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Geo-Electric and Hydrogeochemical Mapping of Quaternary Deposits at Orerokpe in the Western Niger Delta

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ABSTRACT: Resistivity surveys have been utilized to delineate the sand horizons and possible water bearing zones in the shallow Quaternary deposits that mask the Benin Formation that underlies the Sombreiro-Warri Deltaic Plain at Orerokpe in the western Niger Delta. Fifteen dug wells and shallow boreholes were sampled for water quality analysis. The results show that from the surface to about 70m, there are four layers of water bearing sands that are separated in places by discontinuous clay horizons. Depth to water level ranges from 3.5m to 5.5m. Ground water flow is from northeast to southwest towards the Warri River. Ground water which is used here for domestic purposes without treatment is soft and it is shown that the most important factor contributing to groundwater chemistry is weathering of the aquifer matrix. The order of preponderance of the cations is $Na^+ > K^+ > Ca^{2+} > Mg^{2+}$ and $HCO_3^- > SO_4^{2-} > Cl^-$ for the anions; trends that are not only a departure from normal pristine conditions, but also basically different from those observed in nearby Warri and indicative of possible contamination. The relatively low calcium and magnesium content is identified as a potential health problem if water constitutes the main source of ingestion of these ions. The results reinforce the complex geological nature and geochemical conditions that exist in the Quaternary superficial deposits of the Niger Delta environment. @JASEM

Keywords: Quaternary, resistivity, groundwater, Niger Delta

The Niger Delta is one of the most important petroleum provinces in the world as a result of which the petroleum geology of the area has been subject of intense study. Unfortunately, the near surface and shallow Quaternary cover appears not to have received as much attention. The practice has been to generally lump these deposits of alternating fine-medium grained sands, silts and subordinate lensoid clays together as the recent and present day deposition of sediments on the Benin Formation, Amajor (1991). However, these important deposits possess distinct characteristics and engineering properties (Bam, 2007), and cover more than 70 per cent of the land surface of Delta State, Nigeria, Figure 1. They are exploited for glass sands and quarried extensively for building purposes (Bam, 2007; Akpokodje and Etu-Efeotor, 1987; Ministry of Commerce and Industry, 2001; Atakpo and Akpoborie, 2011). Furthermore, they constitute the shallow aquifers that are exploited by shallow (<30m) boreholes and dug wells that serve as the primary water supply source for rural as well as many peri-urban and urban communities. The location of permeable clean sands in these deposits that are capable of yielding useful quantities of water to wells is therefore an important consideration in water supply development.

The quality of water yielded is also crucial but various studies (Ejechi et al., 2007; Akpoborie et al. 2000; Olobaniyi et al. 2007; Abimbola et al. 2002) have indicated that these shallow aquifers are highly vulnerable to contamination from surface sources as a result of which the quality of groundwater in many cases been compromised by contaminants.

Based on these considerations, the primary objective of this study is to identify and delineate at greater depth than that penetrated by dug wells, the configuration of the Quaternary sands and clays that are known to underlie the Orerokpe area as well as establish general ground water conditions. A second objective is to determine and document the existing quality of ground water and thus refine for this locality the regional and general characterization of groundwater quality in a large tract of the western Niger Delta proposed by Olobaniyi et al. (2007). This is particularly important for Orerokpe because of its proximity to Warri, the hub of the oil and gas industry in the western Delta. Land use planning, housing, industrial and infrastructural development requires a clear understanding of the underlying geology as well as ground water conditions for the purposes of aquifer vulnerability assessments and the design of waste disposal systems.

The electrical resistivity method that is selected for this study has been used successfully for many geological and ground water investigations in the Niger Delta (Atakpo and Akpoborie, 2011; Etu-Efeotor, and Michalski, 1989; Atakpo et al., 2008; Okolie et. al. 2000.).

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Location and Physiography: Orerokpe lies between latitude 5°31′N and 5°40′N and longitude $5^0$54′E and 5°57′E, Figure l. It is the administrative headquarters of Okpe Local Government Area as well as well as the seat of the Orodje of Okpe Kingdom. The proximity to Warri makes it a choice location for commuters who work in Warri as well as for the location of oil service and related industries; hence the community is experiencing a surge in population and associated increased demand for land and infrastructural facilities.

Orerokpe is also situated in the low-lying physiograhic province known as the Sombreiro-Warri Deltaic Plain. The plain is generally flat and rises only very gently towards the north and northeast with a gradient of about 1:960 (Odemerho and Ejemeyovwi, 2007). Secondary tropical lowland forests prevail on the plain because much of the original primary forest has been lost to farming and timber exploitation. Rain falls year round and the annual ten year mean is about 2652mm while the mean daily temperature is 31.2^0C (Nigerian Meteorological Agency,2003).

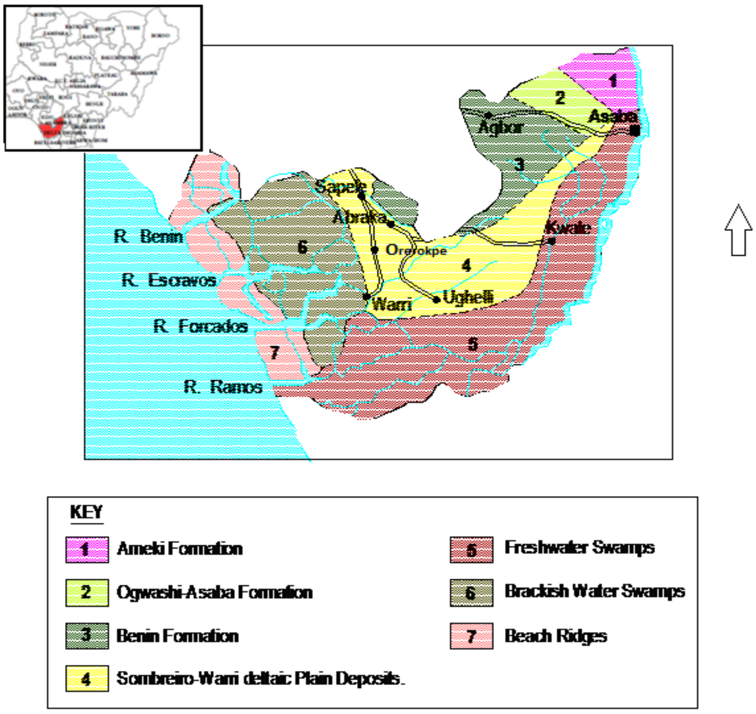

Fig 1: Aerial distribution of Quaternary- Holocene deposits and the Benin Formation in part of the western Niger Delta. The map of Nigeria is shown as an inset. (Modified from Akpoborie et al., 2011).

Regional Geology: The sedimentary environments and morphological features of the Niger Delta are much studied. (Short and Stauble,1967; Allen,1965,1967; Oomkens,1974; Durotoye,1989; Odemerho and Ejemeyovwi (2007). Specifically, Orerokpe is underlain by the deposits of the Quaternary Sombreiro-Warri Deltaic Plain that conformably overlie the Benin Formation, the youngest of the three important formations that constitute the sedimentary fill of the Niger Delta Basin. The Benin Formation consists of massive continental/fluvial sands and gravels. The older formations which are encountered only in the subsurface are the Agbada Formation of paralic sands and shales and the basal Akata Formation which consists of holomarine shales, silts and clays. Their lateral equivalents at the surface are the Ogwashi-Asaba Formation and Ameki Formation of Eocene-Oligocene age (Short and Stauble, 1967; Asseez, 1989).

The sands and clays of the Sombreiro-Warri Deltaic Plain are one of four suites of Quaternary- Holocene deposits in the western delta that mask the Benin Formation, the others being the Beach Ridges, the Freshwater Swamps, and the Brackishwater/Mangroove Swamps. These deposits have not been assigned formal names because they are universally considered to be recent expressions of and a continuation of the Benin Formation. Their aerial distribution and inferred boundaries which coincide with the physiographic provinces that are used to describe them are shown in Figure 1. These sequences of medium to coarse-grained sands, sandy clays, silts and subordinate, lensoid clay bands are thought to have been laid down during Quaternary interglacial marine transgressions (Durotoye,1989; Oomkens,1974). Amajor (1991) has shown that they are an admixture of fluvial/tidal channel, tidal flats and mangrove swamp deposits.

The sands are micaceous and feldspathic, sub rounded to angular in texture and constitute good aquifers. However depth of occurrence and thicknesses is irregular and may not be predicted with accuracy at specific locations either at Orerokpe or generally on the Sombreiro-Warri Deltaic Plain due to rapid horizontal and vertical facie changes. Ground water occurs generally under water table conditions and sometimes semi-confined conditions where the lensoid clays attain adequate thickness. Seasonal ground water level fluctuations monitored for one year at Okurekpo, about five kilometers east of the study area is in the range of 5m (Akpoborie et al., 2000).

Methodology: Vertical electrical soundings (VES) were carried out using the Schlumberger electrode configuration. The ABEM SAS 1000 terrameter was used with a maximum current electrode spacing (AB/2) of 225m. According to Kunetz (1966), current penetration in an electrode spread ranges between 1/ 4 and 1/ 3. The VES curves were interpreted by partial curve matching technique with two-layer master curves in conjunction with auxiliary point diagram (Zhandov and Keller, 1994). The resistivity values and thicknesses obtained from the partial curve matching were used for computer iteration.

Furthermore, and in order to determine the quality of groundwater, replicate water samples were collected from fifteen selected hand-dug wells into sterilized polyethylene bottles. The set of samples designated for heavy metal analysis were immediately stabilized with acid. Electrical conductivity and Total Dissolved Solids were measured in situ using the HACH Conductivity/TDS meter. The pH was determined by means of a Schott Gerate model pH meter and temperature was determined using mercury–in-glass thermometer calibrated in 0.2^{o}C units from 0^{o}C to 100^{o}C. Nitrate was determined with the HACH Spectrophotometer using the cadmium reduction method, while the sulphate content of all the samples was determined by the turbidimetric method. Salinity, total hardness, total alkalinity, as well as the cations and anions Na^+, K^+, Ca^{2+}, Mg^{2+}, HCO_3^-, CO_3^-, Cl^-, NO_3^- and metals Pb^{2+}, Cd^{2+}, Zn^{2+} and Cu^{2+} were determined in the laboratory with the appropriate titrimetric, flame photometric and atomic absorption spectrometric methods (APHA, 1992)

Finally, rest water levels of all sampled wells were measured with a dipmeter within one day during the dry season in April 2010. An Ertec model GPS instrument was used to position the wells as well as determine the approximate elevation of each well head. A contouring computer package was employed in generating the depth to water level and head distribution which were superimposed on the Orerokpe street map.

RESULTS AND DISCUSSION

Geo-electric interpretations and hydrology: The interpreted geoelectric sections Figure 2, show four to five distinct geoelectric layers and characterized by HQ, QQ, KH and KHQ hybrid model curves. The first layer is the top soil with resistivity values ranging from 90.20Ωm-611.7Ωm and varying in thickness from 0.6m-1.6m. The second layer has a resistivity values ranging from 301.50Ωm-985.3Ωm and thickness ranges from 3.7m-47.2m, the inferred lithology is fine sand. This is probably the source of water for dug wells. The third layer has resistivity values ranging from 74.1Ωm-1850.6Ωm and thickness ranging from 4m-37.8m, the inferred lithologies includes coarse grained sand, medium grained sand, clayey sand, sandy clay and clay. The coarse grained sand (VES 5) and medium grained sand (VES 4) are also water bearing.. The fourth layer has resistivity values ranging from 718Ωm-3570.7Ωm occurring at depths between 12.20m-70.60m. The inferred lithologies include gravelly sand, coarse grained sand and medium grained sand, the base of this layer could not be determined except at VES 3 and VES 15 where it has a thickness of 11.7m and 15.70m respectively.

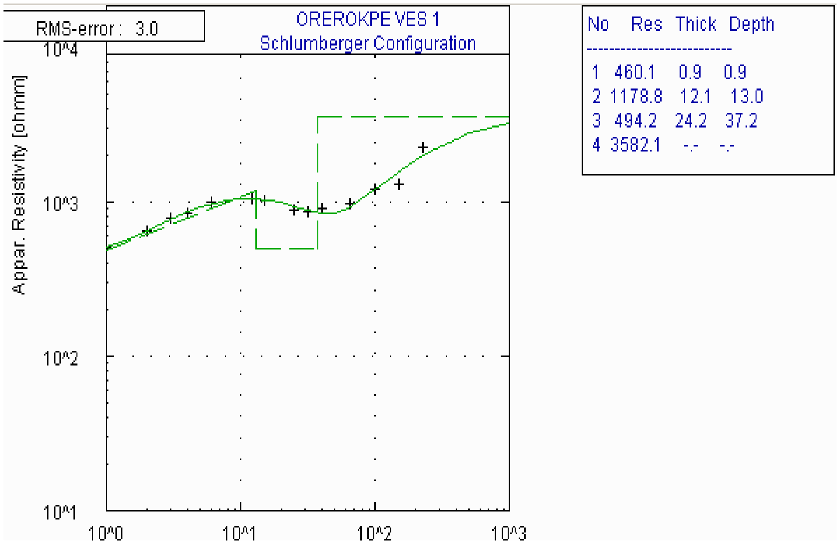

Fig 2: Typical VES Curves from Orerokpe

Coarse sands and gravelly sands were intercepted as the fifth layer beneath VES 3 and VES 15 with resistivity values ranging from 1602.2Ωm-8501.5Ωm, occurring at depths between 20.8m and 40.40m to depths that could not be ascertained by the sounding. The third, fourth and probably the fifth layers, thus, form part of the aquifer in the study area.

The shallow layers are exploited in Orerokpe and indeed everywhere in the Sombreiro –Deltaic Plain with dug wells. Shallow boreholes penetrate and tap water from the second and deeper layer. All the layers which are in hydraulic continuity because of the discontinuous clay beds together constitute the potential aquifer system which is unconfined and locally semi- confined.

Depth to water is virtually uniform over the town at an average of about 4m below ground surface, Table 1.

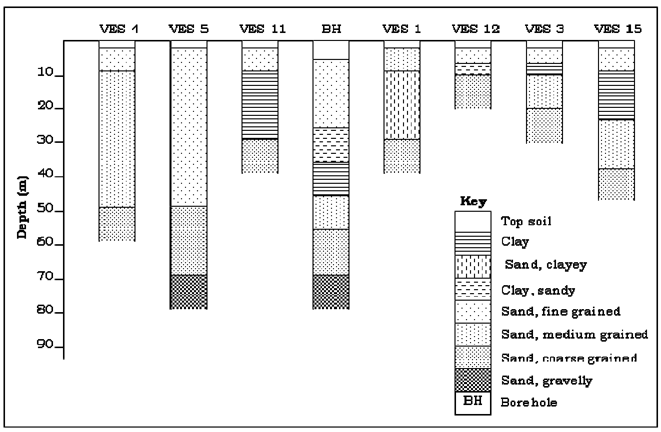

Fig 3: Selected geoelectric sections and borehole log from Orerokpe.

Groundwater flow is from northeast to south west towards the Warri River, Figure 5. The Public Water Works with the associated borehole(s), Figure 5, is insulated somewhat from domestic waste and associated leachates because it is fortuitously located north of and away from the built up areas. On the other hand, the General Hospital's private water supply borehole is highly vulnerable to contamination as the hospital is located in the south central area and thus in direct path of ground water flow from the larger part of the town. The quality of water from the borehole should thus be periodically monitored. The configuration of the contours is indicative of a rather uniform aquifer texture and moderately high transmissivity. Permeability of the unconsolidated sands in the Sombreiro – Warri Plain is in the range of 3.1 x 10^{-4}m/s (Akpoborie et al.,2000; Olobaniyi and Owoyemi, 2004) while Transmissivity estimated from a pump test on the sandy deposits at Sapele is 350m^2/day (McGill Engineers, 2005).

Table 1: Depth to water level and calculated head at sampled dug well

	Latitude	Longitude	Elevation (m)	Water Level (m)	Head (m)
1.	N05^{0} 38.533^{1}	E005^{0} 53.869^{1}	11.82	4.182	7.62
2.	N05^{0} 38.081^{1}	E005^{0} 53.503^{1}	10.00	3.636	6.36
3.	N05^{0} 38.040^{1}	E005^{0} 53.309^{1}	10.61	5.182	5.41
4.	N05^{0} 37.962^{1}	E005^{0} 53.297^{1}	09.70	4.909	4.8
5.	N05^{0} 37.998^{1}	E005^{0} 52.905^{1}	08.48	3.697	4.8
6.	N05^{0} 38.193^{1}	E005^{0} 52.593^{1}	09.69	4.242	5.45
7.	N05^{0} 38.313^{1}	E005^{0} 52.854^{1}	10.30	4.242	6.06
8.	N05^{0} 38.404^{1}	E005^{0} 53.211^{1}	11.21	4.545	6.66
9.	N05^{0} 38.685^{1}	E005^{0} 53.462^{1}	12.42	4.697	7.72
10.	N05^{0} 38.666^{1}	E005^{0} 53.865^{1}	13.63	5.454	8.18
11.	N05^{0} 38.511^{1}	E005^{0} 54.008^{1}	12.12	4.272	7.85

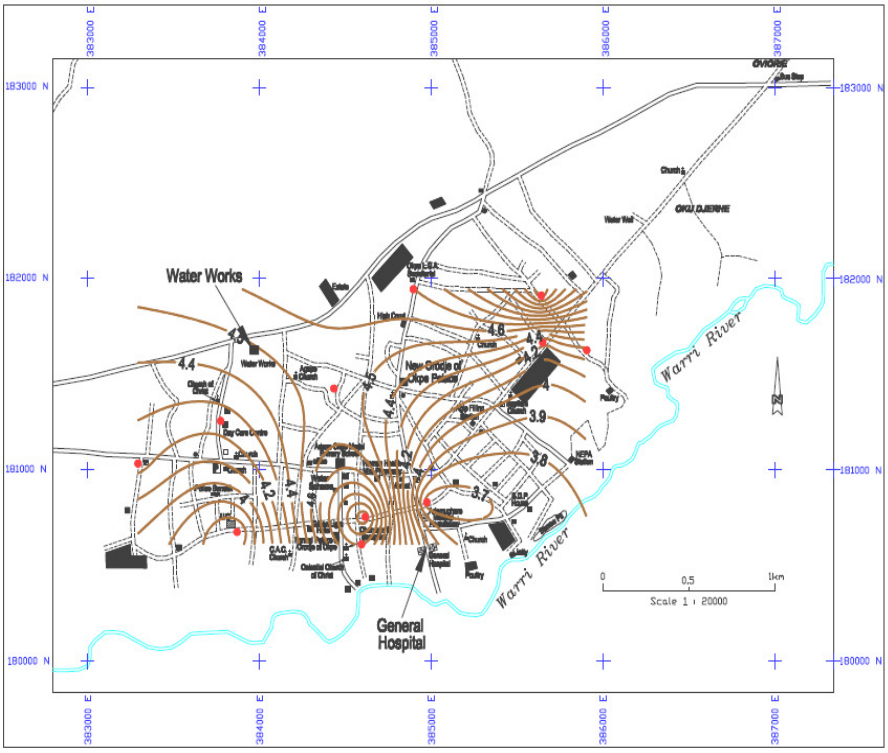

Figure 4: Configuration of Depth to Water Table at Orerokpe

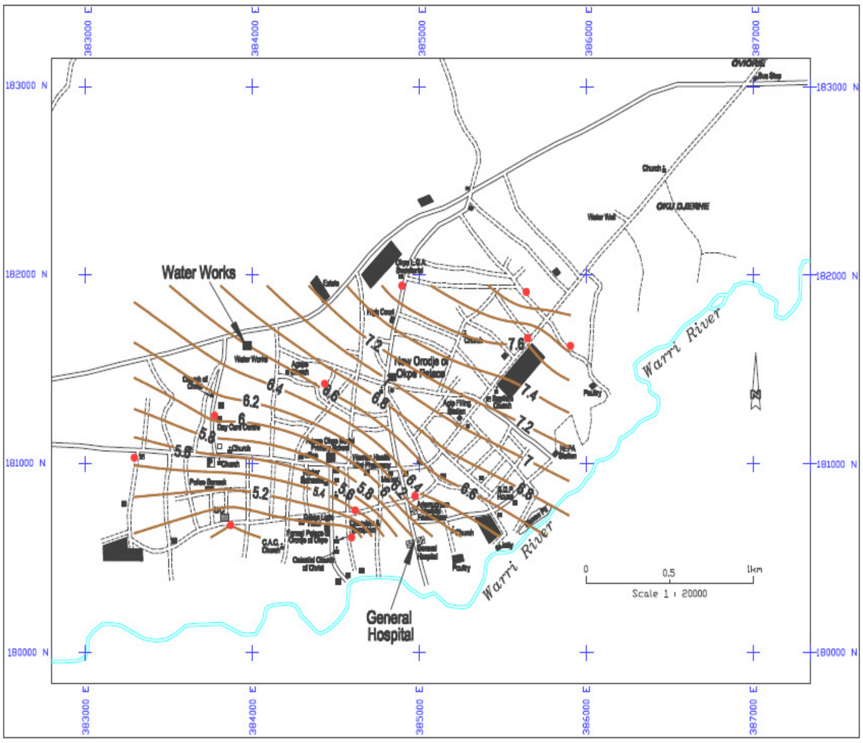

Figure 5: Ground water head distribution at Orerokpe

Groundwater Geochemistry: The results of the analyses of water samples collected from dug wells are shown in Table 2. Acidity or hydrogen ion activity ranges from 4.6 to 6.7 with a mean of 5.73, an indication of mild acidity a trend that appears to be common in the western Niger Delta (Akpoborie et. al, 2000; Olobaniyi et. al, 2007, Olobaniyi and Efe ,2007) among others. The trend has been attributed to the daily flaring of up to 42.5 million cubic meters of natural gas at oil and gas facilities in the region. Rain water the main source of aquifer recharge is thus laden with oxides of nitrogen and sulfur (Efe, 2005). Total Dissolved Solids are relatively low at a mean value of 211mg/l. The major cations Na^+, K^+, Ca^{2+} and Mg^{2+} are all low with mean concentrations of 15.59 mg/l, 13.26/l, 7.82 mg/l and 5.87mg/l respectively. The major anions HCO_3^-, Cl^- and SO_4^{2-} are also low at means of 14.71mg/l, 5.23mg/l and 7.38mg/l respectively. Thus the sequence of abundance of the cations is Na > K > Ca> Mg, while HCO_3 > SO_4> Cl is the sequence for the major anions. The cation trend differs significantly from the natural order in pristine groundwater which is Ca > Mg > K > Na and this variation could be indicative of salinization and other geochemical processes that would be altering and possibly resulting in water quality deterioration (Akujieze and Oteze, 2002; Karanth, 2006).

Furthermore, the dominance of rock weathering in determining the chemical composition of groundwater in tropical regions as suggested by Kilham (1990) is indicated by Figure 6, where most of the samples plot in the central region and to the right of the indentation in Gibbs' (1970) boomerang. Chemical weathering of the aquifer matrix would be further enhanced by the mildly acidic rainfall and which acidity appears to be indeed retained by ground water in Orerokpe.

There also appears to be continuous natural softening of ground water whereby monovalent Na^+ ions are replacing divalent Ca^{2+} by cation exchange (Hem, 1989) resulting in decreasing levels of Calcium and Magnesium while there is Sodium enrichment. This is significant because Cotruvo and Bartram (2009) draw attention to the potential negative consequences of inadequate intake of calcium and magnesium for human health which include increased risks of osteoporosis, nephrolithiasis (kidney stones), colorectal cancer, hypertension, associated alcoholism and stroke among others. Drinking water guideline values for calcium and magnesium are however not specified in the WHO Drinking Water Guidelines (2006) nor in the Nigerian Drinking Water Standard (2007) possibly because excess calcium poses no problems to most people. Calcium and magnesium are ingested largely through regular dietary intake especially milk, with drinking water contributing only a small percentage of required daily intake. However for individuals who avoid dairy products or lack access to them, water may represent an important source of the mineral. Thus if drinking water is inordinately low in these minerals such individuals may be at increased risk of calcium deficiency. In Orerokpe, the routine method of enhancing levels of calcium/magnesium through public water supply treatment systems may not be immediately applicable because the public water supply is inadequate as it is in all other parts of Delta State. Advocating increased intakes of dairy products is not a solution either because the poor and most vulnerable groups may not have access to such products or manufactured bottled water. Continuous monitoring of drinking water quality from dug wells and shallow boreholes is therefore recommended while studies are initiated to identify any effects of calcium/magnesium deficiency in the population. Nitrates, lead, cadmium, zinc are present in all water samples but in concentrations that are well below WHO Guidelines for Drinking-Water Quality (2006), and the Nigerian Standard for Drinking- Water Quality (2007).

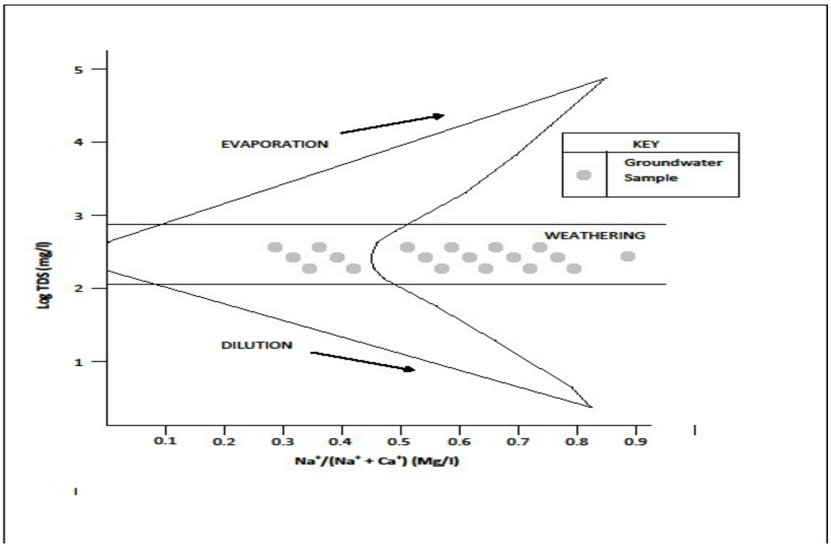

Figure 6: Gibbs'(1970) Boomerang for Orerokpe ground water

Table 2: Mean concentration vales of physico-chemical parameters of groundwater from Orerokpe.N=15

Parameters	Min	Max	Mean	Std. Deviation	WHO	SON
pH	4. 60	6. 70	5. 73	0. 53	-	6.5-8.5
Conductivity {µs/cm}	111. 6	23. 10	157. 98	40.79	-	1000
Temperature {^{0}C}	23. 00	28. 00	25. 20	1. 72	-	-
TDS {mg/l}	170. 6	282. 4	211. 2	44. 93	-	500
Total Hardness {mg/l}	20. 53	74. 42	48. 05	20. 29	-	150
Na^+ {mg/ l}	10. 31	23. 10	15. 59	5.20	-	-
K^+ {mg/ l}	12.50	20.50	13. 26	4. 23	-	-
Ca^{2+} {mg/l}	3. 21	15. 20	7. 28	4. 26	-	-
Mg^{2+} {mg/l}	2. 20	9. 00	5. 77	2. 66	50	0.20
Pb^{2+} {mg/l}	<0. 01	<0. 01	<0. 01	-	0. 01	0.01
Cd^{2+} {mg/l}	<0. 01	<0. 01	<0. 01	-	0. 01	0.003
Zn^{2+} {mg/l}	0. 18	0. 25	0. 218	0. 09	1. 5	5.0
Cu^{2+} {mg/l}	0. 01	0. 13	0.048	0.09	1. 0	1.0
Cl^- {mg/l}	3. 00	9. 00	5. 23	2. 14	-	250
HCO_3^- {mg/l}	8. 65	19. 40	14. 71	4. 03	-	-
SO_4^{2-} {mg/l}	2.50	15. 50	7. 38	4. 56	-	-
NO_3^- {mg/l}	1. 32	5.40	2. 64	1. 47	50	50

CONCLUSION: This investigation has successfully used the resistivity method to show that Orerokpe is generally underlain by a succession of medium to coarse grained siliceous sands. A thin and subordinate clay layer does occur in places and is thus lensoid in nature and may not be encountered in all parts of the town. It may therefore not be relied upon to protect underlying groundwater from contaminant sources on the surface. Groundwater flow is southwestwards and towards the river.

Ground water is soft and its chemical composition is being controlled in the main by weathering of the geologic fabric which is accelerated by the mildly acidic nature of recharging rainfall. Calcium and magnesium are low and because groundwater is the main source of drinking water supply the potential exists for calcium and magnesium deficiency for those consumers in Orerokpe whose main source of ingesting these elements is drinking water. Finally, the results of this study reinforce the complex geological nature and geochemical conditions that exist in the Quaternary superficial deposits of the Niger Delta environment.

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