Electrical Resistivity Mapping; A Case Study of Groundwater Iron Concentration in Otuoke and Environs

Abstract

The resolution of subsurface structures using electrical method is often beclouded by uncertainty due to geophysical similarities in the behavior 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 insitu 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 aquiferousformations andto infer the specteral variationofiron concentration levels. From the results, two layers were delineated; a clay top soil with a maximumdepth of 0.5 m to 1.3 m, resistivity range of 14.5 Ωmto 52Ωm and a coarse sand aquiferous layer encountered at depth 1.7 to 3.5 m with resistivity of 84.5Ωm to 225Ωm both separated by a transition zone of sandyclay, fine sand and dry coarse sands identified on the geoelectric section with a resistivity range of 74.5Ωm to 112Ωm occurring at 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 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.

Key words: Otuoke**,** *Resistivity, groundwater, iron concentration*

1. Introduction

In most developing countries like Nigeria, human settlements that were commonly referred to as rural areasare gradually migrating into urban settlement due to population growth with a shift from traditional means to increasing demand for social amenities. The strategic position of water to human existence has made the quest for improved quality and quantityof potable water central to these urbanization. This has resulted innot only a heavy reliance on ground water as a primary source for domestic water supply but also for both agricultural and local industrial uses. Before recent, most communities within the lower ebb of the River Niger due to theirriverian nature source water from local streams and hand dug wells.But Otuoke one of such communities, due to the sitting of a university and some government parastartals the area has witnessed an influx of associated companies and peoplewith its attendant demand for portable water.

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

Presently, groundwater explorationin Otuokewith reference to quality has yielded low success as typified by the extremely high iron concentration in bore hole water and the number of abandoned wells.This is due to a lack of adequate knowledge of the geological, geophysical and hydrogeological estate of the subsurface (Okiongbo and Akpofure, 2012), (Thankgod and Lawrence, 2022).The quality of groundwater in a particular region is a function of physical, chemical and biological parameters, variation of which are greatly influenced by geological formations and anthropogenic activities (Subramani and Damodarasamy 2005).

Presently, evaluation of aquifers for ground water yield and quality has been simplified with the application of geoelectric method, principally the Vertical Electrical Sounding (VES)technique which has witness rapid advances in field procedures, microprocessors and associated numerical modeling solutions (Ward, 1990; Loke, 2000; Okiongbo and Akpofure, 2012).VES methods has been found useful in delineating aquifer zones, iron (Fe) and other heave metal concentration in ground water(Loke, 2000; Kasidi S., 2017; Okiongbo et al., 2019).

This study attempts to understand the lithologic variation within the study area, identify the aquifer configuration and to determine theiron 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, depth and also reduce the economic and health implication 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 (Olayinka, 1990). Geological, the study area falls within the quaternary alluvium sediments (gravel, sand, clay and silt intercalation) which ranges 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 (Allen 1965)Table 1.The location of study issurrounded by a dense rain forest and a network of lakes, river, and streams responsible for effective groundwater recharge which accounts for a shallow water table of between5m - 10m in most areas. During the peak of raining season (June to July) groundwater seepage are 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. Groundwater exploration studies within the region showa widespread, heterogeneous (both vertically and horizontally) high Fe (>0.3 mg/L) concentration in groundwater (Okiongbo et al., 2019;).

Table 1. Stratigraphic column of thequatenaryNiger Delta (after Allen, 1965).

Geologic Unit	Lithology	Age
Alluvium	Gravel, sand, clay and silt	
Freshwater Backswamp, Meander Belt	Sand, clay, silt and Gravel	Quatenary

Mangrove and Salt Water/Backswamps	Medium-fine sands, clay and silt	
Active/Abandoned Beach Ridges	Sand, clay, and silt	
Sombreiro-Warri Deltaic Plain	Sand, clay, and silt	
	Benin Formation	

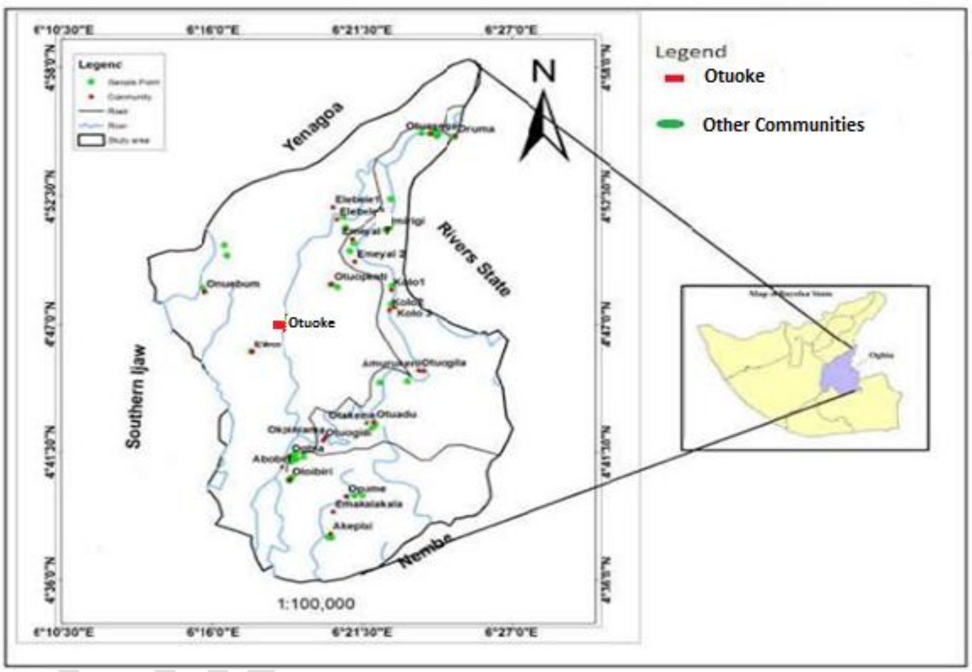

Figure 1. Map of Study Area (Otuoke Community within Ogbia LGA, Bayelsa State).

2. Materials and Methods

Geoelectrical drilling was done using SAS 1000 ABEM Terrameter. Vertical Electric Sounding (VES) technique using slumberger array was carried out in eight (8) locationswithin the vicinity of existintingboreholesfrom which lithostratigraphic and hydrologicdeduction were made.The slumbergerarraywas preferred due to its renown for high signal-to-noise ratios, good resolution of horizontal layers, and good depth sensitivity (Ward, 1990; Steve, 2000;Sikander, 2010).

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 forwarditerative modeling to reach the best fit between the calculated and the smoothed field curve. *4.* Using inversion software, a model of geoelectrical distinct layers within thestudydepth of80m was established. Well logs were also used to constrain VES results.

hydrochemical analysis of water samples from borehole within the studydepth range were analyzed for Fe concentration.

3. Result and Discussion

Table 2. Summary of aquifer geoelectric and geochemical parameters.

VESNo.	Layer Thickness (m)			Resistivity of Layers (Ωm)			Iron Concentration (ppm)
	H1	H2	H3	ρ_1	ρ_2	ρ_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	14.5	107	225	0.9
Loc 4	1.34	2.20	78.5	14.5	112	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	84.0	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	82.0	3.4

Lithologic Correlation

The geoelectric sections indicated a three layer system while the borehole section BH (Fig.2) indicted a two layer structure. The second layer in the geoelectric section is observe from drill cuttings to be a transition zone between the upper clay unit and the aquiferous zone made up of claysand, fine sand and dry coarse sands. Correlation along North -South trend (Fig.2), shows a relatively thin clay topsoil in most areaswith resistivity range of 14.5 Ωm to 52Ωm, but its 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 aquiferous sand is characterized by resistivity varying between 84.5Ωmto 225Ωm with considerable thickness range of about 67 to 86 meters and extending below the study depth. Figure 2, shows that both layers are continuous over the study area.

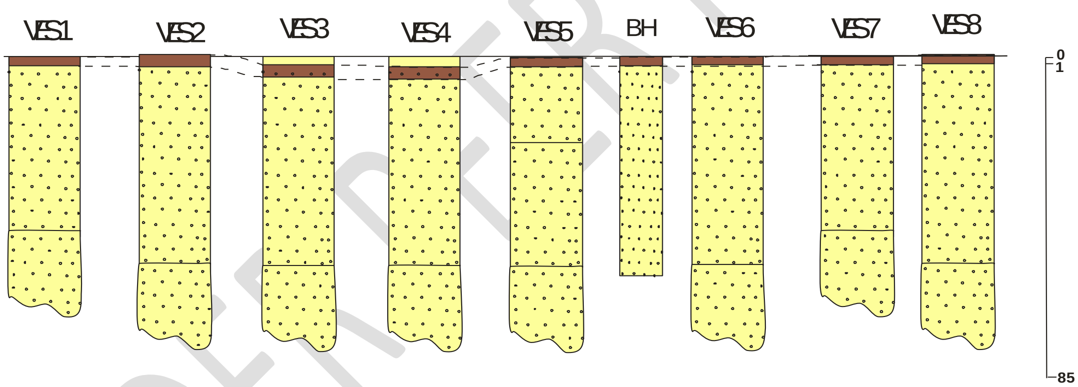

Figure 2: North – South lithostratigraphic correlation

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 World Health Organization (WHO) standard of 0.3 (ppm). 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 with the highest occurring around Loc 1 with 3.0 ppm. When compared to the resistivity values, it is observed that low resistivity values corresponds to a high iron concentration vic-versa. (Table 2).

In VES 1 aquifer resistivity value 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 1.1pmm, 0.9 ppm and 0.7 ppm respectively; this correlation agrees with empirical theory of current conductivity for earth materials. According to Kasidi (2017); Okiongboand Edirin (2012); Keller and Frischnechk, (1966); ,on a purely empirical basis the hydraulic conductivity of aquifer sediment could be linked to the conductive nature of pore fluid content. At shallow depth, the presence of water controls much of the conductivity variation and the measurement of resistivity is, in general a measure of water saturation, mineral composition and connectivity of pore space (Sikander, 2010;Steve, 2000).This electrolytic conduction is via the movement of ions in groundwater.This mechanism isthe major form for current flow at shallow depths in the absence of conductive minerals like sulfides and graphites.

Conclusion

Lithostratigraphic delineation, identification of the aquiferous zone, the estimation of groundwater quality and variationwithin the study area was 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 14.5 Ωm to 52Ωmand a coarse sand aquiferouslayer with resistivity varying between 84.5Ωm to 225Ωm both separated by a transition zone of sandyclay, fine sand and dry coarse sandsidentified on the geoelectric section with a resistivity range of74.5Ωm to 112Ωmoccurring at depth 0.5 m to 1.3 m with a maximum thickness of 2.2 m with an exception of Loc 1.. Depth to the aquifer ranges from 1.7 mto 3.5 m in most areas with a resistivity range of 74.5Ωm to 225Ωm. However, correlation of geoelectric sounding and hydrochemical analysis results showed that the variations in resistivity value within the aquifer zone was due to the variation in iron concentration level witnin 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 resistivities and high hydraulic conductivities, and vice versa.The study also highlights a very low groundwater quality and an imminent health and economic challenge for residence of the study area were groundwater is presently the main source for portable water. This explains the redish,-yellow staining on laundry, household fixtures, and the metallic taste and offensive odor of table water

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