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INVESTIGATIONS OF GROUNDWATER QUALITY AND EVOLUTION IN AN ESTUARY ENVIRONMENT: A CASE STUDY OF BURUTU ISLAND, WESTERN NIGER DELTA, NIGERIA

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This paper evaluates groundwater quality in an estuary environment, using a vertical electrical resistivity sounding (VES) coupled with physiochemical analysis of subsurface groundwater samples. The interpretation of the VES data revealed 5 distinctive geoelectric sections. Lithologically, topsoil, silty sand, clay and sand were inferred from interpretation of resistivity data and the aquifer is semi-confined as the clay delineated is not continuous. The hand-dug wells are characterized by high values of electrical conductivity, total dissolved solids, Na^+, Cl^{-1}, SO^-_4, and HCO^-_3 , which are noticeably higher than those obtained for boreholes. The enhanced concentrations of these parameters were thought to have emanated from contamination from runoff as most of the wells lacked concrete rings; refuse dumps and septic tanks. The values of Fe^{2+} are depth dependent and are commonly higher among the borehole samples than the hang-dug wells. The quality of groundwater is exclusively driven by the concentration of iron in groundwater. A scatter plot of the ionic ratios revealed no marine influence on groundwater quality. The result obtained from Piper plot shows $Na^+ + K^+ - Cl^{-1} - SO^-_4$, as the major hydrochemical facies. The groundwater quality is controlled by ion exchange, anthropogenic factors and the concentration of iron. The paper concludes that the groundwater quality depicted in the study is common to a transitional environment. The concentration of iron is not restricted to shallow aquifers and its delineation can only be achieved through a coupled VES and geochemical approach. Our results also bring into question the widely held assumption that these aquifers are affected by saltwater intrusion.

INTRODUCTION

The quality of groundwater in any aquifer is greatly influenced by its geographical location on the earth surface and the impact of anthropogenic activities as well as the interaction between groundwater and the aquifer media. The quality of groundwater in an urban area situated inland may be different from that situated in a coastal area. Inland, the most dominant influence is pollution emanating from different sources, such as sewage disposal systems, leachate from landfill sites and underground storage tanks and host of others. On the other hand, all the above mentioned sources of contamination combined with the interaction between the ocean and adjacent aquifers as well as estuaries, have significant impact on the quality of groundwater in coastal regions.

The coastal area of the Western Niger Delta consists of freshwater and mangrove swamps. As the distance from the shoreline increases towards the land, the freshwater swamps become more abundant than the mangrove swamps (Oteri, 1984). The mangrove swamps are disconnected from the ocean by sand beach ridges and they are associated with freshwater swamps vegetation (Allen, 1965; 1970, Nedeco, 1961; Weber, 1971; and Oteri, 1984). Freshwater can be found in the unconfined aquifers of the sand beach ridges, river point bars and sandy islands of the mangrove swamps (Oteri, 1984) and also in confined aquifers which occur at greater depth beneath the sand ridges, river point bars and sandy islands

The Western Niger Delta is importantly known of being host to oil and gas exploration and exploitation by multinational companies. In spite of these vast and abundant resources of oil and gas in the area, the inhabitants of these communities lack potable drinking water. They rely mostly on rain harvesting and sachet water popularly known as "pure water" and rarely bottled water sourced from Warri and its environs for their daily water consumption and domestic needs. The lack of available public water for the people of these communities has become a culture and it is due to the lackadaisical attitude of Federal, State and Local Governments towards provision of pipe borne water. The problem of la ack of potable drinking water has become endemic in the coastal area of the Niger delta in general and the western Niger Delta in particular.

The Forcados river, a part of the Niger river is slightly brackish at Burutu and the salinity tends to increase towards the ocean, an indication of the hydrodynamic effect of the hydrological process on the river at Forcados and tidal inlets that connect the area to the ocean. The effect of this hydrological process operating in the Burutu areas has created the impression that the groundwater in Burutu is brackish. The existence of some abandoned boreholes in Burutu has been alleged to have been caused by saltwater intrusion (Oteri, 1984). The presence of freshwater swamp vegetation in the Burutu environment substantially contradicts the saltwater intrusion preposition except at the banks of the Forcados river that support mangrove swamps because of the influx of saline water from the ocean.

The assumption of saltwater intrusion in Burutu is somehow dissimilar to other coastal regions of the world which have experienced and are still experiencing saltwater intrusion into freshwater aquifers. Such areas are characterized by high population, which influences the over-stressing of groundwater from aquifer for irrigation, domestic and industrial purposes. All these characteristics are conspicuously absent in the area of study in particular and most of the coastal areas of the delta in Nigeria. The population of Burutu is very small and there are no industries that may support the kind of groundwater over-pumping from the aquifers that could precipitate saltwater intrusion; there are no commercial large scale farming activities that require over-pumping of groundwater aquifer for irrigation purposes, and lastly there are no industrial companies, in fact Burutu to a large extent is a small rural community and consequently its aquifers cannot be thought to be experiencing saltwater intrusion. The reason why most boreholes drilled in Buturu are abandoned is attributed to inability of those involved to carry out a proper hydrogeological and geophysical investigation prior to drilling.

The objective of the paper is to ascertain the quality of groundwater through the use vertical electrical sounding coupled with geochemical analysis of groundwater samples with the sole aim of ascertaining the existence of marine influence on groundwater aquifers and groundwater evolution.

Description of the study area

Burutu is an island situated about 19 kilometers from the Atlantic Ocean (Fig.1) and bounded by River Forcados and its tributaries and the River Ramous. Common in the town were relicts of Port and harbor, which existed at the period of colonial rule in Nigeria. It is a transitional environment; where freshwater from the continent meets marine saline water. The bank of river Forcados at Burutu supports mangrove swamps due to influx of saline water from the ocean during high tide, while freshwater swamp vegetation is supported by areas not affected by saline water, specifically in the town. The area is typical rainforest region with high annual rainfall above 3500mm and with two seasons of rainy and dry, but with almost rainfall every month of the year. It is drained by rivers Forcados and Ramous their distributaries and creeks. Temperatures are high during the day and lower during the night with minimum and maximum temperature of 25^0C to 34^0C respectively. The population of the area is relatively small and majority of the dwellers have fishing as their main occupation.

Hydrogeology and Geology

The stratigraphy of the Niger delta has been comprehensively described in (Allen, 1965; Reyment, 1965; Short and Stauble, 1967) and others. The lithostratigraphic units consist of the youngest Benin Formation at the top, Agbada Formation at the middle and Akata Formation at the base. Benin Formation consists predominantly of unconsolidated sand, gravel and occasionally intercalation of shales. It is a freshwater bearing formation in the Niger Delta region. Its thickness is about 2000metres and ranges from Oligocene to Pleistocene in age. The Quaternary-Recent sediments known as the Somebreiro-Warri Deltaic Plain sand overlies the Benin Formation in the western Niger delta, which is characterized by fine- medium- coarse grained sands. This sub-formation of the Benin Formation forms the beach sand sediments that bound the Atlantic Ocean and the Forcados estuary.

The Agbada Formation is the oil bearing formation of the Niger Delta sedimentary basin. It is of Eocene to Oligocene in age. It consists of alternate sand and shale sequence and about 3000 meters thick. The Akata Formation is the basal units of the Niger Delta sedimentary basin. This formation is highly pressured and compositionally it is made up of open marine facies. Its thickness is estimated to be 1000m and the age is from Eocene to Oligocene.

Like other areas of the western part of the Niger Delta, groundwater bearing formation is the same Somebreiro-Warri Deltaic coastal plain sands. The aquifer media consists of silty clays, clays, silty and fine, medium, coarse sands and gravels. It has high hydraulic conductivity, transmissivities, and high specific yield. Aquifer is very shallow and water table levels are very high and less than 0.6m and sometimes during the rainy season, it is almost at the surface. Recharge of aquifer is mainly by precipitation and the area is drained by the Forcados and its tributaries. The aquifer is shallow and unconfined in in most of its parts and usually confined at deeper depths. Clay lenses are occasionally present within the aquifers.

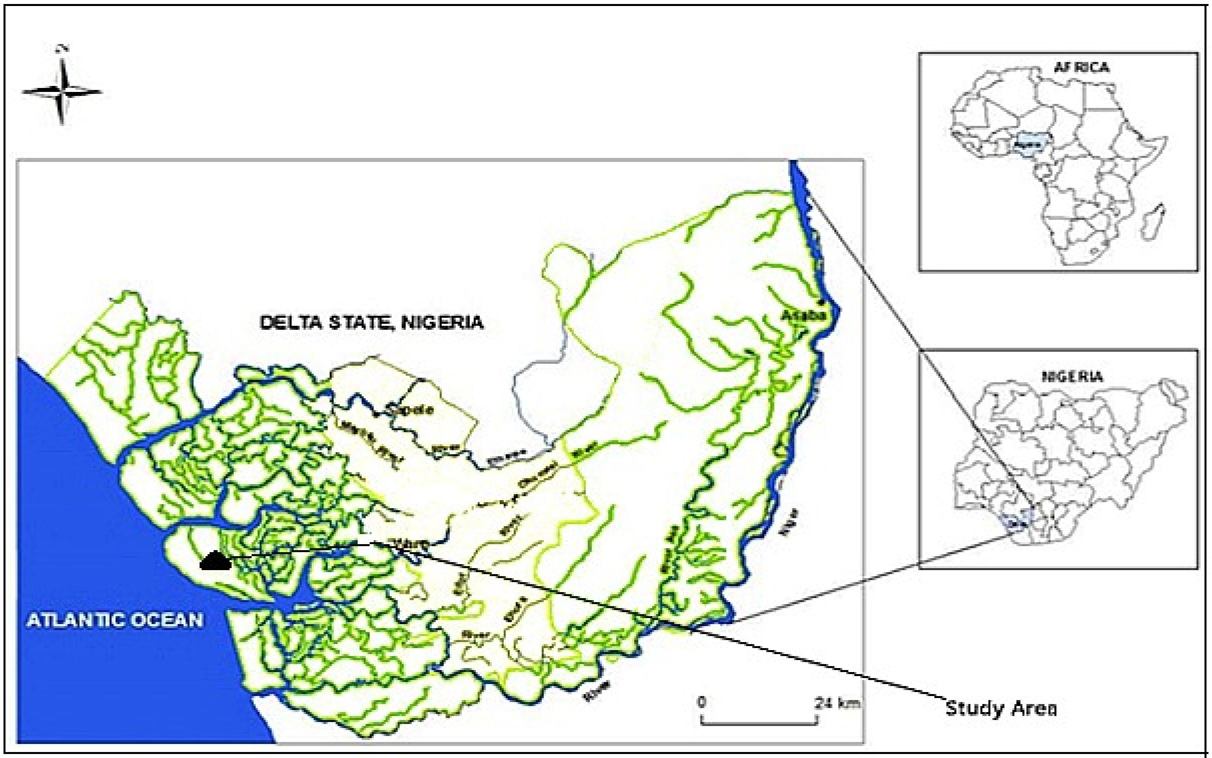

Figure 1. Map of the study area relative to the maps of Nigeria and Africa.

Materials and Methods

A schlumberger configuration array, with a maximum current electrode spacing of AB/2 of 250 was used for the acquisition of geophysical data at five different locations in the town of Burutu as stipulated by Parasnis, (1979) and Zohady, (1974). A portable chargeable 4pointLight 10w, Lippmann geophysical instrument Tarameter was used for the survey. The Lippmann 4light Tarra meter is designed automatically to select and inject current into the subsurface through two electric electrodes and measured potential difference through two other potential electrodes. It is also designed to convert readings into apparent resistivity values and stored same in its internal memory. These values were subsequently downloaded from the Tarrameter with the aid of USB cable connected to a computer. The VES curves were obtained by plotting half- current electrode spacing distance against the apparent resistivity values. The curves were interpreted by partial curve matching with a standard curve; the results were subsequently interpreted by inputting them into computer iteration IPI2win software.

Furthermore, depth to water level and water level were measured in boreholes and hand-dug wells with the aid of Solinst Water Level Meter (Model 101). The depth of well obtained from measurement were tied to resistivity data obtained from vertical sounding to delineate groundwater quality. Few water samples collected because numbers of boreholes were abandoned; consequently, groundwater samples were collected from 3 boreholes and 5 hand-dug wells and were designated S1-5 and BH1-3. To avoid the contamination of samples; polyethylene bottles were sterilized and rinsed with samples several times before collection. Each sample in a plastic container was well labeled and placed in ice box and subsequently taken to the laboratory for physiochemical analysis. Prior to sample collection, pH, total dissolved solids, and electrical conductivity were determined in the field. Physiochemical component of cations and anions of all samples collected were analyzed in accordance with the standard prescribed by the American Public Health Association (APHA, 2005)

RESULTS AND DISCUSSION

Resistivity Investigation

The results of the interpretation VES and typical computer models curves are presented in Table 1 and Figure 2. Table 1 shows five distinct different geoelectric sections, resistivity values for the survey ranged from 5.7Ωm to 9225 Ωm, while thickness of the layers ranged from 0.2049m to 80.3m. The first layer is interpreted to represent the topsoil, with resistivity values ranging from 38 Ωm to 4668 Ωm and thickness varying from 0.2049m to 2.04m. In VES 4 and 5, this layer is characterized by high resistivity values, which is interpreted as disturbed part of the topsoil reclaimed by sand filling, especially at the School of Marine Technology and the Burutu Township Stadium. The Second layer has resistivity values varying between 358Ωm and 4328 Ωm and, with thickness varying between 0.601m and 6.73m. Texturally, it consists of fine- through- medium- to -coarse grained sand. The shallow groundwater resource of Burutu is usually sourced from this layer through hand-dug wells that penetrate the aquifers occurring in this layer. The Third layer has resistivity values varied from 58.2Ωm to 1782Ωm and, thickness varying from 4.72m to 46.9m, the lithologies of this layer are interpreted to composed of clay, silty sand, , coarse grained sand, groundwater is sourced through boreholes from this layer. The Fourth layer has resistivity values ranged from 5.7 Ωm to 8601 Ωm and thickness ranging from 11.52m to 80.3m and also water bearing, the interpreted lithologies for this layer is clay, medium and coarse grained sand and gravel. The Fifth layer has resistivity values that ranged from 86 Ωm to 9225 Ωm, the thickness and the depth at which it occurs cannot be determined by the sounding, however, it is very deep and water bearing horizons.

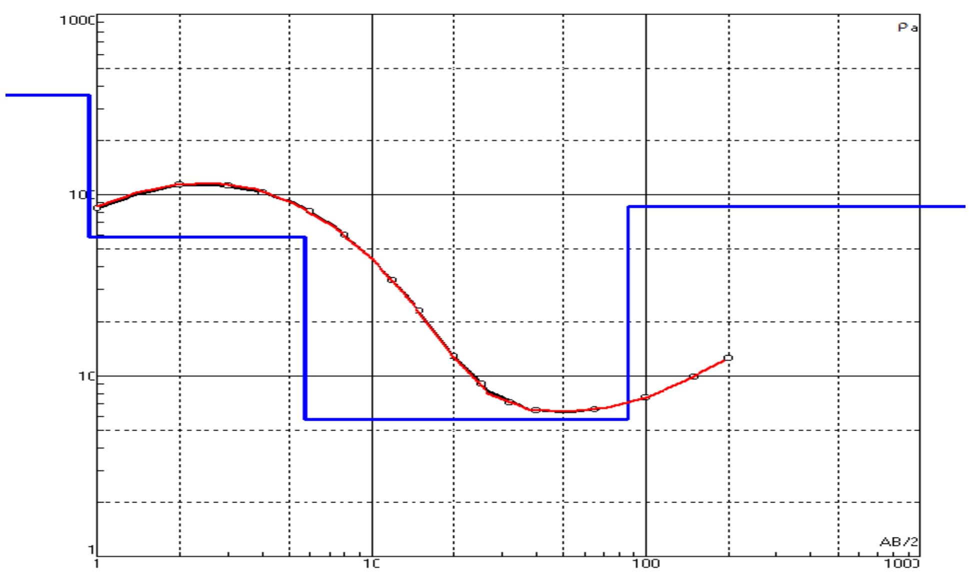

Figure 2: A typical computer model of the VES curve for the study area.

The presence of clay in the third and fourth layers of VES 2 and absence of same in other VES layers is a reflection that the hydraulic conductivity of the aquifers is somehow interconnected. The aquifer may be categorized into unconfined in certain part of the study and semi-confined in other places as showed by evidence of clay layers which anyway, are discontinuous. Groundwater in the areas can be sourced from four layers except in the first layer and the quality of groundwater is greatly influenced by presence of iron dissolved in aquifers which probably difficult to be delineated with vertical sounding, because to distinguish the concentrations of iron in water from other cations and anions from the total dissolved solid often use as proxy for interpretation of resistivity values is not feasible.

Table 1. Summarized results of vertical electrical sounding and interpretations.

VES No.	Resistivity (Ohm-Meter)	Thickness of layer (m)	Depth (m)	Geoelectric section	Interpretation
1	87.78	0.2049	0.2049	Fine to Silty sands	Topsoil / furrigeniced with iron unsaturated sand
	404.8	4.836	5.041	Medium sands	Saturated with groundwater that is poor in quality
	2793	17.03	22.07	Coarse sands	Poor groundwater
	400	20.47	42.54	Medium sands	Poor /good groundwater aquifer with Iron
	2959	-	-	coarse sand	Iron water
2	38.8	0.328	0.328	Clayey sand	Topsoil
	356	0.601	0.928	sand	Dry sand
	58.2	4.72	5.65	clay	Confining layer
	5.75	80.3	85.9	Clay	Confining layer or brackish groundwater(?)
	86	-	-	Sandy clay	Saturated with poor groundwater
3	258	0.4402	0.4402	Sand	Topsoil/ dry unconsolidated sand
	588	3.468	3.908	Sand	Saturated with good groundwater
	143.7	11.52	15.43	Sand	Saturated sand/good to very poor groundwater
	1138	54.94	70.37	Sand	Saturated sand/ probably poor in quality
	9225	-	-	Sand	Poor quality water
4	531	2.04	2.04	Sand	Topsoil/ reclaimed land
	4329	2.15	4.19	Sand	Saturated with good/poor quality water
	140	16.5	20.69	Sand	Saturated/ good quality
	642	38.8	59.49	Sand	Poor quality water
	6310	-	-	Sand	Poor quality groundwater
5	4668	1.11	1.11	Sand	Topsoil/reclaimed by sand filling
	975	6.73	7.84	Sand	Poor or good water(?)
	1782	46.9	54.74	Sand	Poor /good water(?)
	8601	13.3	68.04	Sand	Poor / good water(?)
	108.7	-	-	sand	Poor / good water(?)

Groundwater Quality and Evolution

The results of the physiochemical analysis are presented in Table 2. The pH values varied from 6.02 to 7.31, with mean of 6.75, an indication of slightly acidic and near neutral groundwater, a property common with shallow groundwater aquifers in the Western Niger Delta. Similar results have also been obtained by Akpoborie et.al, (2000); Olobaniyi et.al, (2007): Ohwoghere-Asuma and Adaikpoh (2013) and among others. The shallow hand-dug wells tend to have pH that is slightly more acidic than the borehole wells, which are slightly alkaline. The acidic nature of shallow groundwater according to Ohwoghere-Asuma and Aweto (2013) and Ohwoghere-Asuma and Adaikpoh (2013) is adduced to environmental influence of indiscriminate dumping of refuse and septic tank leakages prevalent in the region. Shallow groundwater aquifers in the Western Niger Delta have been reported to be hydraulically connected to septic tanks and therefore prone to contamination (Ohwoghere-Asuma and Adaikpoh (2013). The electrical conductivity (EC) ranged from 235µs/cm to 1479µs/cm with a mean of 736µs/cm. Of the entire sample analyzed, samples S1 and S2 have values of EC higher than the specified values of WHO (2006) and the Nigerian Standard for Drinking Water Quality, (NSDWQ, 2007). The total dissolved solid (TDS) varied from 117mg/l to 491.5mg/l, with mean of 367.7625mg/l and hardness, which ranged from 14.5mg/l to 124.97mg/l, with mean values of 75.0025mg/l. Two of the samples have TDS values which were higher than the 500mg/l stipulated by WHO (2006) and the other lower though slightly elevated, while hardness values are generally lower than the 200mg/l of NSDWQ (2007) and WHO (2006). The elevated level of some of the above physical properties compared to other probably underpinned pollution of groundwater, especially the shallow wells.

The concentration of Na^+ ions are more preponderance than those of K^+, Mg^{2+}, and Ca^{2+}, with values ranging from 58.68mg/l to 175.1, with average of 136.35mg/l. The values of Na^+ in hand- dug wells are well above those of boreholes. Furthermore, values of K^+ ranged from 9.32mg/l to 36.11mg/l, with mean of 19.88125mg/l, while Mg^{2+} ranged from 8.58mg/l to 22mg/l, with mean of 14.045mg/l, and those for Ca^{2+} returned values which ranged from 0.3 mg/l to 3.22 mg/l and with mean of 1.885mg/l.

The order of preponderance of the major cations in the groundwater samples is represented by $Na^+ > K^+ > Mg^{2+} > Ca^{2+}$. This order, thus depict a deviation from the normal order of $Ca^{2+} > Mg^{2+} > K^+ > Na^+$

Table 2: Summary of physiochemical parameters of groundwater.

	S1	S2	S3	S4	S5	(BH1)	(BH 2)	(BH 3)	Min	Max	Mean
PH	6.44	6.71	7.04	6.02	6.35	7.13	7.01	7.31	6.02	7.31	6.751
E/C(µs/cm	1018	1479	569	601	235	236	767	983	235	1479	736
TDS	509	739.1	284.5	300.5	117	117	383.5	491.5	117	739.1	367.76
Hardness	14.5	38.11	35.05	98.7	111.35	124.97	75.8	101.54	14.5	124.97	75.002
Cl^{-1}	500	400	150	130.06	300.9	50.985	6.67	53.983	6.67	500	199.07
NO_3^-	1.01	1.43	0.87	2.041	1.745	3.19	0.085	1.174	0.085	3.19	1.443
$SO4^-$	125.2	76.9	38.1	21.05	101.28	1.85	62.1	5.3	1.85	125.2	53.972
HCO_3^-	6.4	5.11	9.52	14.64	21.62	14.64	24.31	20	5.11	24.31	14.53
Ca^{3+}	3.22	1.36	0.3	3.1	2.01	1.05	1.97	2.07	0.3	3.22	1.885
Na^+	135.77	160.95	58.68	123.42	149.02	175.1	127.83	160.03	58.68	175.1	136.35
Mg^{2+}	9.06	11.27	10.3	8.58	10.92	19.91	22.05	20.27	8.58	22.05	14.045
K^+	13.52	16.03	13.8	9.32	12.01	36.11	29.6	28.66	9.32	36.11	19.881
Fe^{2+}	0.001	0.554	0.486	<0.001	0.15	3.55	<0.001	3.267	0.001	3.55	1.334

s = hand-dug wells, BH are borehole samples for pristine groundwater. According to Akujieze and Oteze,(2002) and Karanth,(2006), this deviation is probably due to salinization and other geochemical process which contribute to the degradation of groundwater quality. Deming (2002) on the other hand, attributed it to ion exchange between groundwater rich in Ca^{2+} and low in sodium flowing from land towards the Atlantic Ocean with coastal plains aquifers. The exchange of ion is responsible for the increase and decrease in sodium and calcium ions normally observed in groundwater aquifers of coastal plains, this process of ion exchange deplete the hardness of the water by the decline in the concentration of Ca^{2+} and Mg^{2+}. Consumption of Na^+ enriched groundwater has health implication of being responsible for high blood pressure among the people. Similarly a correlation between people consuming Na^+ enriched groundwater from coastal plain aquifers and increase of heart diseases has been demonstrated by Chapelle (1997). More also, the preponderance of the sequence of cations may also be attributed to the chemical weathering taking place in the aquifer matrices, which can lead to the alteration of the quality of groundwater aquifers.

Figure 3 reveals that the groundwater samples appeared below the equal line of the scatter plot of ratios of Ca^{2+} + Mg^{2+} versus HCO^-_3+ SO^-_4 represents silicate weathering and those above suggest carbonate weathering. Hussein and Mohammed (2006) has used similar plot to indicate silicate weathering in groundwater aquifer resulting in increment in the concentration of Na^+ ions in coastal aquifers.

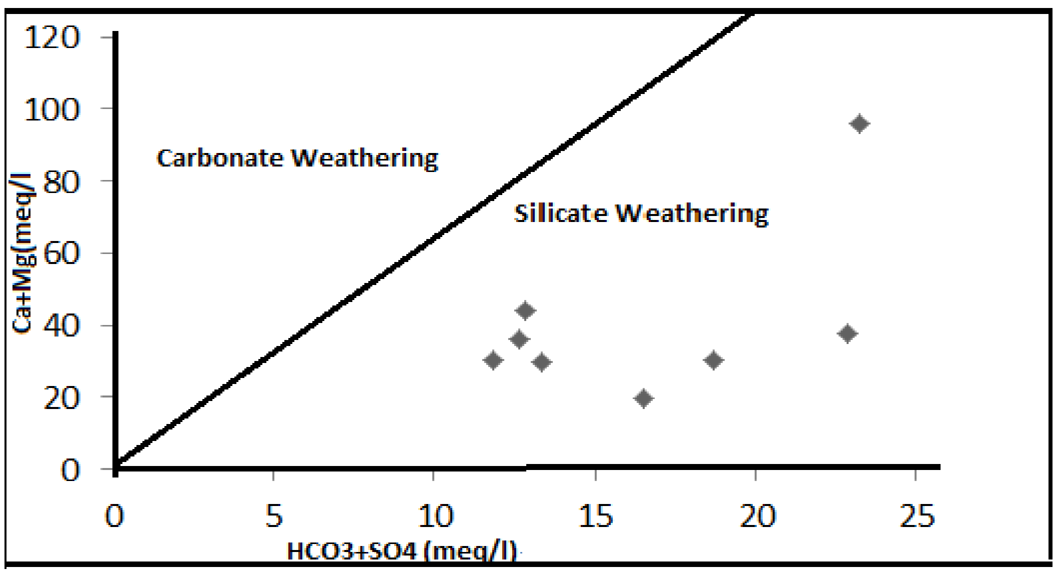

Figure 3. Scatter plot of Ca^{2+} + Mg^{2+} versus HCO^-_3+ SO^-_4

Obviously no samples plotted above the equal line which could have depicted carbonate weathering groundwater. Carbonate weathering tends to explain the degree of influence marine has on the ion exchange process taking place in groundwater aquifer rich marine shells. Since none of the sample points is plotted above the slope line, it strongly reflects that carbonate weathering has no significant impact on the ionic exchanges process in the groundwater aquifer of the study area.

Among the anions, Cl^{-1} has the highest concentration, which ranges from 6.67mg/l to 500mg and average of 199.0748mg/l. The values of SO^-_4 varied between 1.8mg/l and 125.2mg/l, with average of 53.9725mg/l, HCO^-_3 ranged from 5.11mg/l to 24.31mg/l and average of 14.53mg/l. While NO^-_3 varied from 0.055mg/l to 3.19mg/l, with average of 1.443125mg/l. The sequence of preponderance of anions is in the order of $Cl^{-1} > SO^{-}_4 > HCO^{-}_3$. The hand-dug wells characterized by elevated concentration of Cl^{-1}, SO^{-}_4, and HCO^{-}_3, which are noticeably higher than those observed for the boreholes samples with the exception of NO^{-}_3 ,which were relatively lower. The elevated high values observed probably indicate pollution from anthropogenic impact on the groundwater quality.

Therefore ionic exchange, anthropogenic influence and silicate weathering are playing dominant role responsible for the salinization of groundwater in the coastal plain of the study area. This is supported in the study in drawing attention to the fact that the parameters of TDS and Cl^{-1} often used as surrogated for saltwater intrusion are well far below the maximum standard guideline stipulated by the United State Environmental Protection Agency and others. According to Barlow (2003), for any groundwater to be regarded as brackish, it must have TDS and Cl^{-1} concentrations that are above the 500mg/l and 250mg/l respectively. Table 3 below further clarifies what value of TDS required for any groundwater to be classified as either fresh, brackish, saline water or brine. Most studies in the Niger delta have made deduction of brackish and saline even when TDS and Cl^{-1} values were below permissible limit of WHO (2006) and NSDWQ (2007), and those specified in the table. The misconception of saltwater intrusion into groundwater aquifers in mangrove swamps in Ughoton has been corrected by Akpoborie and Aweto (2012), as their work accentuated that groundwater condition in a mangrove swamp in the western Niger delta is not saline despite being situated in a tidal creeks. Their finding is rather contrary to a previous one that assigned brackish status caused by saltwater intrusion into groundwater aquifer in Warri and environs.

Table 3. Classification of saline groundwater after Carroll (1962).

TDS mg/l	
Freshwater	0-1000 mg/l
Brackish water	1,000-10000 mg/l
Saline water	10,000-100,000 mg/l
Brine	>100,000 mg/l

However, the concentration of iron recorded in the groundwater samples is very high (Table 2), these values are far higher than those specified for safe drinking water by WHO (2006) and NSDWQ (2007). The value of Fe^{2+} ranges from 0.001mg/l to 3.55mg/l and with mean of 1.334667mg/l. The values of Fe^{2+} are commonly higher among the borehole samples than the hang-dug wells. There are many boreholes and hand-dug wells in the study area, but of the lot, only water from S4-(hand-dug well) and BH2 (shallow borehole) are considered safe for drinking by the inhabitants of the study area, surprisingly they have concentrations of Fe^{2+} that are lesser than 0.001mg/l, while others are abandoned due to the abundance of Fe^{2+}, an indication that iron is unevenly distributed in the area.

The concentration of iron in boreholes and hand-dug wells is caused by the leaching of iron impregnated soils by precipitation through the permeable and porous soils to the aquifers. Surprisingly not the whole area are characterized by the presence of iron impregnated soil. The only plausible explanation for the uneven and spatial distribution of iron can only be explained by existing of reducing condition of the environment during deposition of aquifer sediments. However other areas which lack dissolved iron in water may be alluded to the prevailing oxidizing environment of deposition which not favourable for precipitation of iron in the aquifers.

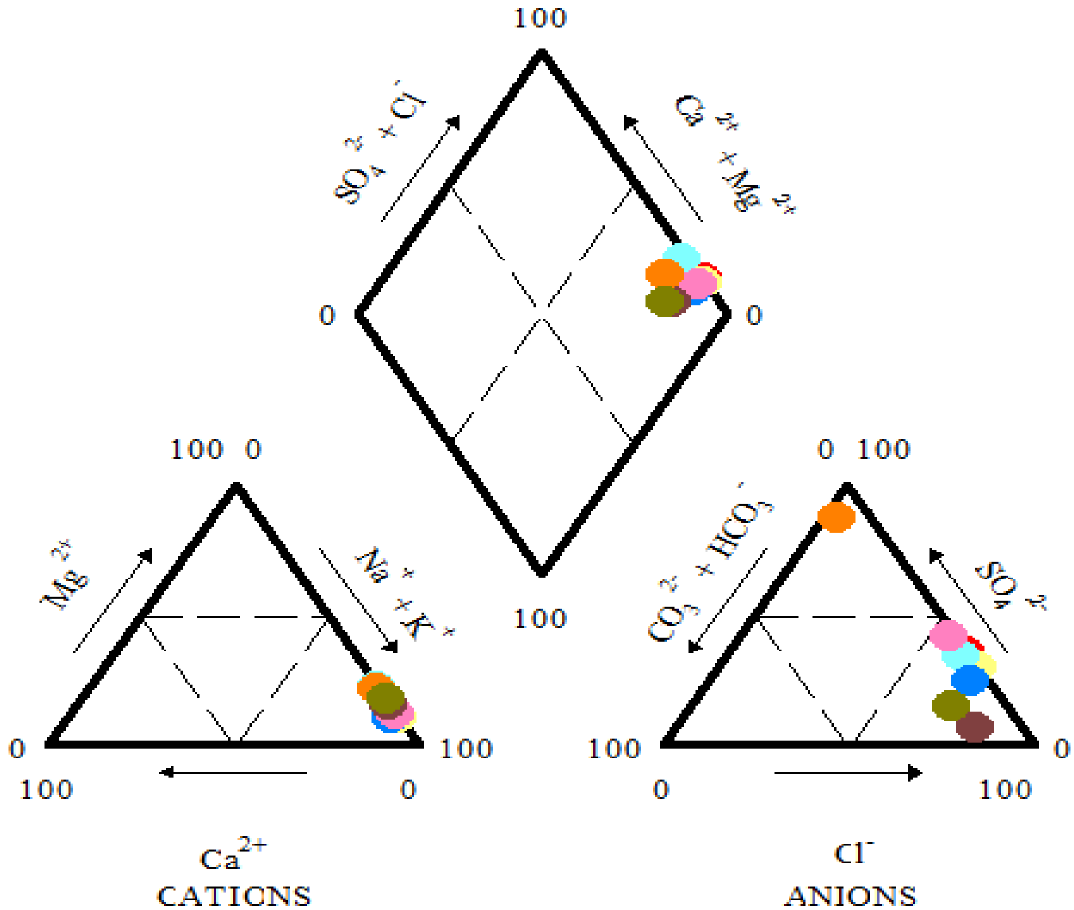

Figure 4: Piper diagram plotted by the GW_Chart calibration plots of the US Geological Survey.

The GW_Chart calibration plots; a graphing tool for model analysis of the US geological survey was used to ascertained the geochemical source of dissolved constituents in water. The cations and anions of $Na^+ + K^+$, Mg^{2+}, Ca^{2+}, Cl^{-1}, SO^-_4, HCO^-_3, while CO_3^- was automatically calculated from the concentration of HCO^-_3 and total dissolved solid by the software. These cations and anions were subsequently plotted on the lower triangles of the piper diagram (Figure 4). The result of the groundwater classification using Piper plot revealed $Na^+ + K^+$- Cl^{-1}- SO^-_4, as the hydrochemical facies of the study area. This, also points to silicate weathering as the major factor contributing to ionic exchange process altering groundwater quality in the area.

Groundwater condition

The depth to water levels and hydraulic heads derived from measurements in hand-dug wells and boreholes are presented Table 3, they ranged between 1.02 and 5.22m for the shallow hand-dug wells and 11.3 and 37m deep for the boreholes for the rainy season period. Some of these shallow boreholes dried up during the dry season period of the year. Figure 5, shows contour plot of water table elevations which reflected groundwater interaction with the River Forcados. The direction of flow is mainly towards the Foracdos River. Consequently the river and the aquifers are regarded as losing aquifer and gaining river as indicated by the heads contour respectively.

Table 3: Depth to water levels and calculated heads.

Latitude	Longitude	Depth to Water level(m)	Calculated head (m)
$5^{0}20^{1}56.3^{11}$	**$5^{0}30^{1}10.5^{11}$**	1.66	3.68
$5^{0}20^{1}54.4^{11}$	**$5^{0}30^{1}12.0^{11}$**	1.77	3.62
$5^{0}20^{1}00.7^{11}$	**$5^{0}30^{1}13.2^{11}$**	1.39	3.9
$5^{0}20^{1}59.1^{11}$	**$5^{0}30^{1}16.9^{11}$**	1.66	3.74
$5^{0}21^{1}02.0^{11}$	**$5^{0}30^{1}16.7^{11}$**	1.63	3.71
$5^{0}21^{1}03.9^{11}$	**$5^{0}30^{1}17.2^{11}$**	1.83	3.87
$5^{0}21^{1}02.9^{11}$	**$5^{0}21^{1}20.4^{11}$**	1.85	3.95
$5^{0}21^{1}02.5^{11}$	**$5^{0}30^{1}22.1^{11}$**	1.44	3.96
$5^{0}21^{1}10.1^{11}$	**$5^{0}30^{1}36.2^{11}$**	1.02	3.91
$5^{0}21^{1}12.4^{11}$	**$5^{0}30^{1}35.5^{11}$**	1.04	3.83
$5^{0}21^{1}12.6^{11}$	**$5^{0}30^{1}33.0^{11}$**	1.38	3.89
$5^{0}21^{1}16.7^{11}$	**$5^{0}21^{1}35.0^{11}$**	1.84	3.59
$5^{0}21^{1}17.6^{11}$	**$5^{0}30^{1}37.0^{11}$**	1.37	3.95
$5^{0}21^{1}20.3^{1}$	**$5^{0}30^{1}41.6^{11}$**	3.00	3.85
$5^{0}21^{1}19.8^{11}$	**$5^{0}30^{1}42.6^{11}$**	2.84	3.59
$5^{0}21^{1}20.8^{11}$	**$5^{0}30^{1}43.6^{11}$**	13.96	3.79
$5^{0}21^{1}19.8^{11}$	**$5^{0}30^{1}44.8^{11}$**	11.3	4.33
$5^{0}21^{1}24.1^{11}$	**$5^{0}30^{1}47.2^{11}$**	1.93	4.84
$5^{0}21^{1}25.7^{11}$	**$5^{0}30^{1}54.1^{11}$**	5.22	4.74
$5^{0}21^{1}05.9^{11}$	**$5^{0}30^{1}02.9^{11}$**	37.36	4.95
$5^{0}21^{1}06.4^{11}$	**$5^{0}30^{1}03.4^{11}$**	1.76	3.15

The source of ground discharge into the River Forcados is from the local shallow aquifers but possibility of regional discharge from Benin aquifer bearing Formation cannot be rule out. The presence of mound close to the river bank is indicative of slight groundwater stressing, which evidently is reflected by the population density clustered around the river bank and decreases with distance from the river. The aquifers are majorly unconfined and semi-unconfined, which has already been shown from interpreted VES data (Table 2). The possibility in reversal of groundwater flow that is from the river into aquifer may not be likely considering the relative high water table elevations which characterized the area. Also, stage measurement during low and high tides made ranged from 1.2m to 0.4m; the prevailing 6 hourly tide may not be high enough to the extent of affecting the aquifer. The

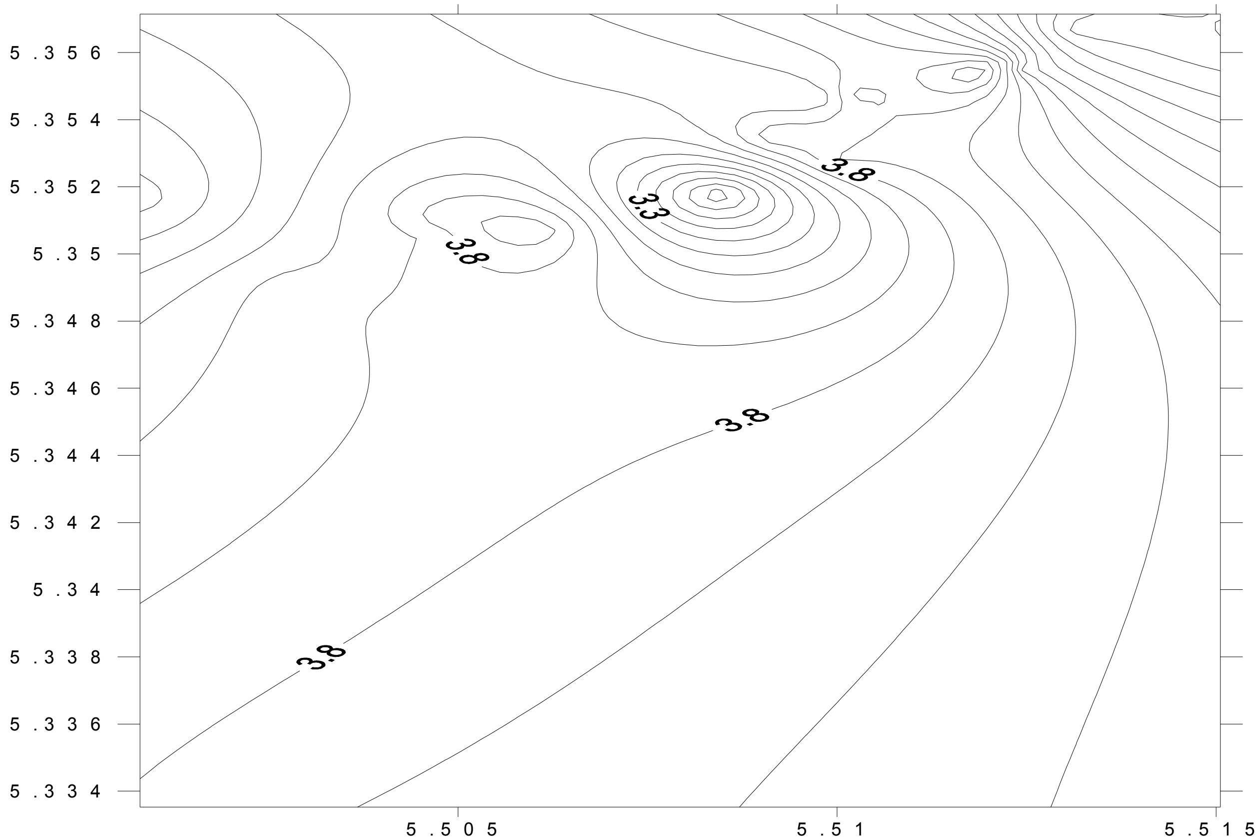

Figure 5: Groundwater flow direction for the study area.

high tide saltwater from the ocean and freshwater incursion are accountable for the flourishing of the mangrove swamp in bank of river Forcados at the study area. The aquifer in area is mainly recharge by precipitation; vulnerability to contamination is facilitated by infiltration and leaching from surface through unsaturated zones into groundwater aquifers. The vulnerability is driven by the high hydraulic conductivity similar to other Somebrerio – Warri plain sands, which have been determined for the Warri area by Akpoborie et al., (2000) to range between $2.8*10^{-4}$ and $2.5*10^{-4}$ m/sec.

CONCLUSION

The study has further demonstrated the efficacy and reliability of results that can be obtained from the combination of the use of vertical electrical sounding and hydrogeochemical methodologies in the investigation of groundwater quality. The quality of groundwater aquifers in the study area is profoundly of poor quality, which would have been difficult to be unraveled by the use of the VES alone; since the observed poor quality obtained from geochemical analysis is latent and has little or no effect in affecting the resistivity values, which would have enhanced its detection using this approach. The dissolved iron in the groundwater, colour and turbidity cannot be detected with the application of VES, but is possible with geochemical analysis.

The geochemical processes altering the quality of groundwater are considered to be controlled by the ionic exchange enhanced by silicate weathering and anthropogenic factors. Anthropogenic impact has greater influence on shallow hand-dug wells than the borehole as shown by having elevated concentration of environmental physiochemical indicators.

The study has shown also that saltwater intrusion is not associated with the degradation of groundwater quality on the bases of the chloride and total dissolved solids, which are often used as a proxy to constrained saltwater intrusion, are below the requirements for groundwater to be considered as being saline or brackish. We however, suggest that further studies should be conducted on the groundwater quality in the study area, using other methodologies which can at least assist in distinguishing anthropogenic sources of chlorides and total dissolved solids from those originating from saltwater intrusion into coastal aquifers.

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