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Full Length Research Paper

Groundwater system evaluation and protective capacity of overburden material at Ile-olujI, Southwestern Nigeria

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Forty (40) Schlumberger depth soundings and inventory of fifty-five (55) hand-dug wells were carried out in Ile-Oluji area, South-western Nigeria, aimed at assessing the groundwater prospect and aquifer vulnerability. The area is characterized by the crystalline basement rocks, mostly of granite gneiss lithology. Major challenges in this area are inadequate municipal water supply coupled with the hydrogeologically difficult terrain, individuals and corporate bodies indiscriminately sinking of tube wells and boreholes within the unconsolidated overburden materials, with obvious lack of concerns for the vulnerability status of aquifers and possible environmental risk. The acquired depth sounding data and wells inventory were critically interpreted and analyzed in order to assess the groundwater prospect in terms of geophysical parameters of the unconsolidated materials overlying the crystalline bedrock. The thickness of the unconsolidated overburden varies from 3 to 54.1 m, where about 35, 47.5 and 17.5% falls within 3 to 4 m, 15 to 30 m and 33 to 54 m brackets respectively, while static water level ranges from 1.7 to 12.9 m. The topmost geoelectric layer has resistivity mostly within 101 to 200 Ωm (50%) and 11 to 100 Ωm (30%) across the area. The resistivity values indicated that the overburden protective cover comprises of clayey sand and clayey materials respectively. This implies that the envisaged protective cover of the aquifers in the study area is generally fairly vulnerable. The interrelationship between the groundwater flow pattern and geoeletrical parameters enabled the rating of the study area into the category of moderate to low groundwater prospect. Finally, results of the geophysical study reasonably provide a basis for which the groundwater potential and vulnerability in the area were appraised.

Key words: Groundwater system, protective capacity, vulnerability, aquifer.

INTRODUCTION

Groundwater constitutes the most reliable and perhaps the largest source of fresh water in most parts of the world. The dynamic nature in urbanisation, industrialisation and irrigation and other agricultural activities make it crucial, not only for targeting of groundwater potential zones, but also to monitor, conserve and identify possible environmental risks to this important resource. Ile-Oluji and environs lie within the Precambrian basement complex terrain of southwestern Nigeria (Rahaman, 1988). In basement terrains, groundwater is generally believed to occur within the overlying unconsolidated material derived from the *in-situ* weathering of rocks and perhaps the fractured/faulted bedrock (Clark, 1985; Jones, 1985; Acworth, 1987; Bala and Ike, 2001). The cost and labour involved in developing surface water is much more, compared to groundwater, hence more emphasis is placed on the development of groundwater which can be achieved within a short time. There are several difficulties confronting development of groundwater resources in hard rock terrains; this include wide and erratic variation of vital parameters (that is fractures, joints, porosity, etc) characterizing the groundwater regime. Spatial variation of these characteristic parameters is attributed to, among other causes, tectonic activities and degree of weathering of near surface rocks (Barker et al., 2001). These processes induce directly or indirectly secondary porosity on the crystalline rocks to a variable extent. As a result,

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the groundwater potential varies significantly from place to place, sometimes within few meters. Moreover, the uncontrolled expansion in the housing estates together with increasing sewage and effluent leakage, indiscriminate waste disposal has increased pollution which can easily provoke permanent damage to the underlying aquifer in study area, where inhabitants rely mostly on groundwater.

The electrical resistivity depth sounding, using electrical resistivity meter, with data interpretation often assisted by modern day algorithm, constitutes a very useful tool in locating areas of maximum aquifer thickness and serves as a good predictive tool for estimation of borehole depth (Draskovic et al., 1995; Lashkarripour, 2003; Omosuyi et al., 2003; Lenkey et al., 2005). Well inventory study of the area (Awotuse, 2008) reveals that people around Ile-Oluji and its environ abstract water from the unconsolidated material overlying the crystalline basement through indiscriminate sinking of tube wells, with obvious lack of concern for aquifer vulnerability to near-surface contaminants and quality status of the groundwater. The need to evaluate the aquifer vulnerability of the study area is thus highly desirable. Van Duijvenbooden and Van Waegeningh (1987) defined the vulnerability of an aquifer as the sensitivity of groundwater quality to an imposed contaminant load, which is determined by the intrinsic characteristics of the aquifer. The parameters affecting vulnerability are mainly permeability and thickness of each protective layer. For unconsolidated sediments, the permeability is strongly related to the clay content which can be deduced indirectly from resistivity methods such as electrical-imaging. Such geophysical methods can be of great help in groundwater vulnerability studies because they disturb neither the structure nor the dynamics of the soil. The intrinsic resistivity of the unconsolidated overburden and that of the crystalline basement differ by orders of magnitude, which makes geoelectric methods suitable to map the thickness and extent of the overburden (Koefoed, 1989; Parasnis, 1997). This work adopted the application of electrical resistivity method in assessing the groundwater prospect of the unconsolidated materials in the area.

In addition, the geoelectrical parameters of the near-surface materials overlying the aquifers were also used to assess the vulnerability of the near-surface aquifers to near-surface contaminants.

Geologic and hydrogeologic setting of the study area

Ile-Oluji lies within longitudes 4° 52' 11.21" and 4° 52' 1.45” and latitudes 7° 12' 59.15" and 7° 13' 6.44" (Figure 1). The study area is located within the basement complex terrain of Ondo State, southwestern Nigeria (Figure 2). The local lithological units identified in the study area are the granites, quartzite and migmatite-gneiss. Quartzite is the most wide spread rock unit in the area, covering over half of the area while granite gneiss occurs as intrusive, low-lying outcrops in the north-eastern and south eastern parts of the area. Quartzite ridges occur in several locations, mostly in the central part of the study area. In a typical basement terrain, groundwater occurs in the weathered mantle (unconsolidated materials overlying the basement rock) and the joints, fractures or faults within the bedrock (Odusanya and Amadi, 1999; Olorunfemi, 1990). The concealed basement rock may contain faulted areas, incipient joints and fracture systems derived from tectonic events earlier experienced. In a typical basement setting, the concealed basement rock due to severe tectonic activities may contain fissure of varying magnitude whose detection and delineation may facilitate the location of groundwater prospect zones (Omosuyi et al., 2003).

MATERIALS AND METHODS

The Schlumberger vertical electrical soundings (VES) were conducted using the Schlumberger electrode array (Zhody et al., 1974). The ‘omega resistivity meter’ was used for earth’s resistance measurement. Forty (40) depth soundings (Figure 1), with maximum current electrode spacing (AB) ranging from 130 to 200 m were conducted across the area. The field curves were interpreted through partial curve matching (Koefeod, 1979), engaging master curves and auxiliary point charts (Orellana and Mooney, 1966; Zhody et al., 1974). The manually derived geoelectric parameters were subjected to an automated inversion (Vander Velpen, 1988), which successfully reduced the interpretation error to acceptable levels. The root mean square error less than or equal to 2.5% is considered acceptable (Barker, 1989). The electrical resistivity contrasts existing between lithological sequences in the subsurface (Dodds and Ivic, 1998; Lashkaripour, 2003) were used in the delineation of geoelectric layers, identification of aquiferous materials (Deming, 2002) and assessment of groundwater prospect of the area. In addition, the resistivity parameter of the uppermost geoelectric layer (topsoil) was used to evaluate, in quantitative terms its permeability to surface/near-surface contaminants, and hence the vulnerability of the underlying aquifers as demonstrated in Draskovits et al. (1995) and Omosuyi (2010). The hydrogeological measurements involving determination of geographic locations and static water levels of fifty five (55) hand-dug wells were carried out. The observed static water levels enabled the computation of hydraulic heads and the determination of general groundwater flow direction in the area.

RESULTS AND DISCUSSION

The curves types obtained from the conducted geoelectric soundings range from simple 3-layer H type (45%), 4-layer KH (37.5%) and QH (7.5%) to complex 5 and 6-layers curves HKH (7.5%) and KHKH (2.5%) respectively. Typical sounding curves generated from the field measurements are shown in Figure 3. Field curves often mirror-image (geoelectrically) the nature of the successive lithologic sequence in a place and hence can be used in qualitative sense to assess the groundwater prospect of an area (Worthington, 1977). The complex curves show the geoelectric complexity often associated with basement complex terrain. The H-

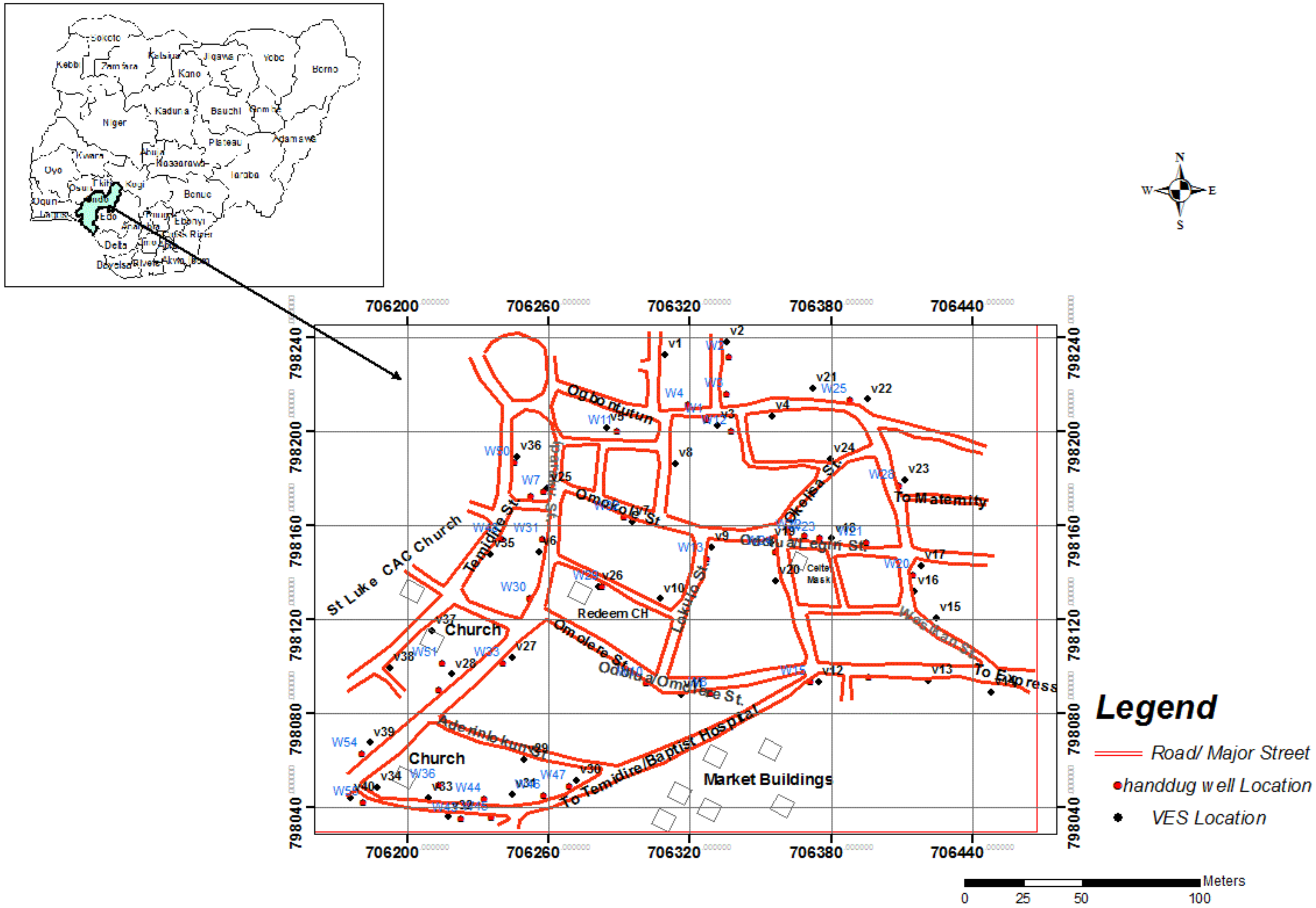


Figure 1. Layout map of Ile-Oluji showing VES and hand-dug wells positions (inset: map of Nigeria).

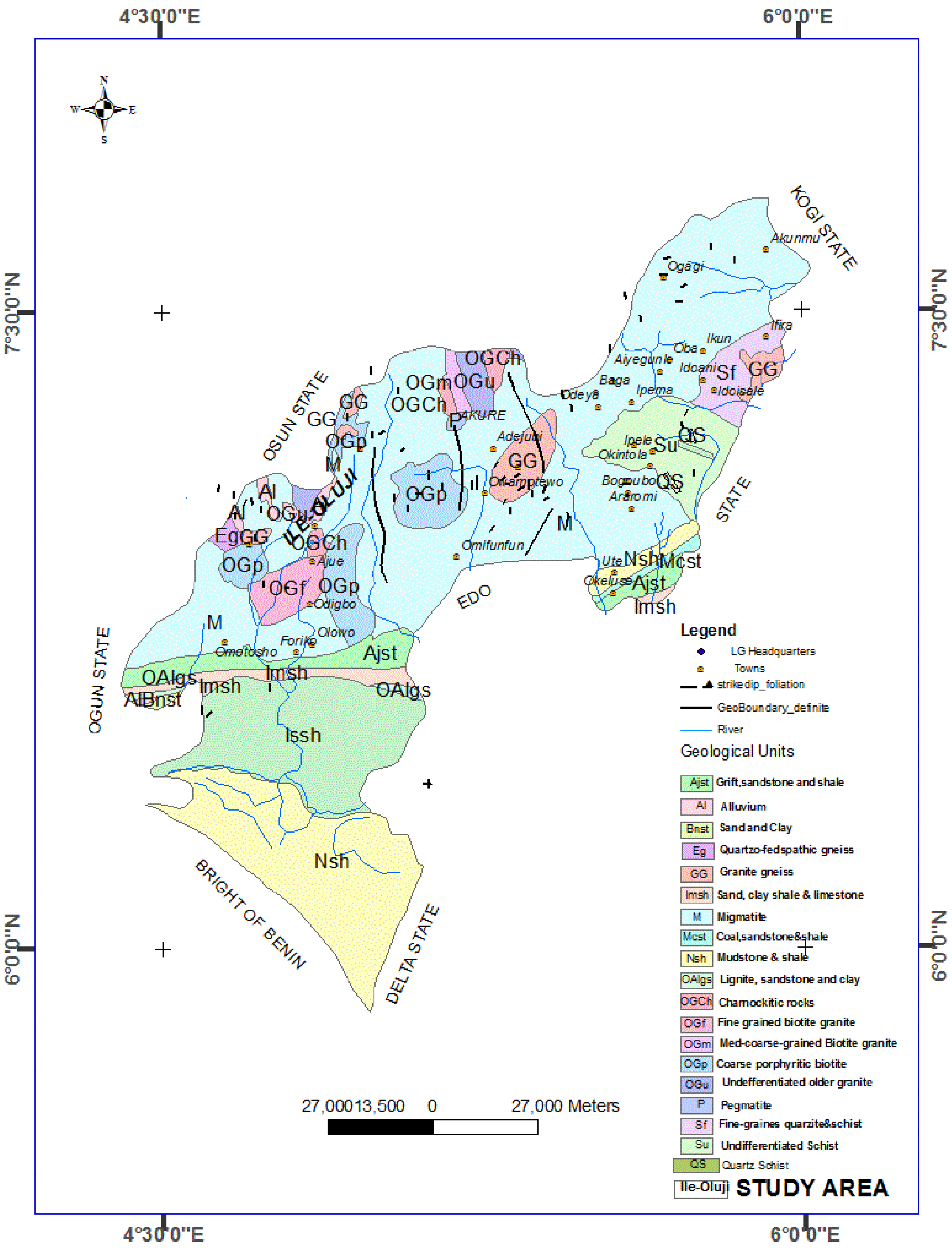
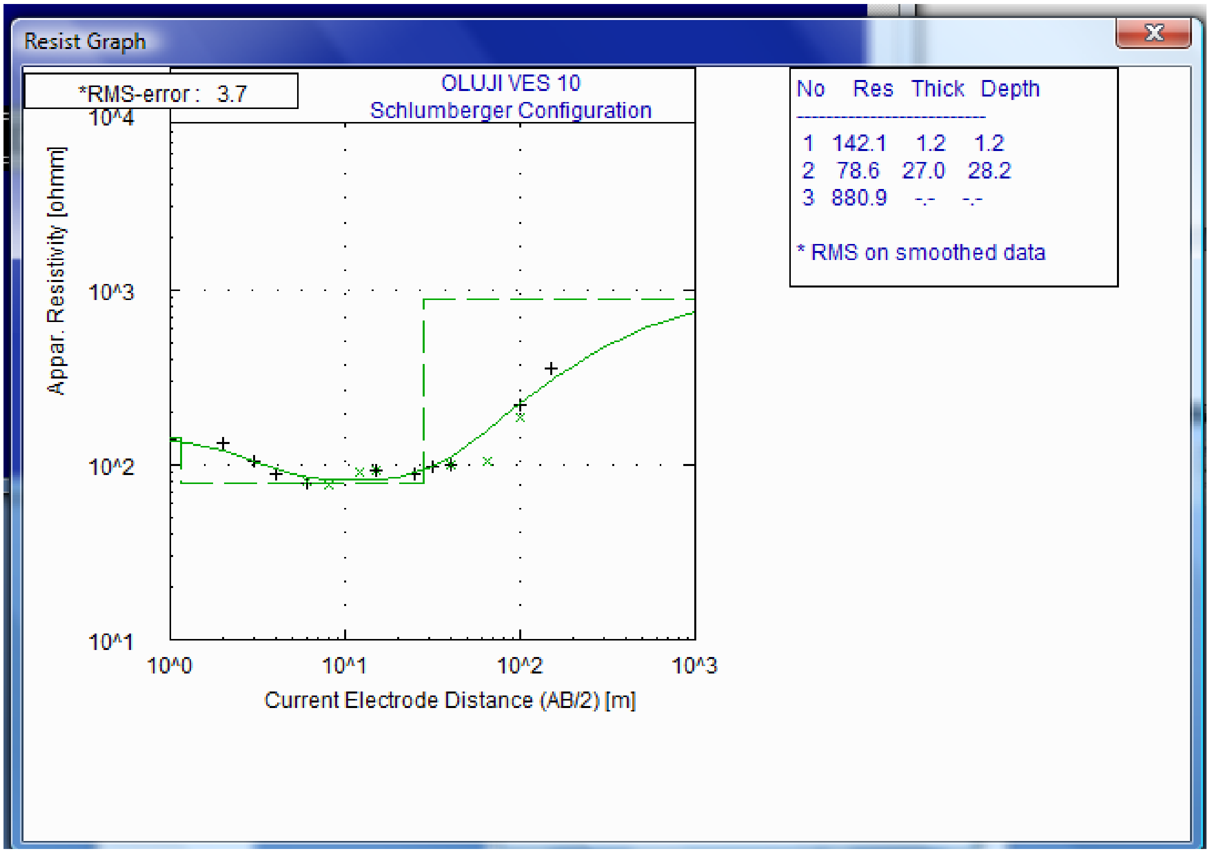


Figure 2. Generalized geologic map of Ondo State.

type curve signature was found to be the predominant type curve in the area accounting for about 45% of the total. The QH, KH and HKH- type curves signatures diagnose a deep seated fractured which are often associated with groundwater possibilities.

Aquifer delineation

Electrical resistivity contrasts exists across interfaces of lithologic units in the subsurface. These contrasts are often adequate to delineate discrete geoelectric layers

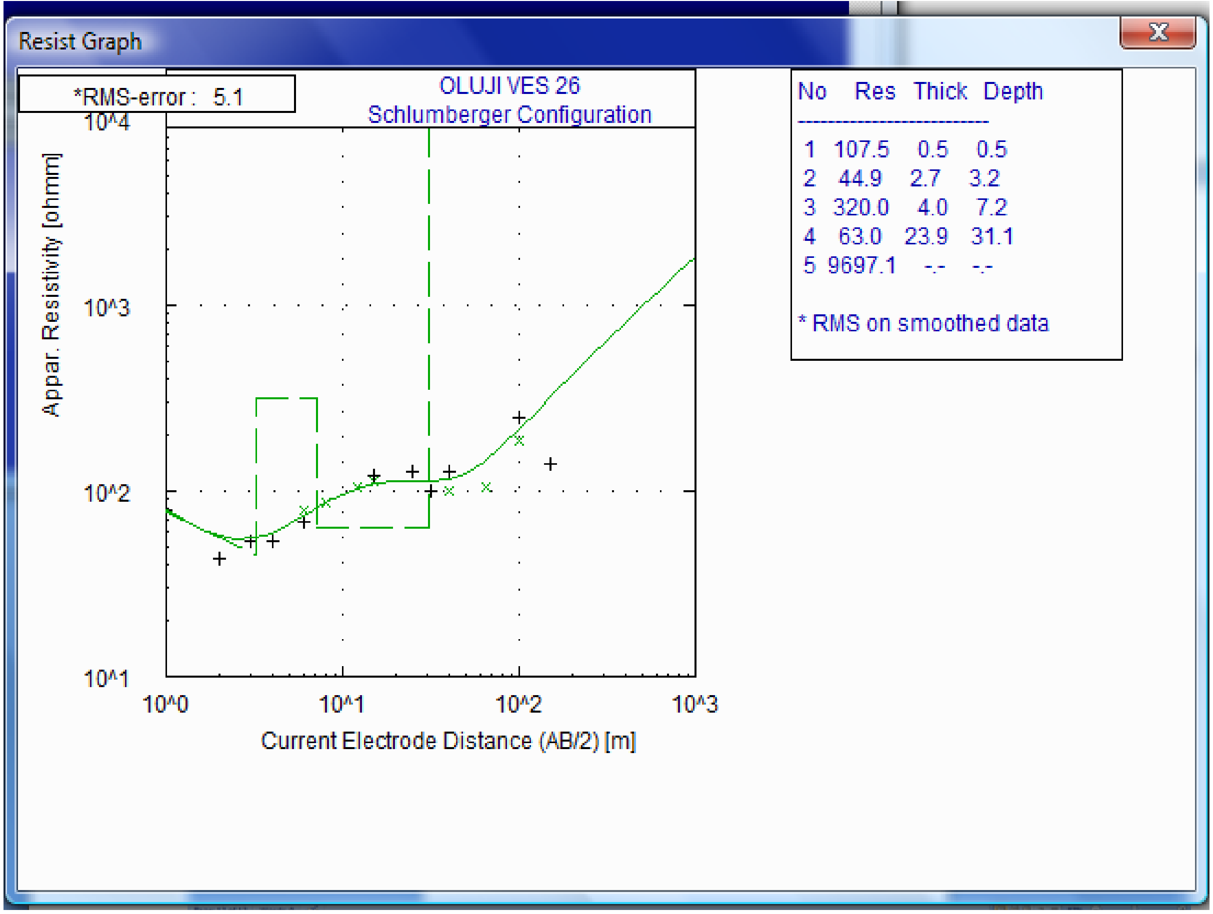


*RMS-error : 3.7

OLUJI VES 10
Schlumberger Configuration

No	Res	Thick	Depth
1	142.1	1.2	1.2
2	78.6	27.0	28.2
3	880.9	-.-	-.-

* RMS on smoothed data

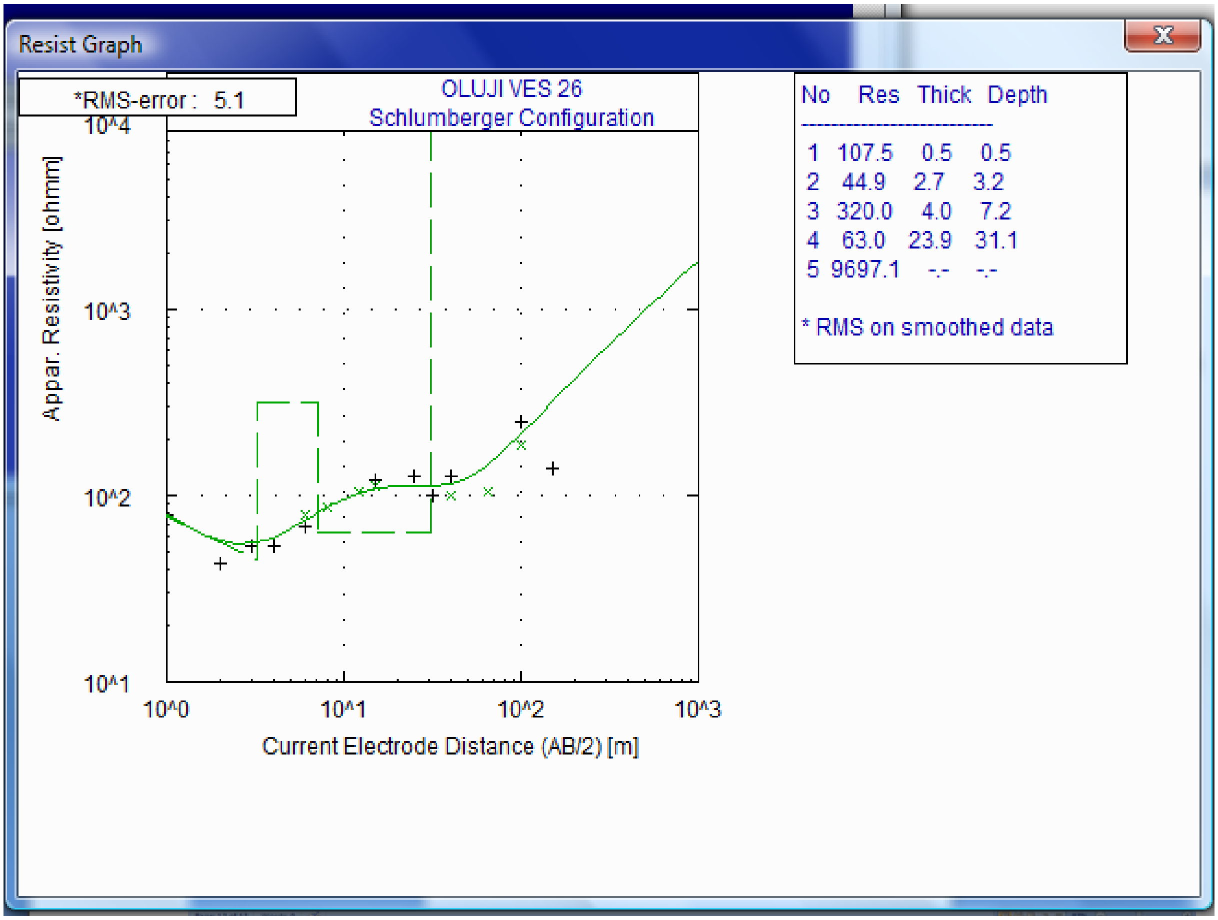


*RMS-error : 5.1

OLUJI VES 26
Schlumberger Configuration

No	Res	Thick	Depth
1	107.5	0.5	0.5
2	44.9	2.7	3.2
3	320.0	4.0	7.2
4	63.0	23.9	31.1
5	9697.1	-.-	-.-

* RMS on smoothed data



*RMS-error : 5.1

No	Res	Thick	Depth
1	107.5	0.5	0.5
2	44.9	2.7	3.2
3	320.0	4.0	7.2
4	63.0	23.9	31.1
5	9697.1	-.-	-.-

* RMS on smoothed data

Figure 3. Typical curve types obtained at Ile-Oluji.

and identify aquiferous or non-aquiferous layers (Schwarz, 1988). The geoelectric parameters of the aquifer units were determined from the interpretation of the sounding curves. The resistivity parameter of a geoelectric layer is an important factor to adjudge an aquifer to facilitate groundwater resources prospect (Lucius et al., 2010; Omosuyi, 2010). The interpreted characteristic geoelectric parameters revealed occurrence of three to six geoelectric layers which give rise to the following aquifer types:

Unconfined aquifers

They are of 3 to 6-layer geoelectric units comprising of top soil, lateritic/highly decomposed weathered layer and fresh bedrock. The topsoil has resistivity values varying from 64 to 648 Ωm with thickness ranging from 0.5 and 8.7 m. The lateritic/weathered material has the resistivity values ranging between 45 and 396 Ωm with thickness varying from 1.4 to 14.4 m. The aquifer unit mapped is characterized by resistivity values of 18 and 197 Ωm with a thickness ranging between 6.3 and 41.4 m while the underlying fractured bedrock and fresh basement has resistivity values varying from 329 to 881 Ωm and 1036 to 5182 Ωm respectively.

Semi-confined/leaky aquifers

They are characterized by a 4-layer lithologic units. The geoelectric sequence comprises of: topsoil with resistivity values range from 105 to 648 Ωm and layer thickness of 0.7 and 3.9 m. The second layer has resistivity of 275 to 597 Ωm diagnostic of quartzitic or gravely sand with thickness ranging from 5.4 to 14.4 m. The third layer has resistivity values of 60 to 114 Ωm and thickness ranging from 17.6 and 36.6 m. The bedrock resistivity varies between 567 to 734 Ωm suggesting fractured bedrock.

Confined aquifers

These are characterized by 4 geoelectric layers. The topsoil has resistivity value of 81 to 753 Ωm, typical of laterite/lateritic sand with a thickness of 0.5 m; the second layer has resistivity value of 371 Ωm and thickness of 7.4 m. The aquifer units here are characterized by resistivity value of 96 Ωm and 9.3 m thick. The bedrock resistivity of 696 Ωm is diagnostic of fractured bedrock.

Groundwater prospect evaluation

In a typical basement setting, the bedrock relief is relevant in the evaluation of its groundwater potential. Of particular attention however is the weathered layer. This layer is also regarded as significant water-bearing layer (Bala and Ike, 2001; Shemang, 1993) especially if considerably thick and the resistivity parameters suggest saturated condition. The cardinal focus on groundwater assessment in the crystalline basement area is where the overburden and fractured basement aquifers are complementary or connected (Lenkey et al., 2005; Omosuyi, 2000; Meju et al., 1999). Figure 4 shows the overburden thickness map while Figure 5 is the graphical display of the thickness of the unconsolidated materials overlying the crystalline basement ranging from 4 to 54.1 m in Ile-Oluji. In Figure 5, overburden thickness of 3 to 4 m, 15 to 30 m and 3 to 54 m in the area constitutes about 35, 47.5 and 17.5% respectively, suggesting that the water-bearing horizon (Lenkey et al., 2005) across the area varied from low to medium. The hydrogeological studies involving taking of inventory of hand-dug wells also corroborated the VES interpreted results as a good number of depth to the bedrock determined from the wells correlates with those determined from the VES data. The static water level measurements ranges from 1.7 to 12.9 m. Figure 6 shows the ground water head map showing groundwater flow direction across the area. The map shows the recharge and discharge areas. In the diagram, there is a valley located at the central part of the study area and depression zones in the western and north-eastern flanks of Ile-oluji. Across the central part, groundwater divides are located at up-gradient sides while in the south eastern part, groundwater divides are located on the maximum gradient sides of the area.

Assessment of aquifer vulnerability

Generally in the crystalline basement terrain, aquifers often occur at shallow depths, thus making them vulnerable to environmental risks. An effective groundwater protection is often provided by impermeable geologic materials or barriers with sufficient thickness and low hydraulic conductivity (Mundel et al., 2003). This is because the earth medium acts as a natural filter to percolating fluids containing contaminants. Its ability to retard contaminated fluid is a measure of its protective capacity (Olorunfemi et al., 1998). The resistivity parameters of the uppermost geoelectric layer in the study area have been used to assess the vulnerability of the underlying aquifers. Relatively, topsoil resistivity of the medium in the range between 20 to 100 Ωm suggest clayey and porous layer while resistivity between 100 to 350 Ωm suggest porous clayey sand/sand layer with resistivity values above 350 Ωm diagnostic of laterite/lateritic or near-surface crystalline outcropping rocks in the area. The low-resistivity porous medium makes the underlying aquifer to be prone to infiltration from runoff water and contaminants from the surface. Laterite/lateritic clay (or hardpan) topsoil with relatively high resistivity assist in preventing the aquifer from being infiltrated by contaminants. Figure 7 presents the contour map of resistivity of the first geoelectric layer in the area while Figure 8 shows the numerical resistivity distribution across the first layer in the area. Zones around the north central part have moderate to good protective capacity. The western part is also characterized by material of good to moderate capacity. The extreme western, south western and eastern parts have weak protective capacity. About 50% of the resistivity values of the topmost geoelectric layer delineated fall within 101 to 200 Ωm range in Figure 8 which typified a geological formation with interconnected pores and hence can store and transmit water. However, about 35% of the resistivity values of the same geoelectric layer estimated fall within 11 to 100 Ωm bracket, thus suggesting a considerable clayey or silt sequences (aquitard) with effective capacity to constitute impervious/semi-impervious barriers.

Quantitatively, the numerical distribution of the aquifer protective layers (Figure 8) shows that the study area can be rated to have weak protective capacity.

CONCLUSIONS

In this study, an evaluation of groundwater prospect and aquifer vulnerability of Ile-Oluji area was undertaken. The unconsolidated materials overlying the crystalline basement rocks around the area constitute the major water-bearing horizon from which the inhabitants abstract water through hang-dug wells for their domestic needs. Geoelectric depth sounding around the area reveals that the thickness of the unconsolidated materials varies from 4 to 54.1 m where values within the range of 3 to 5.9 m and 15 to 17.9 m constitute about 17.5 and 27.5% respectively. This indicates that the unconsolidated material in the area is generally fairly thick, thus suggesting that the groundwater potential is moderate to low. About 50% of the resistivity values of the topmost geoelectric layer delineated fall within 101 to 200 Ωm, diagnostic of clayey sand to sandy materials while estimated 30% of the resistivity values of the layer falls within 11 to 100 Ωm typical of clayey or sandy clay materials. In other places (about 20%) the topsoil resistivity values range over 300 Ωm. This shows that the study area is overlain mostly by materials of weak

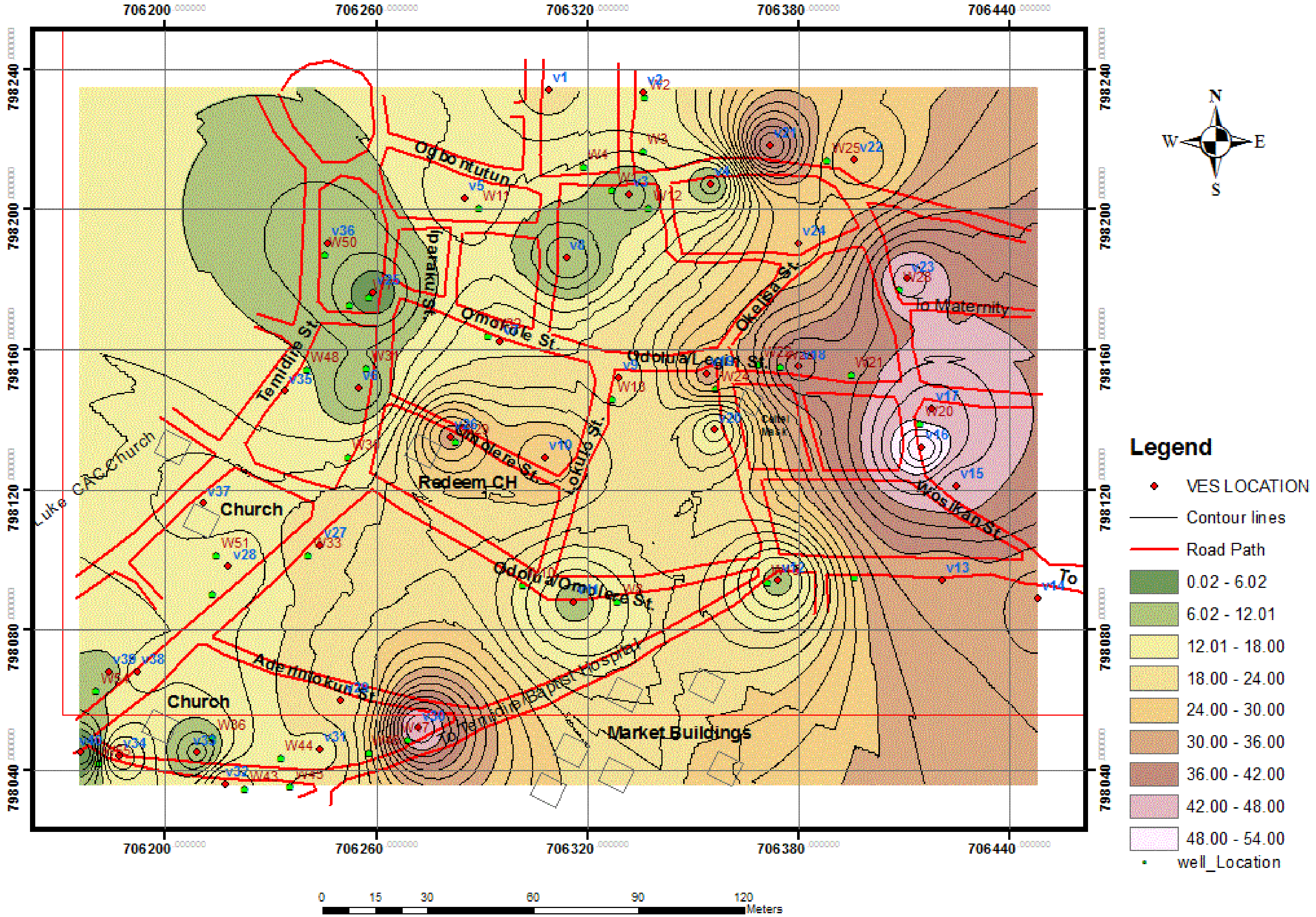


Figure 4. The overburden thickness map.

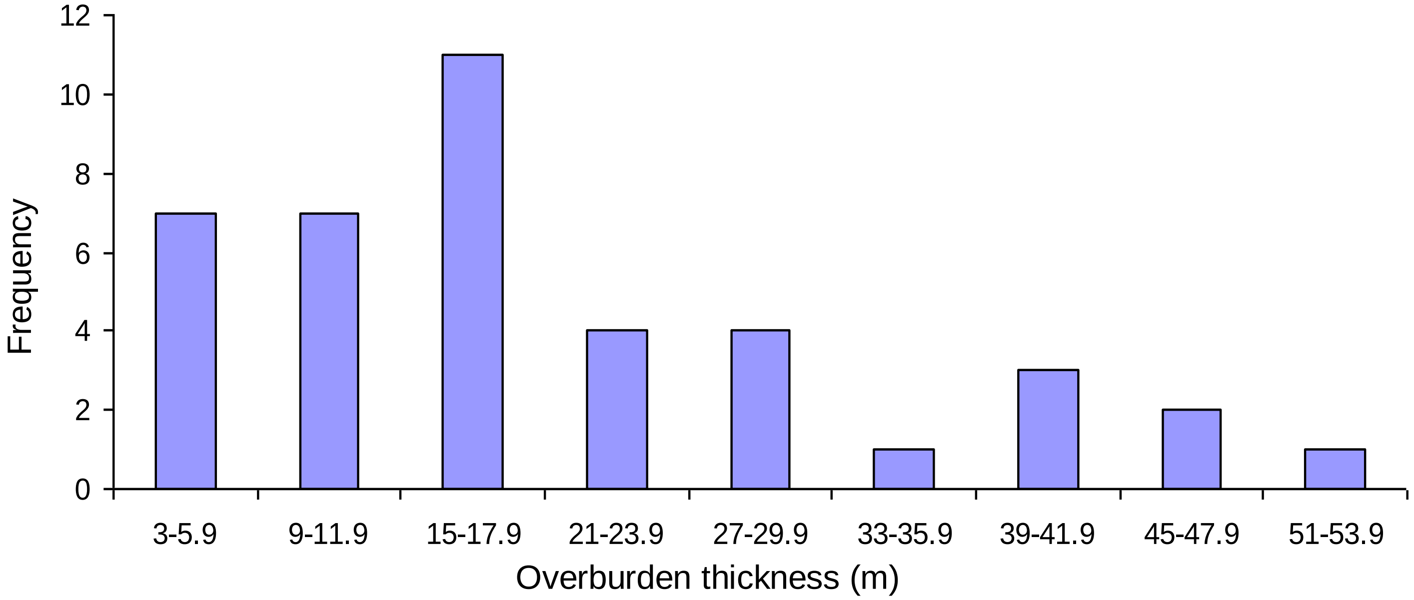


Figure 5. Distribution of thickness of unconsolidated material at Ile-Oluji.

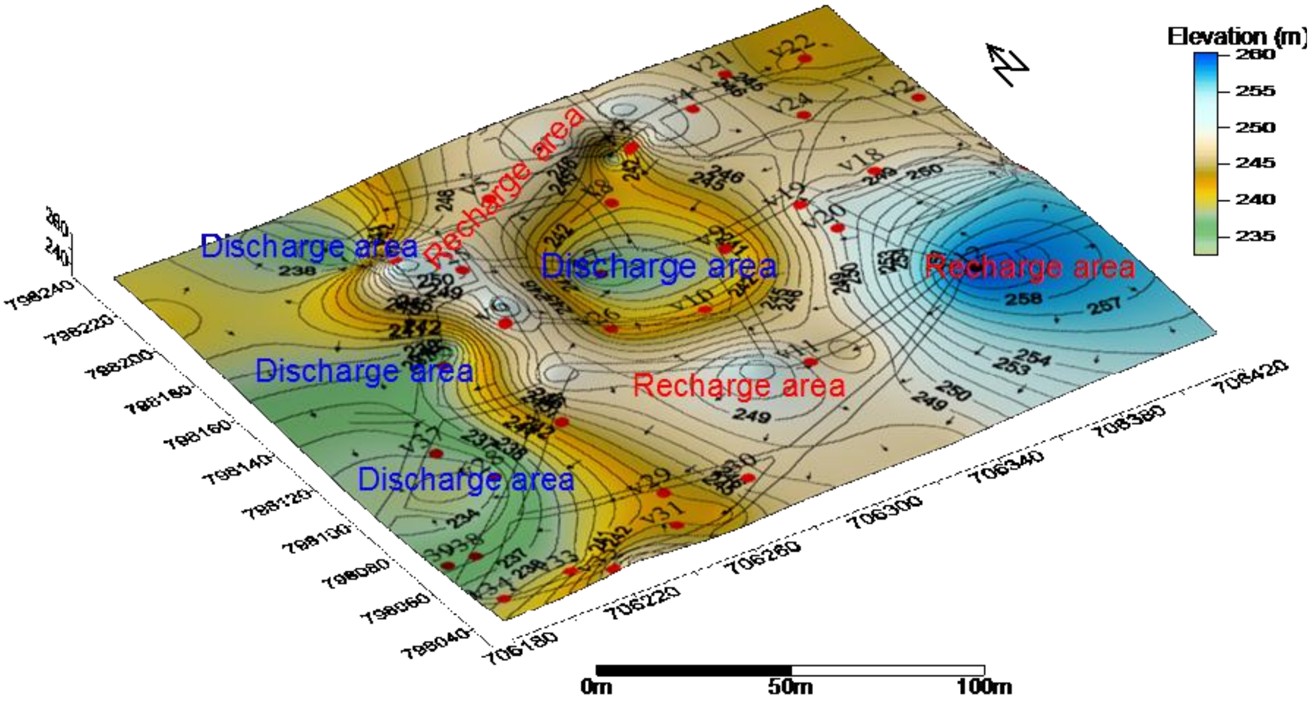


Figure 6. Groundwater flow pattern of Ile-Oluji.

protective capacity. It is therefore evident that groundwater in most part of the area is vulnerable to pollution that may arise from runoff water, sewage, effluent and indiscriminate waste disposal in the study area. Vulnerable zones include areas around the extreme western, southwestern and eastern parts. However, some parts of the north central and western areas were identified to be less susceptible to contaminants because they are overlain by materials of moderate to good protective capacity. Indiscriminate dumping of refuse

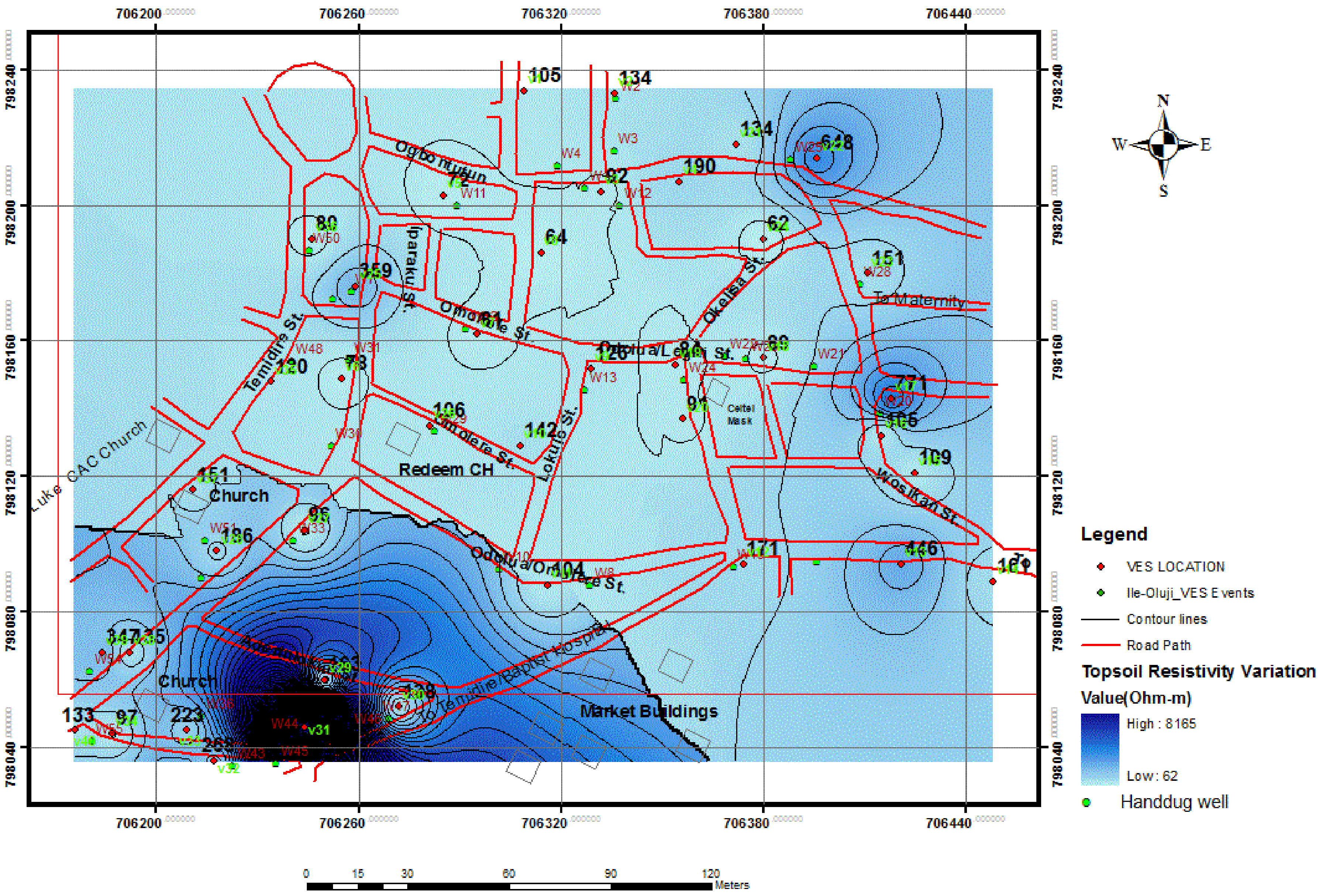


Figure 7. Contour map of resistivity distribution in the first layer at Ile-Oluji.

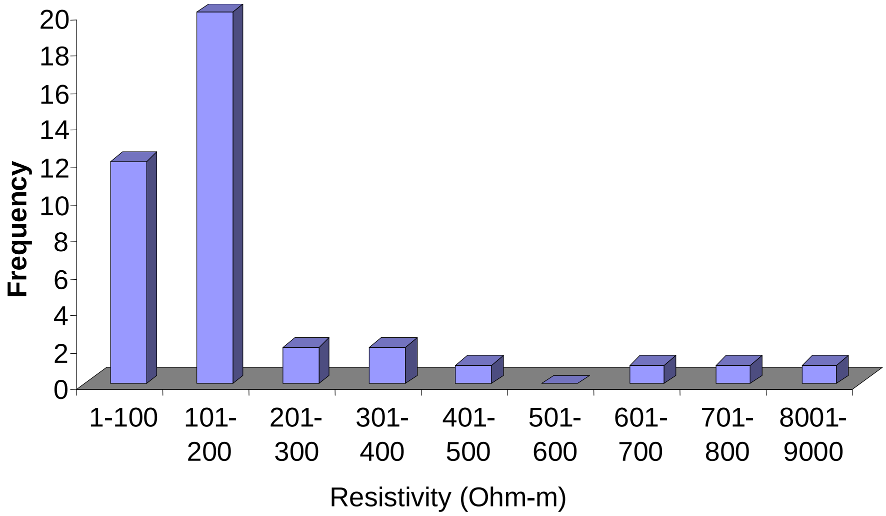


Figure 8. Distribution of resistivity in the topmost geoelectric layer at Ile-Oluji.

refuse and proper sewage disposal should be encouraged by the inhabitants of the community; this is desirable in order to protect the potability of groundwater in the area.

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