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RESEARCH

Integrated assessment of pollution status of MSW sites: a case study of Uyo, Ikot Ekpene and Oron, Akwa Ibom State, southern Nigeria

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Abstract One of the main causes of contaminated groundwater in emerging nations is improper trash disposal in urban areas, which affects the level of groundwater contamination caused by contaminants of municipal solid waste (MSW) origin within the three local government headquarters in Akwa Ibom State, southeastern Nigeria. The main thrust of this research survey is to assess the level of groundwater contaminations and their consequences. The research used statistical data generated from the Electrical Resistivity Survey (ERS) in combination with hydrogeochemical investigations. Analysis of variance of resistivity between Uyo, Ikot Ekpene and Oron was carried out. The test result indicated significant difference in contamination among the three cities. This was followed by a *t*-test between each pair of dump and control sites in the three cities. The test results showed significant difference between each control and dumpsite. The results showed that leachate layer conductivity is always higher than that of the layer above it. All water samples from boreholes close to the dumpsites were identified by hydrogeochemical analysis to exhibit pH (3.70–4.15) lower than the permissible limit of the WHO; few water samples exhibit increased electrical conductivity (EC), cadmium and total dissolved solids (TDS). Similarly, the bacteriological analyses indicated a high level of microbial load due to the waste dump. Formations found in boreholes close to the dumpsite have litho-correlations which depict intercalations of comparatively impermeable and porous materials. The findings reveal that leachate (contaminate) travels slowly downward, allowing for physical, chemical and biological processes to filter out impurities before they get to the aquifer. It is recommended that no new water supply wells should be placed in areas of abnormally low resistivity and physicochemical and bacteriological parameters, until the reasons for these values are properly assessed.

Keywords Groundwater · Pollution · Resistivity · Test statistics · Dumpsite

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Introduction

In underdeveloped nations, improper garbage disposal is a significant source of pollution (Ariyo et al., 2013; Olayinka & Olayiwola, 2001; Tijani et al., 2004). The infiltration of rainwater into landfills and the biological and chemical breakdown of the wastes produce leachates that contain considerable suspended particles, varying in organic and inorganic contents (Mosuro et al., 2017). Strong waste landfills comprise essential components of the soil's hydrological system and represent a significant threat to groundwater and downstream surface water (Dahlin et al., 2010). The hydrodynamic behaviour of solid waste dumps must consequently be understood and quantified. High concentrations of things including heavy metals, fertilizers and organic compounds in landfills raise the possibility of environmental damage. The amount and quality of water that seeps through the landfill and reaches the surroundings determine the pollution load to the ecosystem. According to Christensen et al. (1992), the primary local environmental problem connected to solid waste dumps is the discharge of leachates into the surrounding groundwater and surface waters. Yes, leakage from MSW sites is frequently accompanied by high ion concentrations and, as a result, extremely low resistivities. This makes geoelectrical imaging technologies particularly attractive for mapping the three-dimensional extent of contamination surrounding landfills (Bernstone & Dahlin, 1999). Our environmental concern in waste dumps lies in assessing the pollution threat they pose since they may contain hazardous substances.

Among all the geophysical techniques applied to characterise aquifers, electrical resistivity tomography (ERT) is among the most widely used ones, mostly due to the sensitivity of hydrologically pertinent amounts (Grunhut et al., 2018). The electrical conductivity of any polluting agent would differ from that of water; therefore, geoelectrical techniques might be helpful to identify and track the development of contamination in the aquifer.

Waste management has become an issue in Nigeria and other developing nations (Agunwamba, 1998; Ogwueleka, 2009). In contemporary urban cities, it is common to see large trash dumps that need treatment surrounded by residential areas. Heavy metals are the predominant contaminants in the majority of these waste sites; nonetheless, it is frequently unknown how much contamination is there (Ogwueleka, 2009). Groundwater contamination under and beside trash disposal sites occurs when rain falls and travels through the landfill, creating a waste fluid known as leachate that can infiltrate through the unsaturated zone and bring contaminated water to the water table (Fig. 1). The leachate may contain every imaginable

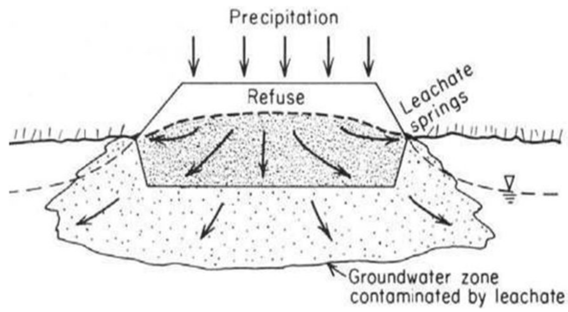


Fig. 1 Conceptual diagram of leachate migration from a landfill and open dumps. Source: World Health Organization (2006)

inorganic and organic component that could deteriorate the quality of the groundwater and provide a major health concern to the neighbourhood.

Akwa Ibom State (Fig. 2), like other parts of Nigeria, faces serious problems with disposal of wastes and contamination. Dumping garbage in the open dumpsites is a low-cost way, and it will remain the main way of getting rid of waste for the foreseeable future (Jegede et al., 2012). Open dumping is the most typical method of trash disposal in poor nations (Rushbrook, 1997; Visanathan et al., 2003).

The description of these wastes is typically not good, and dangerous wastes may be disposed of together with non-hazardous garbage. Dumpsites are typically unmanaged, which poses serious risks to people's health and the environment (Pugh, 1997). Open waste dumping sites usually lack trustworthy natural or man-made barriers, which makes leaching of toxins into groundwater a problem, especially for trash placed in erosion gullies and ravines (as in Uyo), many of which extend to below the groundwater table. The study's subjects (Fig. 2) are people who live in the 754,067-person Uyo, Ikot Ekpene and Oron local government areas (Nigeria Population Commission (NPC), 2006); 90% of their water consumption is based on groundwater. Elevated urbanisation population growth has accelerated issues with the disposal and collection of both liquid and solid wastes. Each year, the importation of packaged consumer goods increases the number of non-biodegradable materials in use. Pollution caused by commercial waste and the dumping of harmful substances and sewage both contribute significantly to marine pollution

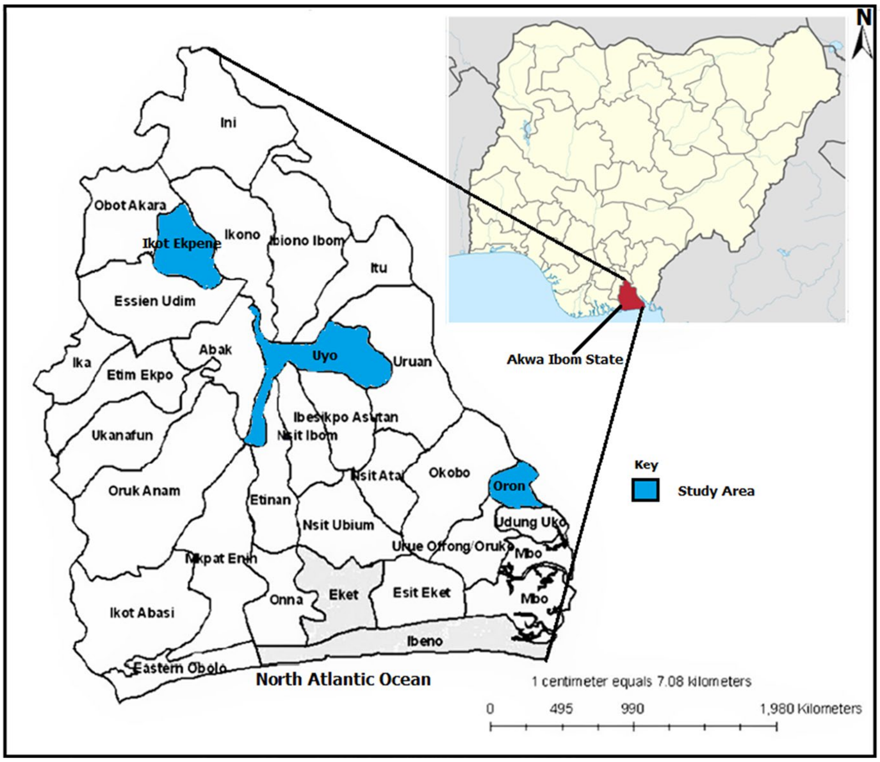


Fig. 2 Map of Akwa Ibom State showing the local government of the study areas (Modified after Ite et al., 2017)

and erosion of the coast. Man-made numerous chemicals, some of which are very harmful, can be challenging to recycle and expensive to destroy. The majority of wastes, whether hazardous or not, are just thrown into the next government-owned area that is available. The frequent use of harmful agricultural chemicals in regions where these can subsequently cause damage is possibly more hazardous to sources of groundwater and rivers. Freshwater sources near agricultural areas can have contaminated groundwater.

Groundwater moves through aquifers, which are often subhorizontal layers of permeable rocks such as porous sands and sandstones, but including crystalline rocks with interconnected fractures and fissures. The top of the water-saturated volume is termed the water table. Aquifers are vulnerable to surface contamination in the recharging regions, such as the sea. It may take years before contamination reaches an extraction point and much longer thereafter to eliminate it; so, monitoring for contamination is another important task (Musset and Khan Aftab, 2000).

Locations of the study

Akwa Ibom State is in the southeastern part of Nigeria, located between latitudes 4°30′ and 5°30′ N and longitudes 7°30′ and 8°20′ E (Fig. 2). The State is bounded on the east by Cross River State; on the northeast and north by Cross River and Abia States; on the west and southwest by Abia and Rivers States; and on the south by the Atlantic Ocean, with a 129-km maritime coastline which extends from Ikot Abasi in the west to Oron in the east. The study areas, viz., Uyo, Ikot Ekpene and Oron, are located in the central, northwest and southeast parts of the State respectively (Fig. 2). Uyo dumpsite is a ravine adjoining Udo and Eka streets and University of Uyo, and has been in operation before 1989 (Figs. 3a, b and 10a). The maps of these locations are shown in Figs. 3, 4 and 5 respectively.

Ikot Ekpene dumpsite has been in operation for about 22 years (Figs. 4 and 10b), while Oron dumpsite has been in operation since the early nineties (Figs. 5 and 10c).

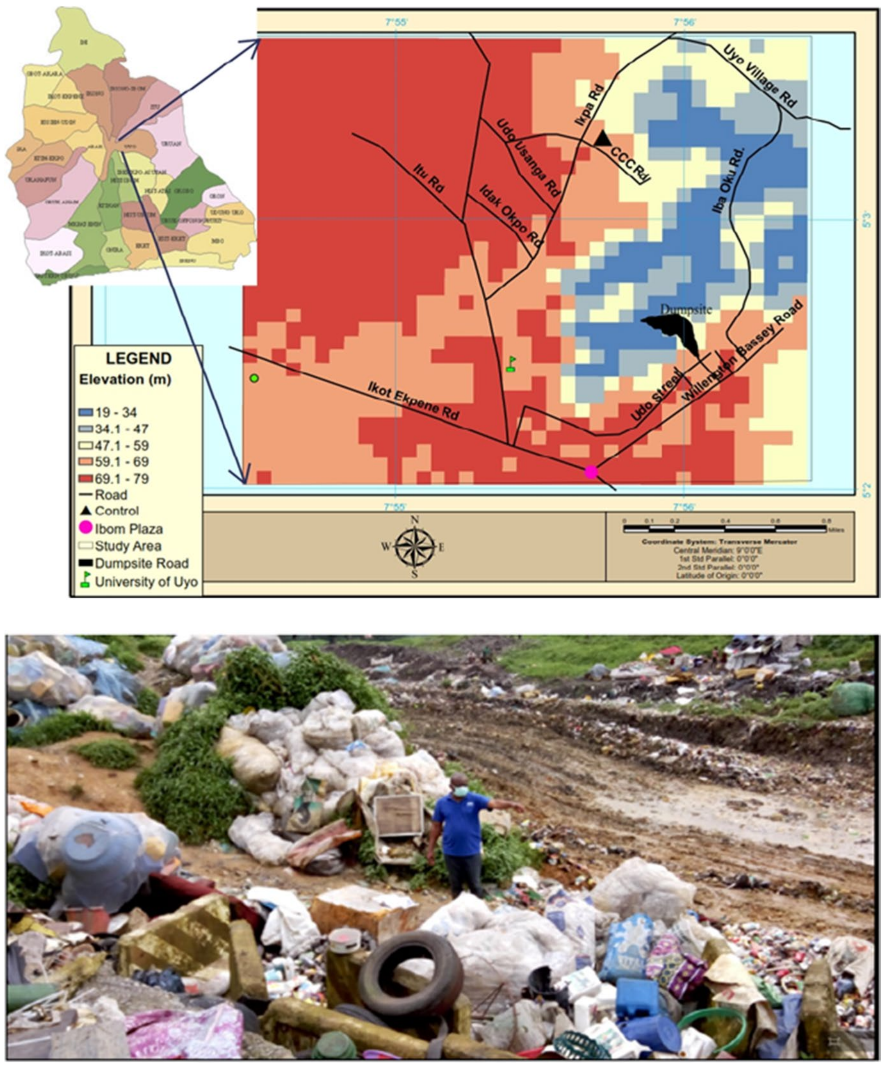


Fig. 3 **a** Google Map of Uyo showing the location of the dumpsite and control site. **b** A photograph of Uyo dumpsite showing materials of various kinds

Geology and hydrogeology of the study area

The geology of the Akwa Ibom area has been extensively studied by several authors (Reyment, 1965; Short & Stäublee, 1967; Murat, 1970; Kogbe, 1989; Wright, 1989). As presented in these publications, the area is underlain by late Cretaceous to Quaternary sediments (Fig. 6).

The lowermost sediment is lateritic sandstone with minor shale of the Maastrichtian Nsukka Formation. Throughout the Palaeocene to Early Eocene, a thick shale intercalated with sandstone and limestone was deposited (Imo Shale Formation), while in the middle of the Eocene, semi-consolidated sandstone, siltstone and minor shale were deposited (Bende-Ameki Formation). Since the Miocene-Oligocene, grit and sand with intercalations of clay and lignite beds were deposited, constituting the Ogwashi-Asaba Formation (Fig. 6). Overlying this formation is a thick sequence of gravel, sand, silt and clay (Fig. 7), constituting the Benin Formation also known as the Coastal Plain Sands and alluvial ridges.

The area has three hydrostratigraphic units, namely the Alluvial Deposit, Coastal Plain Sand and Lower Sand Aquifers (Edet, 1993; Esu et al., 1999). The Coastal Plain Sand (Benin Formation) aquifer is the most extensive and is separated from the Lower Sand aquifer by the Imo Shale aquiclude. The aquifer is composed of sand, gravel and sandstone with

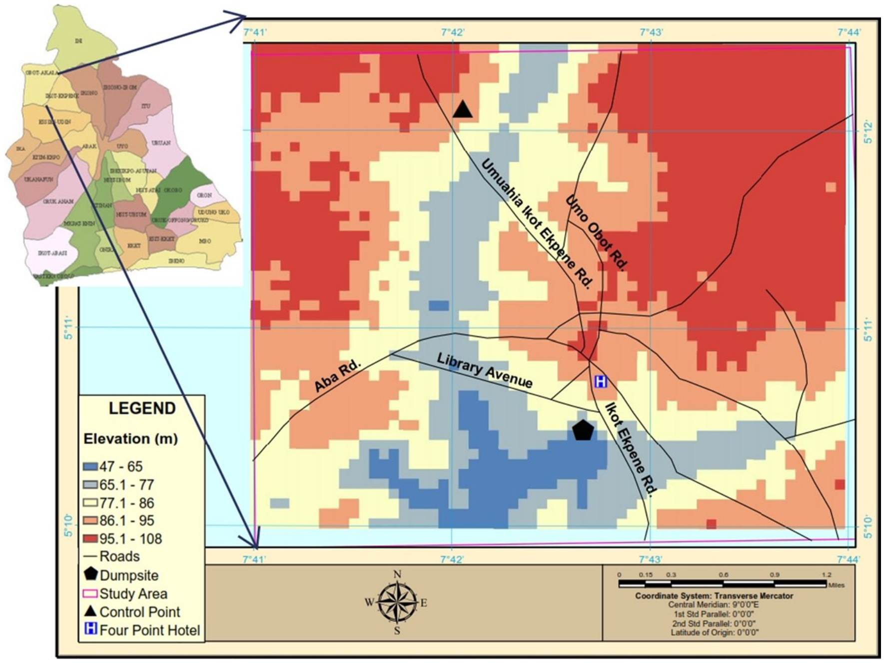


Fig. 4 Google Map of Ikot Ekpene showing the position of the dumpsite and control site

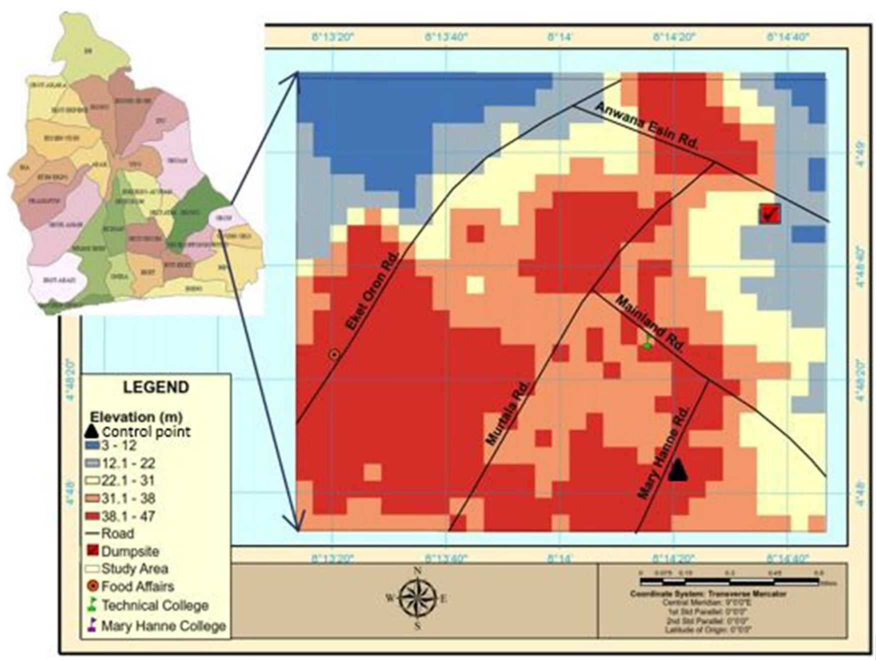


Fig. 5 Google Map of Oron showing the location of the dumpsite and control site

clay intercalations. The thickness of the aquifer varies between 35 m in the north and 200 m in the south. The aquifer is considered to be semi-confined or unconfined, especially in the southern parts of the area. These characteristics result in good porosity and effective permeability for effective retention and mobility of groundwater and other liquid substances within the subsurface (Nwankwo & Emujakporue, 2012). The main groundwater flow direction (Figs. 8 and 9) is from north to south into the Atlantic Ocean. There are also

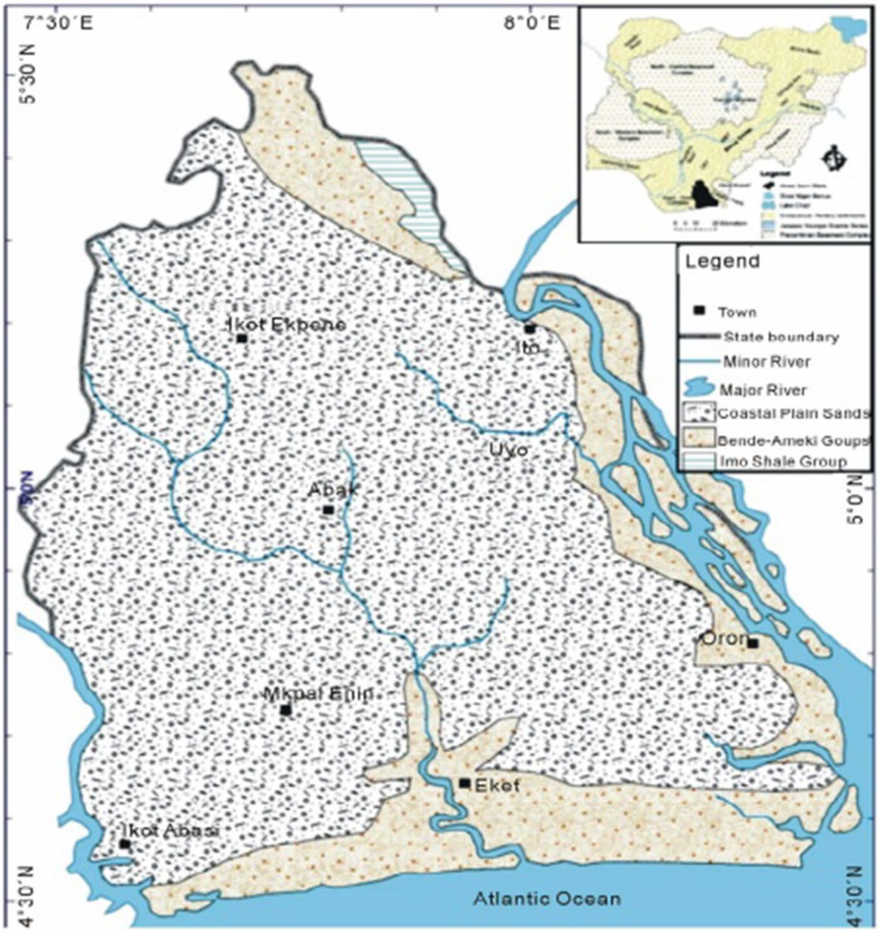


Fig. 6 Geological map of Akwa Ibom State (adapted from Edet et al. 2014)

variations in the northeast-southwest and northwest-east directions into the Imo River and the Cross River.

Methods of the study

Geoelectric survey

The Schlumberger configuration was used with current electrode spacing (AB/2) ranging between a minimum value of 1.5 m and a maximum value of 150 m in some areas with enough space and 80 m in some places with limited space (Fig. 10a–c). The potential electrode spacing (MN/2) ranged between a minimum value of 0.5 m and a maximum value of 30 m for areas with much space and 10 m for areas with limited space. The Schlumberger array was used to collect vertical electrical sounding (VES) data along profile lines with survey stations placed at equal intervals (30 m) apart. Four-point multiple vertical electrical sounding (MVES) such as the Schlumberger array run at constant station interval along a profile is synonymous with electrical resistivity tomography (ERT) and gives subsurface layered resistivity images in two dimensions when modelled. The advantage of this survey type is that it allows the subsurface variation of resistivity values to be modelled both vertically and laterally, thus giving a clear resistivity image of the subsurface in 2D. Vertical electrical sounding (VES)—also called depth sounding or sometimes electrical drilling—is used when the subsurface approximates to a series of horizontal layers, each with a uniform but different resistivity (Musset and Khan Aftab, 2000). As the distance between the current electrodes is increased, the depth to which

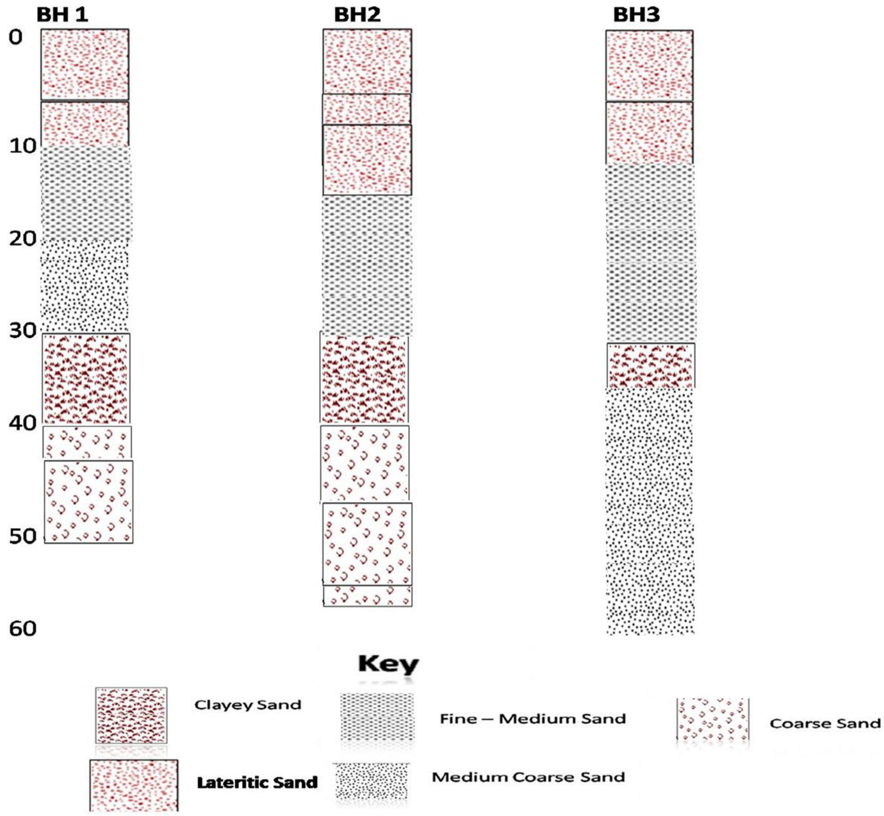


Fig. 7 Lithologic profiles of boreholes near Uyo dumpsite (depth in metres)

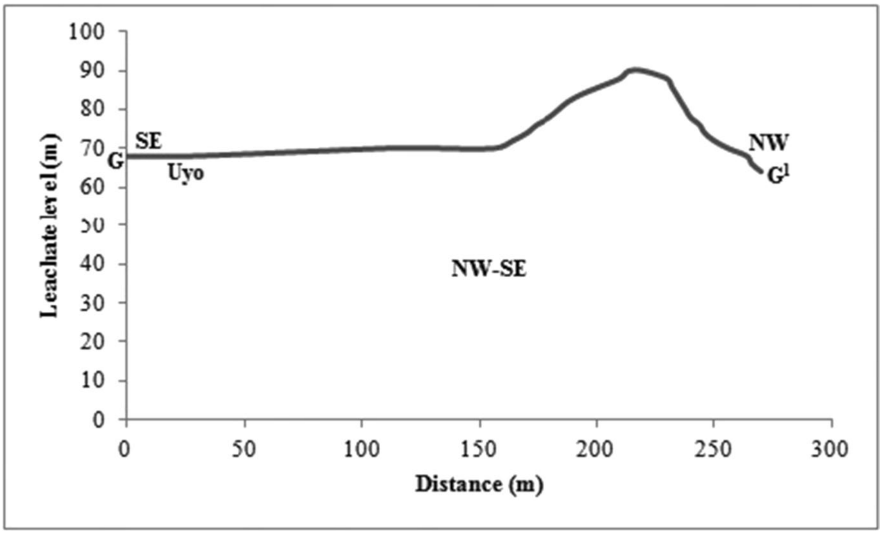


Fig. 8 Cross-section showing the direction of leachate flow across Uyo dumpsite (Udoh et al., 2021)

the current penetrates is increased. For a depth sounding, measurements of the resistance ($\partial V/I$) are made at the shortest electrode separation and then at progressively larger spacings. At each electrode separation, a value of apparent resistivity (ρ_a) is calculated using the measured resistance in conjunction with the appropriate geometric factor for the electrode configuration and separation being used. The resistivity data was then used to generate the statistical data used for this research.

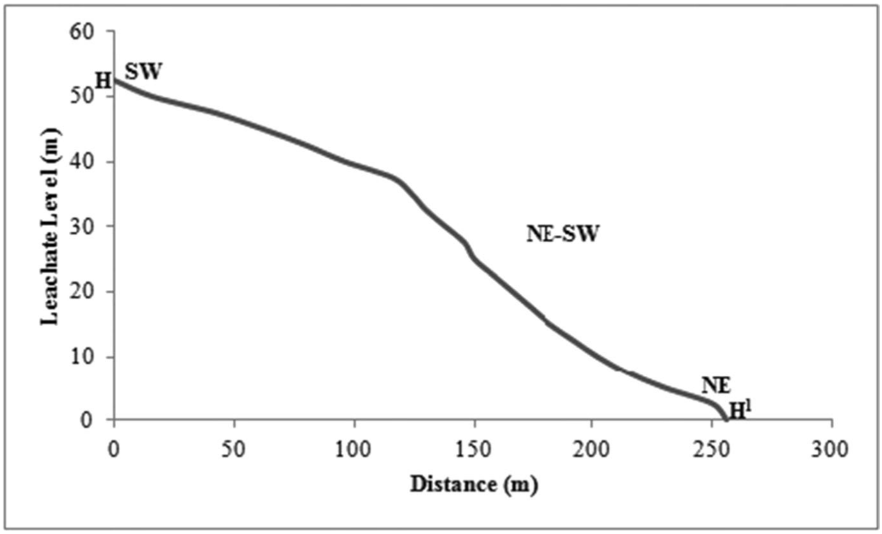


Fig. 9 Cross-section showing the direction of leachate flow across Oron dumpsite (Udoh et al., 2021)

Statistical method

Variance of resistivity in Uyo, Ikot Ekpene and Oron dumpsites

In this section, we consider analysis of variance proposed for this work. This is a parametric test that compares the mean effects of more than two populations or sample distributions. Here, we have three dumpsites, namely Uyo, Ikot Ekpene and Oron, and this explains the reason to adopt the analysis of variance. Moreover, the justification for the proposed analysis of variance is predicated upon the fact that the data collected have met the underlying conditions or assumptions for the use of analysis of variance test. These conditions include the following: (i) the data collected from the three dumpsites are independent; (ii) the data are normally distributed; and (iii) variances of the distributions are homoscedastic (Gujarati & Porter, 2009). To conduct the analysis of variance test, estimations of parameters, such as sum of squares due total, sum of squares due to treatment and sum of squares due to error, are useful input measures.

Estimation of parameters

$$\text{Total sum of squares, } SS_T = \sum X_{ij}^2 - SS_\mu \tag{1}$$

$$SS_\mu = \frac{T^2}{ab} \tag{2}$$

$$\text{Sum of squares due to treatments, } SS_t = \frac{\sum T_i^2}{b} - SS_\mu \tag{3}$$

$$\text{Sum of squares due to error, } SS_e = \sum X_{ij}^2 - \frac{\sum T_i^2}{b} \text{ or } SS_e = SS_T - SS_t \tag{4}$$

where SS_μ is the sum of squares due to mean, *a* represents the number of treatments (study towns) and *b* represents the number of responses.

Here, we present a statistical method for resistivity analysis for the three dumpsites, namely Uyo, Ikot Ekpene and Oron. The specific method proposed for the analysis is a two-sample *t*-test statistic for each pair of the dumpsites. Table 1 displays analysis of variance method for statistical measures and test of significance in the three dumpsites.

Statement of hypothesis

H$_0$: Resistivity at Uyo, Ikot Ekpene and Oron dumpsites is the same.

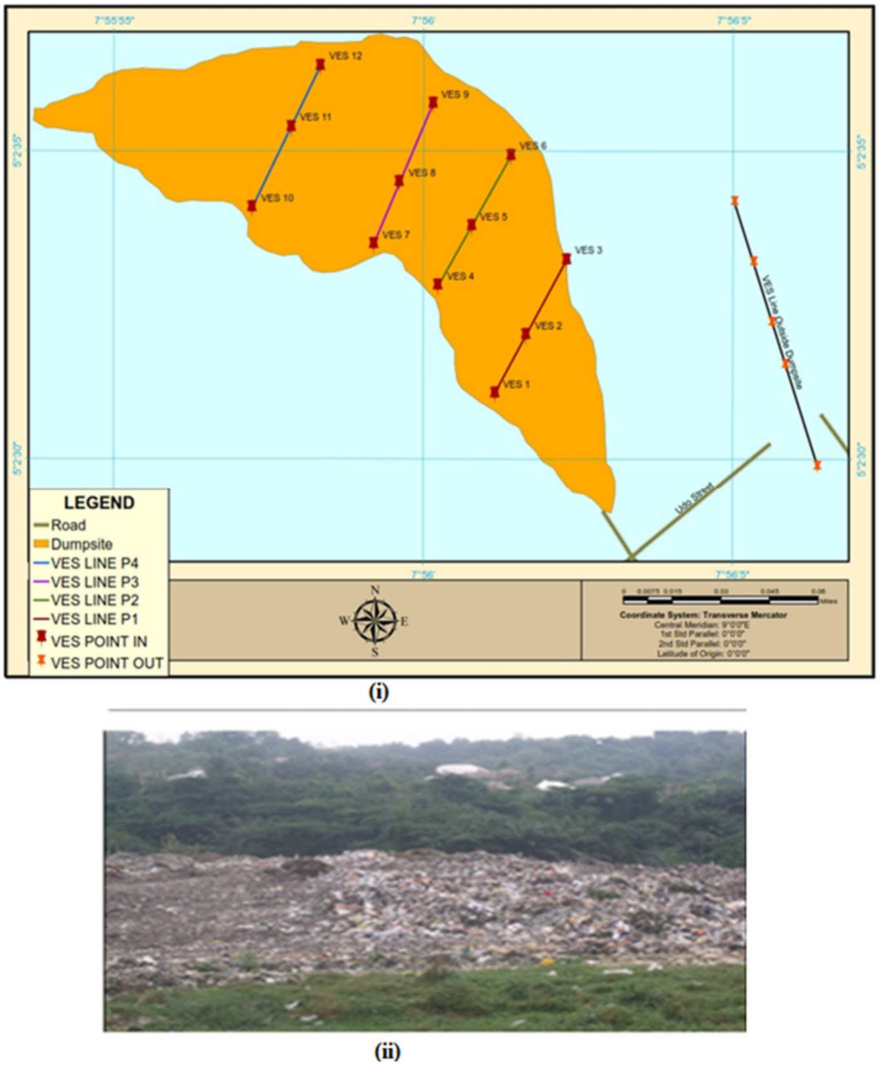


Fig. 10 **a** Map showing (i) the sounding points and (ii) pictures of the Uyo dumpsite (Udoh et al., 2021). **b** Map showing the sounding points and pictures of the Ikot Ekpene dumpsite. **c** Map showing the sounding points and pictures of the Oron dumpsite

H_1: Resistivity at Uyo, Ikot Ekpene and Oron dumpsites is not the same.

Decision rule H_0 is rejected if $F_{\text{calculated}} > F_{\text{tabulated}}$.

Two-sample t-test for control and dumpsites

The test statistic is presented as

$$t = \frac{\overline{x}_c - \overline{x}_d}{S_p\sqrt{\frac{1}{n_c} + \frac{1}{n_d}}} \quad (5)$$

where $s_p = \sqrt{\frac{(n_c-1)S_c^2+(n_d-1)S_d^2}{n_c+n_d-2}}$

$\overline{x}_c$ and $\overline{x}_d$ are the resistivity means at the control and dumpsites respectively.

S_c^2 and S_d^2 are the resistivity variances at the control and dumpsites respectively.

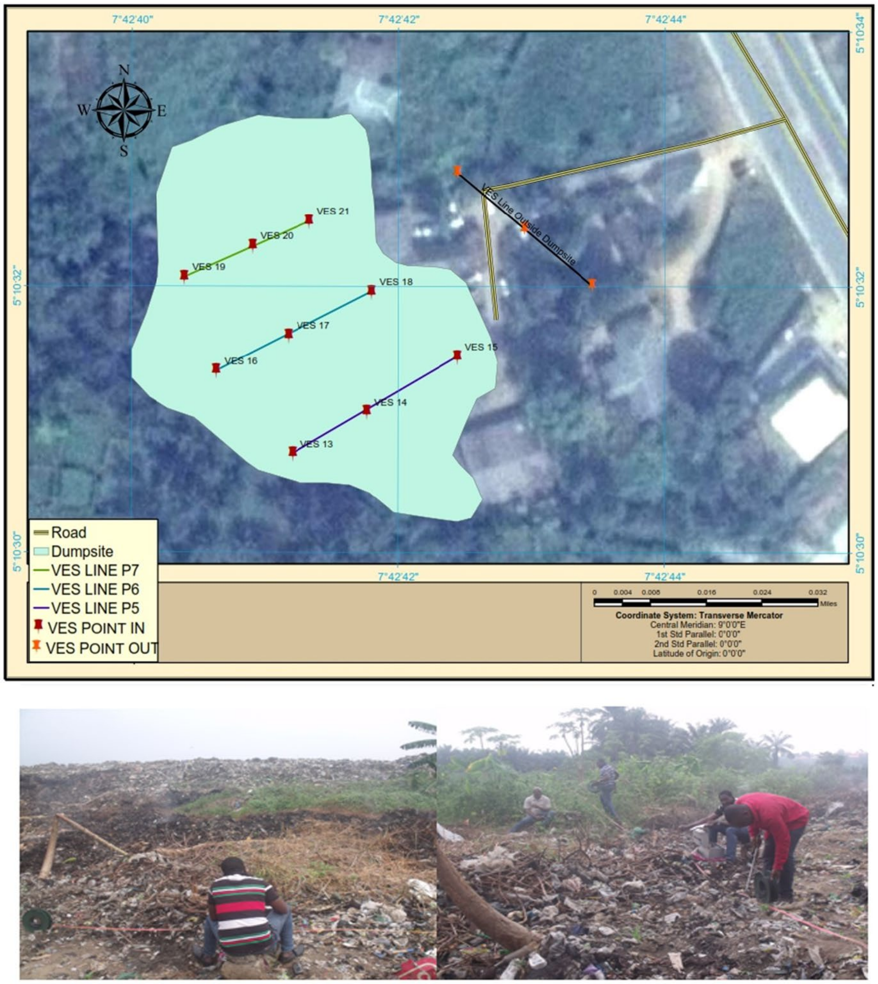
n_c and n_d are the resistivity sample sizes at the control and dumpsites respectively.

(a) *Statement of hypothesis*

H_0: There is no significant difference in the resistivity analysis between the control and dumpsites.

H_1: There is a significant difference in the resistivity analysis between the control and dumpsites.

Fig. 10 (continued)



(b) *The distribution of t and test criterion*

i. Distribution: $t \sim t_{n_c+n_d-2,1-\propto}$.

ii. Test criterion: Accept H_0 if $t_{\text{calculated}} \leq t_{\text{tabulated}}(t_{n_c+n_d-2,1-\propto})$; otherwise, reject.

Analysis and results

Analysis of variance estimates and results

$$\sum X_{ij}^2 = 125.554^2 + 111.941^2 + 93.861^2 + \cdots + 574.596^2$$
$$= 17,310,939.$$

$$SS_\mu = \frac{T^2}{ab} = \frac{560060623}{3 \times 20} = 9,334,343.72$$

$$SS_T = \sum X_{ij}^2 - SS_\mu$$
$$= 17,310,939 - 9334343.72$$
$$= 7,976,595.28$$

$$SS_t = \frac{\sum T_i^2}{b} - SS_\mu$$
$$= 12944107.2 - 9334343.72$$
$$= 3,609,763.48$$

$$SS_e = SS_T - SS_t = 7976595.28$$
$$- 3609763.48 = 4,366,831.8$$

$$F_{\text{calculated}} = 23.56,\ F_{tabulated} = F_{2,57,\ 0.05} = 2.39.$$

Observation and decision From Table 2, it is observed that $F_{\text{calculated}} > F_{\text{tabulated}}$. H_0 is rejected.

Fig. 10 (continued)

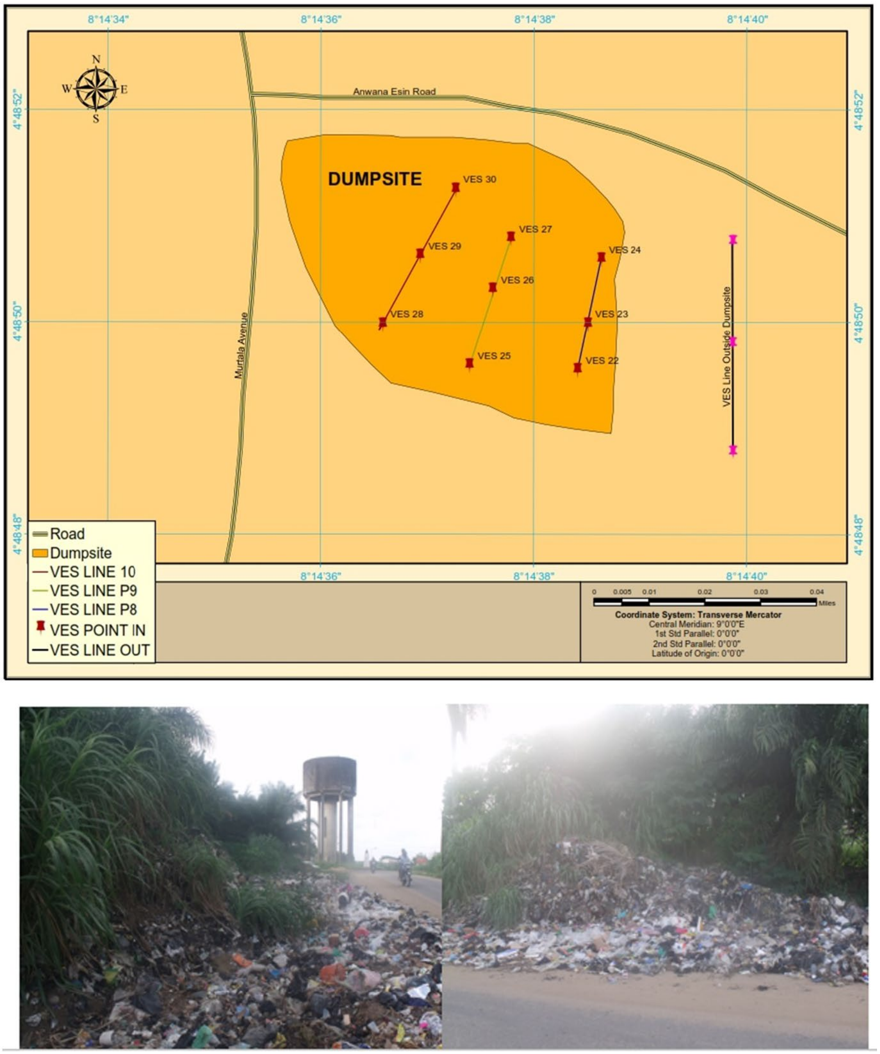


Table 1 ANOVA method

SV	DF	SS	MSS	*F*-ratio
Treatment	a-1	SS_t	SS_t/a-1	MSS_t/MSS_e
Error	a(b-1)	SS_e	SS_e/a(b-1)	
Total	ab-1	SS_T		

Table 2 ANOVA results

SV	DF	SS	MSS	*F*-ratio
Treatment	2	3,609,706	1,804,853	23.56
Error	57	4,366,870	76,612	
Total	59	7,976,576		

Hence, resistivity at the dumpsites of Uyo, Ikot Ekpene and Oron dumpsites is not the same.

Resistivity analysis of control and dumpsite

Uyo control and dumpsite

Basic statistical measures are as follows:

$\overline{x}_c = 619$ and $\overline{x}_d = 102.7, S_c^2 = 669,124$ and $S_d^2 = 102,201$, $n_c = 25$ and $n_d = 21$

$$s_{p=}\sqrt{\frac{(25-1)(669124)+(21-1)(102201)}{25+21-2}} = 641.4294$$

From Eq. (1), we have

$$t = \frac{619 - 102.7}{641.4292\sqrt{\frac{1}{25} + \frac{1}{21}}} = 2.7$$

$$t_{n_c+n_d-2,1-\alpha}) = t_{44,0.95} = 1.679$$

Observation and decision $t_{\text{calculated}} > t_{\text{tabulated}}$. H_0 is rejected. Hence, resistivity at the control site is greater than the resistivity at the dumpsite in Uyo.

Ikot Ekpene control and dumpsite

Basic statistical measures are as follows:
$\overline{x}_c = 1342.6$ and $\overline{x}_d = 693.5, S_c^2 = 7,569$ and $S_d^2 = 178,084$, $n_c = 22$ and $n_d = 20$

$$s_{p=}\sqrt{\frac{(22-1)(7569)+(20-1)(178084)}{22+20-2}} = 297.5964,$$

$$t = \frac{1342.6 - 693.5}{297.5964\sqrt{\frac{1}{22} + \frac{1}{20}}} = 7.0598$$

$$t_{n_c+n_d-2,1-\alpha}) = t_{40,0.95} = 1.684.$$

Observation and decision $t_{\text{calculated}} > t_{\text{tabulated}}$. H_0 is rejected. Hence, resistivity at the control site is greater than the resistivity at the dumpsite in Ikot Ekpene.

Oron control and dumpsite

Basic statistical measures include the following:
$\overline{x}_c = 711.3$ and $\overline{x}_d = 397.1, S_c^2 = 50,338.5$ and $S_d^2 = 43,237.5$, $n_c = 24$ and $n_d = 20$

$$s_{p=}\sqrt{\frac{(24-1)(50338.5)+(20-1)(43237.5)}{24+20-2}} = 149.3875,$$

$$t = \frac{711.3 - 397.1}{217.0855\sqrt{\frac{1}{22} + \frac{1}{20}}} = 4.70$$

$$t_{n_c+n_d-2,1-\alpha}) = t_{40,0.95} = 1.682.$$

Observation and decision $t_{\text{calculated}} > t_{\text{tabulated}}$. H_0 is rejected. Hence, resistivity at the control site is greater than the resistivity at the dumpsite in Oron.

Resistivity analysis of two locations

Statement of hypothesis

H_0: Resistivity at two dumpsites is equal.
H_1: Resistivity at one dumpsite is greater than the other.

Uyo and Ikot Ekpene dumpsites

Basic statistics are:
$\overline{x}_{\text{IK}} = 693.5$ and $\overline{x}_{\text{UYO}} = 102.7, S_{\text{IK}}^2 = 178,084$ and $S_{\text{UYO}}^2 = 10,180.81$, $n_{\text{IK}} = 20$ and $n_{\text{UYO}} = 21$

$$s_{p=}\sqrt{\frac{(20-1)(178,084)+(21-1)(10,180.81)}{20+21-2}} = 303.2817$$

From Eq. (1), we have

$$t = \frac{693.5 - 102.7}{303.2817\sqrt{\frac{1}{20} + \frac{1}{21}}} = 6.23$$

$$t_{n_{Ik}+n_{Uyo}-2,1-\alpha})) = t_{39,0.95} = 1.685.$$

Observation and decision $t_{\text{calculated}} > t_{\text{tabulated}}$. H_0 is rejected. Hence, resistivity at the Ikot Ekpene dumpsite is greater than the resistivity at the Uyo dumpsite.

ii. Uyo and Oron dumpsites

Basic statistics:
$\overline{x}_{\text{Oron}} = 397.1$ and $\overline{x}_{\text{UYO}} = 102.7, S_{\text{Oron}}^2 = 43237.5$ and $S_{\text{UYO}}^2 = 10,180.81$, $n_{\text{Oron}} = 20$ and $n_{\text{UYO}} = 21$

$$s_{p=}\sqrt{\frac{(20-1)(43237.5)+(21-1)(10,180.81)}{20+21-2}} = 162.1275$$

Therefore,

$$t = \frac{397.1 - 102.7}{162.1275\sqrt{\frac{1}{20} + \frac{1}{21}}} = 5.8119$$

$t_{n_{Oron}+n_{Uyo}-2,1-\propto)} = t_{39,0.95} = 1.685.$

Observation and decision $t_{\text{calculated}} > t_{\text{tabulated}}$. H_0 is rejected. Hence, resistivity at the Oron dumpsite is greater than the resistivity at the Uyo dumpsite.

iii. Ikot Ekpene and Oron dumpsites

Basic statistics:
$\bar{x}_{\text{IK}} = 693.5$ and $\bar{x}_{\text{Oron}} = 397.1, S^2_{\text{IK}} = 178,084$ and $S^2_{\text{Oron}} = 43237.5, \quad n_{\text{IK}} = 20$ and $n_{\text{Oron}} = 20$

$$s_{p=}\sqrt{\frac{(20-1)(178,084)+(20-1)(43237.5)}{20+20-2}} = 332.6571.$$

Therefore,

$$t = \frac{693.5 - 397.1}{332.6571\sqrt{\frac{1}{20}+\frac{1}{20}}} = 2.8176$$

$t_{n_{Ik}+n_{Oron}-2,1-\propto)} = t_{38,0.95} = 1.685.$

Observation and decision $t_{\text{calculated}} > t_{\text{tabulated}}$. H_0 is rejected. Hence, resistivity at the Oron dumpsite is greater than the resistivity at the Uyo dumpsite.

Hydrogeochemical analyses

The hydrogeochemical methodology within the study involves the collection of twelve (12) different underground water samples with the aid of clean water bottles, rinsed with ethanol and rinsed several times with incoming sample before the water was collected, to ensure that microbes are eliminated from the bottle and also to forestall the interference of the ethanol with the sample. A cotton wool soaked with ethanol is used to clean the tap and burn around the tap while collecting the sample. When the bottle is filled, it was capped and sealed around with masking tape. It was then preserved in a cooler with ice blocks and taken to the laboratory of Akwa Ibom State Water Company within 2 days for analyses. The collected samples were analysed for the physicochemical and microbiological characteristics standard practice of the World Health Organization (WHO).

Furthermore, the analysis of the anions was performed with an ultraviolet (UV) spectrophotometer, and the analysis of the cations was performed with an atomic absorption spectrometer (AAS). The titrimetric method was used to analyse a few parameters. Mercury-in-glass thermometers were used to measure temperature at in situ in the field, while pH and turbidity were measured in the field at in situ using portable pH metres and turbid metres.

Results and discussion

Statistical results

Analysis of variance of resistivity between Uyo, Ikot Ekpene and Oron dumpsites showed a significant difference, as the null hypothesis of equality of the three dumpsites was rejected. The *t*-tests carried out for Uyo control and dumpsite, between Ikot Ekpene control and dumpsite and between Oron control and dumpsite showed significant differences. These test results showed the effects of dumpsites on resistivity. Also, the *t*-tests carried out between each pair of Uyo and Ikot Ekpene dumpsites, between Uyo and Oron dumpsites and between Ikot Ekpene and Oron dumpsites revealed statistical significance. Hence, no each pair of the dumpsites has the same resistivity effects.

Physiochemical result

The physiochemical analysis shows that in Oron, borehole water near the dumpsite had lower temperature than that situated away from the dumpsite, temperatures being 25.7 °C and 31 °C respectively. High temperatures in water favour microbial activity. In Uyo, a borehole sited near the dumpsite had temperatures between 22.7 and 29.4 °C. Boreholes sited away from dumpsite (Table 3) show variable temperatures of 31.7 °C for Calabar Itu Road, 26.1 °C for Ewet Housing and 22.9 °C for Akpabio Street. In Ikot Ekpene, water sample from the Ikot Ekpene club shows ambient temperature of 22.9 °C and the borehole is sited close to the dumpsite. For Ikot Abia Idem in Ikot Ekpene local government area, the borehole is sited away from the dumpsite and shows an ambient temperature of 26.0 °C. In this research, it is observed that areas away from the dumpsite have almost the same range of temperature with those close to the dumpsite.

In addition, all samples near the dumpsite show very low pH (3.70–4.15) and this is attributed to

Table 3 Results of hydrogeochemical analysis (Udoh et al., 2021)

Parameters	IK club (DS1)	Murtala Way Oron (DS2)	64 UDO ST (DS3)	58 UDO ST (DS4)	68 UDO ST (DS5)	WHO (2017)
Appearance	Clear	Clear	Clear	Clear	Clear	Clear
Colour (ILU)	5	5	5	5		15
Odour	Unobjectionable	Unobjectionable	Unobjectionable	Unobjectionable	Unobjectionable	Unobjectionable
Temperature, °C	22.9	25.7	29.4	29.2	22.7	Ambient
pH	3.86	4.15	3.93	3.70	3.82	6.5–8.5
Turbidity (NTU)		0.28	0.50	0.00	1.17	5′
Iron (Fe^{3+}), mg/L	BD	0.08	BD	0.16	0.25	0.3
Salinity, %	0.5	0.06	0.00	0.1	0.1	0.50
Electricity conductivity, µs/cm	1022	1224	40.0	131.4	231	1000
Total dissolved solid, mg/L	480	574	16.4	79.3	110.1	500
Residual chlorine (d_2), mg/L						0.2–0.25
Manganese, mg/L	BD	BD	0.035	0.000	BD	-
Nitrates (NO_2), mg/L	0.015	0.01	0.06	−0.02(BD)	0.4	50
Nitrite (NO_2), mg/L	BD	BD	0.006	0.001	0.013	0.2
Ammonia (NH_3), mg/L	0.00	0.00	0.00	0.00	0.00	0
Phosphate (PO_1^{3}), mg/L	0.031	0.05	0.025	0.043	0.006	3.50
Suspended solid, mg/L	17	BD	8	15	BD	10
Total silica (SiO_2), mg/L	BD	BD	0.029	0.002	0.035	17
Sulphate (SO_1^{2}), mg/L	3.0	BD	5	3	5	1000
Total hardness, mg/L	220	130	36	46	32	500
Calcium hardness (Ca^2), mg/L	140	34	14.0	20	30	75.0
Magnesium hardness, mg/L	80	96	BD	BD	BD	0.2
Acidity, mg/L	0.04	0.8	0.04	0.64	0.08	4.5–8.2
Total alkalinity, mg/L	12	62.4	4.8	4.88	24	100–200
Chlorine demand, mg/L						0.2–0.25
Chloride (Cl), mg/L	0.1	BD	0.6	0.1	0.00	250
Methyl alkalinity, mg/L			4.8		2.4	100–200
Aluminium ($A1^{3+}$), mg/L	BD	BD	0.01	0.04	0.00	0.2
Selenium (Se), mg/L	0.02	BD	0.101	0.04	0.00	-

Table 3 (continued)

Parameters	IK club (DS1)	Murtala Way Oron (DS2)	64 UDO ST (DS3)	58 UDO ST (DS4)	68 UDO ST (DS5)	WHO (2017)
Phenolphthalein alkalinity, mg/L			0.0		0	0
Chromium (Cr^{61})	BD	0.00	0.0	0.01	0.01	0.05
Cadmium (Cd), mg/L	0	0.00	1	1	0.004	0.003
Copper (Cu^{2+}), mg/L	0	BD	0.17	0.12	0.17	1
Cyanide (CN), mg/L	0.00	BD	0.005	0.0	0.006	0.01
Lead (Pb), mg/L	BD	BD	0.6	0.0	0.003	0.01
Zinc (Zn), mg/L	0.01	BD	0	BD	0.05	3
Arsenic (As), mg/L			0.03			0.01
Barium, mg/L	BD	BD	7	7	BD	0.7
Fluoride (F), mg/L	0.00	BD	0.07	BD	0.01	1.5
Mercury (Hg), mg/L						-
Dissolved oxygen (O_2), mg/L	1.0	1.10	43.4	10.8	1.2	1.0–5.0

WHO, World Health Organization

Key symbols: *DS*, water sample from boreholes proximal to dumpsite; *BD*, below the detection limit

organic decomposition of waste and infiltration and percolation of by-products into the various locations near the dumpsite. It is observed that the sample from the Akpabio Street has the lowest pH being 3.26 which is highly acidic; all other samples have pH of about 5.0 which is a reflection of the natural water quality within Akwa Ibom State. The pH of the water is perhaps the best sign of leachate pollution; these pH values range from 3.7 to 4.2. According to Martins and Idowu (2020), low pH values may cause considerable amounts of clay minerals to dissolve and release abnormally high silica (and alumina) levels into the water, which is the main cause of the interpretation issue. Low pH values are also attributed to humic acid from decaying vegetative matter. Drinking low pH water (<4.0) could lead to redness and irritation of the eyes (WHO, 1996). Therefore, it is recommended that neutralising filter containing calcite or ground limestone be used to raise the pH of the groundwater before use by the population (Edet, 2017).

Furthermore, some areas albeit away from the dumpsite as Ikot Abia Idem have an iron level of 0.64 mg/L which is high and over the WHO's permitted limit, which states that specification for iron concentration in water should be 0.3 mg/L. However, all areas near the dumpsite show iron content within the permissible limit of 0.3 mg/L. High iron content in water decolourizes water and makes it unfit for drinking.

Most of the samples within and outside the dumpsite show calcium hardness content within specification of the WHO. Magnesium hardness is observed in high concentrations over the WHO's permitted limit, as seen in DS1 being 80 mg/L and DS2 being 96 mg/L. This perhaps may have occurred naturally in the water as seen in S1, being 100 mg/L in Table 4. Magnesium has no known negative health impact. Also, barium occurs in most water as a natural element in the terrain. Barium is responsible for most respiratory problems resulting in issues such as hypertension and heart attack. The result of the analysis shows that samples DS3 and DS4 have high amount of barium above the permissible limit of the WHO being 0.7 mg/L maximum. Nevertheless, the result of the analysis shows that most of the heavy metals were found in concentrations within the permissible limit

Table 4 Results of hydrogeochemical analysis of control sites

Parameters	45 Calabar Itu Road Uyo/S1	Ewet Housing Uyo/S2	3 Akpabio Street Uyo/S3	Ikot Abia Idem Ik/S4	Nkanga Road Ik/S5	Effiong Esang Oron/S6	WHO
Appearance	Clear	Clear	Clear	Clear	Cloudy	Clear	Clear
Colour (ILU)	5	5	5	5	5	5	15
Odour	Unobjection-able	Unobjection-able	Unobjection-able	Unobjection-able	Unobjection-able	Unobjection-able	Unobjec-tionable
Temperature, °C	31.7	26.1	29.9	26.0	27.1	31.9	Ambient
pH	5.7	5.09	3.26	5.58	6.67	5.19	6.5–8.5
Turbidity (NTU)	1.19	4.72	0.30	0.31	12.2	0.83	5′
Iron (Fe^{3+}), mg/L	BD	0.18	BD	0.64	0.11	0.02	0.3
Salinity, %	0.0	0.00	0.1	0.0	0	0.0	0.50
Electricity conductivity, µs/cm	4548	63.6	262	20.9	40.2	24.6	1000
Total dissolved solid, mg/L	18.8	30.9	127	8.4	16.4	9.7	500
Manganese, mg/L	BD	0.018	BD	BD	0.025	0.000	-
Nitrates (NO_2)	BD	0.06	0.04	BD	0.06	0.65	50
Nitrite (NO_2)	0.00	0.014	BD	0.07	0.004	0.008	0.2
Ammonia (NH_3)	0.02	BD	0.00	0.00	0.00	BD	0
Phosphate (PO_1^3), mg/L	BD	0.252	0.081	0.0023	0.089	0.136	3.50
Suspended solid, mg/L	20	BD	4	BD	12	17	10
Total silica (SiO_2), mg/L	BD	0.048	BD	BD	0.034	BD	17
Sulphate (SO_1^2), mg/L	0.0	8	5	2	8	8	250
Total hardness, mg/L	148	18	106	56	14	44	500
Calcium hard-ness (Ca^2)	48	52	56	58	16	48	75.0
Magnesium hardness, mg/L	100	0	50	BD	BD	BD	0.2
Acidity, mg/L	4	0.12	0.16	0.08	4	8	4.5–8.2
Total alkalin-ity, mg/L	13.2	6	10.8	18	9.6	25.2	100–200
Chlorine demand, mg/L	-	0.8	-	-	-	-	0.2–0.25
Chloride (CT), mg/L	BD	0.5	BD	0.1	0.8	0.6	250
Methyl alkalin-ity, mg/L	13.2	6	10.8	18	9.6	25.2	100–200

Table 4 (continued)

Parameters	45 Calabar Itu Road Uyo/S1	Ewet Housing Uyo/S2	3 Akpabio Street Uyo/S3	Ikot Abia Idem Ik/S4	Nkanga Road Ik/S5	Effiong Esang Oron/S6	WHO
Aluminium ($A1^{3+}$), mg/L	0.02	0.00	BD	0.00	0.05	BD	0.2
Selenium (Se), mg/L	0.01	0.01	0.01	BD	0.04	0.02	-
Phenolphthalein alkalinity, mg/L	0	0.005	0	0	-	0	0
Chromium (Cr^{61})	0.01	0.31	0.00	BD	0.00	0.01	0.05
Cadmium (Cd), mg/L	0.00	0.000	BD	BD	0.04	0.005	0.003
Copper (Cu^{2+}), mg/L	0.01	0.000	BD	0.16	0.001	0.02	1
Cyanide (n), mg/L	0.001	0.03	0.003	0.000	0.16	0.001	0.01
Lead (Pd), mg/L	BD	-	-	BD	0.004	BD	0.01
Zinc (Zn), mg/L	0.05		BD	0.05	0.08	0.01	3
Arsenic (As), mg/L	-		-	-	-	BD	0.01
Barium, mg/L	BD	4	0.05	BD	6	0.06	0.7
Fluoride (F), mg/L	0.00	BD	-	BD	BD	-	1.5
Mercury (Hg), mg/L		-	0.06	-	-	0.09	-
Dissolved oxygen (O_2), mg/L	0.9	0.2		0.2	0.1		1.0–5.0
Residual chlorine (Cl_2)		0.8	-				
Total coliform	60	4	130	0	160	6	
E. coli	5	0	20	0	10	2	

WHO, World Health Organization

Key symbols: *DS*, water sample from boreholes proximal to dumpsite; *BD*, below the detection limit

of the WHO. However, samples DS3 and DS4 show high level of cadmium above the permissible limit of the WHO. Cadmium is toxic to man and the kidney is the main target organ for cadmium toxicity (W.H.O., 2017). Cadmium enters the food chain through crops or water. The uptake of cadmium by roots depends mainly on the soil pH. The presence of cadmium in groundwater has been monitored in particular in certain intensively farmed regions (Kovalevsky et al., 2004). Moreover, the findings reveal that samples DS3 and DS4 have a significant amount of oxygen that has been dissolved and there is no health-based guideline value recommended by the World Health Organization (WHO, 2017), though very high levels of dissolved oxygen may exacerbate corrosion of metal pipes (Martins & Idowu, 2020).

Bacteriological analysis

The results of the analysis show that, with the exception of S4, every sample had high levels of bacterial contamination, with counts of *Escherichia coli* and total coliforms above the WHO's permitted limit. *Escherichia coli* is present in very high

Table 5 Results of 48-h water culture in (CFU) per 100 mL

Samples	NA	MAC	Factor	Average	Total	WHO
Ikot Abia Idem (Ikot Ekpene)	0	0	10^{-2}	0	0	0
Nkanga Road Nkap (Uyo)	0	10	10^{-2}	5	500	0
Effiong Esang (Oron)	2	0	10^{-2}	1	100	0
45 Itu Road (Uyo)	5	0	10^{-2}	2	200	0
Ewet Housing (Uyo)	0	0	10^{-2}	0	0	0
Akpabio Street (Uyo)	20	4	10^{-2}	12	1200	0

Table 6 Total coliform test—result of water culture at 48 h in CFU per 100 mL

Samples	NA	MAC	Average	Factor	Total	WHO
Ikot Abia Idem (Ikot Ekpene)	0	0	0	10^{-2}	0	0
Nkanga Road Nkap (Uyo)	160	150	130	10^{-2}	1300	0
Effiong Esang (Oron)	6	2	4	10^{-2}	400	0
Itu Road (Uyo)	60	50	50	10^{-2}	5000	0
Akpabio Street	4	3	3	10^{-2}	300	0

Table 7 Test for total coliform—report of water culture in (CFU) per 100 mL at 48 h

Samples	MAC	NA	Average	Factor	Total	WHO
Murtala way (Oron)	20	60	40	10^{-2}	4000	0
Ikot Ekpene club	0	3	1	10^{-2}	100	0

Table 8 Total coliform test—result of water culture for 48 h in CFU/100 mL at Oron/Ikot Ekpene

Samples	NA	MAC	Average	Factor	Total	WHO
(Oron)Murtala way	0	0	0	10^{-2}	0	0
Ikot Ekpene club	0	0	0	10^{-2}	0	0

numbers in human and animal faeces and is rarely found in the absence of faecal pollution, although there is evidence for growth in tropical soils. The objective of zero *E. coli* per 100 mL of water is the goal for all water supplies and should be the target even in emergencies (W.H.O., 2008) (Table 5, 6, 7 and 8). To preserve people's health, extensive borehole treatment must be carried out due to the significant health concerns involved.

The most frequent and ubiquitous health concern associated with drinking water is microbial contamination; therefore, maintaining control over it is always crucial (WHO, on guidelines for drinking water quality, 2008). Illnesses brought on by contaminated drinking water have a significant financial impact to human health. Better drinking water quality has considerable health benefits (WHO, 2008).

Summary and conclusion

Domestic and industrial activities produced million tons of wastes that were dumped in the three solid waste dumping sites. Other municipal and liquid wastes were also placed in these dumps. Leachate, generated by rainfall and surface water percolating through the waste, has polluted adjacent aquifers, the principal source of drinking water for the local community surrounding the dumpsites. The hydrogeochemical characteristics of leachate from dumpsites were determined in order to ascertain its potential ability to contaminate groundwater resources by using water samples. Experiments on water of surrounding boreholes of the dump indicated higher total dissolved solids (TDS), a lower pH and higher electrical conductivity (EC). Earth resistivity, measured at the surface, has the potential to noninvasively detect this contaminated groundwater.

Conventional drilling and direct sampling methods have limitations in terms of spatial coverage, the size of the sampled volume and the sampling density even if they can generate exceptionally accurate data. But when dealing with contaminated locations where accurate characterisation is essential, all direct sampling procedures have the potential to spread contaminants, posing a risk to both personnel and the environment.

Recommendations

This study hereby proposes a strategy for averting a future garbage crisis that receives nearly unanimous approval, at least in theory, in the face of opposition from citizens and environmentalists to all sorts of open dumps and incinerators: recycling. From a local perspective, recycling initiatives decrease the demand for additional landfills and incinerators by reducing the amount of waste that must be disposed of. In a broader sense, recycling protects natural resources like trees and metal-bearing ores while also reducing energy use.

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Author contribution Abraham Udoh was responsible for the acquisition of the original field geophysical (electrical resistivity) and hydrogeochemical data. Anthony Usoro generated statistical data from the geophysical data and Ifeanyi Chinwuko carried out hydrogeochemical interpretation. All authors reviewed the manuscript.

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Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication I declare that all of the data and material are owned by the authors and no permissions are required.

Competing interests The authors declare no competing interests.

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