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Hydrogeophysical delineation of groundwater prospect zones at Odigbo, Southwestern Nigeria

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Data from dc resistivity depth sounding and hydrogeologic measurements from Odigbo, Nigeria, were incorporated to delineate the groundwater prospect zones in the area. The area is underlain by the basement complex rocks of southwestern Nigeria, and characterised by biotite-gneiss and quartzite lithologies. The hydrogeologic data acquisition involved determination of depths (of wells) and static water levels which enabled determination of thickness of vadose and phreatic zones in 45 existing wells. The dc resistivity measurements involved Schlumberger depth soundings in 61 locations. The interpretation of the sounding data enabled the delineation of geoelectric sequence across the area. Depth to water table (groundwater head) ranges from 2.3 to 9.6 m while the thickness of the phreatic zone, an approximation of water column thickness, varies from 0.1 to 3.0 m, with the thickness in the range of 2.1 to 3 m constituting about 9%, and occurring in the central segment of the study area. The regolith overlying the basement rock constitutes the main water-bearing layer, since the resistivity parameters of the bedrock across the area do not suggest significant fractures or faults. The northwest – southeast and north – south trend of the aquifer unit within the regolith, with resistivity below 210 Ω-m, and constituting about 62% of the area, are considered the groundwater prospect zones. Based on aquifer thickness parameters, the groundwater prospect zones have been classified into low (< 20 m), medium (20 to 40 m) and high (> 40 m) respectively. 46% falls within the medium/high groundwater prospect rating while 54% falls within the low rating. The maps derived from the above are considered reliable prospect guides for groundwater developers in the area.

Key words: Groundwater, unconsolidated regolith, phreatic zone, resistivity sounding, geoelectric layers.

INTRODUCTION

Advantages of groundwater over other sources have been severally empasised in literatures. Higher percentage of water users world wide depend mostly on groundwater (Reilly et al., 2008). The urge to sustain groundwater need by the people has strenghened the application of appropriate hydrogeologic and/or geophysical search (Lashkaripour, 2003; Batayneh, 2010; Omosuyi, 2010; Anudu et al., 2011) to enable locating areas of high and reliable groundwater prospect or characterise seasonal changes in the near-surface aquifer (Webb et al., 2011).

Worldwide, areas underlain by the basement complex rocks are generally characterised by low groundwater prospect (Louis et al., 2002). In a typical hardrock setting, the geological stratification normally encoutered consists of a hardrock basement overlain by variably thick unconsolidated materials referred to as the overburden or the regolith. The overburden is further stratified into the vadose and phreatic zones, separated by the water table (Fetter, 1980; Hiscock, 2005). The igneous and/or

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metamorphic bedrock occur at varying depths and mostly at low degree of decomposition, thus suggesting low porosity and permeability. This informed why groundwater prospects of aquifers within bedrocks are mosly rated low, or of minor hydrogeologic importance. Consequently, the major focus for groundwater development in hardrock terrain is the aquifer within the regolith material (Clark, 1985; Acworth, 1987; Das et al., 2007). However, a borehole anticipated to provide long term good yield is one which penetrates fairly thick overburden and additionally intersects available fracture(s) within the underlying bedrock.

In Nigeria, especially the rural and municipal/urban settings underlain by hardrock, groundwater, mostly abstracted through hand dug wells, provides the only realistic water supply option. Wells in this terrain, terminating mostly within the overburden, are however not uniformly productive, aptly informed by the heterogeneous nature of the partly autochthonous and largely allochthonous materials. Accordingly, a good knowledge of the hydrogeologic framework in the heterogeneous unconsolidated regolith, particularly within the zone of saturation (phreatic zone), and the hydrogeophysical parameters of the horizon are very important in the evaluation of the overall groundwater potential, and in specific delineation of groundwater prospect zones (Sen, 1994; Rubin and Hubbard, 2005; Vereecken et al., 2006).

In this study, hydrgeologic measurements from existing wells and geoelectric data from resistivity depth sounding were used to evaluate the groundwater prospect of the regolith and underlying hardrock at Odigbo. Since groundwater is a major source of water supply worldwide (Reilly et al., 2008), the exercise was aimed at establishing the conceptual hydrogeologic framework to enable sustainable groundwater management strategies in the area.

Location and geologic setting

Odigbo is located on Latitudes N06° 47' 21'' and N06° 48' 36'' and Longitudes E04° 51'27'' and E04° 52'50'' (Figure 1) with an elevation of approximately 125 m above sea level. The area falls within the tropical rain forest belt, with a mean annual rainfall of over 1500 mm and a temperature range of 23 to 27°C with evergreen tropical rain forest vegetation. The study area is situated within the pre-Cambrian basement complex rocks of southwestern Nigeria (Figure 2). Four broad lithologic groups have been identified across the area (Rahaman, 1988): the meta-sedimentary and meta-volcanic rocks, consisting of the schist belts; the migmatite-gneiss complex, consisting of migmatites and gneisses of various kinds; the older granites, characterized mainly by granites and syenites, and the younger granites which are alkaline to Para-alkaline bodies.

The local geology consists of quartzite and biotite granites. Field observation shows that biotite granites in the area occur as large igneous bodies, or as boulders, with grey to pink in colours, and largely coarse-grained (Omosuyi and Oseghale, 2012). Fractures and minor faults were noticed in both the quartzite and biotite granites outcrops across the area.

METHODOLOGY

The hydrogeologic measurements involved determination of well depths and static water levels in forty five (45) existing non-flowing wells across the area (Figure 1). The measurements engaged steel tape, whose lower end was marked with carpenter's chalk, as practiced in Moore (2002), to enable a reading to be taken from the submerged portion. To ensure accuracy, two measurements were taken at each well location, and the average values were determined. Since the depth to the static water level is construed an approximation of the interface between the vadose and phreatic zones in a non-confined aquifer setting (Fetter, 1980; Moore, 2002), the measurements were used to compute the thickness of the vadose (zone of aeration) and phreatic (zone of saturation) zones across the area.

The resistivity measurements engaged the Schlumberger field procedure (Zhordy et al., 1974). The Ohmega resistivity meter (a product of Allied Associates Geophysical Limited) was used for the data acquisition. Sixty one (61) depth soundings were conducted (Figure 1). Current electrodes (AB) separation ranged between 130 and 200 m. The depth sounding data were presented as sounding curves (Figure 3). Manual interpretation of the VES curves (Koefoed, 1979) and subsequent interactive adjustment with *Resist Version 1.0* software (Vander, 1988) enabled the delineation of the geoelectric parameters at each sounding location. The electrical resistivity contrast between lithological units enabled the delineation of geoelectric layers and identification of aquifer units.

RESULTS AND DISCUSSION

The depth to static water level (water table), as delineated from hydrogeologic measurements, ranges from 2.3 m to 9.6 m, with a modal range of 4.1 to 5.0 m. Figure 4 is a map showing spatial variation of water table depth across the area. The north-west, north-east and south-west portions of the area have low thickness (3.5m) while relatively thick values (5 to 9.5 m) characterize the north, north central, western and eastern segments.

Water column thickness ranges from 0.1 to 3.0 m across the area (Figures 5a and 5b). The range within 0.1 to 1.0 m constitutes about 71% (Figure 5a) and can be observed across the study area (Figure 5b). The thickness within the 1.1 to 2.0 m range, and constituting about 20%, can be observed in the northwest, northeast and south central segments. The upper thickness range of 2.1 to 3.0 m constituting about 9% can be noticed in the central segment of the area. The above range suggests that water column (or the phreatic zone) is generally not significantly thick in the area.

The groundwater elevation map (Figure 4) and water column thickness map (Figure 5b) generated from the hydrogeologic measurements constitute reliable

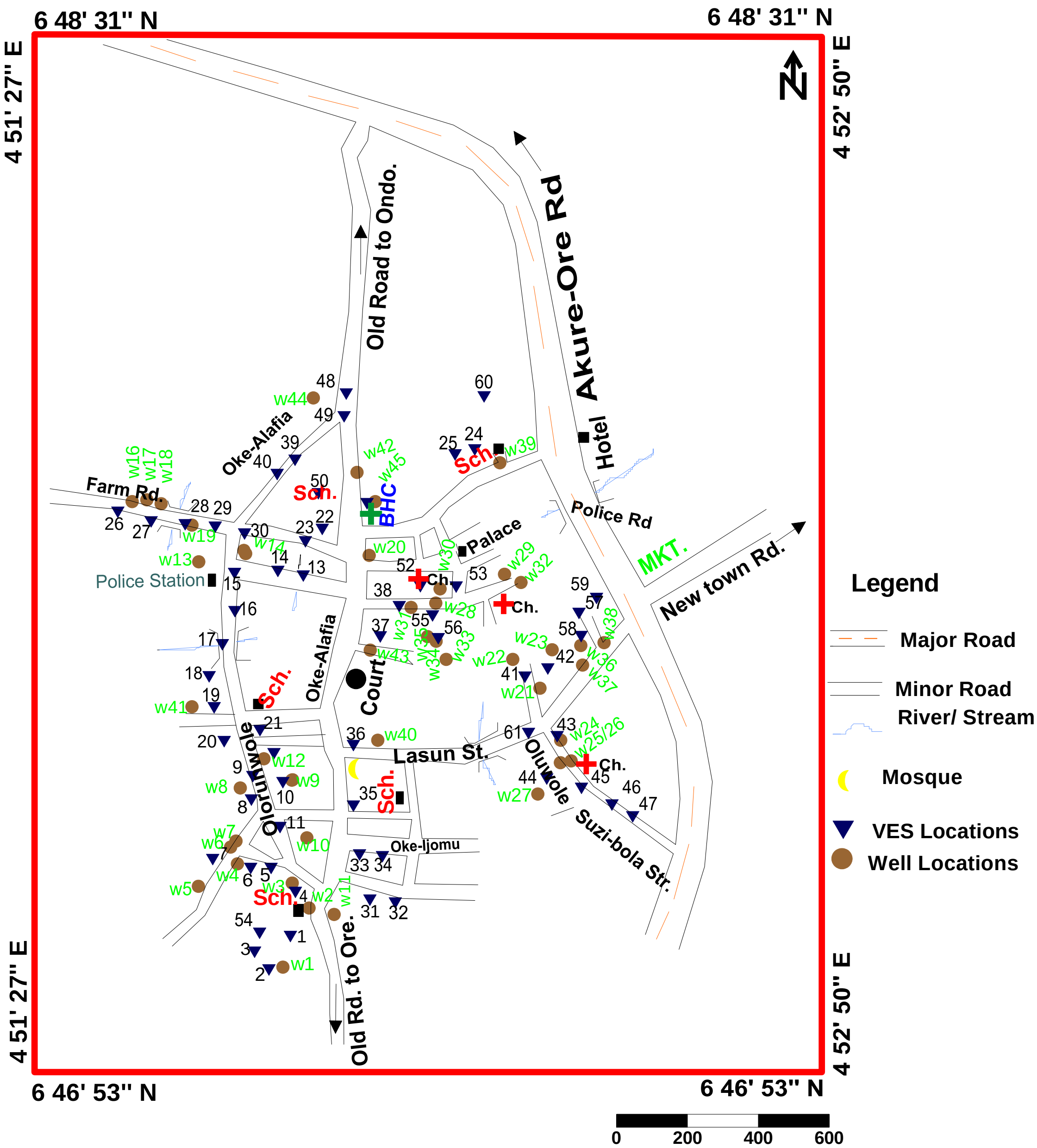


Figure 1. Map of Odigbo showing wells and VES locations.

groundwater occurrence guide in the area, since depth to water table cannot be reliably delineated from VES data interpretation.

The geoelectric data interpretation delineated four distinct geoelectric layers across the area. Resistivity and thickness values in these layers range from 33 to 707Ω-m and 0.1 to 3.5 m for the topsoil; 34 to 1114 Ω-m and 1.1 to 19.7 m for the unconsolidated sandy/clayey sand sub-stratum, while the resistivity and thickness of the partially weathered portion of the bedrock range from 526 to 981 Ω-m and 5.6 to 43.5 m respectively. Bedrock resistivity is generally in the upward of 913 Ω-m. Geoelectric sections derived from the interpretation (Figure 6) show geoelectric layer stratifications in the area.

Groundwater prospect evaluation

In a typical basement complex terrain, groundwater prospect evaluation is mostly based on the thickness of the unconsolidated regolith overlying the bedrock and the extent of the zone of weathering within the bedrock. The consolidated crystalline rocks underlying the regolith often constitute bedrock aquifers if the rocks are sufficiently fractured (Lucius et al., 2001; MacDonald et al., 2005; Omada et al., 2009).

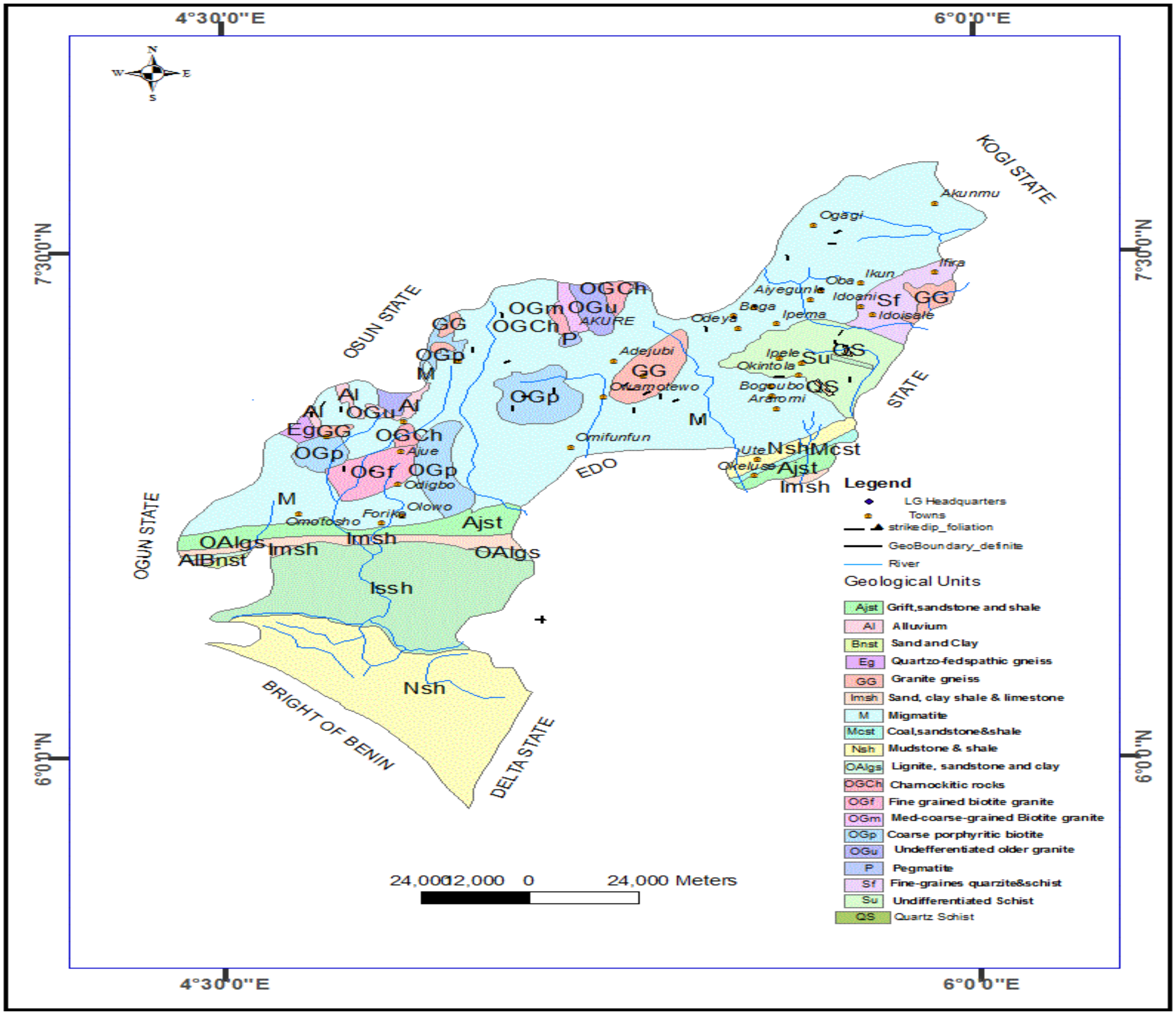


Figure 2. Geological map of Ondo State showing the study area (Modified from NGSA, 2006).

The unconsolidated regolith overlying the basement rock (Figure 7) constitutes the main water-bearing layer unit in the area, since the resistivity parameters of the bedrock across the area (Figure 8) does not suggest the presence of significant fractures or faults. However, the resistivity parameters of these horizons, particularly the unit(s) adjudged the aquifer (Figure 9), are important consideration in the assessment of their groundwater holding potential. In the study area, aquifer units were delineated within the regolith. The resistivity values in the range of < 210 Ω-m in this unit constitute about 62% of the study area (Figure 9). This zone trends northwest – southeast and north – south, while areas with resistivity > 210 Ω-m constitute 38% of the investigated area.

The above parameters enabled the rating of the area (based on the thickness of the aquifer unit within the regolith) into groundwater prospect zones: low (< 20 m), medium (20 to 40 m) and high (> 40 m). 46% of the study area falls within the medium/high groundwater prospect rating zones while 54% falls within the low prospect rating (Figure 10).

Conclusion

This study incorporated hydrogeologic and dc resistivity data to delineate groundwater prospect zones at Odigbo, underlain by the basement complex rocks of Southwestern Nigeria. The depth to static water level (water table), as delineated from hydrogeologic

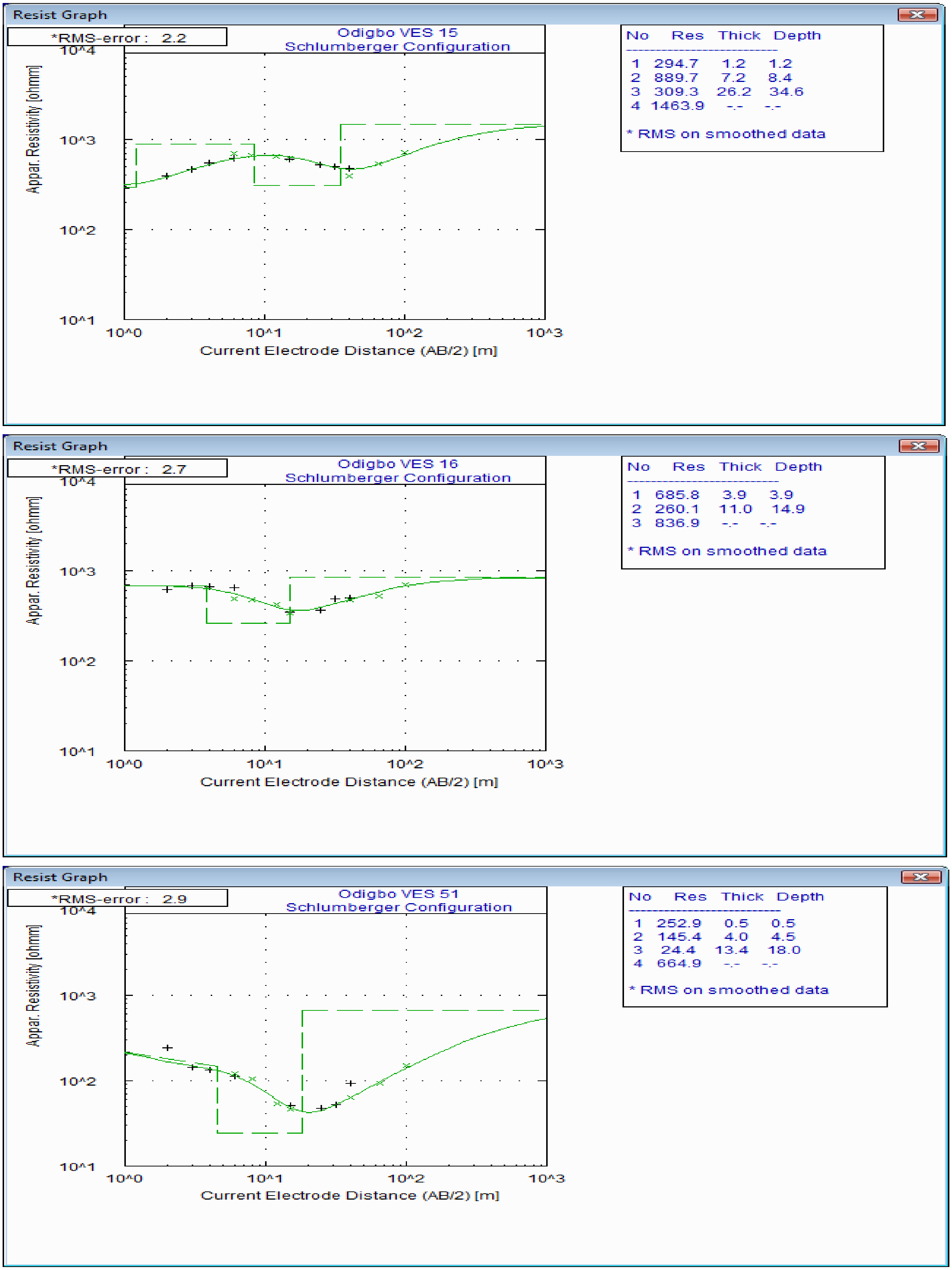


Figure 3. Typical VES curves from Odibgo.

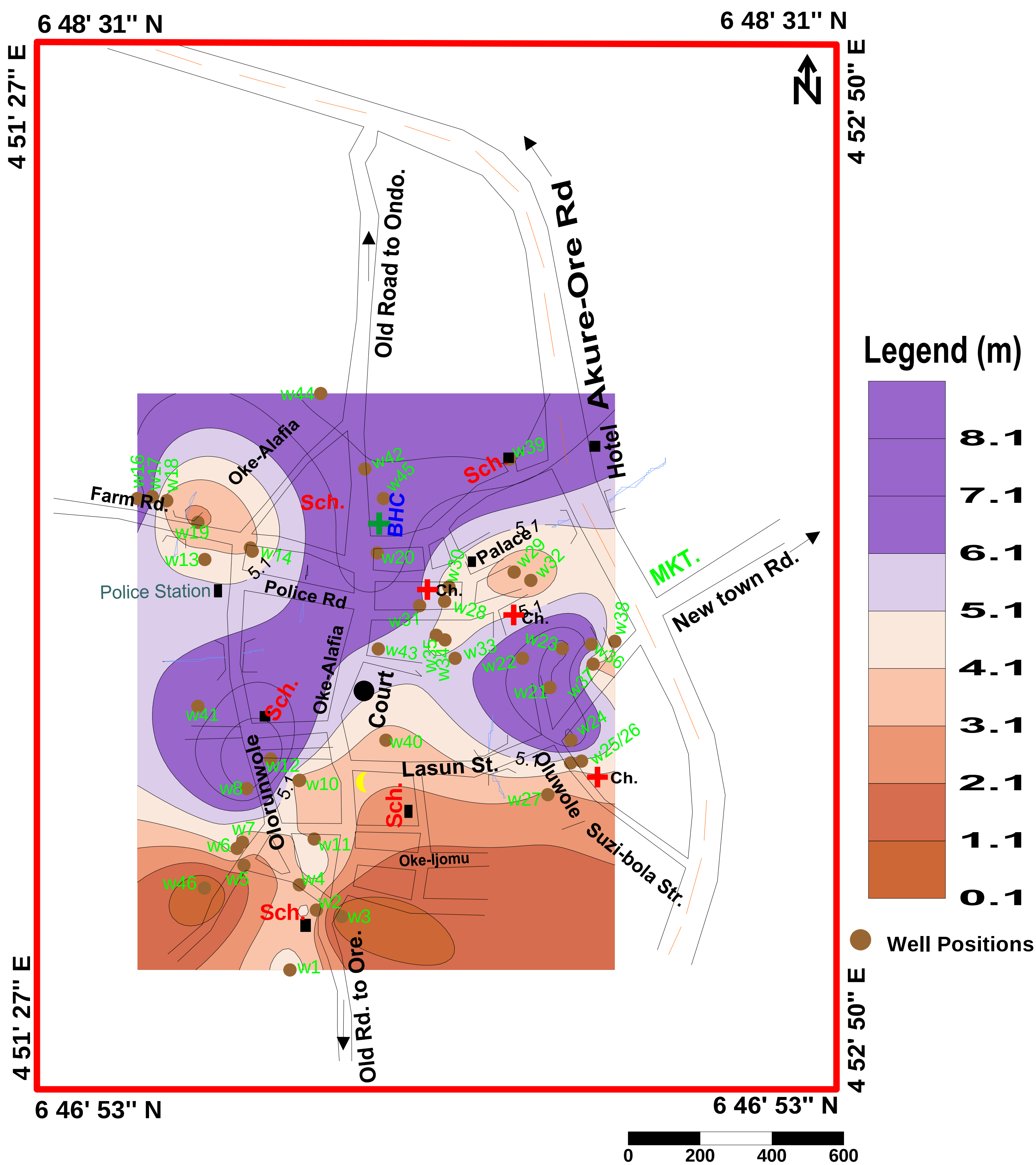
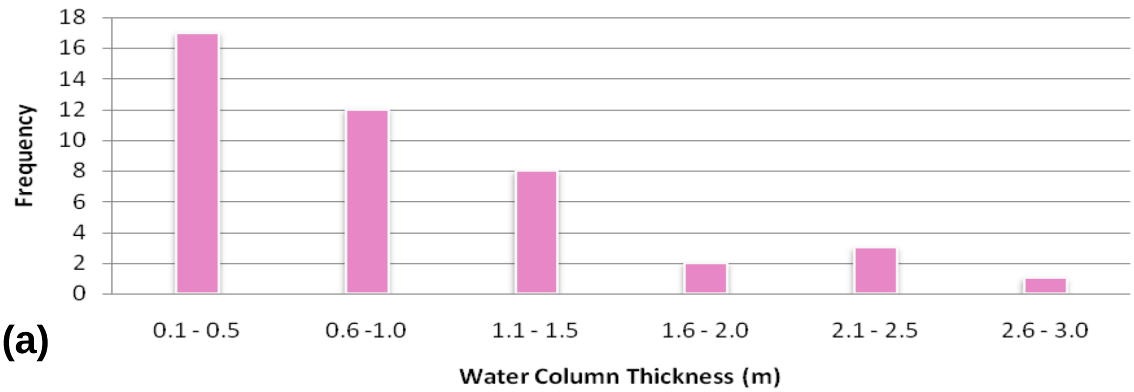
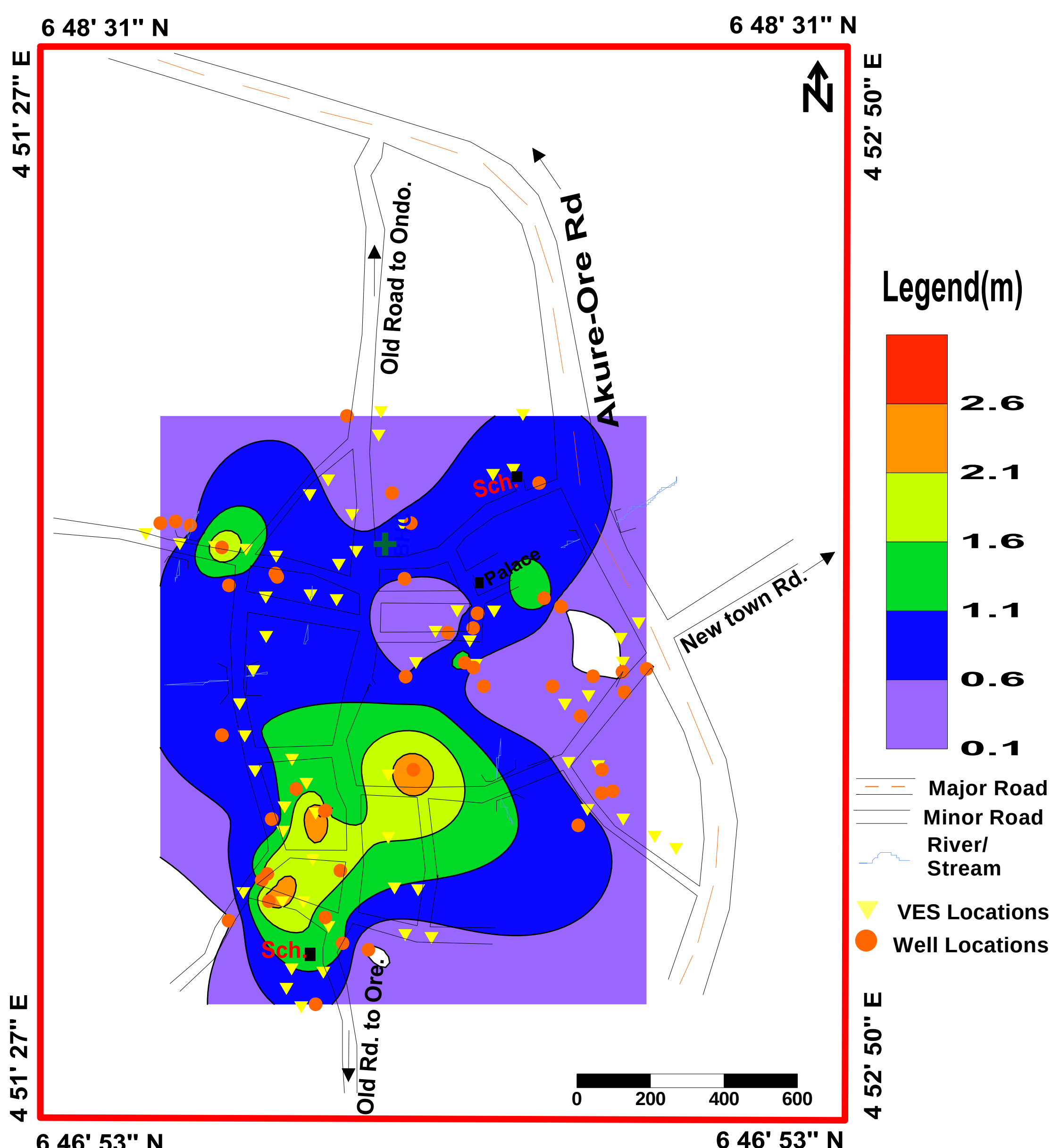


Figure 4. Groundwater elevation map of Odigbo.

measurements, ranges from 2.3 to 9.6 m, with a modal range of 4.1 to 5.0 m. Water column thickness also ranges from 0.1 to 3.0 m across the area. The upper thickness range of 2.1 to 3.0 m constituting about 9% can be noticed in the central segment of the area. The above range suggests that water column in wells is generally



(a)



(b)

Figure 5. (a) Bar chart showing water column thickness in Odigbo (b) Contour map of water column thickness in Odigbo.

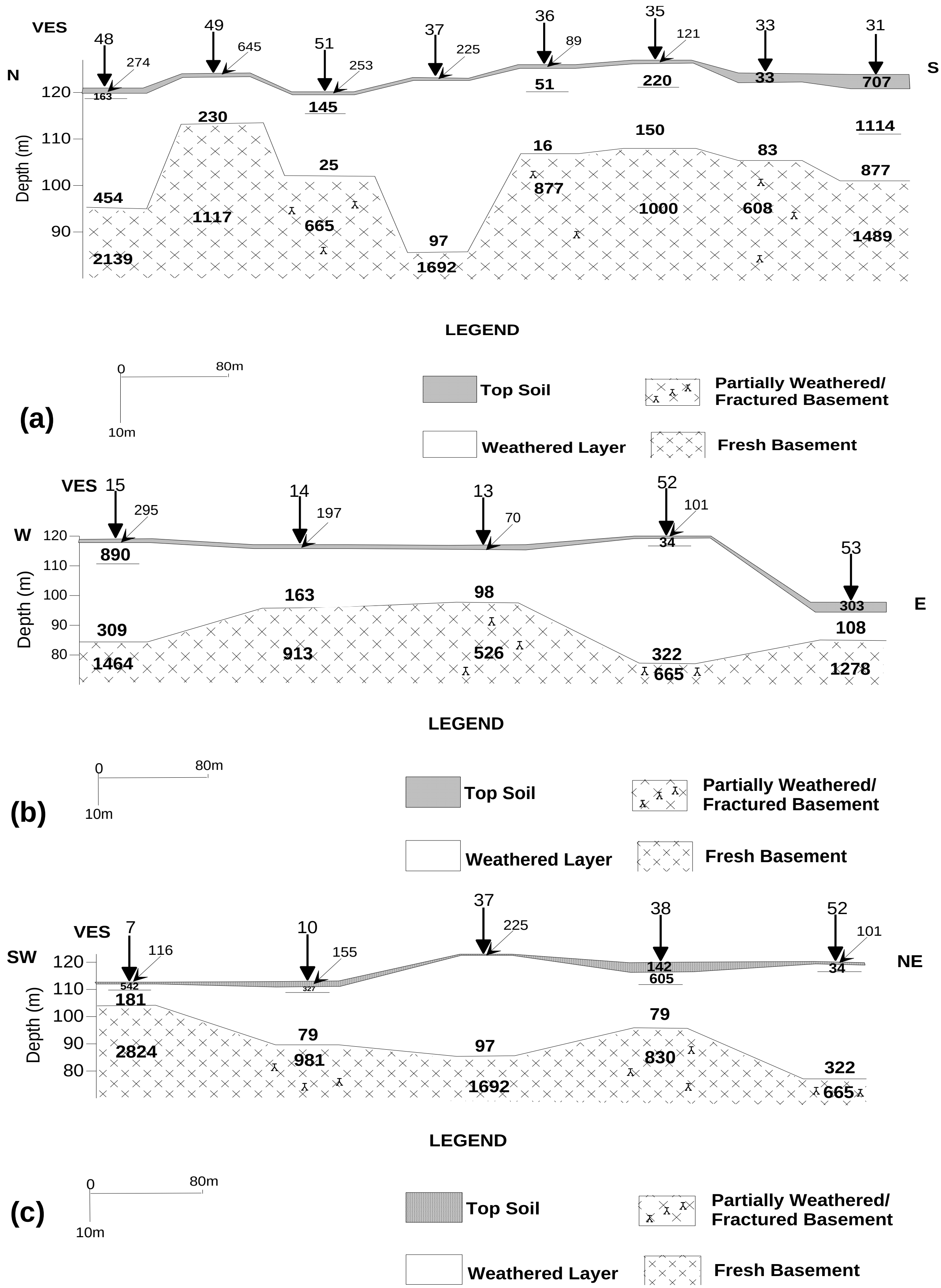
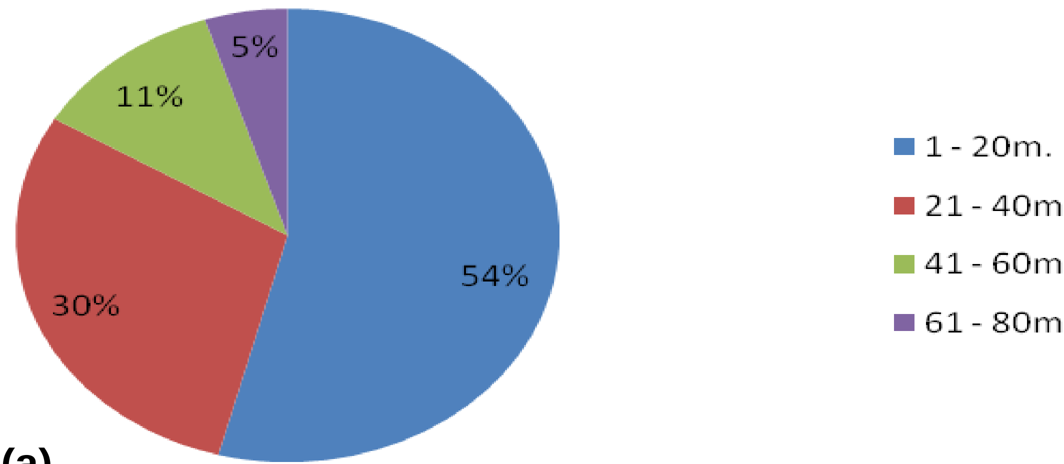
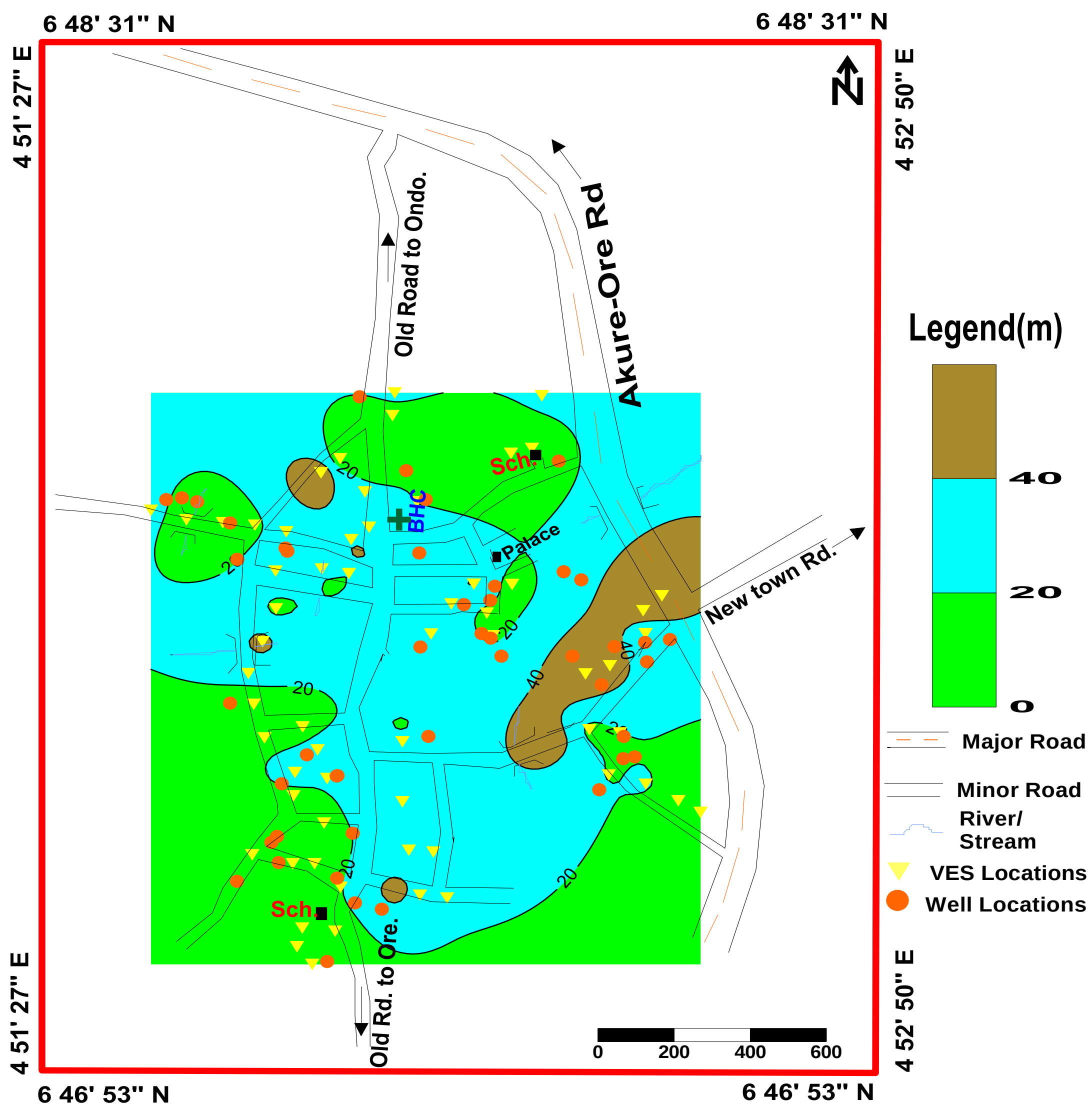


Figure 6. Geoelectric sections in: (a) the north-south, (b) west-east, and (c) southwest-northeast directions of the study area.



(a)



(b)

Figure 7. (a) Percentage distribution of overburden thickness in Odigbo **(b)** Contour map showing overburden thickness distribution in Odigbo.

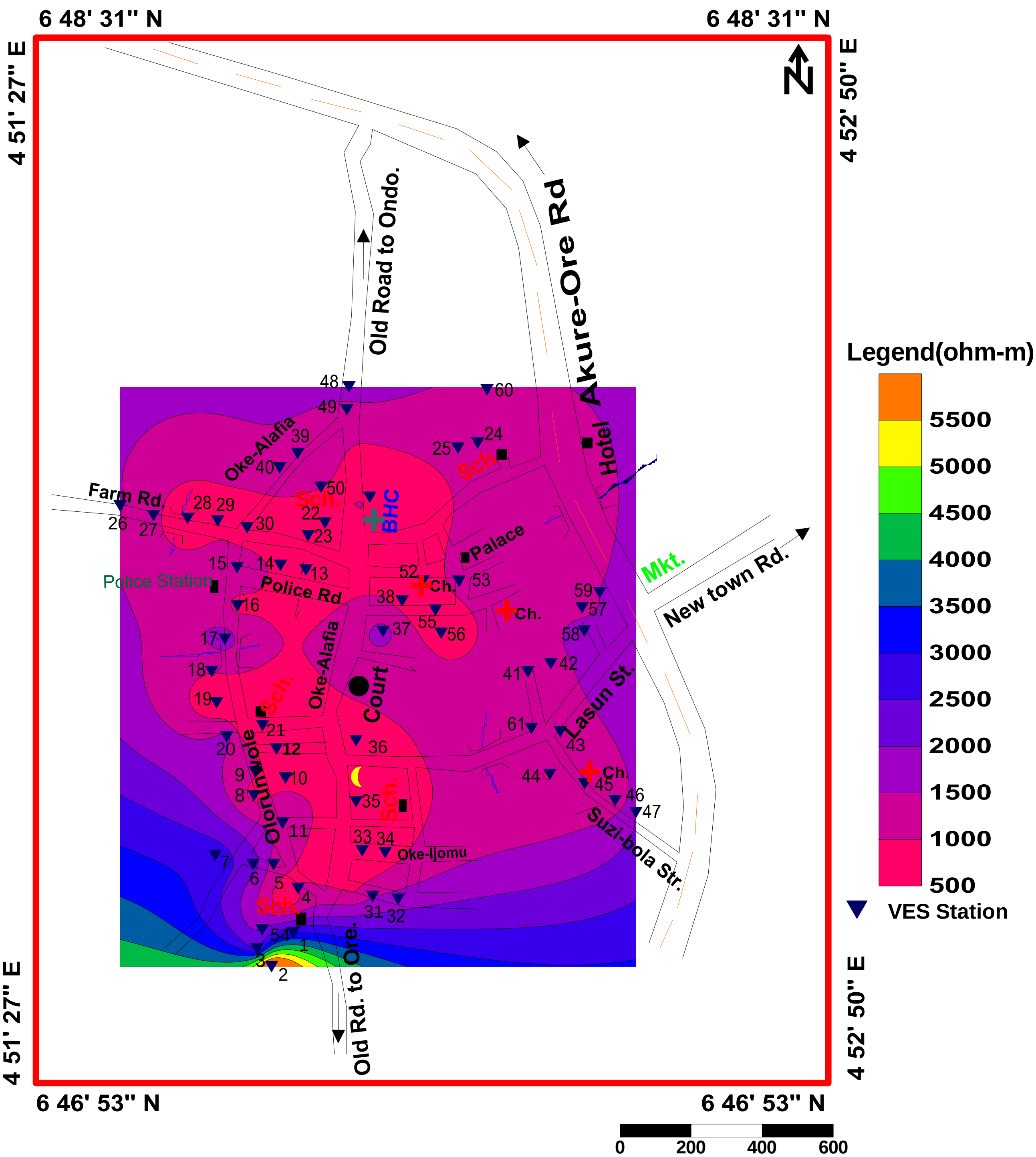


Figure 8. Map of bedrock resistivity distribution in Odigbo.

not significantly thick across the area. The groundwater elevation map and water column thickness map generated from the hydrogeologic measurements constitute reliable groundwater occurrence guide in the area.

The resistivity depth sounding enabled the delineation of the unconsolidated regolith overlying the bedrock and the weathered portion of the bedrock, taking into consideration the hydrogeologic implications of the resistivity characteristics of these horizons. The unconsolidated regolith constitutes the main water-bearing layer. The aquifer unit within the regolith, with

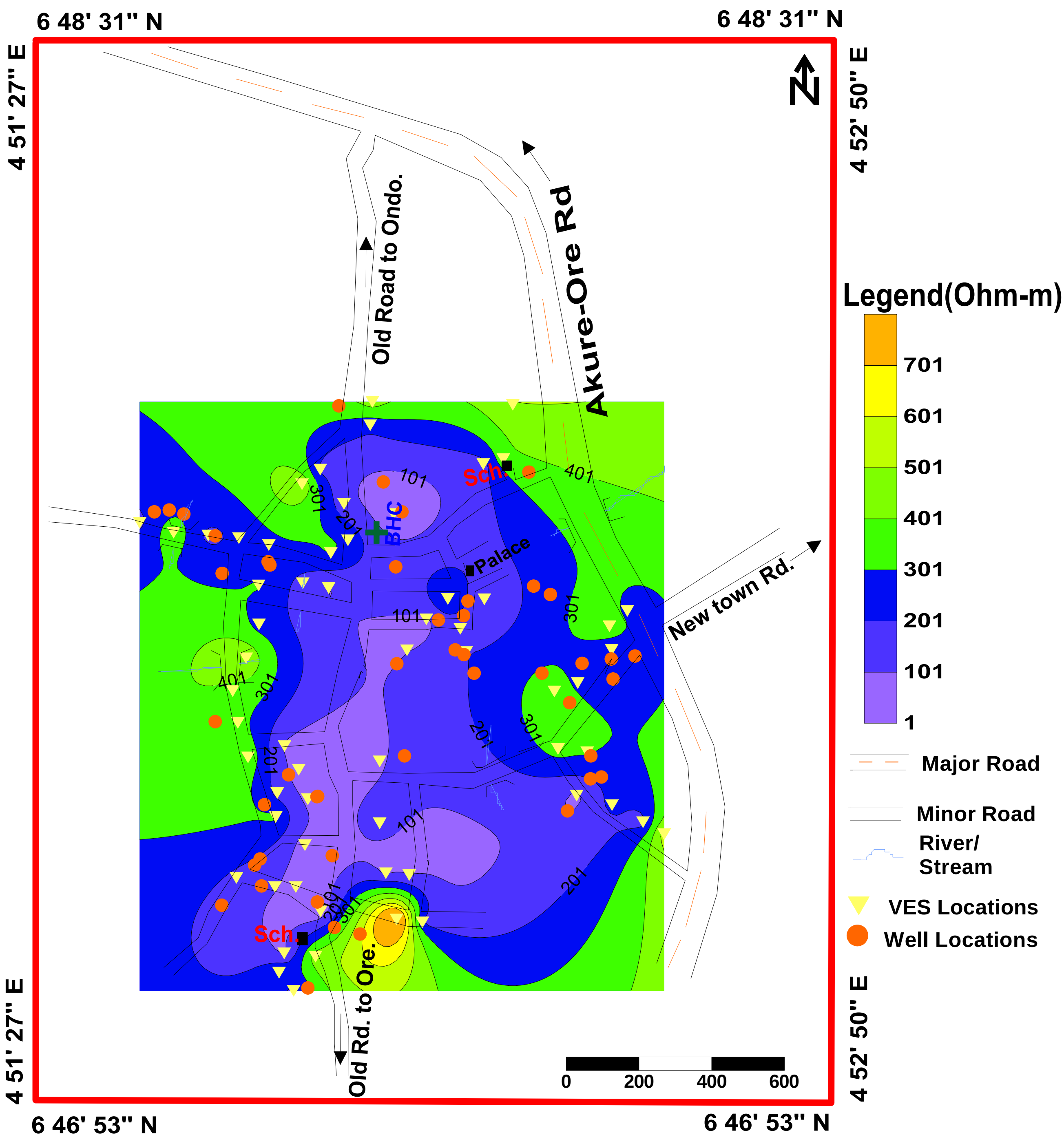


Figure 9. Contour map of aquifer resistivity in Odigbo.

resistivity values within 1 to 210 Ω-m brackets, and constituting about 62% of the investigated area trends northwest – southeast and north – south, while the portion with resistivity values greater than 210 Ω-m constitutes about 38% of the study area. Regions with resistivity values lower than 210 Ω-m are considered the groundwater prospect zones. Based on the thickness of the aquifer unit within the unconsolidated regolith, the area has been delineated into groundwater prospect rating zones: low (< 20 m), medium (20 to 40 m) and high (> 40 m). 46% of the area covered by this study falls within the medium/high prospect rating while 54% falls within the low prospect rating zone. The maps generated from these are considered reliable prospect guide for

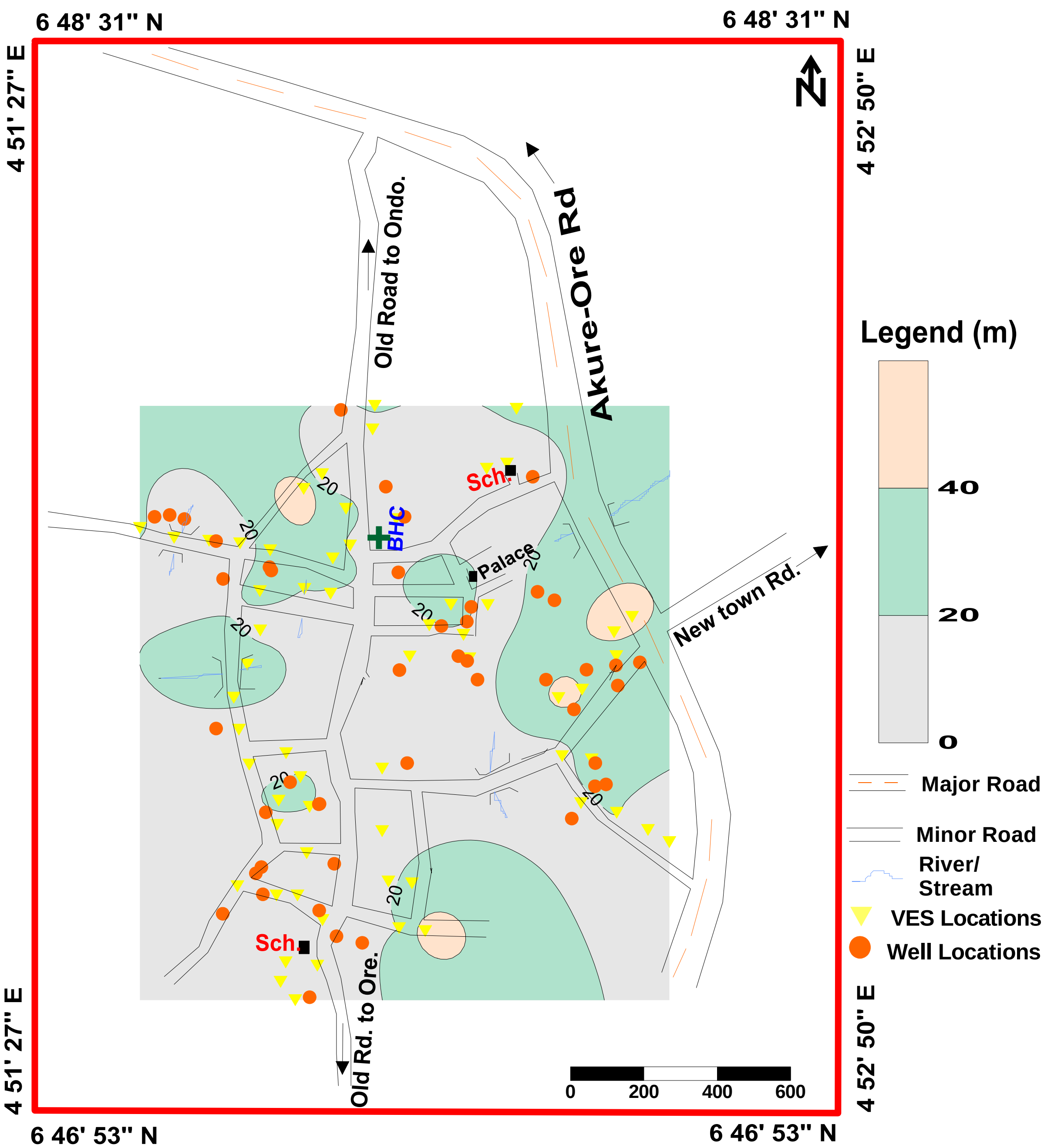


Figure 10. Map showing aquifer thickness distribution in Odigbo.

groundwater developers in the area.

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REFERENCES

Acworth RI (1987). The development of crystalline basement aquifers in a tropical environment. Quart. J. Eng. Geol. 20:265-272.

Anudu GK, Onuba LN, Ufondu LS (2011). Geoelectric sounding for groundwater exploration in the crystalline basement terrain around Onipe and adjoining areas, southwestern Nigeria. J. Appl. Technol. Environ. Sanit. 1(4):343-354.

Batayneh AT (2010). Mapping Quaternary deposits in the El-Jufr playa (Southeastern Jordan Plateau) using geoelectrical techniques: implications for geology and hydrogeology. Sci. Res. Essays 5(20):3183-3192.

Clark L (1985). Groundwater abstraction from Basement Complex areas

of Africa. Q. J. Eng. Geol. 18: 25-34.
Das SN, Mondal NC, Singh VS (2007). Groundwater Exploration in Hard Rock areas of Vizianagaram District, Andhra Pradesh, India. J. Ind. Geophys. Union 11(2): 79-90.
Fetter CW (1980). Applied Hydrogeology. Charles E. Merrill Publishing Company, London, p. 488.
Hiscock KM (2005). Hydrogeology: Principles and Practice. Blackwell Publishing, p. 389.
Koefoed O (1979). Geosounding Principles 1. Resistivity sounding measurements. Elsevier Scientific Publishing Company, Amsterdam, p. 275.
Lashkaripour G R (2003). An investigation of groundwater condition by geoelectrical resistivity method: A case study in Korin aquifer, southeast Iran. J. Spatial Hydrol. 3(1):1-5.
Louis IF, Louis FI, Grambas A (2002). Exploring for favourable groundwater conditions in hardrock environments by resistivity imaging methods: Synthetic simulation approach and case study example. J. Electr. Elect. Eng. Spec. Issue, pp. 1-14.
Lucius JE, Bisdort RJ, Abraham J (2001). Results of electrical survey near Red River, New Mexico. USGS Open-File Report 01-331, p. 24.
MacDonald A, Davies J, Calow R, Chilton J (2005). Developing Groundwater: A guide for rural water supply. ITDG Publishing, Warwickshire, UK, p. 358.
Moore JE (2002). Field Hydrogeology: A guide for site investigations and report preparation. Lewis Publishers, New York, p. 182.
Nigeria Geological Survey Agency (NGSA) (2006). Published by the Authority of the Federal Republic of Nigeria.
Omada JI, Omali A, Akuh T (2009). Groundwater resources of Lokoja metropolis, central Nigeria. J. Min. Geol. 45(1):41-51.
Omosuyi GO (2010). Geoelectric assessment of groundwater prospect and vulnerability of overburden aquifers at Idanre, southwestern Nigeria. Ozean J. Appl. Sci. 3(1):19-28.
Omosuyi GO, Oseghale A (2012). Groundwater vulnerability assessment using geoelectric and hydrogeologic parameters in Odigbo, southwestern Nigeria. Am. J. Ind. Sci. Res. 3(6):501-512.
Rahaman MA (1988). Recent advances in the study of the Basement complex of Nigeria. Precambrian Geology of Nigeria. A Publication of Geological Survey of Nigeria, pp. 11-41.
Reilly T, Dennehy KF, Alley WM, Cunningham WL (2008). Ground-Water availability in the United State. US Geological Society Circular 1323. 70 p.
Rubin Y, Hubbard SS (2005) (ed). Hydrogeophysics. Springer, pp. 1-23.
Sen Z (1994). Hydrogeophysical concepts in aquifer test analysis. Nordic Hydrol. 25:183-192.
Vander Velpen BPA (1988). Resist Version 1.0. M.Sc. Research Project, ITC, Deft, Netherlands.
Vereecken H, Binley A, Cassiani G, Revil A, Titov K (ed) (2006). Applied Hydrogeophysics. Springer, the Netherlands, pp. 1-8.
Webb SJ, Ngobeni D, Jones M, Abive T, Devkurran N, Goba R, Ashwal LD (2011). Hydrgeophysical investigation for groundwater at the Dayspring Children’s Village, South Africa, doi: 10.1190/1.3575291, Lead. Edge 30(4):434-440.
Zhordy AAR, Eaton GP, Mabey DR (1974). Application of surface geophysics to groundwater investigations: Techniques of water resources investigations of U.S. Geological Survey: Book 2. Chapter D1.