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Geoelectrical Imaging and Physicochemical Assessment of Waste Dumpsite: Implications on Groundwater Quality

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The most unregarded cause of water pollution is the inappropriate dumping of wastes and improper treatment of solid wastes. The current research examined the impacts of a solid waste disposal site on water quality of the residential areas bounded by the site by integrating 2-D resistivity imaging, physical, chemical and bacteriological analyses of water samples from twelve hand-dug wells (HdW) and two boreholes (BH) using standard field and laboratory procedures. The results of the 2-D resistivity imaging of the subsurface along four traverses around the refuse dumpsite showed anomalously low resistivity zones, intermediate resistivity zones and high resistivity zones interpreted to be soil or sand saturated with contaminant leachate, rock materials having varying moisture content and composition and rock materials contaminated with dumpsite gases, respectively. The study observed that these contaminants have migrated to the depth of 25 m below the aquifer and over 20 m distance away from the edge of the dumpsite. Apart from nitrate, phosphate and turbidity, all the other physicochemical parameters tested were within the WHO recommended limits. However, the trace metals (Fe, Mn, Cr, Pb and Zn) and the total bacteria count were generally above the recommended limit. Consequent upon the associated health implications due to elevated levels of some of the contaminants, which were attributed mainly to leachate from the dumpsite, the study suggested adequate corrective measures and a programme enlightenment campaign to all end users.

Keywords: heavy metals, leachate, dumpsite, waste disposal, geoelectrical imaging, bacteria count.

Introduction

Inappropriate treatment and disposal of wastes are among the major problems threatening many nations of the world and have led to a high contamination risk of soil, air, groundwater and surface water quality with accompanied adverse effects on human and environmental health. The direct consequence of depositing waste on the earth's surface is that rainwater and melting snow infiltrate through the waste, picking up and carrying dissolved chemical compounds and microorganisms that contaminate soil and underground water (Davis and Cornwell, 2008). Generally, poor accessibility to water is mainly due to an increase in population, rapid expansion of cities and continuous discharge of harmful wastes into streams, rivers and water bodies without any regard for environmental consequences (Longe and Balogun, 2010). Indeed, the leachate resulting from the seepage of rainwater into refuse infiltrates and pollutes the groundwater. The soil and groundwater system can be polluted due to poorly designed waste disposal facilities, leakage from underground storage tanks and agricultural wastes. Soil and groundwater acidification and nitrification have been linked to waste dumps as well as microbial contamination of the soil and groundwater system (Bacud et al., 1994). Pollution of soil may have negative effects on people living on it, roots of plants that penetrate into it, and animals that move around over it. Sia Su (2008) attributed cancer, heart diseases and teratogenic abnormalities to groundwater contamination via leachate from waste dumps.

Municipal landfill leachate comprises 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; Tengrui et al., 2007). The composition of leachate could vary from one part of a landfill to another and, thus, have detrimental effects on the environment (Tricys, 2002). The pollution levels, therefore, depend on its sources (sewage, detergents, industrial effluents and agricultural drainage) and volume. One major risk associated with drinking water sources is the siting of a drinking water system (hand-dug wells and boreholes) close to a refuse dumpsite or landfill. The dumping of human and animal excreta (faeces) in an area is responsible for the enrichment of the soil with bacteria such as total coliform and E. coli, and it is an indication of a poor sanitary situation (Tijani, 2004). In addition, fertilisers and agrochemicals are sometimes wrongly applied and, thus, they percolate down the groundwater. All these often contribute to the inorganic and organic contaminants in the aquifer.

Landfill related studies have been carried out using the 2-D resistivity imaging method by various authors (Olayinka and Olayiwola, 2001; Samsudeen et al., 2006). The use of this method may be attributed to an inherent ability to detect vertical as well as lateral resistivity changes related to variations in fluid content, chemical composition, and contaminant migration. Integrated geophysical methods have led to a better understanding of sites in terms of determining the effects of refuse dumping on the quality of groundwater (Oluwafemi, 2012). Water quality is determined by assessing three classes of attributes, which are biological, chemical, and physical, and there are standards of water quality set for each of these three classes of attributes. The usefulness of groundwater is consequent on the national and international standards for drinking water, which are developed by the Nigerian Environmental Protection Agency (EPA), Nigerian Standard for Drinking Water Quality (NSDWQ) and World Health Organization (WHO). All municipal (public) water supplies must be measured against these standards. Given these standards, stream and groundwater supplies should be of high quality because natural processes are not effective in removing chemical contaminants from groundwater.

The quest for this study is borne out of mind on the poor access to potable water revealed by a long queue of citizens at boreholes within the study area. Improper disposal and unpleasant odour emanating from a waste dump site in the study area have led to the integration of geoelectrical imaging and hydro-physicochemical analysis to examine the effects of solid waste disposal on the groundwater quality under the residentials located around the dumpsite because it is safer to source for good quality water for drinking and other domestic uses for a healthy living.

Materials and Methods

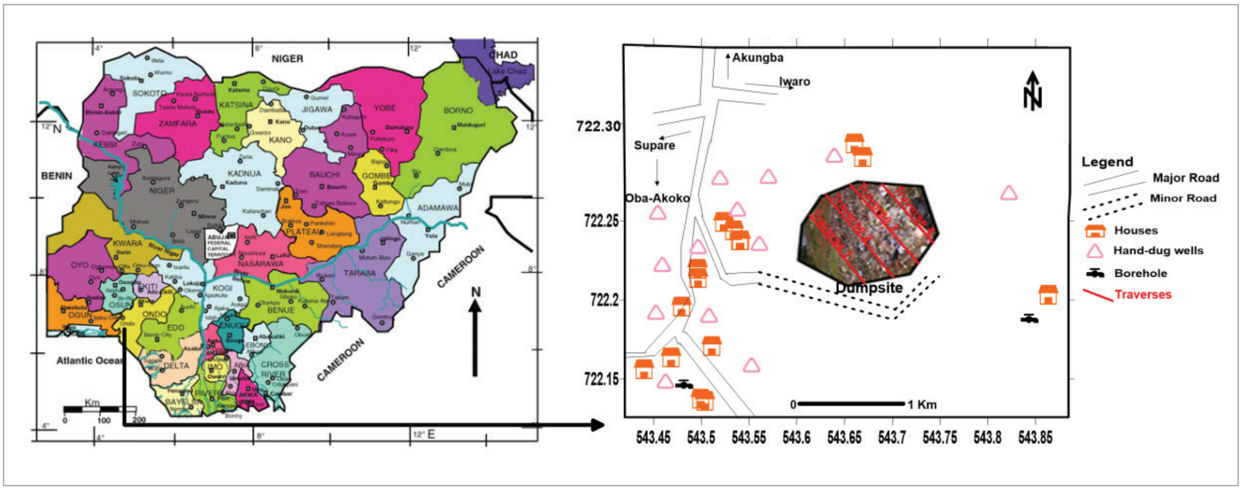
Study area (Geology and Hydrogeology)

The ancient town of Oba-Akoko is located within the North Senatorial district of Ondo State, Nigeria. It lies between latitudes 7° 22.11' N and 7° 22.47' N and longitudes 5° 43.23' E and 5° 43.47' E as shown in Fig. 1. The town is situated in the humid tropical region of Nigeria, characterized by alternating wet and dry seasons with a mean annual rainfall of over 1,500 mm. The area is also characterised with a fairly uniform temperature and high relative humidity (NIMET, 2007). Inhabitants of this town are mainly indigenes of the town and government workers. This restricts their occupation mainly to farming and civil service. Sited within this location is a big waste dumpsite, which covers an area of about 200 to 300 square metres. The dumpsite is an open dumping system, which began over 38 years ago. Indiscriminate and unregulated waste disposal within the site makes it difficult to have an accurate data on the quantity of the waste being disposed. However, not less than 2 trucks of waste are disposed at the site on a daily basis. Waste types dumped on the site are mainly municipal solid wastes. This waste consists of both biodegradable and non-biodegradable materials. Residential buildings are located around the dumpsite at a very close range (Fig. 1). The environment is noted for unpleasant odour emanating from the dumpsite. The area is drained by the River Ajon and the River Aton, which are seasonal. The two rivers dominate the drainage system of the study area, and it is mainly dendritic. It has an approximated elevation of about 357 m.

The study area falls within the Precambrian basement complex rocks of southwestern Nigeria. It is underlain by the migmatite-gneiss-quartzite complex with granite gneiss and grey gneiss being the major rock units as shown in Fig. 2 with a minor amount of porphyritic granite (Rahaman, 1989). Granite gneiss is metamorphosed granite, widely distributed in the study area, and it is of two types; biotite rich gneiss and banded gneiss. Biotite rich gneiss is fine to medium grained, shows strong foliation trending westwards and is usually dark in colour. Banded gneiss shows parallel alignment and alteration. It occurs mostly as hills, boulders and flat lying exposures, which are dark to light grey in colour and porphyroblastic in texture. There are several quartzite intrusions cutting across granite.

Fig. 1

Map of the study area showing (a) Nigeria and (b) sampling sites



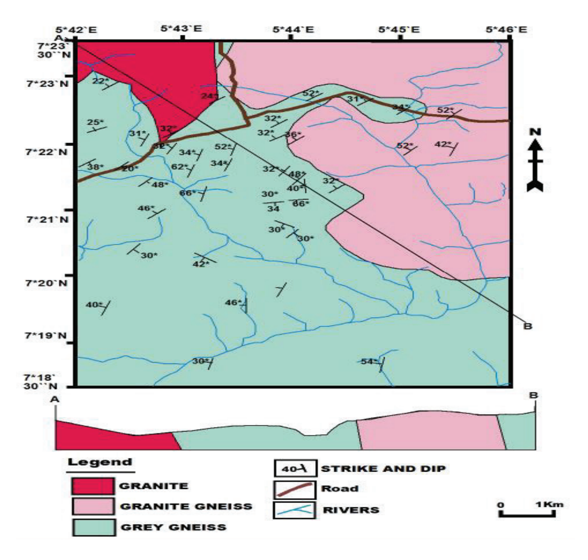
Grey gneiss in the study area varies from light to dark grey. Different textural varieties have been recognised, but the most common type is a medium grained rock with regular and persistent banding of varying thickness. Granite rocks are of the older granite suite. Based on the textural characteristics, there are fine-grained biotite granite and medium to coarse porphyritic biotite-hornblend granite. Migmatite gneiss is the predominant rock unit that underlies the waste dumpsites. Sources of surface water supply to the study area are the River Aton and the River Ajon and their major tributaries. In the basement complex area, groundwater is contained within the weathered and/or fractured/jointed basement columns. The unconfined nature and the near-surface occurrence of the aquifer system makes it vulnerable to surface/near surface pollutants such as leachate from a waste dumpsite.

Two-dimensional (2-D) resistivity imaging

Two-dimensional (2-D) resistivity imaging was carried out with a digital read-out Abem Terrameter SAS 1000C, using dipole-dipole array. Four traverses were occupied, rightly located on the dumpsite parallel to each other. Measurements were made at sequences of increasing offset distances at electrode spacing of 5 m along each traverse oriented in the east-west direction.

Fig. 2

Geological map of the study area



Sampling and sample preparation

Sampling sites were chosen with the aim of collecting water samples that truly represents the entire locations. A global positioning system (GPS) was used at each sample station to measure coordinates of the station and heights above the sea level. Duplicate water samples were collected using pre-cleaned bottles to which a rope was attached in the case of hand-dug wells. At the point of collection, bottles were rinsed for about 3 times with water samples. Each bottle was labelled according to the sampling location. Fourteen representative water samples (12 from different hand-dug wells, HdW 1 – HdW 12, and 2 from boreholes, BH 1 and BH 2) were collected randomly from different locations as presented in Fig. 1. Water levels of the hand-dug wells were measured and the elevation of the water level in each well was determined. The depth of the HdWs varied between 2.22 m and 4.50 m. Samples for anion analyses were unfiltered and unacidified. However, samples for the analysis of dissolved trace elements were filtered through a 0.45-μm cellulose acetate membrane filter (Whatman, Schleicher and Schull FP 30) and acidified with 30 μL of HNO_3 (conc. Suprapure) (Nickson et al., 2005). Samples were transported in an ice-box to the laboratory and later stored in the refrigerator at a temperature of about 4°C prior to the analysis (American Public Health Association (APHA) 2005). Parameters like pH, electrical conductivity (EC), turbidity and temperature were determined in the field using calibrated Hannah pH meter, EC meter, turbidity meter and mercury-bulb thermometer, respectively.

Chemical analysis

The physicochemical parameters observed in this study were determined using the standard methods (APHA, 2005). Chloride and sulphate were determined using Mohr's and turbidimetric methods, respectively. For nitrate and phosphate, the cadmium reduction method and ascorbic acid methods were employed, respectively. Others like total dissolved solids (TDS), total hardness (TH) and all the mineral elements were determined using titration methods. The concentrations of trace metals in water samples were determined after digestion with acid mixture (HCl/HNO_3) with flame atomic absorption spectrophotometer (Alpha 4AAS). The calibration standards were prepared using the metal stock solutions. The bacteriological quality analysis included the determination of total heterotrophic bacteria (THB), total coliform bacteria (TCB) and faecal coliform (FC). The total bacterial count was determined by a pour plate technique and the most probable number (MPN) index techniques following the standard method.

Statistical data analysis

All the data obtained were subjected to statistical analysis; the mean, range, standard deviation, analysis of variance (ANOVA) and t test were calculated.

Quality assurance and quality control

Quality assurance and control of data obtained in this study were evaluated through recovery tests, standard additions and duplicate analyses of data. Selected samples were spiked with a known amount of either $NiCl_2$, $ZnSO_4.7H_2O$, $Cd(NO_3)_2$, or $PbNO_3$ using the standard procedures (APHA, 1998). Blanks were prepared with distilled deionised water. Analyte recovery in spiked samples ranged from 91% to 106%. Detection limits (µg/L) were as follows: Cd – 0.003; Pb – 0.003; Ni – 0.021; and Zn – 0.023.

Results and Discussion

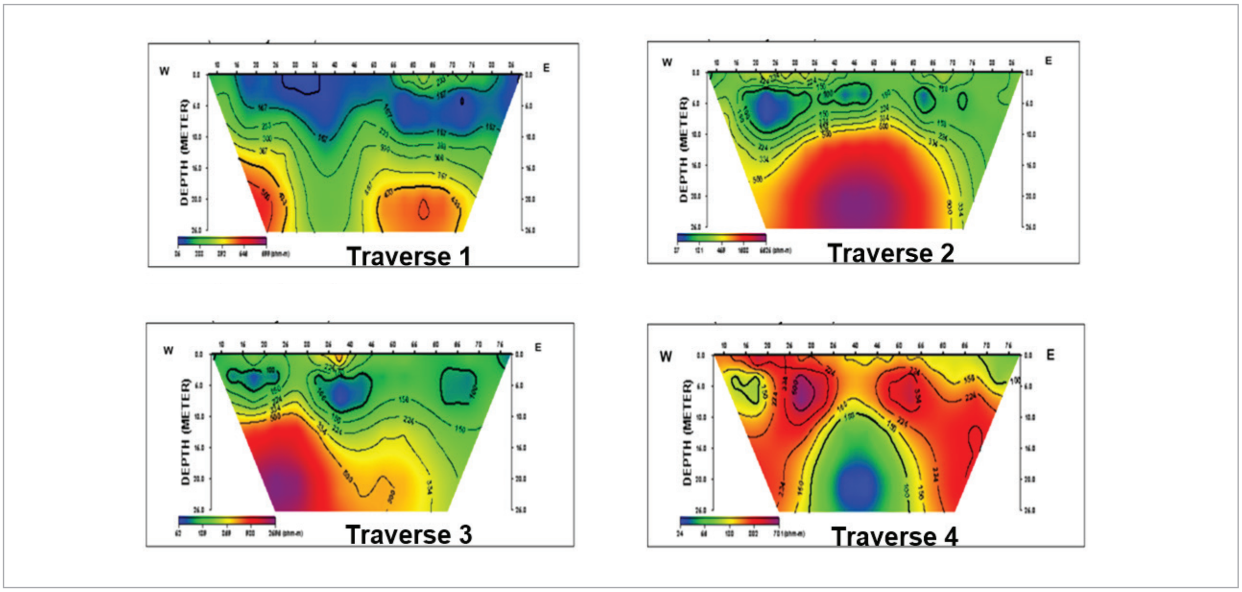
2-D resistivity structures

The measured 2-D resistivity data taken along the 4 traverses were processed and inverted into 2-D resistivity structures, using the DIPRO for windows (2000) software. The results are displayed as inverted sections indicating the lateral variation of the subsurface lithology with depth (Fig. 3). Both the field and theoretical data pseudosections are included as supplementary information (S1). The sections were visually inspected to determine areas of anomalously high or low resistivity related to subsurface structures.

Leachate is a liquid formed from decomposed waste and has higher conductivity due to the presence of dissolved salts. Also, leachate plume generated at a waste disposal site generally contains high ion concentrations and, hence, results in low resistivity of the rock formations containing them (Cristina et al., 2012). Consequently, the electrical resistivity of leachate is often very much lower than natural groundwater. This makes geoelectrical techniques most adequate for mapping the extent of leachate contamination around landfills (Bernstone and Dahlin,

Fig. 3

2-D subsurface resistivity images along traverses 1– 4



1999). The 2-D resistivity imaging mapped out zones of anomalously low resistivity (deep blue) across all the traverses, which are the zones of contaminant leachate plumes with very low resistivity values at depths of about 10 m in all the traverses except traverse 4, in which the accumulation of leachates at the base of the dumpsite is at the depth of 25 m. The high resistivity zone is isolated as an oval/dome shaped anomaly (brown to red to purple) with resistivity varying between 648 Ωm and 2887 Ωm interpreted as soil or sand saturated with dumpsite gases at a depth of 25 m in all the traverses as well. Lying between these zones of anomalously low and high resistivity zones is an intermediate resistivity zone (light green to yellow) with resistivity < 648 Ωm, which is an indication of rock materials having varying moisture content and composition. A static water level of the hand-dug wells in the area ranges from 2.22 m to 4.50 m. Since groundwater moves from a region of high concentration and altitude to a region of low concentration and low altitude. It implies that groundwater in the study area flows in the E–W and SE–NW directions.

Water physicochemical parameters

The results of the groundwater physicochemical parameters are presented in Table 1. However, the distribution pattern across the various sampling locations is as presented in Fig. 4. The bigger part 71% of the water sampled is colourless and odourless with a temperature range between 25.8°C and 27.7°C. The pH of the HdWs varied from 6.7 to 8.1, while for the BHs, it ranged between 6.7 and 6.9, indicating that the groundwater is generally neutral-alkaline (43% of the water samples showed slight alkalinity). The pH data generally fell within the 6.5–8.5 range of WHO standard for drinking water and water intended for aquatic life and recreational activities (DWAF, 2002; WHO, 2008; US EPA, 2004). The total dissolved solids (TDS) of the HdWs ranged between 97.8 and 572.6 mg/L with the mean value of 268.0±141.4 mg/L, while for the BHs, it ranged between 233.2 and 286.0 mg/L with the mean value of 260.0±37.3 mg/L. Therefore, the two types of water used in the study can be described as freshwater (TDS < 1 g/L) based on Freeze and Cherry's (1979) classification. To corroborate the freshness of these samples, the electrical conductivity values ranged from 178 to 1041 µS/cm and 424 to 520 µS/cm for HdWs and BH respectively, which was < 1500 µS/cm for freshwater according to Mondal et al. (2008). The range falls respectively within the stipulated 1,000 mg/L and 500 mg/L recommended by the WHO and the NSDWQ. This further re-affirms absence of salt-water intrusion from the area. The range in chloride concentration was very wide (4.3–22.5 mg/L) for the HdWs. However, for the BHs, there were no significant differences (SD < 0.5) in chloride concentrations. The low concentrations of electrical conductivity coupled with low chloride levels as later observed indicate that there is absence of salt water intrusion in the study area.

The boreholes and wells have mean turbidity values of 3.0 and 4.3 NTU, respectively. This suggests that BH water was clearer than HdW water and contained less dissolved organic matter. However, the high turbidity values above the recommended value of 5 NTU (WHO, 2011) observed within some HdWs are indications that the wells are either not lined or improperly lined. It also suggests enhanced suspended inorganic materials, which have penetrated into the wells due to the unstable side walls of the wells (Akinbile, 2006). More importantly, the observed high turbidity values in some samples (HdW 9, HdW 10, HdW 11 and HdW 12) may be attributed to closeness to the dumpsite leading to higher sediment flow when compared with others. This implies that hand-dug wells in the study area need to be lined to prevent ingress of soil particles. The mean total hardness (TH) values of the HdWs and the BHs are 196 mg/L and 227 mg/L, respectively. Based on Abd El-Salam and Abu-Zuid's (2015) classification, the HdWs and the BHs could be classified as hard and moderately hard, respectively. Water hardness is usually due to the multivalent metal ions from minerals dissolved in the water, and hard waters are unsatisfactory for household cleansing purpose. Values above 200 mg/L for total hardness do not have any adverse effect health-wise on humans but it is an indication of deposits of calcium and magnesium ions. The implication is that forming lather with soap will be the main challenge for domestic users.

Nitrates and phosphates are two important nutrients that have been increasing markedly in natural waters since the mid-1960s (Hodgson, 2004). Unpolluted

Table 1

Statistical description of chemical characteristics of water samples in the study area and their comparisons with the WHO and NSDWQ standards

Parameters		Min.	Max.	Mean±SD[a]	WHO (2011)	NSDWQ (2007)
1		2	3	4	5	6
pH	HdW	6.7	8.1	7.4±0.5	6.5–8.5	6.5–8.5
	BH	6.7	6.9	6.8±0.1		
EC (µS/cm)	HdW	178	1041	487±257	1,000	
	BH	424	520	472±68		
Cl^- (mg/L)	HdW	4.3	22.5	8.5±4.6	250	250
	BH	7.9	8.4	8.1±0.4		
Turbidity (NTU)	HdW	2.1	7.3	4.3±1.6	5	
	BH	2.3	3.7	3.0±1.0		
TH (mg/L)	HdW	74.2	279.6	195.9±59.1	500	200
	BH	200.5	252.9	226.7±36.5		
Co_3^{2-} (mg/L)	HdW	7.6	98.5	23.9±25.5	600	
	BH	21.3	25.7	23.5±3.1		
TDS (mg/L)	HdW	97.8	572.6	268±141.4	1,000	500
	BH	233.2	286.0	260±37.3		
SO_4^{2-} (mg/L)	HdW	5.0	60.3	17.9±15.8	250	250
	BH	16.4	23.1	19.8±4.7		
PO_4^{3-} (mg/L)	HdW	4.0	82.4	23.6±22.4	5.0	
	BH	27.4	28.8	28.1±1.0		
NO_3^- (mg/L)	HdW	1.0	14.2	7.5±5.2	10	50
	BH	12.5	14.2	13.4±1.2		
Ca (mg/L)	HdW	9.3	55.2	33.1±12.7	200	200
	BH	23.5	44.5	34.0±14.8		
Mg (mg/L)	HdW	12.4	46.5	27.6±9.1	150	
	BH	34.5	34.5	34.5±0		
Na (mg/L)	HdW	15.3	87.5	51.9±23.7	200	200
	BH	18.5	73.4	45.9±38.9		
K (mg/L)	HdW	1.2	26.7	6.0±7.2	50	50
	BH	1.2	4.6	2.9±2.4		

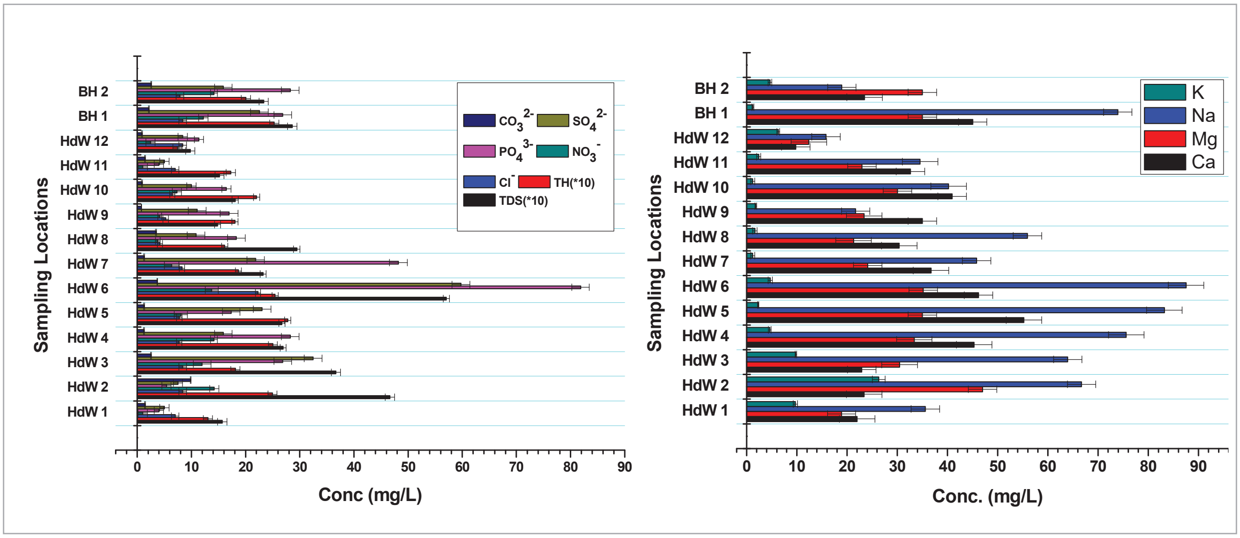
[a] SD = standard deviation, Min. = minimum, Max. = maximum, NSDWQ = Nigerian Standard for Drinking Water Quality. Where a = n_1 or n_2: n_1 = number of samples for HdW = 12 and n_2 = number of samples for BH = 2.

natural waters usually contain only minute amounts of nitrate. In the study, nitrate concentrations ranged from 1.0–14.2 mg/L and 12.5–14.2 mg/L in the HdW and the BH, respectively. However, phosphate recorded a higher range of 4.0–82.4 mg/L and 27.4–28.8 mg/L, respectively. The natural levels of nitrate in groundwater may be increased by leaching wastewaters from waste disposal sites, agricultural chemicals and sanitary landfills. High nitrate concentrations have adverse effects on infants (Longe and Balogun, 2010). An increase in these nutrients, particularly phosphate, as exemplified in the present report over nitrate is of environmental concern and was not unexpected. This is because, in anaerobic environment, as being created through the waste dumpsite, nitrates are in low concentration. The low biological productivity can result in an appreciable amount of phosphate (Hammerton and Sherah, 1992). The levels of NO_3^- and PO_4^{3-} obtained in this report can be considered too high for drinkable water and are exceedingly too high for both aquatic life and irrigation purposes with guideline values of <0.5 mg/L for NO_3^- and <0.05 mg/L for PO_4^{3-}, respectively (FEPA, 1992; Campolo et al., 2002). The water is not equally suitable for livestock watering and recreational activities with a guideline of < 10 mg/L for NO_3^- and < 0.05 mg/L for PO_4^{3-}, respectively (FEPA, 1992; WHO, 2008). Chloride, sulphate and carbonate concentrations in the water samples are far below the WHO limits for pollution in both HdW and BH across the various sampling locations. The increasing order follows: $Cl^- < SO_4^{2-} < CO_3^{2-}$.

The mean Na concentrations of the BHs (46 mg/L) and wells (52 mg/L) were below the WHO and SON tolerable limits of 200 mg/L (Fig. 4). This is also true of Ca with mean values slightly lower than those of Na. The level of Na obtained in the study suggests strong water aquifer interaction related to their cation exchange or anthropogenic pollution. However, unlike Na and Ca, the mean concentration of Mg in the BHs (35 mg/L) and the HdWs (28 mg/L) were far above the 0.2 mg/L permissible limit as recommended by the SON. The high concentration of Mg re-affirms the high total hardness earlier reported. The elevated level of Mg in the study may be attributed to Mg-rich carbonates within the aquifer of both the BHs and wells including kaolinite, hematite and basalt (Trostle et al., 2014). Comparatively, levels of Mg in the study fall below the 68–173 mg/L range obtained from the groundwater in Manali, India (Antony et al., 2008). The characteristics of the groundwater upstream of the dumpsite fall within the acceptable limit and are not in any way unsuitable for both domestic and agricultural purposes.

Fig. 4

Distribution pattern of some physicochemical parameters and mineral element across sampling locations



Heavy metals distribution

A summary statistics of the total metal concentrations in water from the study area are presented in Table 2, while Fig. 5 displays the distribution of each metal (Fe, Mn, Pb, Zn and Cr) across the various sampling locations. Apart from Fe, Mn, Pb, Zn and Cr, other metals like Cd, Cu and Ni were below the instrument detection limits. Across all the locations, the concentrations (in mg/L) of Fe, Pb, Zn and Cr in the HdWs and the BHs were found to significantly exceed the recommended WHO limit and the NSDWQ maximum concentration for drinking water (WHO, 2011; NSDWQ, 2007). These are indications of their release from toxic wastes. Of serious concern is the level of Pb recorded in the study because of its lack of any known biological function in the body. The mean Pb concentration in both BHs and HdWs (0.7 mg/L and 0.8 mg/L, respectively) are far greater than the mean concentration of 0.03 mg/L and 0.04 mg/L obtained in a similar study within rural community in North Central Nigeria (Sojobi, 2016). Thus, adverse effects such as anaemia, abdominal discomfort, convulsion, organ failure, goitre in adults, objectionable tastes and precipitation problems, neurological problems and corrosion of intestinal tracts due to of Fe, Mn, Pb, Zn and Cr may occur (Geraldi et al., 2002; Khan et al., 2013; Longe and Balogun, 2010; WHO, 2011). Like many other studies, the elevated level of these trace metals particularly in HdW 6, HdW 9, HdW 10, HdW 11 and HdW 12 may be attributed to the closeness to and leaching from the waste dumpsite based on previous reports (Ololade et al., 2009; Oni and Hassan, 2013; Sojobi, 2016). This suggests that wells should not be sited very close to dumpsites in order to avoid heavy contaminations. Statistical analysis of the data revealed no significant difference at a 90% confidence level in all the metals between the sampling locations as $0 \leq \rho \leq 1.7$. This shows that the background

Table 2

Statistical description of heavy metals in water samples

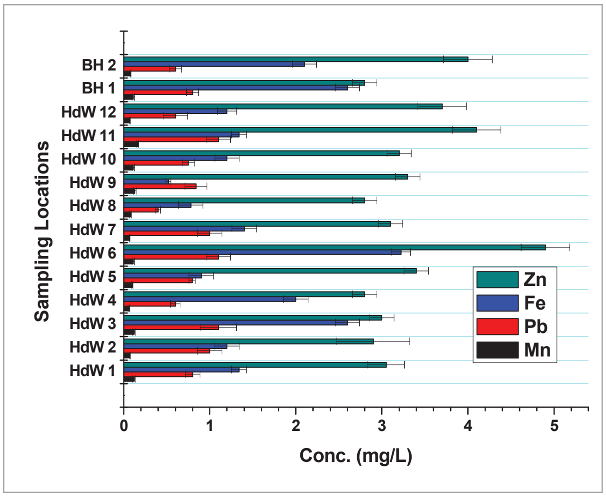
Parameters (mg/L)		Min.	Max.	Mean±SD[a]	WHO (2011)	NSDWQ (2007)
1		2	3	4	5	6
Fe	HdW	0.6	3.2	1.5±0.8	0.3	0.3
	BH	2.1	2.6	2.4±0.4		
Mn	HdW	0.06	0.16	0.1±0.03	0.3	0.2
	BH	0.08	0.11	0.1±0.02		
Pb	HdW	0.4	1.1	0.8±0.2	0.01	0.01
	BH	0.6	0.8	0.7±0.1		
Zn	HdW	2.7	4.9	3.4±0.6	3 - 5	3.0
	BH	2.8	4.0	3.4±0.8		
Cr	HdW	0.03	1.1	0.4±0.4	0.05	0.05
	BH	0.08	1.0	0.5±0.7		
Cd	HdW	nd	nd	nd	0.003	0.003
	BH	nd	nd	nd		
Cu	HdW	nd	nd	nd	2.0	1.0
	BH	nd	nd	nd		
Ni	HdW	nd	nd	nd	0.07	0 (< 0.01)
	BH	nd	nd	nd		

[a] SD = standard deviation, Min. = minimum, Max. = maximum, WHO = World Health Organization, NSDWQ = Nigerian Standard for Drinking Water Quality, nd = not detectable. Where a = n_1 or n_2: n_1 = number of samples for HdW = 12; n_2 = number of samples for BH = 2.

concentration of heavy metals in groundwater of the study area is very high. The analysis of variance (ANOVA) shows that the sampling location has influence on the concentration of the metals reported in the study as the variance among the samples and total variance is 23.14 and 0.61 for Fe, 0.10 and 0.001 for Mn, 6.62 and 0.05 for Pb, 107.46 and 0.36 for Zn and 1.41 and 0.15 for Cr.

Fig. 5

Heavy metal distribution across sampling locations



Bacteriological characteristics

The bacteriological counts of the water samples from the study area are summarized in Table 3. Water samples analysed from the HdWs showed average concentration of total heterotrophic bacteria count of 4.4×10^5±1.3×10^5 cfu/100 mL, while that of the BHs showed average concentrations of 4.9×10^5±0.5×10^5 cfu/100 mL. The temperature of any water body affects the rate of proliferation of micro-organisms (Pelczar et al., 2005). The temperature range of 25.8°C and 27.7°C could be responsible for the growth of heterotrophic bacteria species present in the samples. The total heterotrophic bacteria count of the water samples does not conform to the limit of 100 cfu/mL allowed for potable water (NSDWQ 2007).

The average concentrations of total coliform bacteria and faecal coliform bacteria of the water samples from the HdWs are 2.9×10^2±2.5×10^2 mL and 3.3×10^2±0.8×10^2 mL, while those of the BHs are 6.4×10^2±6.6×10^2 mL and 3.4×10^2±1.0×10^2 mL in 100 mL of the original water sample, respectively (Table 3). The total coliform bacteria exceeded the acceptable level of no bacteria. The WHO (2011) specified that potable drinking water should be devoid of total coliform and faecal coliform in any given sample. The total heterotrophic bacteria, coliform bacteria and faecal coliform are high and greater than one in all the samples analysed, which is an indication of faecal pollution of human wastes from the dumpsite. This also confirms bacteriological pollution from the remains of dead animals. The results of the current study show that the samples do not conform to the WHO and NSDWQ requirements for bacteriological characteristics for human consumption. The presence of these microbes in the samples of the study area is

Table 3

Statistical description of bacteriological counts of water samples

Parameters (cfu/100 mL)		Min.	Max.	Mean±SD[a]	WHO (2011)	NSDWQ (2007)
1		2	3	4	5	6
THB count	HdW	2.9×10^5	6.6×10^5	4.4×10^5±1.3×10^5	100cfu/mL	100cfu/mL
	BH	4.5×10^5	5.2×10^5	4.9×10^5±0.5×10^5		
Total coliform	HdW	0.6×10^2	1.0×10^3	2.9×10^2±2.5×10^2	0/100 mL	0/100 mL
	BH	1.7×10^2	1.1×10^3	6.4×10^2±6.6×10^2		
Faecal coliform HdW		2.1×10^2	4.5×10^2	3.3×10^2±0.8×10^2	0/100 mL	0/100 mL
	BH	2.7×10^2	4.1×10^2	3.4×10^2±1.0×10^2		

SD = standard deviation, Min. = minimum, Max. = maximum, WHO = World Health Organization, NSDWQ = Nigerian Standard for Drinking Water Quality. Where a = n_1 or n_2: n_1 = number of samples for HdW = 12; n_2 = number of samples for BH = 2.

also an indication of possible groundwater contamination by leachate from the dumpsite.

Conclusion and Recommendations

This study examined the effects of solid wastes disposal on the quality of groundwater. The results of the 2-D resistivity imaging and hydro-physicochemical studies attributed the presence of contaminants in the analysed groundwater to leachate from the dumpsite. The 2-D resistivity imaging was able to indicate the zones of anomalously low and high resistivities across all the traverses, which represent zones of contaminant leachate plumes and soil or sand saturated with gases, respectively. The hydro-physiochemical analysis revealed that not all groundwater, even borehole water, is suitable for human consumption as excessive concentrations of some anions and cations in groundwater have potential effects on the quality of drinking water, which are associated with human and environmental health. Enhanced heterotrophic bacteria growth was partly attributed to temperature effects and equally suggestive of leachate contamination from the dumpsite since the contaminants reached the depths of 25 m below the aquifer and even at 20 m distance away from the edge of the dumpsite. Hence, walls of wells have to be lined and cemented to prevent the ingress of soil particles, wastewater from waste disposal sites and agricultural chemicals into wells. The study observed that concentrations of all parameters in the BH are generally lower than in the HdW. This was expected considering the depth of the BH and the piping involved that limits the extent of exposure to pollutants, unlike in the HdW. In addition, several transformations, e.g., dilution, must have taken place during downward migration of pollutants before reaching the BH basement, unlike in the HdW.

It is recommended that government should provide waste disposal facilities to the Waste Management Authority and enforce strictly siting of dumpsites far away from residential areas in line with the design of a modern landfill system to minimize pollution of water bodies. In addition, geologists must ensure that BHs are drilled far away from dumpsites. More importantly, inhabitants within the location must be enlightened on the importance of assuring a clean and hygienic environment around the source of their water in order to avoid associated health problems.

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Atliekų sąvartyno geoelectrical imaging ir fizikocheminis vertinimas: poveikis požeminio vandens kokybei

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Labiausiai neįvertinta vandens taršos priežastis - netinkamas atliekų laidojimas ir netinkamas kietųjų atliekų apdorojimas. Dabartiniai tyrimai ištyrė kietųjų atliekų šalinimo vietos poveikį gyvenamosioms teritorijoms, kurios ribojasi su teritorija, vandens kokybe, integruojant 2-D rezistikų vaizdus, fizikines, chemines ir bakteriologines vandens mėginių iš dvylikos rankinių gręžinių (HdW) ir du gręžiniai (BH), naudojant standartines lauko ir laboratorines procedūras. Dvigubo paviršiaus dvigubo paviršiaus matavimo rezistorių, išilgai keturių takų aplink šiukšlių sąvartyną, rezultatai parodė, kad anomališkai mažos pasipriešinimo zonos, tarpinės atsparumo zonos ir didelės varžos zonos, interpretuojamos kaip dirvožemio arba smėlio, prisotintos taršos šaltu vandeniu, skirtingos drėgmės kiekis ir kompozicija ir akmens medžiagos, užterštos sąvartynų dujomis. Tyrimas parodė, kad šie teršalai migruoja į 25 m gylyje žemiau už vandeningojo sluoksnio ir daugiau nei 20 m atstumu nuo sąvartyno krašto. Be nitratų, fosfatų ir drumstumo, visi kiti fizikocheminiai parametrai, išbandyti, atitiko rekomenduojamas PSO ribas. Tačiau metalų pėdsakai (Fe, Mn, Cr, Pb ir Zn) ir bendras bakterijų kiekis paprastai viršijo rekomenduojamą ribą. Atsižvelgiant į susijusias su sveikata susijusias pasekmes dėl padidėjusio tam tikrų teršalų kiekio, kuris daugiausiai buvo siejamas su išpraustytomis medžiagomis, tyrimas pasiūlė tinkamas koregavimo priemones ir programos nušvietimo kampaniją visiems galutiniams vartotojams.

Raktiniai žodžiai: sunkieji metalai, išplovimas, sąvartynas, atliekų šalinimas, geoelectrical imaging, bakterijų skaičius.