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Estimation of total dissolved solid in groundwater using multiple linear regression analysis around Igando dumpsites in Lagos, South-West, Nigeria

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Abstract
This study presents a multiple linear regression (MLR) TDS model that relates the TDS data obtained from groundwater samples to the geophysical data obtained from Electromagnetic (EM) data, as an alternative approach to mapping and monitoring the impact of TDS in groundwater. The predictive power of the developed MLR TDS model was appraised to determine the feasibility of using the TDS model to predict groundwater TDS around the study area. Although, the accuracy of the developed TDS model is site specific, the EM data around the area can be applied to the model to determine TDS concentration in groundwater, thus reducing the time and cost of acquiring and monitoring both parameters separately. The utilisation of the proposed MLR TDS model could assist in the implementation of seasonal groundwater quality monitoring programmes around the dumpsites. From the results also, association between TDS and EC and between TDS and $N0_3$ are 0.93 and 0.67 respectively, while that between TDS and hardness is 0.81, suggesting common source of contamination around the sites. Generally, there are relatively higher values of the measured physicochemical properties of water around the North-western part of Solous 1, North-western and South-western part of Solous 2, South-western and South-eastern part of Solous 3 dumpsite when compared with other parts investigated. Therefore, groundwater within the study area may have been impacted by the leachates from the decomposed refuse, and boreholes located at positions other than these zones are likely to yield uncontaminated water
Keywords: Total dissolved solid; conductivity; prediction; linear regression model; dumpsite

Introduction

The dumpsites at Igando (Solous 1, 2 and 3) are improperly designed and therefore not protected by either impermeable soil or polyethylene geomembrane liner. This practice has exposed the vicinity around these dumpsites to environmental pollution. Deposited waste materials like metals, electronics, tyres, batteries, paints, institutional and domestic wastes are predominant on the dumpsites. Over time, the biodegradable components of theses waste can be decomposed and leached into the subsurface environment. The threats by the pollutantsto surface and groundwater and, by extension, on the economic survival and sustainable development of the inhabitants of Lagos requires cost-effective approach to mapping and monitoring the impact of TDS and other physico-chemical parameters on soil water chemistry. Soluble salts in the soil solution exert additional soil moisture tension, which can exceed the crops salt tolerance (salinity threshold), thus causing potential yield reduction (Brian et al., 2002).In landfills without liners there might be migration of different organic and inorganic chemical compounds to the unsaturated zone of the soil which may reach the saturated zone (Mondelli, 2004).Thus, if there is no proper prevention of this occurrence in place, leachates can penetrate fast into groundwater and cause a lot of damage to it and the environment at large. There is therefore the need for constant information on the status of groundwater quality around such dumpsites.

One of the ways in which this can be achieved is through the characterisation of groundwater quality and the establishment of the degree of relationship among water quality parameters and geophysical survey parameters in

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order to assist in groundwater quality monitoring and prediction.Basically, two distinct methods exist for the determination of TDS in soil water. These methods can be described as destructive and non-destructive. The former involves taking repeat samples using a soil auger/core sampler, hence the geology is continually disturbed. Alternatively, standpipe piezometers can be installed or the groundwater level obtained from existing wells (Oyedele, 2009). 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. Among the available surface geophysical methods, electrical resistivity and electromagnetic methods have been found very suitable due to the conductive nature of most contaminants (Atekwana et.al, 2000; Orlando and Marchesi, 2001). Most researchers obtain these set of geophysical data and physicochemical parameters of groundwater independently in the course of their research. This is time consuming and may not be cost effective. Most of the multiple terrain conductivity parameters (HD 20, HD 40 and VD 40) measured in this study showed strong linear relationship with the TDS concentration of groundwater obtained around the vicinity of the EM profile lines. The objective of this study therefore is to attempt to develop a multiple linear regression equation that relates the EM parameters obtained from the geophysical survey with the total dissolved solid content of ground water obtained from the same vicinity. Compared with the approach of other workers, the method used in this study can provide a quick, independent, and cost-effective estimation of groundwater TDS by simple measurement of multiple EM geophysical data.

The study area

The Solous dumpsites are situated at Igando in Alimosho Local Government Area of Lagos State(Figure 1). Operation commenced in the year 1992 with a projected lifespan of between 5 and 6 years (LAWMA, 2010). Alimosho Local Government Area is the largest local government in Lagos, with 1,288,714 inhabitants, according to the official Census (2006). The Solous dumpsites lie approximately between longitude $3^{0}15^{1}0^{11}$E to $3^{0}15^{1}30^{11}$E and latitude $6^{1}34^{1}0^{11}$N, to $6^{0}34^{1}30^{11}$N.The area's hydrogeological profile is composed of a top layer of lateritic clay and thick strata of clay underlain by fine grained sand. The basal sand and the first aquifer horizon are underlain by clayey sand of extensive thickness (Idowu and Olubumi, 2013).The climate of Igando and its environs is of the warm tropical type, having little seasonal variation. Mean annual temperature is around 30^{0}C with narrow diurnal and annual ranges while humidity is about 75 percent with a steady vapour pressure. As a result of urban pull and push situation, these dumpsites are now surrounded by residential, commercial and industrial activities. Waste materials here are therefore mostly of domestic, commercial, institutional and industrial origin. According to NPC, 2006, Lagos State which covers an area of 3,577 km^2 accounted for about 9,013,534 (6.43%) with 3.2% annual growth rate, out of Nigeria's total population of 140 million. Solous dumpsite is sub-divided into three (3) sections namely Solous 1(closed), Solous 2 and 3(existing). The scope of this work covers three of them. The existing landfill (Solous II) covered about 7.8 hectares of land with an average life span of 5 years and receives an average waste of about 2,250 tonnes per day while the closed landfill covered about three (3) hectares of land (LAWMA, 2010)

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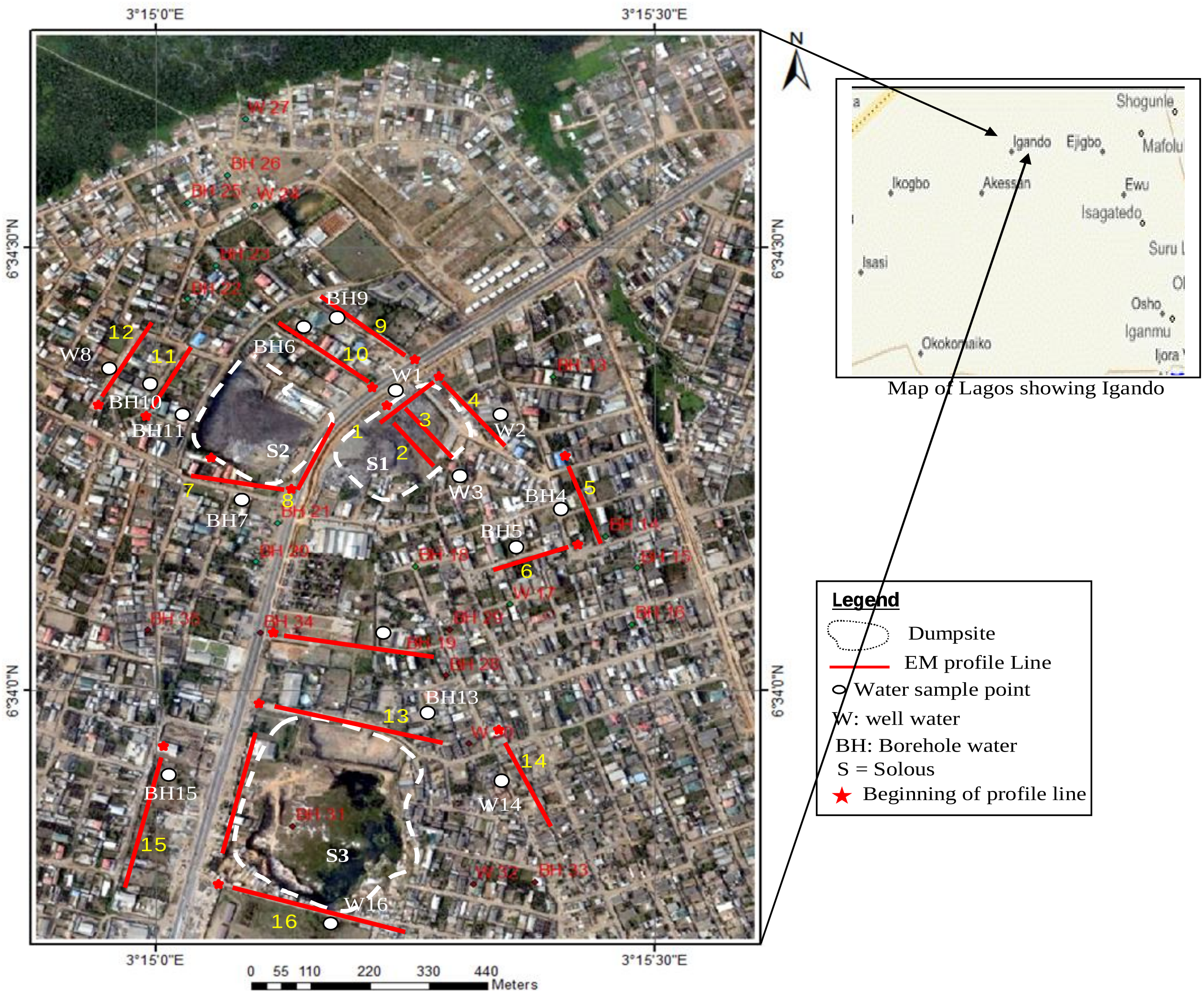

Figure 1: EM data acquisition map of Solous1, 2 and 3 dumpsites and surrounding areas showing EM profiles and water sample points

Materials and Methods

Geophysical method

The research work utilised both geophysical survey and physicochemical assessment of groundwater in delineating the effects of the dumpsite on the subsurface hydrogeological unit within the study area.Electromagnetic surveys

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are particularly useful in such environmental studies as they can delineate waste, conductive fluids and buried metals. Degradation of organic material in field-saturated conditions produces a terrain conductance signature that is enhanced above background conditions. The elevated signature can be used to locate waste, delineate the waste boundaries and provide a rough estimate of depth of wastes (Sunmonu et.al, 2012).The materials deployed for the EM data acquisition include the Geonics EM-34 ground conductivity meter, which consist of the transmitter and receiver, transmitter and receiver coils, the 10 m, 20 m and 40 m cables and batteries. 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-34 data can be collected in the vertical and horizontal dipole configurations. Thus, it allows for two depth determinations and for average soil conductivities. It uses three frequency/coil spacing pairs which are 10, 20, and 40 m spacings, using frequencies of 6,400, 1,600, and 400 Hz, respectively. A total of 22 profile lines were traversed with the total line length of each profile varying between 110 to 240 m (Figure 1). Some of the profiles were occupied within the dumpsites with profile spacing varying, depending on available space, while the remaining profiles serve as control and were located at varying distances ranging between 100 to 600 m away from the dumpsite (Figure. 1). Along each profile, vertical and horizontal dipole measurements were collected. The field data was interpolated using Kriging technique to produce the TDS prediction map and subsurface conductivity maps of the area using ArcGIS software.

Water sample analysis

In order to ascertain the degree of possible groundwater contamination by the solid waste leachate, 16 boreholes and hand dug well water samples within and around the dumpsites were analysed for the content of their total dissolved solid (TDS), pH values, hardness, electrical conductivity (EC) and nitrate content. The water samples were collected around the vicinity of the EM profile lines to enable accurate TDS prediction from the EM data. For the physical property analysis, the samples were collected in a bowl and these properties were measured *insitu* 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.

Statistical analysis of data

In a 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 utilised for this analysis. For correlation analysis, Pearson's product moment correlation was employed, while the regression analysis was achieved using the MLR statistical tools.

Mathematically, the correlation coefficient is defined as:

$$r = \frac{N\sum XY-(\sum X)(\sum Y)}{\sqrt{[N\sum X^2-(\sum X)^2][N\sum Y^2-(\sum Y)^2]}} \qquad (1.0)$$

Where:

$$N = \text{number of pairs of scores}$$
$$\sum xy = \text{sum of the products of paired scores}$$
$$\sum x = \text{sum of x scores}$$
$$\sum y = \text{sum of y scores}$$

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$$\sum x^2 = \text{sum of squared x scores}$$
$$\sum y^2 = \text{sum of squared y scores}$$

Considering the generalised Multiple Linear Regression;

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots \beta_n X_n + \eta_i \qquad (2.0)$$

Where;

Y = Dependent variable predicted by regression model
β_0 = Intercept Of the regression line
β_1 through βn are the slopes of the regression line
X_1 throuhg X_n are the independent variables
η_i = is the error term

The correlation and multiple linear regression analysis were conducted to investigate the relationship between terrain conductivity (EC) and TDS of groundwater quality parameters measured around and within the dumpsites. The EM 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 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.
The multiple linear regression model is expressed therefore as;

$$Y = \beta_0 + \beta_1 (\text{HD } 40) + \beta_2 (\text{VD } 20) + \beta_3 (\text{VD } 40) \qquad (3.0)$$

Where;

Y = Total Dissolved Solid obtained from borehole and hand dug well 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

Results and discussion

Physicochemical analysis of groundwater around the dumpsites

The water obtained from the boreholes and hand dug wells around the study area is used for domestic and other purposes. Table 1 shows the values of the physicochemical parameters obtained from the analysis carried out on the water samples, and also the maximum permissible limit as recommended by World Health Organisation (WHO, 2004) and Standard Organisation of Nigeria (SON 2007). The pH values ranged from 4.05 to 7.37 and were mostly acidic with the exception of locations BH 7 and BH 11, around Solous 2 that are alkaline. The TDS concentration was found to be low at all the locations and less than the standard limit of 500mg/l except at W 1, W 2, and BH 11 around Solous 1 and 2. The concentration of Electrical Conductivity (EC) versus WHO (2004) standard for drinking water quality across the sampled locations revealed that, EC exceeded the standard limit (1000 µS/cm) for drinking water quality at locations W 1, W 2 and BH 11, but lower than the permissible limits in all the other locations also. Hardness is normally expressed as the total concentration of Ca^{2+} and Mg^{2+} in mg/l, equivalent $CaCO_3$. Hardness ranged from 15 to 105 mg/l. Nitrates are nitrogen-oxygen chemical units, which combine with various organic and

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inorganic compounds and its greatest use is for the production of fertilizer (USEPA, 2012). Excess NO_3^- concentration in water samples are key indicators of contamination. They showed strong correlation with the TDS, EC and the hardness values measured. Association between TDS and EC and between TDS and $N0_3$ concentrations of all samples measured around the dumpsites are 0.93 and 0.67 respectively, while that between TDS and hardness is 0.81, suggesting common source of contamination. This strongly suggests common source of contamination around the area. The NO_3 values are all below the minimum requirement (10 mg/l) set by WHO except at W 1, W 2 BH10 and BH 11.This trend could be associated with contaminant migration from the nearby dumpsites into the boreholes and hand dug wells where these samples were obtained. The nitrate levels in these locations call for urgent attention by relevant Government agencies so as to avert any health risk associated with the use of the water. Generally, the results of the water sample analysis revealed that there is substantial impact of the leachates from the decomposed refuse materials on groundwater. This was confirmed as there are relatively higher values of the measured physicochemical properties of water around the North-western part of Solous 1 dumpsite, the North-western and South-eastern part of Solous 2 and South-western and South-eastern part of Solous 3when compared with the other parts investigated. And so this implies that groundwater movement around this area may be associated with these directions, and boreholes located at positions other than these zones are likely to yield uncontaminated water for the inhabitants living around the dumpsites.

Multiple Linear regression TDS model

The mean values of the measured subsurface conductivity and the observed groundwater TDS parameters within and around the dumpsites were regressed on the Microsoft Excel software. From the summary of the multiple linear regression analysis, the coefficients, $\beta0 = -25.52$, $\beta1= 0.94$, $\beta2=3.0$ and $\beta3= -1.67$ are obtained (Table 2). Therefore, substituting into equation 3.0, the multiple linear regression equation for TDS estimation around the dumpsites is:

$$TDS = -25.52 + 0.94(HD40) + 3.0(VD20) - 1.67(VD40) \qquad (4.0)$$

Equation (4.0) is a multiple linear regression (MLR) equation having TDS as the dependent variable and HD 40, VD 20 and VD 40 as the multiple independent variables. Hence, equation 4.0 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.

Conductivity has strong relationship with salinity and soluble salts and so therefore, significant information can be obtained from groundwater quality data through the use of correlation and multiple linear regression statistical methods. Also, utilisation of the multiple linear regression model and information on the degree of association between TDS and other hydrophysical parameters provided by the correlation analysis could assist in the implementation of seasonal groundwater quality monitoring programmes around the dumpsites.

Sensitivity analysis result of the developed MLR TDS model

The sensitivity analysis carried out on the developed MLR TDS model enabled parameters' significance evaluation (Kehinde et.al, 2014). Table 2 presents the parameters' evaluation results of the developed MLR TDS model. This was with a view of evaluating the effectiveness of the independent variables (predictors) in modelling the groundwater TDS estimate in the area. As shown in Table 2 and Equation 4.0, the positive sign of the beta coefficients and the t-values of HD 40 and VD 20 indicate that a positive relationship exists between TDS values and the terrain conductivity values obtained using the HD 40 and VD 20 coil spacing, while a negative relationship was established between TDS and VD 40 data obtained around the study area. The high absolute t-stat value of VD 20 (18.25) and the small P- value (1.3332E-12) suggest that the VD 20 values are very important variables in the prediction of the TDS of the groundwater within and around the dumpsites at Igando as expressed in figure 4a. Also the F statistics has a p value well below 0.5 or 0.1 (3.34767E-14) 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 97.7 % of the variance in the TDS concentration of the groundwater around the study area. This work is similar to the work of

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Idowu and Olubumi (2013)who evaluated groundwater quality around Igando dumpsites in Lagos metropolis using correlation and regression analysis without using geophysical data.The TDS model can also be used reliably for estimating and predicting TDS content in groundwater in the non-investigated part of Igando if the required HD 40, VD 20 and VD 40 geophysical parameters in the study area are known.

Table 1: Physicochemical analysis of water samples obtained from boreholes and hand dug wells around Soluos 1, 2 and 3 dumpsites

Sample	**Location**	**Coordinate**	**pH**	**Temp (°C)**	**EC (µS/cm)**	**TDS (mg/l)**	**Hardness (mg/l)**	**NO_3 (mg/l)**
W 1	Karim Olawuyi Street	06^0 34′ 18.90″N 003^0 15′ 21.22″E	4.62	26.8	1123	750	105.0	14.2
W 2	Dele Salami Street	06^0 34′ 09.27″N 003^0 15′ 24.07″E	4.95	27.3	1006	501	98.0	10.8
W 3	Dele Salami Street	06^0 34′ 07.36″N 003^0 15′ 25.78″E	4.69	26.2	705	350	75.0	4.6
BH 4	Bamshak Street	06^0 34′ 03.99″N 003^0 15′ 25.43″E	5.41	26.6	71	46.0	15.0	1.0
BH 5	Olorunshogo Street	06^0 34′ 05.16″N 003^0 15′ 18.94″E	5.57	28.4	74	40.0	25.0	8.2
BH 6	Kemi Adekunle Street	06^0 34′ 07.44″N 003^0 15′ 13.89″E	6.10	26.2	40	29.0	50.0	6.1
BH 7	OtumbaOladokun Street	06^0 34′ 02.16″N 003^0 15′ 13.21″E	7.37	25.8	127	61	55.0	0.1
W 8	Afamani Street	06^0 34′ 29.22″N 003^0 14′ 58.61″E	5.67	28.5	307	170	50.0	3.4
BH 9	BintuBolajoko Street	06^0 34′ 29.37″N 003^0 15′ 01.69″E	4.05	27.0	473	236	75.0	3.2
BH 10	Afamani Street	06^0 34′ 23.57″N 003^0 14′ 55.04″E	6.70	26.7	819	353	65.0	10.9
BH 11	Afamani Street	06^0 34′ 25.63″N 003^0 14′ 56.57″E	7.21	30.1	1346	650	95.0	11.4
BH 12	Odubanjo Street	06^0 33′ 54.24″N 003^0 15′ 15.52″E	4.87	28.5	27	13	15.0	0.8
BH 13	Ariyibi Street	06^0 34′ 34.46″N 003^0 15′ 04.78″E	4.91	27.9	106	40	40.0	2.1
W 14	By Miracle Centre	06^0 33′ 50.10″N 003^0 15′ 16.71″E	6.07	28.3	600	248	60.0	7.0
BH 15	SegunAlaka Street	06^0 33′ 56.80″N 003^0 14′ 58.92″E	6.48	28.6	360	208	55.0	4.6
W 16	Raimi Ajibowo Street	06^0 33′ 45.11″N 003^0 15′ 07.32″E	6.23	26.9	788	295	75.0	6.4
	WHO/SON Standard		6.5-8.5	-	1000	500	150	10

NB: W= Hand dug well, BH= Borehole

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Table 2: Summary statistics for regression model using all data variables

	Coefficients	Stand. Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95%	Upper 95%
Intercept	-25.5169	12.9499	-1.9704	0.0653005	-52.83899	1.805196	-52.83899	1.8051965
HD 40 (mean)	0.940069	0.14399	6.52853	5.156E-06	0.6362685	1.243887	0.6362684	1.2438702
VD 20 (mean)	3.003527	0.164608	18.24651	1.333E-12	2.6562342	3.3508206	2.6562342	3.3508206
VD 40 (mean)	-1.66805	0.167708	-9.9462	1.675E-08	-2.021891	-1.3142250	-2.021891	-1.314225

Table 3: Record of the Observed and Predicted TDS

S/n	*Observed TDS(mg/l)*	*Predicted TDS (mg/l)*
1	750	763
2	501	421
3	350	299
4	46	61
5	40	58
6	29	30
7	52	39
8	650	633
9	170	178
10	353	436
11	236	258
12	63	66
13	34	20
14	248	231
15	208	229
16	295	313

Appraisal of model prediction accuracy

The predictive power of the developed TDS model was also apprised to determine the justification of using it to predict and estimate groundwater TDS around the study area. Zhuo and Yuhong (2004) suggested a systematic measure of accuracy for any forecast obtained from a model. This measure is called the Theil inequality coefficient, which is given by;

$$Y = \frac{\left[\sum_{t=1}^{n}(X - X_i)^2\right]^{1/2}}{\left[\sum_{t=1}^{n}X_i^2\right]^{1/2}} \qquad (5.0)$$

Where X_i is the observed TDS obtained from groundwater within and around the dumpsite, X is the corresponding predicted TDS from the TDS model (table 3), and Y the Theil's inequality coefficient. Equation (5.0) was used to measure the prediction accuracy of the TDS model. The determined Theil's inequality coefficient Y value for study area is 0.021.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 naïve guess. The result obtained confirmed the reliability and accuracy of using the TDS models to predict groundwater TDS in the non-investigated parts of the area.

Spatial distribution of estimated TDS and EM34 data

Based on the data in table 3, the predicted TDS from the MLR TDS model for this area was interpolated using Kriging technique to produce the TDS prediction map of the study area (Figure 2). It was observed from the model

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map that the TDS in groundwater for the study area varies between 8.0 and 762 mg/l. The visual interpretation of Figure 2 using the legend zoning class values shows that the TDS observed around Soluos 1 and 2 dumpsites shows decrease in concentration from the dumpsite to the surrounding groundwater and a convergence of contaminant at the middle of the two sites (figure 2). It is also an indication that the groundwater at close proximity to the dumpsite has high concentration of TDS than those farther away from the dumpsite. The high values of TDS observed around the sites could be attributed to the high level of impact of the leachate from the decomposed materials on the sites. The spatial distribution of TDS shows a general increase towards the Western part of Soluos 1 and towards the Eastern part of Soluos 2. The North-eastern part of Soluos 1, the Southern and the North-western part of Soluos 2 show low to medium concentration of TDS in the study area. The Eastern and South-eastern part of Soluos 3 dumpsite is bounded by low to medium concentration of TDS distribution in groundwater around the study area whereas the Southern part shows relative high level of TDS concentration as a result of leachate emanating from decomposed materials on the adjacent dumpsite. Figures 3a-c shows the contour plots of apparent conductivity, generated using the HD 20, HD 40 and VD 40 data.

The HD 20 plot (figure 3a) shows apparent conductivity values that ranges from 10 to 249mS/m, with conductivity value between 10 –63mS/m used as the background value for non-polluted region, and the EM profiles were interpreted relative to these values. It is clear that with this coil separation, the plot shows high apparent conductivity values on/around the vicinity of Soluos 1 and 3 dumpsites. There is clear trend of Northward and Southward migration of leachates around Soluos 1 and 3 respectively as supported by a contour map of groundwater flow directions produced for the area. This high conductivity values around these sites is attributed to the decomposed refuse materials deposited on the sites. The Soluos 2 site shows high conductivity towards the North-western part of the study area, whereas the South-eastern part of the map generally has low to medium conductivity values and therefore represents the non-polluted area. The HD 40 plot (figure 3b) shows conductivity values that ranges from 12 to 242mS/m with conductivity value between 12–88mS/m used as the background value for non-polluted region. From this coil separation data, similar trend is observed when compared with the HD 20 plot with high conductivity values decreasing from the three dumpsites.

The maximum depth of pollution around Soluos 1 and 2 according to a recent 2D ERT survey is about 75 m from the surface of the ground so it is expected that the high conductivity values at 30 m is realistic. Generally, most part of the study area with low to medium conductivity values represent the uncontaminated zones. The VD 40 plot (figure 3c) shows conductivity values that ranges from 18 to 338mS/m with conductivity value between 18–89mS/m used as the background value for non-polluted region. At the 60 m depth of investigation by this coil separation, a relatively higher conductivity values are observed around the Eastern portion of Soluos 2 dumpsite and South-western part of Soluos 3 dumpsite thereby validating the result of the recent 2D electrical resistivity survey conducted around these sites in the cause of this research (Not shown). Generally, the Eastern, central and western part of the study area with low to medium conductivity values represent the non- contaminated zones. The recorded results were used to generate linear graphs showing relationship of the estimated TDS values versus the VD 20, HD 40 and VD 40 values as shown in Figures 4a-4c. Relationship between TDS and VD 20 (0.826) shows high positive correlation, while there is a moderate positive correlation between TDS and HD 40 (0.495). The degree of positive correlation between TDS and VD 40 (0.389) is weak.

Therefore, the conductivity anomalies mapped out around the dumpsites in this study are attributed to the leachates formed from the biodegradable components of the waste materials deposited on the dumpsites. These leachates were mobilized by precipitation from rainfall and moved into the subsurface environment where they impacted the groundwater. The depth to the groundwater table around the area and the respective investigated depth of the EM instrument (VD 20, HD 40 and VD 40) accounted for the trend of correlation between the TDS and

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the conductivity parameters. The depth to groundwater table around the study area varied between 15 m to 25 m and the VD 20 and HD 40 has maximum investigative depths of 30m. This implies that the conductivity values measured by these tools reflected greatly the conductivity of the groundwater, and hence the relatively better relationship that exists between the TDS and the VD 20 and HD 40. The VD 40 on the other hand has maximum investigative depth of 60 m and this largely accounted for the weak correlation between the TDS and VD 40.Again the relationship amongst the parameters validates the developed MLR TDS model and therefore can reliably be used for estimating and predicting TDS content in groundwater in the non-investigated part of the study area. The interpretational problem here is to explain the changes in conductivity variations caused by other parameters such as changing lithology. In this study, lithology variations are not considered potential contributing factor at the sites but conductivity resulting solely from the decomposed refuse materials deposited on the dumpsites. The spatial distribution maps of TDS and conductivity produced for the area in this study demonstrated that groundwater within the study area has been impacted by the leachates from the decomposed refuse and mobilized along probable groundwater flow directions. Boreholes and hand dug wells located at positions other than these zones are likely to yield uncontaminated water.

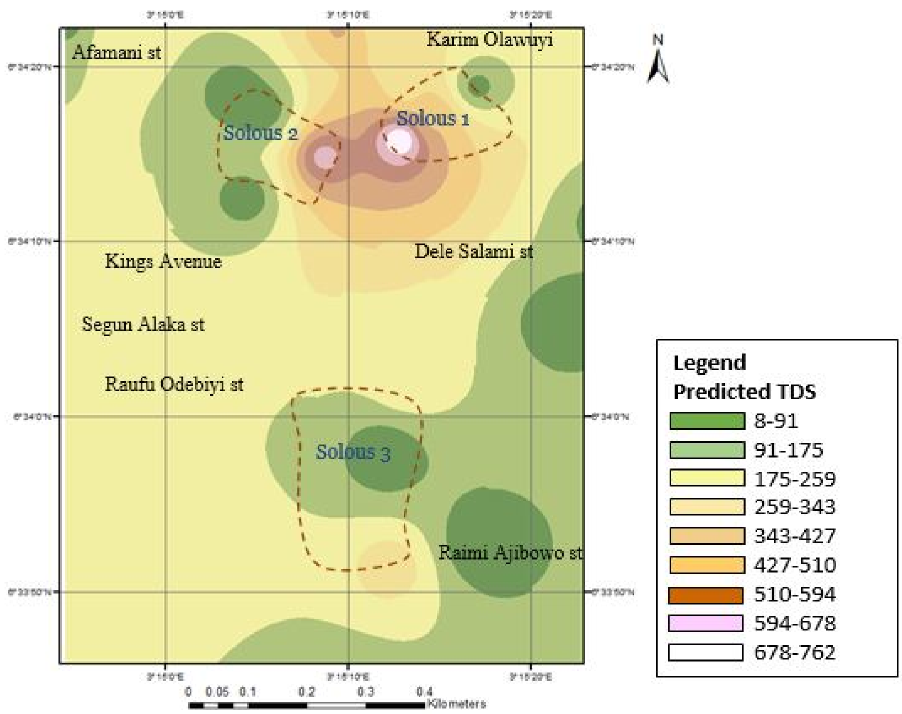

Figure 2: Spatial distribution of estimated TDS around Igando dumpsites(a)

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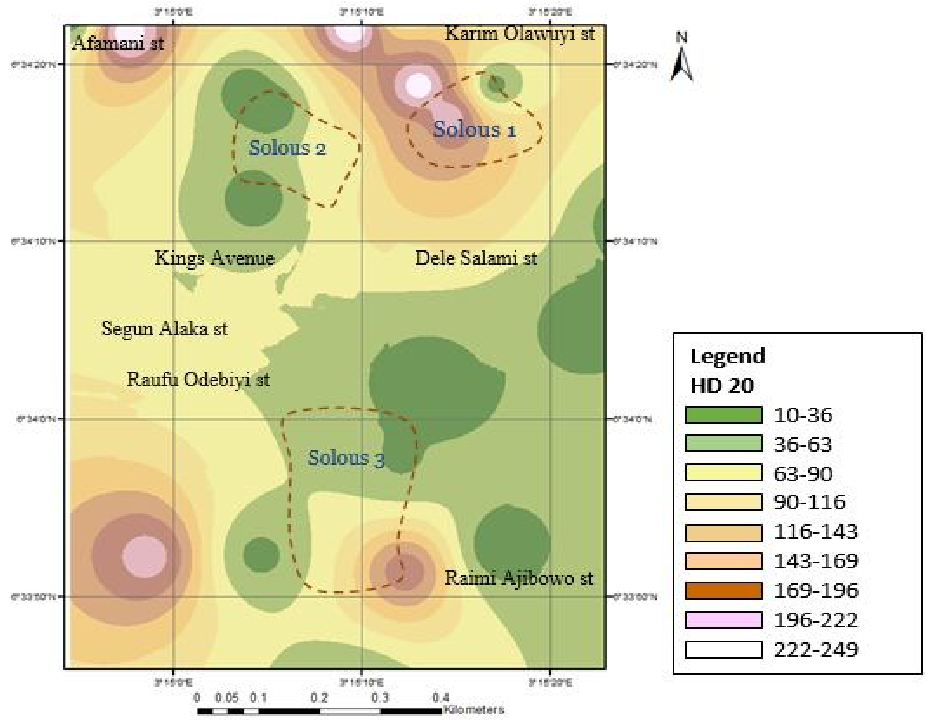
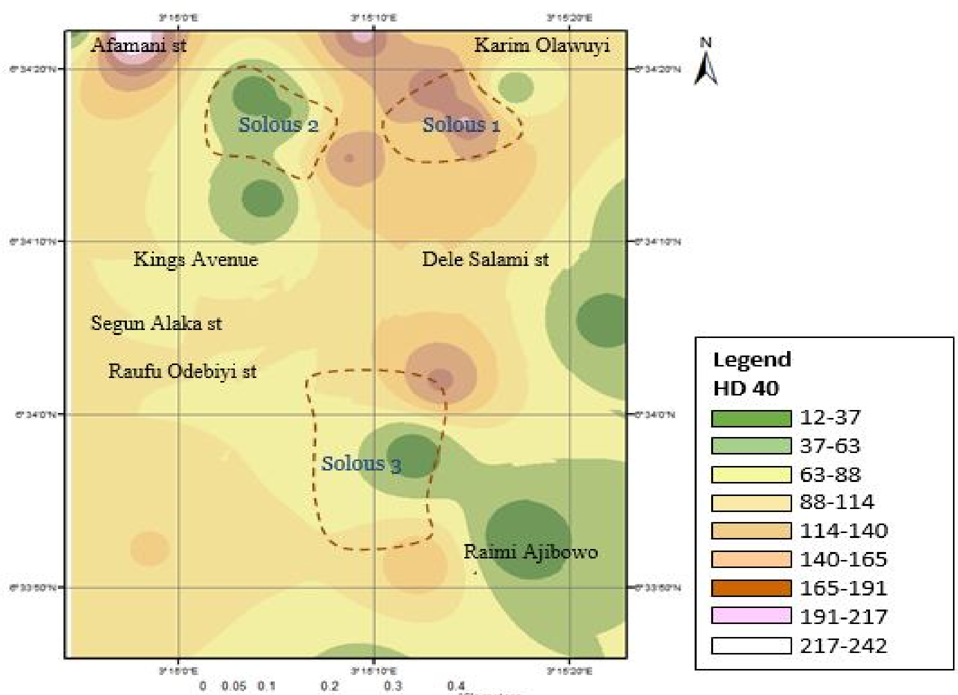


(b)



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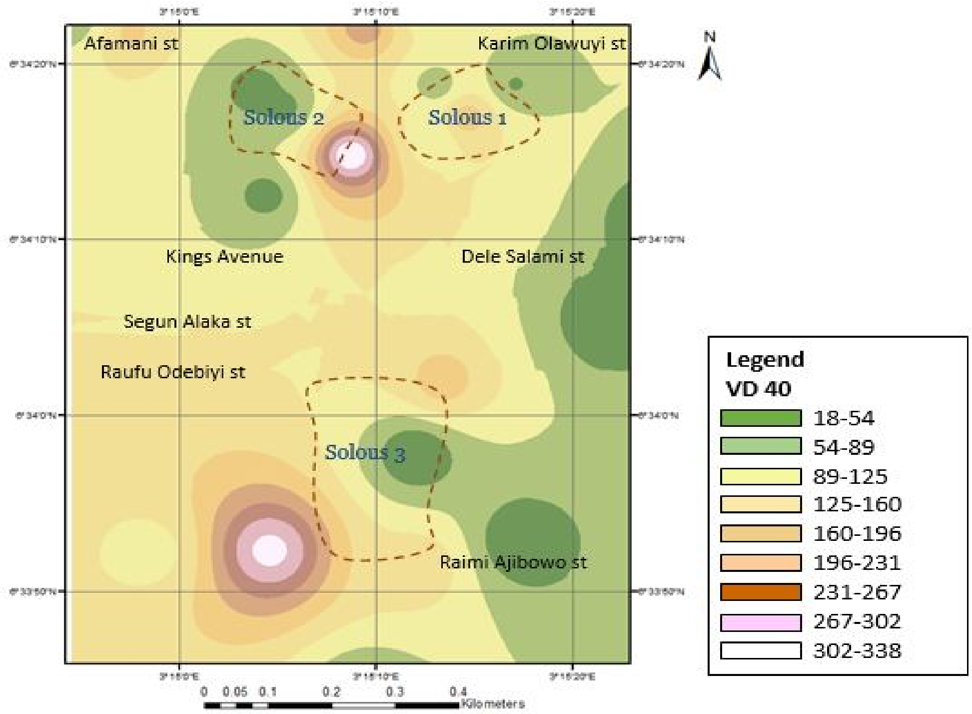

Figure 3: Contour plot of apparent soil electrical conductivity measured using EM34 in horizontal and vertical dipole modes: (a) 20 m (b) 40 m and (c) 40 m coil spacing

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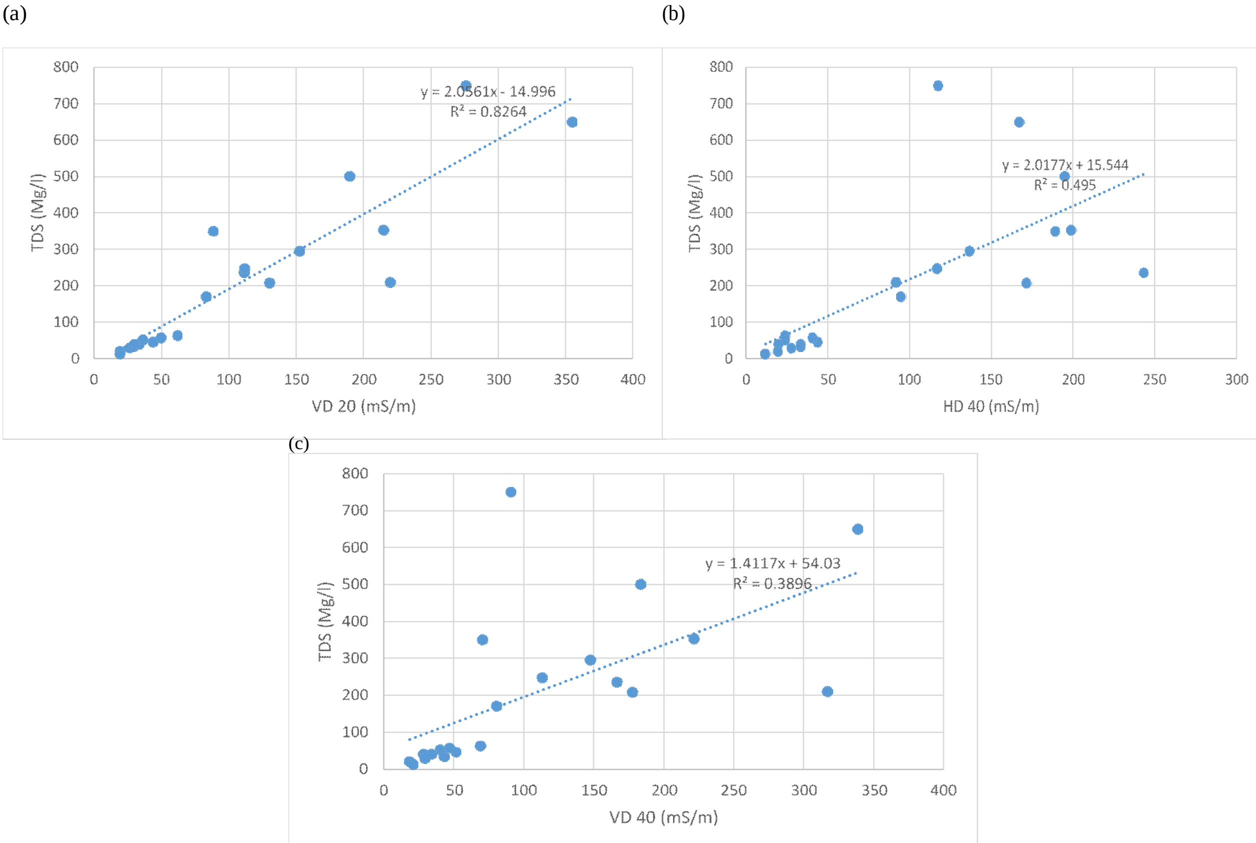

Figure 4: Linear relationships between TDS and VD 20(a) HD 40(b) and VD 40(c)

Conclusion

In this study, the geophysical investigation using the Electromagnetic survey and groundwater analysis on the three dumpsites at Igando revealed regions that have been impacted by the leachate. These regions were found from the analysis and interpretation of the EM data acquired around the areas to be more at the vicinity of the dumpsites and less at other areas. Generally, there are relatively higher values of the measured physicochemical properties of water around the North-western part of Solous 1 dumpsite, the North-western and South-eastern part of Solous 2 and South-western and South-eastern part of Solous 3 when compared with the other parts investigated. And so this implies that groundwater movement around this area may be associated with these directions, and boreholes located at positions other than these zones are likely to yield uncontaminated water for the inhabitants living around the dumpsites. Also ,from the results, groundwater TDS concentration assessment was adequately evaluated around the study area using the proposed MLR TDS model. Although, the accuracy of the developed TDS model is site specific, 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 predict TDS concentration in groundwater, thus reducing the time and cost of determining and monitoring both parameters separately. The model can also be applied for TDS estimation and assessment in other areas of similar geology for the purpose of groundwater resources monitoring and evaluation.

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