

HYDROGEOLOGICAL STUDY OF THE GROUNDWATER POTENTIAL OF ILARA-MOKIN SOUTHWESTERN NIGERIA

M. I. OLADAPO, O.O. ADEOYE-OLADAPO, AND K. A. MOGAJI

(Received 24, August 2007; Revision Accepted 6, March 2009)

ABSTRACT

Geoelectric study of the groundwater potential of Ilara-Mokin in Ondo State Southwestern Nigeria was carried out using electrical resistivity (Vertical Electrical Sounding) method with the view to providing adequate information on the different sub-surface geoelectric layers, structural configuration of the concealed basement rocks and the groundwater potential of the study area.

Forty-one Schlumberger vertical electrical soundings (VES) were conducted across the study area. The computer assisted VES data interpretation enabled generation of geoelectric curves, sections and overburden thickness map which were used in the delineation of key hydrogeologic features like the topsoil, weathered basement, fractured basement and the fresh basement. Resistivity values range from 21 Ω -m to 798 Ω -m in the topsoil, 14 Ω -m to 209 Ω -m in the weathered basement, 51 Ω -m to 209 in the partially weathered/fractured basement and 312 Ω -m to ∞ within the fresh basement. Layer thickness values also vary from 0.3 m to 6.1 m in the topsoil and 0.9 m to 28.6 m in the weathered basement. The depth to the resistive bedrock ranges from 0.3 m to 29.3 m across the study area.

The study revealed that greater part of Ilara-Mokin town is underlain by marginally thick overburden thus constituting shallow aquifer units with poor to marginal groundwater potential. Partially weathered/fractured basement were delineated in isolated cases with tendency for low to marginal groundwater yield around central and northeastern areas of the town. The results reasonably provide basic information that is expected to assist in the future development of groundwater resources in Ilara-Mokin.

KEYWORDS: electrical resistivity, hydrogeologic, geoelectric, bedrock and weathered basement

INTRODUCTION

The study area, Ilara-Mokin in Ondo State, Southwestern Nigeria, is a developing town situated on a basement terrain with inadequate potable water supply. The population of the town is increasing with establishment of a polytechnic in the community and the proximity of a Federal University. The populace depends mainly on groundwater resources for their domestic needs.

The electrical resistivity method is one of the most popular of the several non-invasive geophysical prospecting methods commonly used for groundwater studies (Zohdy, 1969; Flathe, 1970; Verma et al, 1980; De Beer and Blume, 1985; Olayinka and Barker 1990; Yang et al, 1994; Moller et al, 1998; Omosuyi et al, 2003; Ekwe et al, 2006; Oladapo and Akintorinwa, 2007). The electrical resistivity is a physical property of rocks and soils most affected by the presence of water. Variation in groundwater chemistry may also affect the electrical properties (Mota, et al., 2004). However, groundwater investigations in basement complex areas are often more difficult, as wide variations of aquifer parameters characterize the groundwater regime. Spatial variations of these characteristics are attributable to, among other causes, tectonism and degree of weathering of the basement rocks (Barker *et al.*, 2001). The Schlumberger vertical electrical sounding adopted in this study is popular for determining the resistivity variation with depth. Beeson and Jones (1988), Olayinka and Barker (1990), Hazell et al. (1988 and 1992), Barker et al. (1992), Carruthers and Smith (1992) and Olayinka

and Olorunfemi, (1992) have demonstrated the use of electrical resistivity method for siting wells and boreholes in crystalline basement terrain.

In this study, a hydrogeophysical evaluation of the area around Ilara-Mokin was carried out. The study was undertaken to determine the geoelectric parameters in form of layer resistivities and thicknesses of the superficial/overburden materials overlying the basement bedrock and the structural framework of the bedrock. The geoelectric parameters were used to generate geoelectric sections and maps.

Description of Study Area

Ilara-Mokin is located along Ilesha-Akure motorway and it is situated about 5 kilometers west of Akure metropolis. The town is situated within latitudes N07° 21' 16" and N07° 22' 20" and longitudes E005° 05' 58" and E005° 07' 12". There are also other minor roads that connect Ilara-Mokin to other rural towns and villages around it. The towns and villages around Ilara-Mokin include Igbaraoke, Ijare, Isharun, Ipogun, Ikota and Ipinsa.

Geology and Geomorphology

Ilara-Mokin is underlain by rocks of the Precambrian Basement Complex of Southwestern Nigeria (Figure 1) (Rahaman, 1976). The lithological units include variably migmatized biotite-hornblende-gneiss with intercalated amphibolite. Low lying outcrops of migmatite-gneiss complex are situated on the western and northeastern parts of the town while boulders of amphibolites/charnockite rocks are located in the central and north central areas of the town.

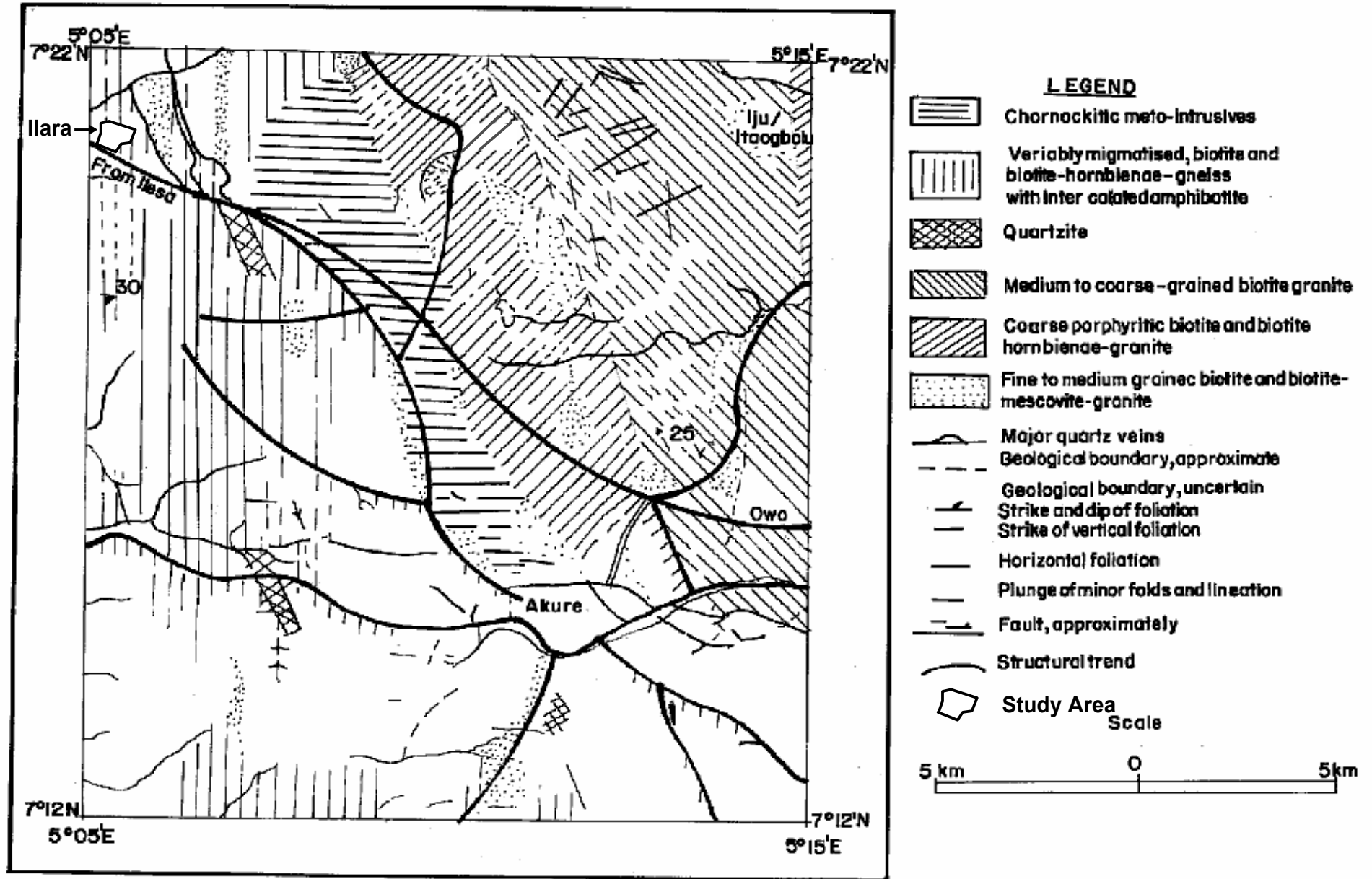


Fig. 1: Geological map of Akure environs showing the study area.

The study area is situated on gently undulating terrain with elevation between 336m and 350m above mean sea level. The region which lies within the tropical rainforest of Nigeria is characterized by two distinct seasons (wet from March to October and dry from November to February). The annual mean rainfall is about 1800mm. The annual mean temperature ranges between 24°C and 27°C.

Hydrogeology

Regolith and fractured basement generally occur in a typical basement terrain (Odusanya and Amadi, 1990). In tropical and equatorial regions, weathering processes create superficial layer with varying degree of porosity and permeability. Studies have shown that the unconsolidated overburden could constitute reliable aquifer if significantly thick (Satpathy and Kanungo, 1976, Offodile, 1983; Olorunfemi and Olorunniwo, 1985; Dan-Hassan and Olorunfemi, 1999; Bala and Ike, 2001). Also the concealed basement rocks may contain highly faulted and folded area, incipient

joints and fracture systems derived from multiple tectonic events they have experienced. These structures may house abundant groundwater in a typical basement setting. Detection and delineation of such structural features may facilitate the location of groundwater prospect zones (Omosuyi et al., 2003).

MATERIALS AND METHOD OF STUDY

Field data acquisition was undertaken along existing road paths using ABEM SAS 1000 Terrameter. Forty-one (41) vertical electrical sounding (VES) locations were occupied within the town (Fig. 2) utilizing the schlumberger electrode configuration. Electrode spacing (AB/2) was varied from 1.0 m to 100 m. The VES data were utilized in generating field curves. The curves were interpreted using partial curve matching technique. The geoelectric parameters obtained from manual interpretation of each VES curve were refined using the software algorithm RESIST version 1.0 (Vander Velpen, 1988).

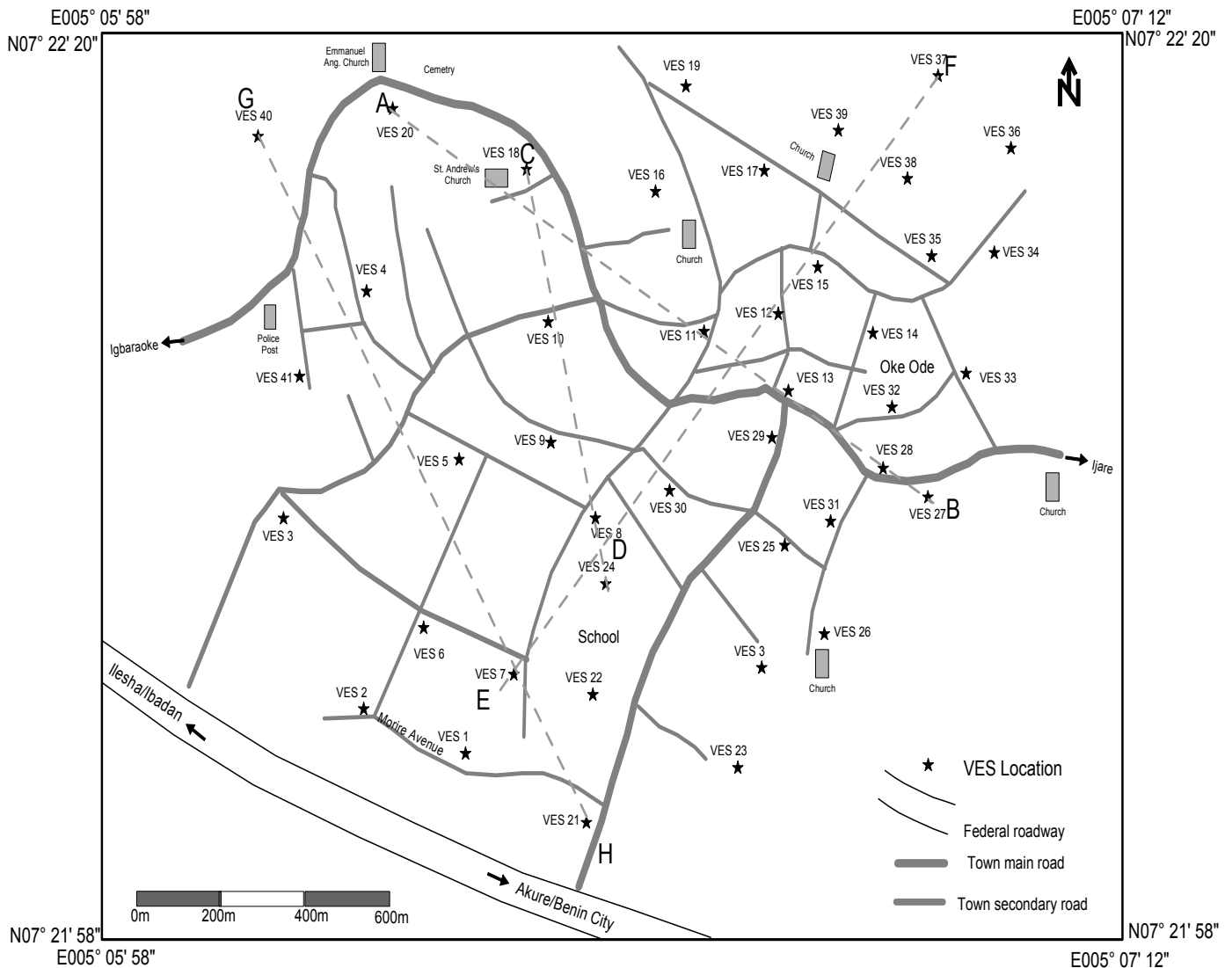


Fig. 2: Layout map of Ilara-Mokin showing VES locations

RESULTS AND DISCUSSION

The results of the study are presented as sounding curves, geoelectric sections and overburden thickness map. The curve types obtained from the study area are the H, A, K, HK, HA, QH and HKH type. The HKH curve type in a typical basement environment in many instances, indicates fracturing and presents favourable zones for groundwater abstraction (Oladapo

et al., 2004). The A-type curves are characterized by a steady rise in resistivity profile from topsoil to the bedrock while the intermediate layer in the H-type is commonly water saturated and is often characterized by low resistivity, high porosity, low specific yield and low permeability (Jones, 1985; Olayinka and Olorunfemi, 1992). The typical VES curves obtained from the study are presented in Figure 3

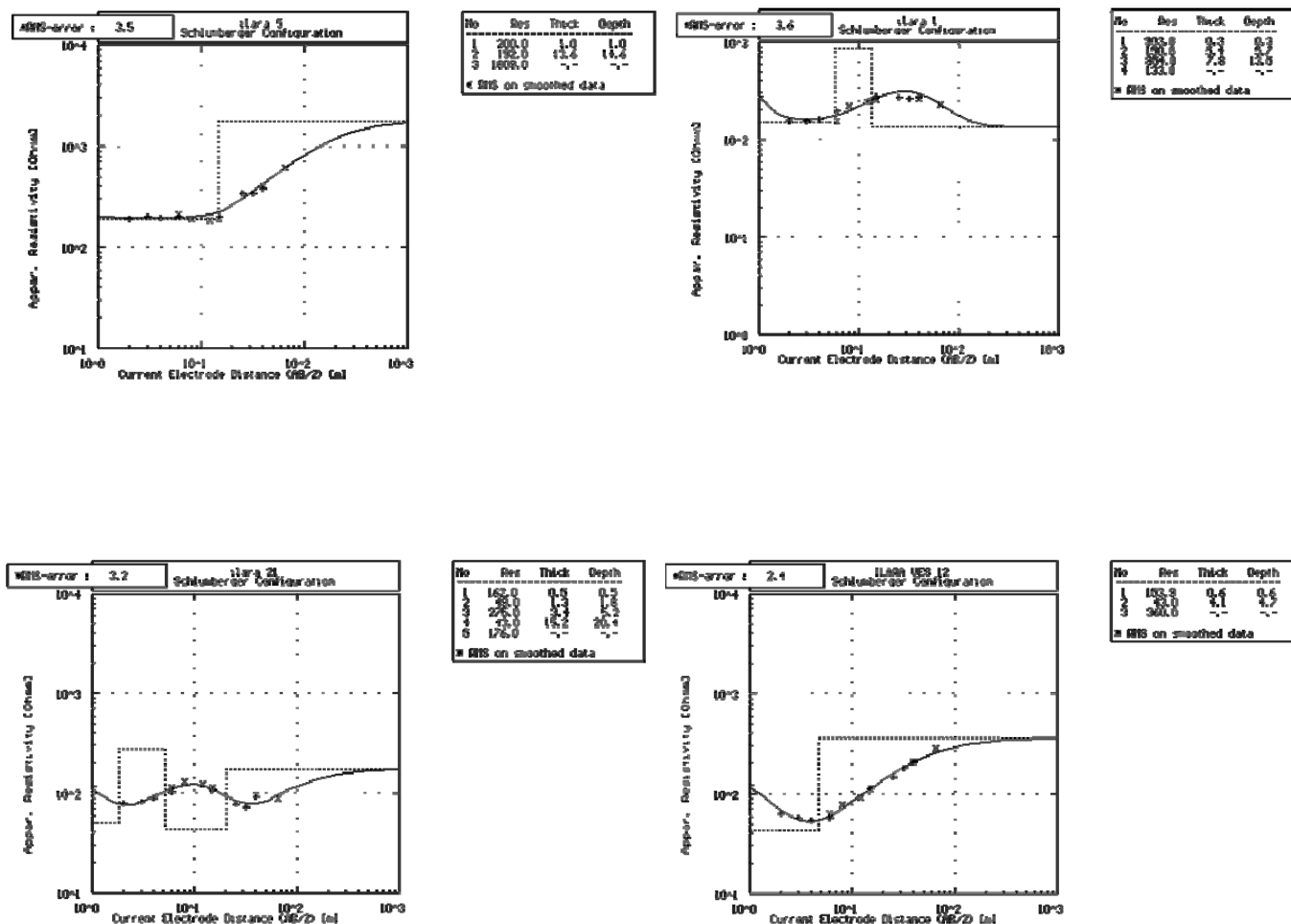


Fig. 3: Typical sounding curves obtained from Ilara-Mokin

The first order parameters obtained in form of layer thicknesses and resistivity values from the interpretation of the field curves (see Table 1) were utilized in generating geoelectric sections and overburden thickness map. The geoelectric sections taken along four directions (A-B, C-D, E-F and G-H in Figure 2) showed that four subsurface geologic layers consisting of topsoil, weathered basement, fractured basement and fresh basement underlie Ilara-Mokin. The section along profile A-B is about 1300 m long and connects VES 20, 18, 11, 13, 28 and 27 along NW-SE azimuth (Fig. 4). The topsoil resistivity values range from 27 Ω-m to 798 Ω-m. The low resistivity (<100 Ω-m) is characteristic of clay while the fairly high resistivity values (>100 Ω-m) may typify sandy clay, clayey sand

and laterite. Topsoil thickness ranges from 0.4 m to 1.0 m along this section.

The second layer (weathered basement) resistivity values vary from 14 Ω-m to 181 Ω-m. The electrical resistivity values of this layer are controlled by the degree of water saturation (Odusanya and Amadi, 1990) and also degree of shaliness. Significant saturation may induce reduction in resistivity. The thickness of the second layer varies from 1.4 m to 12.9 m.

The fresh basement resistivity varies from 361 Ω-m to ∞. VES 13 exhibits the thickest overburden (13.3 m) within the section. However the weathered materials are characterized by low resistivity (44 Ω-m) indicative of clay. Thus, poor hydrogeoelectric characteristics exist along the section.

Table 1: Summary of Results obtained from Ilara-mokin Geoelectric Study

VES No	Location Description	Depths (m) $D_1/D_2/.....D_{n-1}$	Resistivity Values ρ_a (Ω -m) $\rho_1/\rho_2/...../\rho_n$
1	Morire Avenue	0.7/2.0/17.3	337/94/307/173
2	Undeveloped Area	6.1/28.2	268/1905/603
3	Hospital Road	2.7/9.5	44/119/ ∞
4	St. John Pry Sch/Alafiatayo Str	1.1/2.8/21.1	102/47/445/72
5	Iloro Street	0.9/14.7	200/193/1868
6	Klova Street	3.9/5.3	179/165/ ∞
7	Klova Street/Olorunfemi Str	1.0/10.1/18.7	62/363/209/ ∞
8	Iloro/Olorunfemi Str Junction	0.9/2.2	91/61/ ∞
9	Ifelodun Street	0.4/3.2	144/31/312
10	Hospital Road	0.3	90/ ∞
11	Christ Love Hosp. Odo Igbeyin	0.4/2.9	55/14/361
12	Opokiti Street	0.6/4.7	154/43/360
13	Market	0.4/13.3	140/44/ ∞
14	Ajigunse Street	9.2	51/ ∞
15	Oke Ode	0.5/15.0	141/63/ ∞
16	St Michael Anglican Church	0.8/3.4	234/15/ ∞
17	Araromi Street	0.9/6.1/15.6	21/78/32/ ∞
18	St Andrew Anglican Pry School	0.5/1.9	798/19/ ∞
19	Risemola Farm	0.6/9.3	170/74/ ∞
20	Emmanuel Ang Pry Sch Ayede	1.0/7.2	233/181/ ∞
21	United Bank for Africa	0.6/1.7/5.0/29.3	153/42/285/49/366
22	Muslim Primary School	0.7/3.1	203/65/ ∞
23	Ajiluyi Street	0.7/2.9	135/28/ ∞
24	Iloro Street	1.6/4.1	66/47/458
25	Oke Peti	1.8/15.3	80/29/ ∞
26	Oke Peti	0.9/12.0	107/418/2605
27	Oke Ode	0.8/4.6	116/39/1292
28	Oke Ode	0.6/8.1	27/24/ ∞
29	Mokin Street	0.6/5.5	93/27/ ∞
30	Ifelodun Street	1.1/7.9	28/60/ ∞
31	Oke Eruku Street	0.8/3.1	54/74/ ∞
32	Oke Ode Street	0.5/1.6/3.8/10.4	92/24/81/23/ ∞
33	Oke Ode Street	1.1/9.9	58/38/ ∞
34	Oke Ode Street	2.0/13.7	30/56/ ∞
35	Oke Ode Street	0.9/2.9	32/73/ ∞
36	Iro Street	0.6/11.0	151/43/474
37	Oke Iro Street	0.4/7.2	84/40/ ∞
38	Oke Iro Street	0.7/3.1	53/39/713
39	Araromi Street	0.4/1.4	412/37/ ∞
40	West of cemetery (Hand-pump well)	1.0/18.7	287/460/31
41	Adekola Street/Abebi Qtrs	0.9/14.6	147/637/1134

The section along profile C-D which is 470 m long (Figure 5) comprises VES 18, 10, 9, 8 and 24 along the NNW-SSE azimuth. Topsoil resistivity values along the

section range from 61 Ω -m to 798 Ω -m with thickness varying between 0.3 m and 1.6 m.

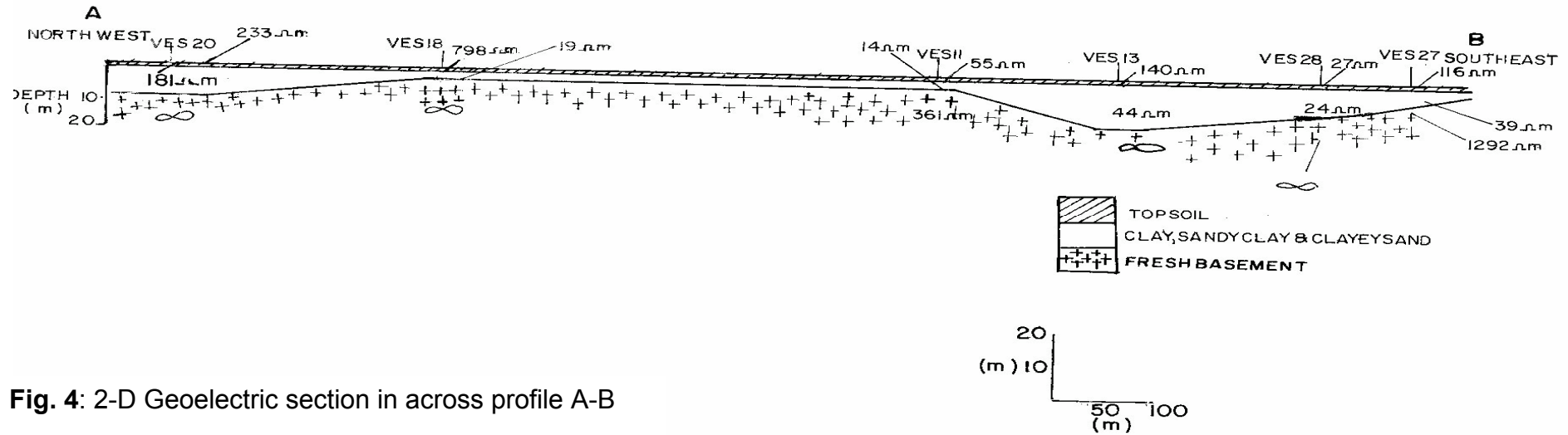


Fig. 4: 2-D Goelectric section in across profile A-B

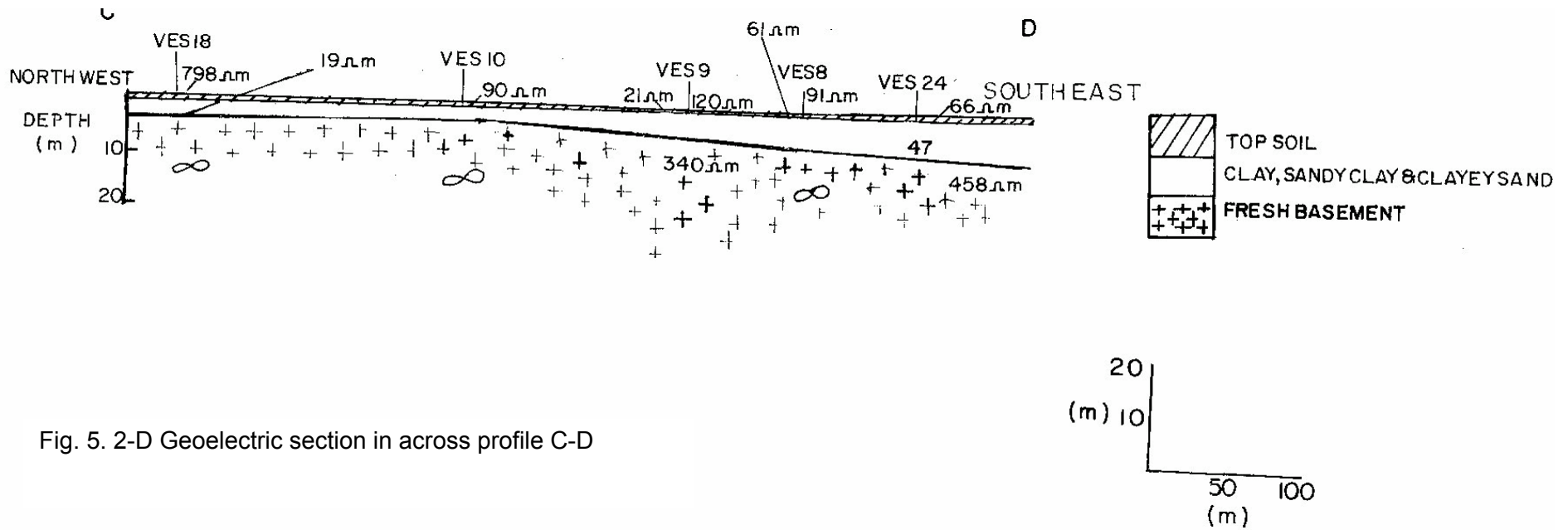


Fig. 5: 2-D Goelectric section in across profile C-D

The weathered basement resistivity values vary from 19 Ω-m to 61 Ω-m while the thickness of the layer varies from 0 m to 2.5 m. The fresh basement resistivity varies from 340 Ω-m to ∞. The geoelectric characteristics along the C-D section present very poor hydrogeological setting.

The section along profile E-F is presented in Figure 6. This section comprises VES 7, 24, 30, 12, 15, 38 and 37 along SW-NE azimuth. Topsoil resistivity values in the E-F section range from 28 Ω-m to 154 Ω-m while layer thickness ranges from 0.4 m to 1.6 m.

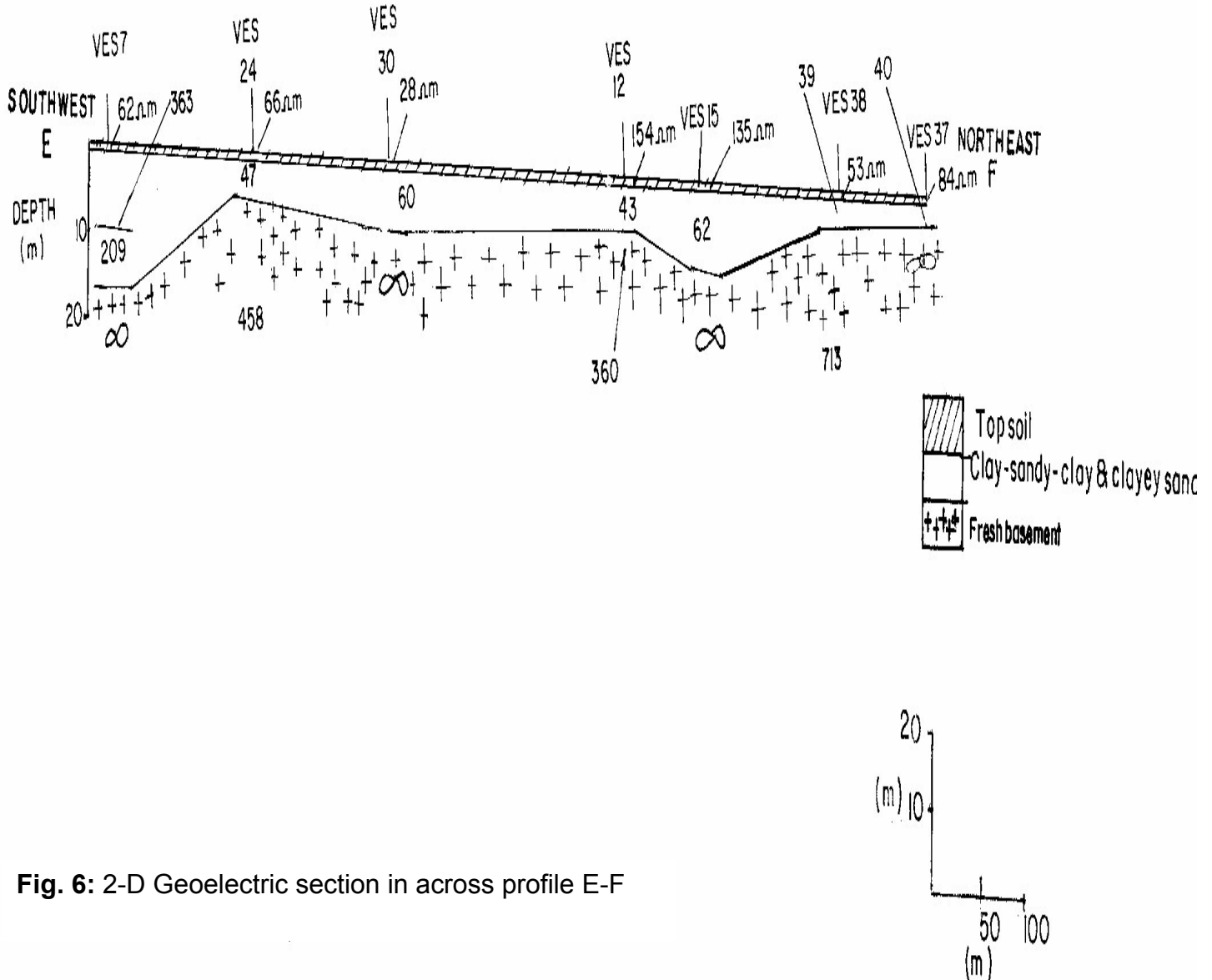


Fig. 6: 2-D Geoelectric section in across profile E-F

The second layer constitutes the weathered basement and is characterized by resistivity values ranging from 39 Ω-m to 363 Ω-m. The thickness of the weathered layer varies from 2.4 m to 16.7 m. The fresh basement has resistivity values ranging from 360 Ω-m to ∞. The weathered materials underlying E-F section are fairly thin and characterized by low resistivity values that may not facilitate sufficient groundwater accumulation.

The section along profile G-H which is presented in Figure 7 comprises VES 40, 4, 5, 7 and 21 and is oriented along NW-SE azimuth. The topsoil resistivity values in the section range from 62 Ω-m to 287 Ω-m

with layer thickness ranging between 0.5 m and 1.3 m. The second layer which is the weathered basement has resistivity values varying from 42 Ω-m to 193 Ω-m. The thickness of the weathered layer varies between 0 m at VES 40 and 13.8 m at VES 5. Fracture bedrock columns were observed at VES 7 and VES 21. The fractured basement resistivity values range from 50 Ω-m to 209 Ω-m while the fresh basement has resistivity values in excess of 366 Ω-m. The combination of weathered and fractured basement beneath VES 7 and 21 in this section constitute relatively deep but clayey aquifer units that may enhance groundwater accumulation.

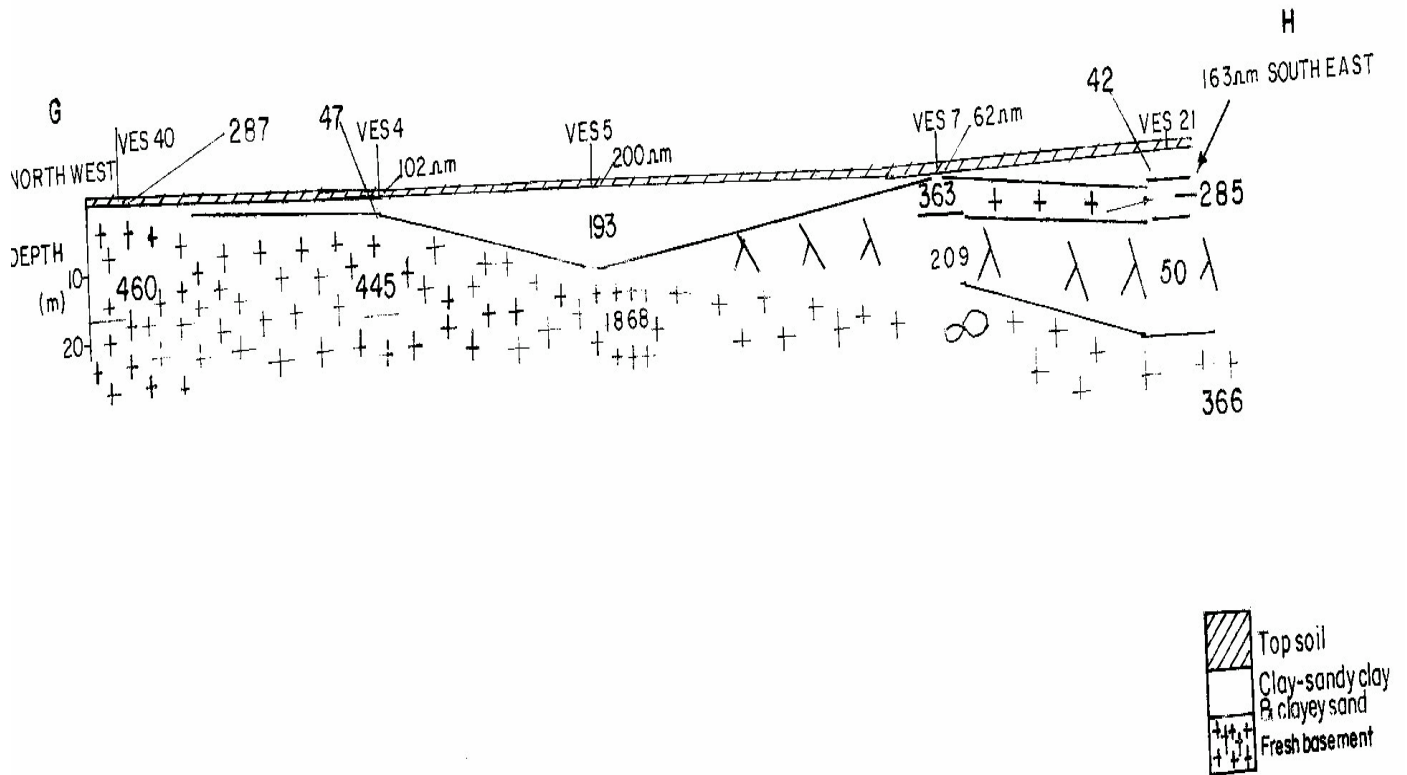


Fig. 7: 2-D Geoelectric section in across profile G-H

Overburden Thickness map

The overburden thickness map of the study area is presented in Figure 8. Thickness of the overburden in Ilara-Mokin varies between 0.3 m at VES 10 (northern flank of Hospital Road) and 17.3 m at VES 17 (Araromi Street). The map was utilized for hydrogeologic characterization of the study area based on overburden thickness values. Thus the town is classified hydrogeologically into poor (thickness < 10.0 m) and marginal (thickness > 10.0 m). The map shows that Ilara-Mokin is generally underlain by thin weathered basement rocks. Areas of thin overburden (central, northwestern, western and eastern flanks) are defined by blank background in the map. Areas of relatively thick overburden are defined by vector pattern. The marginal thickness areas which are in isolated patterns are situated on the central and northeastern areas of the town.

Groundwater Potential Evaluation

The groundwater potential of Ilara-Mokin was evaluated based on the geoelectric sections (Figures 4 to 7) and overburden thickness map (Figure 8) generated from the characteristic geoelectric parameters, obtained from the VES interpretation results. The map as hatched presents local groundwater prospect of the town classified into poor and marginal potentials. The map shows that poor groundwater potential zones (areas of thin overburden) are ubiquitous in the town (blank pattern areas of figure 8). The works of Okhue and Olorunfemi, (1991) and Bala and Ike, (2001) indicated that areas underlain by thick and sandy (relatively permeable) overburden materials are high groundwater potential zones. Such high groundwater potential zones are however absent in Ilara-Mokin.

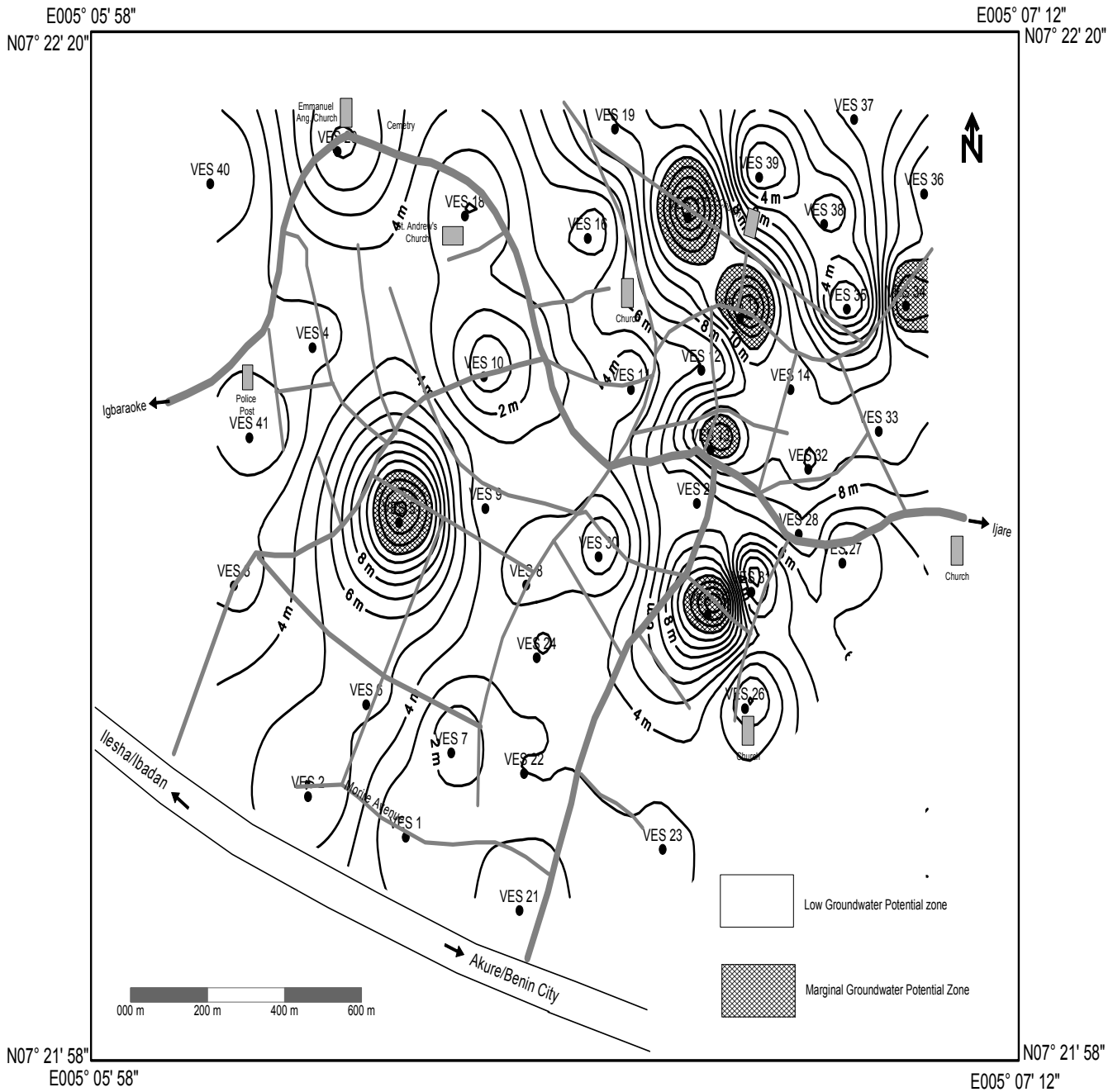


Fig. 8: Overburden thickness map of Ilara-Mokin

CONCLUSION

In this study, the hydrogeologic evaluation of Ilara-Mokin has been undertaken. The study revealed that marginal groundwater potential zones only exist in isolated structures around Iloro Street in the central area and Oke Ode, Araromi, Oke Peti and Iro in the northeastern area of the town. Unfavourable hydrogeologic setting is prevalent

in Ilara-Mokin. The VES stations underlain by marginal groundwater potential zones are envisaged to be marginally viable for groundwater development. No area of Ilara-Mokin can be classified as medium or high groundwater potential zone. The zones delineated as

marginal groundwater potential zones in this study should therefore constitute priority areas for groundwater development in Ilara-Mokin.

REFERENCES

Bala, A.N and Ike, E. C., 2001. The aquifer of the crystalline basement rocks in Gusau area, North-western Nigeria. *Journal of Mining and Geology*, 37(2): 177-184.

Barker, R, RAO T V and Thangarajan, M. 2001. Delineation of contaminant zone through electrical imaging technique; *Curr. Sci.* 81(3):7y 277-283.

- Barker, R. D., White, C. C. and Houston, J. F. T., 1992. Borehole Siting in an African Accelerated Drought Relief Project. In: E. P. Wight and W. G. Burgess, (eds), *The Hydrogeology of Crystalline Basement Aquifers in Africa*. Geological Society Special Publication, 66: 183-201.
- Beeson, S. and Jones, C. R. C., 1988. The Combined EMT/VES Geophysical Method for Sighting Boreholes. *Ground Water*, vol. 26 (1):54-63.
- Carruthers, R. M. and Smith, I. F., 1992. The Use of Ground Electrical Methods for Siting Water Supply Boreholes in Shallow Crystalline Basement Terrains. In: E. P. Wight and W. G. Burgess, (eds), *The Hydrogeology of Crystalline Basement Aquifers in Africa*. Geological Society Special Publication, 66: 203-220.
- Dan-Hassan, M. A. and Olorunfemi, M. O., 1999. Hydrogeophysical investigation of a basement terrain in the north central part of Kaduna State Nigeria. *Journal of Mining and Geology*, 35 (2): 189 - 206.
- De beer, J. H. and Blume J., 1985. Geophysical and Hydrogeological investigations of the Ground-water resources of Western Hereroland, South West Africa/Namibia *Trans Geol. Soc. S. Africa*, 88: 483 – 493
- Ekwe, A.C. Onu N.N. and Onuoha K. M., 2006. Estimation of aquifer hydraulic characteristics from electrical sounding data: the case of middle Imo River basin aquifers, South- eastern Nigeria. *Journal of Spatial Hydrology*, 6 (2): 121-132
- Flathe, H., 1970. Interpretation of Geoelectrical Resistivity Measurements for Solving Hydrogeological Problems. In Morely, E. W. (ed.), *Mining and Groundwater Geophysics: Geological Survey of Canada Economic Geological Report*, no. 26: 580-597.
- Hazell, J. R. T., Cratchley, C. R. and Jones, C. R. C., 1992. The hydrogeology of Crystalline Aquifers in Northern Nigeria and Geophysical Techniques used in their Exploration. In: E. P. Wight and W. G. Burgess, (eds), *The Hydrogeology of Crystalline Basement Aquifers in Africa*. Geological Society Special Publication, No. 66, pp. 155-182.
- Hazell, J. R. T., Cratchley, C. R. and Preston, A. M., 1988. The Location of Aquifers in Crystalline Rocks and Alluvium in Northern Nigeria using Combined Electromagnetic and Resistivity Techniques. *Quarterly Journal of Engineering Geology*, 21: 159-175.
- Jones, M. J., 1985. The weathered zone aquifers of the basement complex areas of Africa. *Quarterly Journal of Engineering Geology*. Pp 35 – 46.
- Moller, I., Sorensen, K., and Christensen, N., 1998. DC - Resistivity Multi-Electrode Profiling in Hydrogeological Investigations: A Comparative Study of the Pulled-Array Continuous Electrical Sounding Method and a Multi-Electrode Method with Fixed Electrodes. *Symposium on the Application of Geophysics to Environmental and Engineering Problems*, pp. 869-874.
- Mota, R., Monteiro-Santos, F. A., Mateus, A., Marques, F. O., Gonclave, M. A. and Figuerias Amaral, J. H., 2004. Granite fracturing and incipient pollution beneath recent landfill facilities as detected by geoelectric surveys. *Journal Applied Geophysics*. 57: 11-22
- Odusanya, B.O. and Amadi, U., 1999. An empirical resistivity model for predicting shallow groundwater occurrence in the basement complex. *Water Resource Journal of Nigeria Association of Hydrogeology*, 2: 77-87
- Offodile, M. E., 1983. The occurrence and Exploration of Groundwater in Nigeria Basement rocks, *J. Min. Geol.* 20 (1 and 2): 131-146.
- Oladapo, M. I., Mohammed, M. Z., Adeoye, O. O. and Adetola, B. A., 2004. Geoelectric investigation of the Ondo State Housing Corporation Estate Ijapo Akure, Southwestern Nigeria. *Journal of Mining and Geology*. Vol. 40(1): 41- 48
- Oladapo, M. I. and Akintorinwa, O. J., 2007. Hydrogeophysical Study of Ogbese Southwestern Nigeria *Global Journal of Pure and Applied Sciences*. 13(1): 55 - 61
- Olayinka, A. and Barker, R., 1990. Borehole Siting in Crystalline Basement Areas of Nigeria with a Microprocessor Controlled Resistivity Traversing System. *Groundwater*, 28: 178-183.
- Olayinka, A. I. and Olorunfemi, M. O., 1992. Determination of geoelectrical characteristics in Okene area and implications for borehole siting. *Journal of Mining and Geology*, 28(2): 403 - 412.
- Olorunfemi, M.O. and Olorunniwo, M. A., 1985. Geoelectric parameters and aquifer characteristic of some parts of Southwestern Nigeria. *J.Min. Geol.*, 35 (2): 207-228
- Omosuyi, G.O., Ojo, J.S. and Enikanselu, P. A., 2003. Geophysical Investigation for groundwater around Obanla-Obakekere in Akure area within basement complex Southwestern Nigeria. *J. Min. Geol.* 39 (2): 109 -116.
- Rahaman, M. A., 1976. Review of the basement geology of southwestern Nigeria: In *Geology of Nigeria* (Kogbe, C. A. Ed). Elizabethan Publ. Co., Nigeria pp. 41-58.
- Satpathy, B. N. and Kanungo, B. N., 1976. Groundwater exploration in hard rock terrain- A case study. *Geophysical prospecting*, 24 (4): 725-763.
- Vander Velper, B.P.A., 1988. Resist version 1.0 M.Sc Research project, ITC, Delft, Netherlands.
- Verma, R.K., Rao, M. K. and Rao, C. V., 1980. Resistivity investigations for groundwater in metamorphic areas near Dhanbad, India. *Ground Water*, 18 (1): 46-55.
- Yang, C., Tong, L. and Jeng, L., 1994. Locating groundwater at selected sites by geoelectric methods: Annual Meeting Abstracts, Society of Exploration Geophysicists, 652-654.
- Zohdy, A. A. R., 1969. The Use of Schlumberger and Equatorial Soundings in Groundwater Investigations near El Paso, Texas. *Geophysics*, 34: 713-728.