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Digital Evaluation of Resistivity Model for Geological Interpretations in Buguma, Rivers State

Oghonyon, Rorome., and Osaki, Lawson Jack.
[1]*Department of Geology, University of Port Harcourt, Rivers State, Nigeria.*
[2]*Department of Physics/Geology, Federal University Otuoke, Bayelsa State.*

Abstract
This study investigates the vulnerability of coastal aquifers in Buguma, Rivers State, Nigeria, to both iron water contamination and saltwater intrusion using geoelectrical methods. The region is part of the Niger Delta and is underlain by the Benin Formation, a highly permeable aquifer system susceptible to contamination due to its shallow water table and proximity to tidal creeks. The electrical resistivity method was employed using ADMT digital terrameter and Pool Finder Plus to characterize subsurface formations and map vulnerable zones. Results revealed two major contamination fronts: ferruginous groundwater at shallow depths (0–85m) and progressive saline intrusion at deeper intervals (120–160m). Low resistivity values at these depths indicate increased ionic concentration, reflecting active intrusion processes rather than static conditions. The findings highlight a dual contamination scenario threatening water quality and availability. The study recommends immediate aquifer protection strategies, including regulated groundwater abstraction, continuous monitoring of the saltwater–freshwater interface, and strategic borehole siting to safeguard potable water supply. This research underscores the importance of integrating geophysical data with hydrogeological understanding for sustainable groundwater management in coastal communities.
Keywords: *Ferruginous water, Buguma, Niger Delta, Coastal Aquifer, Benin Formation, Resistivity.*

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I. Introduction

The increasing demand for potable water in the Riverine areas of Niger Delta has called for a scientific approach to the existing insufficient water supply in the region. The attempt to augment surface water supply and rain harvesting, which is of narrow opportunity in the Niger Delta with groundwater has called for a critical groundwater research. Thus, it is imperative to take a detail look on the water resources in Buguma, Rivers State, because of its expanding population, especially in this coastal region. However, proper management, development, and use of fresh water in coastal areas are necessary to prevent saltwater contamination of existing water supplies. Sound management decisions can be made best when based on available information; therefore, it is desirable to gather as much data as is economically reasonable to support these decisions.

Access to potable groundwater remains a critical challenge in many low-lying coastal regions of the Niger Delta, where rapid population growth and increasing water demand are exerting pressure on fragile aquifer systems. Unlike inland aquifers, coastal aquifers are particularly vulnerable to dual contamination processes iron enrichment from ferruginous sediments at shallow depths and saltwater intrusion at greater depths. These processes compromise water quality, infrastructure integrity, and public health, often leaving communities with limited safe water options (Werner et al., 2013; Post et al., 2018).

The Niger Delta, located in southern Nigeria, is characterized by extensive fluvio-deltaic deposits, high rainfall, and complex hydrological interactions. The regional aquifers are largely unconfined, with high permeability and shallow water tables, making them highly susceptible to both natural and anthropogenic influences. Iron contamination is common in these aquifers, typically resulting from the dissolution of iron-bearing minerals under reducing conditions. This leads to elevated iron concentrations in groundwater, imparting a reddish-brown color, metallic taste, and staining of plumbing fixtures — all indicators of poor water quality (Appelo & Postma, 2005).

More critically, the intrusion of seawater into freshwater aquifers due to hydraulic gradient reversal and over-abstraction has been widely documented in coastal zones worldwide (Barlow & Reichard, 2010; Werner et al., 2013). Saltwater intrusion lowers freshwater availability, increases total dissolved solids (TDS), and leads to long-term aquifer degradation that is difficult and expensive to reverse. In places like Buguma, where groundwater is the major source of potable water, this situation represents both an environmental and socio-economic threat.

The essence of employing the use of electrical surveys is to determine the subsurface resistivity distribution by making measurements on the ground surface and with the view of understanding certain points along the earth surface in which borehole drilling can be done. From these measurements, the true resistivity of the subsurface can be estimated. The ground resistivity is related to various geological parameters such as the heavy metals, fluid content, porosity and degree of water saturation within the subsurface layers. Electrical resistivity surveys have been used for many decades in hydrogeological (involving borehole drilling activities), mining and geotechnical investigations. More recently, it has been used for environmental surveys.

Extensive exploitation of coastal aquifers that are hydraulically connected to the sea usually results in a reduction in groundwater quality due to seawater intrusion. However, continued groundwater withdrawals, compounded by a decrease in groundwater recharge, can trigger the seawater–freshwater interface to move inland resulting in additional salinization of the coastal aquifer. In this case, coastal aquifers are threatened by an increase in seawater intrusion with sea level rise.

One of the methods of monitoring depths to iron water presence within the subsurface rock layers and saltwater movement in coastal areas is the use of electrical resistivity. This method allows monitoring of a large area at a comparatively small cost. In addition, surface resistivity measurements can be used to give supplemental water quality control in areas between observation wells. The purpose of this study is to investigate using electrical resistivity tools (ADMT: Digital Resistivity Terrameter and Pool Finder Plus) to aid in defining depths to fresh water Aquifers, iron water presence and fresh water/saltwater interface at the subsurface layers at Mr. Obene Basoene Cotterell's Compound, Buguma, Rivers State.The work involves the use of electrical resistivity method in exploring for Aquifer depths to freshwater Formation for borehole drilling and to evaluate areas within the subsurface layers where saltwater intrusions occur.

Conventional methods of groundwater exploration are often insufficient to detect these subtle hydrochemical transitions at depth. Electrical Resistivity Tomography (ERT) has emerged as an effective non-invasive geophysical technique capable of resolving variations in subsurface electrical conductivity, thereby distinguishing between freshwater, iron-rich groundwater, and saline water zones (Loke et al., 2013; Chambers et al., 2014). Its sensitivity to ionic concentration and lithological variations makes it particularly suited for mapping saline–freshwater interfaces, identifying contaminated zones, and guiding borehole placement for sustainable water development.

This study applies ERT to investigate the subsurface geological and hydrogeophysical structure of Buguma in Rivers State, with a specific focus on iron water formations at shallow depths and saltwater intrusion from approximately 120m to 160m downward. By integrating geoelectrical data with hydrogeological knowledge of the region, the study aims to generate high-resolution subsurface information that can support sustainable groundwater abstraction, protection, and management in the area.

The specific objectives of this study are to characterize the subsurface geoelectric structure of Buguma using ERT, identify and delineate iron water zones at shallow depths and map and evaluate the extent of saltwater intrusion at greater depths.

Geologic Setting and Hydrogeology of the Area

Buguma town is an administrative town as it is the headquarters of Asari-Toru Local Government Area. It is also a traditional headquarters of the Kalabari ethnic nationality. Buguma can be accessed by road and water from Port Harcourt and all other towns and villages surrounding. The town has a general hospital and as well as three primary school and secondary schools and also a magistrate court. The main economic activities in the area are transportation, fishing, trading and other local craft activities. Tourists are attracted to the place because of it natural beaches and also the traditional festivals that go on every quarter of the year.

Buguma is located within the central part of the Niger Delta, southern Nigeria. The area lies within the low-lying coastal plain and deltaic environment characterized by recent and Tertiary sediments. The subsurface geology is dominantly composed of the Benin Formation, which forms the uppermost lithostratigraphic unit of the Niger Delta Basin. This formation is made up primarily of coarse to medium-grained, poorly consolidated sands, with minor clay and shale intercalations. The high porosity and permeability of these sediments make them an excellent aquifer system (Short & Stauble, 1967).

Stratigraphically, the Niger Delta is divided into three main formations:

1. Benin Formation (topmost) – continental sand and gravel sequences.
2. Agbada Formation (middle unit) – alternating sand and shale layers of delta front to prodelta origin.
3. Akata Formation (basal unit) – marine shale and clay sequences.

Buguma falls within the Benin Formation as seen in Figure 1 below, which is Pliocene to Recent in age and is several hundred meters thick in some areas. These sediments were deposited in a fluvio-deltaic environment under high-energy conditions, resulting in loose and highly permeable sand bodies. The area is underlain by shallow aquifers with significant groundwater potential but is also highly susceptible to saltwater intrusion due to its proximity to tidal creeks and the Atlantic coast.

Structurally, the Niger Delta is characterized by growth faults, rollover anticlines, and other syndepositional tectonic features, although these are more pronounced offshore. In Buguma, the terrain is generally flat and swampy with a shallow water table. The area is also influenced by marine and fluvial processes, leading to constant sediment reworking and deposition.

Hydrogeologically, the shallow sandy aquifers of the Benin Formation serve as the main source of potable groundwater. However, these aquifers are vulnerable to contamination from both iron-rich ferruginous sediments at shallow depths and saline intrusion from the adjacent brackish water systems.

Aquifers of the Benin Formation (where this work was done) bears the ground water needs of the region, the poorly sorted coastal sands become increasingly sandy and unconsolidated towards the surface. These parameter increases the porosity and permeability and thus, the increase in storage coefficient of the aquifer. Recharge through the surrounding water bodies and extensive rainfall percolating down with a fairly, thick vegetation run-off is negligible, this has resulted in a prolific hydrologic unit within the area.

It is typified by uniformly high temperature throughout the year, intense rainfall which occurs almost every month of the year, seasonally variable and energetic in down pour with increasing distance from the ocean (Mmom and Fred-Nwangwu, 2013). This often graduates to thunderstorm at its onset and cessation with variation in duration and amount between 4,700mm and 4,500mm in July – September, especially in popular rainfall stations like Opobo, Okrika and Bonny that are in the same geographical location with Buguma City (Fashiola et al, 2013,). The riverine area encompassing Buguma in Asari-Toru Local Government Area of Rivers State is divided into three main hydro-vegetation zones. The beach ridge is extensively vegetated by fresh water swamp trees, palm and shrubs on the sandy ridges and mangroves in the intervening valleys, creeks or tidal flats. The salt-water (mangrove) swamp zone is the tidal flat vegetated by the red salt-rooted mangrove (Rhizophoraracemosa) and two other species including the nypa palm that grows extensively under the influence of brackish water system and marine regimes. The fringe areas of raised alluvial coastal plain terrace within the swamps are vegetated by tall luxuriant forest tree species and oil palm.

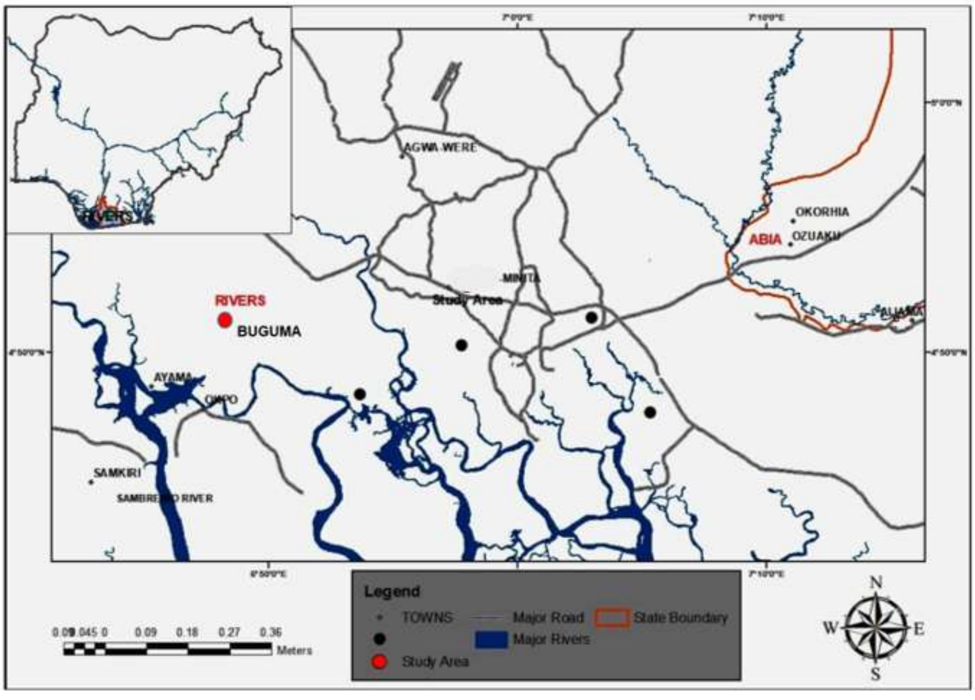

Figure 1: Geologic map of the study area.

II. Methodology

The instrument is connected to the APP through the built-in Bluetooth, so you can use the APP to realize all the operations of the instrument such as measurement signal input, data checking and processing. Using wireless sensor probe, you can complete all the measurements just by walking and stopping. No need long cable, saving time and manpower (Figure 2 and 3).

ADMT series products are a new generation intelligent prospecting instruments designed by AIDU and Guilin Technology Hydrogeological Investigation Institute. Based on more than 4 decades R&D experiences, we use mobile phone or table PC to run the complicated data calculation to realize the quickly calculation inversion and rapid graph drawing. Then we can quickly draw 2D/3D profile maps, contour maps and curve diagrams by an APP. This is a leap in technology because it makes the complicated geophysical survey becomes easier and simpler. With the APP you could use many intelligent functions such as field measurement control, instantly data process, data cloud backup, online expert analysis and Bluetooth data transaction etc.

Main Features

The main features include:

1. Instant Mapping: Directly drawing the 2D/3D map by the APP after data collection
2. Simple Operation: Walking and stopping to complete the measurement, so easy.
3. Efficiency: Unique wireless prospecting tech, one person can complete all work, saving time and manpower.
4. Precision: Strong anti-interference ability, field source correction and patent tech to process data.

Many innovative designs make the instruments become more intelligent, efficient and accurate to obtain dozens of invention patents.

Figure 2: A digital Terrameter for Groundwater Exploration.

Figure 3**:** A Pool Finder Plus for Groundwater Exploration.

Figure 4: Groundwater Resistivity Meter.

III. Results And Discussion

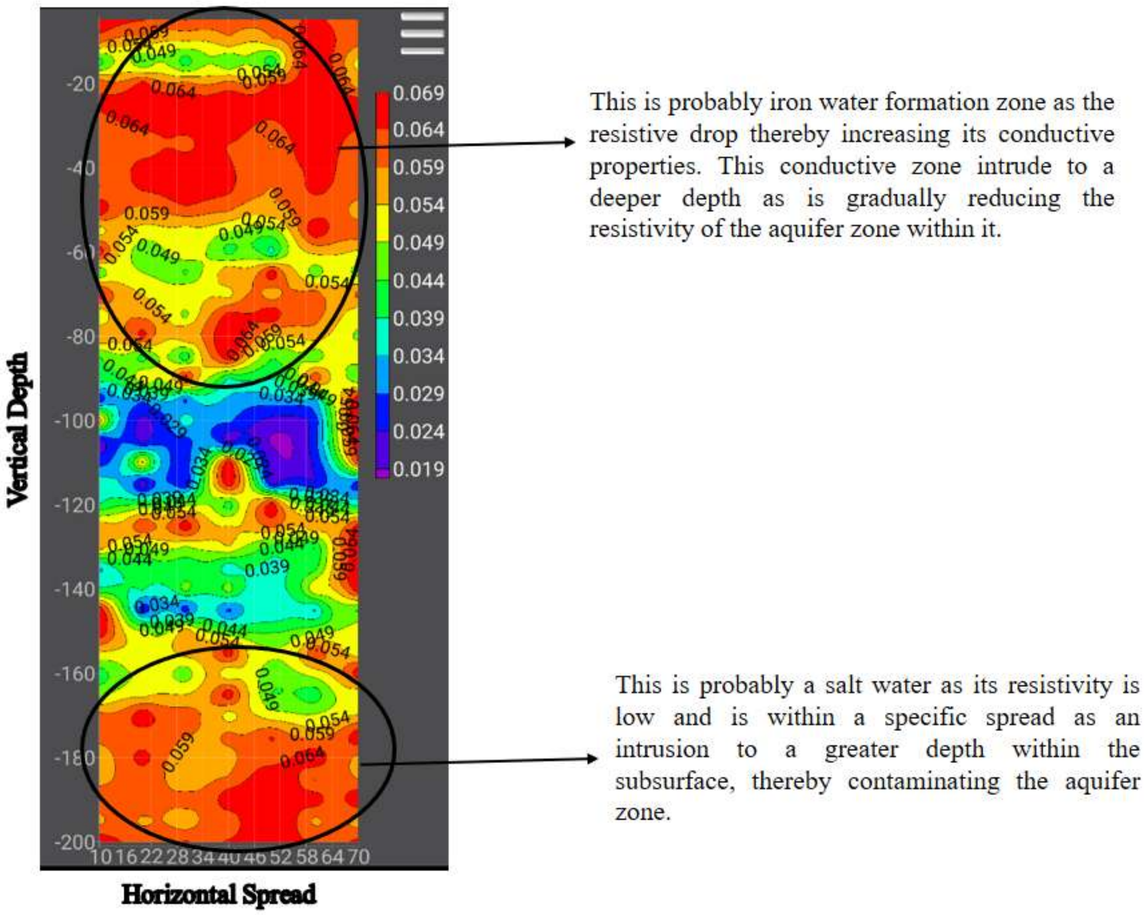

Figure 5: The ERT subsurface image of Buguma.

The electrical resistivity tomographic image clearly reveals zones of significant conductive anomalies within the subsurface profile. At the shallow depth interval, the anomalously low resistivity values are indicative of high conductivity (0 – 85m), which is most likely associated with ferruginous groundwater. The presence of iron-rich water at this level suggests a geochemical alteration of the aquifer matrix due to the infiltration of ferruginous fluids or oxidation-reduction processes within the aquifer system. This condition aligns with typical signatures of iron contamination, where iron-bearing minerals dissolve into the groundwater, increasing electrical conductivity. The resultant fluid is generally brownish-red in colour, corrosive to infrastructure, and unsuitable for domestic use without proper treatment.

More critically, the lower sections of the profile approximately from 120m to 160m and progressively downward display a continuous conductive zone, which is consistent with the intrusion of saline water into the freshwater aquifer. Such low resistivity zones at these depths are symptomatic of saltwater encroachment, a common hydrogeological challenge in coastal areas like Buguma, where hydraulic connections between freshwater aquifers and marine water bodies exist. This pattern indicates a landward migration of the freshwater–saltwater interface, likely driven by overexploitation of the freshwater lens, natural hydraulic gradients, or rising sea levels.

The persistence of these conductive zones with increasing depth suggests a progressive and active intrusion process rather than a static interface. This is a critical hydrogeological concern because saltwater intrusion tends to degrade water quality, increase total dissolved solids, and reduce the availability of potable water. The observed geoelectrical behaviour reflects the inherent vulnerability of the aquifer system in this region to both iron contamination and saline intrusion, emphasizing the need for urgent management interventions.

IV. Summary And Conclusions

The electrical Resistivity tomogram image above show the subsurface formation and using Figure 4, there is urgent need for quick intervention as the formation is highly vulnerable due to the salt and iron water intrusion both at the shallow depth and at deeper depth as the intrusion is still continuous rendering the deeper zone a dangerous zone.

The whole formation at a shallow depth has been compromised due to the concentration of the conductive fluid probably as a result of intrusion of ferruginous material thereby contaminating and changing the chemistry of the potable water in that zone to probably an iron water which is unsuitable for consumption and thereby unsafe.

the formation at a deeper depth has also been intruded and render unsafe for use as the depth has been jeopardized. The contamination is still continuous and probably increases as the depth increase.

The ERT subsurface image provides a clear diagnostic view of the vulnerability of the Buguma aquifer system. Shallow aquifer units (0 – 85m) are already compromised by iron water contamination, while deeper units (120m–160m and beyond) are progressively intruded by saline water, as evidenced by sustained low resistivity values. This dual contamination scenario poses a serious threat to groundwater quality and long-term water supply sustainability in the area.

Therefore, proper aquifer protection strategies including regulated groundwater abstraction, continuous monitoring of the freshwater–saltwater interface, artificial recharge, and possibly relocating borehole installations to less vulnerable zones are urgently recommended to safeguard potable water resources.

In conclusion, the introduction of geophysical (resistivity) investigation to obtain a quick look of the subsurface layers in Buguma, Rivers State, highlighted area of quick remediation as the subsurface is higly vulnerable.

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