*Journal of Geography, Environment and Earth Science International*

*Volume 27, Issue 11, Page 147-152, 2023; Article no.JGEESI.107644*
*ISSN: 2454-7352*

# Using the Electrical Resistivity Method to Assess Groundwater Iron Concentration in Otuoke and Environs (Nigeria)

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***Authors' contributions***

*This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.*

***Article Information***

DOI: 10.9734/JGEESI/2023/v27i11731

**Open Peer Review History:**
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/107644

***Original Research Article***

***Received: 14/08/2023***
***Accepted: 22/10/2023***
***Published: 17/11/2023***

## ABSTRACT

The resolution of subsurface structures using the electrical method is often beclouded by uncertainty due to geophysical similarities in the behaviour of earth materials. Thus the integration of techniques aimed at constraining the level of uncertainty. This was archived in this study using a combination of electric method, geochemical analysis and in-situ borehole login samples. 8 vertical geoelectrical soundings, 8 groundwater samples and 1 borehole log were analyzed with the aim of lithostratigraphic mapping of shallow sediments to identify aquiferous formations and to infer the spectral variation of iron concentration levels. From the results, two layers were delineated; a clay topsoil with a maximum depth of 0.5 m to 1.3 m, resistivity range of 15.8 Ωm to 112 Ωm and a coarse sand aquiferous layer encountered at a depth of 1.7 to 3.5 m with a resistivity of 84.5 Ωm to 225 Ωm both separated by a transition zone of sandy-clay, which becomes fine sand with depth, identified on the geoelectric section with a resistivity range of 12.5 Ωm to 74.5 Ωm occurring at

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depth 0.5 m to 1.3 m with a maximum thickness of 2.2 m. High iron concentration levels were observed to correlate with low resistivity values and vis-vaser, which agrees with empirical facts, that the electrical conductivity of porous mediums at shallow depth is principally a function of pore fluid conductivity which by extension the concentration of conductive minerals in groundwater.

*Keywords: Otuoke; resistivity; groundwater; iron concentration.*

## 1. INTRODUCTION

In most developing countries like Nigeria, human settlements that were commonly referred to as rural areas are gradually migrating into urban settlements due to population growth with a shift from traditional means to increasing demand for social amenities. The strategic position of water in human existence has made the quest for improved quality and quantity of potable water central to this urbanization. This has resulted in not only a heavy reliance on groundwater as a primary source of domestic water supply but also for both agricultural and local industrial uses. Before recently, most communities within the lower ebb of the River Niger due to their riverine nature source water from local streams and hand-dug wells. But Otuoke is one such community, due to the sitting of a university and some government parastatals the area has witnessed an influx of associated companies and people with its attendant demand for portable water.

Various attempts at developing a municipal water supply system are visible within the community but not functional or abandoned, this has created an avenue for self-help which is typified by the indiscriminate sinking of boreholes.

Presently, groundwater exploration in Otuoke with reference to quality has yielded low success as typified by the extremely high iron concentration in borehole water and the number of abandoned wells. This is due largely to a lack of adequate knowledge of the geological, geophysical and hydrogeological estate of the subsurface [1-4]. Ranjana 2010 clearly stated that the quality of public health depends greatly on the quality of groundwater. The presence of heavy metals like iron, even at small concentrations in water is an indication of contamination and the persistent consumption of such water could result in adverse health effects [5]. The quality of groundwater in a particular region is a function of physical, chemical and biological parameters, variations of which are greatly influenced by geological formations and anthropogenic activities [4-8].

The cost implication of geophysical know-how has been one of the major factors that have increased the gap in knowledge, thus the need for cost-effective methods to bridge the gaps. Since a correlation between hydraulic and electrical properties is possible [7], as both properties are related to the pore space structure and heterogeneity, the integration of aquifer parameters from geoelectrical parameters extracted from surface resistivity measurements is an effective method for estimating aquifer properties and potentials [9-11].

Presently, the evaluation of aquifers for groundwater yield and quality has been simplified with the application of the geoelectric method, principally the Vertical Electrical Sounding (VES) technique which has witnessed rapid advances in field procedures, microprocessors and associated numerical modelling solutions [3,7,12] VES methods has been found useful in delineating formations and aquifer zones [2, 7, 3], saline water intrusion and other heavy metal concentration in groundwater [6,12].

Physio-chemical studies within the study area have shown that for the heavy metals, iron was most predominant, ranging from 0.11 to 10 mg/L. [5] similar results were obtained in most parts of the state with above 60% of groundwater sampled showing results in excess of the domestically acceptable limit of 0.3 mg/L [9].

This study attempts to understand the lithologic variation within the study area, identify the aquifer configuration and determine the iron distribution pattern in groundwater within the shallow aquifer zone. Such a pattern will enable further scientific deductions to be made and hence guide the choice of suitable location, and depth and also reduce the economic and health implications of high iron contamination in groundwater.

### 1.1 Study Area

The hydrogeology of an area is controlled by its climate and the underlying geological formations [3]. Geological, the study area falls within the

**Table 1. Stratigraphic column of the quaternary Niger Delta [2]**

| Geologic Unit | Lithology | Age |
|---|---|---|
| Alluvium | Gravel, sand, clay and silt | Recent |
| Freshwater Backswams p, Meander Belt | Sand, clay, silt and gravel | Quaternary |
| Mangrove and Salt Water/Backswamps | Medium-fine sands, clay and silt | Quaternary |
| Active/Abandoned Beach Ridges | Sand, clay, and silt | Quaternary |
| Sombreiro-Warri Deltaic Plain | Sand, clay, and silt | Quaternary |
| Benin Formation | | Miocene |

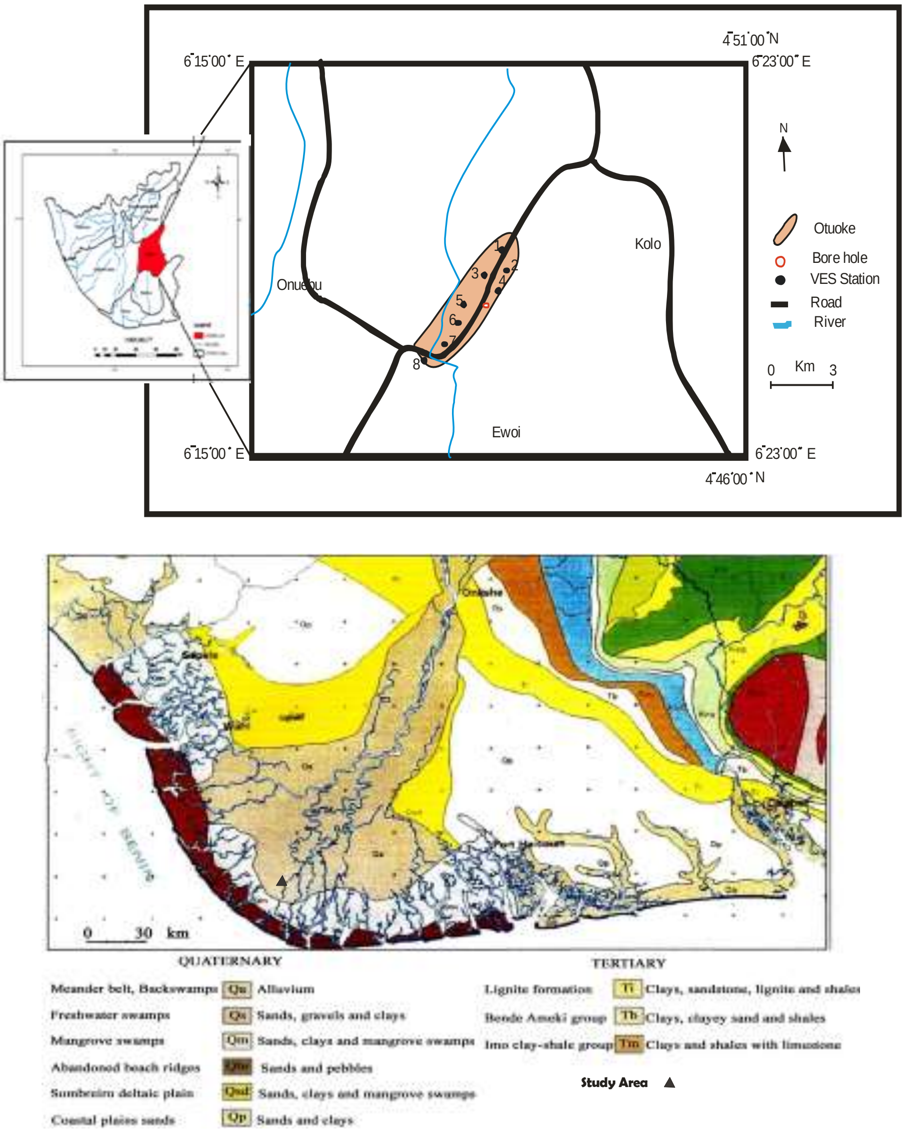


**Fig. 1. Map of Study Area (Otuoke Community within Ogbia LGA, Bayelsa State). After [2]**

quaternary alluvium sediments (gravel, sand, clay and silt intercalation) which range between 40 - 150 m thick underlay by the Benin Formation which is a part of the lithological sequencing o the Niger Delta region. It serves as a high-yielding and productive aquifer for the region [2]

Table 1. The study area is located within the freshwater tropical rain forest of the Niger Delta region with the attendant dense rain forest and swamps which are the vegetative flats formed by the network of river, and streams tributaries of the river niger responsible for effective groundwater recharge which accounts for a shallow water table of between 5m - 10m in most areas. During the peak of the rainy season (June to July), groundwater seepage is commonly observed with high iron content which is visible as reddish iron stains along seepage tracks on sands and on every borehole treatment and storage facility within the study area. The area is drained by the same network of rivulets that empties into the Atlantic Ocean. Groundwater exploration studies within the region show a widespread, heterogeneous (both vertically and horizontally) high Fe (> 0.3 mg/L) concentration in groundwater [4].

## 2. MATERIALS AND METHODS

Geoelectrical drilling was done using an SAS 1000 ABEM Terrameter. Vertical Electric Sounding (VES) technique using a Schlumberger array was carried out in eight (8) locations within the vicinity of existing boreholes from which lithostratigraphic and hydrologic deduction were made. The Schlumberger array was preferred due to its renown for high signal-to-noise ratios, good resolution of horizontal layers, and good depth sensitivity [4,13].

Field data were interpreted through the following steps; *1.* partial curve matching of field and geoelectric standard curves *(auxiliary method)*, *2.* an initial geoelectrical model (thicknesses and corresponding resistivities) depending on the geology of the area was prepared, and entered into the geoelectric modeling package. *3.* Each VES was subjected to forward iterative modelling to reach the best fit between the calculated and the smoothed field curve. *4.* Using inversion software, a model of geoelectrical distinct layers within the study depth of 80m was established. Well logs were also used to constrain VES results.

Hydrochemical analysis of water samples from boreholes within the study depth range were analyzed for iron (Fe) concentration.

## 3. RESULTS AND DISCUSSION

### 3.1 Lithologic Correlation

The geoelectric section result as presented in Table 2, indicates a three-layer system (H1, H2 and H3) while the borehole (BH) section (Fig. 2) indicates a two-layer structure. Layer 1, with an average thick of 0.7 m and a resistivity range of 15.8 Ωm to 112 Ωm occurring as the topmost unit is interpreted as clay. Layer 2, with an average thickness of 7.2 m and resistivity range of 12.5 Ωm to 74.5 Ωm was observed from drill cuttings to be a transition zone between the upper clay unit and the aquiferous zone and is made up of sandy clay which becomes fine sand with depth. Layer 3, which is interpreted as the aquiferous sand [5,4] is characterized by resistivity varying between 84.5 Ωm to 225 Ωm with considerable thickness range from 67 m to 86 m and extending below the study depth.

Correlation along North-South trend (Fig. 2), shows a relatively thin clay topsoil in most areas but it is observed to be capped by a thin top sand unit in Loc 3 and 4. This sand unit is due to the sand filling done within the Federal University campus before construction. The basal unity (aquiferous sand) and the clay topsoil are both continuous over the study area.

**Table 2. Summary of aquifer geoelectric and geochemical parameters**

| VES No. | Layer Thickness (m) | | | Resistivity of Layers | | | Iron Concentration (ppm) |
|---|---|---|---|---|---|---|---|
| | **H1** | **H2** | **H3** | **$\rho$1** | **$\rho$2** | **$\rho$3** | |
| **Loc 1** | 0.5 | 27 | 40.5 | 52 | 74.5 | 84.5 | 3.0 |
| **Loc 2** | 0.5 | 2.0 | 77 | 15.8 | 12.5 | 164 | 1.1 |
| **Loc 3** | 1.35 | 2.20 | 78.5 | 107 | 14.5 | 225 | 0.9 |
| **Loc 4** | 1.34 | 2.20 | 78.5 | 112 | 14.5 | 217 | 0.7 |
| **Loc 5** | 0.5 | - | 67.0 | 52.0 | - | 74.0 | 2.5 |
| **Loc 6** | 0.5 | 1.20 | 66.7 | 52.0 | 74.5 | 84 | 3.2 |
| **Loc 7** | 0.5 | 1.20 | 52.8 | 52.0 | 74.5 | 80.1 | 2.9 |
| Loc 8 | 0.5 | 25 | 42 | 52.0 | 74.0 | 82 | 3.4 |

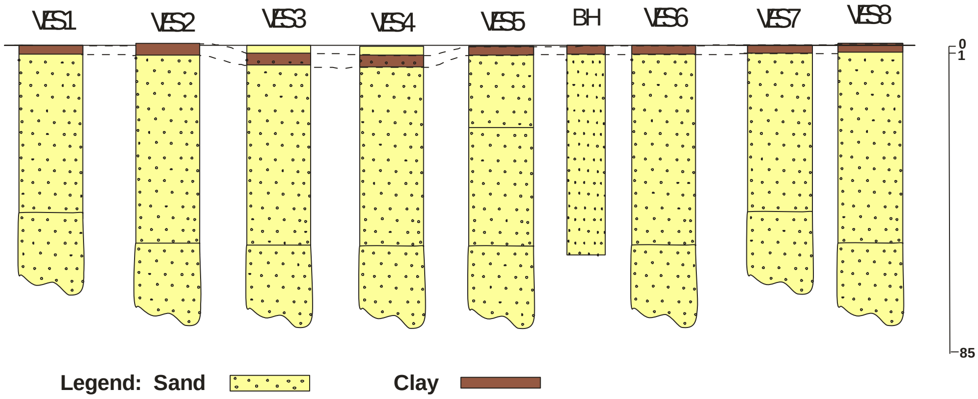


**Fig. 2. North – South lithostratigraphic correlation**

### 3.2 Iron Concentration Correlation

Hydrochemical analysis of groundwater samples from boreholes adjacent to Vertical Electric Sounding (VES) were analyzed for iron concentration level in relation to the World Health Organization (WHO) standard of 0.3 (ppm) and are presented in Table 1. The iron concentration level within the aquiferous zone in the area was observed to be extremely higher than the WHO standard of 0.3 ppm [5], with the highest occurring around Loc 1 with 3.0 ppm. When compared to the resistivity values, it is observed that low resistivity values correspond to a high iron concentration and vice versa (Table 2). In VES 1 aquifer resistivity value is 74.5 Ωm, the iron concentration level is 3.0 ppm, while in VES 6, VES 2, VES 3 and VES 4 the aquifer resistivity values are 84 Ωm, 164 Ωm, 255 Ωm and 217 Ωm respectively and the iron concentration levels are 1.1 ppm, 0.9 ppm and 0.7 ppm respectively; this correlation agrees with empirical theory of current conductivity for earth materials. According to [1,14,14] on a purely empirical basis, the hydraulic conductivity of aquifer sediment could be linked to the conductive nature of pore fluid content. In most rock materials the porosity and the chemical content of the water filling the pore spaces are more important in governing resistivity than the conductivity of the mineral grains of which the rock is composed [14]. When porous rocks, particularly those with large concentrations of magnetite or graphite, lie at shallow depths or occur at such great depths that all pore spaces are closed by ambient pressure, the conduction through them takes place within the mineral grains. But, at shallow depths in terrains with low conductive rock matrix as typified in the study area and most areas in the Niger Delta region [2] with loss of sand sediments, the presence of water controls much of the conductivity variation and the measurement of resistivity is, in general, a measure of water saturation, chemical composition and connectivity of pore space [13,15-17]. This electrolytic conduction is via the movement of ions in groundwater. This mechanism is the major form for current flow at shallow depths within the study area as collaborated by resistivity variation with varying iron concentrations.

## 4. CONCLUSION

Lithostratigraphic delineation, identification of the aquiferous zone, and the estimation of groundwater quality and variation within the study area were archived using a combination of geoelectric sounding, insitu well logging and hydrogeochemical analysis. Two principal layers were identified; a clay top soil with a resistivity range of 15.8 Ωm to 112 Ωm and a coarse sand aquiferous layer with resistivity varying between 84.5 Ωm to 225 Ωm both separated by a transition zone of sandy-clay which becomes fine sand with depth. This unit is identified on the geoelectric section with a resistivity range of 12.5 Ωm to 74.5 Ωm occurring at depths 0.5 m to 1.3 m with a maximum thickness of 2.2 m with the exception of Loc 1. Depth to the aquifer ranges from 1.7 m to 3.5 m in most areas with a resistivity range of 74.5 Ωm to 225 Ωm. However, the correlation of geoelectric sounding and hydrochemical analysis results showed that the variations in resistivity value within the aquifer zone were due to the variation in iron concentration level within the pore fluid. This agrees with the empirical conclusion that the hydraulic conductivity of aquifer sediment could be linked to electrical resistivity through the concept of pore fluid content. High conductive content generally corresponds with low resistivity and high hydraulic conductivities, and vice versa.

The study also highlights a very low groundwater quality and an imminent health and economic challenge for residents of the study area where groundwater is presently the main source of portable water. This explains the reddish-yellow staining on laundry, and household fixtures, and the metallic taste and offensive odor of table water.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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