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APPLICATION OF ELECTRICAL RESISTIVITY METHOD IN EVALUATION OF AQUIFER PROTECTIVE CAPACITY AND SOIL CORROSIVITY: A CASE STUDY OF WAJARI AND ENVIRONS, NORTHEASTERN, NIGERIA

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ABSTRACT

Electrical resistivity technique was deployed in the study of extent of corrosivity and aquifer protective capacity (APC) or aquifer vulnerability of the overburden units around Wajari and environs, north eastern Nigeria. The objectives of this research includes; outlining areas that have high susceptibility to groundwater pollution from surface pollutants and subsurface soils that could be corrosive to buried metal pipes. Twelve (12) vertical electrical sounding (VES) locations were studied using electrode spreads of AB/2 equals to 80 m. OHMEGA Terrameter was deployed to acquire the data by employing Schlumberger array method. The analysis (interpretations) of the results were assisted by employing Win-Resist, Microsoft- Excel and surfer-13 Software The resistivity data interpretation revealed 4 geo-electric layers and the generated distribution curves are of type A, H, K, HK, and QQ. The measured thickness of the overburden lithologic units are in the range of 0.396 m to 27.2 m, with an average value of 5.407m. The longitudinal conductance of the overburden geologic units are in the range of 0.0199 mhos to 3934 mhos. VES 04 of the current study showed quite high topsoil resistivity signatures which is virtually non-corrosive (VNC). However, VES 08, 09 and 10 have moderate corrosivity and VES 01, 02, 03, 05, 06, 07, 11 and 12 are slightly corrosive. Five noticeable aquifer protective capacity zones were demarcated, on the basis of the obtained values of longitudinal conductance; namely poor (VES 03, 04, 05 and 08), weak (VES 01, 07 and 10), moderate (VES 02 and 06), very good (VES 09) and excellent (VES 11 and 12). VES 01, 03, 04, 05, 07, 08 and 10 of the research area could be susceptible to surface pollution whereas, VES02, 06, 09, 11, and 12 might not be susceptible to pollution due to the variation in the APC. Therefore, considering the planned siting of industrial park along this area (Gombe - Dadin Kowa route) by the Government of Gombe State. The results of this research shall form parts of the technical issues to be considered for groundwater, industrial, and infrastructural development planning of the area.

Keywords: Resistivity, Corrosivity, Aquifer, Protective Capacity, Evaluation, Wajari and environs.

INTRODUCTION

A geophysical evaluation via Electrical Resistivity method was deployed in order to evaluate soil corrosivity and aquifer protective capacity or aquifer vulnerability of the overburden lithologic units around Wajari and environs. The research involved the application of Vertical Electrical Sounding (VES) technique using Schlumberger electrode spreads.

The degree of groundwater pollution is determined by porosity, permeability, and overburden thickness of geologic formations (Obiora et al., 2015). The presence of

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unconsolidated geological materials such as coarse grained sand can allow the fleeing of adulterating emissions into the ground to pollute the groundwater, thereby making the soil corrosives and forming a polluting cloud that covers several hundreds of meters (Obiora, et al, 2015). However, pollution of the hydro geologic system in majority of the porous/permeable media zones appears to be a worldwide phenomenon (Oladapo et al., 2004, Mohammed, 2007). The following items constitute a major threat to hydro geologic system /or porous and permeable aquifers, these includes; Septic tanks, buried petroleum products storage tanks, municipal refuse landfills, agricultural practices, nuclear sites, and abandoned hazardous waste sites etc. (Mohammed, 2007).

This research is intended (aimed) at demarcating areas that are very susceptible to groundwater pollution owing to surface pollutants and to assess top soils that are liable to corrosion when service pipes are buried within the top soil segment. This involves evaluating the aquifer protective capacity, longitudinal conductance, and corrosivity of top layer parts in the subsurface of the research area.

The aim was achieved through: Conducting VES survey at different locations via the Schlumberger arrangement, Interpreting the geophysical results through application of the computer software (WINRESIST) to obtain geological characteristics and the groundwater potentials zones of the area of interest, determining the primary geo-electric parameters from the sounding data of the area, generating the secondary geo-electric parameters from the primary geo-electric parameters, and evaluating top soil corrosivity and aquifer protective capacity or vulnerability to contaminations.

Location and Accessibility of the Study Area

The research location is found in Yamaltu /Deba local government area of Gombe State. It covers an area of about 25km^2 which is within Latitudes 10º15' 00" N and 10º 18' 14.2" N and Longitudes 11º 23' 00" E and 11º 26' 16.2" E (Figure 1).

Accessibility in the area of study is mostly achieved by the use of major roads and major foot paths that link the other villages with the Gombe-Biu road that transverse the area in an East-west pattern. The area can generally be described as being easily accessible due to the non-hilly nature of the terrain.

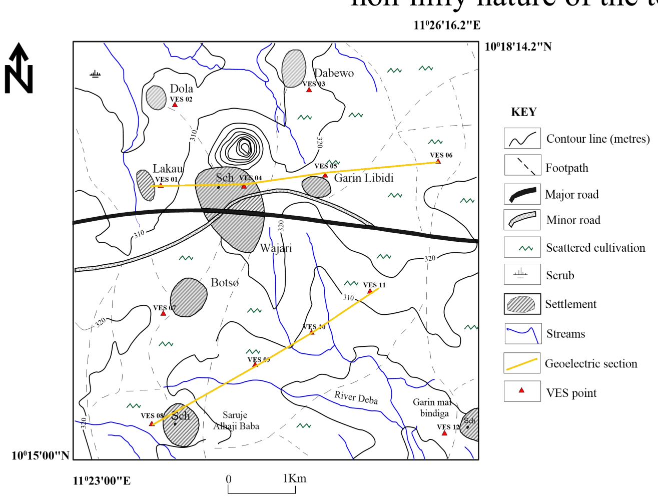

Figure 1: Topographic view of the research area indicating VES location.

Previous Works

Several geophysical studies aimed at investigating for groundwater were conducted in different areas of the world. Electrical resistivity methods were successfully applied in investigation for groundwater occurrences because it is considered to be a non-invasive, cheap, quantitative assessment process (Sikander et al., 2010). Apart from its application in the search for groundwater, the method is found to be efficient, and economical during the investigation for the extents of soil corrosivity, and the emission of the pollutant with a different salinity compared to the existing groundwater (Oladapo et al., 2004; Mogaji et al., 2007).
Dan-Hassan (2001) applied electrical resistivity and borehole lithologs which revealed the presence of weathered overburden as the predominant aquifers found within the north central basement rocks of Nigeria. There is always a possibility of pipelines leakage, breakage, or failures that can cause a severe hazard to both the environments, and humanity due to leakage and explosion occurrences (Yahaya et al., 2009). Application of geophysical techniques enables the efficient evaluation of an environment with little or no interference with the hydro geologic system (Mogaji et al., 2007). Moreover, a study by Abiola et al., 2009, who investigated the groundwater potentials and aquifer protective capacity (APC) of the overburden units of the areas around Ado-Ekiti and environs, three main zones of groundwater potentials of low, moderate, and high classes, as well as four classes of aquifer protective capacity zones of poor, weak, moderate, and good classes were revealed. Other recent research works, where electrical resistivity techniques were applied in the study of aquifer protective capacity and soil corrosivity in Nigeria includes; Adeniji et al., 2014, and George et al., 2014. Arabi et al. (2009) conducted VES survey of Gombe town and its vicinity and deployed Schlumberger arrangement pattern using a maximum electrode distance intervals of AB/2 equals to 200 m. The study was able to mapped suitable locations that are good for boreholes siting. Obiora et al. (2015) used electrical resistivity method in the appraisal of APC of overburden units and soil corrosivity around Makurdi region, Benue state. Abdurrahman et al., (2017) employed 26 VES to obtain secondary geo-electric parameters from the primary geo-electric parameters in evaluating soil corrosivity and aquifer protective capacity across Gombe, metropolis, Northeastern Nigeria. The application of geophysical principles in both mapping, and groundwater quality assessments has recorded a dramatic increase because of the rapid improvements in microprocessors and related mathematical modelling solutions. The VES method has demonstrated its wide application in groundwater investigations owing to the easiness of the method. Careful examination of studies conducted around this area of study as well as the need for increase physical development of the study area owing to its proximity to Gombe towns as well as the planned siting of industrial park around this area (Gombe – Dadin Kowa route) necessitated this study.

Geology of the Study Area

The following rock types were identified. These include; the Bima Sandstone Formation, the Yolde Formation and the Basalt plug (Figure 2).

Bima Sandstone Formation

The Bima sandstone Formation which is Albian in age covers about Eighty-five percent (85%) of the study area (Figure 2). The Bima group is the oldest of all the sedimentary in fillings in the Upper Benue Trough of Nigeria (Abubakar, 2006). It is

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unconformably overlaying the Basement complex. The lower part of Bima consist mainly of conglomeratic Alluvial fan deposits, while the middle Bima is characterised by trough cross bedded Sandstones with clays occurring on top of the medium - very coarse grained feldspartic Sandstone displaying a fining upward order. The Upper Bima is fairly homogeneous relatively fine to coarse grained Sandstone which is characterised by overturned cross bedded sandstones (Abubakar, 2006).

The Yolde Formation

The Yolde Formation lies in the western fragment of the research area and covers about Twelve percent (12%) of the research area (Figure 2). The Yolde Formation is a transitional sequence between the continental Bima Formation and marine Pindiga Formation (Abubakar, 2006). The lower sandstone-mudstone portion of the Yolde formation is interpreted to be of fluvial origin; while the upper portion with more thinly and regularly bedded sandstone and low diversity bivalves is of shallow marine origin (Abubakar, 2006). In the field, The Yolde formation was mostly found in stream channels which display topography often with sparse vegetation. The Yolde formation at the lower sandstone-mudstone and the upper portion with more thinly bedded bioturbated sandstone. The textures of the sandstone are mostly coarse grained.

The Basalt Plug

The basalt plugs which is the youngest in the study area lies in the North Western part and covers three percent of the study area (Figure 2). This is a very fine grained melanocratic rock that was found to have pierced through the existing Bima Sandstone.

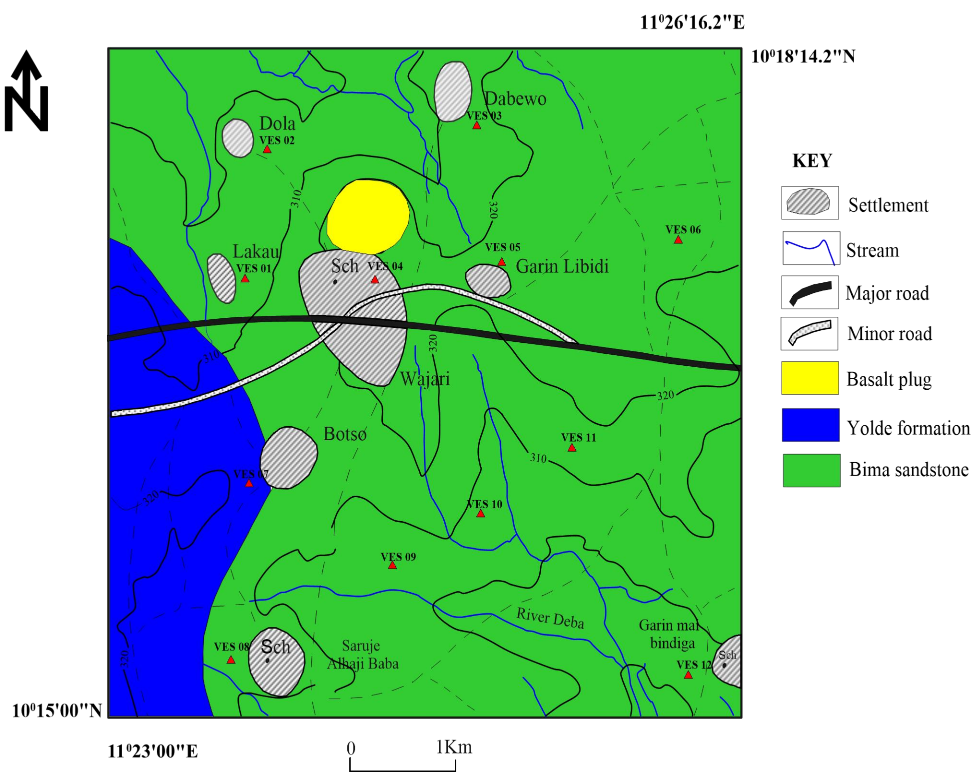

Figure 2: Geologic Map of Study Area. (After NGSA, 200

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MATERIALS AND METHODS

Schlumberger Array

This arrangement is the most commonly applied in electrical investigation because it offers better resolution, simpler to operates, take less time to execute and requires less labour. This was the arrangement adopted during the data collection stage of the present research. Four pairs of electrodes were positioned laterally in a straight line on the ground surface following the order of AMNB (Figure 3).

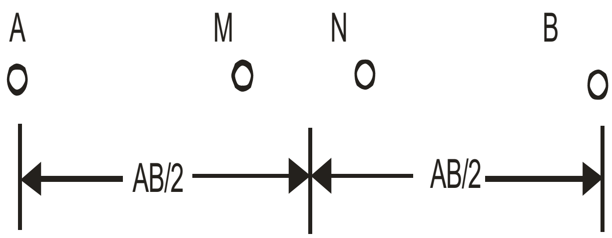

Figure 3: Schlumberger electrode arrangement showing position of electrodes.

$$\rho a = \frac{(AB/2)^2 - (MN/2)^2}{MN} \Delta V/I$$

Where: AB represents the current electrode spacing, MN represents the Potential electrode spacing, I represents the Current Value in amperes, V represents Voltage value in volts, and ρa denotes measured resistant in Ohm's.

In this configuration, the pairs of current and potential electrodes have a common mid-point, but the distance between adjacent electrodes are different, usually AB ≥ 5MN. The separation of the current and potential electrode is: r1, R2 and r2 R1 respectively as shown in Figure 4.

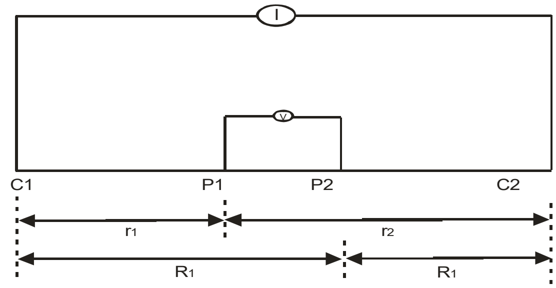

Figure 4: Schlumberger Electrodes Arrangement Showing Electrodes spread.

The different materials used for the resistivity survey are: Terrameter, Metal electrodes, Cable wire for current and potential electrodes, Crocodiles clip, Hammer, Measuring tape, GPS (Plate I).

The Terrameter was used to measure the resistivity of the ground after inducing electric current via electrodes. (Plate 1).

Electrodes, are steel conductive spikes (Plate 1) that serve as a media through which induced electric currents are introduced into the ground, it also serves as paths through which induced potential are detected and sent. Two pairs of electrode (C_1 and C_2) are the points through which the current is passed and received by the potential electrodes (P_1 and P_2).

There were four cable wires used in connecting the electrodes to the Terrameter (Plate 1). They are 200m in length and 0.2m in diameter and are rolled in a wheel- like shape made up of plastic material. During the field operation, the four rolled wires are extended by turning the wheel while spreading of electrode. Moreover, crocodile clips were used to connect cable wires to the electrodes. (Plate 1).

Hammers are used in fixing the electrodes into the ground, two Hammers were used to hit them down, until when a meaningful

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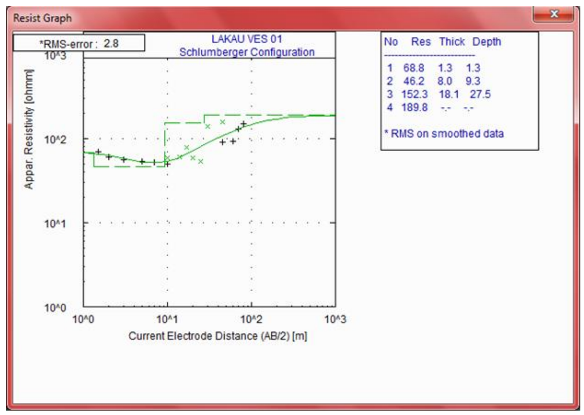
reading is observed on the Terrameter. (Plate 1).

The measurement tape was used to measure the separation of both currents and potential electrodes from one point to another (Plate 1). Moreover, the used of GPS in recording the coordinates and elevation of positions in the field was employed throughout the survey time. The two potential electrodes (P_1 and P_2) were place at 0.5 meter intervals, while the two current electrodes were placed at an intervals of 2, 3, 5, 10.15, 20, 30, 40, 50, 60, 70, and 80 meters.

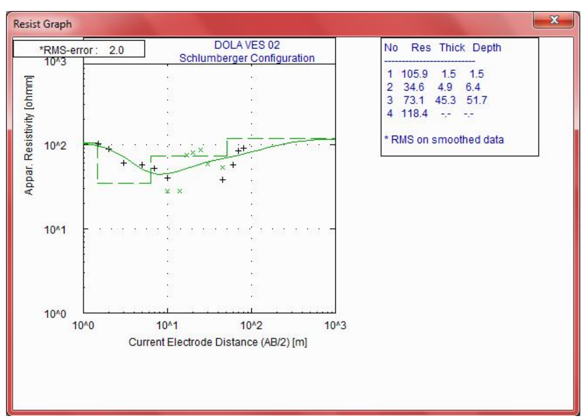
Plate 1: Set of survey equipment.

RESULTS

The results of the geo-electric curves derived from the VES data acquired in the study area are displayed in Figure 5. The curves are also accompanied by presentation of the quantitative parameters (such as resistivity, thicknesses of the layers) in (Table 1). The table provides additional facts relating to the curves. Quantitative interpretation of the data was done with Win-Resist interpretation software adopted for use on personal computer. Basically Win-Resist is a forward plus inverse modelling package applied in studying electrical resistivity data taken with the various resistivity sounding method such as the Schlumberger Sounding System. DC resistivity sounding method is designed to be interpreted in terms of a layered earth solution. The algorithm deduced the model whose hypothetical geo-electric curves best suited the field information by continuous repetition controlled by the numerical platform in which appraisal of input factor is prepared for every single layer and the practical (observed) and hypothetical curves were computed in the course of the study. Additional iteration decreases the inconsistencies to a fixed value or less as the case may be.



(A) VES 01 (A- curve type)



(B) VES 02 (H- curve type)

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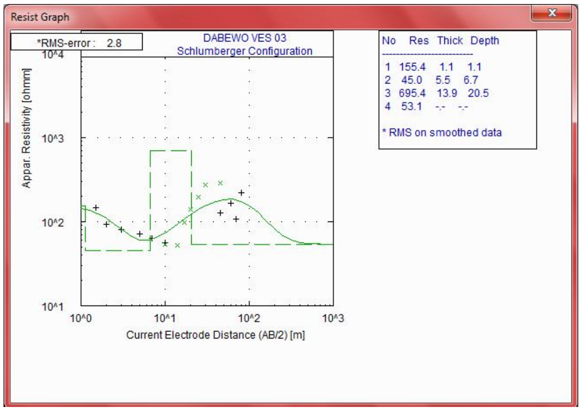
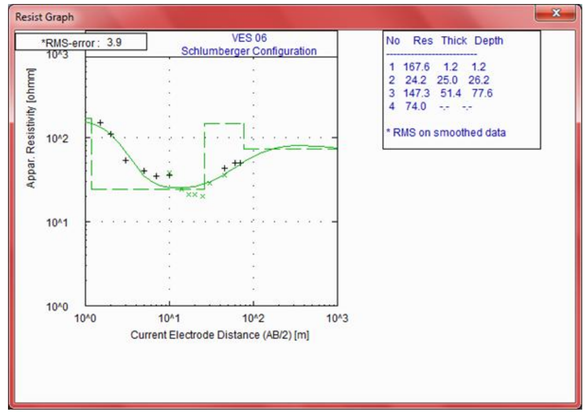
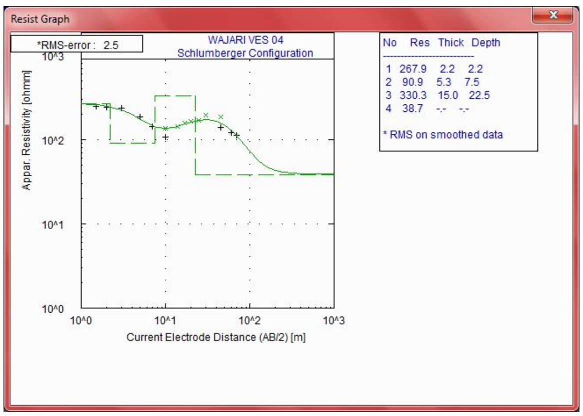


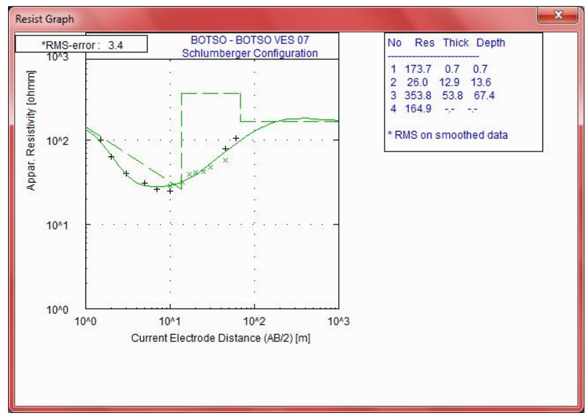
(C) VES 03 (HK-curve type)



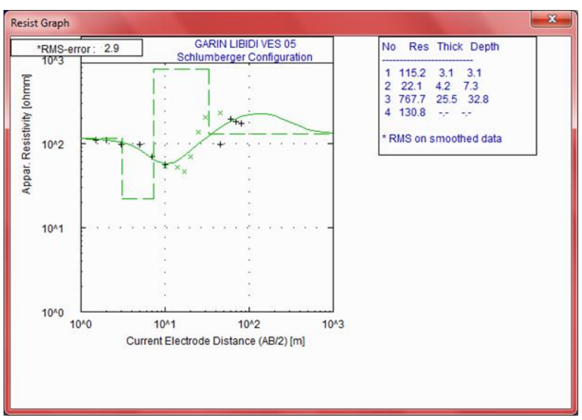
(F) VES 06 (H- curve type).



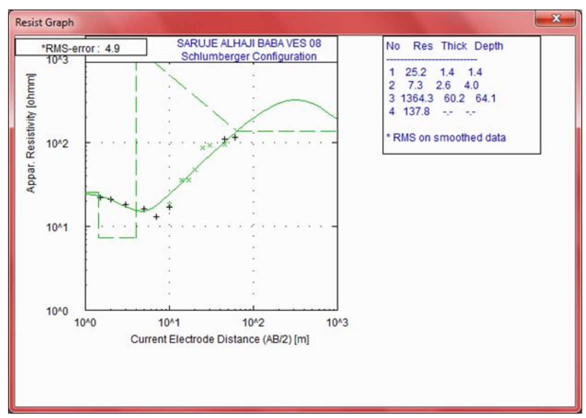
(D) VES 04 (QQ- curve type)



(G) VES 07 (H- curve type)



(E) VES 05 (HK- curve type)



(H) VES 08 (A- curve type)

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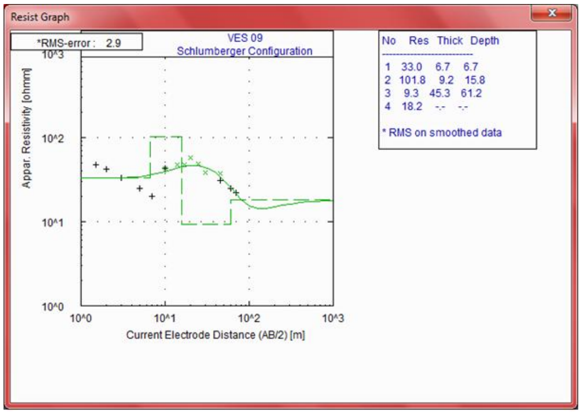
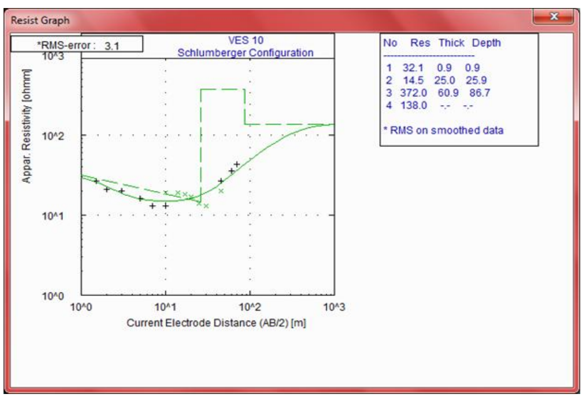
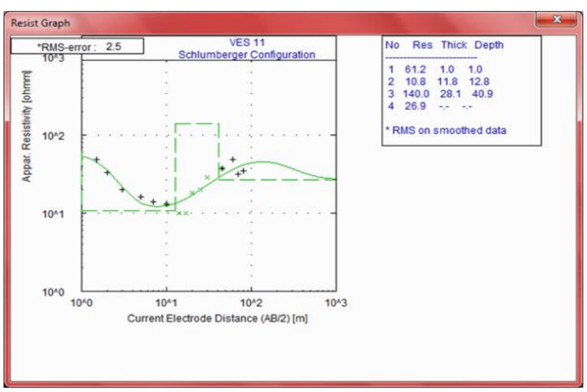


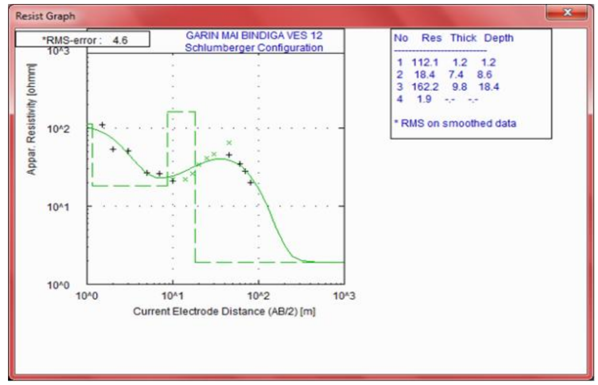
(I) VES 09 (K-curve type)



(J) VES 10 (A-curve type)



(K) VES 11 (HK- curve type)



(L) VES 12 (QQ- curve type)

Figure 5: (A-L): different Curve types generated from the acquired field data across the various VES points.

12 VES data stations were acquired for the research location and are presented in (Table 1). During the interpretation process, it was assumed that the underlying formation is flat and parallel to the earth's surface. The result of the interpreted data shows that the fitting error in the study area ranges from 2.0% - 4.9% as shown on the different data sheets.

However, four geo-electric layers were established at each VES point, with resistivity values ranging from 1.9 Ωm – 1364.3 Ωm (Table 1). The measured electrical resistivity is considered to be reliable when the percentage error is very low and vice-versa. Table 1 presents the summary of the interpreted VES curves.

Generally, for any data obtained in either sedimentary or basement environment, during interpretation the following four kind of curves shall be obtained. These are A, Q, H, K and a combination of two or more.

Five different sounding curve types where obtained from the 12 VES points acquired in the research location which include: type A, H, K, HK, and QQ curve types. The curve type distributions are presented in form of pie chart as shown below (Figure 6).

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Table 1: Summary of geo-electric parameters, inferred lithology, and curve models for the VES points

VES-No/ Location	Coordinates & Elevation	Layer No.	Resistivity (ρ)	Thickness (m)	Curve type	Inferred Lithology
VES01	N10º17'4.3"	1	68.8	1.3	A	top soil
Lakau	E11º23'36.8"	2	46.2	8.0		Shale
	ELEV.304m	3	152.3	18.1		Medium grained sandstone
		4	189.8			Clayey sand
VES02	N10º17'41.3"	1	105.9	1.5	H	top soil
Dola	E11º23'32.7"	2	34.6	4.9		Shale
	ELEV.309m	3	73.1	45.3		Medium grained sandstone
		4	118.4	----		Clayey sand
VES03	N10º18'04.7"	1	155.4	1.1	HK	top soil
Dabewo	E11º25'26.8"	2	45.0	5.5		Shale
	ELEV.327m	3	695.0	13.9		Medium grained sandstone
		4	53.1	---		Clayey sand
VES04	N10º16'41.5"	1	267.9	2.2	QQ	top soil
Wajari	E11º24'17.9"	2	90.9	5.3		Shale
	ELEV.322m	3	330.3	15.0		Medium grained sandstone
		4	38.7	---		Clayey sand
VES05	N10º17'07.1"	1	115.2	3.1	HK	top soil
Garin LibidI	E11º25'02.2"	2	22.1	4.2		Shale
	ELEV.321m	3	767.7	25.5		Medium grained sandstone
		4	130.8	---		Clayey sand
VES06	N10º17'20.3"	1	167.6	1.2	H	top soil
	E11º25'54"	2	24.2	25.0		Shale
	ELEV.322m	3		51.4		Medium grained sandstone
		4	74.0	---		Clayey sand
VES07	N10º16'10.8"	1	173.7	0.7	H	top soil
Botso	E11º23'50.9"	2	26.0	12.9		Shale
	ELEV.321m	3	353.8	53.8		Medium grained sandstone
		4	164.9	---		Clayey sand
VES08	N10º15'18.6"	1	25.2	1.4	A	top soil
Saruje Alhaji Baba	E11º23'44.9"	2	7.3	2.6		Shale
	ELEV.313m	3	1364.3	60.2		Medium grained sandstone
		4	137.8	---		Clayey sand
VES09	N10º15'56"	1	33.0	6.7	K	top soil
	E11º24'18"	2	101.8	9.2		Shale
	ELEV.306m	3	9.3	45.3		Medium grained sandstone
		4	18.2	---		Clayey sand
VES10	N10º15'52"	1	32.1	0.9	A	top soil
	E11º25'04"	2	14.5	25.0		Shale
	ELEV.308m	3	372.0	60.9		Medium grained sandstone
		4	138.0	---		Clayey sand
VES11	N10º16'20.5"	1	61.2	1.0	HK	top soil
	E11º25'00"	2	10.8	11.8		Shale
	ELEV.310m	3	140.0	28.1		Medium grained sandstone
		4	26.9	---		Clayey sand
VES12	N10º15'20.3"	1	112.1	1.2	QQ	top soil
Garin Mai-Bindiga	E11º26'03.4"	2	18.4	7.4		Shale
	ELEV. 296m	3	162.2	9.8		Medium grained sandstone
		4	1.9	---		Clayey sand

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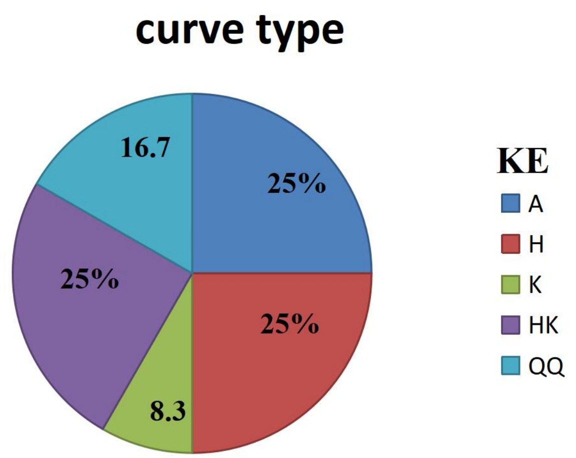

Figure 6: The percentage distribution of curve type of the research area

i. **A-type curve:** has resistivity P1<P2<P3, and constitutes 25% of the total curves (Figure 6 above) and were obtained at VES 01, 08 and 10. (Table 1)

ii. **H-type curve:** with resistivity characteristics P1>P2<P3, also constitutes 25% of the total curves (Figure 6, above) and were obtained at VES 02, 06 and 07. (Table 1)

iii. **K-type curve:** with resistivity P1<P2>P3, constitutes 8.3% of the total curves (Figure 6) and was obtained at VES 09. (Table 1)

iv. **HK-type curve:** with resistivity P1>P2<P3>P4, constitutes 25% (Figure 6) of the total curves and were obtained at VES 03, 05 and 11. (Table 1)

v. **QQ-type curve:** Where P1>P2>P3>P4, constitutes 16.7% of the total curves (Figure 6) and were obtained at VES's 04 and 12 (Table 1, above).

Geo-electric Section

The modelling of the VES data (values) conducted at the 12 locations were applied to construct the geo-electric outlines for the two profiles (Figures 7 and 8). The geo-electric section along VES 01, 04, 05 and 06 reveals four geologic strata. The 1st stratum represents top soil that has resistivity values varying from 68.8-267.9 Ω-m and thickness ranging from 1.2 m - 3.1 m, the second stratum which is shale is characterized by the resistivity values varying from 22.1 Ω-m - 90.9 Ω-m with thickness ranging from 4.2 m - 25.0 m, the third layer is medium grained sandstone which has resistivity that ranges between 147.3 Ω-m - 767.7 Ω-m and thickness ranging from 15.0 m - 51.4 m. The 4th stratum is clayey sand with the resistivity values varying from 22.1 Ω-m - 90.9 Ω-m and an undefined thickness. The geo-electric section along VES 08, 09, 10 and 11 also reveals four geologic strata. The 1st stratum along this profile is top soil with resistivity and thickness range from 25.2 Ω-m to 61.2 Ω-m and 0.9-6.7m respectively, the second stratum consist of shale that has resistivity varying from 73.1 Ω-m -101.8 Ω-m, and thickness ranging from 2.6 m - 25.0 m, the third layer is medium grained sandstone which has resistivity that ranges between 9.3 m - 1364.3 Ω-m and thickness ranging from 28.1 m - 60.9 m. The 4th stratum is clayey-sand having the resistivity values that varies from 18.2 Ω-m - 138 Ω-m and an undefined thickness.

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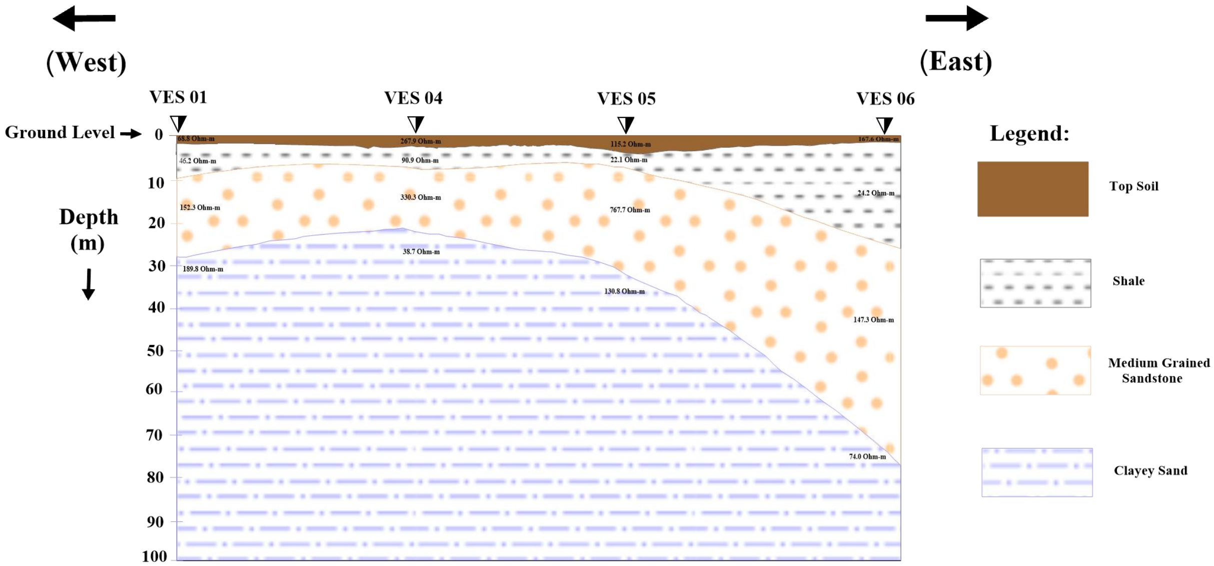

Figure 7: Geo-electric section along VES 01, 04, 05 and 06 plotted in an east- west direction.

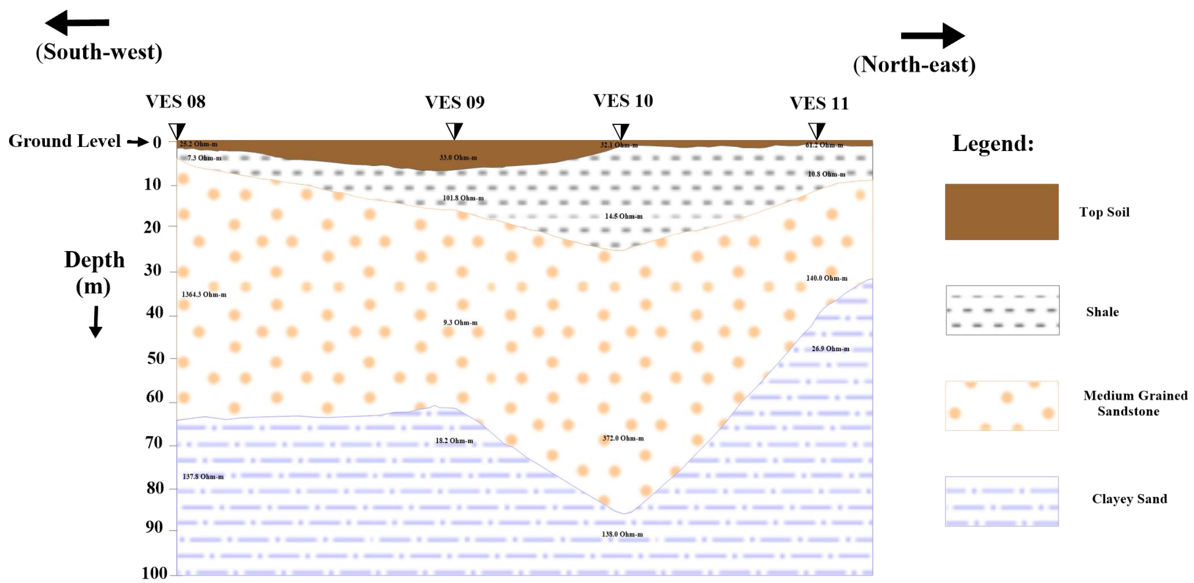

Figure 8: Geo-electric profile along VES 08, 09, 10 and 11 plotted in a northeast- southwest direction.

Iso-Resistivity Map at 30/2m

The Iso-resistivity plot (map) was generated via plotting the resistivity values gotten from the VES curves at a specified electrode intervals (distance) that is applicable to all the survey stations as AB/2=30m (Figure 9). Positions displaying the same resistivity measurements are contoured. The Iso-resistivity plot aid in the qualitative interpretation of the results. It indicates the changes in resistivity at a specified electrode intervals, in addition to an overall lateral variation in the electrical characteristics of the site. A visual check on the Iso-resistivity map (Figure 9) shows the presence of high anomalies towards the northern segment. The

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northern part further displayed a greatest resistivity value of 240 Ohm-m around Dabawo. While, major anomaly low were depicted near the Southern parts of the map which has the greatest value of 40 ohm-m at Saruje Alhaji baba and Garin Mai Bindiga. This indicate that the southern portion of the research area is a higher prospective region for groundwater investigation (Figure 9).

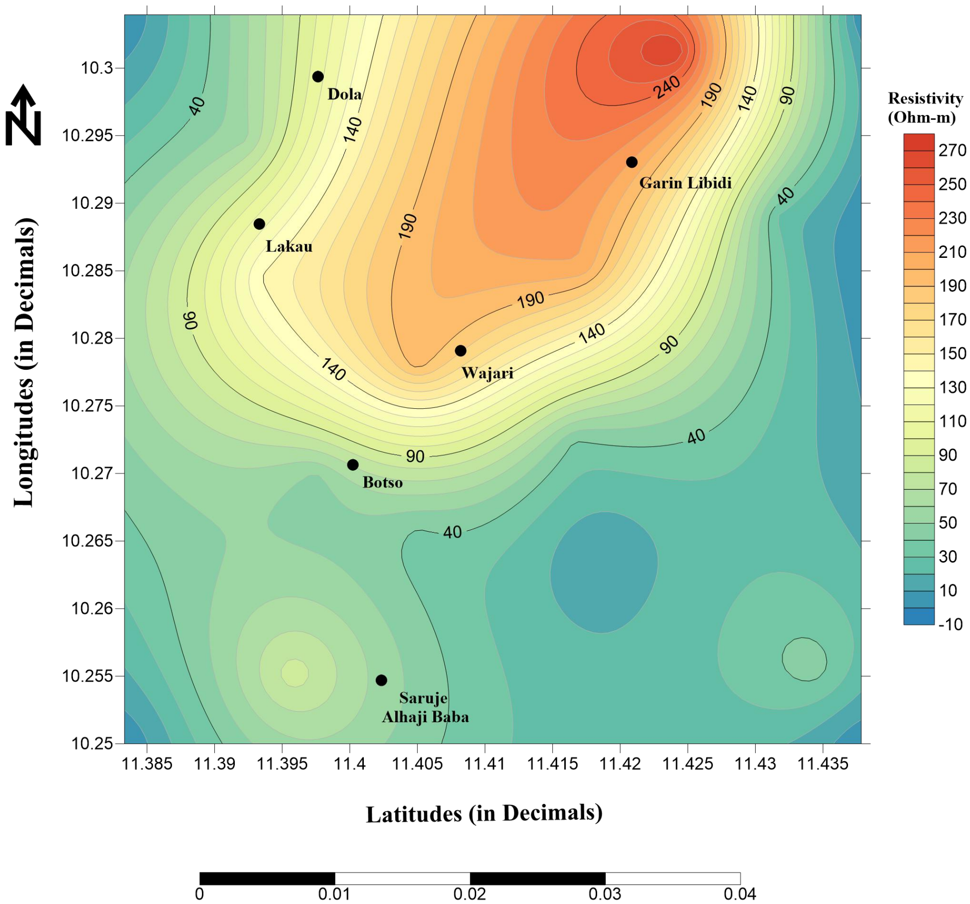

Figure 9: Iso-resistivity map of the study area at AB/2=30/2m (map scale is in Km).

Evaluation of Soil Corrosivity

The interpreted resistivity values derived from the first/top stratum of the area were utilised to generate a corrosivity map plot for the entire area of the research (Figure 10). The corrosivity map plot was employed in the assessment of the level or extent of soil corrosivity at a shallow depth of the study sites, thereby providing the basis for burying utility (metal) pipes that will be used for groundwater reticulation services, in addition to other engineering practices. Regions depicting fairly small resistivity values are regarded as corrosive. However, regions depicting large resistivity values are regarded as non-corrosive. Civil engineering construction activities usually involve laying of metallic pipes. However, underground (concealed) metal pipes are liable to corrosion and consequent leakage if the host soil medium is corrosive and destructive

(Akintorinwa and Abiola, 2011). Topsoil encompasses the stratum within which common civil engineering bases (foundations) and service pipes are concealed. Topsoil resistivity values were categorized based on

DOI: 10.56892/bima.v6i03.67

soil corrosion adopting Agunloye (1984), and Oladapo et al. (2004) soil resistivity grouping model (Table 2). The topsoil / 1st stratum resistivity gotten from the analyses of the Sounding outcomes were applied in appraising the corrosivity of the sub soils. This stratum has a thickness of range 0.7 to 6.7m. Whereas, the layer's resistivity is in a range of 25.2 Ω-m to 267.9 Ω-m (Table 3).

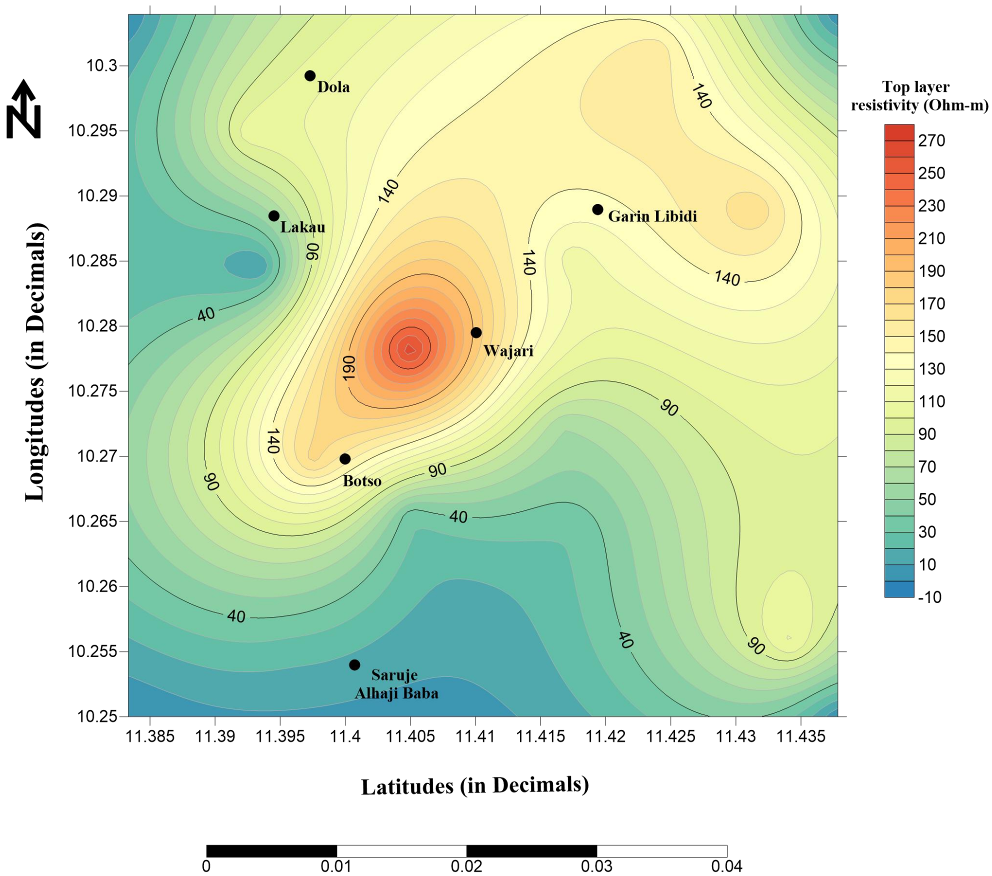

Figure 10: Top Soil/First stratum corrosivity map of the study area (map scale is in Km).

Table 2: Grouping of soil resistivity in terms of corrosivity (Agunloye 1984, and Oladapo et al., 2004).

Soil resistivity (Ω-m)	Soil corrosivity
<10	Very strongly corrosive (VSC)
10–60	Moderately corrosive (MC)
60–180	Slightly corrosive (SC)
>180	Virtually noncorrosive (VNC)

Table 3: Classification of soil corrosivity in terms of top soil resistivity of the study area.

DOI: 10.56892/bima.v6i03.67

VES No.	Location	Top soil section resistivity (ρ)	Layer unit thickness (h)	Soil corrosivity Classes
01	LAKAU	68.8	1.3	SC
02	DOLA	105.9	1.5	SC
03	DABEWO	155.4	1.1	SC
04	WAJARI	267.9	2.2	VNC
05	GARIN LIBIDI	115.2	3.1	SC
06	--------------------	167.6	1.2	SC
07	BOTSO	173.7	0.7	SC
08	SARUJE ALHAJI BABA	25.2	1.4	MC
09	--------------------	33.0	6.7	MC
10	--------------------	32.1	0.9	MC
11	GARIN MAI BINDIGA	61.2	1.0	SC
12	GARIN MAI BINDIGA	112.1	1.2	SC

The top stratum resistivity measurement ranges from 25.2 to 267.9 Ω-m, in addition to an average value of 415.41 Ω-m. The top stratum corrosivity varied from 'virtually noncorrosive (VNC)' to 'moderately corrosive (MC)'. A section of the central zones (Wajari areas) of the study area (Figure 10) are considered to be non corrosive (ρ >180 Ω-m). Whereas, the surrounding zones adjoining it up to the eastern part of Garin Libidi are of the slightly corrosive class (60-180 Ω-m; Figure 10). VES 04 (Wajari) depicts fairly high top stratum resistivity value that indicates low chances for corrosion which is in 'virtually non-corrosive (VNC) class. VES 01 (Lakau), 02 (Dola), 03 (Dabewo), 05 (Garin libidi), 06, 07 (Botso), 11 (Garin mai Bindiga) and 12 (Garin mai Bindiga) of the study area (Table 3) are slightly corrosive, while VES 08 (Saruje Alhaji baba), 09, and 10 have moderate corrosivity of which metal services (utility) pipes laid within them can be prone to corrosion.

Evaluation of aquifer protective capacity

An aquifer protective capacity (APC) simply refers to the capability of the overburden stratum to slow down and sieve percolating ground surface contaminating liquid into the acquiferous part. The 2nd order geo-electric factor (Dar Zarouk factor), longitudinal conductance was appraised from the primary factors (thickness and resistivity) of the geo-electric subsurface strata that were employed in the categorisation of the APC of the area.

The longitudinal unit conductance map (Figure 11), was employed in grading (rating) the protective capability of the overburden stratum of the study site. Usually, Clays and Shale materials (which are normally highly impermeable in nature) tend to display high longitudinal conductance due to their low resistivity values. However permeable materials, for instance gravels and sands depict low longitudinal units conductance values (owing to their high resistivity measurements). Consequently, high longitudinal unit conductance conforms to excellent and good APC. Moreover, low longitudinal unit conductance records are attributed to "poor and weak APC" category.

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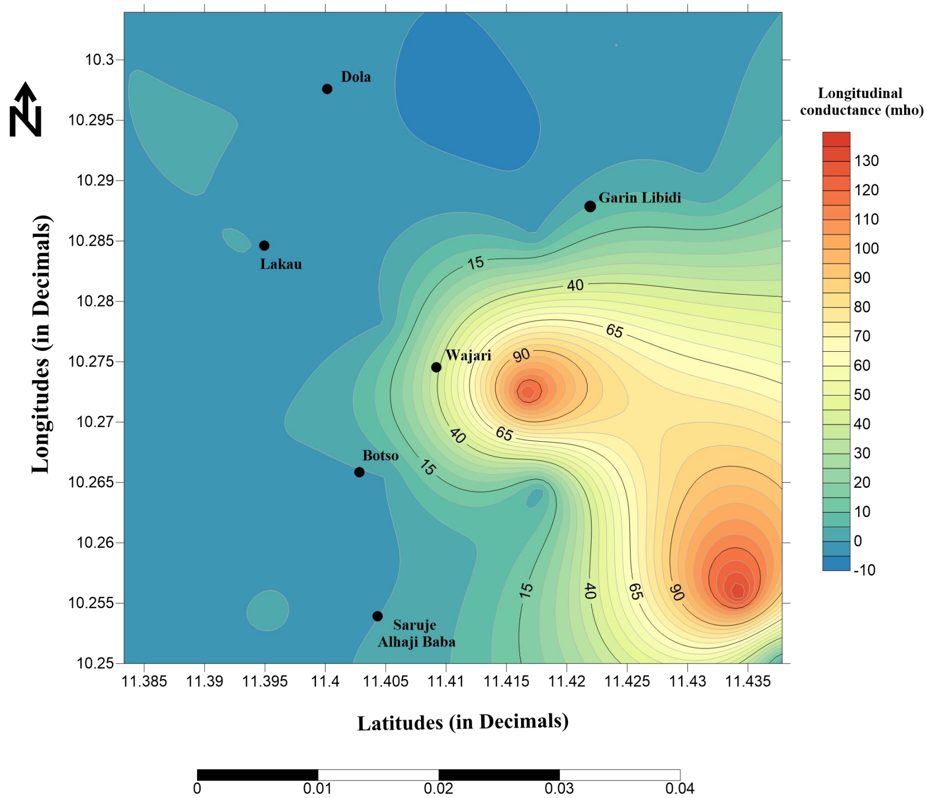

Figure 11: Longitudinal unit conductance map of the study area (map Scale is in Km).

Now, following the soils classification provided by Oladapo et al. (2004) (Table 4), the longitudinal unit conductance measurements computed for whole of the present research area are grouped into poor, weak, moderate, very good and excellent protective capability areas (Table 5).

Table 4: Modified longitudinal conductance/aquifer protective capacity rating (Oladapo et al, 2004).

Longitudinal Conductance (mhos)	Aquifer protective capacity rating
>10	Excellent
5–10	Very good
0.7–4.49	Good
0.2–0.69	Moderate
0.1–0.19	Weak
<0.1	Poor

DOI: 10.56892/bima.v6i03.67

Table 5: Classification of longitudinal conductance in terms of aquifer protective capacity of the study area.

VES No	Location	S (mhos)	AQUIFER PROTECTIVE CAPACITY RATING
01	LAKAU	0.1188	Weak
02	DOLA	0.6196	Moderate
03	DABEWO	0.0199	Poor
04	WAJARI	0.0454	Poor
05	GARIN LIBIDI	0.0332	Poor
06	--------------------	0.3499	Moderate
07	BOTSO	0.1520	Weak
08	SARUJE ALHAJI BABA	0.0441	Poor
09	--------------------	4.8709	Very good
10	--------------------	0.1637	Weak
11	GARIN MAI BINDIGA	3934	Excellent
12	GARIN MAI BINDIGA	1589.5	Excellent

--------------------------denotes VES points devoid of settlement

VES 01(Lakau), 03 (Dabewo), 04 (Wajari), 05 (Garin libidi), 07 (Botso), 08 (Saruje Alhaji baba), and 10 of the study area are occupied by poor and weak APC regions and they may be prone to surface pollution sources (release of leachates from decomposed garbage (refuse) dump sites and diffusion of contaminants from farming events) in the area. The moderate (VES 02 (Dola), 06), very good (VES 09) and excellent (VES 11) (Garin mai Bindiga), 12 (Garin mai Bindiga) protective capacity regions of the study area displayed greater opposition character to polluted liquids, such that when facing pollution such regions are superficially harmless.

Transverse Unit Resistance Map.

The transverse unit resistance (T) is among the major factors (parameters) being applied to delineate target zones of good prospect for groundwater occurrences. Based on empirical consideration, it can be disclosed that the relation between Transmisivity of an aquifer and that of its transverse resistance is directly proportionate in nature. This implies that the maximum values of T reveal most probably the maximum values of Transmisivity of the acquiferous areas and vice versa (Ward, 1990). The transverse unit resistance values range from 0.060419Ωm-m to 82,130Ωm-m (Figure 12). Region around VES 07 (Botso) is characterised by relatively high transverse unit resistance value.

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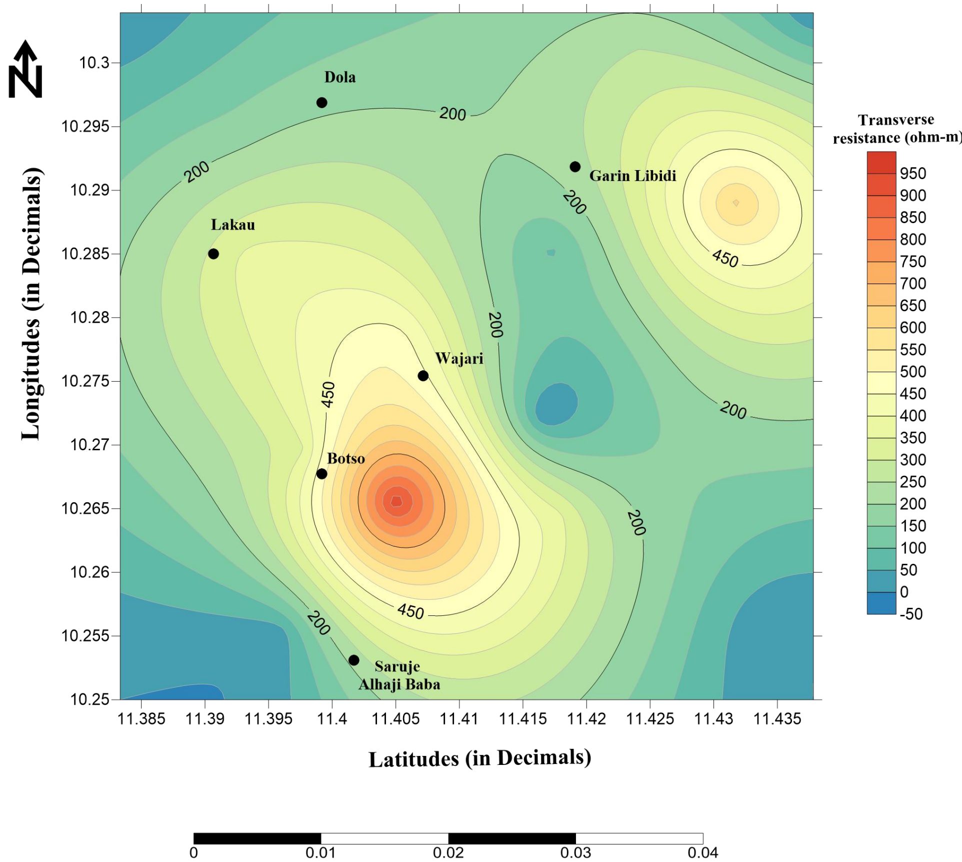

Figure 12: Transverse Unit Resistance Map of the study area (map scale is in Km).

Table 6: Dar Zarouk parameters for the VES Points.

VES NO/ Location	Coordinates & Elevation	Layer No.	Longitudinal conductance (mhos)	Transverse resistance (Ωm)
VES01	N10º17'4.3"	1	0.0188	89.44
LAKAU	E11º23'36.8"	2	0.1731	369.6
	ELEV.304m	3	0.1188	275.63
VES02	N10º17'41.3"	1	0.0141	158.85
DOLA	E11º23'32.7"	2	0.1416	169.54
	ELEV.309m	3	0.6196	3311.43
VES03	N10º18'04.7"	1	0.0070	170.94
DABEWO	E11º25'26.8"	2	0.1222	247.5
	ELEV.327m	3	0.0199	966.06
VES04	N10º16'41.5"	1	0.0082	589.38
WAJARI	E11º24'17.9"	2	0.0583	481.77
	ELEV.322m	3	0.0454	4954.5
VES05	N10º17'07.1"	1	0.0269	357.12
GARIN LIBIDI	E11º25'02.2"	2	0.1900	92.82
	ELEV.321m	3	0.0332	19576.35
VES06	N10º17'20.3"	1	0.00715	201.12
	E11º25'54"	2	1.02040	612.5
	ELEV.322m	3	0.34894	7471.2
VES07	N10º16'10.8"	1	0.00402	121.59
BOTSO	E11º23'50.9"	2	0.49615	335.4

DOI: 10.56892/bima.v6i03.67

	ELEV.321m	3	0.15206	19034.4
VES08	N10º15'18.6"	1	0.0555	35.28
SARUJE ALHAJI BABA	E11º23'44.9"	2	0.35616	18.98
	ELEV.313m	3	0.044125	82130.8
VES09	N10º15'56"	1	0.2030	221.1
	E11º24'18"	2	0.09037	936.56
	ELEV.306m	3	4.87097	421.29
VES10	N10º15'52"	1	0.02803	28.89
	E11º25'04"	2	1.7241	362.5
	ELEV.308m	3	0.1637	22,654.8
VES11	N10º16'20.5"	1	0.0163	61.2
	E11º25'00"	2	127.44	1.09259
	ELEV.310m	3	3934	0.2007
VES12	N10º15'20.3"	1	0.01070	134.52
GARIN MAI-BINDIGA	E11º26'03.4"	2	136.16	0.40217
	ELEV.296m	3	1589.56	0.060419

CONCLUSION

The study area is part of Gombe topographic sheet 152NE of Gombe State, Nigeria. The area is about 25sqkm. Geographically, it lies between latitudes10º15' 00" N to 10º 18' 14.2" N and Longitudes 11º 23' 00" E to 11º 26' 16.2" E. The study area forms part of the Gongola Arm of the Northern Benue basin of North Eastern Nigeria.

The interpretation of geo-electric units revealed the curve types obtained include A, H, K, HK, and QQ. The geo-electric sections display the differences of resistivity values and thicknesses of layers within the depth investigated by the VES and the profiles disclosed 4 subsurface strata. The subsurface sequence comprises of topsoil, shale, medium grained sandstone and clayey sand.

The results of the investigation show that in slightly corrosive areas, VES 01 (Lakau), 02 (Dola), 03 (Dabewo), 05 (Garin Libidi), 06, 07 (Botso), 11 (Garin mai Bindiga) and 12 (Garin mai bindiga) concrete underground containers can be built for water storage. Besides, metal pipelines can be employed for transmitting oil and gas around this locality. In the moderately corrosive regions (VES 08 (Saruje Alhaji baba), 09, and 10) underground metal (iron) storage reservoirs are not recommended to be buried in these zones. However, plastic pipe is preferable to avoid possible leakage due to corrosion. water reticulation, movement of oil and gas via galvanised conduits might rust, break, or escape owing to the reaction of the corrosive material to the buried metal pipes, as it can results to severe threats to the environment. Virtually non-corrosive zone VES 04 (Wajari) is completely good for laying of steely underground containers without corrosion.

Five evident aquifer protective capacity regions were distinguished, viz.; poor protective capacity areas; VES 03 (Dabewo), 04 (Wajari), 05 (Garin libidi), and 08 (Saruje Alhaji baba), are susceptible to pollution and adulteration if there is an incidence of oil discharge, leakage in underground storage container, rupture of petroleum pipelines, and diffusion of leachate from decayed dump site. Areas of weak protective capacity VES 01(Lakau), 07 (Botso), and 10 are less susceptible to groundwater pollution or contamination but can be more susceptible with time as contaminant continues to interacts. Regions of moderate protective capacity VES 02 (Dola), 06, and good protective capacity (VES 09) offer greater

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resistance characteristics to adulterated fluids so that in the events of contamination those regions can superficially be harmless.

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