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# HYDROGEOPHYSICAL INVESTIGATION OF SOUTHERN ANAMBRA BASIN NIGERIA.

N. N. ONU and C. U. IBEZIM

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**ABSTRACT**

This study was undertaken to study the hydrogeophysical properties of the geologic formations that underlie the Southern Anambra Basin and to help in delineating sites for drilling of productive boreholes in the area. The North-south trending Awka-Orlu cuesta divides the study area into two relief features, viz; the western uplands underlain by the Eocene Ameki Formation and the Miocene Ogwashi-Asaba Formation and the eastern lowlands underlain by the Paleocene Imo shale Formation. Surface water is uncommon in the western uplands. Forty-two Schlumberger electrical soundings were carried in the study area to a maximum current electrode separation of 1200m. Eleven of the soundings were conducted besides boreholes already drilled in the area.

From the data, variations of the depth to the water table, longitudinal conductance, transverse resistance and the thickness of the aquiferous layer have been established. The analytical relationship between the Dar Zarrouk parameters and the hydraulic characteristics were used to assess the hydrogeological condition of the basin. These have led to inferences about the aquifer hydraulic conductivities and transmissivities and $K\partial$ product across the area. Consequently favourable areas have been suggested for future groundwater development in the area. Hydrochemical analysis carried out on the water samples indicates that the water samples are suitable for human consumption as well as for industrial uses.

**KEYWORDS:** Hydrogeophysical, Aquifer, Hydrochemical, Groundwater.

## INTRODUCTION

The progress of human societies has always been conditioned by the availability of water resources. The problem of water has nowadays acquired new dimensions due not only to the growth of population but also to the needs of agriculture and industry and to rapid urban growth. Water management has therefore become a key factor in economic and social development. A water crisis which affects both the quantity and quality of water resources is being felt in an ever-increasing number of localities; so, water supply problems are not new to southern Anambra Basin Nigeria where several boreholes have been drilled by both individuals, State and Federal Governments in order to supplement the surface water resources.

In the project area it is common to see shallow boreholes/wells which experience declining yield with time or even dry up at the peak of dry season. Evidently these shallow boreholes/wells never tapped the correct aquifer. Some of them tapped aquiclude, perched aquifer or even infiltrated water at near surface. Part of the problem was due to the fact that no geophysical or hydrogeological study was carried out prior to the sitting of the boreholes.

The proper utilization and management of ground water in any project area, either as a single source of supply or in conjunction with the surface water, requires its meaningful quantitative assessment before starting its full scale exploitation. For quantitative assessment of ground water potentials of an area, it is necessary to determine the basic formation characteristics of the aquifer system namely, hydraulic conductivity; transmissivity, and aquifer geometry.

This study was carried out to help map out zones for drilling of productive boreholes in the study area and to study the hydrogeophysical properties of the Ogwashi-Asaba, Ameki and Imo Shale Formations which are the geological formations that underlie the study area. The present project is also undertaken to assess the suitability of the water resource for domestic-industrial and agricultural uses.

## LOCATION, PHYSIOGRAPHY AND CLIMATE

The study area is part of the southern Anambra Basin and lies within latitudes $6^0 15'$ and $6^0 40^1$ N and longitudes $6^0 4^5$ and $7^0 15'$ E. The study area covers an area of approximately $3080 km^2$ with an estimated population figure of 780,546 based on the 1991 census. Figure 1 is the geological map of the study area showing access roads and locations of the electrical resistivity soundings. The important settlements within the study area include Ihiala, Okija, Ozubulu, Oraifite, Oba, Onitsha, Obosi, Nneokwa, Abatete, Oraukwu, Agulu, Awka and Amawbia. These communities are connected by a network of tarred, untarred and earthroads.

The study area has a fairly marked to somewhat undulatory relief. One major relief feature of the study area is the north-south trending ridge (Awka-Orlu Cuesta). The Cuesta divides the study area into two distinct relief features; the western uplands and the eastern lowlands. Although irregular

N. N. ONU, Department of Geology, Federal University of Technology, Owerri, Nigeria
C. U. IBEZIM, Department of Geology, Federal University of Technology, Owerri, Nigeria

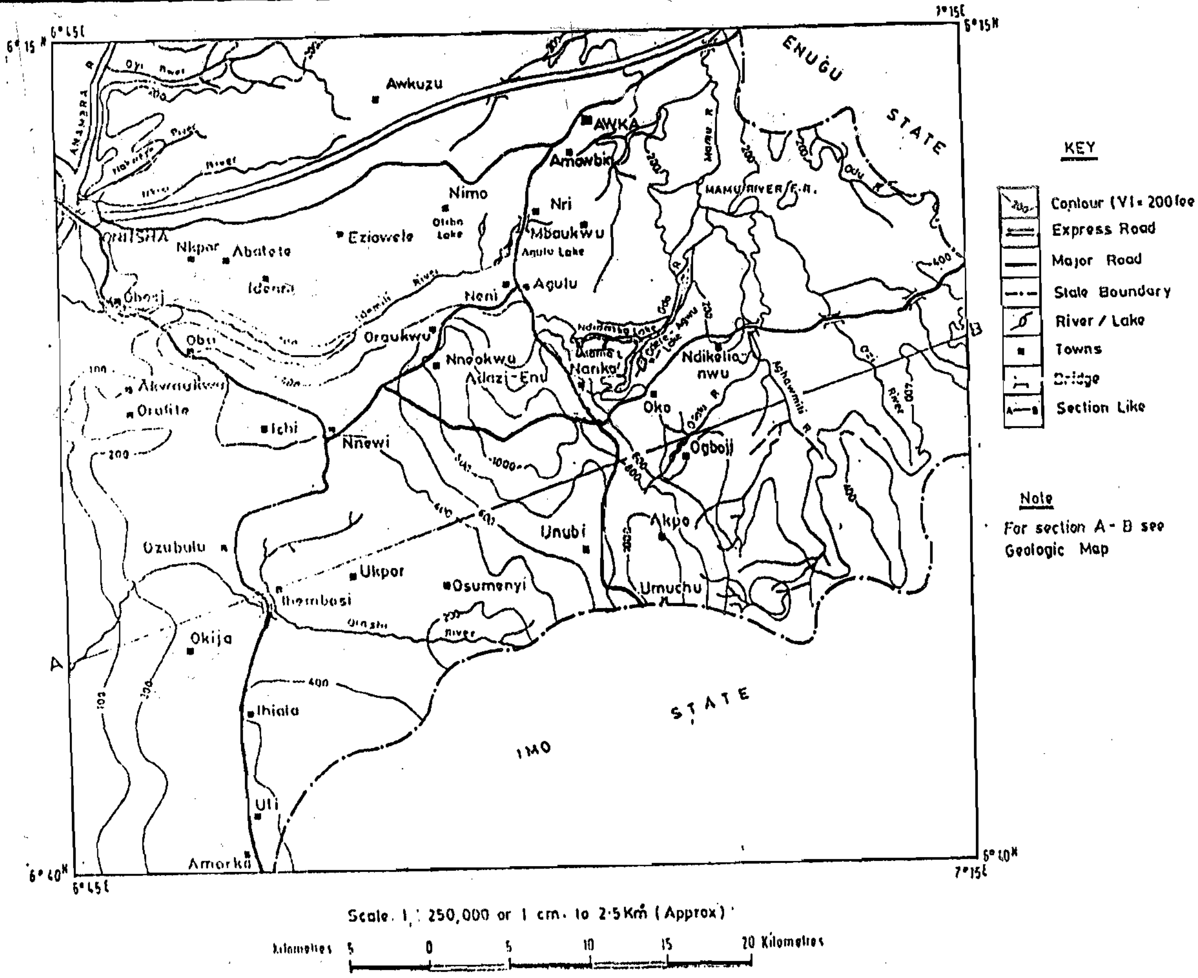


*Fig. 1: Topographic Map of the Study Area*

landscape (Imo Shale capped with laterites) also exists, the monotony of the lowlands is occasionally broken by gently rolling hills. These landforms vary in elevation from 65 to 212m above sea level. The western uplands drop from 366m at Igboukwu to 92m amsl at Idemili valley at Agulu lake area and then rise again to 122m and above at Nri (Ogbukagu, 1984).

Two distinct conditions ie. dry and wet months characterized the study area. The wet season lasts from March to October during which time the temperature varies from 23 to 26$^{0}$C and the winds are predominantly south-west. September and part of October are months with the high rainfall. The dry season commences in November and lasts up to April. During this period temperature ranges from 26 to 30$^{0}$C with February – April being the hottest months of every year. The coldest months are from November to February, when the dry cold northeast harmattan winds from the Mediterranean region and Sahara blow across the land. During this period the temperature is as low as 15$^{0}$C or lower. The severity of the dry cold winds is very much diminished as one moves from the source area through northern Nigeria down to the South.

The above climatic conditions supported a great rainforest belt, which has almost disappeared. Extensive deforestation has occurred. Forests were cleared for agriculture, urban development, road construction, timber, and so on thereby leaving most of the study area devoid of thick vegetation. Thick vegetation may still be seen along streams and rivers channels, and around lakes. Trees such as iroko also occur scattered in villages where they have been allowed to grow until maturity when they are cut down for the building industries. The smaller trees, bushes and grasslands are exposed to incessant bush burning by farmers or hunters. Hence, for most periods of the year, the lands are laid threadbare to the vagaries of the inclement weather.

The study area is part of the drainage systems of several major rivers and lakes. The rivers include the Idemmili and its tributary the Obibia, Odo and the Orashi.

The major lakes includes Agulu, Otibia and Uchu. The rivers or some of their tributaries originate from these lakes and/or from the groundwater through effluent see pages.

## GENERAL GEOLOGY OF THE AREA

Anambra Basin lies in the lower Benue Trough, Nigeria. The sequences of events which led to the formation of the Trough and its component units are now well documented (Short and Stauble, 1967, Burke

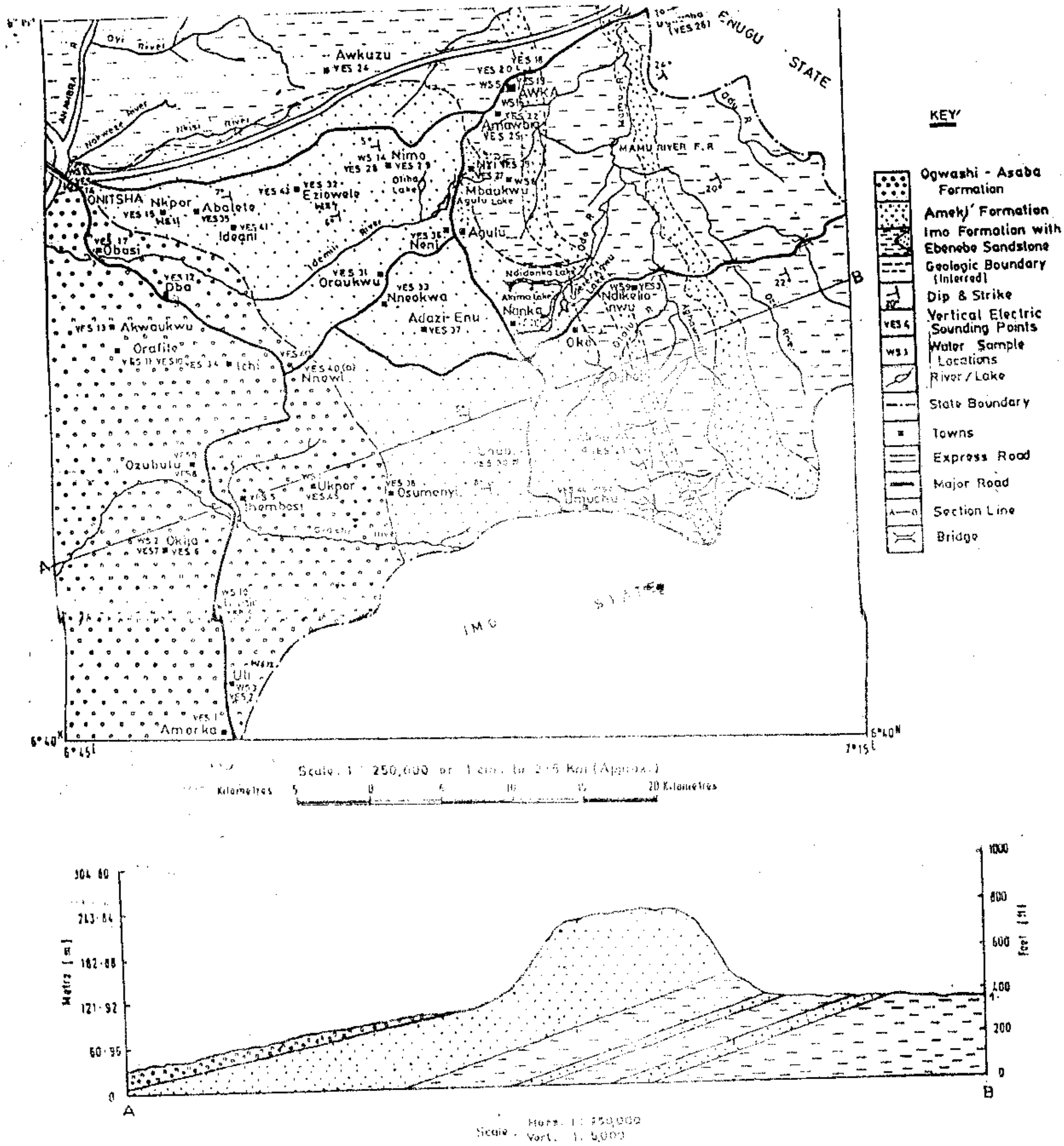


*Fig. 2: Geologic Map of the Study Area showing the VES and Water Sample Locations (Adapted from Nwajide, 1977 and Ogbukagu, 1984 & 1986)*

et al, 1970, Nwachukwu, 1972). It was suggested (Cratchley and Jones, 1965) that the Benue trough originated as an extensional rift valley in which subsidence took place while sediments were being laid down. There were three main tectonic and depositional cycles in the southern Nigeria part of the trough. The first cycle (Albian-Sanstonian) was confined to the entire trough. The second (Campanian – Eocene) filled the Anambra Basin and Afikpo syncline and the third cycle paved the way for the development of the modern Niger Delta (Short and Stauble, 1967; Burke, et al. 1970).

With the initiation of the Anambra Basin during Coniacian to early Santonian and following the Santonian deformation espisode, deposition shifted westward from Abakaliki Benue Rift into Anambra Basin.

Although the parallic Enugu and Nkporo Formations, the Coal measures: Mamu and Nsukka Formations and the fluvia-deltaic Ajali Sandstone may be encountered on the surface and in deep boreholes at various localities within the Anambra Basin, five known Tertiary formations are found in the down – up eastern part of the Basin. Nearly all the formations grade laterally into the Benin Formation with facies changes. These formations include Imo Shale Group

Formation (Paleocene) Ameki Formation (Eocene) Ogwashi-Asaba (Miocene) Benin Formation (Pleistocene) Marine deltaic alluvium Formation (Recent).

It is however very important to note that only three of the tertiary Formations listed above occur in the study area. These are the Imo Shale, Ameki and Ogwashi/Asaba Formation (Fig.2). The description of the Lithologic units are outlined in table 1.

## DATA COLLECTION AND ANALYSIS

A total of 42 vertical electrical soundings (VES) were carried out in the study area using the Schlumberger electrode array. The locations of the soundings stations are shown on figure 2. Current electrodes were expanded to a maximum separation of 1.20km. The instrument used was the ABEM Terrameter SAS $300^B$ which is a digital signal averaging instrument. Eleven of these soundings were made at the sites of existing boreholes for comparative purposes. Existing boreholes besides which the soundings were conducted are Okija, Ihembosi, Ozubulu, Akwukwu, Orsumagho, Oraukwu, Nri, Eziowele, Awka, Ogboji and Amawbia. The respective VES stations are 7, 5, 8, 13, 38, 31, 40, 32, 19, 21 and 25. The profiles were aligned along footpaths, within lawns and open fields provided reasonable profile lengths could be accommodated. The interpretation was by curve – matching techniques and the use of auxiliary diagrams (Zhody, 1965, 1974).

The data obtained from both curve matching techniques and the method of asymptotes were used as input data for a final computer modeling using a programme based on Henker, (1985) which obtained fits with field curves by parameter adjustment. The data are presented in the form of tables and geoeletric cross-sections.

## HYDROCHEMICAL ANALYSIS

Water samples were collected from fifteen (15) locations in the study area for hydrochemcial analysis. The locations where the water samples were collected are show in figure 2. These include; (Umuatuogwu) Okija, (Therapeutic day care) Ihiala, (Amampute) Uli, (General Hospital) Onitsha, (Tracy Hotels) Awka, (Ohofia) Abagana, (Afor) Nkpor, (Mofer Borehole) Awka, (Umuduji) Ukpor, / Community Borehole) Ndikelionwu, (Akabo) Mbaukwu, (Health Center) Eziowelle, Umubazi-Uli, Ezicheke Abagana and (General Hospital) Umuchu. The water samples were stored in plastic containers at room temperature prior to analysis. Water samples were collected at the source or as close to the source as possible. Before samples were collected, water was allowed to flow/run until the temperature and conductivity stabilized. Water samples from boreholes were collected before treatment.

The chemical analyses of the water samples were done using atomic absorption spectrophotometer technique for the caution species, and the titration method for anions. In the atomic absorption spectrophotometer technique, water sample was first treated as outlined in the analytical manual. The pre-treatment process is specific for each caution. The pre-treated water is subsequently aspirated into a flame to produce atomized monochromatic light. A photo detector measures the concentration of particular cation from the appropriate component of the monochromatic light. The anions concentrations were determined by titration with a standard solution of hydrochloric acid equivalent. The end point of the titration was observed by calorimetric procedure using phenolphthalein indicators. The resulting data are presented in table 2.

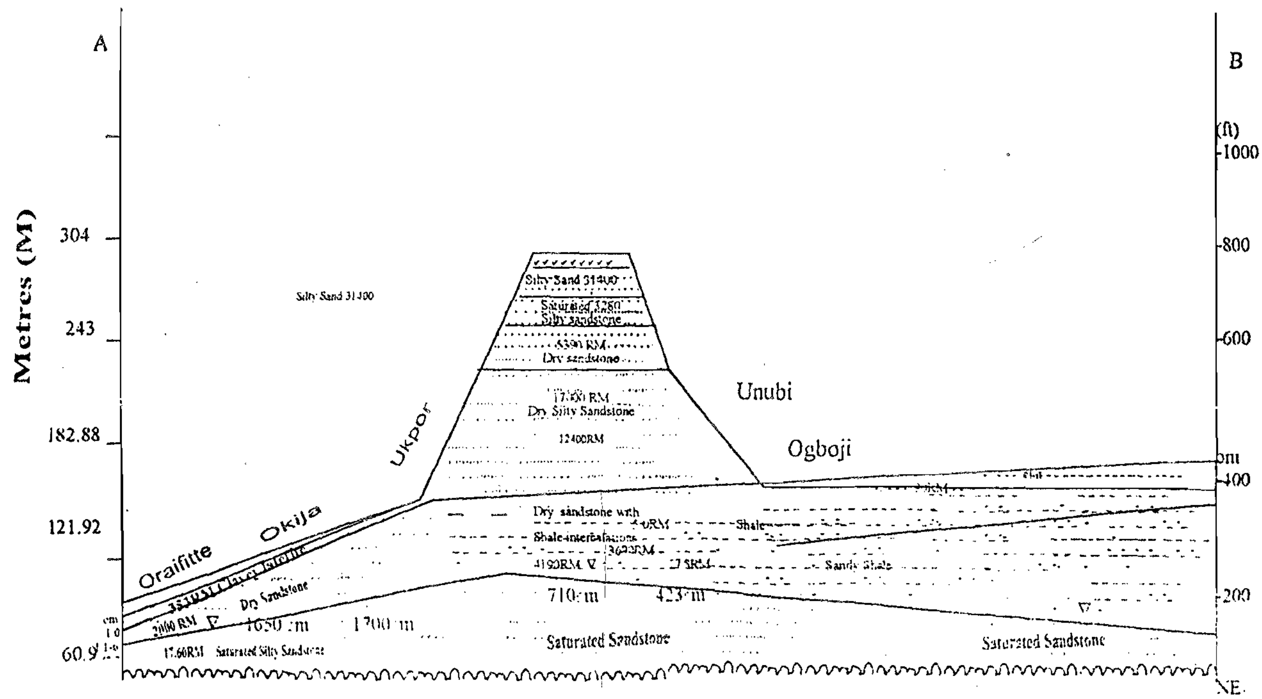


*Fig. 3: Geoelectric X-section AB*

***Table 1: Principal Rock Units and their Hydrologic Proper***

| SYSTEM | SERIES | FORMATIONS | DESCRIPTION | OCCURRENCE | GENERAL HYDROLOGICAL PROPERTIES |
|---|---|---|---|---|---|
| | Miocene | Ogwashi-Asaba | The lighter-clay seams of Ogwashi-Asaba formation have sandy layers in some horizons | Western uplands South of Ameki Formation | Ogwashi-Asaba forms productive aquifer. It is moderately water bearing unit; Moderate porosity and permeability and therefore overlysing coastal plan sands. |
| | Eocene | Ameki | The sand member (Nanka sands) is multi-colour, purple, grey, pink, clay-shale Siltone and Ironstone bands features at Different horizons. | Cuesta zone Western upland (Nanka sands) | The Nanka sands generally yeild large springs water wells. It is sufficiently water bearing unit, coarse to fine grained and poorly to moderately sorted High porosity And permeability. |
| | Paleocene | Imo | The Imo shale is interbedded With the Ebenebe Sandstone. The shale yields no water to Wells. The sandstone is Porous and permeable and Can act as a source of water to small populations or industry. | Eastern Lowland Ebenebe (Sandstone and Imo shale) | Generally, not be regarded as a prolific aquifer. |

## RESULTS

In presenting the results, the following steps were taken;

a). The soundings were collated along a profile AB to provide a geoelectric cross section.
b). Development of maps of longitudinal conductance, transverse resistance, Kσ product across the study area.
c). Development of isopach map and isoresistivity map of the aquiferous layer from the data.
d). Determination of aquifers characteristics – hydraulic conductivity, transmissivity from geoelectrical sounding data.
e). Development of water table contour map.

## GEOELECTRICAL CROSS SECTION

The data from the sounding points were collated along profile AB shown on fig. 3 to generate geoelectrical cross section. The point A is located near VES 6 at Okija on the western part of the study area while the point B is located near VES 21 at Ogboji. These points can be ascertained from figure 2.

Combining the interpreted geoelectrical sounding results with the information obtained from lithological logs of boreholes already drilled in the area, we arrive at the conclusion that;

The topmost layer or the first geoelectric layer is lateritic soil consisting mainly of sands with a resistivity which ranges from 439Ωm.

The second geoelectric layer is clayey laterite in the western part and in the eastern low land entirely clay. The resistivity values range from 90Ωm to 353Ωm.

The third geoelctric layer is silty sand and saturated silty sandstone with resistivity values of about 3280Ωm when dry and about 31400Ωm when saturated. These layers occurred mainly in the central part.

The fourth year of resistivity values 5390Ωm – 7220Ωm is mainly sandstone. This is followed by dry silty sandstone with resistivity value of between 12400 – 17000Ωm. These two geoelectric layers are found in the central part only.

The sixth geoelectric layer is dry sandstone in the western part, towards the central part, the dry sandstone became intercalated with shale and in the eastern lowland it is sandy shale-shale. The resistivity values range 9000Ωm - 9100Ωm, 3690Ωm - 4190Ωm and 5.0Ωm-27.3Ωm respectively.

The seventy geoelectric layer is saturated sandstone (in some places silty) with resistivity range of 423Ωm - 1760Ωm. This is the most promising aquifer.

## MAPS OF AQUIFER LONGITUDINAL UNIT CONDUCTANCE(S) AND TRANSVERSE RESISTANCE TR.

Both the resistivity (e) and the thickness (h) of these layers are obtained from the quantitative interpretation of the VES.S and $T_r$ are obtained from the relation $S = h/e$ and $T_r = he$ ........................ (1)

A map of the aquifer longitudinal conductance S, is shown in (Fig.4). The figure shows that around Awka, Agulu and Akpo which lie within the Imo Shale formation, the aquifer S values are high (0.05 – 0.1 mhos) whereas the S values are low around Oba, Nkpor, Okija and Nnokwa (0.008 – 0.06) which are underlain by the Ogwashi-Asaba and Ameki Formation respectively. The northern and the eastern half of the study area and other zones of high S values are probably underlain by thick layers of conducting

***Table 2. Hydrochemical Analysis of Groundwater***

| | PH | Temp 0$^0$ | Appearance | Colour | Turbidity | Conductivity (Hmhos/cm) | Calcium (mg/l) | Magnesium (mg/l) | Sodium (mg/l) | Potasium (mg/l) | Sulphate (mg/l) | Choride (mg/l) | Bicarobate (mg/l) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WHO Standard | 6.5-8.5 | | | 50 | 50 | 500 | 200 | 250 | 200 | 200 | 400 | 250 | 500 |
| WS1 | 7.3 | 30 | | 5600 | 800 | 40 | 29 | 9 | NIL | 2 | NIL | NIL | 133 |
| WS2 | 7.7 | 25.7 | CLEAR | 300 | 50 | 197.6 | 4 | 15 | NIL | 2 | 10 | 7 | 74 |
| WS3 | 7.6 | 26 | CLEAR | 38 | 20 | 340 | 25 | 15 | NIL | 1.5 | 2 | NIL | 35 |
| WS4 | 6.0 | 32 | CLEAR | 250 | 40 | 82.9 | 13 | 17 | NIL | 2.5 | 9 | NIL | 3.7 |
| WS5 | 5.9 | 28.7 | CLEAR | 5 | 1 | NIL | NIL | 0.15 | NIL | NIL | NIL | 9 | NIL |
| WS6 | 5.6 | 29 | | 5 | 0.5 | 56 | 7 | 11.5 | NIL | NIL | NIL | 5 | NIL |
| WS7 | 6.4 | 29.4 | CLEAR | 10 | 25 | 14.5 | NIL | NIL | NIL | NIL | 2 | 0 | NIL |
| WS8 | 7.1 | 30 | CLEAR | 60 | 20 | 80 | 1.8 | 1.5 | NIL | 2.4 | 10 | NIL | 30 |
| WS9 | 8.0 | 25 | CLEAR | 65 | 10 | 29.6 | 180 | 227 | NIL | 7.0 | 35 | 30 | 88 |
| WS10 | 5.5 | 29 | CLEAR | 350 | 80 | 144.8 | 5 | 3 | NIL | 4 | NIL | NIL | 118 |
| WS11 | 7.2 | 29 | CLEAR | NIL | NIL | 289 | 54 | 71 | NIL | 4.5 | NIL | NIL | 41 |
| WS12 | 6.3 | 1.1 | CLEAR | NIL | NIL | 103 | 14 | 11 | NIL | 2.6 | 11 | NIL | NIL |
| WS13 | 6.2 | 30 | CLEAR | 5 | 0.5 | 54 | 39.2 | 10.8 | NIL | NIL | NIL | 5 | NIL |
| WS14 | 6.9 | 29.3 | CLEAR | 5 | 0 | 14.5 | NIL | NIL | NIL | NIL | NIL | 5 | NIL |
| WS15 | 5.8 | 27.8 | CLEAR | 5 | 0 | 14.5 | NIL | NIL | NIL | NIL | 5 | 260 | NIL |

***Table 2 contd.***

| | Carbonate (mg/l) | Nitrite (mg/l) | Niterate (mg/l) | Phosphate (mg/l) | Floride (mg/l) | Chlorine (mg/l) | Iron (mg/l) | Magnanese (mg/l) | Copper (mg/l) | Total (mg/l) | Salinity | Total Dissolved Solid | Feacal Coliform |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WHO :andard | 500 | 0.1 | 10 | 10 | 105 | 0.5 | 0.3 | 0.01 | 1 | 500 | 500 | 500 | 2 |
| WS1 | NIL | 0.05 | 4.84 | 2.5 | NIL | NIL | 0.1 | NIL | 0.09 | 38 | Nil | 20 | Nil |
| WS2 | NIL | 0.17 | 10.56 | 1 | NIL | NIL | NIL | NIL | 0.1 | 19 | 11.6 | 98.9 | Nil |
| WS3 | NIL | 0.1 | 4.4 | 0.8 | NIL | NIL | 0.01 | 0.15 | 0.2 | 40 | Nil | 165.1 | Nil |
| WS4 | NIL | 0.099 | 8.8 | 1.8 | NIL | NIL | 0.18 | 0.5 | 0.4 | 30 | Nil | 41.5 | Nil |
| WS5 | NIL | NIL | 8 | 0 | NIL | NIL | 0.8 | 0.15 | NIL | 28 | Nil | Nil | 40 |
| WS6 | NIL | NIL | 0.06 | 0 | NIL | NIL | 0.5 | NIL | NIL | 18.5 | 8.3 | 63 | Nil |
| WS7 | NIL | NIL | 0.5 | 0.2 | NIL | NIL | 1 | NIL | NIL | 16.0 | Nil | Nil | Nil |
| WS8 | NIL | 0.01 | 2 | 1 | NIL | NIL | 0.1 | 0.08 | 0.3 | 3.3 | Nil | 40 | Nil |
| WS9 | NIL | 0.07 | 70.4 | 1.8 | NIL | NIL | 0.25 | 0.5 | 0.9 | 407 | 49.5 | 149 | Nil |
| WS10 | NIL | 0.05 | 0.44 | 1.5 | NIL | NIL | NIL | 0.25 | 0.2 | 8 | Nil | 72.4 | Nil |
| WS11 | NIL | 0.07 | 6.6 | 1.6 | NIL | NIL | 0.25 | 0.06 | 0.2 | 125 | Nil | 142 | Nil |
| WS12 | NIL | 0.03 | 8.8 | 1.8 | NIL | NIL | 0.05 | 0.1 | 0.3 | 25 | Nil | 51.5 | Nil |
| WS13 | NIL | NIL | 0.03 | NIL | NIL | NIL | 0.57 | NIL | Nil | 50 | 8.3 | 94 | Nil |
| WS14 | NIL | NIL | 9 | NIL | NIL | NIL | 0.08 | 0.05 | Nil | 20 | Nil | Nil | Nil |
| WS15 | NIL | NIL | 12 | 0.2 | NIL | NIL | 0 | 0.17 | Nil | 20 | Nil | Nil | Nil |

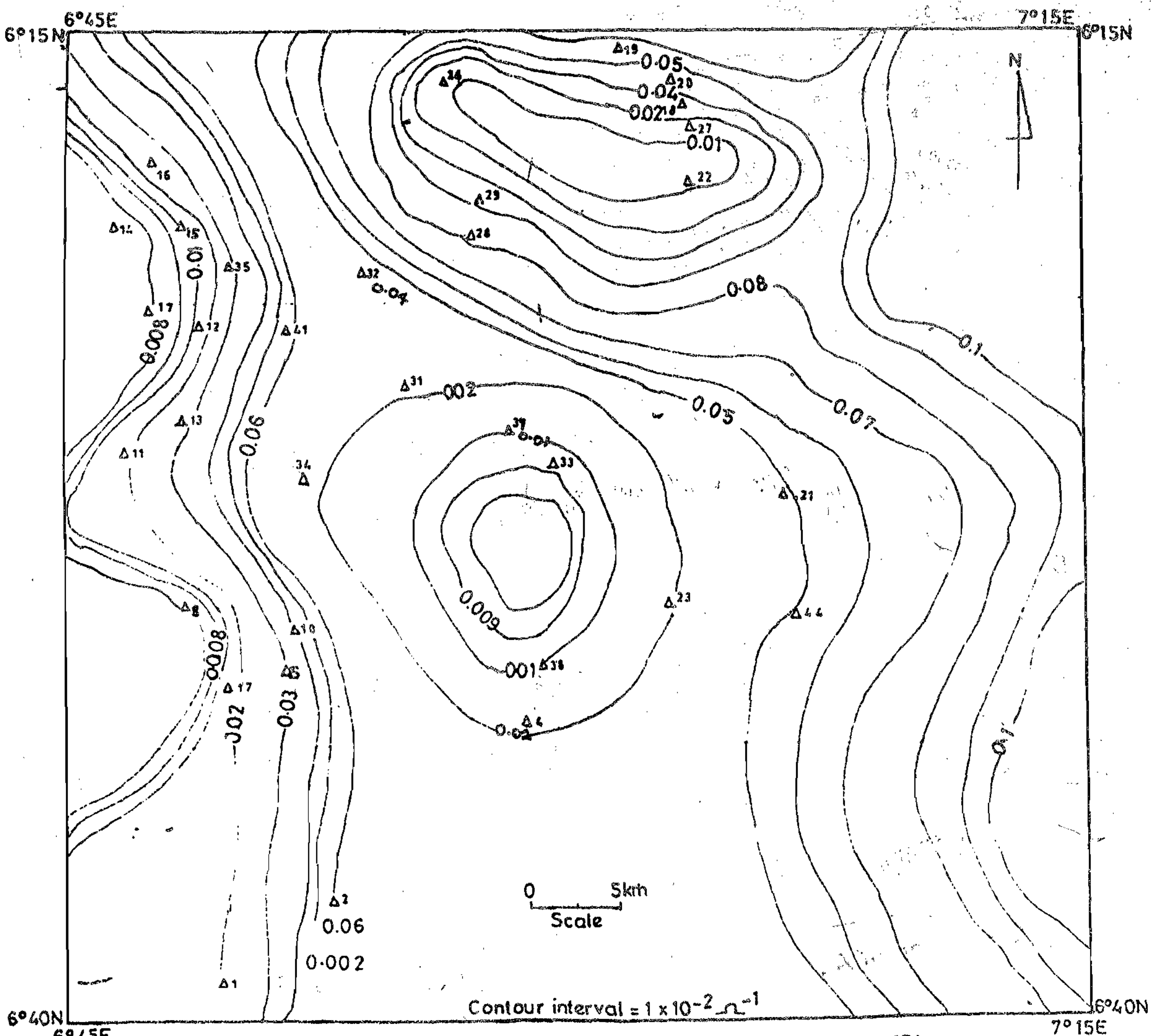


*Fig. 4: Map of Aquifer longitudinal Conductance (S)*

sediments. These could either be fully saturated zones or areas with high percentage of conducting clays or both. Although the aquifer thickness is larger in the central and western half of the study area, underlain by the Ameki and Ogwashi-Asaba Formations, the relatively higher resistivity for the aquiferous zones could account for the lower values of S in these areas. The longitudinal conductance map may characterize the relief of the supporting horizon.

Fig.5 shows the variation of aquifer transverse resistance $T_r$ across the study area. The $T_r$ values are highest towards the central and the western parts underlain by the Nanka Sands/Ameki and the Ogwashi-Asaba Formation respectively.

The transverse unit resistance (T) map is considered a unique map for hydrological classification of an environment with a thick sedimentary sequence, as is the case under study. This is because the transverse unit resistance (T), which is a product of aquifer thickness (h) and resistivity (p), is closely related to transmissivity (T) which is a product of aquifer thickness (h) and hydraulic conductivity (k). Thus the central and western parts of the study area (fig.5) where the total transverse unit resistance values are high, are expected to correlate with areas having the highest hydraulic transmissivity (T) and storage coefficient whereas the eastern and northern parts of the study area with low values of total transverse unit resistance ($T_r$) are expected to have the least transmissivity (T) and permeability values.

## ISO RESISTIVITY MAP OF THE STUDY AREA.

The aquifer resistivity map across the study area (fig.6) indicates that the eastern and northern parts of the study are a which are underlain by the Imo Formation show a progressively decrease in resistivity towards the east and north. This could be attributed to either the high clay-shale content of the Imo Formation or to the high ground water potential. The first reason is more plausible because from the water table map, (fig. 8) it is evident that groundwater potential is low in the eastern and northern parts of the study area.

The resistivity values increase from west and east towards the central parts of the western district, which is underlain by the Nanka Sands/Ameki Formation. Although the highest resistivity value of 2590Ωm is recorded at Adazi-Enu (VES 37, Ameki Formation), high resistivity of values also occur in the area underlain by Ogwashi-Asaba Formation to the

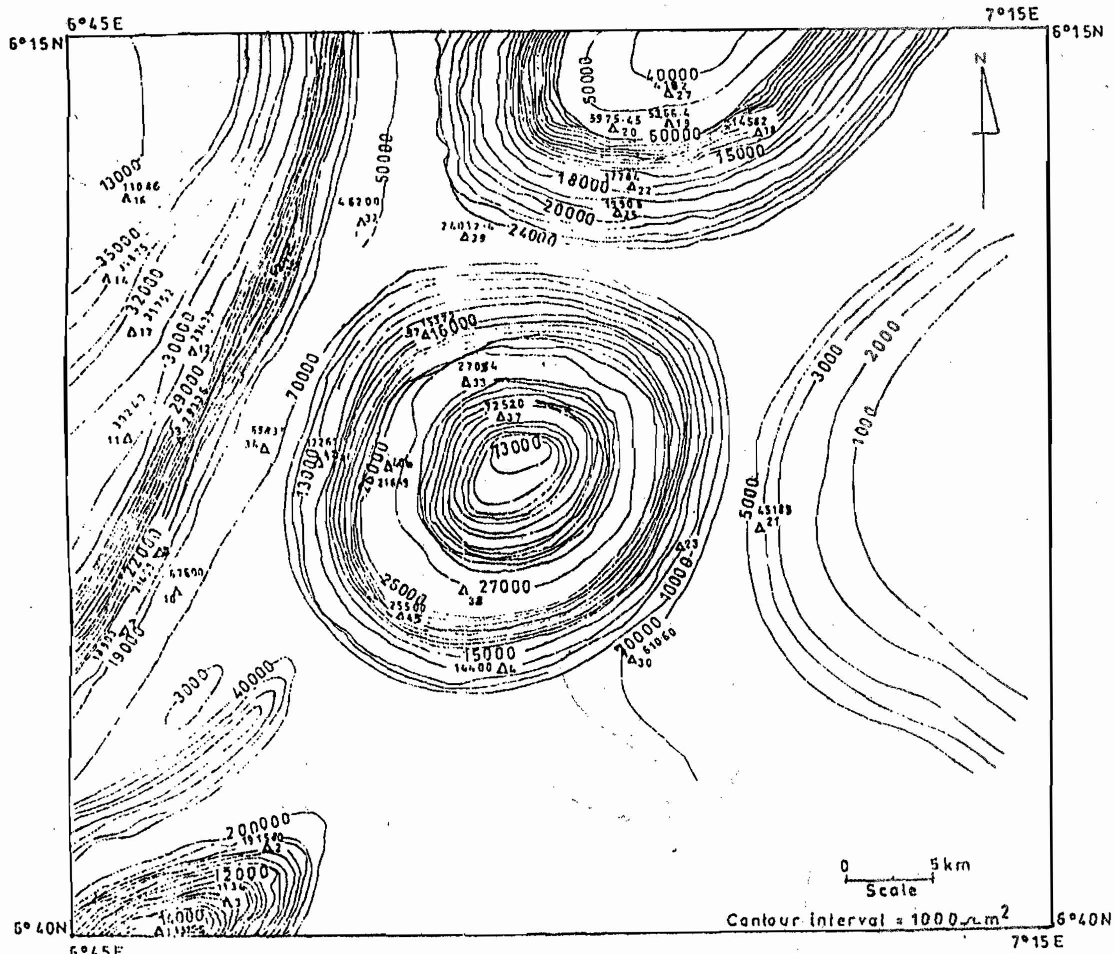


*Fig. 5: Map of Aquifer Transverse Resistance (Tr) of the study area*

west of the study area. These high resistivity values recorded in the western district could be attributed to the arenaceous nature of the formations which are mainly sandstone, siltysandstone, siltstone and in few places clay bands.

## ISOPACH MAP OF THE STUDY AREA

The Isopach map shows a progressive increase in aquifer thickness from the eastern, western and northern ends towards the central part of the study area (fig 7). This pattern or trend corresponds with the water table map (fig 8), which indicates low groundwater potential in the eastern and northern parts of the study area. Obviously, where groundwater potential is low, aquifer thickness is expected to be thin if it exists.

In the western part dominated by the Ogwashi-Asaba Formation the aquifer thickness is thin to fairly thick. It is evident therefore that the western part dominated by the Ogwashi – Asaba Formation can form good aquifers, but Ameki Formation in the central part of the western district can form better aquifers. This figure (fig 7) could definitely be of great help in future water well drilling programmes in the area. The abortive boreholes drilled in parts of Ighoukwu, Nneokwa and Nri within the study area may be due to the thinness of the aquifers in these areas.

## WATER TABLE MAP

The depth to the water table have been deduced from the sounding results and the indications are that the water table is shallow in the area underlain by the Ogwashi-Asaba Formation, fairly deep in the Nanka Sands/Ameki formation and much deeper in the area underlain by Imo Shale Formation. A contour map of the depth to the water table is shown (fig 8). In the eastern and northern parts of the study area underlain by the Imo Formation the depth to the water table increases from a depth of 55m at Agulu in the Nanka Sands/Ameki Formation to a depth of 279m at NRI. In the western and central parts of the study area underlain by the Ogwashi-Asaba and Ameki Formations respectively the depth to the water table increase from 40m at Okija to a depth of 170m at Nneokwa.

On the other hand, the depth to water table decreases towards the west and the central part of the study area underlain by the Ameki. A regional groundwater divide occurs at the central part of the study area and is suggestive of a regional suggestive of a regional surface water divide (fig. 8). The surface water divide which runs north-south with streams and rivers flowing away, from it on both sides could be attributed to the existence of a north-south trending ridge (the Awka-Orlu Cuesta). The Cuesta which

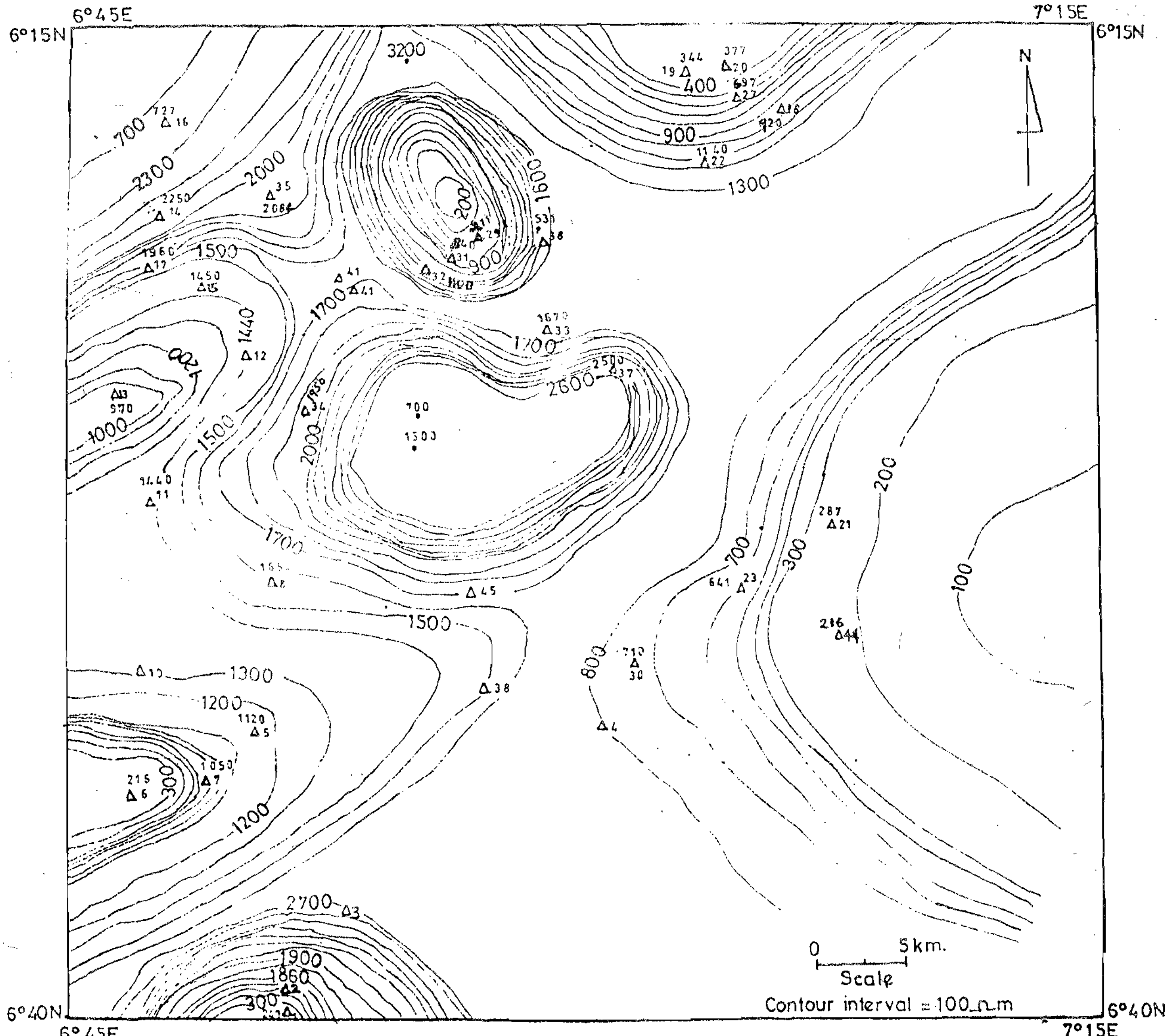


*Fig. 6: Iso Resistivity map of the study area*

divides the study area into the western upland and the eastern lowland is underlain by the Nnaka Sands/Ameki Formation and attains a maximum altitude of about 366m at Igbo –Ukwu (Ogbukagu, 1984). The Cuesta has gullies of variable magnitude deeply incised at different locations along the scarp fronts (Ogbukagu, 1976).

From the depths to water table and the surface water flow pattern as suggested by the relief and divide, it is clear that most of the eastern districts commonly lack good groundwater potential but appears to have adequate source of surface water. On the other hand the western upland is rich in groundwater but generally deficient in surface water.

## DETERMINATION OF AQUIFER PARAMETERS FROM GEOELECTRICAL DATA

Niswas and Singhal (1981) had established an analytical relationship between aquifer transmissivity and transverse resistance on the one hand and between transmissivity and aquifer longitudinal conductance on the other. These relationships are given as:

$$T = K\partial T_r = Ks/\partial = Kh \text{ ------------------------- (2)}$$

Where T is aquifer transmissivity, K is hydraulic conductivity, $\partial$ is the electrical conductivity = 1/p; P is the resistivity, $T_r$ is the transverse resistance of the water bearing layer, S is the longitudinal conductance of the aquiferous layer and h is the aquifer thickness. It has also been established by Niswas and Singhal (1981), that in areas of similar geologic setting and water quality, the product k$\partial$ remains fairly a constant. The aquifer resistivity ($\partial$) and acquifer thickness (h) were the geoelectrical data. Hydraulic conductivity (K) values were obtained from few control points: (Okija, Ihembosi, Ozubulu, Akwukwu Orsumogho), (Oraukwu, Nri and Eziowelle) and (Awka; Ogboji and Amawbia) for Ogwashi Asaba, Ameki and Imo Formations respectively.

The product K$\partial$. for the control points were determined. The average value of K$\partial$ obtained for each of the three formations are presented in Table 3 and fig.9. From the estimated K$\partial$ products, it van be seen that in areas with similar geologic setting the product K$\partial$ remains fairly constant. K$\partial$ has a an average value of 2.5658413 x $10^{-4}$ for Imo Formation, 1.2848983 x $10^{-4}$ for Ameki Formation and 3.2573583 x $10^{-4}$ for Ogwashi – Asaba Formation of the study area.

Now having obtained the Kρ products for the geologic Formation and with $T_r$ extracted from the aquiferous layers for each sounding location, it is possible to estimate K and T for all sounding locations including areas where there are no existing boreholes. Table 3 summarizes the average values of the aquifer characteristics for some locations within the study area.

## WATER QUALITY

Table 2 shows that the $P^H$ value ranges from 5.5 to 8.0. According to Johnson. (1951) water with a $P^H$ value of less than 7.0 is acidic in its reaction and tends to be corrosive, whereas one with a $P^H$ of greater than 7.0 is alkaline in its reaction and tends to be encrusting.

Although $P^H$ range of between 5.5 and 7.5 is normal, the permissible value by the WHO standard is 6.5-8.5. Water samples 10 (Ws 10) with $P^H$ value of 5.5 may be adjusted by treating with small quantity of lime.

A temperature is high, an external source of heat is suspected. The temperature values of the tested/analyzed water samples fall within 25-32 $^{0}$C. Thus the temperature of groundwater is fairly constant. This is an advantage for drinking and industrial utilization.

The colour of the samples varies appreciably from 0 –5 Hazen units in clear and colourless water to 150 –300 units in turbid water. An exceptionally high value of 560 occurred in Ws1 at Ukpor. The colour could be as a result of the materials in the path movement of water. Turbidity, which is related to colour, is the appearance of water by virtue of sediments in suspension. The highest value of 800 also occurred in Ukpor. Where materials in the path movement of water show a greater resistance to be incorporated or washed into the water, the colour and or turgidity are expected to be lower.

The range of 20 – 165. 1mg/1 of total dissolved solids (TDS) in the tested samples falls within the WHO recommended guidelines. The samples are notably low in TDS. Skougstad (1981) states that water containing less than 500ppm of dissolved solids is generally satisfactory for domestic use and for many industrial purposes. The results indicate that water samples are both low in dissolved solids and in electrical conductance. Water with the highest electrical conductance of 3340 micro mhos/cm also has the highest TDS of 165.1. WS15, WS7, WS14, and WS5 have low conductivity (14.5 micromqos/cm) and as such low TDS. The low specific conductance is therefore due to low total

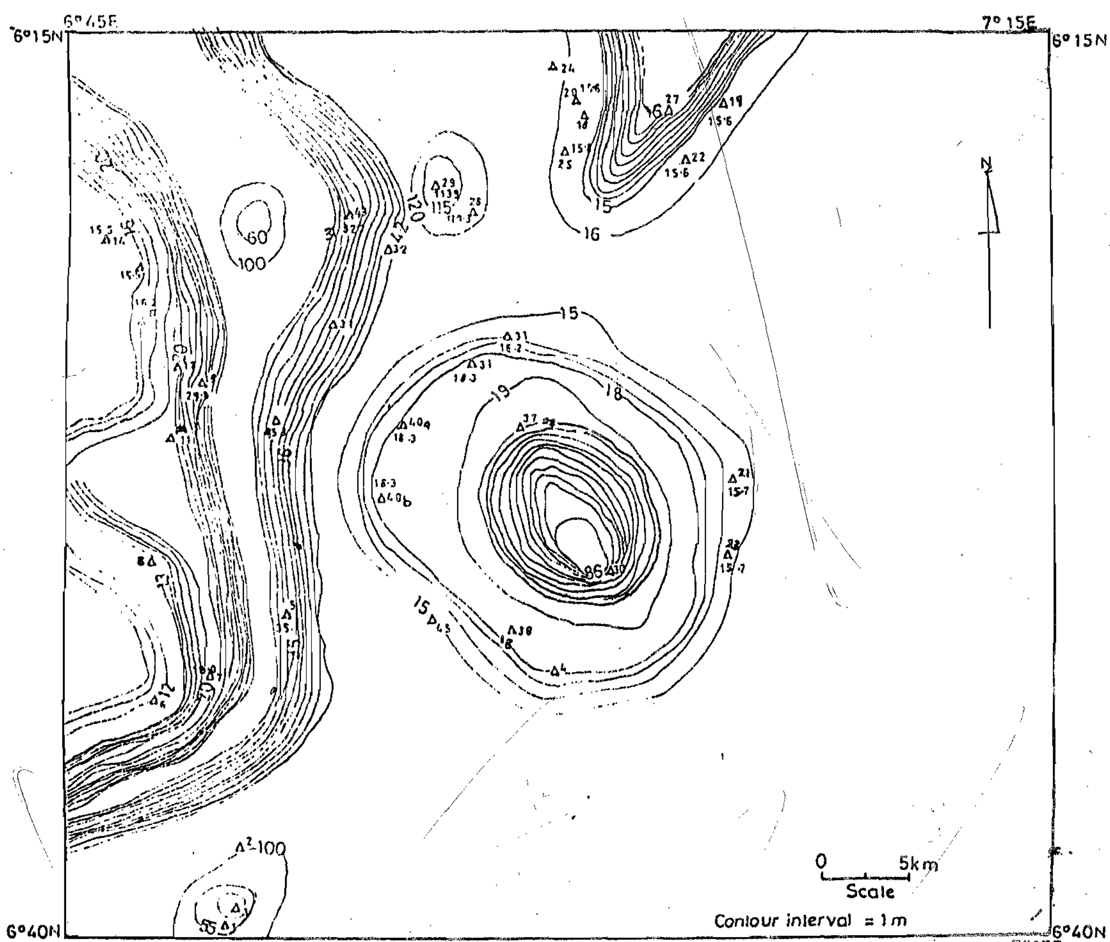


*Fig. 7: Isopach map of the study area*

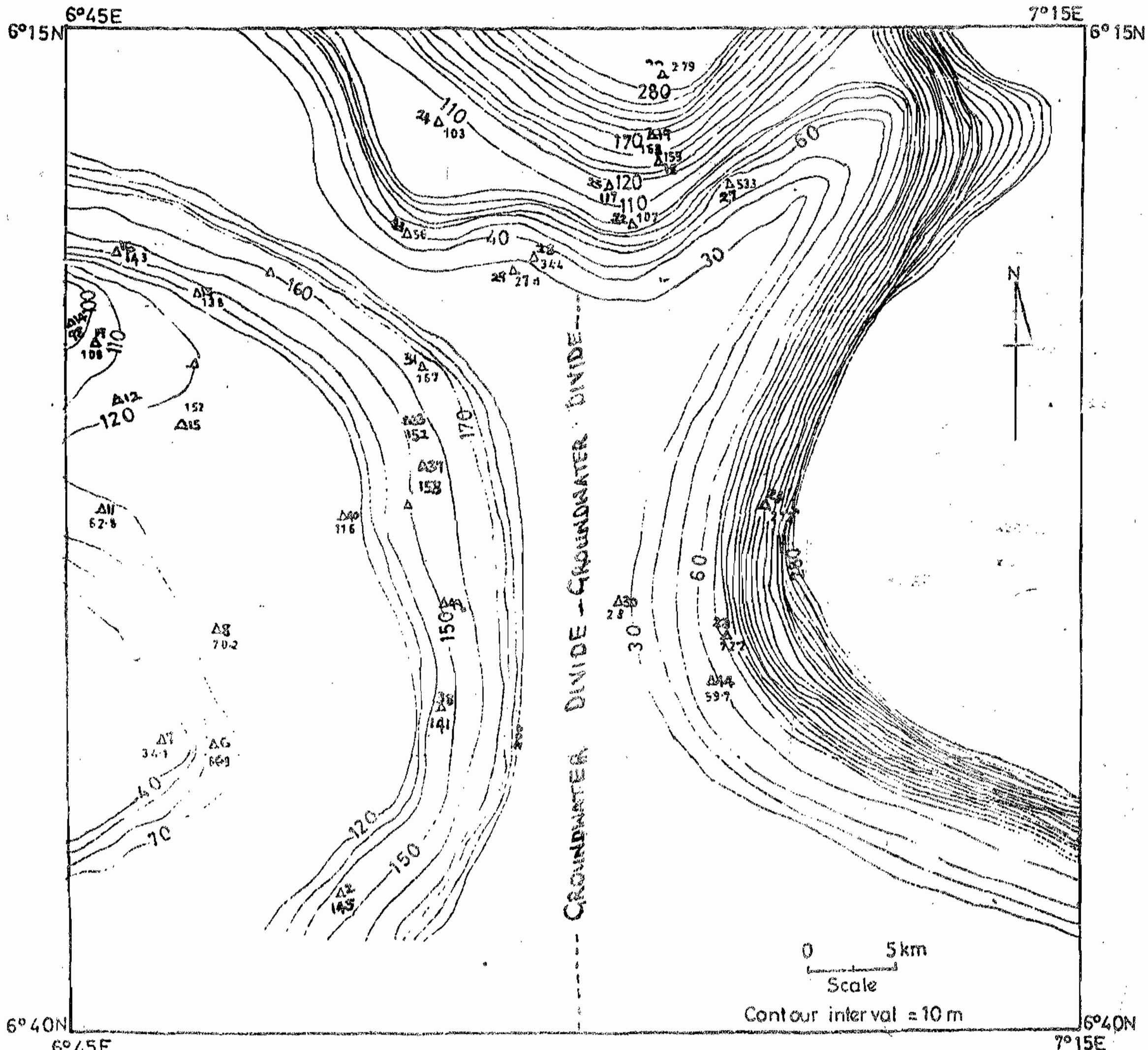


*Fig. 8: Water table map of the study area*

dissolved solid contents. The iron content in the water samples range from 0-1.0mgl. According to WHO, (1971) the highest desirable level of iron for potable water is 0.3mgl. This limit is without any prejudice to physiological consideration as human being. e.g. require 5-6mg of iron per day for existence. Four (4) of the tested water sample WS7 = 1.0, WS5 = 0.8, WS16 = 0.5 have iron content in excess of this allowable upper limit. The iron is thought to be principally derived from the overburden of red earth overlying the Formations. It is also possible that part of the iron emanated from chemical weathering of minerals like pyrite and marcasite. Pyrite and marcasite occur in intervening shale beds.

All the tested water samples fall within the recommended WHO, (1971) standards as regards to total hardness. According to the classification of Linsley and Granzini (1979); two of the tested water samples belong to the very soft water category. Eleven of the fifteen (15) tested water samples belong to the soft water category. One of the tested water samples belong to hard water category and one (1) also belongs to very hard water category. The tested water samples in the soft categories are therefore suitable for the operation of laundries and commercial boilers.

The water samples are generally low in Ca and Mg ions indicating that the formations are deficient in minerals capable of providing these ions. Ferromagnesian minerals such as amphiboles, olivine and pyroxene furnish Mg ions. Ca ions can be introduced from gypsum and/or calcite. Both $Mg^{2+}$ and $Ca^{2+}$ can emanate from dolomite and/or clay minerals. Only one of the tested water samples WS9 showed, appreciably high values of Ca and Mg ions. This can be attributed to the high clay minerals content of the area.

The tested water samples all have salinity and Cl – ion values that fall within the WHO, (1971) recommended guidelines. Also Coliforms which are higher in surface water than in groundwater are absent in all but one of the tested water samples, WS5. This high coliform count of 40 (WS5) can be attributed to the miscellaneous impurities within the reach of groundwater as it percolates or moves through its tortuous path.

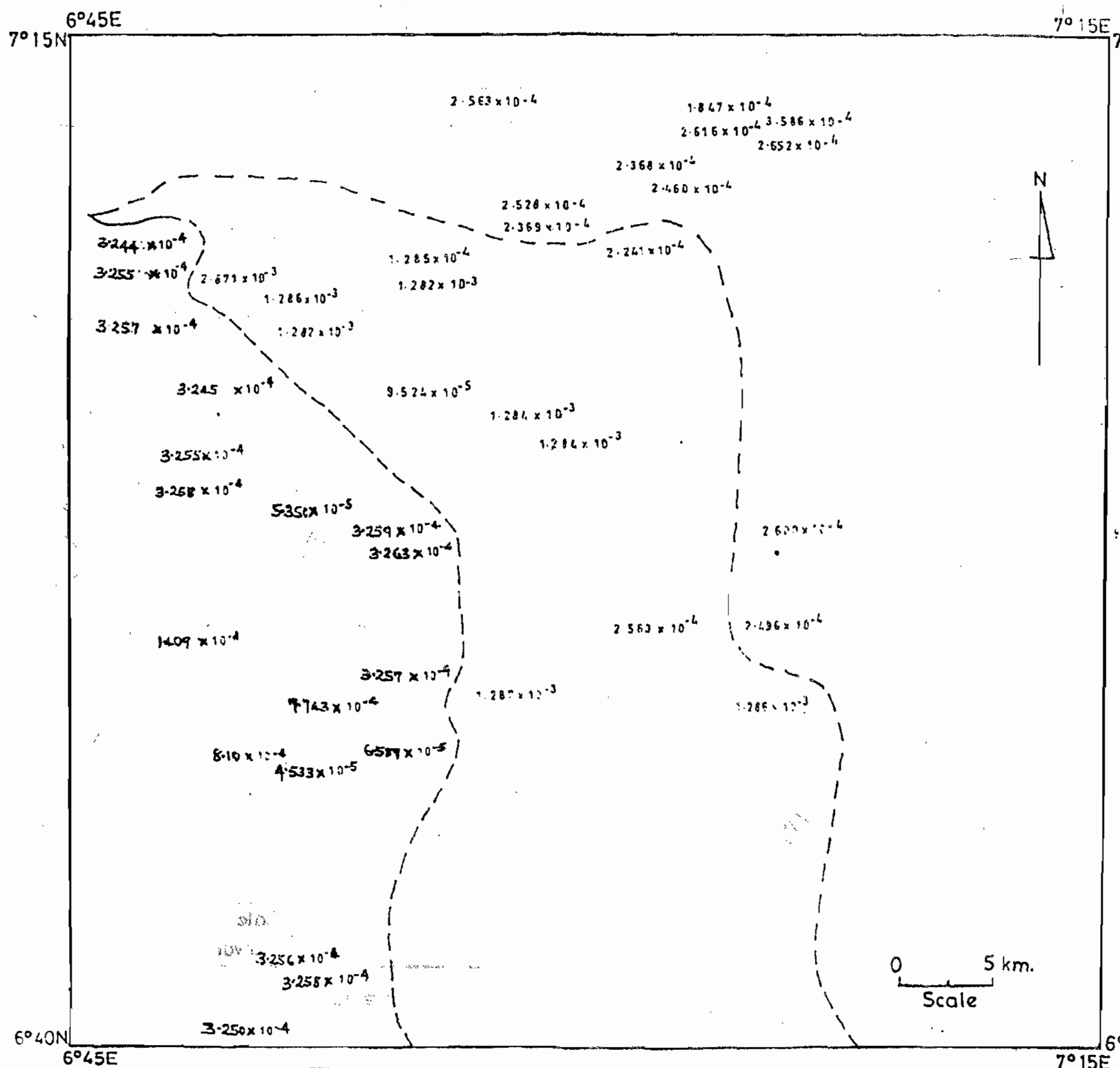


*Fig. 9: Map of K6 values*

## DISCUSSIONS AND CONCLUSIONS

The electrical resistivity sounding method is widely used for groundwater exploration. Two important limitations are however inherent in this method. These are the problems of equivalence and suppression (Kunetz, 1966; Salat, 1968). However, computer oriented direct interpretation methods are capable of resolving the thickness and resistivities of various subsurface layers from the surface resistivity measurements. These results are free from human bias, which is always present in the conventional curve matching techniques.

The analytical relationship established by Niswas and Singhal (1981) between the Dar Zarrouk parameters and the hydraulic characteristics has been applied in this study. The K? product has been used to subdivide the study area into three zones with distinct hydrogeological characteristics and these agree with the geologic maps produced by Nwajide (1997) and Ogbukagu (1984, 1986) which demarcated the study area into three distinct geologic units namely a northern and eastern part underlain by the Imo State Formation, a central part underlain by the Ameki formation and the western part underlain by the Ogwashi-Asaba Formation.

High S but low $T_r$ values were obtained for the aquiferous zones in the Imo Shale formation while relatively low S but high $T_r$ values were obtained for the aquiferous zones in the Ogwashi-Asaba and Ameki Formations. The high S values obtained in the Imo Shale formation can be attributed higher salinity of the groundwater or high clay content or both. Suffieciently high $T_r$ coupled with good aquifer thickness is necessary for water well exploitation. Consequently the most prospective areas for the drilling of the productive boreholes can be delineated in the vicinities of Adazi, Enu, Ichi, Unubi and Eziowelle.

The depth to the water shows an increasing trend as we move from the Ogwashi-Asaba Formation to the Imo Formation. Greater depths to the water table coupled with low transmissive properties of the aquifer materials make the environment of the Imo Formation low in groundwater potentials. Ogbukagu (1984) has observed that the eastern lowlands have low groundwater potentials while the western uplands have high groundwater potentials.

This study has helped us provide data on the aquifer geometry and hydrogeophysical (K), Transmissivity (T), aquifer thickness (h), depth to water table, and the Dar Zarrouk parameters: longitudinal unit conductances (S) and the transverse resistance ($T_r$) of the aquifer zones. The estimated aquifer parameters revealed that hydraulic conductivities (K) and transmissivity (T) values are 0.05-0.31m/hr, 0.0.8-6.82m$^2$/hr, 0.078-0.638m/hr and 1.50-4.90m$^2$/hr, 1.50-291.21m$^2$/hr, 0.429-10.34m$^2$/hr for Imo, Ameki and Ogwashi-Asaba Formations respectively.

A good correlation is found to exist between the surface measured Dar-zarrouk parameters and such hydrological parameters as transmissivity, hydraulic conductivity permeability, and specific yield of aquifer mapped. The zone with the highest transverse resistance ($T_r$) values is expected to give the give the highest borehole yield. Consequently, favourable areas for future groundwater development have been suggested on the above bases.

The physical and chemical properties of water from the project area are generally satisfactory for domestic and most industrial uses, although four samples (WS10), (WS15), (WS4), (WS5) indicated slight drop from the permissible P$^H$ values. One sample (WS5) contains coliforms in excess of the permissible limit of 2 per 100ml of water and therefore need some treatment.

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