ROLES OF HYDRAULIC PARAMETERS IN DELINEATION OF AQUIFER PROTECTIVE ZONES AND SOIL CORROSIVITY IN KALTUNGO AND ENVIRONS, NORTH-EASTERN, NIGERIA

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ABSTRACT

The aquifer protective capacity and corrosivity of near surface materials in Kaltungo and environs was evaluated using Electrical resistivity method. Thirty-five Vertical Electrical Soundings (VES) stations were employed using Schlumberger configuration. The result indicates Five geoelectric layers with varying thicknesses and resistivities. Layers four and five are the likely aquiferous horizons with resistivities 47.4Sm. The depth to the aquiferous horizon wide-ranging between 7.3m-92.0m, and has a rather irregular distribution and thicknesses. Corrosivity, and longitudinal unit conductance (S) maps were generated from the combination of first and second order geoelectric parameters. The results indicate that the Kofar Sarki, Baganje and Okra areas are characterized by poor protective capacity; Karel, Ledeben and Popandi areas are characterized by weak protective capacity (0.1-0.2 mhos) while other locations investigated are underlain by materials which could be regarded as moderate (0.2-0.69 mhos) to good (0.7-4.9 mhos) protective capacity. Resistivity values within the first layer (8.0-141.3 Sm) indicate that this layer is moderately aggressive and may likely form corrosion which may lead to significant corrosion failures of shallow subsurface installation facilities. The results of this research highlight certain environmental factors (corrosivity and protective capacity) that should be considered at the planning stages of residential estates.

Keywords: Corrosivity, geoelectric, longitudinal conductance, resistivity and transverse unit resistance

INTRODUCTION

Electrical resistivity method is one of the most versatile and cheap geophysical methods employed in groundwater investigation, especially, in Basement Complex area (Olorunfemi, 2009). The electrical resistivity method is a geophysical method that has been successfully used by several researchers for groundwater investigations. Due to resistivity contrasts obtained when the groundwater zone is reached, non-invasive electrical resistivity method is preferable. Consequently, study in groundwater geophysics shows that this technique has been employed successfully for delineating/mapping, accessing and evaluation of subsurface material that guides exploration of groundwater resources as well as underground installation (Metwaly et al., 2012; Oyedele et al., 2009). Groundwater is that water found within the saturated voids beneath the ground. The source of groundwater is chiefly from precipitating atmospheric moisture, which has percolated down into the soil and subsoil layers. It is available only when the rocks in the zone of saturation are permeable enough to transmit sufficient quantity of water to wells, springs or streams (Strahler 1973). Geologically, in the basement terrain, groundwater is believed to occur within the overlying unconsolidated material derived from in-situ weathering of rocks and perhaps the faulted /fractured bedrock while in the sedimentary terrain, it is accumulated within the porous and permeable layer of the saturated zone in the subsurface (Clark, 1985; Bala and Ike, 2001). However, groundwater is largely protected from pollution by natural barriers, in areas with thin weathered layers and where aquifers are in hydraulic continuity with the ground surface, groundwater could be vulnerable to pollution from surface sources. In addition, today tasks are not only to delineate new groundwater resources but to protect them. The rate of groundwater contamination depends on permeability, porosity, and overburden thickness of geologic formations. When the underlying geologic material is unconsolidated and uncompacted, such as coarse sand and gravel, the polluting influents are capable of escaping into the subsurface to contaminate groundwater, rendering the soil corrosive and forming a polluting plume that extends hundreds of meters (Keswick et al., 1982). There is always a chance that pipelines could leak or rupture and a pipeline failure can constitute serious hazards to the environment, assets, and even humans due to explosion and leakage (Yahaya et al. 2009). Using geophysical techniques, environment can be studied without tempering with the hydrogeologic condition (Mogaji et al., 2007). However, Kwami et al. (2019) studied the aquifer potential and aquifer protective capacity of overburden units in Gombe and environs and delineated two groundwater potential zones (medium to high) and aquifer protective capacity (moderate to good) in the study area. Omoyoloye et al. (2008) defined overburden protective capacity as the ratio of the overburden thickness to its resistivity. The higher the overburden longitudinal conductance, the higher its protective capacity. In addition to its use in groundwater exploration, resistivity method has been efficient and economical method of determining the degree of corrosiveness of soils and the spread of a contaminant whose salinity is different from the existing groundwater (Schwartz and Mc-Clymont, 1977; Oladapo et al., 2004; Mogaji et al., 2007). In this study, the electrical resistivity method is employed in Kaltungo and environs to evaluate the protective capacity and corrosivity of near surface materials overlying the aquifer. It is hoped that this will aid in the planning, development and management of the groundwater resource.

Study Area

Kaltungo area and environs is the study area located in the north eastern part of Nigeria and is defined by Latitudes 9˚45'00"N and 9˚51'00"N and Longitudes, 11˚15'00"E and 11˚21'00"E of the equator of the Greenwich meridian and covers an area of about 121 km^2. The study area characterized by tropical continental (Sudan) climate. It is also characterized by two seasons; a rainy season, which starts in April and ends in October and the dry season, which normally spans between November and April. The vegetation of the area is of Sudan Savannah type which covers more than half of northern Nigeria. It is characterized by short grasses with sporadic thorny bushes and scattered trees. The grasses dry and trees shade off their leaves during dry season and flourish again when wet season returns. The topography of the area is generally hilly with some parts having elevations more than the other surroundings.

The elevation ranges from about 450 m to 850 m (Figure 1). The outcrops generally consist of rocks which are made up of Coarse Porphyritic granite, Biotite granite, Bima sandstones and Tertiary Basalt. Surface drainage systems in the study area comprise numerous streams formed in the direction of the river basin towards the southeast.

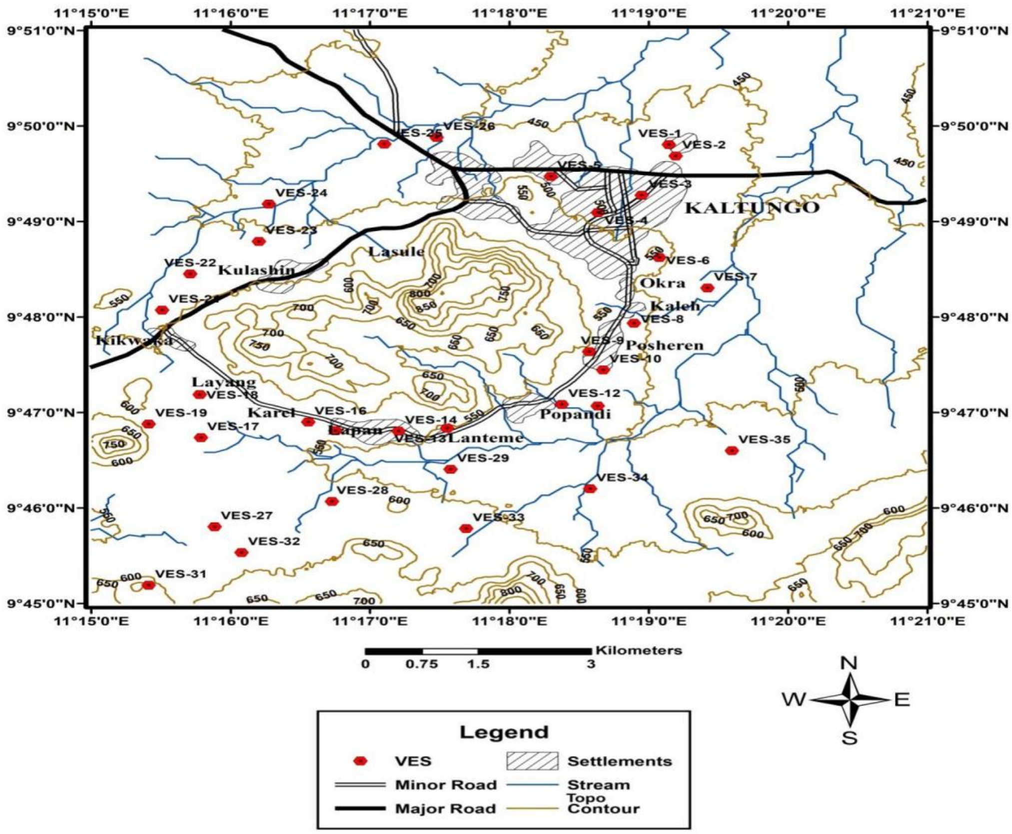

Figure 1: Base map of the Study Area showing VES Points

Geology of the Study Area

The study area is underlain by Pre Cambrian Basement Complex rocks and Cretaceous sediments. The basement Complex rocks are represented by Coarse Porphyritic Granite and Biotite Granites, the Cretaceous sediment is represented by Bima Formations and the Tertiary Volcanic Rock is represented by Basalt (Figure 2). Studies indicate that the rocks in the area were subjected to a wide range of tectonic disturbances involving Faulting. The orientation of the fault is mainly trending NE-SW. The cross section A-B (Fig. 2) indicates (in younging order), the area constituted Basement rocks, Bima Formations, and capped by Tertiary volcanic Basalt.

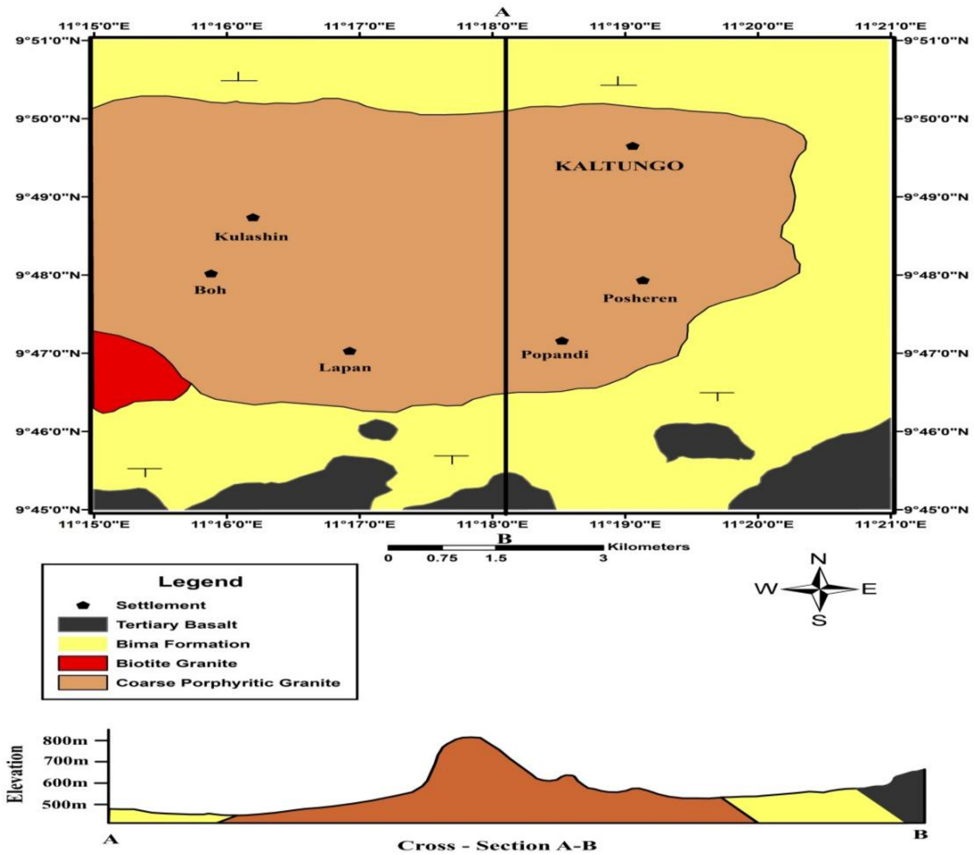

Figure 2: Geological Map of Kaltungo

In the study area, continental Bima formation is the basal part of the sedimentary successions. It lies unconformably on the Precambrian Basement Complex. It ranges in age from Upper Aptian to Lower Albian (Allix et al., 1981). The sediments consist of poorly sorted, angular, highly arkosic pebbly sandstones, granulestones and pebble conglomerates (Zarboski et al., 1997). However, over 50% of the area is underlain by coarse porphyritic granite intruded by small portion of fine grained biotite granites on the extreme south western part of the study area (Figure 2), volcanic rocks are also common. The southern, northern and eastern portion of the area is underlain by Bima Sandstone with intrusions of basalt to the southern part, which belongs to the Tertiary Volcanic Basalt that intruded into the Benue Trough.

MATERIALS AND METHODS

Resistivity sounding

A total of thirty five (35) vertical electrical soundings (VES) were carried out in the research area (Fig. 1). The electrode configuration used for the work was Schlumberger array. Field data acquisition was carried out rapidly since it requires mainly the movement (adjustment) of the current electrodes. Electrodes were laid out with non-conducting measuring tapes. The field procedure consists of expanding the current electrodes 'AB' while keeping the potential electrodes'MN'relatively fixed. For each reading, the current was sent into the ground through A and B which setup the measured potential difference between the potential electrodes M and N, the magnitude of the potential difference developed is a measure of the electrical resistance between probes. The resistance is in turn a function of the geometrical configuration of the electrodes and the electrical parameters of the ground (Dobrin, 1976). The electrode separation (AB/2) is varied from 1 to 100m. The ABEM SAS 4000 Terrameter was positioned half way between the potential electrodes M and N, and was connected to terminals P1 and P2 and to terminals M and N. The current electrodes A and B was connected to terminals C1 and C2 respectively, these cables were run in parallel adjacent to the ABEM SAS 4000 Terrameter and was arranged symmetrically with respect to the potential electrodes. This method can be used in groundwater to determine depth, thickness, and boundary of an aquifer (Zohdy, 1969). In this study, the Schlumberger array was performed using the vertical electrical sounding field procedure to assess the electrical resistivity of the subsurface and the thickness of the aquifer. The apparent resistivity (ρ_a) was calculated using (Ibuot et al., 2013):

$$\rho_a = \pi * \left[\frac{(AB/2)^2 - (MN/2)^2}{MN} \right] * R_a \qquad (1)$$

Where AB is the distance between the two current electrodes, MN is the distance between the potential electrodes, and Ra is the apparent electrical resistance measured from the instrument. The equation can be simplified to (Ibuot et al., 2013)

$$\rho_a = K * R_a \qquad (2)$$

Where the geometric factor

$$K = \pi * \left[\frac{(AB/2)^2 - (MN/2)^2}{MN} \right]$$

Partial curve matching methods was adopted with two-layer master curves couple with auxiliary point diagrams (Orellana and Mooney 1966), the first estimates of VES data was achieved. From this, estimates of layer resistivities and thicknesses were obtained, which served as starting points for computer-assisted interpretation. The conventional curves and auxiliary point diagrams (theoretical curves) used in the interpretation helped in obtaining a good fit between the observed field curves and the theoretical curves during total and partial matching. The computer software program WinResist was used and the datasets obtained from the manual interpretation were keyed as inputs into the computer modeling software (WinResist) to generate data for the estimated model. Figures 3–4 show examples of modeled VES curves obtained within the research area.

It was possible to compute, for every VES station the longitudinal conductance from the interpreted data using equation (3) (Zohdy et al., 1974):

$$S = \sum_{i=l}^{n} \frac{hi}{\rho i} \qquad (3)$$

Where h_i, the saturated thickness of each layer, ρi is the true resistivity of each layer. However, the longitudinal conductance (S) is a measure of the impermeability of a rock layer (Billing, 1972). Electrical anisotropy is a measure of stratified rock which is generally more conductive in the parallel plane than in the perpendicular plane (Malick et al., 1973; Cihan et al., 2014). Earth materials act as a natural filter to percolating fluids and that its ability to retard and filter fluids is a measure of its protective capacity (Mogaji et al., 2007). According to Oladapo and Akintorinwa (2007), protection capacity rating can be classified on the basis of the total longitudinal unit conductance (Table 1). However, soil corrosivity was evaluated using the resistivity value of the first layer on each VES point in the study area by comparing with the corrosivity rating (Table 2).

Table 1: Modified longitudinal conductance/protective capacity rating (Henriet 1976; Oladapo et al., 2004).

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

Table 2: Classification of soil resistivity in terms of corrosivity (Baeckmann and Schwenk, 1975; Agunloye, 1984; 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	practically noncorrosive (PNC

RESULTS AND DISCUSSION

The interpretation of geophysical investigation reveals that the study area geoelectric parameter shows four to five geoelectric layers with different curve types across the research area, and was characterized by varying resistivity values which includes number of layers and their apparent resistivity, thicknesses, depth, curve type and aquifer systems (Table 1)

About 9 curve types were identified in the study area. Groundwater is known to accumulate in the interconnected pore spaces within the lithologic units. The shape of the VES curves depends on the thickness of each layer, the number of layers in the subsurface and the ratio of resistivity of the layer. The geo-electric characteristics give the respective layer resistivity values and thickness. The section gives a maximum of 5 layers with varying resistivity and thicknesses across each VES point. The first layer (Top soil) which comprised of sandy soil, laterites, sand and clayey sand has resistivity ranges from 9.6 Ωm to 924.6 Ωm and thickness varied from 1.0m to 5.7m. The second layer is comprised of partially weathered basement, alluvium, sandy clay and clayey sand in some places. This layer is characterized by resistivity values varied from 24Ωm to 2194.7Ωm and thickness varying between 4.4m and 26.5m, the third layer which also composed of partially weathered basement, fractured basement, and fresh basement in some areas was characterized by resistivity values ranging between 31.5Ωm to 1568Ωm and thickness varied between 20.8Ωm and 69.5 Ωm. The fourth layer composed of fractured basement and fresh basement in some places with resistivity values ranging from 10.1Ωm to 1484.7Ωm and thickness varying 17.4m to 41.8m which indicate high degree of fracture and/or water saturation. It is of infinite thickness where it is the last observable layer. Whereas the fifth layer consist of fractured basement and fresh basement in some areas and is characterized by resistivity values from 16.7 Ωm to 2203 Ωm.

Thirty five (35) VES points, which cut across the study area were selected and used to evaluate the protective capacity of the aquifer in the study area. Using the inferred layer resistivities and thicknesses, longitudinal conductance (a Dar Zarrouk parameter) was used as a criterion for the aquifer protective capacity rating according to the rating in (Table 1). The four distinct zones defined are weak, poor, moderate, and good aquifer protective capacity, based on the numerical values assigned to each point. The value of the longitudinal conductance in the area ranged from 0.01388047 Ω to 3.98095238Ω with an average of 0.53457848Ω. Therefore, VES 5, 7, 14, 20, 22, 24, 30, 32, 34, and 35 have good protective capacity covering 29% of the mapped area. 11% Moderate Protective capacity was obtained in VES 2, 18, 28 and 33; 20% Weak protective capacity in VES 3, 4, 12, 15, 21, 27 and 31; 40% poor protective capacity in VES 1, 6, 8, 9, 10, 11, 13, 16, 17, 19, 23, 25, 26 and 29 (Table 3 and Figure 4).

The earth's medium acts as a natural filter to percolating fluid. The ability of the earth to retard or accelerate and filter percolating fluid is a measure of its protective capacity (Barker et al. 2001). Figure 3 shows the distribution of longitudinal conductance/aquifer protective capacity in the study area. The aquifer protective capacity of the area range from poor to good indicating that the aquifers are not protected and most of the aquifers are vulnerable to contamination due to the dominant of poor and weak protective capacity zones. In addition, the poor and weak zones are zones which are vulnerable to surface contaminant materials, which have less protective capacity. The study also revealed that areas with aquifer protective capacity ranging from moderate to good coincide with zones of appreciable overburden thickness with shale and clayey columns, which are thick enough to protect the aquifer in the area from surface polluting fluid. However, good protective capacity is mostly found around the central part and southern portion of the area (Figure 3).

Table 3: Aquifer Protective Capacity Rating of the Study Area

Ves	Ves locations	Longitudinal conductance	Protective capacity rating
1	Kofar Sarki	0.046275395	Poor
2	General Hospital	0.376494024	Moderate
3	Health Tech. Kaltungo	0.107405591	Weak
4	Ledeben. B	0.138507241	Weak
5	Baganje	1.1328125	Good
6	Obasanjo Qtrs.	0.07657391	Poor
7	GSSS Kaltungo	0.84040747	Good
8	Okra	0.074797844	Poor
9	Termana	0.07357473	Poor
10	Posheren	0.071951907	Poor
11	Popandi I	0.049849448	Poor
12	Popandi II	0.142734061	Weak
13	Lapan I	0.040222147	Poor
14	Lapan II	1.184115523	Good
15	Karel I	0.149671621	Weak
16	Karel II	0.096441465	Poor
17	Layang I	0.063124176	Poor
18	Layang II	0.523630908	Moderate
19	Layang III	0.013880466	Poor
20	Boh I	0.890495868	Good
21	Boh II	0.151330135	Moderate
22	Boh III	0.848595849	Good
23	Kulushin I	0.090304836	Poor
24	Kulushin II	1.606349206	Good
25	Lakorin I	0.060623018	Poor
26	Lakorin II	0.066913809	Poor
27	Layang III	0.196324144	Moderate
28	Karel III	0.404651163	Moderate
29	Lapang III	0.072142286	Poor
30	Lakorin	1.018087855	Good
31	Kikwaka I	0.10430464	Weak
32	Kikwaka II	1.98342541	Good
33	Lanteme I	0.47671233	Moderate
34	Lanteme II	3.98095238	Good
35	Kaleh	1.72027972	Good

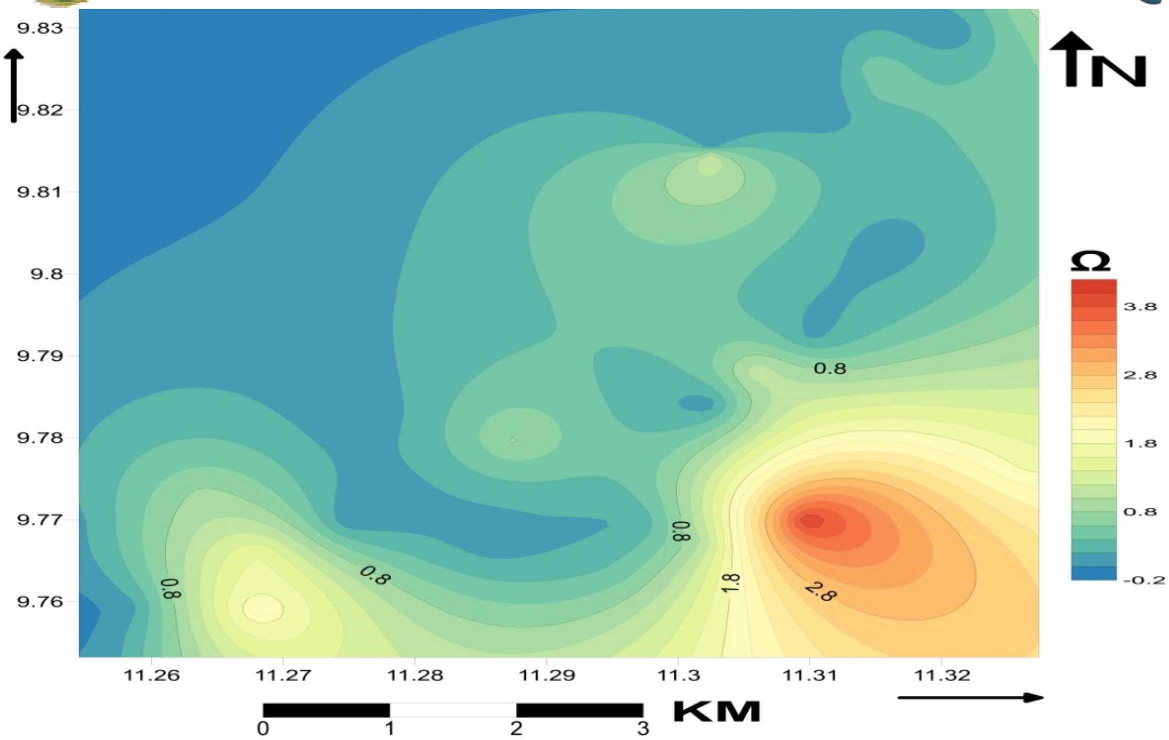

Figure 3: Map of the study area showing variation of aquifer protective capacity

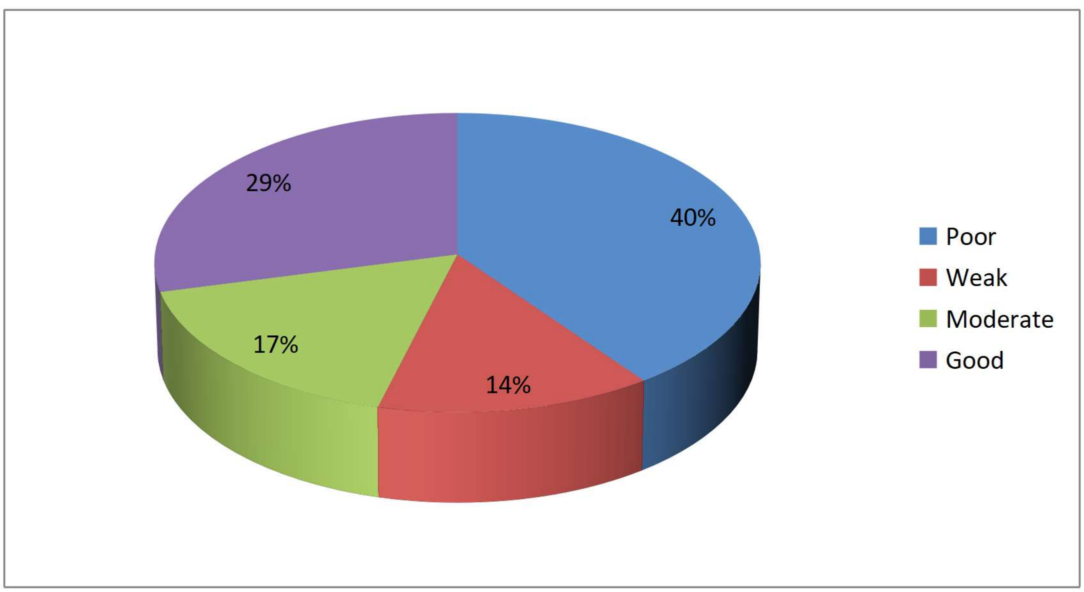

Figure 4: A Pie chart showing aquifer protective capacity distribution rating of study area.

The soil corrosivity in the study area was also determined from table 1, using the first layer resistivity and comparing with that of (Table 3). VES 3, 6, 8, 10, 12, 17, 19, 20, 22 25 and 27 covering 31.42% of the mapped area suggest that the subsurface (soil) is practically noncorrosive. 34.29% slightly corrosive was obtained in VES 2, 4, 7, 9, 11, 13, 15, 16, 21, 23, 26, and 29 which indicates slightly corrosive material . Twenty nine (29%) was also obtained in VES 1, 5, 14, 18, 28, 30, 32, 33, 34, and 35 which suggest moderately corrosive material. VES 24 and 31 indicate strongly corrosive material (Figure 5).

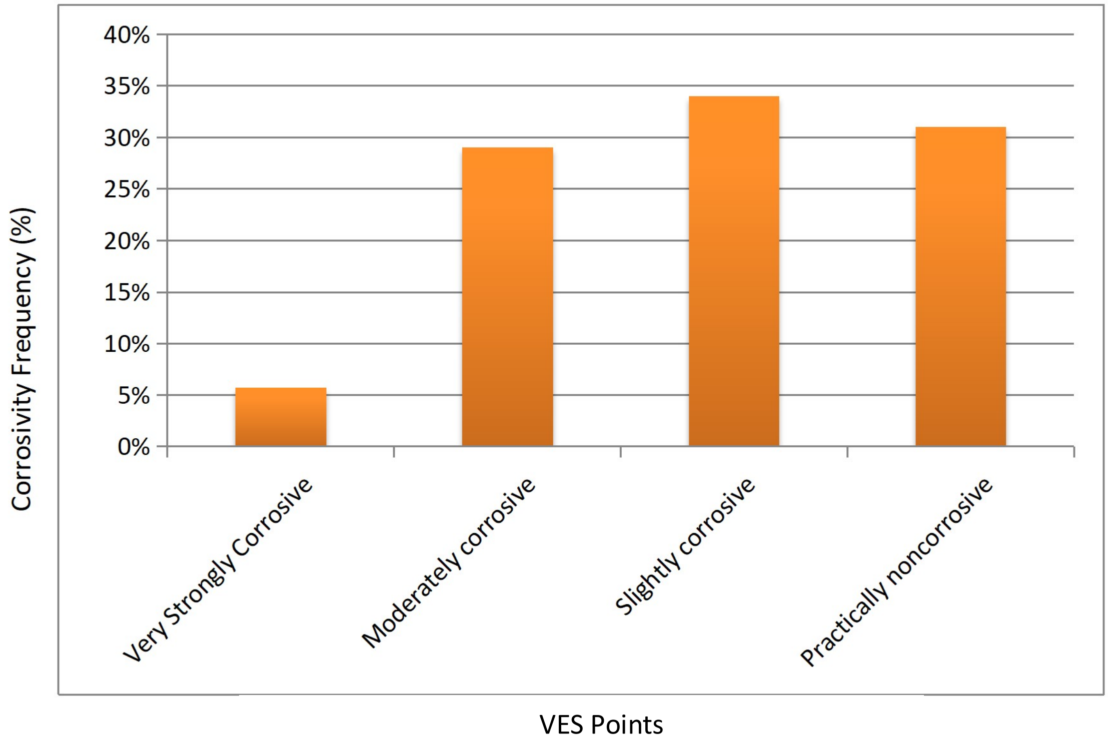

Figure 5: Bar chart showing frequency of corrosivity type distribution in the study area.

CONCLUSION

In this study, the protective capacity and corrosiveness of the overburden soil materials overlying the aquiferous horizon was estimated using Geoelectric parameters. The study reveals that north western portion (Layang I) and the eastern portion (Obasanjo Qtrs.) are underlain by poor to weak protective capacity. The groundwater in areas of poor to weak protective capacity is therefore vulnerable to pollution if there is leakage of buried underground storage tanks. Other locations are underlain by materials of moderate to good protective capacity. These areas coincide with zones of appreciable overburden thickness with clayey columns thick enough to protect the groundwater in the area. Corrosion cells which may lead to significant corrosion failures may occur in the first layer due to its low resistivity values. The results of this research have indicated certain environmental factors (corrosivity and protective capacity) that should not be ignored at reconnaissance stages of residential and industrial estates by estate managers.

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