

# Aquifer Vulnerability to Surface Contamination: A Case of the New Millennium City, Kaduna, Kaduna State Nigeria

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**Abstract:** The study seeks to evaluate potential environmental impact on surface and groundwater as well as aquifer protective capacity to suggest possible solutions in some section of Kaduna Millennium City. A total of thirty Vertical Electrical Soundings (VES) were carried out using Schlumberger electrode configuration with current electrode spacing of a maximum of 200 m. The interpreted data revealed the weak aquifer protective capacity zones which were found in some parts of northeast and central parts (VES stations A4, A5, A6, B4, C3 and C4) with its longitudinal conductance range from  $0.114 - 0.194 \Omega^{-1}$  which represent 20% of the study area. Average/good aquifer protective capacity zones has longitudinal conductance ranging from  $0.210 - 0.559 \Omega^{-1}$ . These zones covered twenty-four (24) VES stations which represent 80% of the study area and it is characterized with high thickness and low resistivity values of the weathered and fracture basement. Hence recommended for borehole siting. Similarly, the aquifer deep zones where the adjoining rocks are highly resistive (VES stations A1, A2, A3, B1, B2, D2, and E3) were also determined for siting waste and sewage disposals. However, the work also suggests that the urban associated development programs due to anthropogenic activities should be properly planned to avoid areas that are prone to contamination.

**Keywords:** Sewage, Protective Capacity, Contamination, Longitudinal Conductance

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## 1. Introduction

All people irrespective of their development, economics and social condition are entitled to have access to drinking water in good quality and quantities [1]. In any environment, there is a strong relationship between human activities and water pollution of that environment due to anthropogenic activities resulting from the growth of waste disposals, agrochemicals, industries and technological advancement [2]. In many parts of Nigeria, where there are large areas of cultivation practices, the contamination of water supplies due to fertilizers and pesticides used in agriculture has become a serious problem. The quality of the built environment, both natural and man-made, depends on its environmental control [3]. Often, there are factors that cause events that leads to water, soil and environmental pollution. While these factors are generally categorized into natural and man-made, their resultant effects are diverse, calamitous and disastrous. While environmental pollution is one of the world known disaster occurs on earth surface, groundwater is one of our most important sources of water for domestic and industrial

purposes. Unfortunately, groundwater is susceptible to pollutants. Groundwater contamination occurs when man-made products such as gasoline, oil, road salts and chemicals get into the groundwater and cause it to become unsafe and unfit for human use. Environmental pollution and contamination are becoming a common occurrence in part of developing countries. According to [1], an estimated 103 million Nigerians still lack sanitation facilities and 69 million do not have access to improved source of water in both rural and urban communities leaving the people vulnerable to diseases. It also established that 15% semi-urban are without access to safe excreta disposal facilities, 75% uses pit latrines and 60% discharge wastewater to the environment directly. The potential sources of pollution in Millennium City Kaduna are open pits, careless waste disposal, haulage roads, degradable materials such as animal remains and agrochemicals. Groundwater and environmental pollution can also result from poor drainage system. Sustainable Drainage Systems are approaches put in place to manage the water quantity (flooding), water quality (pollution) and amenity issues in the environment. Good drainage system

provides opportunities to reduce the causes and impacts of flooding, remove pollutants from urban runoff at source, and combine water management with recreation and wildlife. In the year 2012, 363 people were feared dead while 2.1 million people were displaced across Nigeria as a result of floods. According to the National Emergency Management Agency (NEMA), 30 states out of 36 in Nigeria including Kaduna state were affected by that flood experience and it was concluded as the worst that has ever happened in the past 40 years, causing damages of an estimated value of N2.6 trillion Naira. These floods also gave rise to environmental pollution problems which affected the health of citizen across Nigeria [4]. The Millennium City is planned to become a centre of attraction and may soon experience a mass influx of people. In order to accommodate this expected population expansion, a proper geophysical investigation is necessary for precise location of sewages and productive boreholes site which will help to curb environmental pollution and groundwater contamination to avert likely future disaster. Hence, while the government is largely responsible to protect life and properties of her citizenry, this research will provide good information of subsurface properties underlain in the study

area in order to adequately advise government on environmental impact.

### 2. The Study Area

Millennium City is located within Kaduna town, the capital of Kaduna State. The area lies within the geographic coordinates of latitude and longitude of 10° 30.47' N to 10° 31.08' N, and 007° 30.06' E to 007° 30.33' E respectively. The location covers a total landmass of 200,000 square meters and is has an average height of 607m above the sea level. The terrane is drained by both surface water and groundwater. The noticeable streams in the study area include Dan-Hono Stream and Kubai Stream, both drain into river Kaduna. The relief of the area is characterized by undulating plain, gentle slopes, and consists of peneplains with eroded flat tops (Figure 1); often capped by layers of indurated laterites. The southern boundary of the farm adjacent to the stream exhibits swampy conditions during rainy seasons, while the upper parts drain freely. The drainage pattern is dendritic while stream flow fluctuates seasonally [5].

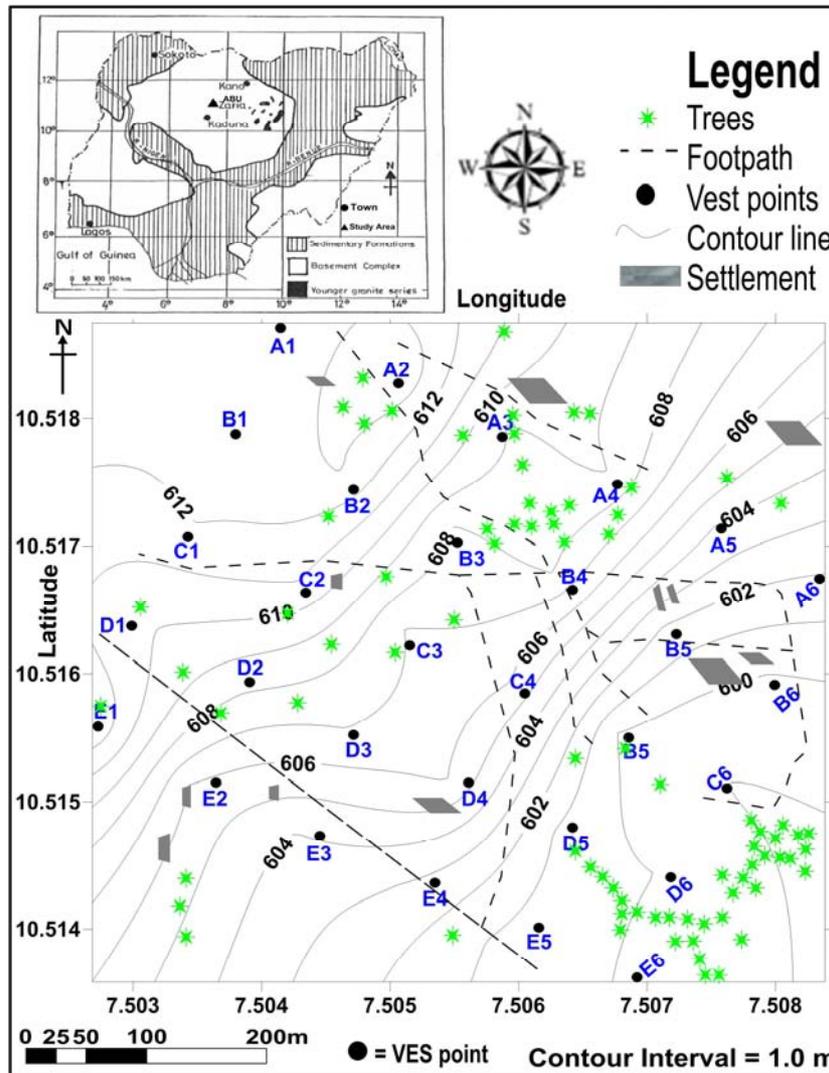


Figure 1. Topographic map of the study area showing VES and Profile locations.

The rocks of the area are capped by laterites; the laterites are sometimes highly consolidated especially at the surface and weathered into lateritic nodules mixed with silty and sandy clays [5]. The typical rock types underlying the entire land area consist of the Precambrian Migmatite-gneiss Complex, meta-sediments/meta-volcanics (mostly schists, quartzites, amphibolites and Banded Iron formations) [6]. The unweathered bedrock is characterized by rapid grain-size variations from micro to pegmatic regions but normal sizes are dominant [7]. The area is drained by both surface water and groundwater. The relief is characterized by undulating plain, gentle slopes, and consists of peneplains with eroded flat tops, often capped by layers of indurate laterites [5].

### 3. Materials and Method

Electrical resistivity is a geophysical survey method in which an electrical current is injected into the ground in order to measure the electrical properties of the subsurface. It is based on the response of the subsurface material to the current flow through electrodes to the ground [8]. In this survey, a total of thirty (30) Vertical Electrical Sounding (VES) points were acquired with maximum current electrode spread of 200 meters with an Omega Resistivity Meter using the Schlumberger configuration. A typical arrangement with 4 electrodes is shown in Figure 2. The fundamental physical law used in resistivity surveys is Ohm's Law that governs the flow of current in the ground. According to Ohm's Law;

$$V = IR \tag{1}$$

The response of the subsurface material to the current flow through electrodes to the ground known as resistivity ( $\rho$ ) is given by;

$$\rho = \frac{RA}{l} \tag{2}$$

where R is resistance. The R of a conductor is related to its length, L with cross sectional area, A and  $\rho$  is the resistivity (property of the material considered). The theoretical study of the earth resistivity methods is to consider the case of completely homogenous isotropic medium but normally, the ground resistivity is related to various geological parameters such as the mineral and fluid content, porosity and degree of water saturation in the rock (Loke, 1990). A typical arrangement with 4 electrodes is shown in Figure 2. The potential difference is then given by;

$$\Delta V = V_C - V_D = \frac{\rho I}{2\pi} \left[ \left( \frac{1}{AC} - \frac{1}{CB} \right) - \left( \frac{1}{AD} - \frac{1}{BD} \right) \right] \tag{3}$$

$$\rho_a = \frac{2\pi \Delta V}{I \left[ \left( \frac{1}{r_A} - \frac{1}{r_B} \right) - \left( \frac{1}{R_A} - \frac{1}{R_B} \right) \right]} \tag{4}$$

$$\text{Hence, } \rho_a = RK \tag{5}$$

Where R is resistivity (*i.e*  $R = \Delta V/I$ ), and K is term called geometrical factor which depends on the arrangement of the four electrodes. K can be defined from Figure 2, [8].

$$K = \pi \frac{[AC][AD]}{[CD]} \tag{6}$$

where (AC), (BC), (AD), and (BD) are the distances in metres between the respective electrodes. For central-symmetric array, when (AC) = (BD) and (BC) = (AD) (Figure 2).

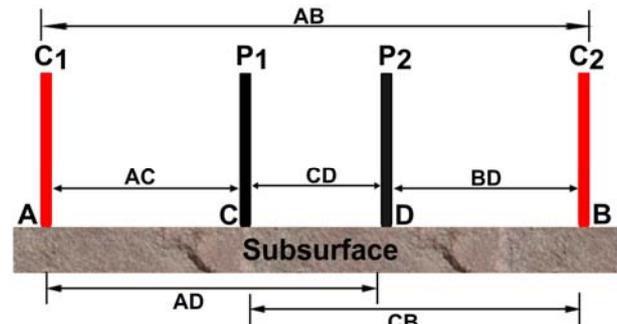


Figure 2. Schlumberger Configuration.

Further derivatives are involved to estimate the aquifer protective capacity using Dar Zarrouk parameters, Transverse resistance (T) and Longitudinal conductance(S).

#### The Dar Zarrouk Parameters

A geoelectric layer is described by two fundamental parameters: its layer apparent resistivity ( $\rho_a$ ) and its thickness (h) [10]. The geoelectric parameters derived based apparent resistivity and thickness, Longitudinal conductance (S)

$$S = h/\rho_a \tag{7}$$

Where S is the longitudinal conductance, h is thickness and  $\rho_a$  is apparent resistivity of the aquiferous layer and the transverse resistance (T) is given by;

$$T = h. \rho_a \tag{8}$$

Where T is the transverse resistance, h is thickness and  $\rho_a$  is apparent resistivity of the corresponding layer. The parameters T and S are named the ‘‘Dar – Zarrouk parameters. The longitudinal conductance (S) is the geoelectric parameter used to define target areas of groundwater potential [10]. High S and T values usually indicate relatively thick succession and should be accorded the highest priority in terms of groundwater potential.

### 4. Data Processing

In order to investigate the subsurface structural trends in the study area, and to reveal the lithological sequence of the subsurface formation of the study area, the field data was interpreted using the computer software *Res ID version 1.00.07 Beta*. The final model geoelectric parameters along the six VES stations along profile C were used for the preparation of the geoelectric/geologic section for that profile as shown in Figures 4a-e. Figure 3 is typical resistivity curve obtained from study area.

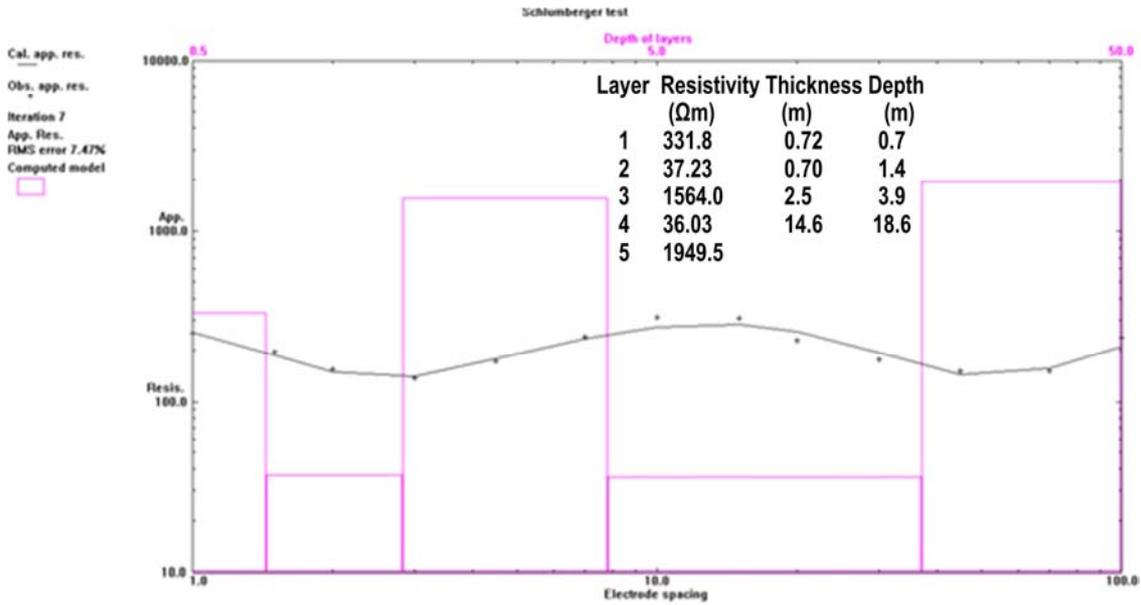
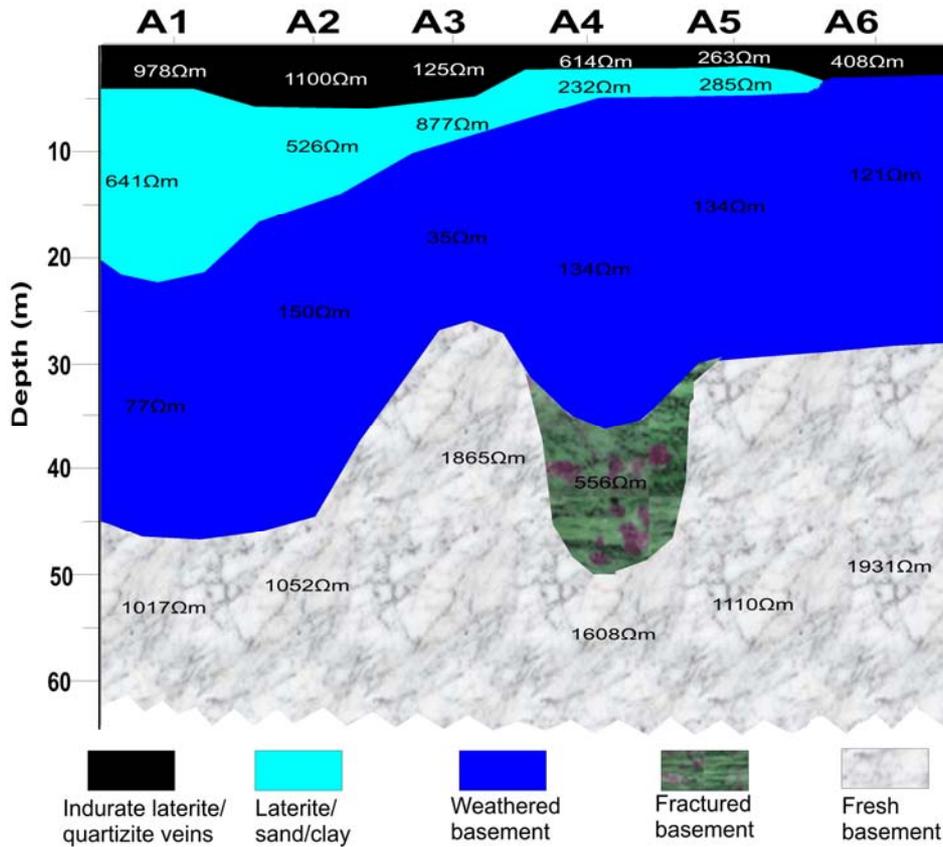


Figure 3. Typical resistivity curves along Profile C VES C3.

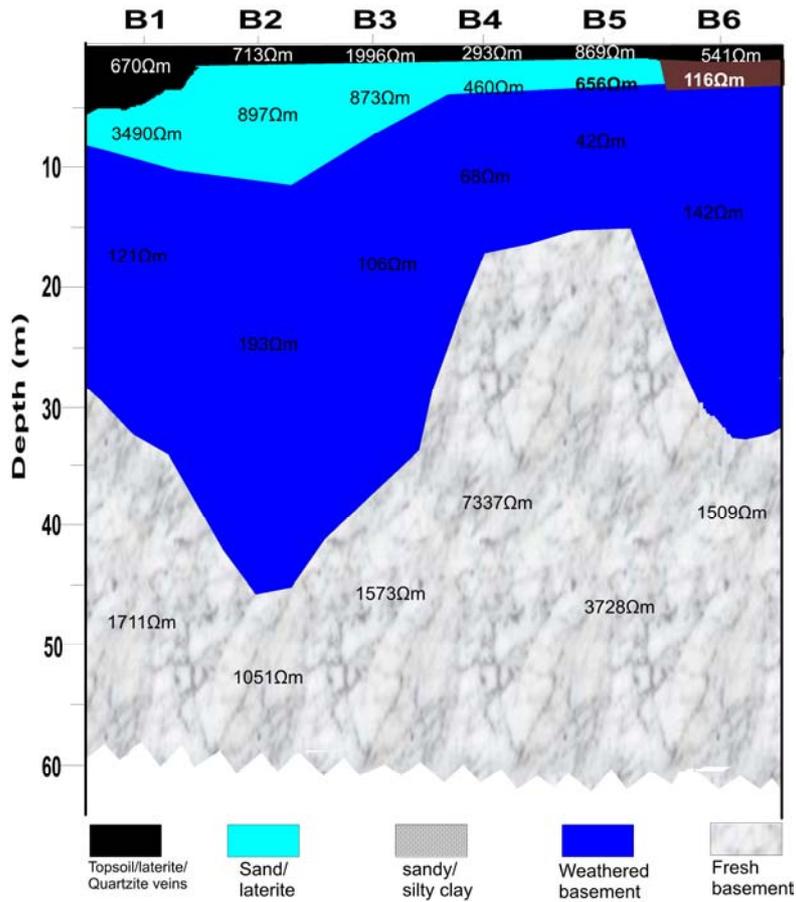
### 5. Results and Discussion

Figures 4a-e show the geoelectric/geologic sections. The study area is highly variable in resistivity and thickness values of layers within the depth penetrated. Generally, the sections revealed three to five subsurface layers: topsoil/laterite/indurated laterite/quartzite veins,

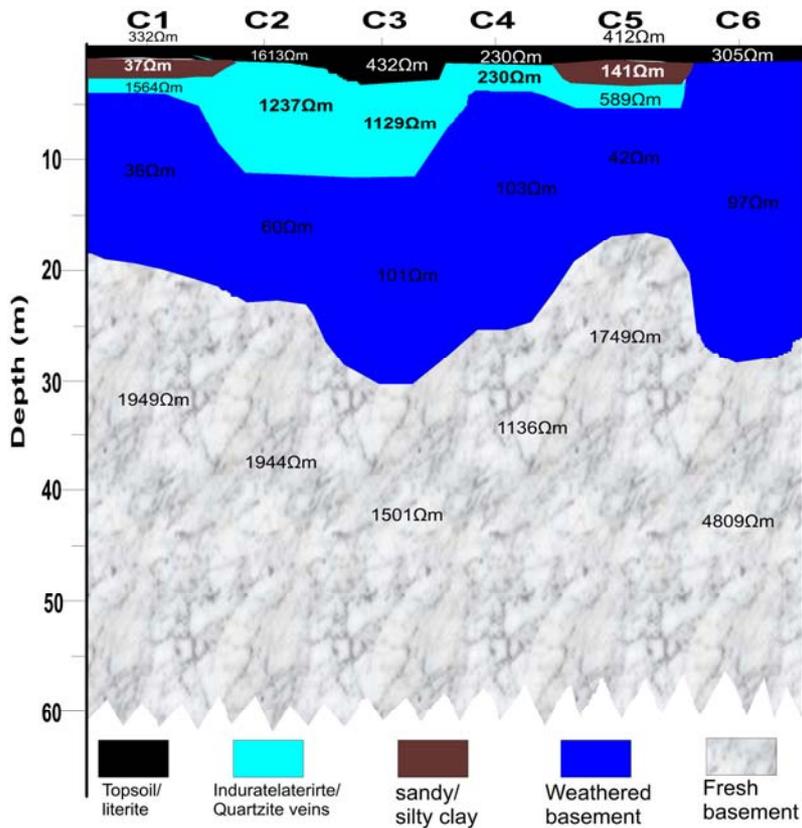
clay/silty/sand, laterite, weathered/fractured layer and the fresh basement. The first layer, often referred to as the engineering layer, has its thickness varying from 0.3m – 10m across the study area. The result shows that the study area is underlain by unfractured basement rocks and the average thickness of the weathered layer is about 23m, although depths of about 42m was encountered.



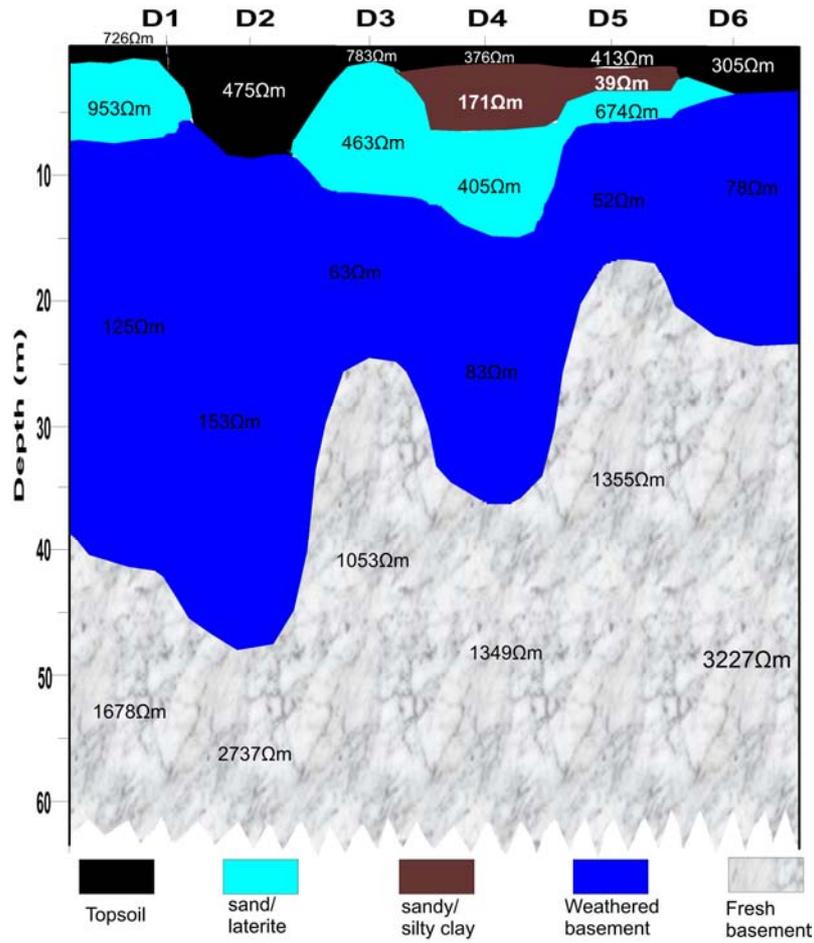
a. Profile 1



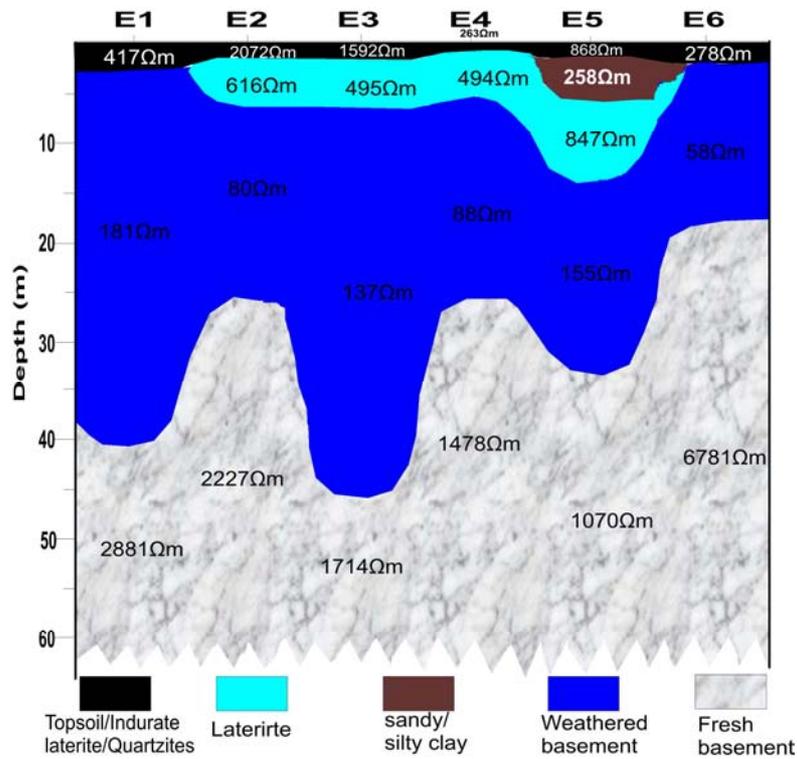
b. Profile 2



c. Profile 3



d. Profile 4



e. Profile 5

Figure 4. Geoelectric/geologic section across the study area.

Figure 5 shows the resistivity of the top layer of the study area. It is highly variable in resistivity. The southwest and some part of north is highly resistive. This may be connected with presence of surface outcrops and indurated laterite in the first layer which may also be of great importance as it reduces surface run off and infiltration into the underlying aquifer. The high resistivity in most parts of the study area at

the top layer indicates low conductivity of the subsurface. Since the earth is a natural conductor, the resistive nature of the top layer could serve as protective capacity to the area aquifer. Also, the presence of laterites and quartzites in the study area beneath the clayey topsoil which extends beyond 2.5m are filter factors which could reduce the degree of aquifer vulnerability from the surface contamination.

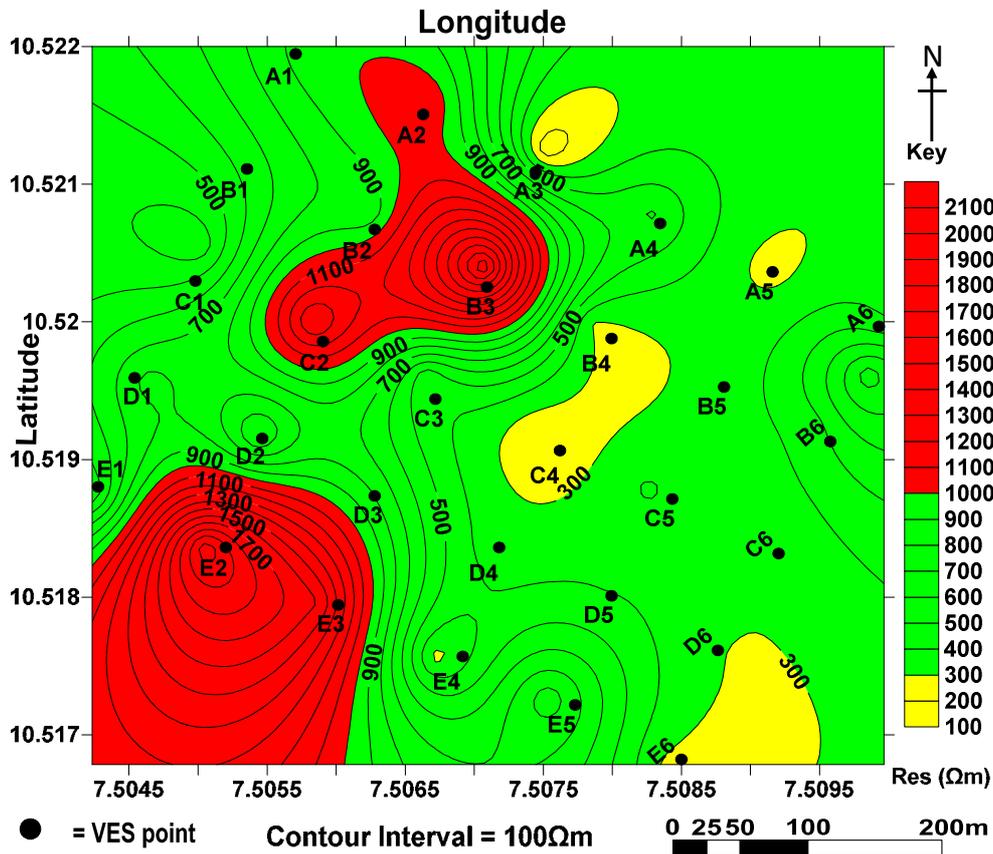


Figure 5. The Top layer resistivity Map.

Figures 6 and 7 show the resistivity and thickness maps of the weathered layer respectively which closely agrees with the work of [11]. The deeper aquifer is found mostly in southwest (VES points D1, D2, E1, E2 and E3), and some parts of north (VES points A2, B2 and B3), and east (VES points B6 and C6), of the map which denoted by deep blue colour. This is also corresponding to the aquifer low resistivity which makes it best region for borehole siting. This information is vital in evaluating the aquifer protective capacity which is the interest of this research work. [11], held that the sections where the aquifer appears thickest with an averagely low resistivity value are the best areas for the

exploitation of underground water or siting boreholes. With the aquifer thickness ranging from about 11.0 m to 42.0 m, the study area appears largely good enough for siting of boreholes except some parts of south-south (VES points C5 and D5), aquifer thickness is relatively low. Figure. 5 and 6 show that the zones depicted by deep and light blue colour coincidence are observed mostly in the study area and it is therefore recommended as the best zone for groundwater development. [12], noted that any region with low aquifer thickness (< 11.0 m) may be prone to contamination from near surface sources such as waste and sewage due to its shallow nature.

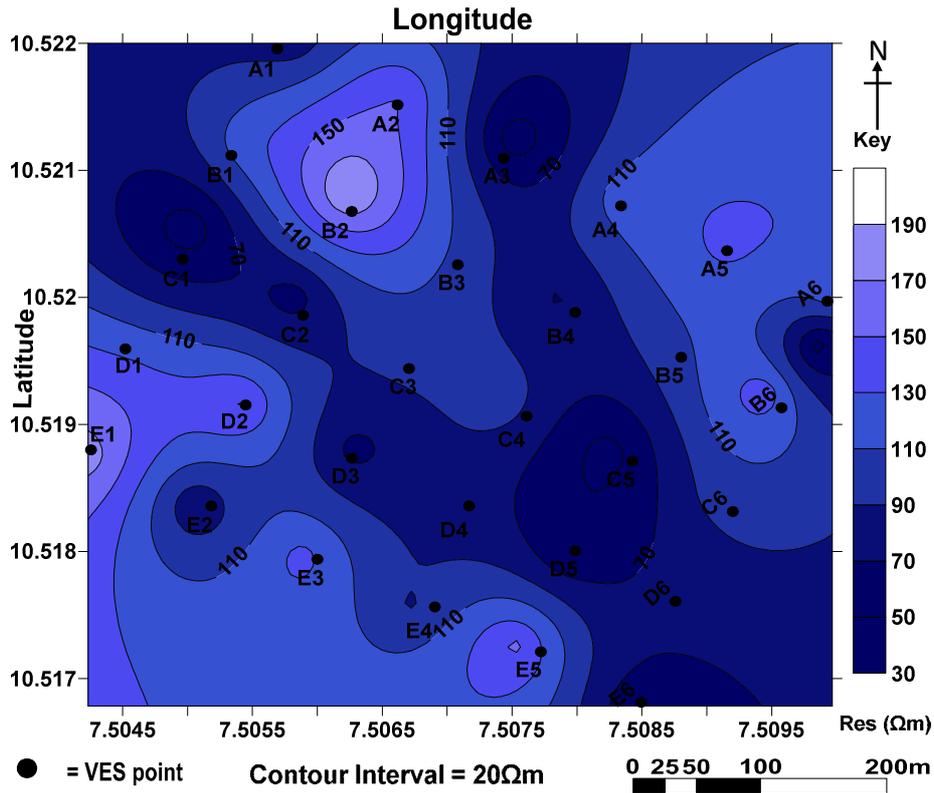


Figure 6. The Iso-resistivity Map of Weathered Basement Layer.

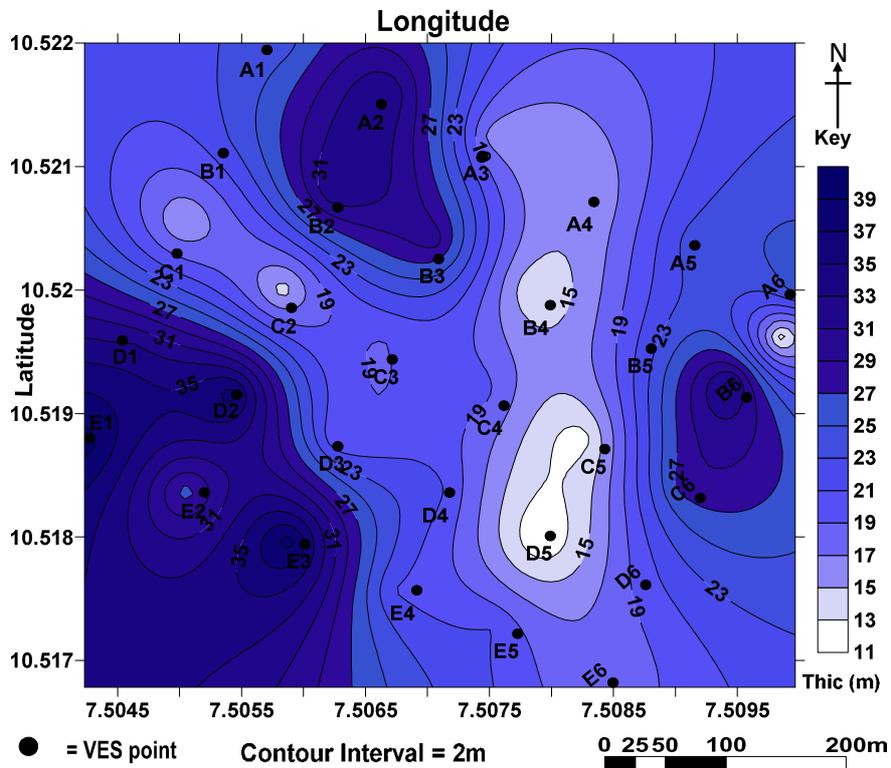


Figure 7. The isopach Map of the Weathered Basement Layer.

Figure 8 and 9 show the resistivity and the depth to the bed rocks respectively. According to [12], when the bedrock has relatively low resistivity (<750Ωm), this could indicate fracturing and high aquifer potentials strength. [13], observed

that the resistivity of a basement is a function of their degree of weathering. The values of basement resistivity range from 1000 Ωm to 7500 Ωm. The VES stations B4 and E6 are highly resistivity (>6000 Ωm). The rocks in these regions are

believed to be fresh basement. The area with low basement resistivity values ( $< 2000 \Omega\text{m}$ ) is also shown on the map, the rocks in these regions may have probably been fractured, faulted or heavily weathered, this could be of great importance to groundwater development.

On the other hand, Figure 9 shows the depth to the

basement rocks, it is highly variable in depth. The observed deep basement in the Northern parts are best region noted for waste and sewage disposal. This is to avoid easy infiltration of surface run off water into the aquifer that can contaminate the groundwater thereby causing pollution which could result into loss of life and waste of resources.

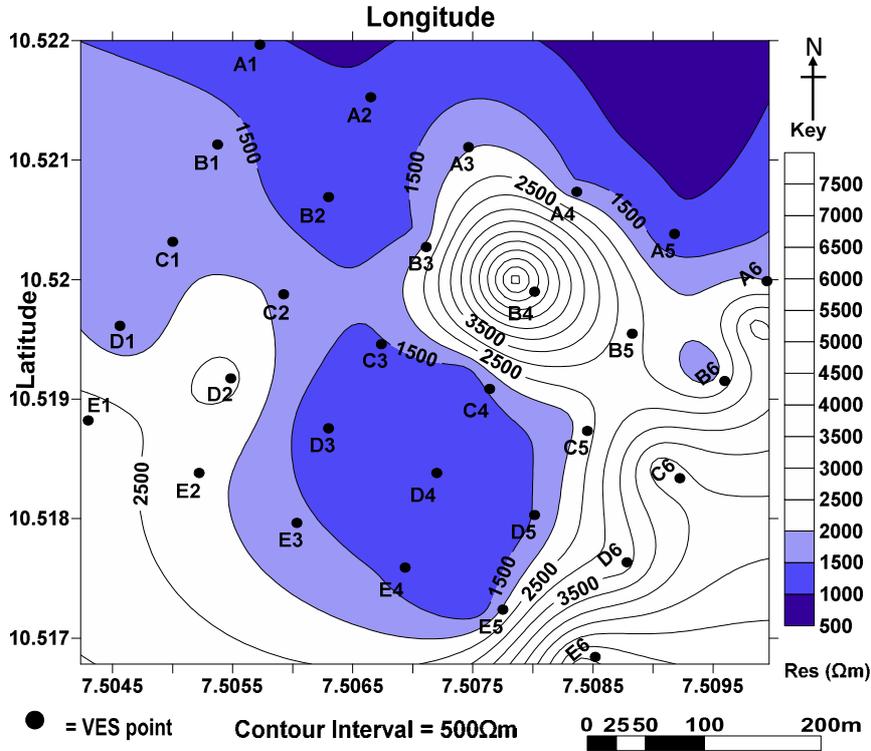


Figure 8. The Basement Rock Resistivity Map.

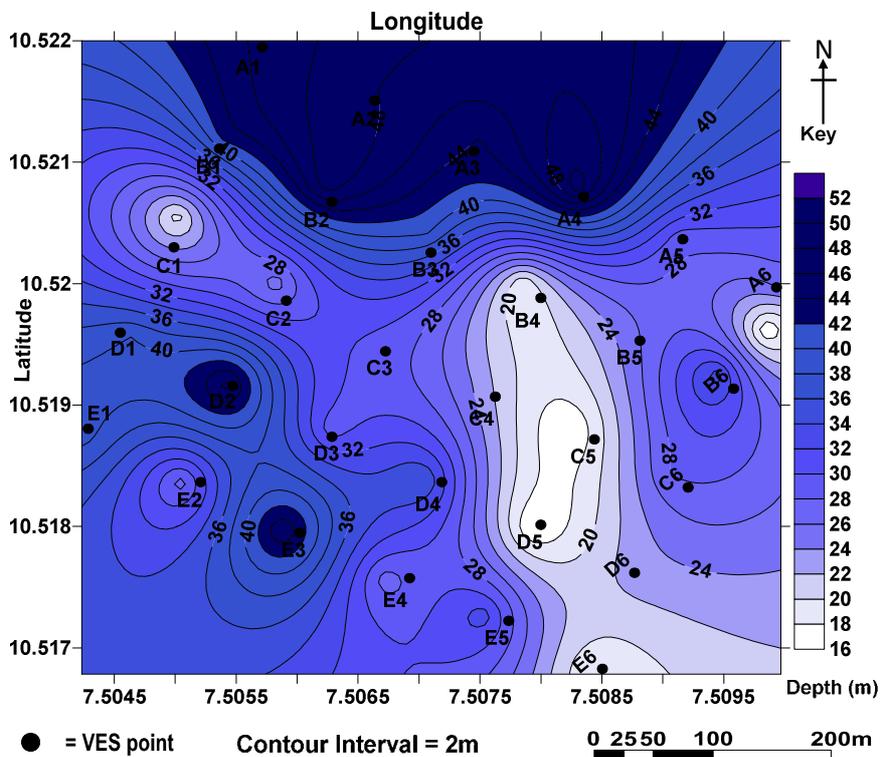


Figure 9. The Depth to the Basement (Overburden Thickness) Map.

## 6. Aquifer Protective Capacity Evaluation

Aquifer protective capacity was evaluated from the aquifer layer resistivity and its thickness using the Dar-zarrouk parameters, (Transverse resistance (T) and Longitudinal conductance (S)). Equation (7) and (8) were used to compute Longitudinal conductance and Transverse resistance respectively shown in Table 2 which was used to determine the overburden protective capacity of the aquifer in the study area. The longitudinal conductance map (Figure 10) was utilized in evaluating the overburden protective capacity since table 1 has already established that the higher the Longitudinal conductance, the higher the aquifer protective capacity. According to [10], the higher the resistivity of a material, the lower its conductivity and vice versa. Since the earth subsurface acts as a natural filter to percolating fluid, its ability to retard is a measure of its protective capacity. For instance, Clayey soil is known to be relatively impermeable, but sandy soil which is relatively permeable can provide an infiltration path for the pollutants to enter the aquifers [14]. The study area is characterized by average values of longitudinal conductance ranging from 0.114 to 0.559  $\Omega^{-1}$  which defined its ability to retard. [15], observed that the

highly impervious clayey overburden that is characterized with relatively high longitudinal conductance, offers protection to the underling aquifer. Considering Table 1, the restive lateritic top layer and clay beneath the laterite, the study area could be considered averagely protective from surface contamination. Twenty-four (24) VES stations is covered moderate longitudinal conductance ( $S > 0.2$  siemens), which represents 80% of the study area is considered relatively protective. However, some parts of northeast and central (VES stations A4, A5, A6, B4, C3 and C4) is found with longitudinal conductance ( $S < 0.2$  siemens) is considered weak and vulnerable to contamination. The regions cover six (6) VES stations which represent 20% of the study area.

*Table 1. Longitudinal Conductance/Protective capacity rating [16].*

| Longitudinal Conductance $\Omega^{-1}$ | Protective Capacity Rating |
|--|----------------------------|
| < 0.1                                  | Poor                       |
| 0.1 – 0.19                             | Weak                       |
| 0.2 – 0.69                             | Moderate                   |
| 0.7 – 4..9                             | Good                       |
| 0.5 – 10                               | Very good                  |
| > 10                                   | Excellent                  |

*Table 2. Computed Geoelectric parameters for VES stations of the study area.*

| S/N | VES Pts | Aquifer Res ( $\Omega m$ ) | Aquifer Thick (m) | Transverse resistance (T) ( $\Omega m^2$ ) | Conductivity ( $\Omega m$ ) <sup>-1</sup> | Longitudinal conductivity ( $\Omega^{-1}$ ) |
|-----|---------|----------------------------|-------------------|--|---|---|
| 1   | A1      | 77                         | 43                | 3311                                       | 0.0130                                    | 0.559                                       |
| 2   | A2      | 150                        | 43                | 6450                                       | 0.0067                                    | 0.288                                       |
| 3   | A3      | 36                         | 16                | 576  | 0.0278                                    | 0.445                                       |
| 4   | A4      | 120                        | 30                | 3600                                       | 0.0038                                    | 0.114                                       |
| 5   | A5      | 134                        | 28                | 3216                                       | 0.0075                                    | 0.210                                       |
| 6   | A6      | 121                        | 26                | 3146                                       | 0.0083                                    | 0.216                                       |
| 7   | B1      | 122                        | 23                | 2806                                       | 0.0082                                    | 0.189                                       |
| 8   | B2      | 193                        | 33                | 6369                                       | 0.0052                                    | 0.172                                       |
| 9   | B3      | 107                        | 30                | 3210                                       | 0.0093                                    | 0.279                                       |
| 10  | B4      | 68                         | 13                | 884  | 0.0147                                    | 0.191                                       |
| 11  | B5      | 42                         | 12                | 504  | 0.0238                                    | 0.286                                       |
| 12  | B6      | 143                        | 34                | 4862                                       | 0.0070                                    | 0.238                                       |
| 13  | C1      | 36                         | 15                | 540  | 0.0278                                    | 0.417                                       |
| 14  | C2      | 60                         | 24                | 1440                                       | 0.0167                                    | 0.401                                       |
| 15  | C3      | 101                        | 19                | 1919                                       | 0.0099                                    | 0.171                                       |
| 16  | C4      | 103                        | 20                | 2060                                       | 0.0097                                    | 0.194                                       |
| 17  | C5      | 42                         | 12                | 504  | 0.0238                                    | 0.286                                       |
| 18  | C6      | 97                         | 28                | 2716                                       | 0.0103                                    | 0.288                                       |
| 19  | D1      | 125                        | 33                | 4125                                       | 0.0080                                    | 0.264                                       |
| 20  | D2      | 153                        | 38                | 5814                                       | 0.0065                                    | 0.247                                       |
| 21  | D3      | 63                         | 19                | 1197                                       | 0.0159                                    | 0.302                                       |
| 22  | D4      | 83                         | 22                | 1826                                       | 0.0120                                    | 0.264                                       |
| 23  | D5      | 52                         | 11                | 572  | 0.0192                                    | 0.211                                       |
| 24  | D6      | 78                         | 20                | 1560                                       | 0.0128                                    | 0.256                                       |
| 25  | E1      | 182                        | 40                | 7280                                       | 0.0055                                    | 0.220                                       |
| 26  | E2      | 71                         | 26                | 1846                                       | 0.0141                                    | 0.367                                       |
| 27  | E3      | 137                        | 40                | 5480                                       | 0.0073                                    | 0.292                                       |
| 28  | E4      | 88                         | 21                | 1848                                       | 0.0114                                    | 0.239                                       |
| 29  | E5      | 155                        | 50                | 7750                                       | 0.0065                                    | 0.325                                       |
| 30  | E6      | 58                         | 17                | 986  | 0.0172                                    | 0.293                                       |

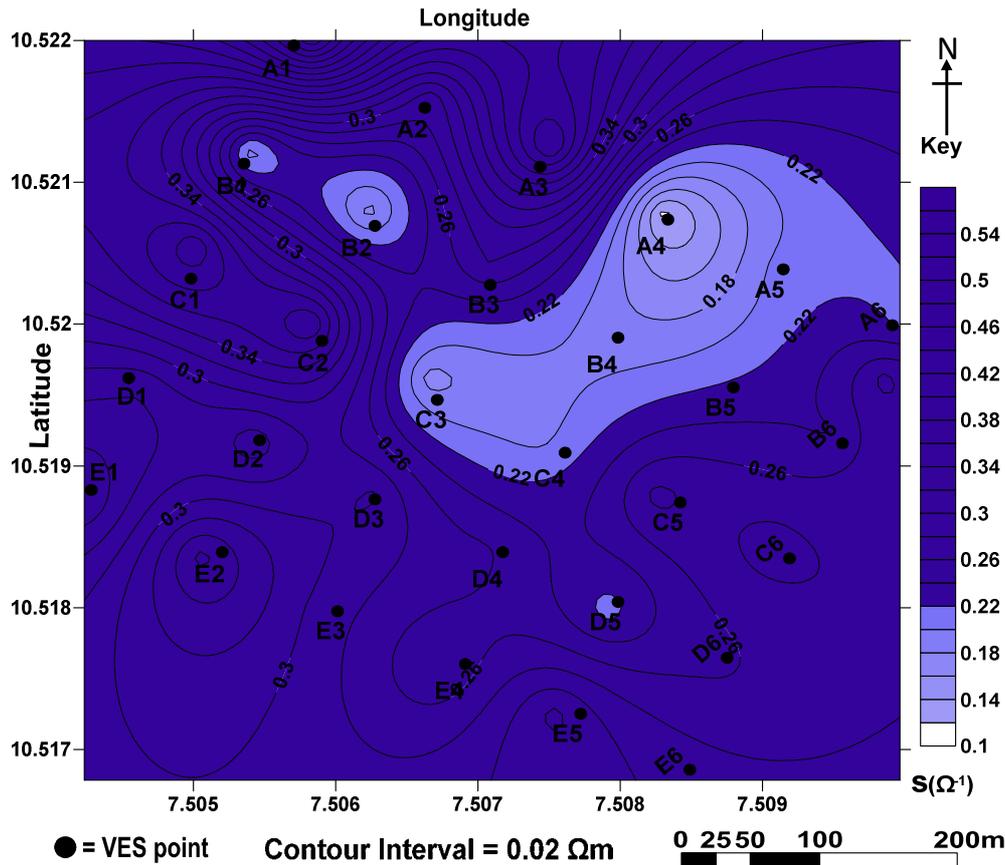


Figure 10. Longitudinal Conductance map of the study area.

## 7. Conclusion and Recommendations

Researches have revealed that human activities, such as farming, urbanization, waste and sewage disposal, within an area have great impact on the quality of groundwater and environmental pollution. The Kaduna Millennium city has shown capacity to accommodate the expected population expansion due to its location, government interest, relief and the groundwater resource as reported by [5]. In this work, the following have been identified:

- i. Weak aquifer protective capacity zones (depicted with light blue colour in Figure 10) which were found in some parts of northeast and central (VES stations A4, A5, B4, C3 and C4). This region's aquifer is relatively vulnerable to surface contamination. Hence, human activities such as agrochemicals, excavation, waste and sewage disposal should be avoided or minimized as much as possible
- ii. Average/good aquifer protective capacity zones (depicted with deep blue colour in Figure 10) which covered a significant part of the study area. These are the regions found to have high thickness with low resistivity values of the weathered and fractured basement. It has high aquifer protective capacity from surface contamination. Hence, best considered for borehole siting.
- iii. Deep zones (depicted with deep blue colour in Figure

9) which were found in the northern and some parts of southwest of the study area (VES stations A1, A2, A3, B1, B2, D2, and E3). These regions are areas where the basement rocks lie deepest, the adjoining rocks are highly resistive ( $> 1000 \Omega\text{m}$ ) and is underlain by unfractured basement rock. Hence, recommended for siting sewage and waste disposal.

However, careless handling of pollutants could have generated negative impact on the area aquifer and hence affects environmental management. It is therefore recommended that urban development programs should be properly planned to avoid areas that are prone to contamination. Adequate solid waste disposal method should be adopted, phasing out open dumpsites to safe-guard public health. Landfill base should be made of concrete and paved surfaces to prevent leaching of poisonous substances into the groundwater.

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