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SOIL CORROSIVITY AND OVERBURDEN PROTECTIVE CAPACITY OVER AQUIFER SYSTEM IN KWAL KANKE NORTHENTRAL NIGERIA

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ABSTRACT

A geophysical survey was carried out in Kwal, Kanke Local Government Area of Plateau State, northcentral Nigeria using electrical resistivity soundings method. This study aimed to demarcate zones that are very susceptible to groundwater contamination from surfacepollutants and subsurface soils that are corrosive to utility pipes. Schlumberger configurations were used to delineate the subsurface geologic layers, corrosivity level and aquifer protective capacity. Fourty (40) Vertical Electrical Sounding (VES) data were acquired using ABEM Terrameter SAS 300B and ABEM 2000 booster resistivity meter with half-current electrode separation (AB/2) of 1 to 125 m. The interpretations of the data collected were aided by computer assisted iterative using the computer iteration algorithm WINRESIST Version 1.0, MS Excel 2016 and surfer 11 software. The curve types obtained include: A, Q, H, K, AK, HA, QH, AA, KH and HK types. Four (4) distinct geoelectric layers were identified namely: topsoil, clayey layer, fractured basement and fresh basement. The topsoil is composed of moderately corrosive materials depicted with green colour having resistivity values in the range of 10 to 60 Ωm with frequency distribution of 22.50%. Slightly corrosive materials with resistivity values of $60 < \rho < 180$ Ωm and frequency distribution of 57.50% is symbolized with yellow colour while the practically non-corrosive with resistivity values in excess of 180 Ωm have 20.00% frequency distribution represented with pink colour. The second layer is made up of moderately corrosive materials having resistivity values in the range of 10 to 60 Ωm (green colour) with frequency distribution of 30.00%. Slightly corrosive materials having resistivity values of 60 to 180 Ωm have frequency distributions of 20.00% is denoted with yellow colour. The practically non-corrosive portions have resistivity values above 180 Ωm and frequency distribution values of 50.00% are depicted with pink colour. Zones of moderate (pink colour), weak (green colour) and poor (yellow colour) overburden protective capacity were delineated, with longitudinal conductance (S) values of $0.2 < S < 0.69$, $0.1 < S < 0.19$ and $S < 0.1$ mhos, respectively. On a regional consideration, 25.00%, 52.50% and 22.50% of the study area is characterised by overburden materials of poor, weak and moderate protective capacity respectively. The measured overburden thickness ranges from 2.6 to 29.6 m. Zones of moderate protective capacity have thick aquifer with thick clay materials above the aquifer that act as seal while areas with poor to weak protective capacity are susceptible to infiltrating contaminating fluid.

Keywords: Moderately corrosive, Geoelectrical Survey, Kwal, Protective Capacity, Overburden thickness

INTRODUCTION

Presentation of civil engineering construction works comprises utility pipes need the knowledge regarding the corrosivity of soil. Soils sustain man-made structures of all types; utilities and infrastructure are buried in it. Buried pipes are vulnerable to corrosion and resulting failure if the host soil medium is corrosive and aggressive. The degradation of buried metallic materials is known as corrosion and metallic substrates are converted into oxides, hydroxides and aqueous salts within a cathode–anode system with resultant loss in strength, ductility and other mechanical properties.

The wide ranges of failures that are often accompanied by a high degree of economic and environmental consequences are as a result of corrosion of cast iron, ductile iron and steel in the soils. For instance, leakage in pipelines could add up to hazards in the environment. Mitigating measures during design and construction as well as an understanding of the corrosive potential in a given soil environment are thus desirable (Akintorinwa and Abiola, 2011; Roberge, 2008). Soil corrosivity depends mainly on the composition of the soil and other environmental factors such as the moisture content, presence of oxygen, content of dissolved salts, pH value and porosity (aeration).

The presence and abundance of oxygen promote corrosivity. High concentrations of soluble salts, high moisture content and a pH indicative of an acidic medium readily promote corrosivity. These factors control the soil resistivity. They are thus the main diagnostic factors. There exists a good correlation between the soil resistivity and corrosion rate of the buried metallic materials. Soil corrosivity is inversely related to the soil resistivity (Saupi *et al.,* 2015 and Adesida *et al.*, 2015).

The occurrence of groundwater is controlled by a number of factors such as type of parent rock, depth, extent and pattern of weathering, the sand/clay ratio and the degree of fracturing, fissuring and jointing (Jayeoba and Oladunjoye, 2013 and Teikeu *et al*., 2012). High soil resistivity slows down the corrosion activities due to less ionic current flow. Resistivity is thus a function of moisture and the concentration of current-carrying soluble ions. Low electrical resistivity is indicative of good electrical conducting path arising from reduced aeration, increased electrolyte saturation or high concentration of dissolved salts in soils (Roberge, 2008; Elarabi and Elkhawad, 2014 and Tijani *et al*., 2014).

Corrosion of cast iron, ductile iron and steel in soils can lead to a range of failures especially in pipelines and buried storage tanks. Integrity assessment of subsurface infrastructure, such as buried steel components, pipelines and steel sheet piles, requires an understanding of the local conditions. Assessment of soil corrosivity is thus germane to design of pipe networks as it provides a useful guides in the selection and prescription of the subsurface steel pipes for a given project and perhaps required treatment to forestall economic waste and varied hazards associated with the rupture of corroded pipes. Poor, weak and moderate aquifer protective capacity zones were delineated in the study area. Areas characterised by poor and weak/moderate aquifer protective capacity should be void of potential contaminant load to ensure overall protection of the groundwater resource.

Installation of facilities, though essential but capable of provoking permanent damage of the underlying aquifers particularly in areas where residents rely mostly on groundwater, mandates an understanding of the aquifer protective capacity of the overburden units of the host soil medium. The overburden encompasses all geomaterials above the contributors of contaminants to the hydrological systems. Gopal, 2010; Braga *et al*, 2006 and Oladapo *et al.*, 2004 revealed that Leachate from dumpsites, mining activities, buried petroleum pipes/tanks and septic tanks and the widespread use of chemical products such as pesticides, herbicides and solvents portend risks to the groundwater quality status. The subsurface layer acts as a natural filter to preclude surface pollutants. The ability of the

geomaterials to impede and filter percolating fluid is a measure of the protective capacity and a function of its transmissivity. Estimating these properties from the traditional methods of pumping tests can be very expensive and time consuming. The electrical resistivity method is significant in situ determination of subsoil characteristics and conditions (Oladapo *et al.*, 2004; Ehirim and Nwankwo, 2010 and Tsepav *et al.*, 2015).
The traditional purpose of electrical resistivity survey is to determine the resistivity distribution of the subsurface by taking measurements on the ground surface. The electric conduction in the subsurface is fundamentally electrolytic through interstitial water in pores and fissures. Groundwater filling the pore spaces comprises natural electrolyte with a significant number of ions. Soil environments have essential electrolytic properties for the redox (oxidation–reduction) reactions that take place during corrosion. Soil resistivity indicates the ability of a soil environment to carry corrosion currents (Mallam and Emenike, 2008; Ojo *et al*, 2015). It is noted that burial of utilities and underground storage tanks are limited to shallow depths. The aim of the study is to examine and evaluate the corrosivity of the subsurface materials in Kwal area with a view to demarcate the subsurface geologic layers and as well determine their corrosion severity using the electrical resistivity method.

Geology, Climate and Description of Location

The study area, Kwal, Kanke northcentral Nigeria, lies within latitudes 9° 21′ 30′′ and 9° 23′ 30′′ N and longitudes 9° 36′ 00′′ and 9° 38′ 00′′ E (Figure 1). The area is underlain by the Basement Complex of northcentral Nigeria comprising the migmatite, Older granite, aplo-pegmatitic granite gneiss and Quartenary Basalts. The Quartenary Basalts which is a NW-SE trending dyke cut across the older surrounding country rocks discordantly in the area (Figure 2). Kwal area belongs to Tropical Savanna climate with two distinct seasons: the wet and dry seasons. The wet season duration is between April and October while the dry season begins from October to April. The highest rainfall is usually recorded in July while dry season is at its climax in January. The annual rainfall and average annual temperature across the area are 1400 and 19.5°C respectively with a relative humidity of about 76 % (NIMET, 2011). Evaporation is usually at minimum rate due to heavy rainfall between June and September thus, promoting infiltration to the water table. Rivers and streams serve as drainage channels within the study area (Olajuyigbe, 2010; Rahaman, 1988).
The area is accessible through Mangu-Pankshin to Langtang road. Tarred roads meandering due to rugged hills, Minor roads and foot paths link the different settlement and villages within the study area. However, some of the areas were not easily accessible due to ruggedness of the terrain.

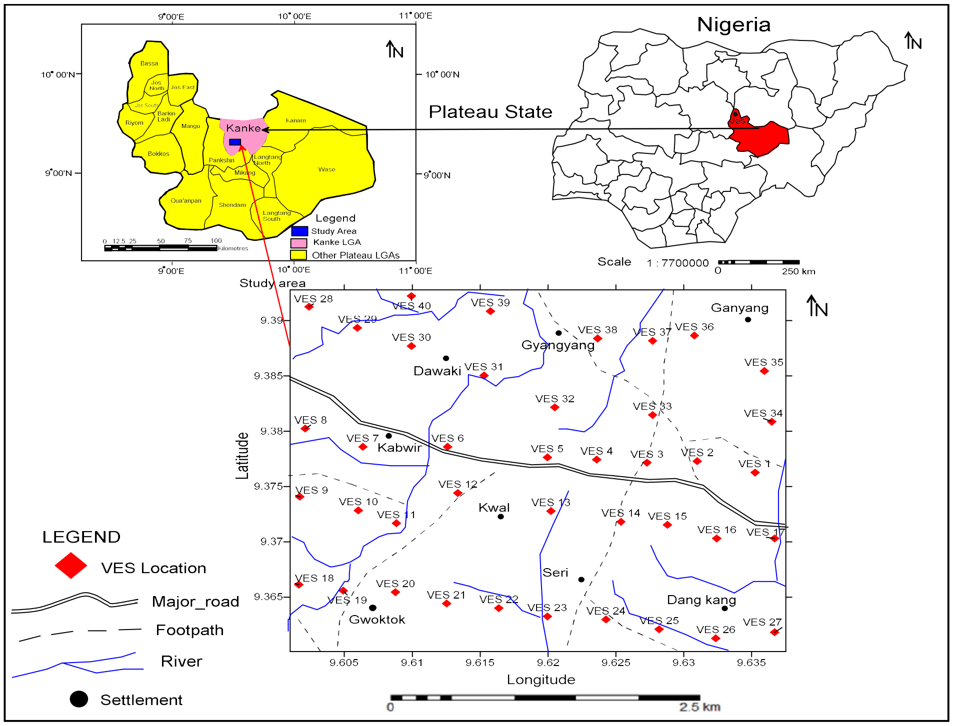

Figure 1: Location map of the study area (NGSA, 2011).

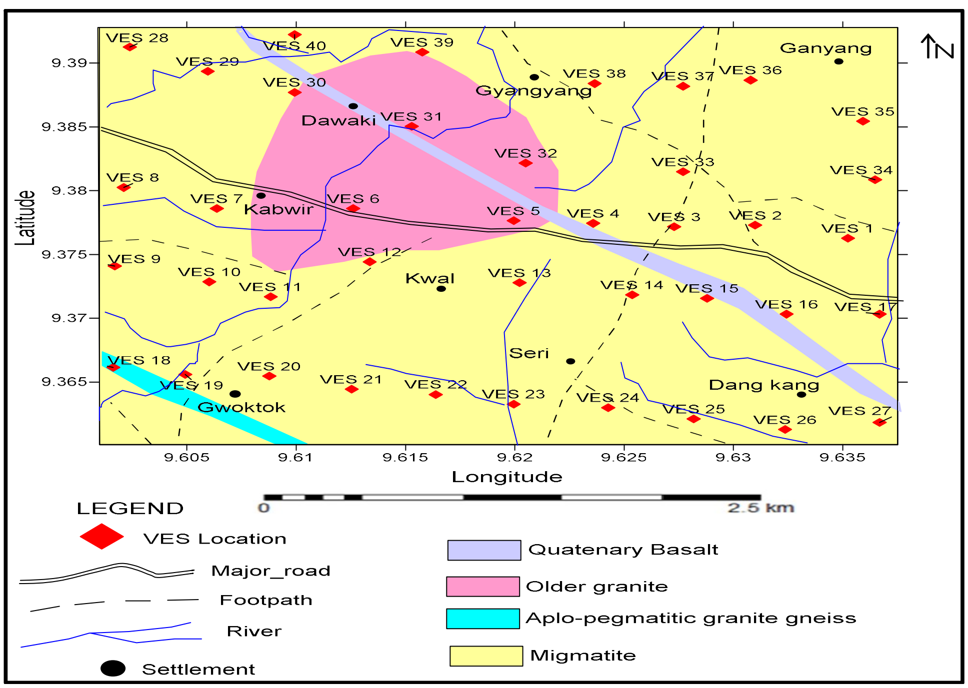

Figure 2: Geological map of Kwal showing VES points (NGSA, 2011).

MATERIALS AND METHODS

The geophysical data were obtained with ABEM Terrameter SAS 300B with ABEM 2000 booster resistivity meter that comprises transmitter unit, through which current enters the ground and the receiver unit, through which the resultant potential difference was recorded. some materials used for geophysical survey consist of: two metallic current electrodes and two potential electrodes; two red coloured connecting cables for current and two black coloured cables for potential electrodes; two reels of calibrated rope; compass for finding the orientation of the traverses; cutlass for cutting traverses, hammer for driving the electrodes into the ground and data sheet for recording the field data. Schlumberger array was used in the data gathering process known as Vertical Electrical Sounding (VES) (Ariyo and Adeyemi, 2009; Ajibade and Ogungbesan, 2013; Emmanuel et al., 2015). Schlumberger VES investigation measures the changes in formation resistivity with depth and electrode spread of AB/2 was altered from 1 to 125 m. It involves that current electrodes spacing, AB is increased after every reading while potential electrodes spacing, MN is kept fixed for most readings but increased when necessary using the control AB/2 > MN/2 (Okolie et al., 2010).

The Schlumberger array was sounded using the terrameter from which apparent resistivity data of the subsurface under investigation were gotten with changing current electrode separations along each traverse at designated stations. Fourty (40) VES readings were acquired from the study area and were interpreted with the aid of computer assisted iterative using the computer iteration algorithm WINRESIST Version 1.0 (Vander Velpen, 1988). The software was further used for both computer iteration and modeling. Computer iteration was carried out to decrease errors to a predicted limit and to improve the goodness of fitting between the computer-generated model and the field data. Soil corrosivity is an indirect measure parameter. One of the recognized classifications of soil corrosivity towards the buried metallic materials is established on a single parameter, which is the soil resistivity.

The soil resistivity reveals the main soil properties as it depends on porosity, degree of electrolyte saturation or concentration of dissolved salts in soils. It is hence a typically indicative of soil corrosivity. This study uses the resistivity of both the topsoil and second layer in considering the soil corrosivity by adopting the resistivity method of Saupi *et al.,* 2015; Kleiner *et al.,* 2010 and Elarabi and Elkhawad, 2014. The Dar-Zarrouk parameters were obtained from the first order geoelectric parameters (i.e. layer resistivities and thicknesses). The Total longitudinal unit conductance (S) is predominantly significant when is used to define a geoelectric section comprising several layers. The total longitudinal conductance (S) of the overburden unit at every vertical electrical sounding location was gotten from the mathematical equation according to Zhody et al., (1974) as shown in equation 1. For n layers, the total longitudinal unit conductance is:

$$S = \sum_{i=1}^{n}\left(\frac{\boldsymbol{hi}}{\boldsymbol{Pi}}\right)= \frac{h1}{\rho 1}+ \frac{h2}{\rho 2} + \frac{hn}{\rho n}\ldots \ldots + \ldots\ldots\ldots\ldots \quad (1)$$

Where hi is the layer thickness, *pi* is layer resistivity whiles the number of layers from the surface to the top of aquifer, (*i*) vary from 1 to n.

RESULTS

The true resistivity for each layer (P), true thickness for each Layer (h), typical curve types, overburden thickness and Total Longitudinal Conductance Unit (S) are presented in Table 1. The summary of the qualitative analysis of the curve types interpretations for the forty (40) VES stations are presented in Table 2. The four (4) representative curve types found within the study area are shown in Figures 3a to 3d, which were obtained from the interpretation of the data with the aid of computer assisted iterative software using WINRESIST Version 1.0 (Vander Velpen, 1988). The resistivity sounding curves obtained from the study area varied from the

3-layer (A, Q, H and K types) and 4-layer (AK, HA, QH, AA, KH and HK) with the A type being the predominant. Figure 4 displays the bar chart frequency of curve types distribution in the study area.

Table1: Calculated geoelectric (Dar-Zarrouk) parameters

	Resistivity (Ohm-m)				Thickness (m)			Curve type		Longitudinal Conductance (mhos)
VES station	ρ_1	ρ_2	ρ_3	ρ_4	h_1	h_2	h_3		Aquifer thickness	
1	36	69.2	596.5	547.5	7	1	16	AK	16	0.24
2	146.4	69.1	34.5		0.8	16.5		Q	16.5	0.24
3	343.1	245.1	104.2		1.3	8.4		Q	8.4	0.29
4	180.4	73.9	31.6		1.9	12.7		Q	12.7	0.18
5	108.8	37	133.5	337.8	1.2	5.4	25.3	HA	25.3	0.35
6	172.3	28.3	159.9	1538.4	0.7	5.9	14.3	HA	14.3	0.3
7	17.3	4957.8	6148.2		2.5	17.2		A	17.2	0.15
8	14.9	76.6	4603.1		2.6	4		A	4	0.23
9	453.9	428.5	1394.7		9.7	17.5		H	17.5	0.06
10	134.6	328.7	856		5.6	4.3		A	4.3	0.05
11	121	47.8	929.7		3.2	5.4		H	5.4	0.14
12	163.1	18.9	315.7	738.6	0.9	2	3.6	HA	3.6	0.12
13	665.9	166.1	37.4	393.4	8.5	4.8	21.6	QH	21.6	0.17
14	45.9	159.2	1294.3	2187.4	7.2	2.6	12.2	AA	12.2	0.18
15	243.7	395.2	621		7.6	2.6		A	2.6	0.04
16	261.8	521.6	729.5		6.3	29.6		A	29.6	0.08
17	224.4	417.9	594.7		7.5	6.5		A	6.5	0.05
18	184.3	498.2	636.9		9.7	26.6		A	26.6	0.11
19	142.2	696.9	360.1	1224.7	5	9.3	19.8	KH	19.8	0.1
20	79.3	312	338.9	1122.5	4.9	6	20.9	AA	20.9	0.14
21	15.2	269.4	4030.5		5.2	6.2		A	6.2	0.37
22	133	54.3	697.4	2670	1.3	6.3	11.5	HK	11.5	0.14
23	453.1	239.7	95.1	536.5	1.4	9.7	26.0	QH	26.0	0.13
24	107.8	55.3	691.2	1827.6	1.2	6.8	12.9	HA	12.9	0.15
25	48.3	328.2	475.5		6.3	7.7		A	7.7	0.15
26	162.4	45.9	621.9		1	13.3		H	13.3	0.3
27	323.7	91.5	1217.2		1	13.1		H	13.1	0.15
28	95.1	287.6	632.3	126.4	0.9	13.5	16.2	AK	16.2	0.08
29	170.4	398.5	425.7		11.6	17.6		A	17.6	0.11
30	306.8	212	195.2		2.6	14.7		Q	14.7	0.31
31	107.2	33.7	261.2	823.1	0.7	3.4	16.2	HA	16.2	0.17
32	71.2	219.6	561.2	2437.6	5.8	6.1	12.7	AA	12.7	0.13
33	243.2	57.6	248.5	1460.2	0.6	7	15.4	HA	15.4	0.19
34	163.6	335.5	881.5	342.2	3.6	3.5	19.4	AK	19.4	0.05
35	113.2	724.6	297.6		6.3	24.1		K	24.1	0.09
36	65.2	23.4	351.8	2328	2.7	3.1	4.5	HA	4.5	0.19
37	85.4	183.3	688.1		6.4	3.4		A	3.4	0.09
38	56.4	160.5	237.1	1943.9	1.5	19	10.6	AA	10.6	0.19
39	83.3	510.1	650		7.7	20		A	20	0.14
40	170.1	281.7	443.9		9.6	9.6		A	9.6	0.09

VES = vertical electrical sounding, ρ_1= first layer resistivity, ρ_2= second layer resistivity, ρ_3= third layer resistivity ρ_4= fourth layer resistivity,

h_1= first layer thickness, h_2= second layer thickness, h_3= third layer thickness,

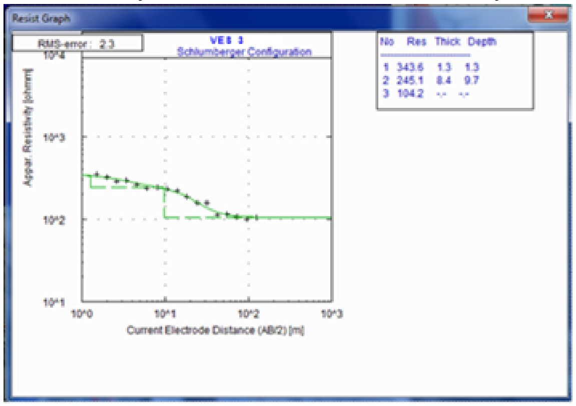

Figure 3a: Type Q curve of the study area

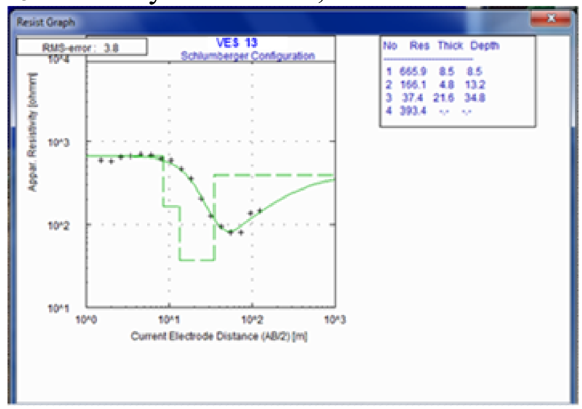

Figure 3b: Type QH curve of the study area

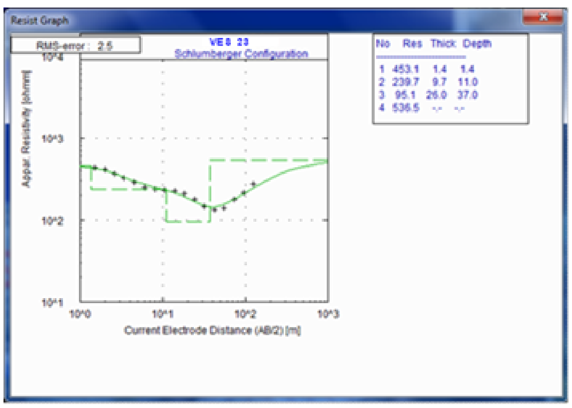

Figure 3c: Type QH curve of the study area

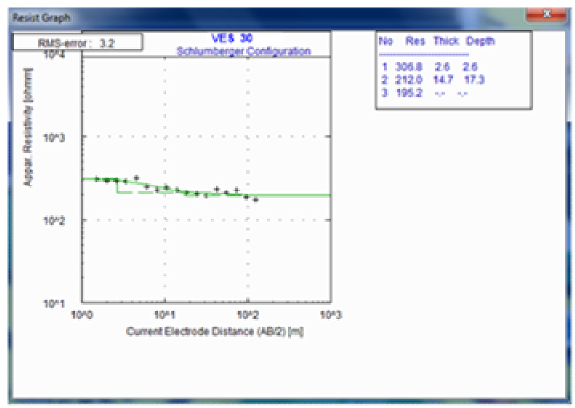

Figure 3d: Type Q curve of the study area

Table 2: Qualitative analysis of curve types

S/No	Curve Type	Frequency	Percentage (%)	Layer's resistivity Relationship	Number of geoelectric layers
1	A	13	32.5	$\rho1 < \rho2 < \rho3$	3
2	Q	4	10	$\rho1 > \rho2 > \rho3$	3
3	H	4	10	$\rho1 > \rho2 < \rho3$	3
4	K	1	2.5	$\rho1 < \rho2 > \rho3$	3
5	AK	3	7.5	$\rho1 < \rho2 < \rho3 > \rho4$	4
6	HA	7	17.5	$\rho1 > \rho2 < \rho3 < \rho4$	4
7	QH	2	5	$\rho1 > \rho2 > \rho3 < \rho4$	4
8	AA	4	10	$\rho1 < \rho2 < \rho3 < \rho4$	4
9	KH	1	2.5	$\rho1 < \rho2 > \rho3 < \rho4$	4
10	HK	1	2.5	$\rho1 > \rho2 < \rho3 > \rho4$	4
Total		40	100		

Note: ρ– resistivity

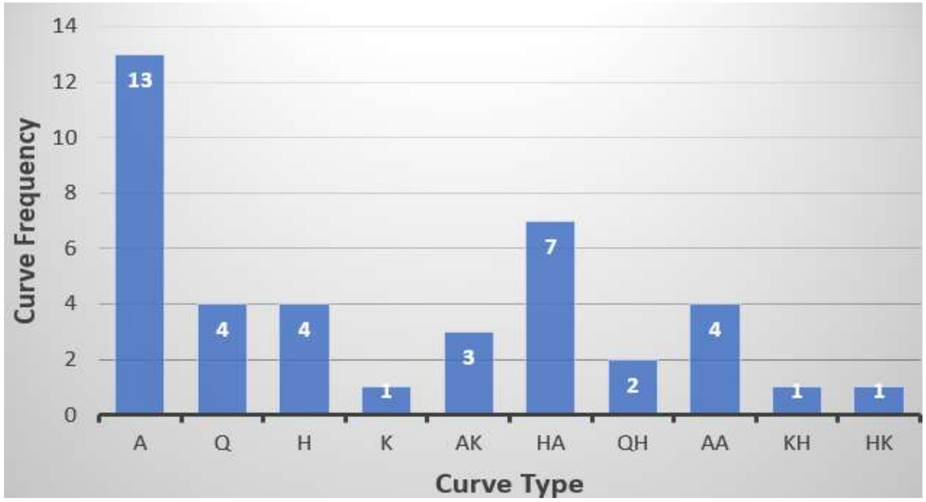

Figure 4: Bar chart showing frequency of curve type distribution in the study area

DISCUSSION

Soil Corrosivity Evaluation

The interpretations of the VES results obtained from both the topsoil (first layer) and second layer values resistivities were used in estimating the corrosivity of the subsoils in the study area. The classification of soil resistivity in terms of corrosivity in Kwal area as shown in Figures 5 and 7 respectively was carried out according to the classification of Oladapo *et al*., 2004; Adeniji *et al*., 2014 and Oki *et al*., 2016. The thickness of the top layer ranges from 0.6 m (VES 33) to 11.6 m (VES 29) whereas the resistivity ranges from 14.9 Ωm (VES 8) to 665.9 Ωm (VES 13). The thickness of the second layer ranges from 1.0 m (VES 1) to 29.6 m (VES 16) while the resistivity ranges from 18.9 Ωm (VES 12) to 4957.8 Ωm (VES 7) as observed in Table 1. Resistivity values of >180 Ωm indicating practically noncorrosive was observed around the area with pink colour while resistivity values of 60 to 180 Ωm indicating slightly corrosive was observed in the area with yellow colour and resistivity values of 10 to 60 Ωm indicating moderately corrosive was observed in the area with green colour as shown in Figures 5 and 7. The result of this study indicates that very strongly corrosive zones <10 Ωm was missing in Kwal area. Civil engineering construction works mostly comprises lying of metallic pipes. Buried pipes are vulnerable to corrosion and subsequent failure if the host soil medium is aggressive and corrosive (Akintorinwa and Abiola, 2011). Most civil utility pipes and engineering foundations are buried within the topsoil layer region and occasionally in the second layer. The nature of residual soils in the study area is determined by the underlying geology. The rates of infiltration and permeability are directly interrelated to soil characteristics. The soil type underlain by migmatite is composed of coarse-textured, greyish brown to brown sandy, fairly clayey soils are widespread in the study area.

Tables 3 give classification of soil corrosivity in terms of resistivity. The frequency distribution of corrosivity level within the topsoil is presented in Figure 6. Topsoil materials indicating corrosivity levels of practically noncorrosive (PNC), slightly corrosive (SC) and moderately corrosive (MC) had coverage of 20%, 57.50% and 22.50% respectively.

A large portion of the study area (% frequency of 57.5 %) is slightly corrosive with resistivity values of $60 < \rho < 180$ Ωm within the topsoil, particularly areas depicted with yellow colour with relatively medium resistivity values. Relatively low resistivity values are indicative of high tendency for corrosivity. Moderately corrosive materials with resistivity values of 10 < ρ < 60 Ωm occupy 22.50% of the topsoil and are observed at the green colour portion of the study area. Practically noncorrosive portion occupy 20.00% of the topsoils with resistivity values of ρ > 180 Ωm are represented with pink colour and have high resistivity values (Figure 5).

Table 3: Classification of soil resistivity in terms of corrosivity

Soil resistivity Ωm	Soil corrosivity
<10	Very strongly corrosive (VSC)
10-60	Moderately corrosive (MC)
60-180	Slightly corrosive (SC)
>180	Practically noncorrosive (PNC)

(Oladapo *et al*. 2004; Adeniji *et al*., 2014 and Oki *et al*., 2016).

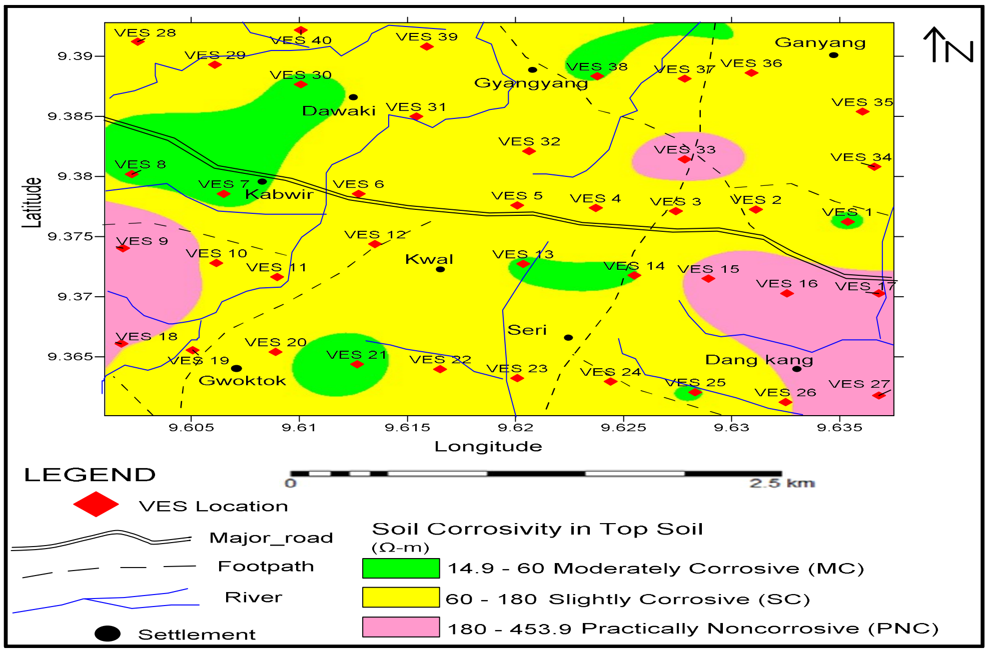

Figure 5: Topsoil Corrosivity map of the study area

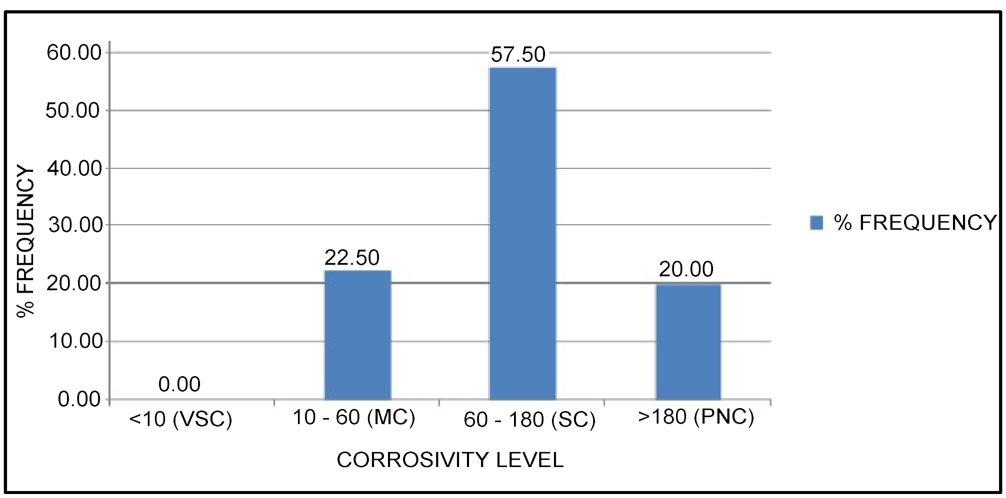

Figure 6: Frequency distribution of topsoil corrosivity level of the study area

The resistivity map of the second layer is characterised by resistivity values ranging from 18.9 to 4957.80 Ωm (Figure 7). The low resistivity end (ρ < 60 Ωm) is diagnostic of silt or clay horizon with little or no sand content. The resistivity values reflect the varying degree of weathering, the bedrock structure and mineralogy. It is typically clayey with low layer resistivity values (ρ < 100 Ωm) over sandy/clayey sand (ρ > 100 Ωm) on fine–coarse-grained granitic/gneissic rocks. Formation of a clayey regolith is enhanced with intense chemical weathering of the parent rocks. The soil corrosivity within the second layer indicates a frequency distribution of 30.00%, 20.00% and 50.00% for MC, SC and PNC levels, respectively (Figure 8). Figure 7 shows correspondingly moderately corrosive and slightly corrosive materials around the green and yellow colours sections. The pink colour parts of the map are practically noncorrosive with resistivity values of ρ >180 Ωm, signifying reduced porosity and negligible fluid content and degree of saturation. The wide resistivity range is a consequence of the variable composition of this layer, degree of fluid saturation (or moisture content) and degree of compaction. Moisture content in soil is significant when considering corrosion potential. A dry soil environment is associated with a high resistivity with practically no corrosion potential. The resistivity decreases rapidly, and corrosion is promoted with increases in moisture content until the saturation point is reached (Elarabi and Elkhawad, 2014; Jayeoba and Oladunjoye, 2013 and Teikeu *et al*., 2012).

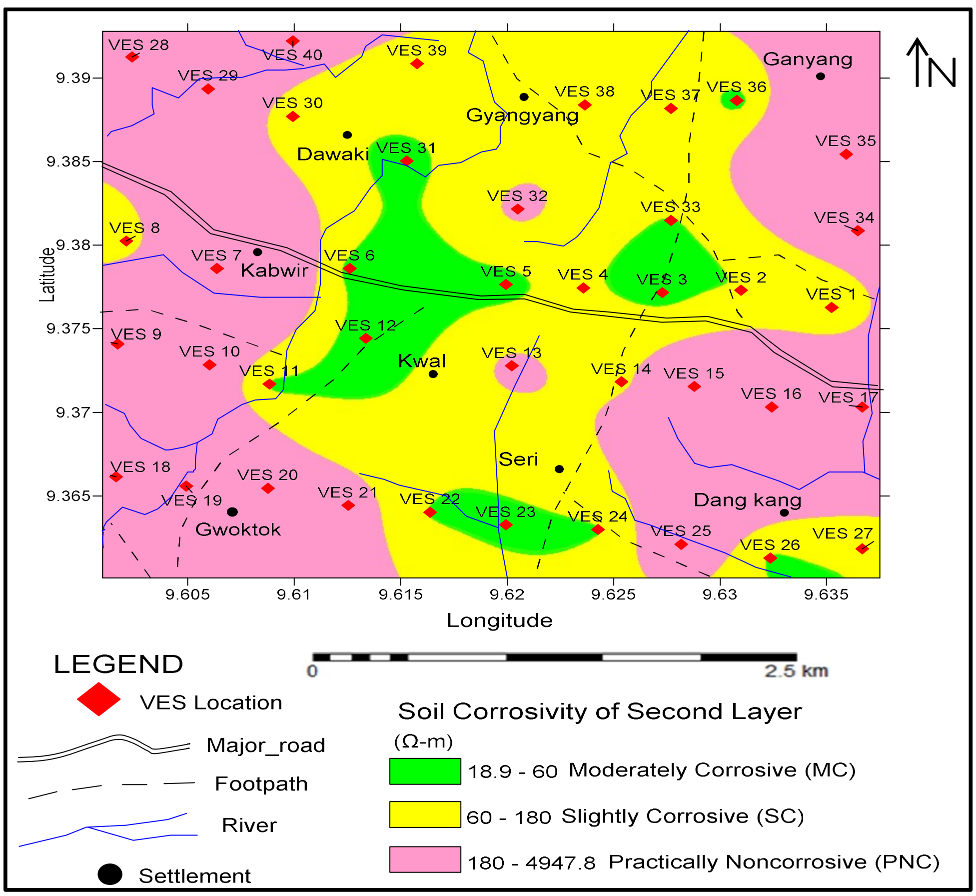

Figure 7: Second layer soil corrosivity map of the study area.

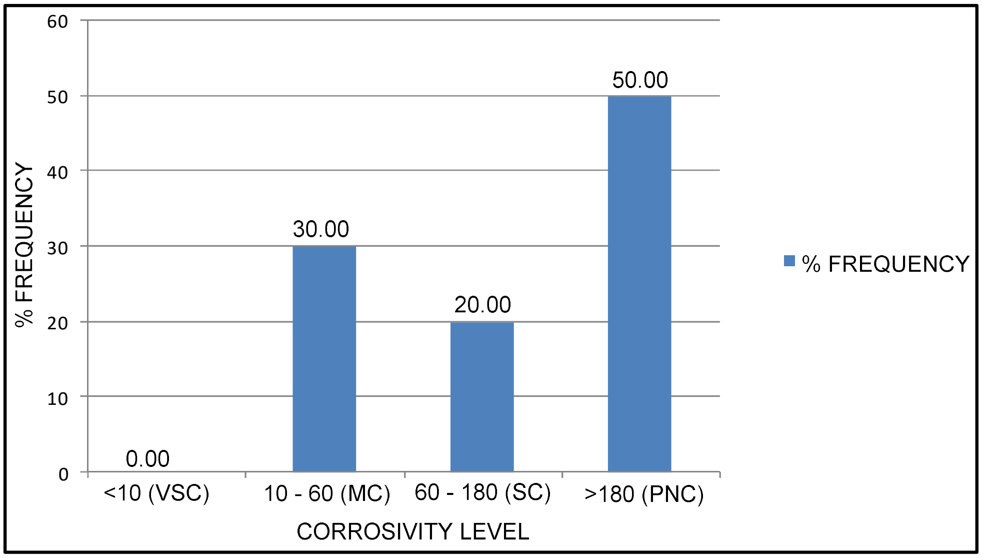

Figure 8: Frequency distribution of second layer corrosivity level of the study area.

Evaluation of the Aquifer Protective Capacity

The nature of the materials that overlain the mapped aquifers were appraised using primary electrical parameters such as resistivity and thickness. The longitudinal unit conductance (S) was used to determine its capacity to stop infiltration of unwanted fluids into the aquifer. The longitudinal unit conductance map was derived from equation (1) for the fourty (40) VES locations (Figure 9). The longitudinal unit conductance (S) value of the study area ranges from 0.01–0.35 mhos and were used for the overburden protective capacity rating. Table 4 shows the longitudinal conductance and Protective capacity rating according to Oladapo *et al*., 2004; Adeniji *et al., 2014*; Obiora *et al*., 2015; Oyedele *et al*., 2017. The study area was classified into three (3) protective capacity zones namely: moderate, weak and poor protective capacity as shown in Figure 9. The portion having conductance values ranging from 0.2 to 0.69 mhos was classified as zone of moderate protective capacity; and area with values ranging from 0.1 to 0.19 mhos were classified as exhibiting weak protective capacity while the zones where the conductance value is less than 0.1 mhos were considered to have poor protective capacity (Figure 9).

The present study shows that the overburden materials in the area around the pink colour portions of the study area have moderate protective capacity (Figure 9) and relatively thick overburden between 20 to 29.6 m thick (Figure 11) while the green and yellow colour areas show weak to poor overburden protective capacity and thin overburden thickness (Figure 9). Figure 10 further shows that about 25% of the study area falls within the poor and 52.50% falls within the weak overburden protective capacity while about 22.50% of the area constitute the moderate protective capacity. The areas covered by poor and weak Aquifer protective capacity regions of the study area will be vulnerable to surface contamination sources such as infiltration of leachates from decomposition of open refuse dumps, leakage from underground petroleum storage tanks and diffuse pollution from agricultural activities. The moderate (pink colour) aquifer protective capacity zones of the study area have higher protective property to prevent contaminated fluids infiltrations into the aquifer so that in the face of contamination such zones are seemingly safe. The earth materials act as a natural filter to infiltrated liquid; thus, its capability to prevent and filter percolating ground surface polluting fluids is a measure of its protective capacity (Adeniji et al., 2014; Olorunfemi et al., 1999). The geologic materials overlying an aquifer could act as protection in preventing the fluid from infiltrating into it. The highly impervious clayey overburden characterized by relatively high longitudinal conductance similar to moderate protective zone (Figure 9) offers protection to the underlying aquifer (Abiola et al., 2009).

Table 4: Longitudinal conductance/ Protective capacity rating

Longitudinal conductance (mhos)	Protective capacity rating
>10	Excellent
5–10	Very good
0.7–4.9	Good
0.2–0.69	Moderate
0.1–0.19	Weak
<0.1	Poor

(Oladapo *et al*., 2004; Adeniji *et al., 2014*; Obiora *et al*., 2015; Oyedele *et al*., 2017)

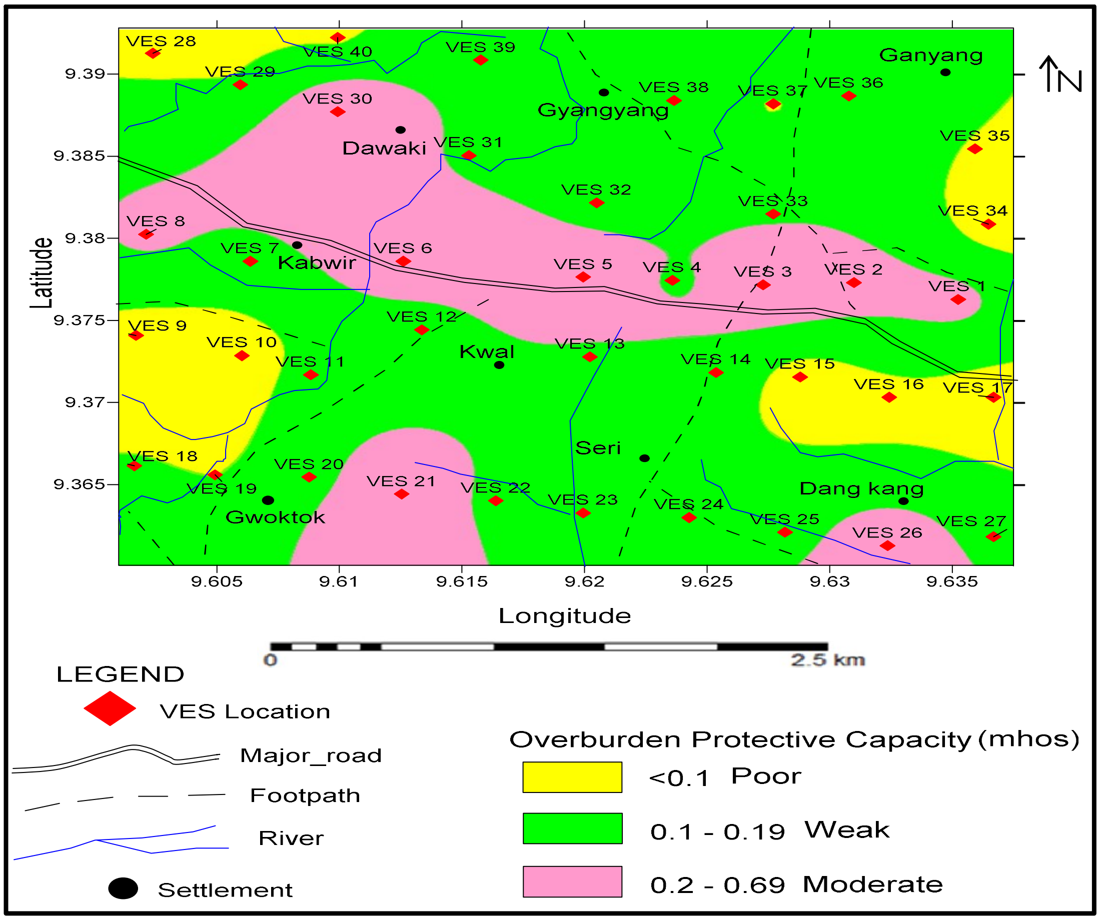

Figure 9: Aquifer protective capacity map of the study area.

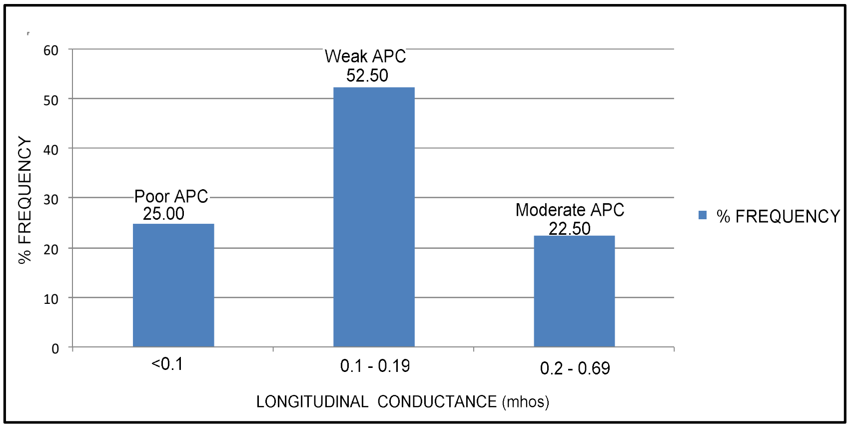

Figure 10: Frequency distribution of aquifer protective capacity of the study area.

Overburden Thickness of the area

The overburden thickness map (Figure 11) shows that the overburden thickness of the area varies from 2.6 to 29.6 m, with a mean value of 14.0 m. The overburden thickness map shows zones of relatively thick overburden with values greater than 20 m and zone of relatively thin overburden with values less than 20 m (Figure 11). Appreciable overburden thickness zones are possible groundwater gathering zones; therefore, unconsolidated material could contain reliable aquifer if thick and sandy (Olayinka et al, 2004). Geophysical studies in southwestern Basement Complex of Nigeria have recognized thick overburden as regions of high groundwater potentials (Olorunfemi and Okhue, 1992; Oladapo et al, 2004; and Oyedele and Olayinka, 2012). This is comparable with the present study where the overburden is fairly thick (13 m to 20 m) and occurs in the green colour portions of the study area (Figure 11). These zones are indicative of probable groundwater potential zones and cover about 6.8 % of Kwal, Kanke area.

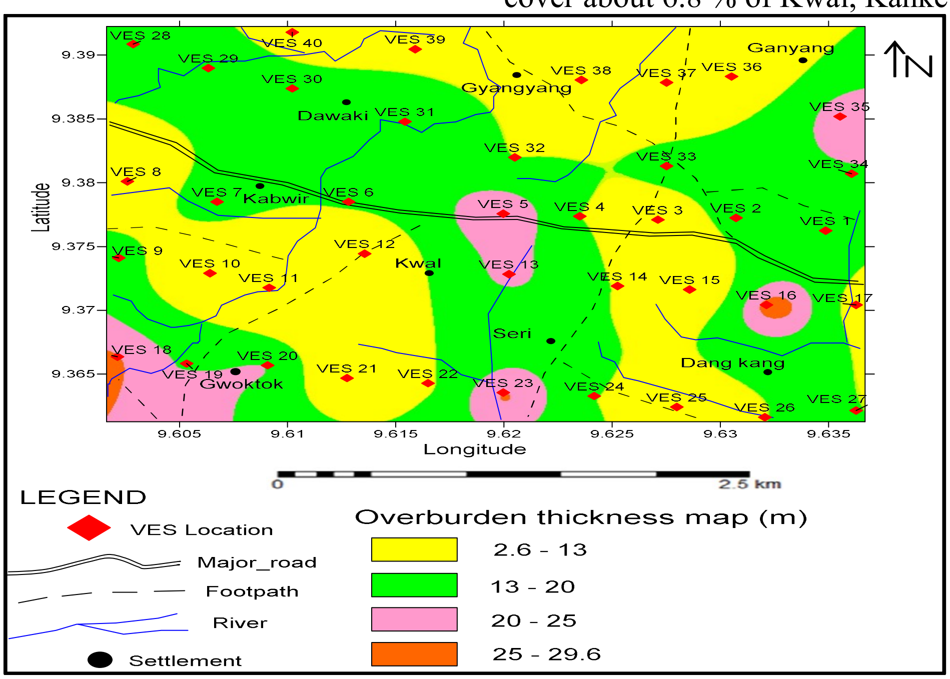

Figure 11: Overburden thickness map of the study area.

Geoelectric Sections

The results of the fourty (40) Vertical Electrical Soundings (VES) carried out in the study area is obtainable in Table 1. Figure 12a displays the Profile ‘A-A’ section and has four (4) discrete geologic layers. The topsoil has resistivities values of 56.4 to 170.4 Ω-m and thickness ranging from 0.9 to 11.6 m. The topsoil has clayey layer at VES 28, VES 39, VES 38, VES 37 and VES 36. The second layer consists of clayey layer at VES 36, with fracture basement at the other VES points that directly underlies the topsoil having resistivities of 23.4 to 724 Ω-m and thickness of 3.1 to 24.1 m. The third layer consists of fractured basement having resistivities of 297.6 to 688.1 Ω-m and thickness of 4.5 to 16.2 m. The fourth layer is made up of fractured/fresh basement having resistivities 126.4 to 2328 Ω-m and thickness of 0.1 to 18 m with an infinite thickness (Figure 12a). Aquifer at VES 28, VES 39, VES 38, VES 37 and VES 36 are protected from surface fluid contaminants owing to thick clayey layer overlying the aquifer. Buried pipes are vulnerable due to corrosion and subsequent failure because clayey soil is aggressive and corrosive to metallic pipe buried in it. The entire profile is good for borehole drilling as a result of very thick aquifer and deeper basement rock with the exception of VES 36 (Figure 12a).

The Profile B-B’ section is shown in Figure 12b and has four (4) distinct geologic layers. The topsoil resistivities range from 14.9 to 343.1 Ω-m with thickness of about 0.7 to 7 m. The topsoil has clayey layer that directly overlies the second layer at VES 8, VES 7 and VES 1. The second layer has clayey unit at VES 8, VES 6, VES 5, VES 4, VES 2 and VES 1 with fresh basement/fractured basement at VES 7/VES 3 underlying the topsoil with resistivities of 28.3 to 4957.8 Ω-m and thickness of 1.0 to 17.2m. The fresh basement (VES 8 and VES 6) fracture basement (VES 6, VES 5, VES 3 and VES 1) and clayey layer (VES 4 and VES 2) have resistivities values ranging from 31.6 to 6148.2 Ω-m and thickness ranging from 1.0 to 17.2 m was identified at the third layer. The fourth layer has fresh basement at VES 6 and fractured basement at VES 5 and VES 1 with resistivities values in the range of 337.8 to 1538.4 Ω-m having an infinite thickness. The clayey layer located at VES 8, VES 7, VES 6, VES 5, VES 4, VES 2 and VES 1 serves as a seal for the aquifer however, corrode metallic pipes buried in it (Figure 12b). VES 8 and VES 7 has thin overburden thickness and will not be favourable for groundwater production whereas VES 3 is vulnerable to fluid contamination as it is devoid of protective sealed above its aquifer.

Figure 12c shows Profile ‘C-C’ section and has four (4) distinct geologic layers. The topsoil layer has resistivities of 15.2 to 453.1 Ω-m and thickness ranging from 1.0 to 9.7 m. The topsoil has clayey layer located at VES 20, VES 21 and VES 25. The second layer consists of clayey layer underlying the topsoil at VES 22, VES 24, VES 26 and VES 27 with resistivities of 45.9 to 696.9 Ω-m and thickness of 6.0 to 26.6 m. The third layer consists of fractured/fresh basement with the fresh basement located at VES 21 and VES 27 with resistivities ranging from 95.1 to 4030.5 Ω-m and thickness ranging from 11.5 to 26 m. The fourth layer has fractured/fresh basement with the fresh basement located at VES 19, VES 20, VES 22 and VES 24 with resistivities ranging from 536.5 to 2670 Ω-m having an infinite thickness (Figure 12c). VES 20, VES 21, VES 22, VES 24, VES 25 and VES 26 has clay layer overlying the fractured basement and VES 27 has clay layer overlying the fresh basement. VES 18, VES 19 and VES 23 are vulnerable to fluid contamination as they are devoid of protective sealed above their aquifers. The clayey layer serves as a seal for the aquifer nevertheless, it corrodes metallic pipe buried inside it (Figure 12c). VES 27 will not be favourable for borehole drilling due to clay layer aquifer which is not permeable. VES 21, VES 22 and VES 24 have thin overburden thickness and will not be favourable for groundwater production

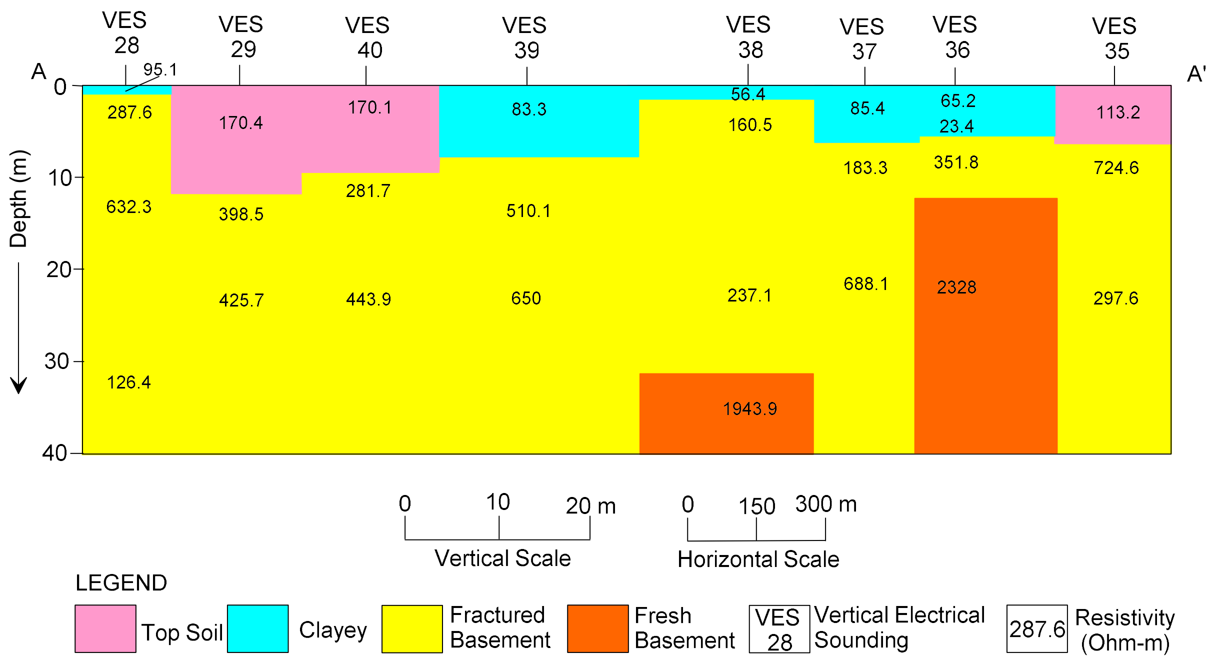

Figure 12a: Geoelectric section for Profile A-A' of the study area

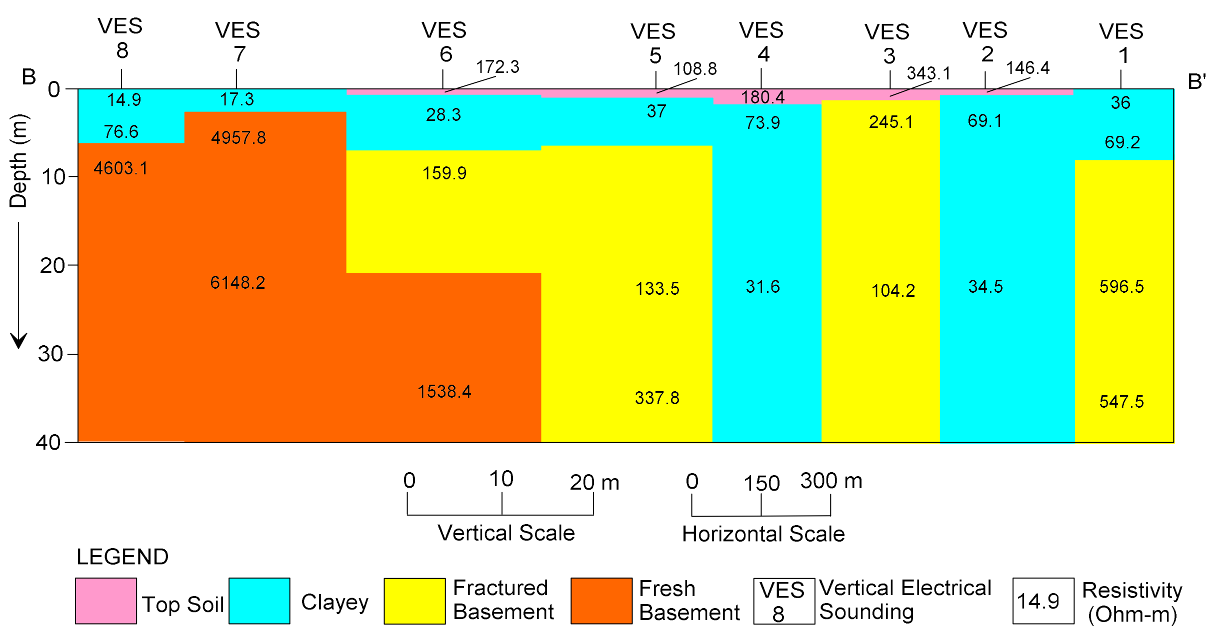

Figure 12b: Geoelectric section for Profile B-B' of the study area

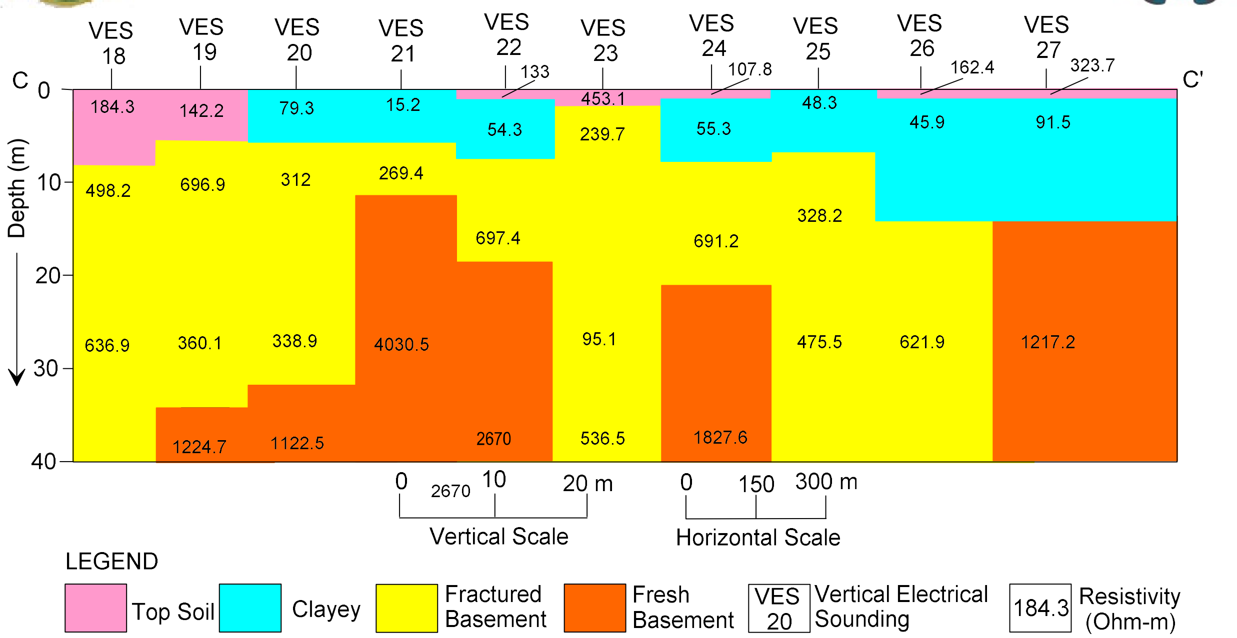

Figure 12c: Geoelectric section for Profile C-C' of the study area

CONCLUSIONS

Evaluation of the soil corrosivity and aquifer protective capacity of overburden units in Kwal northcentral Nigeria had been conducted. The geoelectric sections display the distinctions in resistivity and thickness values of layers within the depth penetrated at the designated VES stations. All the three profiles show four subsurface layers and they comprise the topsoil, clayey layer, fractured basement and the fresh basement. The study area was classified based on the values of longitudinal unit conductance into three (3) protective capacity zones namely: moderate, weak and poor. 77.50% of study area is underlain by materials of poor to weak protective capacity while about 22.50% is underlain by materials of moderate protective capacity. The areas covered by poor and weak aquifer protective capacity regions will be vulnerable to surface contamination sources while moderate aquifer protective capacity zones have higher protective property to prevent contaminated fluids infiltrations into the aquifer. The areas with moderate protective capacity coincided with zones of appreciable overburden thickness with clayey columns sufficiently thick to protect the aquifer from peculating fluid contaminants. The zones with thin overburden also coincided with weak to poor protective capacity thereby exposing the groundwater to pollution and the area is vulnerable to peculating fluid contaminants. The Topsoil and second layer resistivity values indicated that the corrosivity varied from practically noncorrosive to moderately corrosive. The topsoil and second layer within the slightly corrosive and moderately corrosive area will make metallic pipes/utility buried in them to be slightly susceptible to corrosion. The use of corrosion resistant pipes is recommended according to the corrosivity level and the design specifications in such areas.

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