



Geophysical and hydrophysical evaluation of groundwater around the Igbenre Ekotedo dumpsite Ota, Southwest Nigeria, using correlation and regression analysis

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Abstract

A study involving geophysical survey and groundwater analysis was carried out at the Igbenre Ekotedo dumpsite in Ota, Southwest Nigeria. The aim was to monitor and track the depth of leachate contamination around the dumpsite. A proposed simple multiple linear regression (MLR) model of groundwater total dissolved solids (TDS) was also developed. This was achieved by correlating the observed TDS of groundwater samples collected within and around the vicinity of the dumpsites with multiple terrain conductivity data derived from a geophysical method. The results of the electrical resistivity tomography (ERT) obtained along four profile lines in August 2014, and a time-lapse survey in December 2015 delineated leachate plumes as low-resistivity zones ranging between 0.54 and 12.5 Ω m around the dumpsite, with good correlation between the wet and dry season models. The results also showed that leachate from the decomposed refuse materials has polluted the subsurface under the dumpsite from the surface to a depth of about 45 m, and by extension contaminating groundwater aquifer around the area. Results from the electromagnetic (EM-34) experiment and groundwater TDS parameters from seven (7) boreholes around the vicinity of the EM profiles showed a strong positive correlation. Therefore, a simple multiple linear regression (MLR) TDS model that relates the TDS data obtained from boreholes to the geophysical parameters obtained from the EM-34 data (HD 20, HD 40, and VD 40) was developed for the purpose of efficient groundwater resources monitoring and management around the dumpsite and their communities. The predictive power of the developed MLR TDS model was also appraised to determine the feasibility of using the TDS model to predict and estimate groundwater TDS around the study area. The developed TDS model can be reliably deployed for groundwater TDS estimation and monitoring around the study area where there are no boreholes, but with only terrain conductivity data. However, where there are borehole and hand-dug wells, terrain conductivity data around the area alone can be applied to the model to determine TDS concentration in groundwater, thus reducing the time and cost of determining and monitoring both parameters independently.

Keywords Terrain conductivity · Linear regression · Groundwater · Imaging · Contaminants

Introduction

The Igbenre Ekotedo dumpsite in Ota is one of the numerous dumpsites located in Ogun State. The dumpsite is characterized by indiscriminate dumping of refuse materials, heavy

burning of wastes by scavengers, and bad odor diffusing into the environment as a result of the breakdown of the biodegradable component of the wastes. Public concern regarding the pollution of the atmosphere as a result of constant burning and smelting of metallic wastes, and contamination of soil and groundwater by leachates (contaminants) emanating from the dumpsite has recently increased in the area. As a way of understanding the gravity of the challenge associated with the community, this study was designed to investigate the extent of the impact of the contaminants on the subsurface environment. Because of the need to continually gather information on the subsurface distribution of contaminants around the many dumpsites scattered around Nigeria, a combination of geophysical survey and groundwater physicochemical studies

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was carried out at the dumpsite. The aim was to monitor and track the depth of leachate contamination around the dumpsite and to develop a simple MLR model of groundwater TDS, by correlating the observed TDS of groundwater samples collected within and around the vicinity of the dumpsites with the multiple terrain conductivity (HD 40, VD 20, and VD 40) data derived from a geophysical method. The electromagnetic (EM) induction method provides fast and low-cost detection of many subsurface waste materials, which change the electrical conductivity where they are deposited. The electromagnetic (EM) induction technique employs a quick and less expensive means of delineating many subsurface waste materials, which change the conductivity where they are deposited (Ayolabi et al. 2014). Surface inductive terrain-conductivity surveys are used to detect conductive features such as buried metal objects, ore bodies, and fluid-filled features and to map conductive plumes, such as landfill leachate or saltwater intrusion (Frischknecht et al. 1991; Grady and Haeni 1984; McNeill 1980; Powers et al. 1999). The electrical resistivity method, on the other hand, measures variation in subsurface resistivity when a current is injected into the earth. Usually, the methods are not used to detect contamination directly, but rather, they reveal contamination through sharp variation in subsurface resistivities as a result of the presence of these contaminants. The electrical resistivity methods are increasingly being deployed in contamination study due to their ability to discriminate between the contaminated zones and the areas free of contamination (Ameloko et al. 2018). The electrical resistivity method is most frequently used in environmental studies because the electrical resistivity of earth materials is determined by parameters such as fluids, conductivity of the matrix, porosity, permeability, temperature, degree of fracturing, grain size, degree of cementation, rock type, and the extent of weathering of the medium (Idornigie et al. 2006; Olorunfemi 2001). General complaint by residents regarding the contamination of soil and groundwater by leachates (contaminants) emanating from the dumpsite has also increased in the area. There is, therefore, the need for constant information on the status of groundwater quality around such a dumpsite. One of the ways by which this can be achieved is through the characterization of groundwater quality and the establishment of the degree of relationship among water quality parameters and geophysical survey parameters to assist in groundwater quality monitoring and prediction.

The study area

The Igbenre Ekotedo dumpsite is located in Ota, along the Sango-Idiroko road (Figs. 1 and 2). It is about 800 m away from the major express road by the High Court, opposite Nestle Company. The landfill is bounded by residential buildings and a very deep gully. Currently, waste is

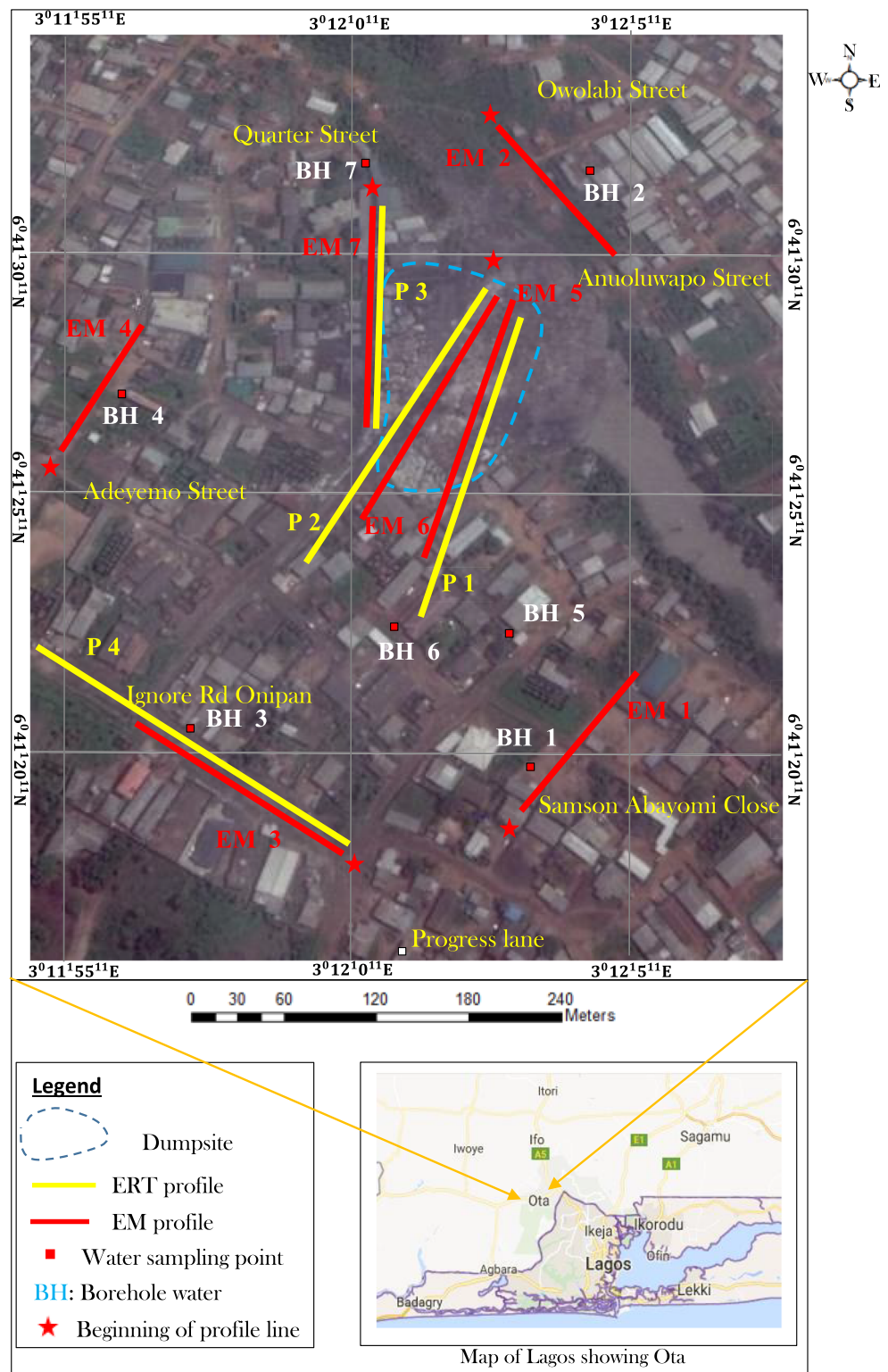
indiscriminately being dumped on the ground surface, without any compaction effort in the site, and all the waste piles usually undergo some degree of heavy burning. Geologically, the study area falls within the sedimentary Basin of southwestern Nigeria popularly called the Dahomey Basin (Fig. 3). The Dahomey Basin constitutes part of the system of West African precratonic (marginal sag) Basin developed during the commencement of rifting, associated with the opening of the Gulf of Guinea in the early Cretaceous to late Jurassic. The Basin is very extensive and consists of Cretaceous Tertiary sedimentary sequence that thins out on the east and is partially cut off from the sediment of the Niger Delta Basin by the Okitipupa ridge. In general, rocky outcrops are poor due to the thick vegetation and soil cover. The knowledge of the geology of this Basin had been improved through the availability of boreholes and recent road cuts. Major lithological sequences associated with the Basin are Abeokuta Formations (Ise, Afowo, and Araromi Formations) and Ewekoro, Akinbo, Oshoshun, Ilaro, and Benin Formations. The lithology is composed of loose sediment ranging from silt, clay, and fine to coarse-grained sand, called coastal plain sand. The exposed surface consists of poorly sorted sands with lenses of clays. The sands are in, part, cross-bedded and show transitional to continental characteristics (Jones and Hockey 1964; Omatsola and Adegoke 1981; Agagu 1985; Enu 1990; Nton 2001).

Materials and methods

Geophysical method

The 2D ERT survey was carried out with the aid of a digital readout Super Sting R8 Earth Resistivity/IP meter along four traverses, using a multi-electrode system with 84 electrodes (Fig. 1). To achieve the objectives of this research work, a 1-year 7-month-long ERT experiment was carried out on and around the dumpsite in May 2014 (wet season) and a time-lapse survey in December 2015 (dry season). The 2D resistivity data were obtained using dipole-dipole and pole-dipole arrays with the spacing of electrodes dependent on the level of accessibility on and around the dumpsite. The choice of the electrode arrays was to enable maximum depth of investigation, good horizontal resolution, and data coverage (Loke and Barker 1996). The 2D data were processed and inverted using the Earth Imager inversion algorithm. The algorithm calculates the apparent resistivity values using forward modeling subroutine (AGI 2003). It generates the inverted resistivity-depth image for each profile line based on an iterative smoothness constrained least-squares inversion algorithm (Loke and Barker 1996). Generally, the program automatically creates a 2D model by dividing the subsurface into rectangular blocks (Loke and Barker 1996), and the resistivity of the model blocks was iteratively adjusted to reduce the difference

Fig. 1 Data acquisition map showing location of dumpsite



between the measured and the calculated apparent resistivity values (a measure of this difference is given by the root mean squared (RMS) error).

EM measurements were collected using the Geonics EM-34 ground conductivity meter. The instrument measures terrain conductivity rather than resistivity. It employs

electromagnetic (inductive) techniques to measure the field strength and phase displacement of subsurface features. EM data can be collected in the vertical and horizontal dipole configurations. Thus, it allows for two depth determinations and average soil conductivities. The coil spacing pairs and frequency of operation are 10, 20, and 40 m and 6400,



Fig. 2 Pictorial view of Igbere Eko-tedo dumpsite, Ota

dumpsite were analyzed for the content of their total dissolved solids (TDS), pH values, hardness, and electrical conductivity (EC). The water samples were collected around the vicinity of the EM profile lines to enable the TDS correlation with the EM data. The samples were collected in a bowl, and these properties were measured in situ with the aid of a portable EC/TDS meter. Global Positioning System (Garmin GPS Channel 76 model) was used to take the coordinates of the sampling locations. The values of the predicted TDS, HD 20, HD 40, and VD 40 data were interpolated using the ArcGIS software to produce the subsurface spatial distribution maps of the area.

1600, and 400 Hz, respectively. A total of 7 profile lines with length ranging between 130 and 200 m were traversed depending on available space around the study area. Profiles 1–3 were carried out within the vicinity of the dumpsite, while four profiles (4–7) were carried out at varying distances away from the dumpsite and meant to serve as a control (Fig. 1). Along each profile, vertical and horizontal dipole measurements were collected.

Hydrophysical method

To ascertain the level of impact of the contaminants from the dumpsite on the water-bearing aquifer units around the study area, seven (7) borehole water samples within and around the

Multiple linear regression analysis

In multiple linear regression, more than one independent variable is included in the regression model. Multiple regression examines how two or more variables act together to affect the dependent variable. The correlation and regression analysis module of the Microsoft Excel, 2010 Statistical Package was utilized for this analysis. For correlation analysis, Pearson’s product-moment correlation was employed, while the regression analysis was achieved using Microsoft Excel’s MLR statistical tools.

Mathematically, the correlation coefficient is defined as:

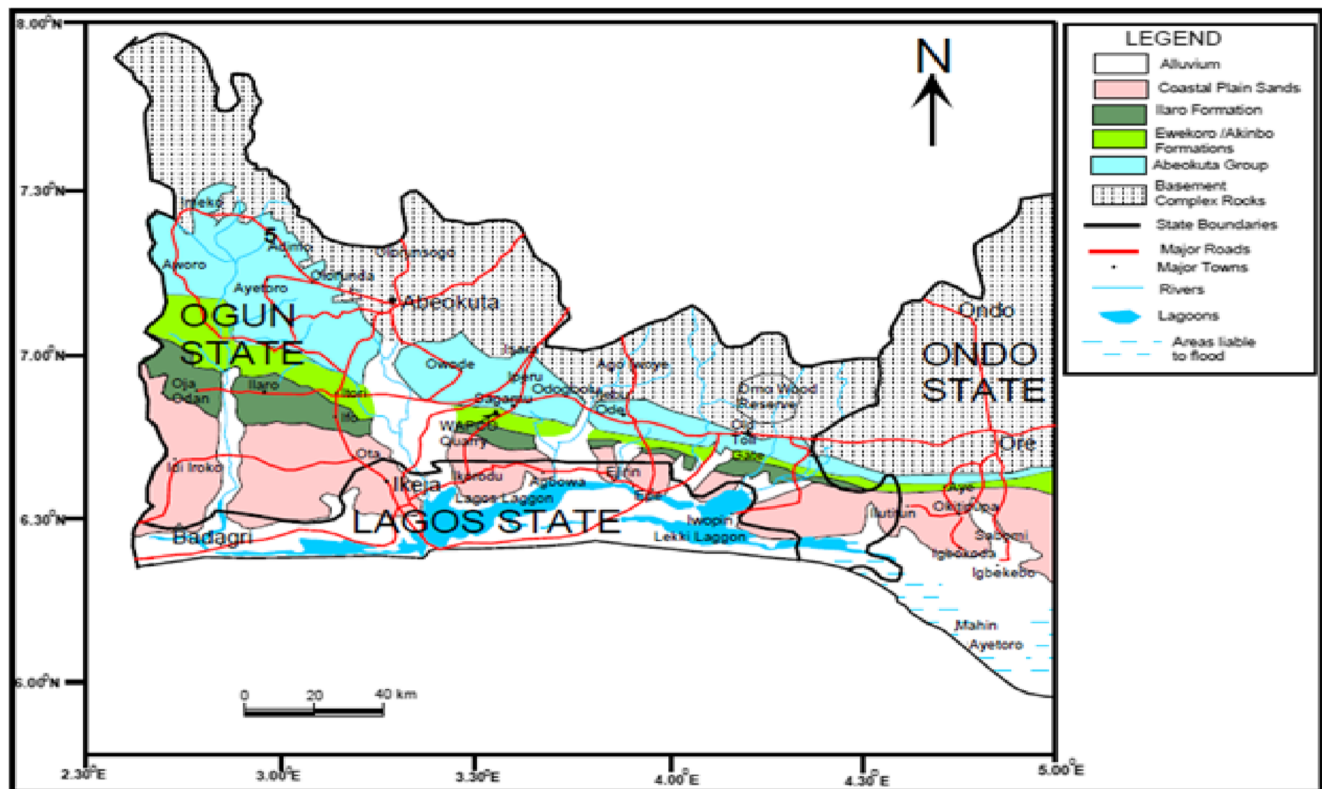


Fig. 3 Geological map of eastern Dahomey Basin (modified after Jones and Hockey 1964)

$$r = \frac{N\sum XY - (\sum X)(\sum Y)}{\sqrt{[N\sum X^2 - (\sum X)^2][N\sum Y^2 - (\sum Y)^2]}} \quad (1)$$

where:

N = number of pairs of scores

$\sum xy$ = sum of the products of paired scores

$\sum x$ = sum of x scores

$\sum y$ = sum of y scores

$\sum x^2$ = sum of squared x scores

$\sum y^2$ = sum of squared y scores

Considering the generalized multiple linear regression:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_n X_n + \eta_i \quad (2)$$

where:

Y = Dependent variable predicted by regression model

β_0 = Intercept of the regression line

β_1 through β_n are slopes of the regression line

X_1 through X_n are the independent variables

η_i = the error term

The correlation and multiple linear regression analyses were conducted to investigate the relationship between terrain conductivity (EC) and TDS of groundwater quality parameters measured around and within the dumpsite. The EC constituents (HD 40, VD 20, and VD 40) were considered as independent variables, while TDS was considered as the dependent variable for the development of the multiple linear regression model in this study. The entire terrain conductivity parameters were initially used for the regression analysis, but the HD 10, HD 20, and VD 10 parameters did not contribute positively to the predictive power of the model and were therefore not statistically significant.

Results and discussion

Figures 4, 5, 6, and 7 show the resistivity sections from the independent inversion of the dipole–dipole and pole-dipole resistivity data sets acquired in May 2014 and December 2015. With all inversion parameters kept the same, the time-lapse inversion of data set obtained in December 2015 was performed with the independent inversion result for the data set acquired in May 2014 used as a reference model. A general look at the inverted reference models and the time-lapse

models shows some level of consistency in the distribution of resistivity of the subsurface with the wet and dry season models. Half of traverse 1 lies on the dumpsite while the remaining part lies outside of the dumpsite. From the model, it is clearly shown that the subsurface under the dumpsite has been impacted by the leachates resulting from the decomposition of the waste products on the dumpsite. Considering information from borehole log obtained around the area and the depth impacted by the leachates (about 30 m) at this point, the aquifer around this area may have been contaminated by leachate from the waste materials. The region from the 72-m mark to the end of the profile, with high resistivity values ranging from 153 to 1000 Ω m, represents lateritic material around this area. The traverse here indicates that the lateritic materials (with low permeability) may have been excavated before the commencement of dumping. This act may have been responsible for the direct exposure of the underlying aquifer to the contaminants. Results from the time-lapse study showed an increase in depth of contamination to about 32 m in 2015. The independent inversion of the reference and the time-lapse data revealed a similar pattern of resistivity distribution on the dipole-dipole and the pole-dipole profiles acquired during the wet and dry seasons. However, a slight increase in the resistivity during the dry season is observed in the first half of the sections impacted by the contaminants from the dumpsite. This is most prominent on the dipole-dipole sections at shallower depth with also a slight increase in resistivity observed on the pole-dipole sections at greater depth (Fig. 4a and b). Profile 2 also shows a strong correlation in resistivity distribution on the dipole-dipole and the pole-dipole profiles. From this traverse, there is also clear evidence of leachate migration from the initial depth of contamination of 30 m in 2014, to a new depth of about 45 m in 2015 (Fig. 5c and d). The absence of the anomaly on only the dipole-dipole section of 2014 (Fig. 5a) could be attributed to factors such as seasonal variation of the moisture content of the surveyed subsurface rock materials, changes in fluid conductivity and the varying temperature of the subsoil. It could also be attributed to noise associated with the data along this profile. The medium resistivity unit (20–153 Ω m) represents the sandy aquifer units in this area, as observed from the borehole log. The inverted resistivity section along this traverse also indicates that there was probably an excavation of the lateritic materials around this area before the commencement of dumping.

Profile 3 was recorded about 5 m away from the dumpsite along the road (Figs. 1 and 6). This traverse is about 168-m long with orientation approximately north-south in direction. The low-resistivity unit (0.54–12.5 Ω m) associated with this profile is indicative of aquifer contamination by the leachate from the decomposing refuse materials on the adjacent dumpsite. The time-lapse inversion result along this profile also showed an increase in the depth of pollution from about 30 m in 2014 to about 42 m in 2015 (Fig. 6c and d). This trend

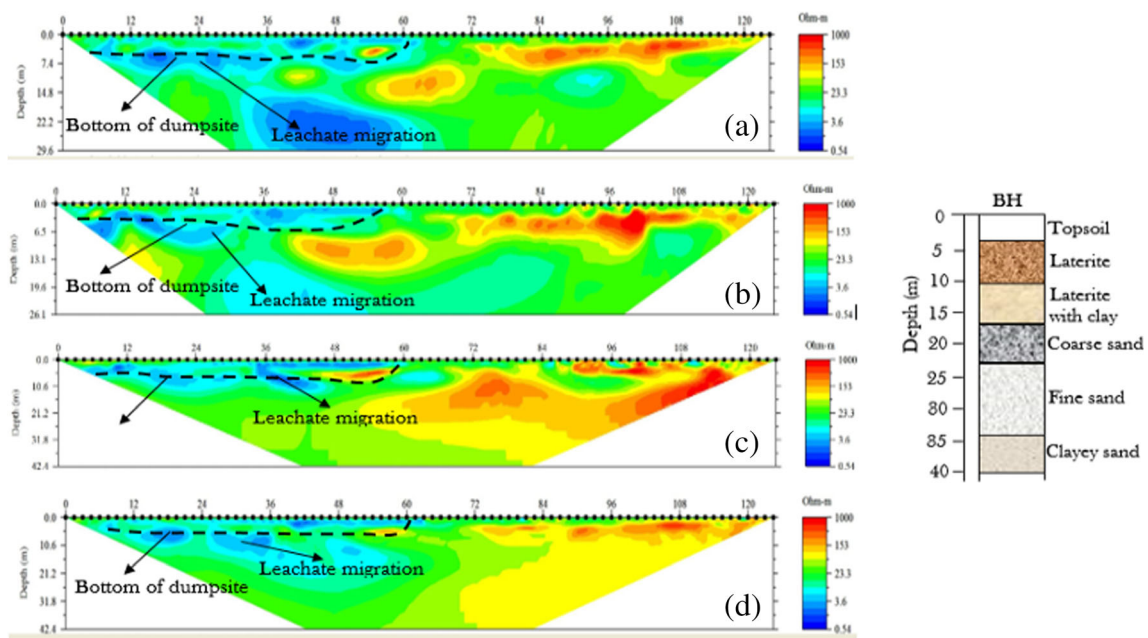


Fig. 4 Resistivity models obtained from the individual inversion of dipole-dipole (a, b) and pole-dipole (c, d) measured in May 2014 and December 2015 respectively along profile 1

is likely to continue if dumping activities are not stopped and environmental remediation steps are taken.

Profile 4 was acquired about 100 m away from the dumpsite, along the Igbenre road, towards the south-western boundary of the dumpsite, to validate the interpretation of data obtained on the dumpsite (Figs. 1 and 7). This traverse is about 420-m long, with orientation approximately in the northwest-southeast direction. The subsurface beneath this traverse is characterized by

resistivity values ranging between 0.54 and 1000 Ω m. The topsoil of sandy clay composition here extended from the surface to a depth of 5 m and characterized by resistivity values between 20 and 88 Ω m. This traverse was used to validate the interpretation of profiles acquired on the dumpsite. As seen from this profile, the absence of low resistivity at the shallow depth implies that contaminants generated on the dumpsite may have been responsible for the predominant low resistivity associated with the other

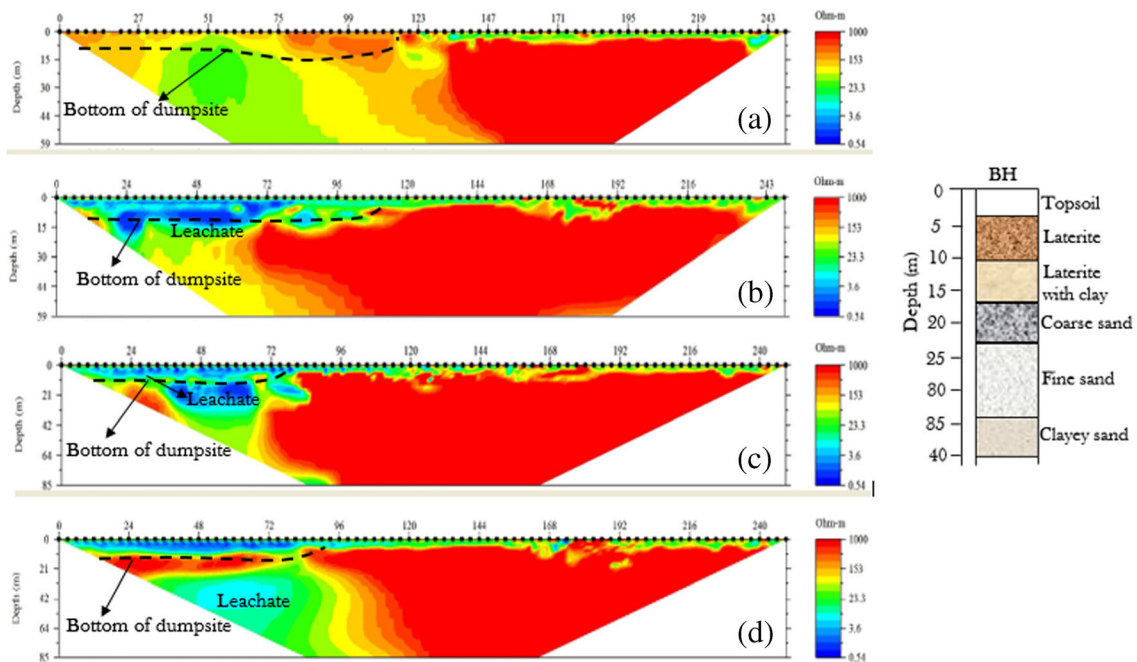


Fig. 5 Resistivity models obtained from the individual inversion of dipole-dipole (a, b) and pole-dipole (c, d) measured in May 2014 and December 2015 respectively along profile 2

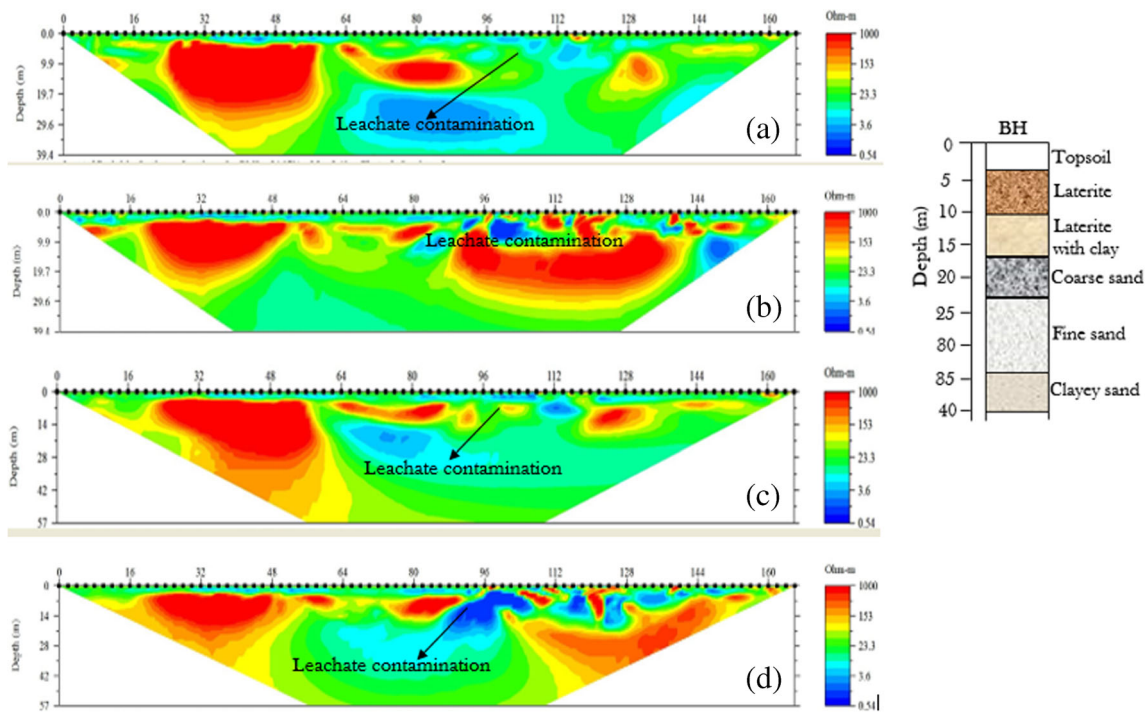


Fig. 6 Resistivity models obtained from the Individual Inversion of dipole-dipole (a, b) and pole-dipole (c, d) measured in May 2014 and December 2015 respectively along profile 3

models. Seasonal variation along this profile shows significant correlation with each other.

The time-lapse analysis of the ERT results showed that there is a steady vertical migration of the leachate materials

into the subsurface environment. Generally, the dry season models are associated with a slight increase in resistivity of the deeper areas. This could have been the result of moisture content variation influenced by seasonal fluctuations of the

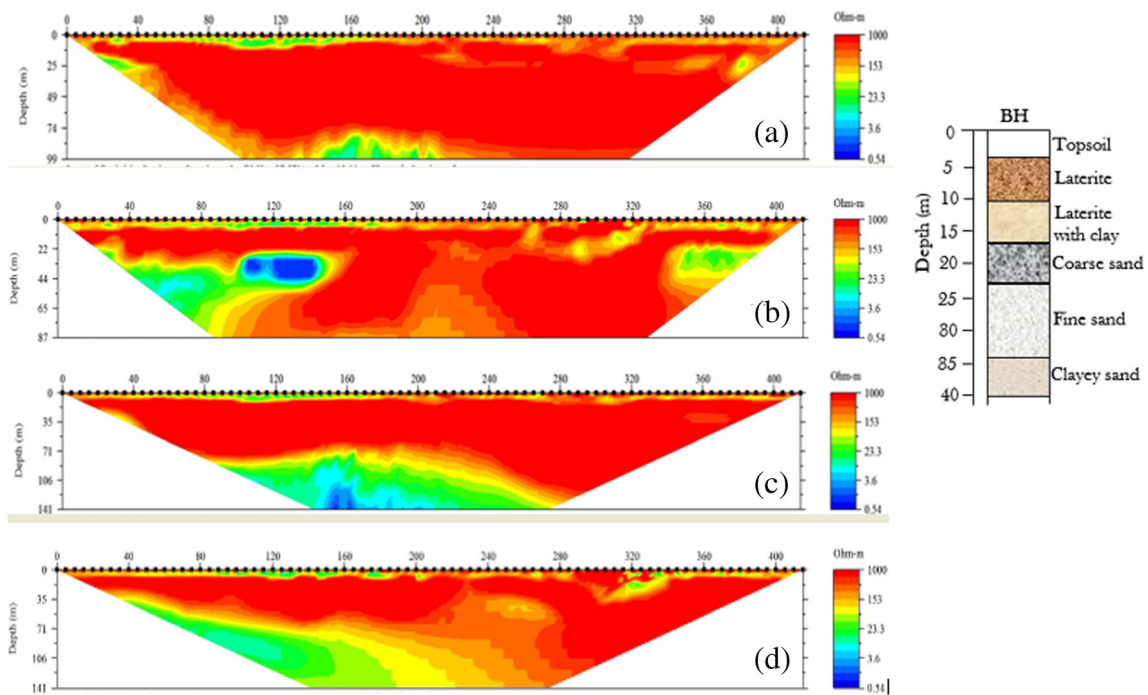


Fig. 7 Resistivity models obtained from the individual inversion of dipole-dipole (a, b) and pole-dipole (c, d) measured in May 2014 and December 2015 respectively along profile 4

water-table (Figs. 7c and d). The low resistivity region on the dipole-dipole model of 2015 (Fig. 7b) along the 100 m to about 135-m mark and depth range of 22 to 45 m may be an artifact resulting from noise in the data.

Multiple linear regression TDS model development

The mean values of the measured terrain conductivity and the observed groundwater TDS parameters within and around the dumpsite, utilized for the correlation and multiple regression analysis, are presented in Table 1. From the summary of the multiple linear regression model using the Microsoft Excel's MLR statistical tools (Table 2), the coefficients, $\beta_0 = -452.78$, $\beta_1 = 2.27$, $\beta_2 = 1.22$, and $\beta_3 = 7.19$, were obtained. The entire terrain conductivity parameters were initially used for the regression analysis but the HD 10, HD 20, and VD 10 parameters did not contribute positively to the predictive power of the model and were therefore not statistically significant.

The multiple linear regression model is therefore expressed as:

$$Y = \beta_0 + \beta_1(\text{HD } 40) + \beta_2(\text{VD } 20) + \beta_3(\text{VD } 40) \quad (3)$$

where:

YTDS obtained from borehole water within and around the site.

HD 40 Horizontal dipole mode data obtained at 40-m coil spacing.

VD 20 Vertical dipole mode data obtained at 20-m coil spacing.

VD 40 Vertical dipole mode data obtained at 40-m coil spacing.

Therefore, substituting the coefficients into Eq. 3, the multiple linear regression equation becomes:

$$\begin{aligned} \text{TDS} = & -452.78 + 2.27(\text{HD } 40) + 1.22(\text{VD } 20) \\ & + 7.19 (\text{VD } 40) \end{aligned} \quad (4)$$

Equation 4 is a MLR equation having TDS as the dependent variable and HD 40, VD 20, and VD 40 as the multiple independent variables. Hence, Eq. 4 is established as the proposed multiple linear regression TDS model developed for the study area. Making use of the MLR TDS model, we have predicted values of TDS as shown in Table 3.

Sensitivity analysis result of the developed MLR TDS model

The sensitivity analysis carried out on the developed MLR TDS model is to evaluating the significance of the parameters. Table 2 presents the parameters' evaluation results of the developed MLR TDS model. This is with a view to evaluate the importance of the independent variables in modeling the groundwater TDS estimate in the area. As shown in Table 2 and Eq. 4, the positive sign of the beta coefficients and the t values of HD 40, VD 20, and VD 40 indicate that a positive relationship exists between TDS values and the terrain conductivity values obtained using the HD 40, VD 20, and VD 40 coil spacing. The high absolute t -stat value of HD 40 (9.04) and the small P value (0.00286) suggest that the HD 40 values are very important variables in the prediction of the TDS of the groundwater within and around the dumpsite. Also, the F statistics have a P value well below 0.5 or 0.1 (0.000447) for the 95% confidence level. So we can say that the model is statistically significant. The adjusted R square indicates that the model accounts for 99.1% of the variance in the TDS concentration of the groundwater around the study area. The TDS model can also be used reliably for estimating TDS content in groundwater in the non-investigated part of the Igbenre Ekotedo if the required HD 40, VD 20, and VD 40 parameters in the study area are known.

Appraisal of model prediction accuracy

The predictive power of the developed MLR TDS model was also appraised to determine the feasibility of using the TDS model to predict groundwater TDS around the study area. Neil and Fenton (1996) and Koutsoyiannis (1977) suggested

Table 1 Observed mean terrain conductivity and TDS parameters from the study area

EM-34	Coordinate	HD 10 (mS/m)	HD 20 (mS/m)	HD 40 (mS/m)	VD 10 (mS/m)	VD 20 (mS/m)	VD 40 (mS/m)	TDS (mg/l)
Traverse 1	6° 41' 21.67" N 3° 12' 03.89" E	49.59	18.44	35.35	38.82	28.50	49.80	30
Traverse 2	6° 41' 22.27" 3° 11' 56.49" E	29.0	19.38	45.47	20.71	48.06	47.59	32
Traverse 3	6° 41' 33.24" N 3° 12' 07.49" E	38.76	48.5	34.29	19.53	36.69	51.35	35
Traverse 4	6° 41' 33.90" N 3° 11' 55.36" E	8.40	56.18	54.06	10.39	45.59	41.22	45
Traverse 5	6° 41' 29.64" N 3° 11' 57.41" E	125.62	250.46	37.72	56.46	159.08	42.27	136
Traverse 6	6° 41' 29.34" N 3° 11' 59.89" E	153.0	256.38	123.45	41.46	140.15	41	275
Traverse 7	6° 41' 28.91" N 3° 12' 01.97" E	168.54	297.92	212.29	38.85	230.67	51.64	692

Table 2 Summary statistics for regression model using all data variables

	Coefficients	Standard error	t Stat	P value	Lower 95%	Upper 95%
Intercept	-452.77828	95.5172	-4.74	0.01780	-756.757	-148.79
HD 40 (mS/m)	2.2714931	0.25139	9.036	0.00286	1.471446	3.07154
VD 20(mS/m)	1.2248831	0.21199	5.778	0.01030	0.550235	1.89953
VD 40(mS/m)	7.1974685	2.04024	3.528	0.03870	0.704504	13.6904

a systematic measure of accuracy for any forecast obtained from a model. This measure is called the Theil inequality coefficient, which is given by;

$$Y = \frac{[\sum_{i=1}^n (X - X_i)^2]^{1/2}}{[\sum_{i=1}^n X_i^2]^{1/2}} \tag{5}$$

where X_i is the observed TDS obtained from groundwater within and around the dumpsites, X is the corresponding predicted TDS from the TDS model (Table 3), and Y the Theil inequality coefficient. Equation (5) was used to measure the prediction accuracy of the TDS models. The determined Theil's inequality coefficient Y value for the model is 0.014. The closer the value of Y is to zero, the better the predictive power of the developed MLR TDS model. A value of 1 means the forecast is no better than a naive guess. The result obtained confirmed the reliability and accuracy of using the TDS model to predict groundwater TDS in the non-investigated parts in the study areas.

Spatial distribution of estimated TDS and EM34 data

Based on the records in Table 3, the predicted TDS from the MLR TDS model was interpolated using the Kriging technique to produce the TDS prediction map of the area

Table 3 Record of the observed and predicted TDS

S/n	Observed TDS (mg/l)	Predicted TDS (mg/l)
1	30	21
2	32	52
3	35	40
4	45	23
5	136	132
6	275	294
7	692	684

(Fig. 8a). It was observed from the model map that the TDS in groundwater for the study area varies between 20.06 and 681 mg/l. The visual interpretation of Fig. 8a using the legend zoning class values shows that the TDS observed around the dumpsite shows a decrease in concentration from the dumpsite to the surrounding groundwater. It is also an indication that the groundwater at proximity to the dumpsite has a high concentration of TDS than those farther away from the dumpsite. The high values of TDS observed around the dumpsite could be attributed to the high level of impact of the leachate from the decomposed materials on the dumpsite. The spatial distribution of TDS shows a general decrease towards the southern, northwestern, and northeastern parts of the mapped area. In contrast, the central portion of the map shows an intermediate concentration of TDS. The relatively high values of TDS concentration are associated with the dumpsite and regions very close to the dumpsite.

Figure 8b to d show the contour plots of subsurface apparent conductivity distribution generated using the HD 20, HD 40, and VD 40 data, respectively. The HD 20 plot (Fig. 8b) shows apparent conductivity values that range from 18.44 to 279.91 mS/m with apparent conductivity value between 18.44 and 80.54 mS/m used as the background value for the non-polluted region, and the EM profiles were interpreted relative to these values. At this depth (15 m), the plot shows a radial spread of apparent conductivity from the dumpsite with a decrease in apparent conductivity from the dumpsite. This high apparent conductivity values around the dumpsite are attributed to the decomposed refuse materials deposited on the site. The northern and southern parts of the map with low to medium apparent conductivity values represent the non-polluted area.

The HD 40 plot (Fig. 8c) shows apparent conductivity values that range from 34.29 to 212.27 mS/m with apparent conductivity value between 34.29 and 73.84 mS/m used as the background value for the non-polluted region. At this depth of investigation (30 m), a similar trend is observed when compared with the HD 20 plot, with high apparent conductivity values radiating and decreasing from the dumpsite around the center towards the other part of the study area. The northeastern, western, and southern parts with low to medium apparent

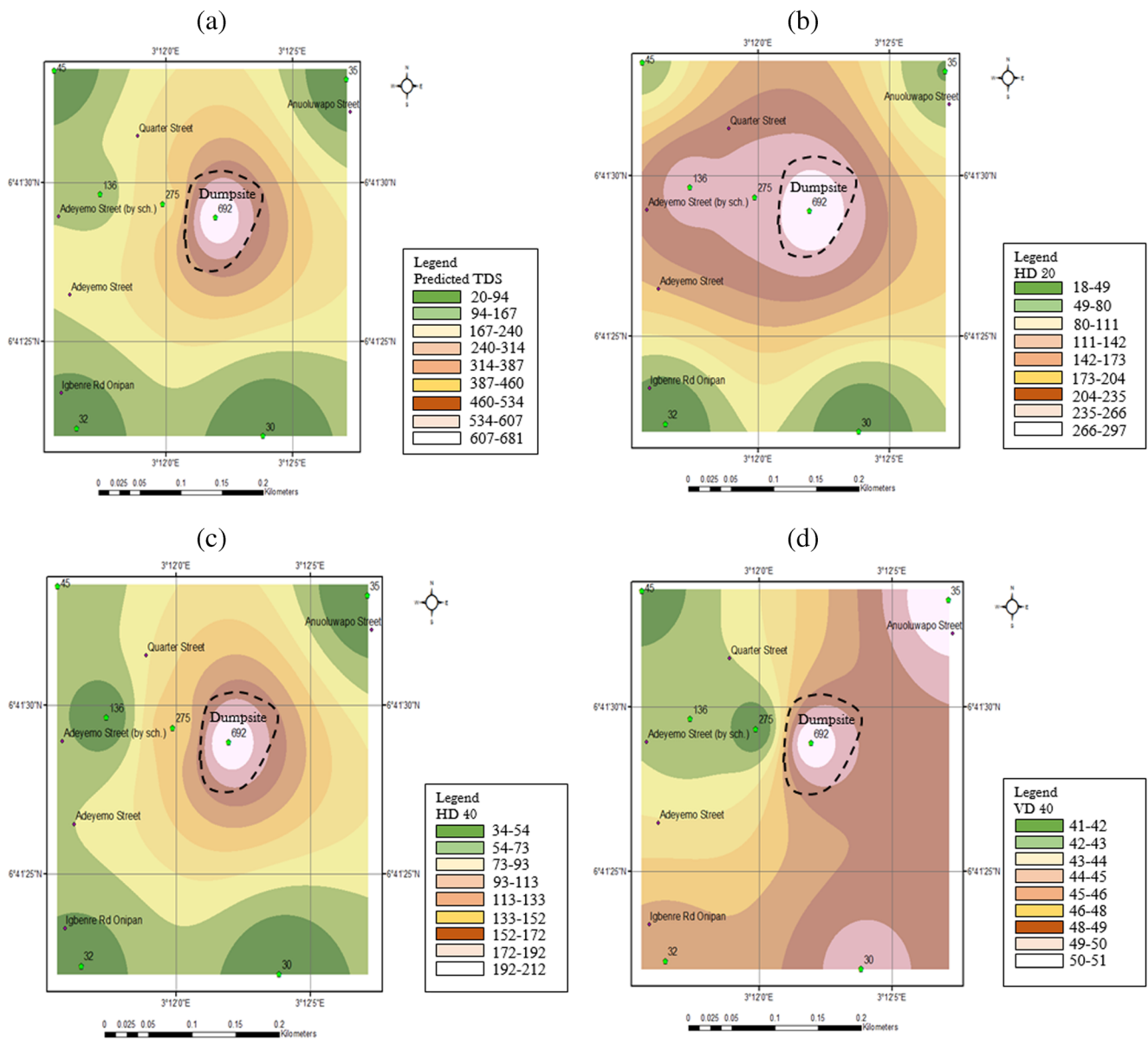


Fig. 8 Contour maps of predicted TDS and terrain conductivity parameters measured in horizontal and vertical dipole modes (a): (HD 20) (b), (HD 40) (c), and (40 VD) (d)

conductivity values represent the uncontaminated part of the study area.

The VD 40 plot (Fig. 8d) shows apparent conductivity values that range from 41 to 51.64 mS/m. At this depth of investigation (60 m) in April 2014, there was a general low subsurface apparent conductivity, but ERT results in December 2015 (Fig. 5c and d) showed that in no distant time from now, the zone might be impacted by the vertically migrating leachate materials.

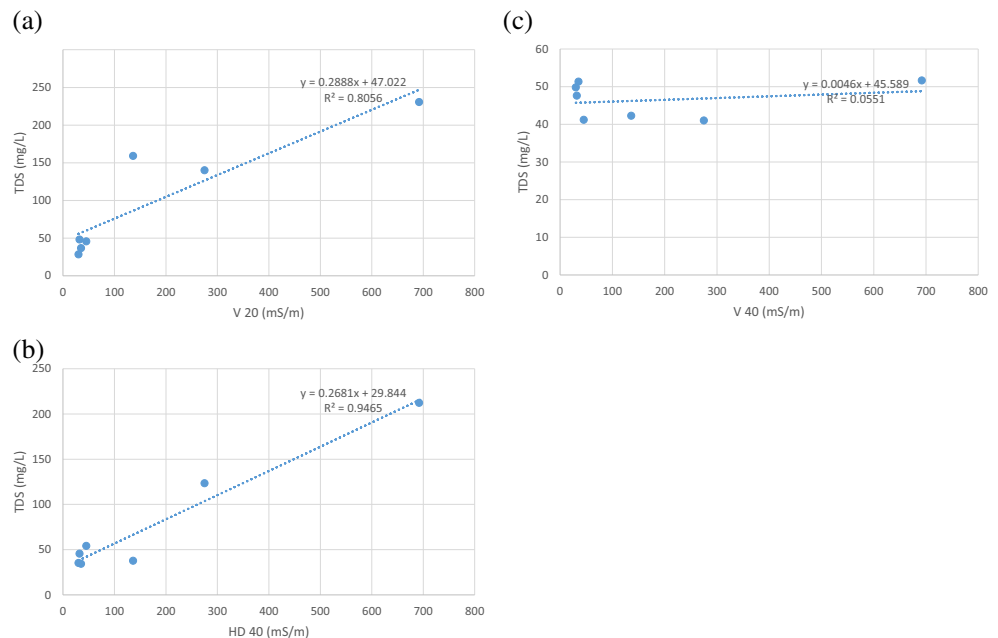
The results in Table 1 were used to generate linear graphs showing the relationship of the estimated TDS values versus

the HD 40, VD 20, and VD 40 values (Fig. 9). Association between TDS and VD 20 (0.805), and HD 40 (0.947) is very high while there is a weak relationship between TDS and VD 40 (0.055) values.

Conclusion

The investigation of the dumpsite using the EM, electrical resistivity tomography, and water sample analysis was crucial

Fig. 9 Linear relationships between TDS and VD 20 (a), VD 40 (b), and HD 40 (c) parameters



in delineating the impact and extent of contamination within the subsurface. The electrically conductive regions were determined to result from decomposed wastes. The results of the resistivity imaging delineated leachate plumes as low-resistivity zones ($0.54\text{--}12.5\ \Omega\ \text{m}$) for the dumpsite, with a good correlation between the wet and dry season models. The time-lapse study also revealed that leachate from the decomposed refuse materials had polluted the subsurface under the dumpsite from the surface to a depth of about 45 m. This high level of pollution has been accelerated by the excavation of the laterite delineated within the study area. Through lateral migration, the leachate materials can move outside of the dumpsite to contaminate boreholes that are further away from the dumpsite. Therefore, remediation measures must be put in place by local authorities to prevent further movement of these contaminants, as they are capable of invading deeper water bodies. From the EM data, groundwater TDS assessment was adequately evaluated using the developed MLR TDS model. Although the accuracy of the developed TDS model is restricted to the dumpsite and its vicinity, it can be reliably deployed for groundwater TDS estimation around the study area where there are no boreholes and hand-dug wells, but with only terrain conductivity data. However, where there are borehole and hand-dug wells, terrain conductivity data around the area alone can be applied to the model to estimate TDS concentration in groundwater, thus reducing the time and cost of determining and monitoring both parameters independently. The model can also be applied for TDS determination and assessment in other areas of similar geology for groundwater resource exploration and exploitation.

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