

Geoelectric Sounding to Delineate Shallow Aquifers in the Coastal Plain Sands of Okitipupa Area, Southwestern Nigeria

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Abstract: In Okitipupa area, southwestern Nigeria, the aquifers of the Coastal Plain sands are largely Quaternary porous sediments, but without records of their subsurface disposition. In this study, 50 Schlumberger soundings were conducted over the study area, aimed at delineating the boundaries, depth range of the shallow aquifer units and assess their vulnerability to near-surface contaminants. The study delineated two major aquifer units within the area: The upper/surficial aquifer system, which occur at depths ranging from 5.8m (around Agbabu) to 61.5m (around Ikoya) and with materials of higher average resistivity (504.7 Ω m), suggestive of gravelly/coarse to medium-grained sand and the intermediate aquifer system, characterised by depth range of 32.1-127.5 m, average resistivity of 296.8 Ω m, typical of medium-grained sand saturated with water. The highly resistive, impermeable materials overlying the aquifer units around Ajagba, Aiyesan, Agbetu, Ilutitun, Igbotako and Erinj suggests that the aquifer units are less vulnerable to near-surface contaminants than in Agbabu, Igbisin, Ugbo and Aboto where aquifers are overlain by less resistive materials. This study enabled the delineation of shallow aquifers, their subsurface disposition and promising areas for elaborate groundwater development in the area.

Key words: Geoelectric sounding, aquifer units, coastal plain sands, aquifer vulnerability

INTRODUCTION

Okitipupa area is underlain by the sedimentary rocks of southwestern Nigeria. The zone constitutes the easternmost segment of the extensive Dahomey basin. Studies have shown that sedimentary basins generally contain enormous quantities of water (Freeze and Cherry, 1979; Fetter, 1980; Kehinde and Loehnert, 1989; Edet and Okereke, 2002). To realise this fact, several countries worldwide have engaged in extensive studies of basins within their frontiers, using geological/hydrogeological, geophysical or chemical data, or a combination of the above, for proper identification and delineation of the water bearing units. Such studies (Leit and Barker, 1978; Overmeeren, 1989; Mbonu *et al.*, 1991; El-Waheidi *et al.*, 1992; Kalinski *et al.*, 1993; Frohlich *et al.*, 1994; Ebraheem *et al.*, 1997; Choudhury *et al.*, 2001; Edet and Okekepe, 2002; Lashkaripour, 2003).

Often afford the optimisation and proper management of the basins in order to enhance safe discharge and appropriately safeguarding the quality status of the water.

However, any rational development groundwater requires geophysical data input, among others. Few studies so far conducted in the area (Ako, 1982; Omosuyi *et al.*, 1999; Omosuyi, 2001) were based on borehole lithologic correlation and hydrogeophysical characterisation of the subsurface sequence for suitable location of groundwater abstraction points.

In this study, geoelectric resistivity sounding data have been used to delineate the boundaries, subsurface disposition and assess the vulnerability status of the shallow water bearing aquifers in the Coastal Plain around Okitipupa. The study is envisaged to upgrade our knowledge of the basin, enhance the success rate of groundwater abstraction boreholes in the area, in addition to serving as a useful guide to an elaborate groundwater development programme proposed for the area.

MATERIALS AND METHODS

Physiography, geology and hydrogeology: The study area (Fig. 1) is bounded by Longitudes 4° 22 'E and 5° 05 'E

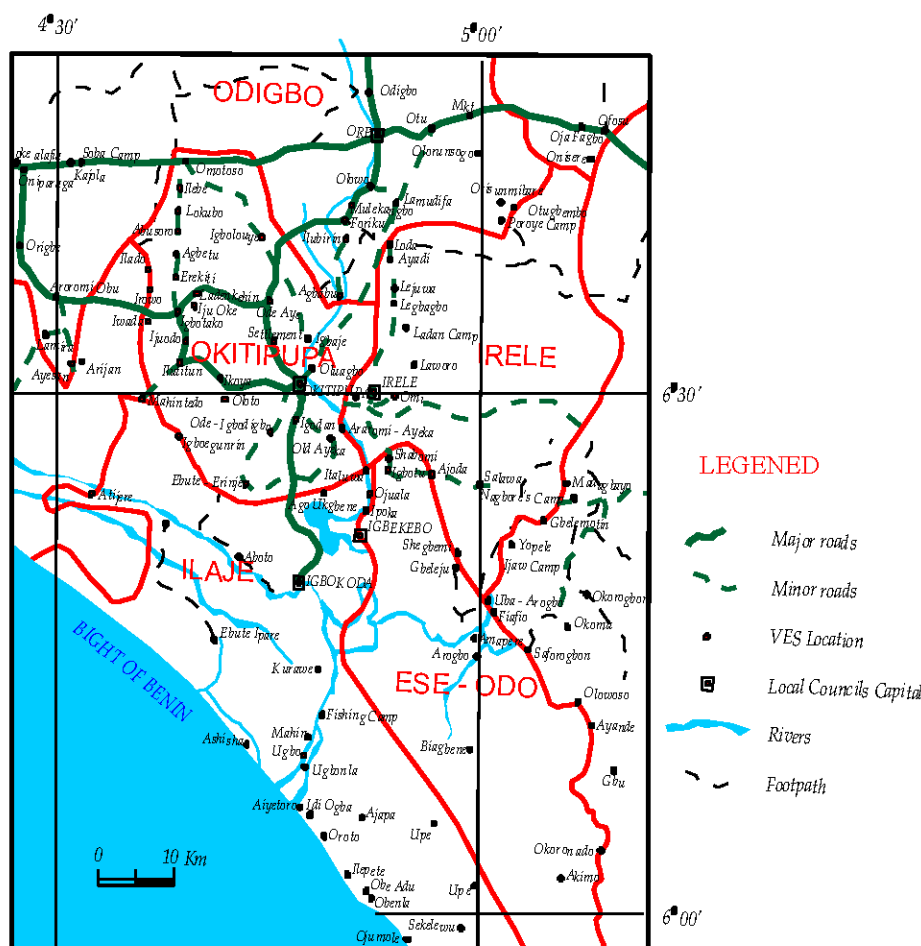


Fig. 1: Location map showing Okitipupa area

and latitudes $6^{\circ} 00'N$ and $6^{\circ} 40'N$. The terrain is regionally gently undulating southward; topographic elevations vary from about 84 m above sea level in the northern part, with gradual slope to a near sea level swamp flat in the coastal area to the south. The area is drained by many perennial streams and rivers among which are Ominla, Oluwa, Akeun, Ufara and Oni, while the southern part is particularly characterised by lagoons, coastal creeks, canals and several tributaries to the extensive River Oluwa. The annual temperature range from $24-27^{\circ}C$ and mean annual rainfall of over 2500 mm (Iloeje, 1981).

The area is underlain by the Coastal Plain Sands or the Benin Formation (Fig. 2). The sediments of the Coastal Plain, deposited during the Late Tertiary-Early Quaternary period (Jones and Hockey, 1964), consist of unconsolidated, coarse to medium-fine grained sands and clayey shale in places (Okosun, 1998). The sands are

generally moderately sorted and poorly cemented. The Benin Formation is overlain by lateritic overburden or recent alluvial deposits and underlain by the Paleocene Akinbo Formation. This formation is predominantly shaly. Outcrops of shales were mapped around a spring at Ode Aye (Omoyi, 2001). The Akinbo shale is underlain by the continental Cretaceous sediments of the Abeokuta Group (Omatsola and Adegoke, 1981).

The Coastal Plain sands constitute the major shallow hydrogeologic units in the area. Aquifers are characteristically continental sands, gravels, or marine sands. The lateritic earth overlying the sands, as well as the underlying impervious clay/shale member of the Akinbo Formation, constitute protective configuration for the aquifer units. Also, the high annual rainfall and other favourable climatic and geologic factors guarantee adequate groundwater recharge in the area.

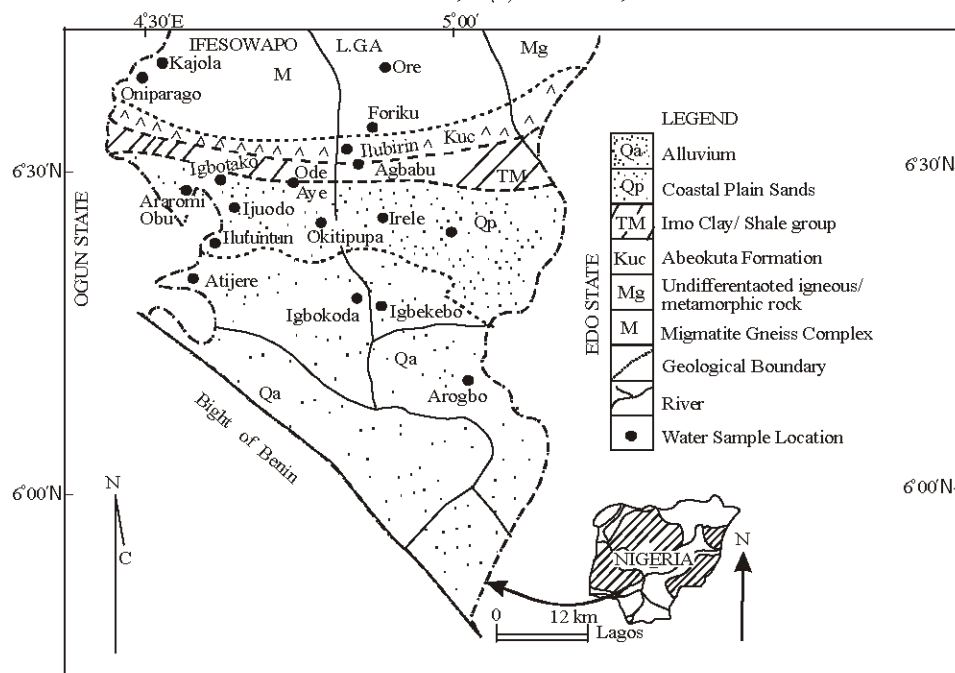


Fig. 2: Geological map of the study area (PTF, 1997)

Data acquisition and interpretation: Fifty Schlumberger Vertical Electrical Soundings (VES) were conducted across the study area using a maximum current electrode separation (AB) of 650 m. Figure 1 shows the VES locations. Resistivity measurements were made with a digital resistivity meter (PASI-E2 DIGIT) which allows for readout of current (I) and Voltage (V).

The field curves were interpreted through partial curve matching (Koefoed, 1979) with the help of master curves (Orellana and Mooney, 1966) and auxiliary point charts (Zohdy, 1965; Keller and Frischnecht, 1966). From the preliminary interpretation, initial estimates of the resistivity and thickness of the various geoelectric layers at each VES location were obtained. These geoelectric parameters were later used as starting model for a fast computer-assisted interpretation (Vander Velpen, 1988). The program takes the manually derived parameter as a starting geoelectric model, successively improved on it until the error is minimised to an acceptable level.

RESULTS AND DISCUSSION

Geoelectric and lithological characteristics: Figure 3 shows typical geoelectric curves corresponding to VES data from the study area. Curve types identified ranges from simple AK, QH, to HKH, HKQ, KHK and complex HAKQ, AKHKQ, etc types, reflecting facies or lithological variations in the area. The AK, HKH and HKQ types are the most preponderant, with each

constituting about 7.9%, while each of QH, KHK, HKHK, HAKQ and QHKQ accounts for about 5.3%. The general signature of the curves suggests alternate sequence of conductive-reflective, resistive-conductive layers, reflecting the unconsolidated nature of the Quaternary coastal plain sequence, characterised by intercalation of sands and clay/shale horizon (Omosuyi *et al.*, 1998). This reflects on the curves as discrete resistivity layers (Fig. 3).

Aquifer delineation: Electrical methods primarily reflect variations in ground resistivity. The electrical resistivity contrasts existing between lithological sequences (Dodds and Ivic, 1998; Lashkaripour, 2003) in the subsurface are often adequate to enable the delineation of geoelectric layers and identification of aquiferous or non-aquiferous layers (Schwarz, 1988). The geoelectric sequence suggests a subsurface geology characterised by alternation of sands/gravels, clay/shale and sandstone occurring at varying depths with variable thicknesses. The sand and gravel layers constitute the aquifer units. The geoelectric parameters of the aquifer units were determined from the interpretation of the sounding curves, assisted by the distinctive resistivity contrasts between the discrete geoelectric layers. The upper and lower aquifer horizons work are referred to as the surficial (upper) and intermediate (lower) aquifers, respectively.

The results of the interpretation were used to construct three interpretive sections AB, CD and EF,

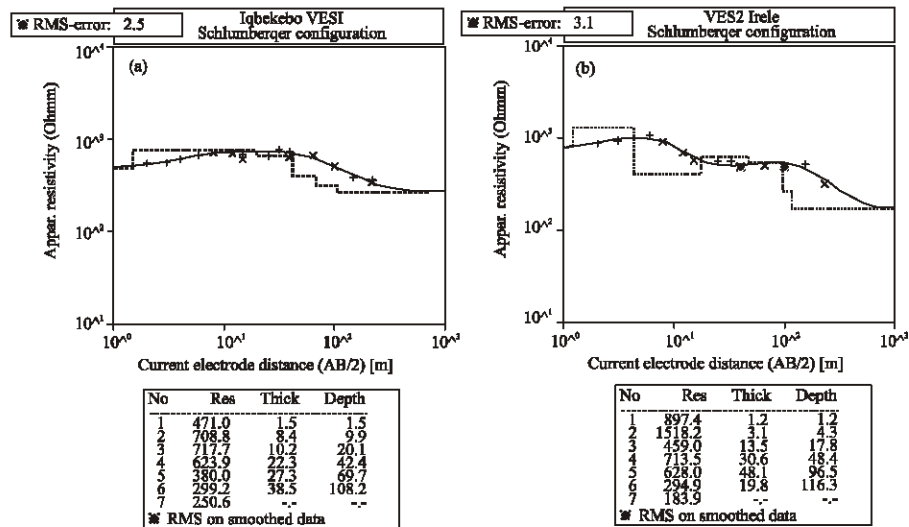


Fig. 3: Typical VES curves from Okitipupa area: (a) Igbotako, (b) Irele

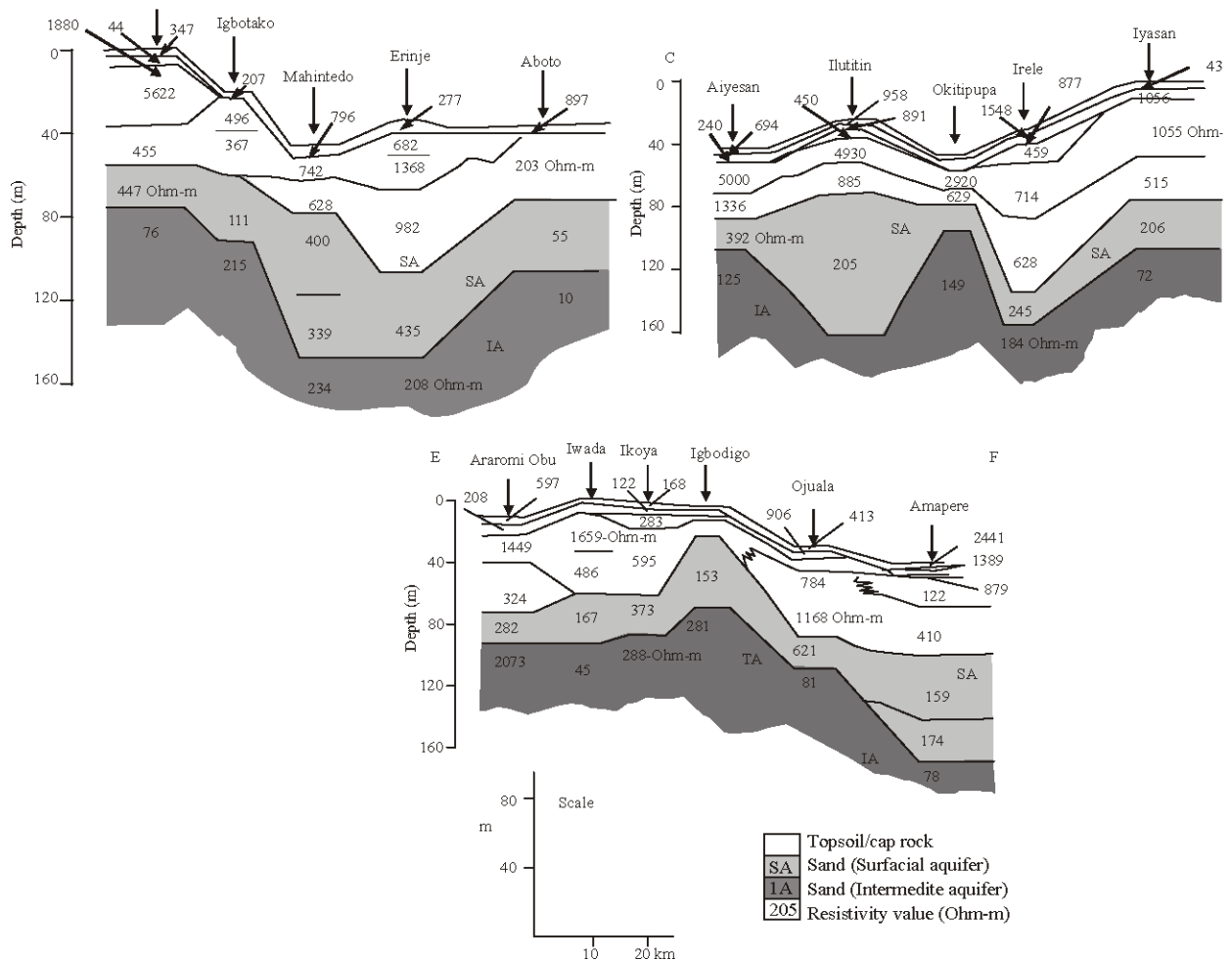


Fig. 4: Geoelectric section along north-south (AB), west-east (CD) and northwest-southeast directions in the area

taken in the north-south, west-east and northwest-southeast directions (Fig. 4). The sections (Fig. 4a, b) reveal that the surficial and intermediate aquifers are overlain in places by materials with variable thickness and resistivity parameters. In section AB (Fig 4a), the resistivity of materials overlying the upper aquifer ranges from 2-5622 Ωm . The depth to the top of the aquifer varies from 20.5-39 m. The high resistivity of the top layers may correspond to the unsaturated zone, as observed in Van Overmeeren (1989). The depth to the intermediate aquifer ranges from 52-79.8 m. In the area, depths to the top of the aquifer horizons tend to increase southward. The thickness and resistivity parameters of materials overlying an aquifer are important parameters in the assessment of the vulnerability of the underling aquifer (Kalinski *et al.*, 1993).

In geoelectric section CD, a west-east cross section (Fig. 4b), depths of occurrences range from 16.1-48.3 m and 28.1-96.4 m in the upper and intermediate aquifers respectively. The northwest-southeast section reveals that depth to the upper aquifer ranges from 15.5-61.5 m, while that of the intermediate aquifer varies between 54.7 and 97.5 m. The geoelectric sections show that the two aquifer units generally dip southward. Contour maps

showing the depth to the top of the aquifer units are shown in Fig. 5a and b.

The isopach maps constructed from the VES results (Fig. 6) show that the surficial and intermediate aquifers are highly variable in thickness across the area. In the former, thickness ranges from 5.1 m (at Loda) to 49.4 m at Erinje, with a mean value of 29.5m. This map shows that this unit thickens to the south in the area. The thickness of the intermediate aquifer on the other hand, ranges from 7.3 m at Ebute Erinje to 80.7 m around Ilutitun, with a mean value of 26.4 m. However, the maximum profile length of AB = 650 m adopted in this work could not delineate the intermediate aquifer in some sounding locations. Areas with thick aquifer unit may be good prospects for drilling boreholes with high yield expectations (Kelly, 1976; Mbonu *et al.*, 1991).

The isoresistivity maps for the area (Fig. 7a and b) are derived from the resistivity parameters of the delineated aquifers. The upper aquiferous zone show relatively high resistivity ranging from 55 Ω -1374 Ωm , with a mean value of 504.7 Ωm . These suggest lithology characterised by gravels and medium to coarse-grained sands (higher values), intercalated with fine-grained sands, silts and

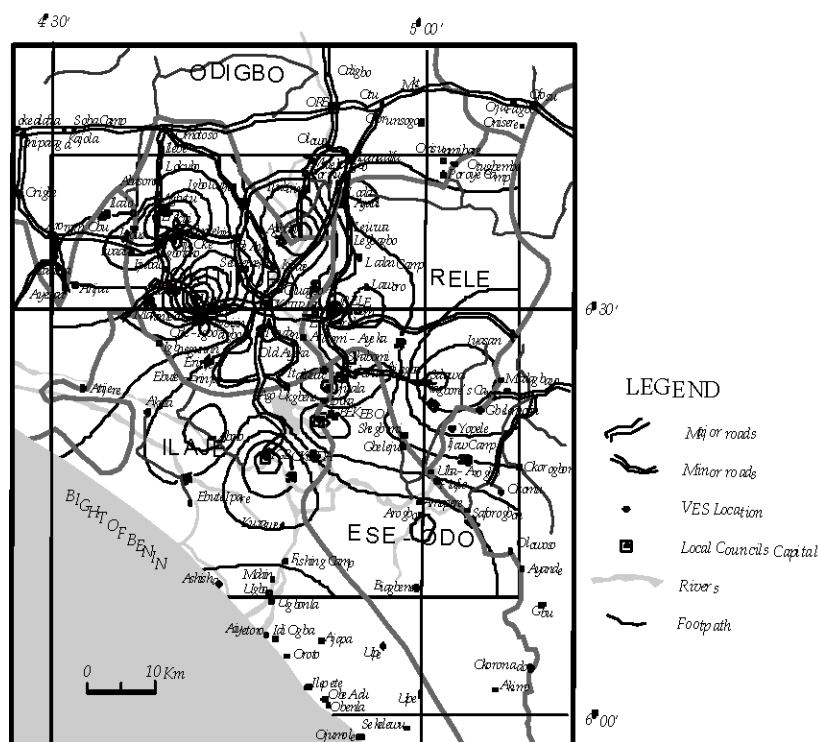


Fig. 5a: Depth to the top of surficial aquifer in the area

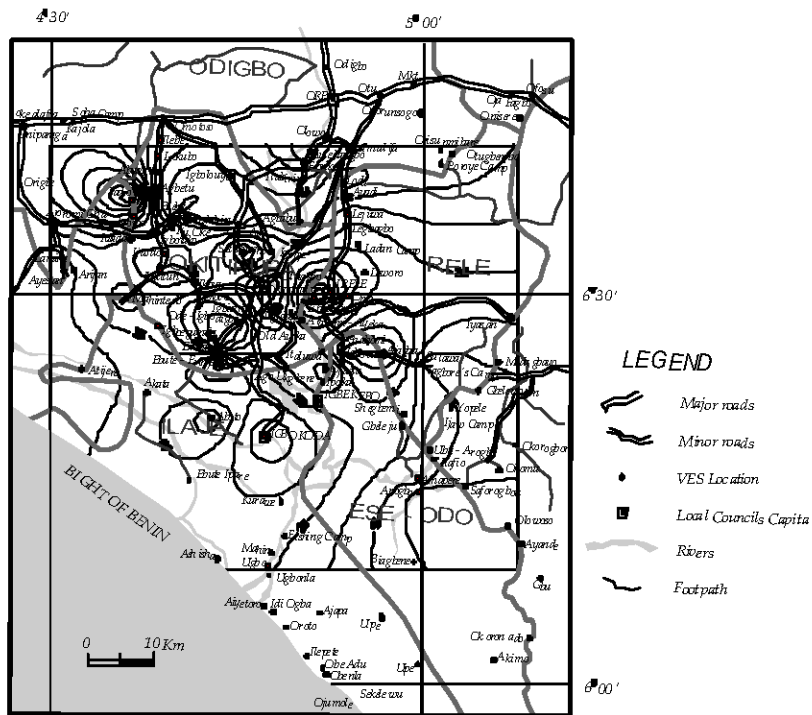


Fig. 5b: Depth to the top of intermediate aquifer in the area

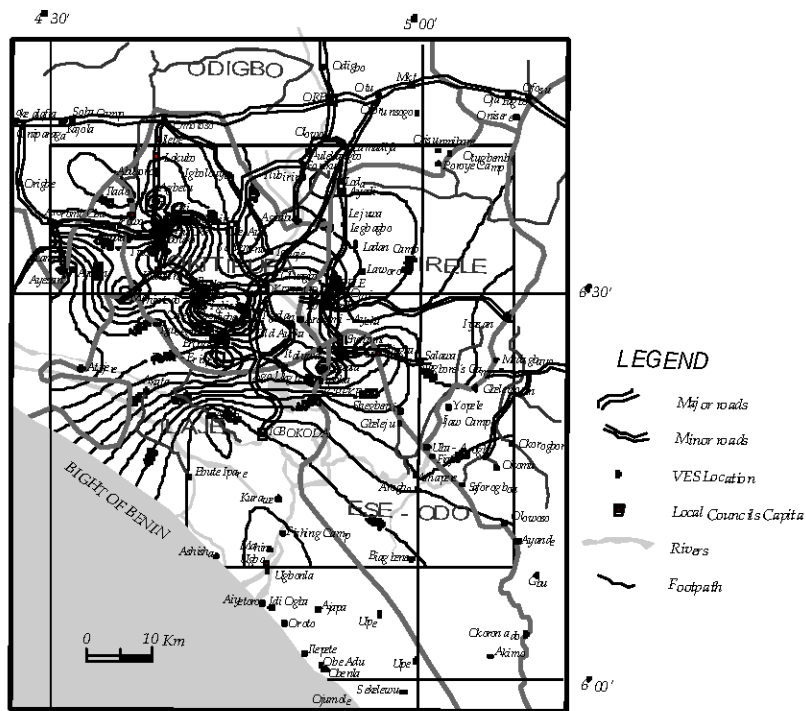


Fig. 6: Isophach map of surficial aquifer around Okitipupa

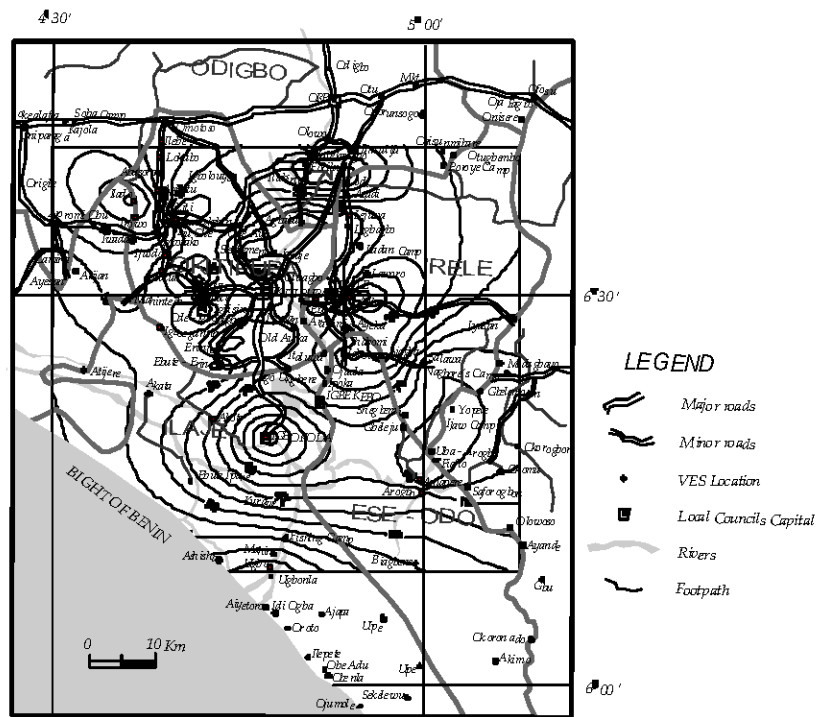


Fig. 6b: Isopach map of intermediate auifer around Okitipupa

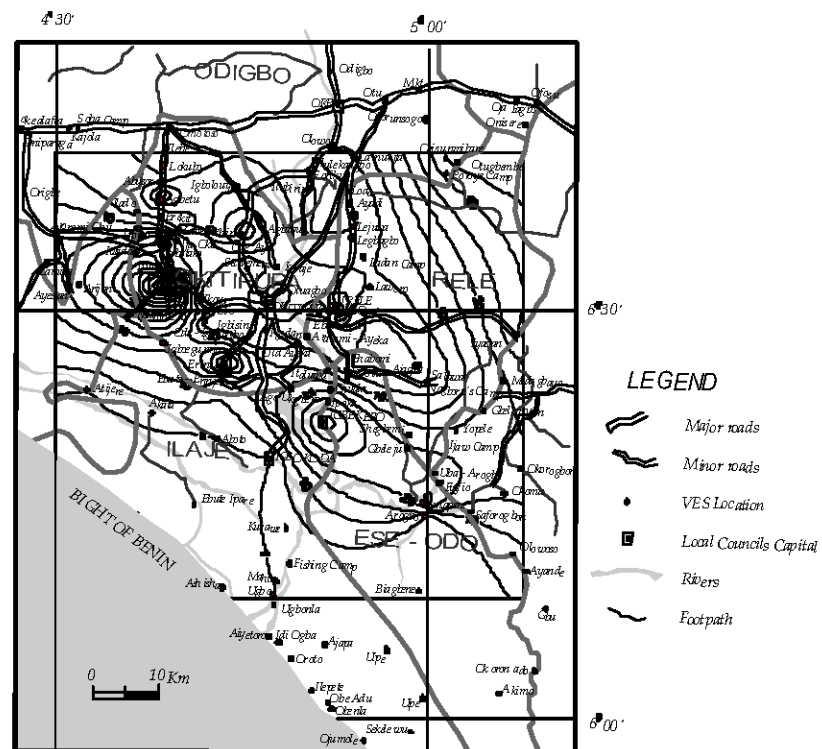


Fig. 7a: Isoresistivity map of surficial auifer around Okitipupa

The map displays the study area in the Odo Oke region, Oyo State, Nigeria. It shows the distribution of VES locations (marked with small squares) and local council capitals (marked with larger squares). The map includes major roads (thick lines), minor roads (thin lines), rivers (wavy lines), and footpaths (dashed lines). The map is bounded by coordinates 4°30'N to 5°00'N and 7°30'E to 8°00'E. A scale bar indicates 0 to 10 Km.

LEGEND

- Major roads
- Minor roads
- VES Location
- Local Councils Capital
- Rivers
- Footpath

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clay (lower values). In the intermediate aquifer, the resistivity range is 11-1001 Ωm , with a mean value of 296.8 Ωm . This value suggests better porosity and permeability and hence better groundwater saturation. Low resistivity values (11-55 Ωm) recorded around Aboto and Arogbo suggest saline or brackish water. Unconfirmed saline water intrusion into the coastal aquifers had earlier been reported in area (Omosuyi, 2001).

Aquifer potential and vulnerability

Potential rating: The assessment of the potentials of the surficial and intermediate aquifers in this study is based on aquifer thickness derived from VES data interpretation. The Quaternary coastal plain sands of the Dahomey basin around Okitipupa are generously porous and permeable (Okosun, 1998) important hydrogeologic parameters often synonymous with groundwater saturation. Studies, Ako (1982) and Omosuyi (2001) have shown that the sands of the Coastal Plain around the area are usually characterised by high resistivity, deriving from the coarse, gravely nature, rather than a measure of groundwater saturation disposition.

The VES-derived aquifer thickness in the upper and lower aquifer units have been used to zone the area into high (>30 m), medium (10-30 m) and low (<10 m) groundwater prospect zones as shown in Fig. 8.

CONCLUSION

The results of surface geoelectric sounding around Okitipupa, southwestern Nigeria, enabled the delineation of two shallow aquifer units within the Coastal Plain sands in the area. The upper/surficial aquifer system occurs at depth ranging from 5.8-61.5 m, with an average thickness of 29.5 m and materials characterised by average resistivity of 504.7 Ωm , suggesting gravely/coarse to medium sand. The top of the intermediate aquifer unit varies from 32.1-127.5 m, with a mean thickness of 26.4 m and relatively lower average resistivity of 296.8 Ωm , indicating medium to fine-grained sand and better groundwater saturation condition.

Based on the resistivity parameters and overall thickness of geoelectric layers overlying the aquifer units, the near surface aquifer systems in the study area are generally protected from contaminants infiltrating from the surface, with the intermediate one being relatively less vulnerable.

The integration of lithologic logs and other drilling data with surface geoelectric studies in the delineation of the aquifer systems and quantification of aquifer vulnerability in the area would enhance the accuracy of

the results. However, this study is envisaged to provide guidance for drilling programmes, continuity for understanding the subsurface disposition of the shallow aquifer systems and constitute a background information or useful guide for more elaborate groundwater development programme in the area.

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