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Full Length Research Paper

Hydrogeophysical Studies for the Delineation of Potential Groundwater Zones in Enugu State, Nigeria

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This report discusses the occurrence of groundwater in Enugu State, Nigeria, as indicated by results of 322 vertical electrical soundings(VES), supplemented by 123 well records. The project area lies within Longitudes 7° 6' E - 7° 54'E and Latitudes 5°56'N- 6 °52'N, and covers an area of about 7161km^2 over eight main geological formations. The thickness, lateral extent and transverse resistance of the aquiferous layers were determined by the electrical survey. Water table information from borehole records was used to construct regional maps of static water level depths and groundwater flow directions. The results show greater depth of the substratum in the central part of the study area as indicated by high transverse resistance and thickness of the aquiferous layers. Lower average values of these parameters were obtained in the southwestern and eastern parts of the study area. Specific discharge and average linear groundwater velocity follow similar trend, generally improving from the western and eastern parts to the central part of the study area. Regional maps of the various geoelectrical and hydrogeological parameters have been produced and the overall results have been used to delineate the study area into five groundwater potential zones for future development and choosing of drilling sites.

Keywords: Resistivity, Transverse resistance, Specific discharge, Velocity.

INTRODUCTION

Enugu state, lies between longitudes 7^0 6^1E and 7^0 54^1E and latitudes 5^0 56^1N and 6^0 52^1N in the Southeastern part of Nigeria, encompassing an area of about 7161km^2, with elevation ranging from 32.01m to 590.24m above mean sea level. Five states, Benue in the Northeast, Ebonyi in the East, Abia in the South, Anambra in the Southwest and Kogi in the Northwest, mark the boundaries of the area under study.(Figure 1).

In the last few decades,there has been an increase in the application hydrogeoelectrical techniques in the location of potential water bearing formations in many parts of the state. Many communities, private individuals and state government have carried out various borehole projects to find clean and safe drinking water.

This study is an integrated geoelectrical and hydrogeological groundwater resource mapping, aimed at establishing a hydrogeophysical database for Enugu state. The study would be helpful in understanding the characteristics of hydraulic head distribution, rech-arge and discharge and also enhance the success rate of future groundwater development in the state.

Physiography

The study area shows two major types of landforms which consists of a high relief central zone with undulating hills and ridges and the lowland area, (Figure 2). Both are related to the geology of the area.

The high relief zone is geologically associated with the outcrops of Ajali Sandstone and Nsukka Formation, while the eastern lowland zone is associated with outcrops of Asu River group, Eze Aku Shale group, Awgu/Ndeabor Shale group, Asata/Nkporo Shale group and parts of Mamu Formation. The western lowland zone is associated with outcrops of the Imo Formation. On the scarp face, slope failures, landslides, soil and gully erosion and slump features are common. . In general terms, the Ajali Sandstone usually underlies areas of height above 300m while the Nsukka Formation is cha-

Figure 1. Map of Nigeria Showing the location of the study area. (World Gazette, 2011)

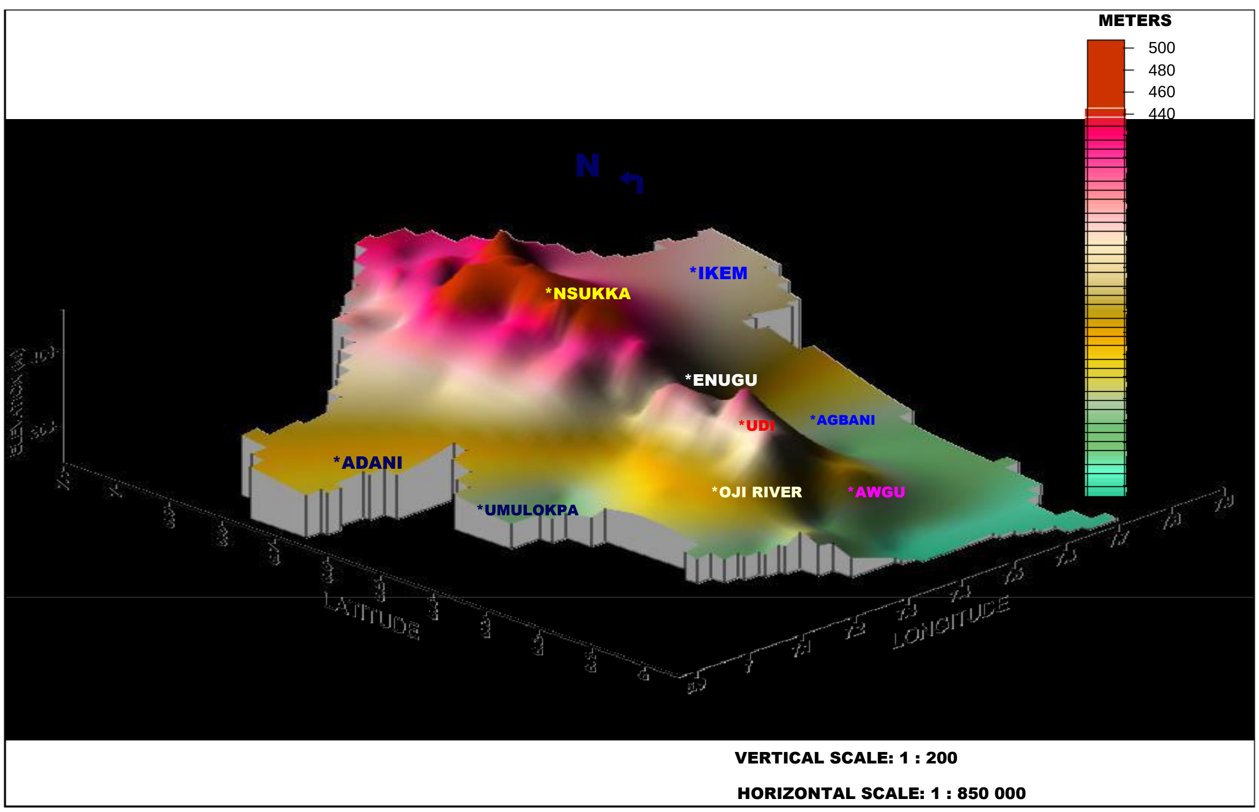

Figure 2. Surface map of the study area.

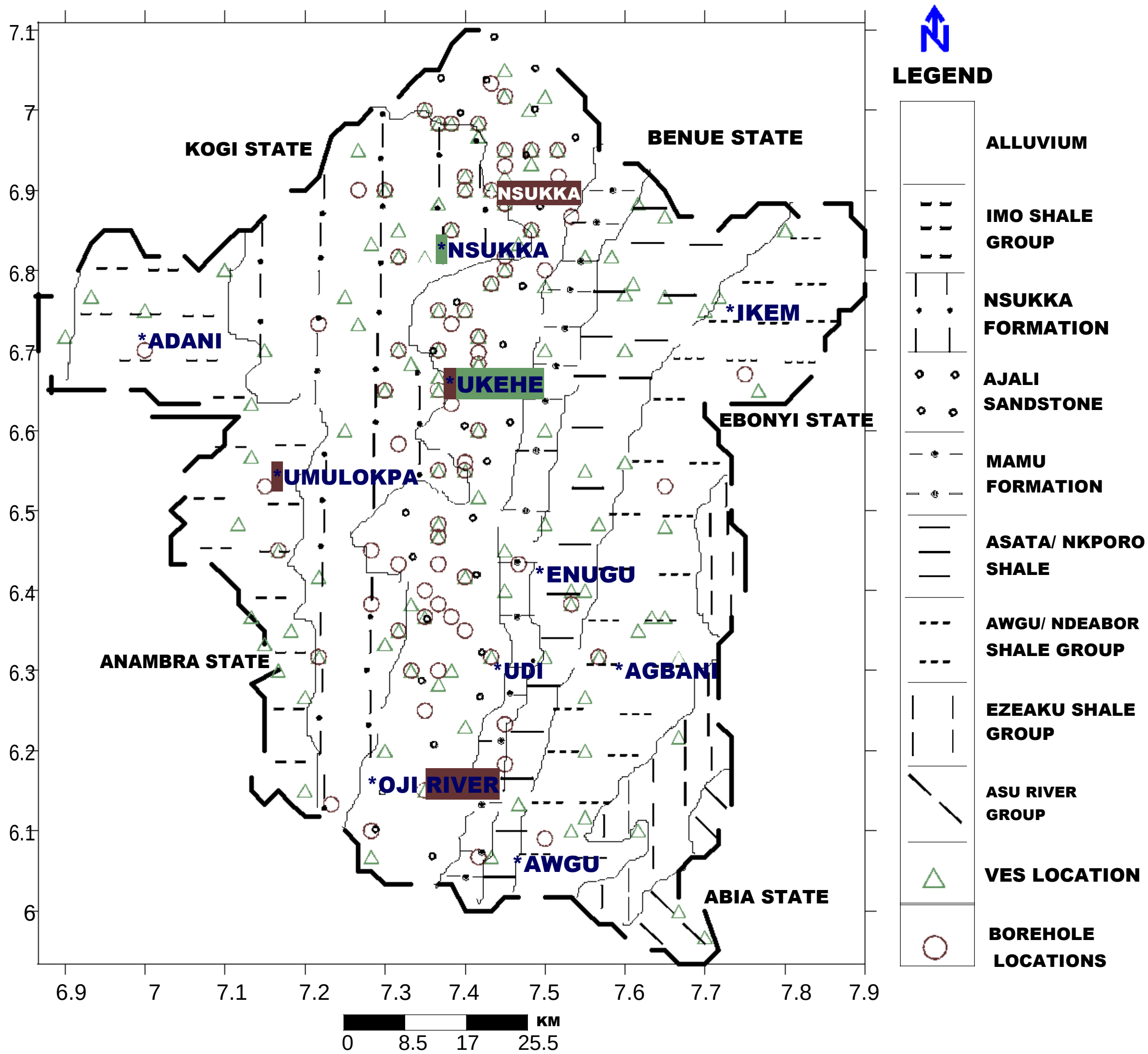

Figure 3. Geologic map of the study area showing VES and borehole locations

racterized by abundant residual hills.

Geology

The study area is underlain by the following geological formations (Figure 3), the Asu River Group, Eze Aku Shale group, Awgu/Ndeabor Shale group, Nkporo Shale, Mamu Formation, Ajali Formation, Nsukka Formation and Imo Formation.

The Asu River group is the earliest recorded marine sediments consisting of bluish grey to brown shale and sandy shale, fine-grained micaceous sandstones and dense blue limestone (De Swardt and Casey, 1963; Reyment, 1965).

The sediments of the Eze Aku formation consist of fossiliferous limestone and shale. The thickness varies, but may attain 1000m in places. The Awgu/Ndeaboh Formation is about 400 thick and consists of bluish grey, well-bedded shales, with subordinate calcareous sandstones and limestones (Kogbe, 1981). The Nkporo Formation comprises dark shales and mudstones, with occasional thin beds of sandy shale and sandstone and thickness of about 150m. The Owelli sandstone, Enugu Shale and Asata shales are lateral equivalents of the Nkporo Shale. The Owelli sandstone comprises medium to coarse-grained sandstones with pebble bands while the Enugu/Asata shales consists of soft dark grey shales and mudstones with occasional thick beds of white sandstones and sandy shales.

The Mamu Formation consist of fine to medium grained, white to grey sandstones, shaly sandstones, sandy shales, grey mudstones, shales and coals. The thickness is about 450m and it conformably overlies the Enugu shale.

The Ajali Formation, also known as False Bedded Sandstone, consists of thick friable, poorly sorted sandstones, typically white in colour but sometimes iron-stained. The thickness averages 300m and is often overlain by considerable thickness of red, earthy sands, formed by the weathering and ferruginization of the formation.

The Nsukka Formation lies conformably on the Ajali sandstone. The lithology is very similar to that of Mamu Formation and consists of an alternating succession of sandstone, dark shale and sandy-shale, with thin coal seams at various horizons. Eroded remnants of this formation constitute outliers and its thickness averages 250m.

The Imo Information consists dominantly of blue to dark grey shales, with occasional bands of clay – ironstone and subordinate thin sandstones. The formation includes thick sandstone units at several horizons and rests conformably on Nsukka Formation with a thickness of about 500m. Quaternary alluvial deposits overlie the Northwestern parts of the area. These areas are within the Anambra River flood plain and are generally less than 100m in altitude.

Hydrogeology

The hydrologic units in the study area include confined, semi-confined, unconfined, perched and fractured shale aquifers.

Confined conditions exist over the Ajali Sandstone in areas overlain by the Nsukka Formation and/or the Imo Formation, and in the Mamu Formation where the overlying Ajali Sandstone and Nsukka Formation are considerably reduced in thickness or eroded. Semi-confined situation exist in places and usually comprise interbedded thick sequence of sand (aquifer) and sandy clay or clayey-sand aquicludes. Various aquifers in this group occur in the upper to middle horizons of Ajali Sandstone and in the upper section of the Mamu Formation and constitute the partial recharge zones for the deeper – seated confined aquifers.(Egboka and Onyebueke, 1990; Akudinobi and Egboka, 1996). Unconfined aquifer units in the study area occur mostly in the Ajali Sandstone, and represent sections of the formation where the semi-permeable or impermeable cap beds have either been eroded or absent. The thickness of these aquifer units vary from shallow to deep in places. Perched aquifer conditions occur mostly in the lateritic/red earth cover over the Nsukka Formation and in the upper sandy units of the Nsukka Formation. The perched aquifer is generally thin and measurements in dug holes gave thickness values ranging from 3m to 8m with an average of about 4.6m (Uma, 2003).

Fractured and fissured shale aquifers exist mostly in the Awgu/Ndeabor and Enugu/Nkporo shale groups where recurrence fractures and weathering result in economic water yield in the upper unites of the shales.

METHODOLOGY

Data acquisition and interpretation

In the present study, a total of three hundred and twenty two vertical electrical soundings (VES) were carried out in one hundred and twenty six locations within the study area. (Figure 3). The Schlumberger electrode spreading was used with maximum current electrode separation ranging from 400m to 1.2km. Most of the soundings were conducted nearby existing boreholes for correlation purposes. The locations of the boreholes are also shown in Figure 3.

The initial interpretation of the VES data was accomplished using the conventional partial curve matching technique, with two-layer master curves in conjunction with auxiliary point diagrams (Orellana and Mooney, 1966; Koefoed, 1979; Keller and Frischknecht, 1966). From this, estimates of layer resistivities and thicknesses were obtained which served as starting points for computer-assisted interpretation. The computer program OFFIX, was used to interpret all the data sets obtained.

From the interpretation of the resistivity data, it was possible to compute, for every VES station, the longitudinal conductance.

S = $HI/\mathrm{L}I$ -- -- (1)

and the transverse resistance,

R = $HI\mathrm{L}I$ -- -- (2)

where hi and LI are layer thickness and resistivity respectively (Maillet, 1947)

RESULTS AND DISCUSSIONS

Maps of aquifer thickness, transverse resistance, water level elevation, and groundwater flow directions have been constructed using the results of the resistivity soundings interpretation and borehole data.

The study area show highly variable aquifer thickness (Figure 4). In the central part, underlain by the Ajali and Nsukka Formations, the thickness range between 45.12m and 206.17m with an average value of 105.20m. Depths to the top of potential aquifers range from 12m to 40m in these areas. In the southwestern part of the study area underlain mostly by the Imo Formation, aquifer thickn-ess range between 31.92m and 204.18m with an average

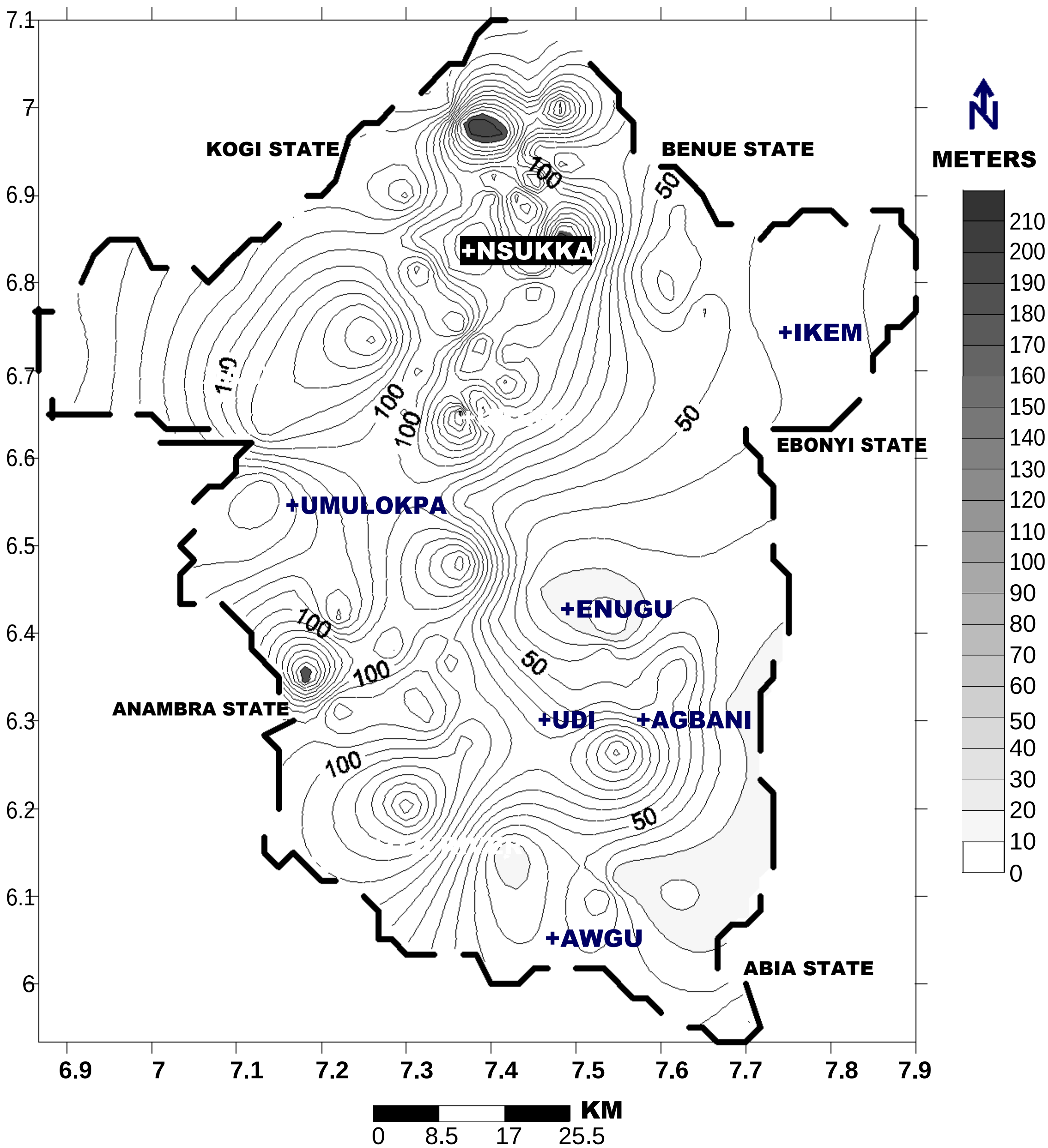

Figure 4. Iisopach map of the aquiferous layer

value of 94.11m, while the range is between 4.3m and 71.2m with an average of 33.78m in the eastern part underlain by the Eze Aku/Awgu Ndeaboh/Nkporo Formations. Potential aquifers occur at depths ranging from 30 to 56m in the southwestern part and from 2 to 24m in the eastern part of the study area.

The distribution of the aquifer raw transverse resistance (TR) computed from the resistivity soun-ding interpretation for the entire area of study is shown in Figure5.

Maximum transverse resistance values were observed in the central portion (Nsukka-Ukehe-Oji River axis) of the study area, underlain by the Ajali and Nsukka Formations, while minimum transverse resistance values were observed in the eastern part of the study area. Based upon the transverse resistance data, the area can be classified into the following five classes of ground water development prospects.

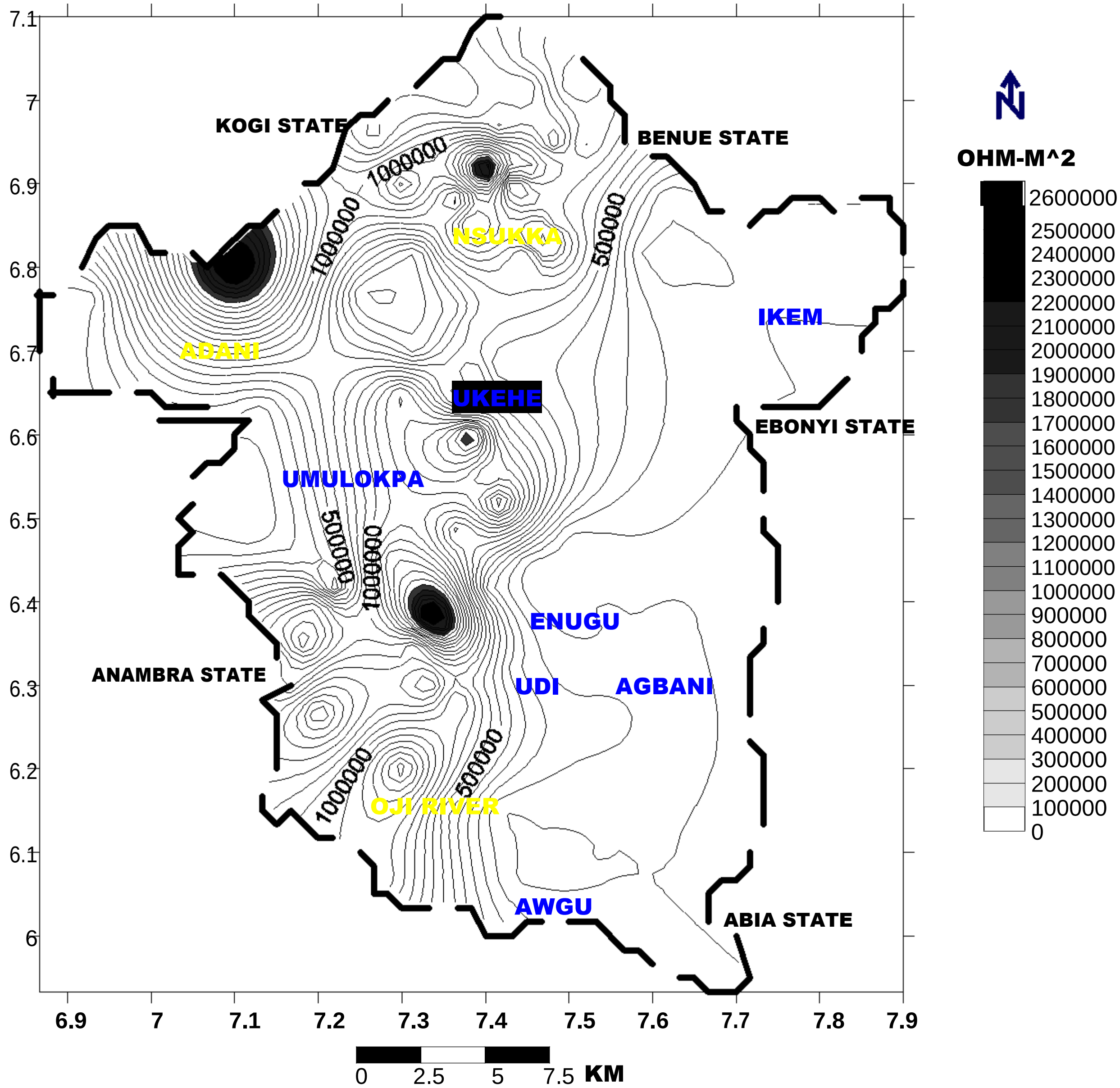

Figure 5. Transverse resistance map of the study area

Transverse Resistance (TR) (ohm-m^2) groundwater development class

TR < 200 000	very low
200000 < TR < 400000	low
400000 < TR < 600000	medium
600000 < TR <1000000	high
TR > 1000000	very high

The values of TR less than 200000 Ohm-m^2 do not indicate altogether absence of aquifer but may imply either inadequate thickness of aquifer or highly mixed finer sediments which poses serious well development problem. The higher limits of TR that is greater than 1000000 ohm-m^2 also need to be fixed in consonance with the local geological and hydrogeological conditions.

Well records (Figure 6) indicate depth to water ranging from 34m at Ngwo to over 220m at Ede-Oballa in areas underlain by Ajli/Nsukka formations (Figure 3) There is also a correlation between depth to water table and the thickness of the weathered red earth and lateritic overburden. Deeper water tables are found where thick layers of the weathered zone occur.

The north – south trending Enugu-Awgu escarpment (Figure 2) constitutes a liner barrier to surface and groundwater flow, causing a major surface / groundwater divide. This divide with the general directional tendency in

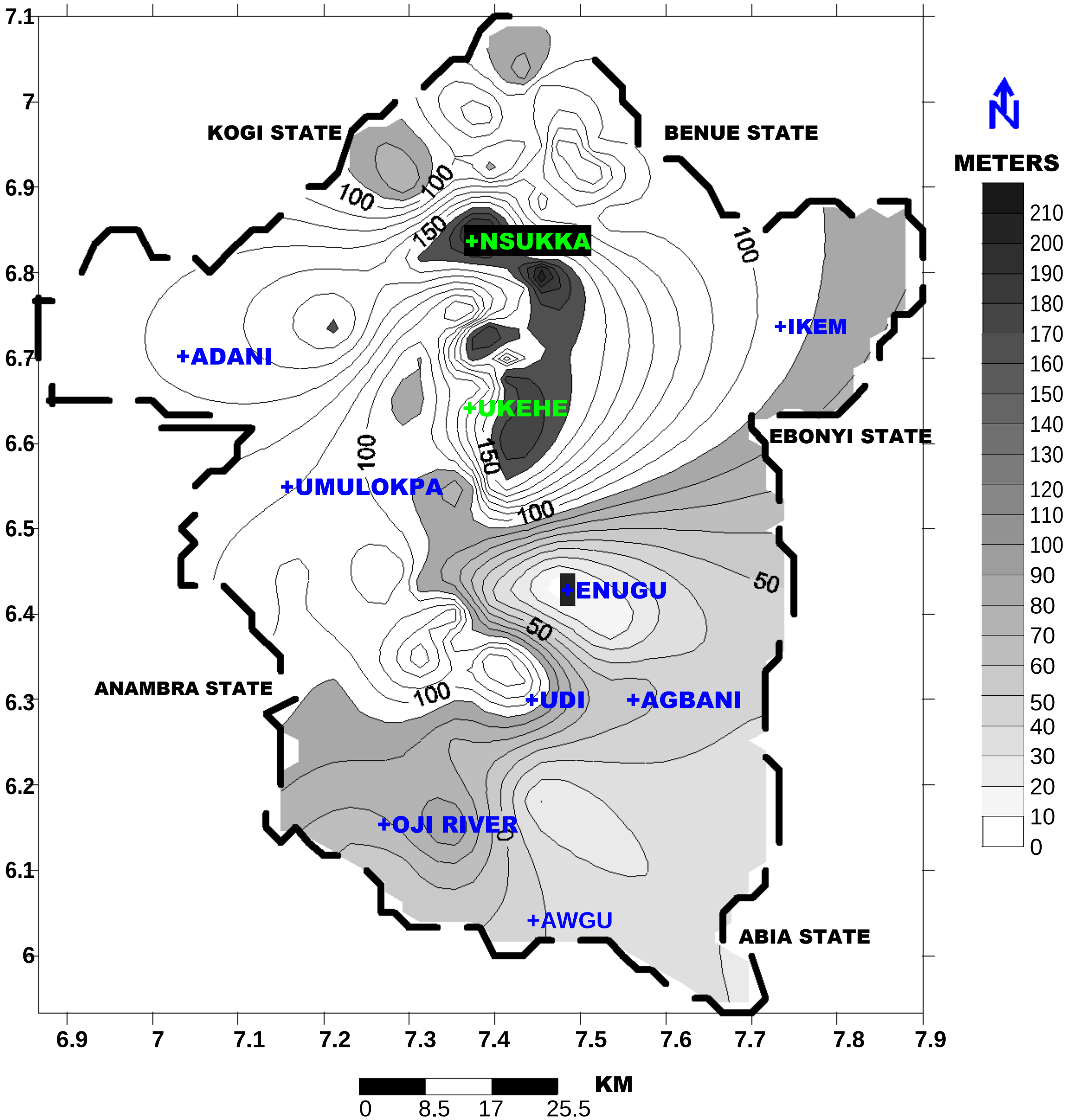

Figure 6. Static water level map of the study area.

flow pattern is shown in Figure 7. The divide allows flow in two principal directions, comprising easterly flow into the cross River Plains and westerly flow into the Anambra Basin. The flow field is further complicated by various minor divides due to flow patterns beneath the residual hills, mostly capped by resistant fractions of Nsukka formation. The groundwater divide is a subtle aquifer region, being prone to high seasonal drawdown and deep water table positions.

The estimated hydraulic gradient westward from the divide was 0.00163. Thus when multiplied by the average hydraulic conductivity k, for the, Ajali / Nsukka aquifer systems which was computed as 11.93 m/day (Ezeh 2011), gave a specific discharge (Darcy velocity) of 0.0194 m/day. For the Imo and Eze Aku / Awgu Ndeaboh/Nkporo Formations, the estimated hydraulic gradients were 0.00209 and 0.00235 respectively, whereas the average field hydraulic conductivities for the two areas were 4.41 m/day and 0.35 m/day respectively. This gave specific discharges of 0.0092 m/day and

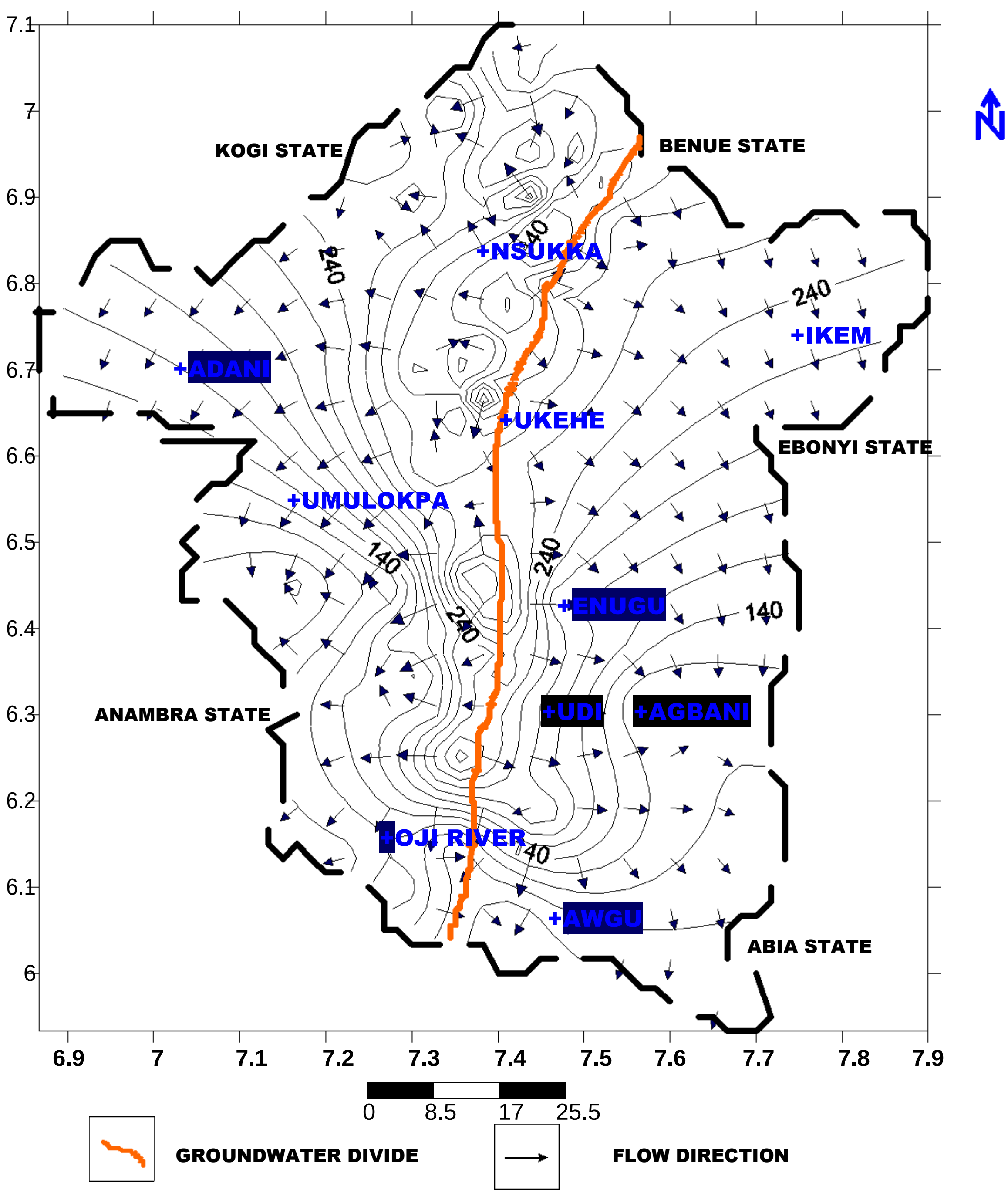

Figure 7. Groundwater flow directions

0.000823 m/day respectively.

The average porosity values for the Ajali/Nsukka, Imo and Eze Aku/Awgu Ndeaboh/Nkporo Formations had earlier been estimated as 25.12%, 29.92% and 59.9% respectively (Ezeh 2011. From these porosity values, the average linear groundwater velocities for these aquifer systems were estimated at 0.0773 m/day, 0.0308 m/day and 0.0038 m/day respectively.

Groundwater potential evaluation

The groundwater potential of the area is a function of Complex inter-relationship between geology, physiography, groundwater flow pattern, recharge and discharge processes.

The present evaluation of the groundwater potential of the study area has been based on aquifer geoelectrical

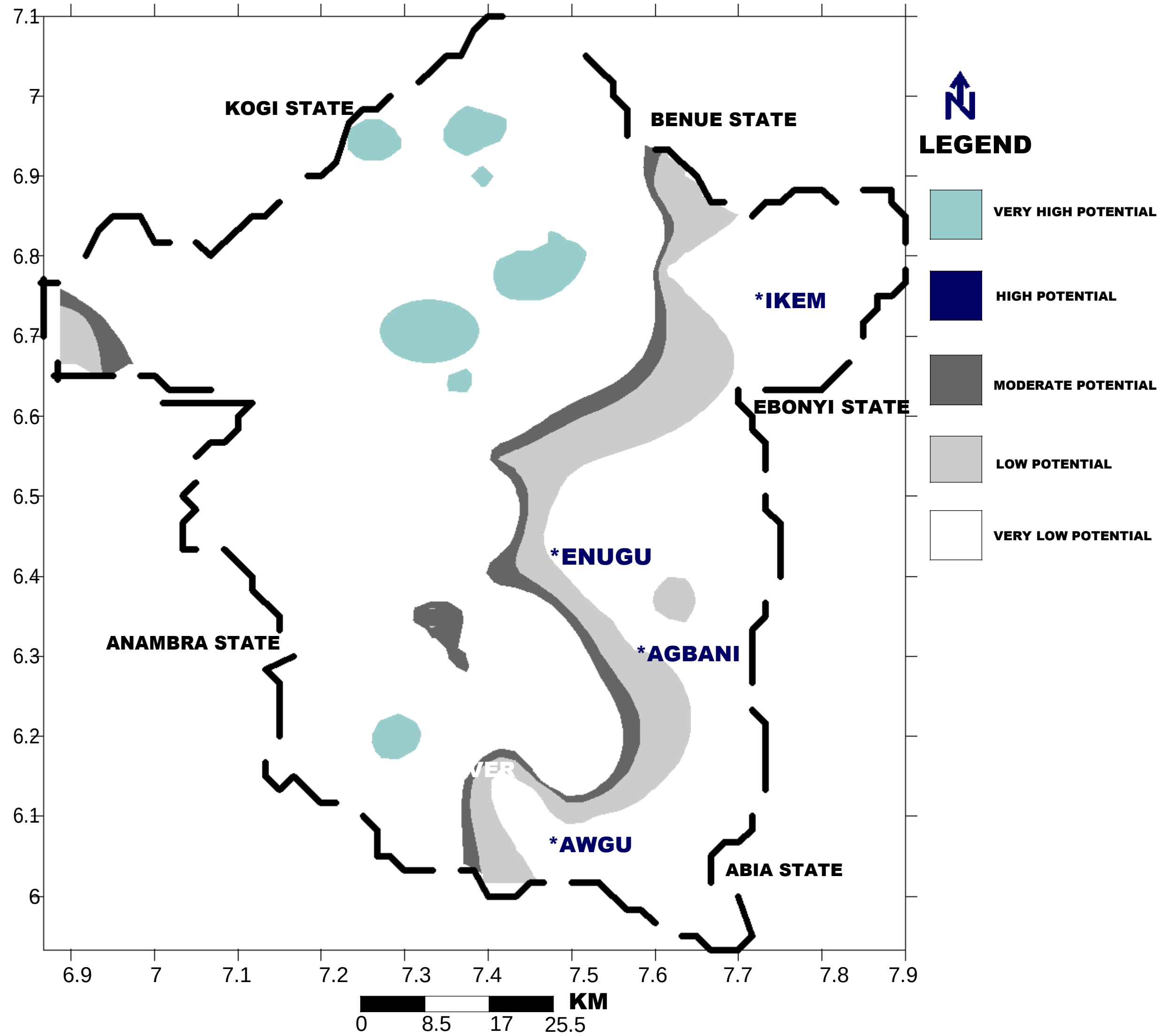

Figure 8. Groundwater potential map of the study area

parameters obtained from VES interpretation result and hydrogeological parameters. Taking into account the classification provided by Gheorghe (1978) and Freeze and Cherry (1979 p.60), the overall results have been used to delineate the study area to very high; high; moderate, low and very low zones for groundwater exploration/exploitation, with the central part (Figure 8) having the highest potential based on high transmissivity (Ezeh, 2011), high aquifer thickness, and high transverse resistance.

CONCLUSIONS

Regional maps of transverse resistance and thickness of the aquiferous layer derived from results obtained from the interpretation of VES data show that areas of high aquifer thickness generally correspond to areas of high transverse resistance and high percolation, and high transverse resistance is associated with high transmissivity in the study area. This implies that the iso-resistivity map derived from surface resistivity soundings can be used to forcast favourable areas for drilling of productive boreholes.

From water table contours (Figure 6), the water level depths increases towards the northern part and can be interpolated at any point within the study area with fair degree of accuracy.

A groundwater potential map of the study area has also been produced from all the parameters calculated. From all the methods of investigation used, it was found that areas within the central part would have high groundwater potentials when compared to the western and eastern parts of the area.

Refinements of various contour maps can be obtained by acquiring additional field data.

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