction of the site is still receiving waste probably from the people living close to this site and also waste produced from the Ile-Epo market, which is about 20 m away. Record from Waste Disposal Board (LWDB2006) indicates that the site received approximately 95,000 tons of waste per day. The waste is estimated to contain 65 % domestic waste and 35 % industrial/commercial waste.

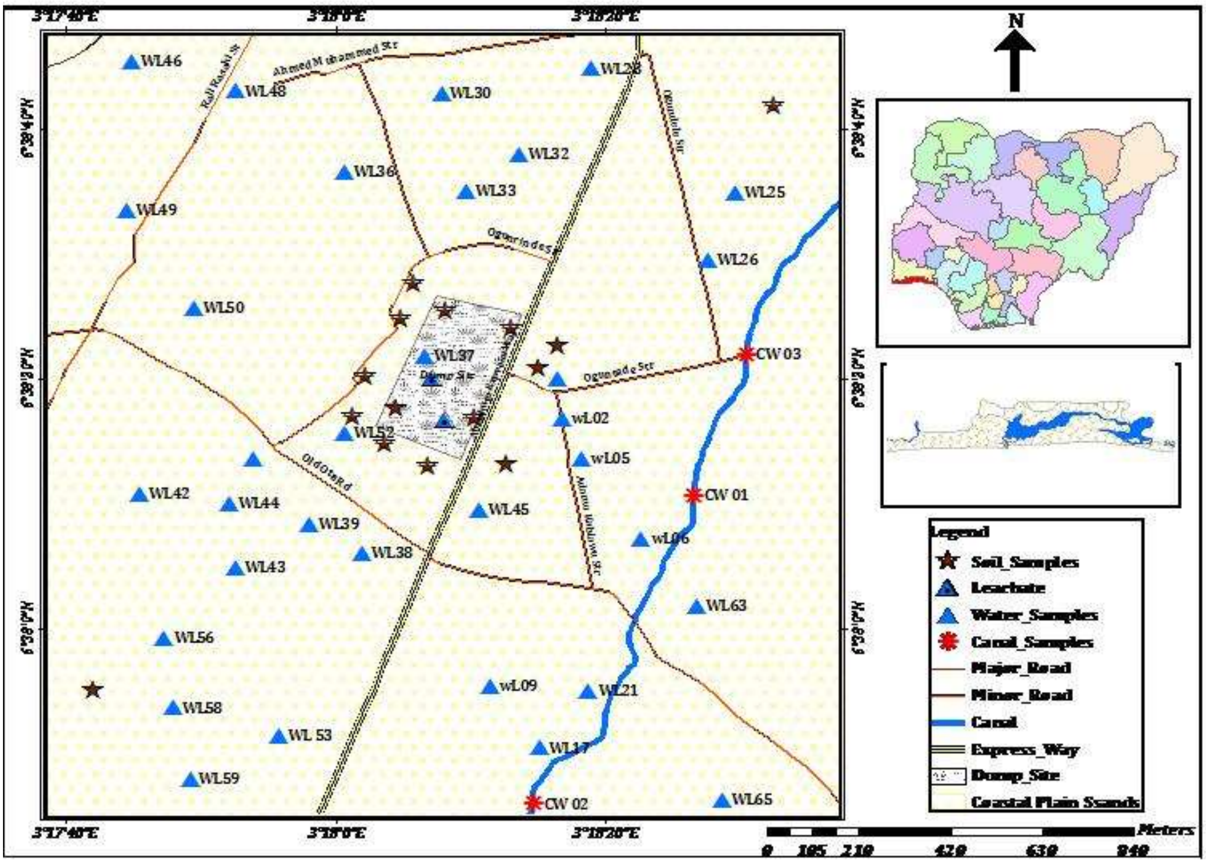


Figure 1: Location and geological setting of the study area including sampling points (Modified from the Geological Map of Nigeria, NGSA 2007). The coastal plain sand legend is not visible enough!

The area is located on an undulating topography with elevations ranging between 24 and 64 m above sea level and it is well drained by network of streams and rivers. The climate is composed of the wet equatorial type with alternating wet and dry seasons. The wet season dominates and spans from April to November; while the dry season begins from December and ends in March. The peaks of rainfall occur in July and September/October, and they are often characterized by floods, which effects are usually aggravated by high water level in this area. Studies show that landfills in wet regions decompose waste at faster rates than areas with dry, arid climates (Kjeldsen *et al.*, 2002).

Figure 2: Active (A) and inactive (B) parts of a dumpsite at Oke-Odo, Lagos State

The amount of precipitation that the landfill receives determines the quantity of leachate that will be created. Additional precipitation raises the water table, thus allow direct interaction between the leachate and groundwater. The vegetation is described as evergreen but most of the vegetation has given way to rapid urbanization in the study area.

Geologically, the area lies solely within the Dahomey Basin which is also called the Keta Basin. The Dahomey Basin was developed in the Mesozoic era (Jurassic – Cretaceous) as the African and South American lithospheric plates separated (Burke *et al*., 1971). According to Kogbe (1975), the first sedimentation in the basin was characterized by a major marine transgression in the southwestern part of Nigeria during the Maastricthtian. The progressive subsidence of the Dahomey Basin led to the accumulation of over 2,000 m thick sediments from Maastrichtian to Recent as revealed by Afowo-1 well situated off the coast of Badagry (Fayose, 1970). Several workers have discussed the classification of these sediments into various lithologic formations amongst which are Jones and Hockey (1964), and Adegoke and Omatsola (1981), as summarised in Fig. 3. The study area falls within the Coastal Plain Sands which is overlain by the Quarternary alluvium.

Hydrogeologically, Alabi *et al*. (2010) identified four major aquiferous units in Lagos metropolis. The first aquifer extends from the ground level to roughly 12 m below the ground surface. It consists of the Quaternary sediments which are made up of lithoral, lagoonal and alluvial deposit with parts of the Coastal Plain Sands. This upper aquifer is of minor importance for large water supply purposes because it is prone to contamination due to its limited depth and unconfined nature. The second aquifer is encountered between 20 and 100 m below sea level. It constitutes the tertiary sediments made up of shale and clay with intercalations of fine sands and limestone. The fissility and laminations of shale as well as limestone solution cavities facilitate transmission channels for the ground water. The third aquifer is encountered at a depth ranging from 130-160m below sea level. The fourth aquifer is located at an elevation of approximately 450 m below the sea level. It is separated from the third aquifer by a rather thick layer of shale of the Ewekoro Formation, hence only few boreholes tap from this aquifer (Jones and Hocky, 1964). With reference to the boreholes and wells sampled, it can be concluded that the hydrogeology of the study area falls within the first and the second aquifers described above with water levels ranging between 1.14 and 26.86 m.

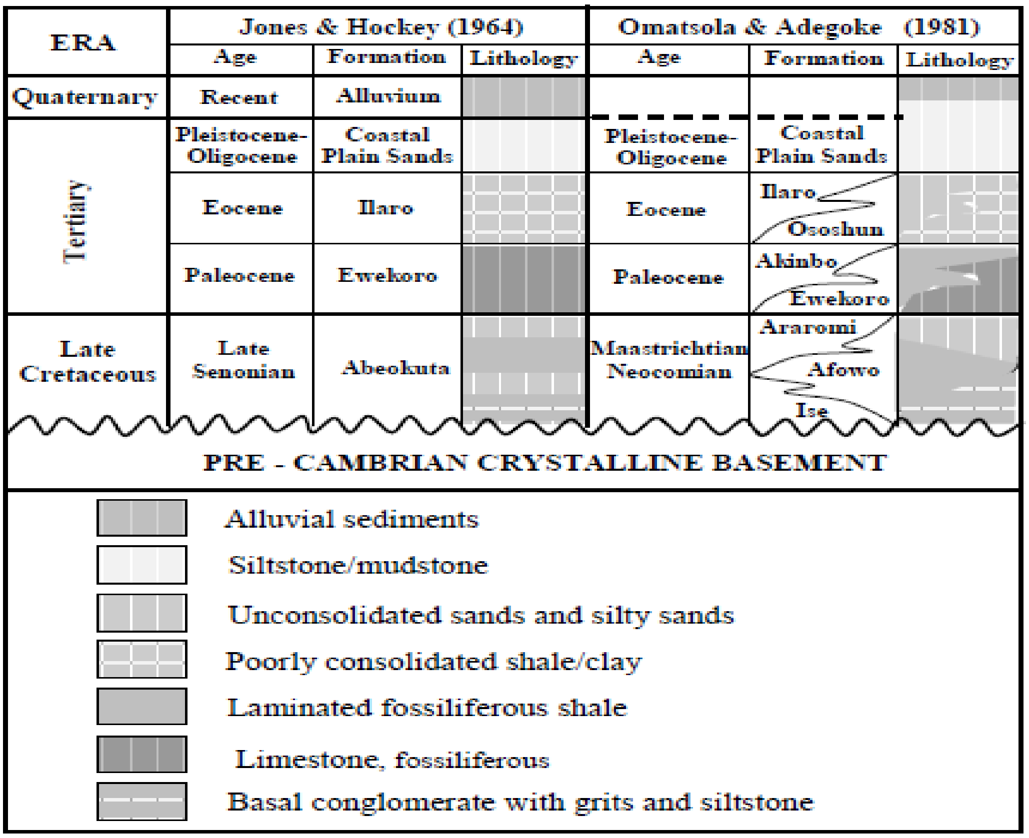


Figure 3: Regional geology and stratigraphic profile of eastern part of Dahomey Basin (Adopted from Nton *et al.,* 2009).

METHODOLOGY

In an effort to study the impact of Oke-Odo waste dumpsite on groundwater and soil quality status, 53 sampling sites were selected within 0.5 and 1.5 km radius of the dumpsite. The samples obtained include two leachate samples, thirty 36 water samples and 15 soil samples. The leachate samples were obtained from the active and inactive parts of the waste dumpsite. However, since the dumpsite was not equipped with a leachate collector, the leachate was sampled randomly at the base of the dumpsite from three different locations at each part and mixed together to obtain a more representative sample. The water samples were collected from shallow hand-dug wells and boreholes. The water was allowed to run for few minutes to avoid possible contamination from the pipe materials. Representative samples were collected in 60 and 120 ml containers after the sample bottles have been rinsed properly using the sampled water to avoid contamination. The samples collected for heavy metals were preserved by the addition of concentrated HNO_3 with the aim of adjusting the pH of the samples to less than 2 and to prevent loss of metals by absorption and precipitation prior to hydrochemical analyses. All the water samples were further preserved in the refrigerator at a temperature of 4 ºC to prevent or reduce change in water quality. Thirteen (13) soil samples were collected from the dumpsite and within 5 m radius of the site at a depth of 0-5 m using hand auger in four cardinal directions with reference to the dumpsite while two samples were obtained from the north east and south western part of the study area at a distance of 750 and 920 m, respectively, from the dumpsite. These two samples served as a control. The soil samples were air dried for two weeks. This was done to obtain reliable results as some soils/sediments undergo irreversible changes when sun dried or oven dried at a temperature of 105-110 ºC, according to British Standard (BS 1377, 1975). Dried samples were then disaggregated using a porcelain mortar and pestle and sieved to obtain the clay sized fraction (<63 µm) for geochemical analyses.

Parameters such as temperature, pH and electrical conductivity (EC) were measured *in situ* using PC Testre Model 35 while the total dissolved solids (TDS) were estimated from the EC values obtained. The cations and trace metal analyses for the groundwater and soils were carried out at Acme analytical laboratory, Canada, using Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) while the major anions such as HNO_3^-, SO_4^{2-}, Cl^-, PO_4^- and HCO_3^- were analyzed using titration method. Furthermore, certain indices such as total hardness (TH) and sodium absorption ratio (SAR) were estimated from the milli-equivalent values of the chemical analyses results involved in respect to the suitability of the water for domestic and agricultural uses. In addition, the major chemical parameters were subjected to hydrochemical plots including cross plots, Piper and Chadha diagrams while the complete data set were subjected to correlation and factor analyses to highlight the possible evolution of the contaminants in the water.

RESULTS AND DISCUSSION

Leachate

The physicochemical parameters of the leachate samples collected from Oke-Odo dumpsite are presented in Table 1. The pH of leachate from the active part of the dumpsite gives a value of 5.1. The inactive part has a pH of 8.1 which is at par with others reported in the literature (Ogundiran and Afolabi, 2008, Aderemi *et al*., 2011). The pH of the inactive site is in agreement with the postulate that the pH of leachate increases with landfill age (Futta *et al*., 1997). The deviation from this observed in the active site is probably due to the fact that the dumpsite is undergoing different phases of degradation. The acidic nature of this leachate can be attributed to the production of carboxylic acid as the waste decomposes and this might likely be an indication that the active site of the dumpsite is undergoing the anaerobic acid phase of degradation as proposed by Barlaz *et al*. (1990) and Kjeldsen *et al*. (2002).

The high values of EC (6800 µScm-^{1}) and TDS (5100 mgl^{-1}) were observed in leachate from the active part of the waste dump, this can be attributed to the presence of inorganic material in the sample and also the fresh release of ions from the waste.

The leachate from the active site contains high concentration of major elements such as Na^+ (234 mg/l), Ca^{2+} (263.7 mg/l), HCO_3^- (213.5 mg/l) and Cl^- (2,061 mg/l) compared with those from the inactive site (223 mg/l for Na^+, 148.7 mg/l for Ca^{2+}, 61 mg/l for HCO_3^- and 756 mg/l for Cl^-) with exceptions of Mg^{2+} and K^+ which are higher in leachate from the inactive site. Nitrate concentrations of 1.072 mg/l and 0.349 mg/l were also obtained in leachate from Oke-Odo waste dumpsite.

The result of the heavy metal investigation of leachate from Oke-Odo waste dumpsite shows trace metals occurring in order of Fe>Zn>Pb>Cu>Cd>Ni>Cr.

Table 1: Physicochemical characteristics of leachate from Oke-Odo dumpsite (mg/l)

Parameters	Active site	Inactive site
Ca^{2+}	263.7	148.7
Mg^{2+}	50	63
Na^{+}	234	223
K^{+}	462	722
HCO_3^-	213.5	61
Cl^-	2061	756
$SO4^{2-}$	0.675	0.116
NO_3^-	1.072	0.349
As	0.3	0.3
Pb	4	4
Cd	0.7	0.7
Cr	0.3	0.3
Ni	0.3	0.3
Zn	6.543	0.369
Cu	3.565	0.119
Fe	11.479	10
Al	5.33	0.708
Mn	1.855	1.223
pH	5.1	8.1
Temp	29.8	29.1
EC	6800	2900
TDS	5100	2175

The high level of Fe (11.479 mg/l) in the leachate sample indicates that Fe and steel scraps are mostly dumped in the landfill. The concentration of Zn (6.543 mg/l) in the leachate shows that the dumpsite receives waste from batteries and fluorescent lamps. Concentrations of Pb (4 mg/l) and Cd (0.7 mg/l) in the leachate could be attributed to the disposal of Pb batteries, chemicals for photographic processing, Pb-based paints and pipes at the landfill site (Moturi *et al.,* 2004; Mor *et al*., 2005). The higher concentration of metals such as Fe, Cu, and Zn in leachate from the active site is an indication that the active site poses an environmental health risk than the inactive site. This agrees with an earlier work done by Ogundiran and Afolabi (2008).

A comparison of the Oke-Odo dumpsite was done with that of global landfills reported in the literature such as Cedar Hill in USA (Hovarth, 1998), El-Akader in Jordan (Abu-Rukah and Al-kafahi, 2001), Olusosun, Nigeria (Ogundiran and Afolabi, 2008), and Mtoni, Dar es Salaam, Tanzania (Riziki, 2010**),** as shown in Table 2. This was aimed at assessing the possible environmental/health risk posed by the dumpsite. The leachate from Oke-Odo dumpsite is acidic in nature with potential effect on the environment and neighbouring groundwater and it is in close relation to the value obtained from Cedar Hills landfill in the USA. The chemical parameters used in this study were found to be higher compared with other landfills with the exception of Ni, Cr and Zn. This may be due to variation in the waste composition across the sites, the rate of rainfall index and the age of the landfill. The Oke-Odo dumpsite showed very high concentrations of these heavy metals in comparison with Olusosun dumpsite in Lagos, Nigeria. This is an indication that the waste dumpsite under investigation has a higher contamination risk than the Olusosun dumpsite which is in the same locality as the studied dumpsite.

The concentrations of Pb , Cd and Cu from Oke-Odo waste dumpsite are higher compared to those obtained from Cedar Hills in USA, El-Akader in Jordan, Olusosun in Nigeria and Mtoni, Dar es Salaam in Tanzania (Hovarth, 1988; Abu-Rukah and Al-Kafahi, 2001; Ogundiran and Afolabi, 2008; Riziki, 2010) as shown in Table 2, indicating that the active site could be a possible source of these metal poisoning if not controlled or treated, since the metals are not degradable.

Table 2: Comparison of heavy metals in leachate from the active part of Oke-Odo dumpsite with that of other dormant sites

Parameters	**El-Akader, Jordan** [a]	**Cedar Hills, USA** [b]	**Mtoni, Dar es Salaam, Tanzania**[c]	**Olusosun, Nigeria** [d]	**Oke-Odo, Nigeria** [e]
pH	7.79	5.4	8.9	8.1	5.1
Pb	0.19	1.4	0.94	0.11	4
Cd	0.012	ND	0.04	0.001	0.7
Ni	18	1.2	1.07	0.07	0.3
Cr	ND	10.5	4.15	0.06	0.3
Zn	95	155	NA	0.264	6.543
Cu	0.21	1.3	NA	0.2	3.565

[a] Abu-Rukah and Al-Kafahi (2001), [b] Hovarth (1998), [c] Riziki (2010), [d] Ogundiran and Afolabi (2008), [e] This study; NA: Not available, ND: Not detectable. All values in mg/l, except pH.

Water

The physicochemical parameters of the sampled water presented in Table 3 show some differences in water sampled within 500 and 500-1,500 m radius from the waste dumpsite. The temperature of the groundwater varied from 27.0 to 30.1 °C for samples within 500 m while samples within 500-1,500 m had temperature variation of 27.2 to 31.7 °C. Samples within 500 m had pH ranging from 4.5 to 8.0, while samples within 500-1500 m had pH values of 5.6-8.3. The pH values at some locations (WL5, WL37, WL38, WL39, WL40, WL 58 and WL 59) are above the recommended World Health Organization (WHO) and Nigerian Standard for Drinking Water Quality (NSWQ) standards of 6.5-9.5. This is possibly an indication that the impact of leachate cannot be ruled out. One major implication of this is the corrosion of plumbing materials observed in locations WL38 and WL40. For samples within 500 m, EC varies from 300 to 6,900 µS/cm with corresponding estimated TDS of 225 to 5,175 mg/l, while for samples within 500-1500 m, EC varies from 100-2,200 µS/cm, with corresponding TDS of 75-1,650 mg/l. Olaniya and Saxena (1977) reported that groundwater pollution from refuse in the vicinity of the dumping sites can be detectable through increased TDS concentration in water. The high concentrations of TDS decrease the potability and may cause gastro-intestinal irritation in human and may also have laxative effect particularly upon transits (WHO, 1997). Total hardness (TH) had values ranging between 7.68-136.5 for samples within 500 m and 4.85-374.1 for samples within 500-1,500 m. Furthermore, the SAR for samples within 500 m range between 0.82-5.80, while samples between 500-1,500 m had values ranging between 0.46-5.34.

Table 4 summarizes the measured hydrochemical data for the major ions and the trace metals along with the WHO (2006) and NSWQ (2007). From the table, the trend for cations in the groundwater samples within 500 m is Na>K>Ca>Mg, while the anions showed the trend of $Cl>HCO_3>NO_3>SO_4>PO_4$. Samples falling between 500 to 1,500 m radius from the site show concentration trend of Ca>Na>K>Mg for the cations and $Cl>HCO_3>PO_4>NO_3>SO_4$ for the anions. In an attempt to assess the hydrochemical characteristics of the groundwater from the study area in relation to their sources, certain plots of the major ions were evaluated. A plot of Ca+Mg against Na+K (Fig. 2a) shows that samples within 500-1,500 m distance from the dumpsite have relatively higher values of Ca+Mg than samples within 500 m radius but Na+K is higher in samples within 500 m distance from the site. This suggests the contribution of leachate to the origin of Na+K and this is evident by the higher values of these ions in the leachate sample. A similar trend is seen in the case of HCO_3 versus Na+K (Fig. 2b), where higher values of Na+K and bicarbonate are observed in wells within 500 m distance from the site. High K in groundwater is an indication of leachate percolation as reported by Loizidou and Kapetanios (1993) and Aderemi *et al*. (2011).

The foregoing inferences on the impact of leachate on the groundwater is supported by the correlation analysis. Correlation analysis is a preliminary descriptive technique used to estimate the degree of association among the variables determined. Correlation matrix between the major ions is shown in Table 5. A very strong correlation between Ca and Mg (correlation coefficient, r, = 0.809) is an indication of a great contribution from the lithology of the area (geogenic sources). Also, Na and K correlated positively well having a value of (r = 0.813) which agrees with the earlier mentioned influence of leachate to the origin of these ions in the water. The strong correlation between Na and Cl^- (r = 0.868) in the system further supports the possible impact of the dumpsite on the chemistry of the water. However, the strong correlation between K and Mg (r = 0.979) is an indication that the geogenic influence cannot be overruled.

Table 3: Physical parameters of sampled water

Sample ID	Locality	Temp (°C)	pH	EC (µS/cm)	TDS (mg/l)	TH	SAR	Dist from dumpsite (m)
Samples within 500m from the site								
WL 1	Fire service	27	7.6	800	600	54.62	5.2173	135.83
WL 2	Abeokuta Expreeway	29.5	6.9	500	375	37.58	2.4757	168.95
WL 5	T.K day care center	27.9	6.2	700	525	29.62	3.1881	278.25
WL 32	God's Favour school	28	8	300	225	63.88	1.3757	400.49
WL 33	Katangua	28.4	7.8	400	300	7.675	1.1018	284.11
WL 36	Church road	28.7	7.6	700	525	17.89	0.8173	449.87
WL 37	Dump site borehole	30.9	4.7	6900	5175	26.99	5.8021	1
WL 38	Oduroye	28.7	4.5	500	375	16.32	1.5696	337.86
WL 39	Oduroye	30.1	5.6	400	300	19.39	1.4095	329.59
WL 40	Fashoba	28.2	5.7	500	375	136.5	1.8618	332.42
WL 45	K & S mount Sinai	29.5	6.9	1200	900	59.9	3.2457	197.97
WL 52	Obitok's medical center	27.4	7.2	400	300	9.208	1.4421	8.17
Samples within 500m to 1500m from the site								
WL 6	Chief Olufeko's resident	29.2	6.2	600	450	44.98	2.7463	500.88
WL 9	Irepodun	27.6	7.4	1100	825	374.1	4.2464	1150.66
WL 17	Arigbanla	28.1	7.2	400	300	175.5	3.0449	910.73
WL 21	Ajiboye	28.6	6.3	300	225	43.08	2.9659	749.86
WL 25	Ogundele	27.5	7.5	400	300	58.8	1.8968	643.24
WL 26	Ogundele	27.2	7.2	700	525	4.858	3.6204	517.07
WL 28	Ahmed Mohammed	28	7.3	500	375	100.7	2.205	650.13
WL 30	Osunde	28.1	7.3	900	675	252.7	3.0886	532.49
WL 42	Snumone Giwa	28.1	6.5	100	75	24.21	1.0559	634.82
WL 43	Ifelodun	28.6	6.4	800	600	18.87	2.7474	555.97
WL 44	Mr Balogun's resident	27.7	6.9	600	450	42.38	3.844	696.84
WL 46	Alh Sadiku	28.2	7.2	700	525	33.7	1.7966	986.88
WL 48	Tunde Lawal	27.6	7.5	600	450	10.36	2.1197	764.08
WL 49	Overcommers	28.7	7.5	500	375	84.18	1.2636	773.88
WL 50	Unity Road	29	8	300	225	9	0.4613	516.49
WL 53	Ogunjobi	29.3	8.3	700	525	25.27	3.8092	821.44
WL 56	Oyewo	27.7	7.2	300	225	18.72	1.6461	764.64
WL 58	Church	29.3	5.8	1000	750	69.22	5.2711	898.66
WL 59	Tutuola	31.7	5.6	1100	825	46.51	4.2963	1007.68
WL 63	Power line	28.2	6.8	900	675	113.1	3.9649	702.38
WL 65	Iresi	30.8	6.8	600	450	84.53	4.2625	1147.19
CW1	Canal	30	6.1	1000	750	88.63	3.341	562.16
CW2	Canal	29.4	6.9	1200	900	112.5	4.3469	1394.17
CW3	Canal	29.9	6.7	2200	1650	104.2	5.3388	823.82

Table 4: Summary of hydrochemical results of the major ions and trace metals with WHO and NSWQ standards

	Samples within 500 m radius				Samples within 500-1,500 m radius					
Parameter	**Min**	**Max**	**Aver**	**Stdev**	**Min**	**Max**	**Aver**	**Stdev**	**WHO Standard**	**NSWQ**
Major ion										
Ca	1.57	51.82	11.32	14.05	1.16	131.1	25.77	33.38	200	NS
Mg	0.8	7.51	2.79	1.98	0.35	11.13	3.22	3.09	150	0.2
Na	9.07	121.5	43.12	36.42	3.71	102.1	48.25	26.99	200	200
K	0.42	89.49	18.38	31.69	0.18	26	7.57	7.12	12	NS
HCO_3^-	30.5	106.75	47.02	22.95	15.25	91.5	44.29	17.98	NS	NS
Cl^-	90	1062	313.05	284.64	126	558	304.23	133.85	250	250
SO_4^-	0.009	0.715	0.18	0.35	0.005	0.29	0.09	0.09	250	100
NO_3^-	0.004	1.282	0.65	0.48	0.004	1.71	0.45	0.57	50	50
PO_4^-	0.006	0.083	0.04	0.03	0	1.77	0.33	0.52	NS	NS
Trace metals										
Al	0.015	1.97	0.61567	0.646	0.033	2.962	0.7015	0.94629	NS	0.2
As	0.0005	0.0013	0.00071	0.00031	0.0005	0.0023	0.00075	0.00055	0.01	0.01
Ba	0.01548	0.1689	0.07011	0.05299	0.01253	0.3075	0.07953	0.07107	0.7	0.7
Br	0.035	0.781	0.26142	0.27396	0.023	0.314	0.10904	0.061	0.01	NS
Cd	0.00005	0.00009	0.00006	1.65E-05	0.00005	0.00104	0.00015	0.00021	0.003	0.003
Cr	0.0014	0.0154	0.00452	0.00389	0.0008	0.0162	0.00424	0.0038	0.05	0.05
Cu	0.0013	2.122	0.18415	0.61028	0.0021	0.0451	0.01118	0.01201	2	1
Fe	0.032	12.63	1.38742	3.60229	0.027	4.305	0.57671	1.08784	0.3	0.3
Mn	0.0128	0.301	0.09621	0.08334	0.0033	0.5573	0.16501	0.17217	0.4	0.2
Mo	0.0001	0.0003	0.00012	5.77E-05	0.0001	0.0067	0.00065	0.00144	0.07	NS
Ni	0.0016	0.0068	0.00295	0.00157	0.0007	0.0117	0.00344	0.00275	0.07	0.02
Pb	0.0021	0.0149	0.00624	0.00462	0.0006	0.0724	0.01427	0.01625	0.01	0.01
U	0.00002	0.00074	0.00025	0.00025	0.00002	0.00113	0.00031	0.0003	0.015	NS
Zn	0.0198	1.322	0.15216	0.36882	0.0159	1.007	0.12148	0.21501	5	3

All values in mg/l; NSWQ = Nigerian Standard for Drinking Water Quality; NS = Not Specified

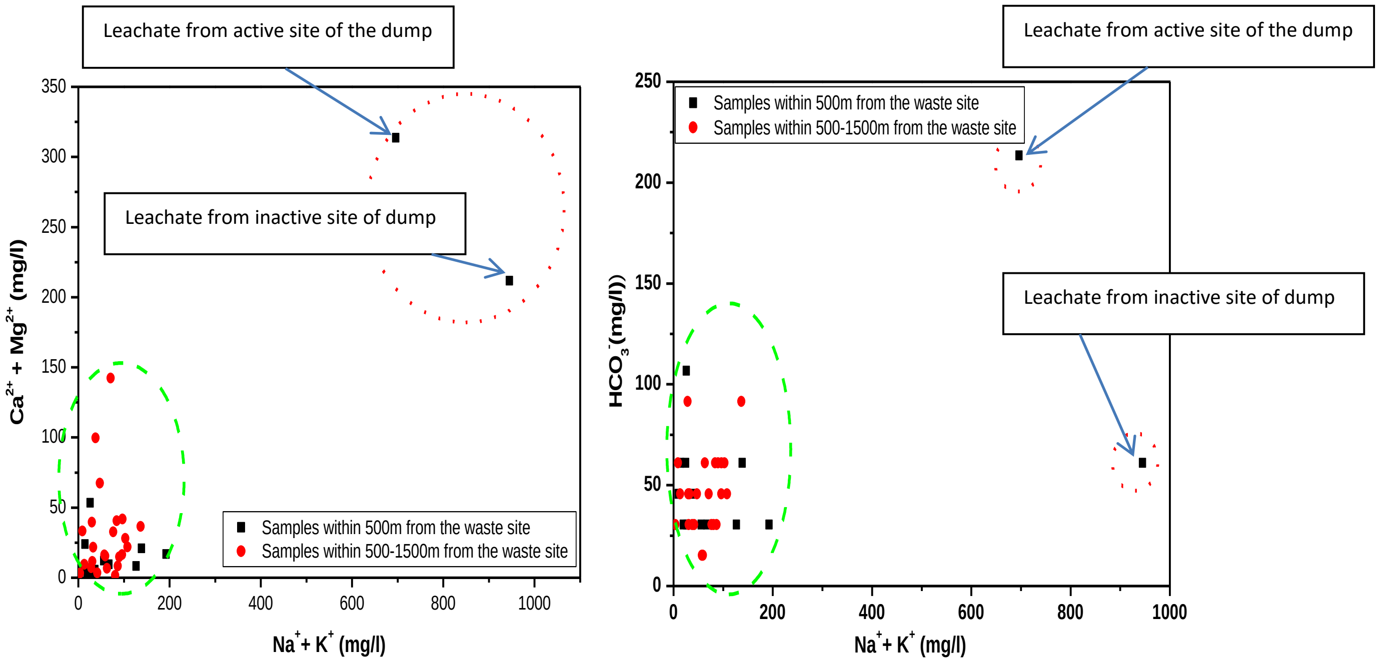


Figure 2: Plots of Ca^{2+}+Mg^{+} against Na+K (a) and HCO_3^- against Na^++K^+ (b) ions in the sampled waters

Table 5: Correlation analysis for major ions in the sampled water

Parameters	Ca	Mg	Na	K	HCO3	Cl	SO4	NO3
Ca	1							
Mg	.809**	1						
Na	.667**	.864**	1					
K	.737**	.979**	.813**	1				
HCO3	.683**	.544**	.503**	.490**	1			
Cl	.665**	.687**	.868**	.615**	.663**	1		
SO4	.614**	.490**	.548**	.393*	.630**	.621**	1	
NO3	.150	.043	.075	.039	.250	.070	.335*	1

* = ?, ** = ?

Furthermore, R-mode factor analysis (Table 6) was employed to find out the underlying controlling variables, known as factors which can explain a large amount of the variance of the analytical data. In other words, factor analysis has the simple objective of revealing the underlying relation that is presumed to exist within a set of multivariate observations (Davis, 1986). The application of factor analysis has proven effective in hydrochemical studies as shown by a host of workers (Seyhan *et al*., 1985; Ruiz *et al*., 1990; Tijani *et al*., 2005; Edet *et al*., 2011). The results of the factor analysis for the major ions revealed a four-factor model that accounted for 93 % of data variance. Factor 1 has an eigenvalue of 5.28 and explains 62.85 % of the variance with high loadings on Ca^+, Mg^{2+}, Na^+, K^+, HCO_3^-, Cl^- and SO_4^{2-}. Clearly, it can be inferred that factor 1 predominantly controls the chemistry of the water sources with high factor loading values of 0.917 to 0.719. Also, the relatively high positive correlation among the variables for factor 1 with exception of the NO_3^- is a reflection of the communality of influence on the water chemistry which could be related to geogenic and anthropogenic sources on the water chemistry. Factor 2 has an eigenvalue of 1.24 and accounts for 15.36 % of the variance in the hydrochemistry with high positive loading on NO_3^- (0.836). This suggests anthropogenic sources to the origin of NO_3^- in the water. Factors 3 and 4 are dormant in the system and they account for only 8.39 % and 5.95 % of the variance in the hydrochemistry.

Table 6: Factor and component analysis for major ions in the sampled water

Parameters	**Component**			
	1	**2**	**3**	**4**
Ca	**.878**			-.327
Mg	**.917**	-.280	.244	
Na	**.898**	-.202		.347
K	**.860**	-.324	.334	-.104
HCO_3^-	**.756**	.322	-.316	-.324
Cl^-	**.865**		-.267	.323
SO_4^{2-}	**.719**	.448	-.282	.116
NO_3^-	.189	**.836**	.494	
%Variance	62.85	15.36	8.39	5.951
Cumulative %	62.854	78.216	86.607	92.89
Eigenvalues	5.28	1.239	0.671	0.476

Water Quality Evaluation and Usability

The quality of water is a function of the physical, chemical and biological parameters and could be subjective since it depends on a particular intended use (Tijani, 1994). Hence, the quality of water is as important as its quantity. Therefore, the presence of harmful substances as well as colour, taste and odour may render the water unfit for domestic, industrial and agricultural purposes. A comparison of the results obtained from the hydrochemical study of the area with standards set by WHO (2006) and NSWQ (2007) were used to determine the potability of the water. Most of the groundwater samples were found to fall within the stipulated limits, implying chemical potability (see Table 4). Ca and Na are within the stipulated groundwater standard by WHO and NSWQ with exception of magnesium whose concentration in all the samples are above the NSWQ standards. Groundwater samples from locations WL01, WL02, WL09, WL44, WL59, WL63 and WL65 display relatively high K concentrations above the WHO and NSWQ standards, and this could be attributed to the influence of leachate percolation. Furthermore, the concentrations of Cl^- C in the groundwater are higher in some locations above the recommended maximum levels set by WHO and NSWQ with the maximum value recorded at the dumpsite borehole (WL37). Although salinity is a component of coastal aquifers, the contribution of leachate to this high Cl^- at some locations closer to the dumpsite cannot be overruled. The concentrations of SO_4^{2-} and NO_3^- are lower in the water samples and are within the acceptable limits of WHO and NSWQ. This could probably be due to SO_4^{2-} reduction and denitrification process around the dumpsite; suggesting an overall minimal influence of leachate on the groundwater. Heavy metals such as, As, Ba, Cd, Cr, Mo, Ni, U, and Zn all fall within the recommended standards of WHO and NSWQ. Furthermore, some trace metals such as Fe, Mn, Pb, Cu and Al showed slightly higher concentrations at locations closer to the waste dumpsite than the recommended standards. This however, indicates less influence of leachate on the groundwater system. Nevertheless, in general with exception of a few locations, the groundwater sources in the study area are potable with respect to their chemical characteristics, although a biological analysis is required to complement the chemical analyses and to make a definite statement on the overall water quality. The suitability of groundwater for irrigation is contingent on the effects of the mineral constituents of the water on both the plant and the soil (Todd, 1980) and also on the local climate and the overall irrigation management (Lloyd and Heathcote, 1985). Hence, certain empirical water quality indices were evaluated from the physical and hydrochemical data to determine the suitability of the sampled water for irrigation purposes. An important irrigation water classification adopted in this study is that of Wilcox (1955) (Fig. 3). This classification scheme encompasses the effect of TDS and SAR. TDS indicates the general nature of water quality or salinity. The primary effect of high EC reduces the osmotic activity of plants and thus interferes with the absorption of water and nutrients from the soil (Belkhiri *et al.,* 2010). When water having high Na content is used for irrigation, the soil becomes saturated with Na which can destroy the soil structure due to dispersion of clay particles. With reference to Table 3 and with exception of locations WL37 and CW3 (dumpsite borehole and canal water), the EC values of the groundwater are below 1,500 µS/cm while the SAR lies between 0.82 and 5.80 meq/l. These values are within the limits of the US Salinity Laboratory diagram, thus indicating low Na and medium to high salinity hazards implying suitability for irrigating certain plants with medium to high salinity tolerance. However, sample from locations WL37 and CW3 have EC value that fall outside the Wilcox diagram, which is an indication of non-suitability for irrigation purposes.

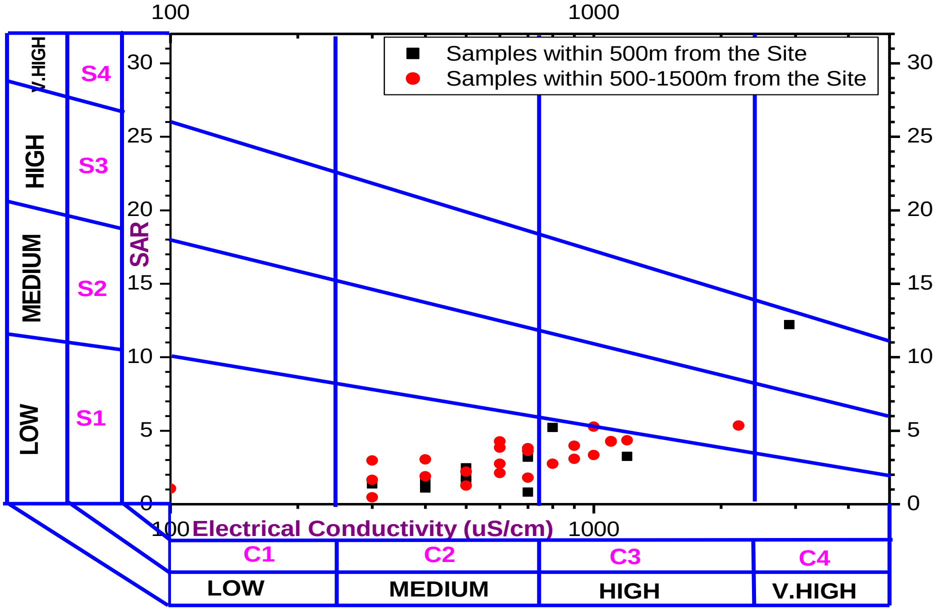


Figure 3: Wilcox's (1955) salinity and sodium hazards diagram of the water samples from the study area

Hydrochemical characterization of the water
The characterization of the water type of groundwater samples from the study area was carried out using the trilinear diagram (Piper, 1944) and Chadha diagram (Chadha, 1999) as shown in Figs. 4 and 5. From the diagrams, the area is dominated by the Na-K-Cl water type which constitutes about 70 % of the water samples. About 30 % of the samples fall within the Ca-Mg-Cl class. A careful look at both diagrams shows that most samples within 500 m radius from the waste dumpsite plots in the vicinity of the Na-K-Cl water composition (Fig. 4) indicating impact from leachate percolation. On the other hand, most of the samples constituting the Ca-Mg-Cl water type are samples outside the 500 m radius from the site. This is suggesting the influence of cation exchange process (Fig. 5) whereby Na is being exchanged for Ca in the aquiferous unit as the water moves away from the dumpsite.

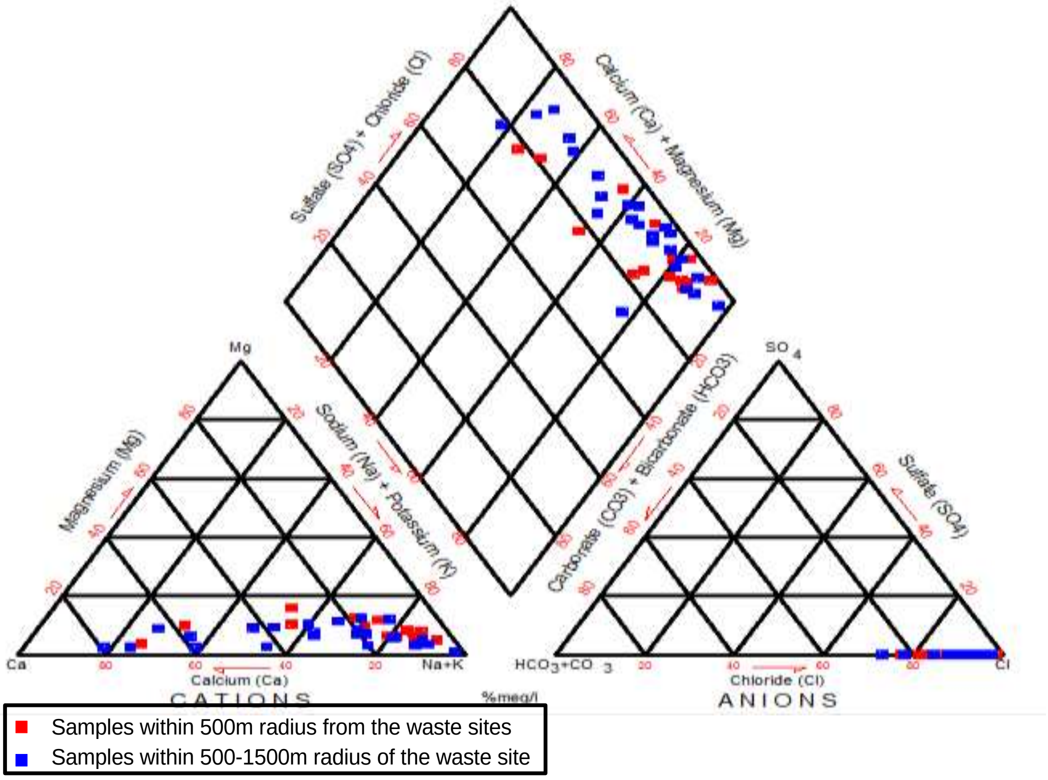
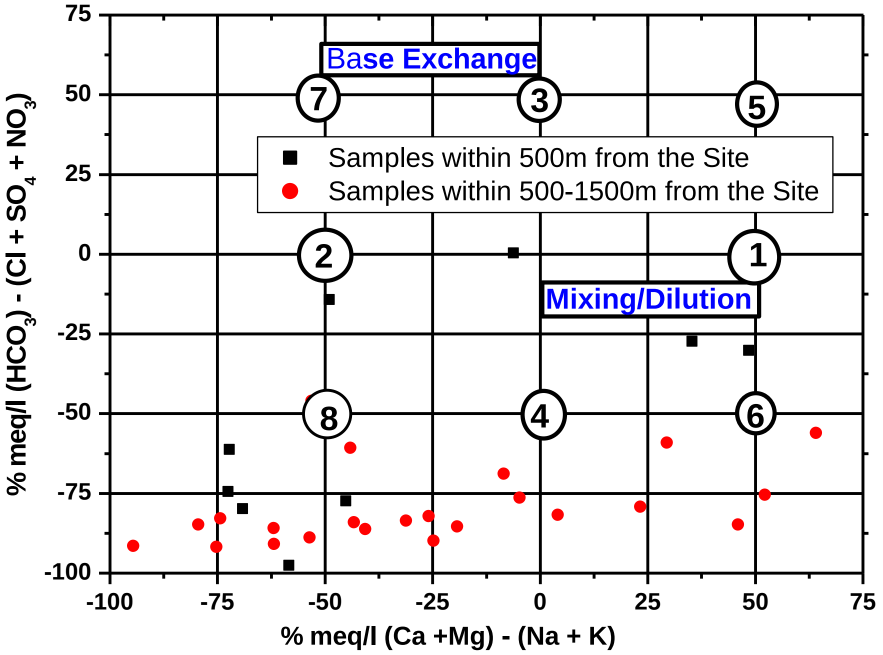


Figure 4: Piper-trilinear plot of the hydrochemical data

Geochemical parameters in soils

Soils are central to the sustainability of our ecosystems, performing essential functions such as nutrient cycling to support plant growth, the attenuation and transformation of potentially toxic compounds and elements and the maintenance of biodiversity. As reported in Ebong *et al*. (2008), leachate from waste dumpsite constitutes a source of heavy metals pollution to both soil and aquatic environments. The geochemical data for surface soils from the study area are summarized in Table 7. The data were compared with surface soils from two control sites (locations SL14 and SL15) obtained from about 750 m and 920 m distance from the waste dumpsite, respectively. This was to provide a better understanding and to show the impact of landfill operations on the natural environment.



Hydrochemical facies/water types

Segment 2-7-3=Na-K-HCO3
Segment 1-3-5=Ca-Mg-HCO3
Segment 1-6-4=Ca-Mg-Cl-SO4
Segment 2-8-4=Na-K-Cl-SO4

Figure 5: Hydrochemical classification based on Chadha diagram

Visual interpretation of individual distribution patterns of trace elements show a significant variation with the control. The concentrations of these metals are higher in soil samples from and within the dumpsite than those obtained from the control sites.

Table 7: Summary of elements in the soils around the dumpsite

Samples within 5m radius from the dumpsite					Control samples			
Parameter	Min	Max	Aver	Stdev	Min	Max	Aver	Stdev
Cu (ppm)	26	1307	331.077	346.917	50	88	69	26.8701
Pb (ppm)	54	10,000	1,871.15	3,616.37	108	193	150.5	60.1041
Zn (ppm)	121	10,000	2,428.92	3,498.96	109	363	236	179.605
Ni (ppm)	16	48	29.3077	12.1545	32	37	34.5	3.53553
Co (ppm)	4	850	113.231	261.635	8	9	8.5	0.70711
Mn (ppm)	330	1,940	687.538	435.422	321	388	354.5	47.3762
As (ppm)	5	8	5.61538	1.1209	5	6	5.5	0.70711
Sr (ppm)	27	283	84.2308	69.0111	40	82	61	29.6985
Cd (ppm)	0.4	12.2	3.70769	3.85324	0.7	1.1	0.9	0.28284
Ba (ppm)	74	853	292.154	200.701	59	157	108	69.2965
V (ppm)	20	138	50.5385	29.3616	46	93	69.5	33.234
Cr (ppm)	52	136	78.1538	24.765	69	80	74.5	7.77817
Fe(%)	1.83	5.18	3.04308	1.01587	2.51	3.58	3.045	0.7566
Ca (%)	0.17	5.95	1.46231	1.66626	0.82	1.72	1.27	0.6364
Mg (%)	0.06	0.63	0.19385	0.16656	0.18	0.19	0.185	0.00707
Al (%)	1.74	11.13	3.83308	2.38152	3.13	8.1	5.615	3.51432
Na (%)	0.05	0.28	0.15308	0.06156	0.07	0.13	0.1	0.04243
K (%)	0.14	0.84	0.34231	0.18217	0.13	0.53	0.33	0.28284

The sequence of metal concentration in the surface soils among the trace metals and major elements are Pb>Zn>Mn>Cu>Ba>Co>Sr>V>Cr>Ni>Cd>As and Al>Ca>Fe>K>Mg>Na, respectively. Trace metals such as Pb, Zn, Cu, Cr, Cd, Co and Ni, which are indicators of contamination in a dumpsite, are showing very high concentration at the dumpsite and around its vicinity than the control samples. The concentrations of lead range from 54 to 10,000 ppm with an average of 1,871 ppm exhibit significant variation with the control sample which has an average concentration of 150.5 ppm. The alarmingly high concentration at locations around the dumpsite can be linked to the discharge from batteries from the mechanic workshop. This result is consistent with that of Adelekan and Abegunde (2011), who investigated the occurrence of heavy metals at automobile mechanic villages in Ibadan and reported concentrations ranging between 18.25 and 15,100 mg/kg in soils. However, the high Zn concentration observed in the soil samples around the dumpsite can be attributed to the automobile spare parts and other metal scrap waste dumped at the site. Co and Ni concentrations in the soils were higher than the control, with the highest concentration recorded in the dumpsite sample. This can be attributed to indiscriminate disposal of waste containing these metals at the dumpsite. This value obtained in this study is higher than the 105-810 mg/kg reported in Awokunmi *et al*. (2010) in soils located within Ikere and Ado-Ekiti, South Western Nigeria. Cr also showed a similar trend. The elevated concentration is ascribed to deposited wastes which contained high concentrations of Cr. As observed by Adelekan and Abegunde (2011), Cr is one of the heavy metals whose concentration in the environment is steadily increasing due to industrial growth, especially the development of metal, chemical and tanning industries.

Contamination factor and contamination degree of the soils

The contamination degree is the sum of the contamination factor of all the elements. The contamination factor is used to classify the level of contamination of metals in the soil samples. The results of the contamination factor and the degree of contamination calculated from the geochemical result of the soil samples from the study area are presented in Tables 8 and 9. From the summary in Table 8, Ni and Cr have average value of contamination factors of 0.45 and 0.93. Hence, they can be classified as having concentration factor of less than 1 (CF>1), indicating low contamination. Mn and As, on the other hand, have average values of 2.88 and 1.40 and are being classified under the 1<CF<3. This implies moderate contamination. Cu, Pb, Zn, Co and Cd all have contamination factors not less than 8 but greater than 90. These metals are classified under 6<CF and it denotes very high contamination factor. Generally, the contamination degree shown in Table 9 reveals that 33.3 % of the soils from the study area are considerably contaminated while 66.6 % are highly contaminated.

Table 8: Summary table for contamination factor of trace metals

Contamination Factor	Aver	Min	Max	Stdev
CF Cu	24.68	2.17	108.92	27.85
CF Pb	91.21	3.00	555.56	189.02
CF Zn	41.09	2.10	192.31	64.05
CF Ni	0.45	0.24	0.73	0.17
CF Co	24.21	0.98	207.32	59.76
CF Mn	2.88	1.44	8.70	1.88
CF As	1.40	1.25	2.00	0.26
CF Cd	8.33	1.00	30.50	9.26
CF Cr	0.93	0.62	1.63	0.28

Table 9: Contamination degree of soils in the study area

Sample ID	Cdeg	Meaning
SL01	575.9378	Very high degree of contamination
SL02	173.8708	Very high degree of contamination
SL03	146.7332	Very high degree of contamination
SL04	58.7074	Very high degree of contamination
SL05	15.50033	Considerable degree of contamination
SL06	29.36979	Considerable degree of contamination
SL07	23.00953	Considerable degree of contamination
SL08	57.14063	Very high degree of contamination
SL09	594.2663	Very high degree of contamination
SL10	84.71274	Very high degree of contamination
SL11	593.9089	Very high degree of contamination
SL12	413.0198	Very high degree of contamination
SL13	106.9192	Very high degree of contamination
SL14	26.18181	Considerable degree of contamination
SL15	28.52507	Considerable degree of contamination

CONCLUSION

The area of investigation is Oke-Odo area of Lagos city and it falls within the Coastal Plain Sands of the eastern Dahomey Basin of southwestern Nigeria. Four aquiferous units have been delineated from the literature but based on the depth of the wells sampled; the area taps from the first and second aquifers only. Groundwater systems have been influenced by infiltration and percolation of leachate from the dumpsite. Hydrochemical assessment of the water and soil samples from Oke-Odo area has been undertaken and this study has revealed a clear difference of the impact of leachate on groundwater systems and the surface soils. The leachate generated from the waste dumpsite has a minimal impact on the groundwater quality in the locality. The soil nature and grain-size distribution underlying the site and its vicinity being predominantly clay and lateritic clay seems to have significantly attenuated most of these contaminants especially heavy metals in the groundwater samples. Hence the soils become the primary recipient of these heavy metals.

From the overall chemical analyses and evaluation of data, the following conclusions can be drawn:

1) The physicochemical characteristics of the leachate from the active part of Oke-Odo waste dumpsite indicate that the leachate is acidic with potential negative effect on the environment and neighbouring groundwater.

2) The active site of the waste dump is a potential source of pollution by ions such as Na, K and Cl^- and heavy metals like Fe, Pb, Cu, Br and Mn; and this impact might aggravate if the present trend of indiscriminate disposal of waste is not controlled.

3) Water samples from the wells within 500 m from the dumpsite were found to have higher concentration with respect to K, Cl^- , Br , Mn , Cu and Fe than those from wells situated farther away, indicating an impact of leachate percolation on groundwater. Although the level of impact is minimal at present, continuous dumping of waste might deteriorate the situation.

4) The sampled water from the area is potable with respect to chemical composition and conforms to the WHO and NSWQ standards for drinking water except in some locations. However, microbial analysis is suggested to complement hydrochemical analysis to better understand groundwater quality in the study area. In terms of irrigation, the groundwater are suitable for irrigation judging from its low SAR with the exceptions of sample locations CW03 and WL37.

5) Based on the hydrochemical evaluation and characterization techniques employed in this study, the sampled waters predominantly represent Na-K-Cl type. This water type has evolved through impact of leachate percolation as typified by samples within 0-500 m distance from the waste dump, with corresponding Ca-Mg-Cl type, which is more represented by samples within 500-1500m distance from the dumpsite.

6) The sampled surface soils within and around the waste dump showed greater concentration in trace metals when compared with the control, indicating great influence from leachate percolation since this soil type interact directly with the leachate and overland flow from around the dumpsite.

7) From the calculated degree of contamination, 33.3 % of the sampled soils showed considerable degree of contamination while 66.6 % was highly contaminated by leachate and direct waste dump activities. This further justified attenuating role played by this soil to minimize metals and ions concentration in the sampled groundwater.

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