IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT)
e-ISSN: 2319-2402,p- ISSN: 2319-2399.Volume 9, Issue 1 Ver. II (Jan. 2015), PP 08-15
www.iosrjournals.org

Ground Water Conditions and Major-Ion Hydrogeochemistry of the Benin Formation and the Ethiope River at the Sapele Municipality, Nigeria

Irwin Anthony Akpoborie[1], Clemency U. Biokoro[2], Onoriode O. Emoyan[3]
[1]Department of Geology, Delta State University, Abraka, Nigeria
[2]Center for Research in Water and Environment, Abraka, Nigeria
[3]Department of Chemistry, Delta State University, Abraka, Nigeria

ABSTRACT: *Field determination of water table head from more than thirty randomly located dug wells have been used to establish that the water table gradient in the shallow sandy Benin Formation aquifer that underlies the Sapele urban area is generally inclined northwards. Groundwater flow is thus mainly northwards from the city center towards the Ethiope River. Transmisivity of the sands at a deeper horizon has been estimated at 27.5m^2 per day. Groundwater is mildly acidic at mean pH 6.5. TDS is generally low at mean 42mg/l and lowest at 15.2 mg/l. Groundwater mixing and ion exchange processes prevent the dominance of specific cations and water types range from Ca +Na + Mg at Shell Rd in the south east to Ca+ Mg at Urhobo Road in the city center. The chloride ion dominates. Water in the Ethiope River is also mildly acidic at mean pH 6.5 and TDS is lowest at PHCN, 12mg/l and highest at AT&P wood works, 184mg/l where sawmill wastes are dumped in the river. Notwithstanding, indices of aquatic ecosystem health are well below recommended threshold values and water in the area is of such exceptionally unique high chemical quality that it may be utilized for water supply irrigation and industry.*

Keywords: *Benin Formation, Ethiope River, groundwater, Niger Delta, Sapele, wood waste.*

I. Introduction

The city of Sapele, Latitude 5^0 5'N - 5^0 55'N and Longitude 5^0 37'E – 5^0 44'E, Fig. 1, Fig. 2 is the head quarter of the Sapele Local government area, Delta State, Nigeria. Located on the south bank of the Ethiope River at its confluence with the Jamieson River, Figure 2 the uniquely crystal clear waters of both conjoined rivers become known as the Benin River west of Sapele. The Benin River empties into the Atlantic Ocean and because the Ethiope River is deep enough at Sapele to accommodate ocean going vessels, Sapele river port is one of the most important in the western Niger Delta.

Sapele town has grown from a small colonial trading post on the Benin River gateway to the Nigerian hinterland in the mid-19th century to today's medium size city of more than 150,000 people [1]. Industries located in the city include timber, rubber and palm oil processing, in addition to which Sapele is reputed to be home to the largest wood production industry in Nigeria [2]. Furthermore, there are numerous petroleum industry related installations including flow stations and numerous pipelines that are prevalent in this petroleum province.

Sapele is in the tropical rain forest region and is characteristically hot (23^{0}C -37^{0}C), humid (Relative Humidity, 50-70 per cent) with a 30 - year mean annual rainfall of 3000mm [3]. The wet season begins usually in March and extends to October. The dry, mainly rainless season stretches from November to March.

Water supply for domestic and industrial uses is from groundwater which is obtained with shallow boreholes and dug wells [4] from the shallow Benin Formation aquifer. The shallow aquifer consists of an alternating sequence of medium to coarse grained sandy deposit with subordinate and discontinuous sandy clay and clay layers that occur in places [5, 6, and 7]. Very low and insignificant levels of selected heavy metals have been reported in groundwater [8] while the surface water in the Ethiope River is reportedly exposed to contaminant loading from sawmill wastes in the vicinity of Sapele [9].

A primary objective of this paper is to build on this existing knowledge and provide detailed information on the hydrogeological setting in this area. An attempt is then made to explain how the groundwater conditions might determine and control the surface water/groundwater interactions and hydrogeochemistry. These issues are essential for urban and regional planning as well as for environmental management in this rapidly expanding urban setting.

1.1 Geology and distribution of Quaternary deposits in the Sapele area

The geology of the Niger Delta petroleum province is much studied [10, 11] and in summary, three important formations constitute the sedimentary fill of the Niger Delta Basin: the youngest Benin Formation which consists of massive continental/fluvial sands and gravels and rests on are the Agbada Formation of paralic sands and shales and the basal Akata Formation which consists of holomarine shales, silts and clays. The two older formations are encountered only in the subsurface but their lateral equivalents at the surface are the Ogwashi-Asaba Formation and Ameki Formation of Eocene- Oligocene age, Fig. 1.

The sedimentary environments and morphological features of the modern Niger Delta have also been described [10, 12, 13] and specifically, the Sapele area is situated on the Sombrero-Warri Deltaic Plain, one of the distinguishable physiographic landforms resulting from Recent and modern delta top deposition. The aerial distribution of these delta top deposits coincides somewhat with the associated physiographic subdivisions shown in Figure 1. Electrical resistivity surveys [7, 14, 15, and 16] have revealed that the near surface deposits that underlie the Sapele area consist of an alternating layering of medium grained to coarse sands. 12m deep borehole logs from the Ogorode area [6, 17] on the northwestern fringe of Sapele reveal a 4m thick sandy and silty clay overburden that overlies a continuous, medium – coarse sand layer. These deposits are universally considered to be recent expressions of the Benin Formation [11, Figure 11.6]) and underlie the Sombrero-Warri Deltaic Plain, Fig.1. They are the sands that constitute the aquifers exploited with dug wells and shallow boreholes for groundwater in the Sapele municipality and all over the Niger Delta.

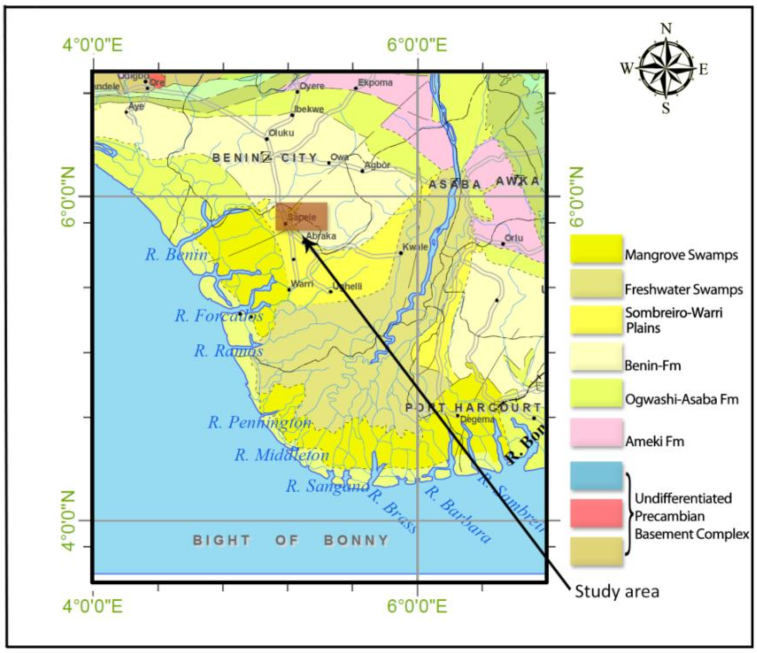

Figure 1 Geological Map of part of the Niger Delta showing the distribution of Quaternary deposits and the location of the Sapele area (Adapted from NGSA [18])

II. Methodology

Thirty two dug wells in Sapele were selected for the study. Depth to water level in each of the dug wells was measured with an electronic water level indicator. An Ertec model GPS instrument was used to determine wellhead coordinates. Because existing topographic maps of the entire area are devoid of contours, averaged elevation readings taken simultaneously from three GPS instruments at each site were used to establish elevation. Surfer [19] was employed in generating the calculated water table head distribution map. Depth to water level was measured at the dug well located by the saw mill at the Sapele Main Market for six months from the end of the dry season in May through the rainy season to October, 2011. Readings were taken once a month on the fifteenth of each month at noon. However, general depth to water level for the remainder wells were measured in mid- October. A set of data from a pump test conducted at Amukpe [20] a suburb of Sapele was used for aquifer parameter estimation.

Ground water as well as surface water from the Ethiope River was sampled for analyses in mid October, 2011. The Ethiope River was sampled at four locations: at Okoloko Bridge just upstream of Sapele; Ogoro Jetty and AT&P wood works, both river bank locations in the city, and downstream of the city at PHCN, Ogorode, Fig. 2.

The sampling procedure consisted of collecting replicate samples 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°C units from 0°C to 100°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^- , Dissolved Oxygen, biochemical Oxygen Demand (BOD)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 [21] as were Nitrate-nitrogen ($N0_3$-N) and Phosphate-phosphorus ($P0_4$-P) after reduction with appropriate solutions.

III. Results and Discussion

3.1 Groundwater conditions

The shallow aquifer which consists of the alternating bands of medium to coarse grained unconsolidated sands in the Sapele area is unconfined and water table conditions are prevalent. Transnmissivity was estimated from data obtained from a 72 - hour pump test conducted at Okpe Grammar School yielded a value of 27.5m^2/day from the Jacob[22] straight line method. Depth to water level observed in October ranged from 10m at Ugberikoko Road at Gana neighbourhood through 4m at Adeniyi Road, 2.5 m at Amukpe to 0.2m at the Ugbeyiyi area. Depth to water level was also monitored continously at the dug well located by the Sapele Main market from May to October, 2011. Levels were lowest at 5.9m in the dry season in May and started rising in June as a result of the rains, peaked and levelled at 3.7m in mid September and October when flow recession commences in the Ethiope River [23]. Thus the water level fluctuation resulting from direct rainfall recharge in the 2011 wet season was approximately 2.2m.

The distribution of water table head in the Saplele area is shown in Fig. 2 from where it is clear that the groundwater gradient is generally inclined north and northwestwards. There is what appears to be a groundwater sink at the western end of New Ogorode Road, and which sink indeed coincides with a major swamp and wetland area that borders Sapele town on the southwest. This sink is bound on the west and east by groundwater mounds in the Gana and Shell Road areas respectively. Thus groundwater movement is from the recharge area at the Shell Road/Mechanic village sector first northwards, and secondly west and northwest through the city center at Akintola Road, Awolowo Road, Benin Road and Urhobo Road areas to the Ethiope River. Third, water also moves from this recharge area eastwards again to the Ethiope River and then westwards to recharge the wetland. From the Gana recharge zone, groundwater moves south east towards the wetland sink and west and northwest in a broad swath towards the Ethiope River. These local groundwater flow systems are characteristic of the Niger Delta region [24] and exist in conjuction with deep regional west and south westward flows in the Benin Formation. East and upstream of Sapele at Abraka, it has been estimated [23] that these local flow systems contribute groundwater that makes up as much as 80 per cent of daily mean flow of 25.12m^3/sec of the Ethiope River from a fraction of the total area of the Ethiope River catchment. An important implication of these flow regimes is that groundwater recharges the Ethiope River in this area and the river does not recharge the shallow aquifer.

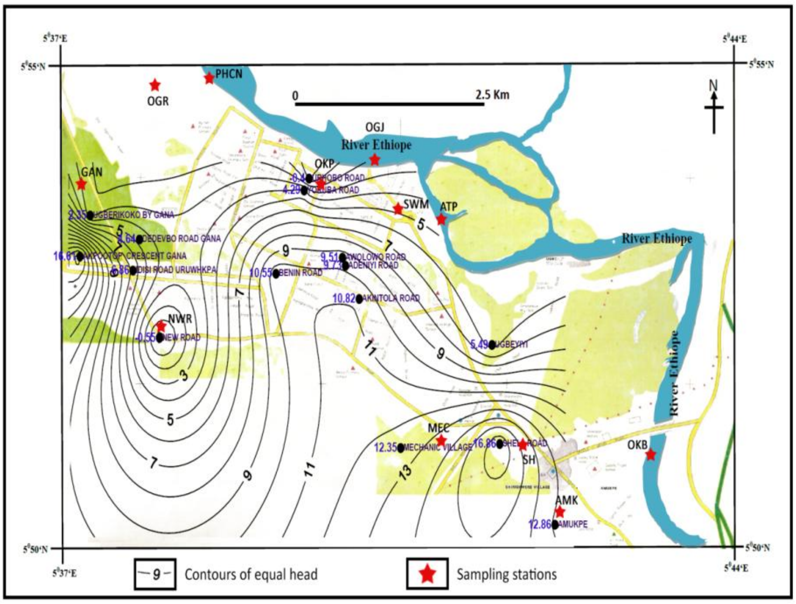

Figure2 Map of Sapele showing water table head distribution and sampling points for ground water and surface water from the Ethiope River

3.2 Hydrogeochemistry

3.2.1 Groundwater

Results of chemical analyses of groundwater samples collected from dug wells at selected sites are shown in TABLE 1. The water sample from public water agency borehole (Wb) in TABLE 1 is placed alongside for comparison. The public agency borehole is about 100m deep, while the dug wells are usually less than 10m in depth. The sample result from rural Ogorode (Ogrd) is the mean from five 12m deep dedicated boreholes drilled for the purpose of collecting pristine groundwater samples for an environmental impact assessment study [16] and is also placed alongside for comparison.

Groundwater is mildly acidic at mean pH 6.3 and mean TDS is 42 mg/l. In comparison, water from the deeper aquifer horizon tapped by the water agency borehole returned the highest TDS at 184mg/l, while that from the city center at Urhobo Road (urb) and rural Ogorode sample returned the lowest TDS at 15.3mg/l and 15.2mg/l respectively. The high TDS from the deep borehole could be explained by the fact that water in the deeper horizons of the aquifer would have had a longer residence time in the aquifer for water-rock interactions to occur and thereby raise its salinity. It is also suggests that vertical mixing of groundwater within the aquifer may be slow and that water that occurs deeper in the Benin Formation may be unaffected by fluxes in the shallower regimes of the aquifer. This potential hydro-geochemical stratification requires further investigation.

Variations in TDS across the city are suggestive of salinization processes engendered possibly by anthropogenic processes. In the shallow horizons, groundwater is constantly being recharged by direct rainfall and also lost to streamflow and other uses and which processes are reflected by the seasonal change in water level of 2.2m recorded during six months of monitoring.

All chemical constituents are quite low and these results are consistent with previous studies undertaken in the Sapele area [7] and elsewhere on the Sombreiro- Warri Deltaic Plain terrain [25, 26]

Table 1: Physical characteristics and major ion chemistry of groundwater from Sapele (All values in mg/l except where indicated)

Parameters	Sample Locations											
	NWR	OKP	SWM	Amk	Okd	Gana	Sh	Mec	Urb	Ugb	Mean	Wb	Ogrd[+]
pH	7.1	8.1	5.3	5.22	5.47	6.09	7.0	6.8	6.3	6.4	**6.3**	6.5	5.62
TDS	115	73.6	110	70.5	16.5	62.5	18.2	16.0	15.3	16.5	**42.43**	184	15.2
EC (µs/cm)	230	147.7	165.9	120.6	23.1	108.5	36.5	32.1	30.4	33.0	**92.78**	368	nd
Ca	0.41	0.21	9.3	5.1	4.6	13.4	4.60	2.30	6.20	3.40	**4.9**	54.4	3.0
Mg	0.88	0.35	4.5	3.5	2.4	3.2	3.40	1.20	4.00	1.90	**2.12**	31.2	2.39
Na	2.5	1.09	11.6	9.8	9.9	11.8	3.56	4.32	3.01	2.54	**6.01**	52.4	0.014
K	0.56	0.84	1.52	0.92	0.42	0.48	2.01	2.76	1.60	1.49	**1.26**	32.7	0.35
HCO_3	1.3	0.98	3.2	7.32	7.08	22.4	2.4	2.22	2.02	1.86	**5.078**	32.5	20.8
SO_4	2.0	1.01	1.34	1.28	0.45	0.22	0.3	0.13	0.5	0.45	**0.77**	0.14	3.48
Cl	7.28	4.34	22.46	19.97	6.24	9.98	10.9	9.6	9.0	9.90	**10.97**	110.4	0.004
NO_3	0.75	0.5	2.88	2.72	1.26	2.24	0.53	0.25	0.43	0.25	**1.18**	0.15	nd

Notes: Nwr = New Road; Okp = Okpe Road; swm = sawmill; okd = Okuadede; Gan = Gana; mec = Mechanic Village; sh = Shell Road; urb = Urhobo Road; ugb = Ugberikoko Road; WB = Urban Water Board,; nd = Not determined

+ogrd = mean value from 5 five shallow boreholes

3.2.2 Surface Water

The physical and chemical characteristics of water collected from sampling stations, Fig. 2 on the River Ethiope are shown in TABLE 2.

Table 2: Physical and chemical characteristics of water from the River Ethiope at selected locations in the vicinity of Sapele (All values in mg/l except where indicated)

Parameters	Sampling points on Ethiope River				
	Okb	ATP	Ogr	PHCN	Chapman[+]
pH	6.5	6.6	6.7	6.8	6.5-8.5
TDS	14.4	121	30.6	12.0	
TSS	0.43	1.17	0.81	0.85	
Turbidity (NTU)	0.88	9.6	3.6	3.87	
EC (µs/cm)	28.9	244	60.4	24.5	
DO	5.4	5.10	5.2	5.6	<10
COD	32.2	24.20	33.3	35.7	20
BOD	5.3	8.40	6.1	5.6	2
N Total	2.30	2.56	2.83	1.47	
NH4-N	1.36	1.54	1.14	0.63	<0.2

P(Total)	0.024	0.03	0.02	.017	<0.02
Eh (mV)	9.80	-7.2	5.9	-3.10	-500 - + 700
Ca	6.3	49.5	15.40	1.5	
Mg	3.2	33.0	9.10	0.9	
Na	2.32	38.04	5.31	2.02	
K	1.8	21.6	4.02	1.99	
HCO_3	1.90	27.9	4.42	1.05	
SO_4	1.54	1.49	1.60	0.10	
Cl	8.7	73.2	18.0	7.4	
NO_3	0.95	0.93	0.87	0.5	<1
Cd	0.002	0.001	0.002	0.00	
Pb	0.001	.001	0.00	0.00	
Cr	0.002	0.001	0.001	0.00	
Fe	1.76	1.05	1.43	0.34	

Notes: OKb = Okoloko Bridge; ATP = AT& P Woodworks; Ogr = Ogoro Jetty; PHCN= Power Station, Ogorode. $^{+}$Chapman, D. [27]

Surface water salinity is also generally low. TDS and TSS vary spatially from Okoloko Bridge at 14.4 mg/l as the river enters the Sapele area through a high of 121mg/l at AT&P woodworks to a low of 12mg/l about 3 kilometers downstream of the woodworks at PHCN, Ogorode when it exits the city, Fig. 2. This low salinity appears to be a characteristic of the many rivers that drain the Sombreiro-Warri Deltaic Plain and other Recent delta top deposits including the upstream portion of the Ethiope River at Abraka [26]

The effects of urbanization on the quality of surface water are clearly displayed in Fig. 3 where there are consistent spikes in the magnitude of occurrence of all anions as the river flows by the city and the AT&P woodworks and Ogoro Jetty from where wood waste has been regularly dumped in the river for decades. These observations are in agreement with previous studies [9] that linked water quality impairment and associated reduction in fish populations in the Sapele stretch of the river to wood waste disposal from the sawmill industry.

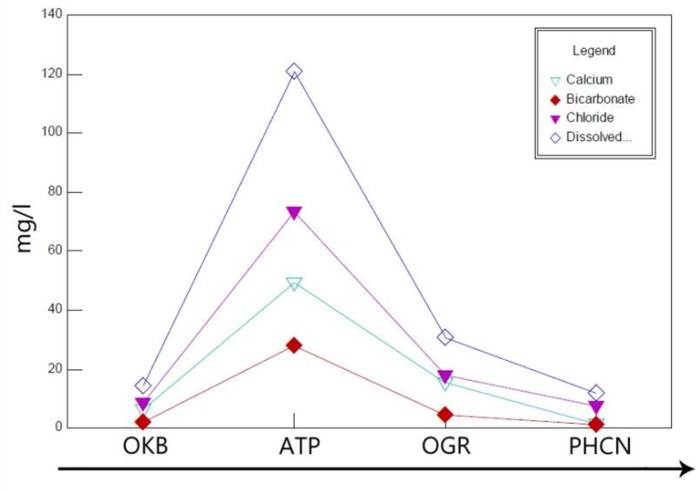

Figure 3: Spatial distribution of selected major ions at selected sampling locations on the Ethiope River. Arrow indicates flow direction and location codes are as explained in Table 2.

Other water quality indices that have implications for fish, other aquatic life and ecosystem health in general include dissolved oxygen (DO), the biochemical oxygen demand (BOD), total phosphorus, total Nitrogen and Ammonia nitrogen values for which in addition to other relevant parameters are shown in TABLE 2. Recommended threshold levels of occurrence for some of the key parameters in healthy aquatic ecosystems [27] are placed alongside for comparison. It is clear from the values returned from all sites that the AT &P site is the most impacted. For example, it has the highest BOD, the lowest DO and also the highest turbidity. While the level of NH4-N at all the sites is high and indicative of persistent anthropogenic and industrial waste, all other values are at reasonably low levels even at the AT&P site. Furthermore, dilution and self regeneration processes in the river are evident such that at less than 3 kilometers downstream from the AT&P woodworks, the quality of water has reverted to the original condition that was recorded at Okoloko Bridge, the point of entry into the Sapele municipality.

3.2.3 Major Ion Geochemistry

Data from TABLE1 and TABLE 2 have been plotted in the Piper interpretive diagram [28] in order to identify water types as well as determine mixing patterns and possible ion exchange processes as groundwater moves in the aquifer. All surface water and groundwater samples except one (gana) plot linearly on the right hand upper quadrant of the central diamond in Fig. 4 which is suggestive of the same origin and similar chemical composition for both waters. This is in agreement with the explanation [23] that Ethiope River catchment is underlain exclusively by the Benin Formation and that annual groundwater contribution to stream flow is approximately 80 per cent. Dry weather flow in the river is indeed 100 per cent groundwater.

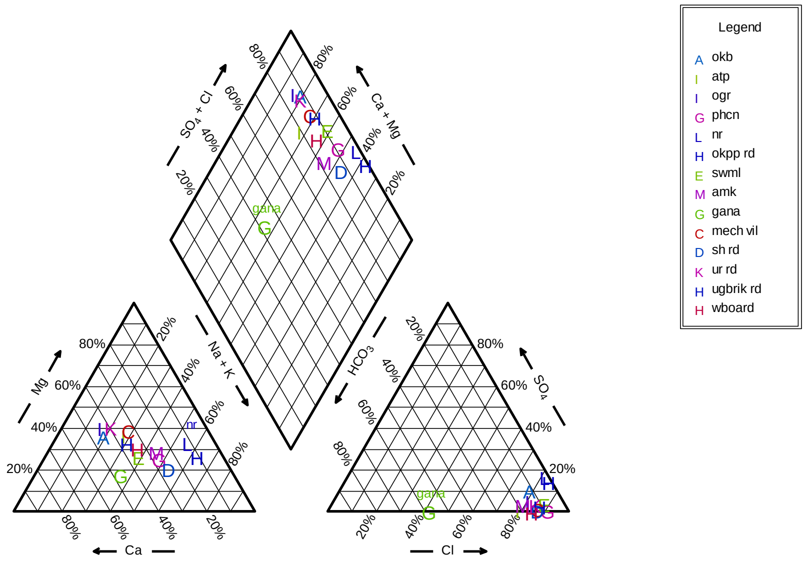

Figure 4: Piper diagram plot of Sapele groundwater and surface water

In the cation ternary diagram all samples plot in a well developed mixing trend that indicate the absence of dominant cations. In the anion ternary, all but water from Gana area cluster in the chloride end. Ground water may thus be classified as the Ca + Mg + Na + K Chloride type. However, the Shell Road (Ca>Na>Mg>K) and Urhobo Road (Ca>Mg>Na>K) samples appear to be end member facies of a distinct mixing line [29] and suggestive of ion exchange processes that result in increased percentages of Ca and Mg in relation to decreased Na ions as water moves north west wards, Fig. 2. These reactions are consistent with ion exchange processes that have been reported in the shallow Benin Formation [26]. The sample from Gana area is uniquely for this area, bicarbonate rich. Similar bicarbonate water in Sombreiro- Warri Deltaic Plain Deposits at Warri, just south of Sapele has been linked [30,31] to the presence of bicarbonate enriched leachate from landfills and dump sites in the Warri area.

3.3 Water Quality and Water Use

3.3.1 Water Supply, Recreation and Industry

The levels of occurrence of all major chemical constituents in both ground water and surface water are well below WHO Drinking Water Quality Standards as well the Nigerian Standard for Drinking Water Quality [32, 33]. The exceptional high quality of groundwater and surface water in the Ethiope River catchment and relatively uniform quality recommends it for many uses including industrial processes that require consistently high quality water.

It is also important to stress that design and location of land based waste management systems recognize the fact that ground water flows from all parts of the city to recharge the Ethiope River, that is to say, the river is very susceptible to contaminant loading from potential city sources.

3.3.2 Irrigation

Universal indices of suitability for irrigation waters have been determined for surface water and ground water in Sapele and the results are presented in TABLE 3. The indices were estimated as follows:

a. Salinity Hazard: Water with TDS that is less than 200mg/l is excellent for irrigation [34], thus all water sampled in Sapele is suitable for irrigation.

b. The Sodium Adsorption Ratio (SAR) was estimated from the relationship:
$SAR = Na^{+} / \{[Ca^{2+} + Mg^{2+}] /2\}^{0.5}$ (35)
Results for all samples are well below 10 and water is thus suitable for irrigation [36].

c. Estimated Magnesium hazard ratios obtained with the relationship:
$MH = (Mg^{2+} \times 100)/ (Ca^{2+} + Mg^{2+})$ [37]

for all sampled water are either close to the threshold value of 50 or higher. The meaning of this is that water in this area is considered harmful to soils and may not be used for irrigation without appropriate treatment.

d. Residual Sodium Carbonate (RSC) obtained from the folowing relationship:
RSC = $(CO_3^{+} + HCO_3^{2-}) - (Ca^{2+} + Mg^{2+})$, where all ionic concentrations are expressed in epm indicates that all values are less than the threshold of + 1.25 [38] and water may thus be safely used for irrigation.

Table 3: Irrigation Indices

Location	SH	SAR	MH	RSC
OKB	Low	$1.88x10^{-3}$	45.6	0.0
ATP	Low	1.03	52.4	0.0
OGJ	Low	$2.65x10^{-3}$	49.4	0.0
PHCN	Low	$3.33x10^{-3}$	49.7	0.0
NR	Low	$5.05x10^{-3}$	78	-
OKP	Low	$3.38x10^{-3}$	73.3	-
SWML	Low	$7.81x10^{-3}$	44	0.0
AMK	Low	$8.18x10^{-3}$	53.1	0.0

Notes: SH = Salinity Hazard; SAR = Sodium Adsorption Ratio; MH = Magnesium Hazard;
RSC = Residium Sodium Carbonate. Location codes as in Table 1 and Table 2.

IV. Conclusion

The disposition of water table head in the shallow sandy aquifer that underlies the Sapele municipality indicates that groundwater flow is generally northwards from the city center and eastwards from the Amukpe area towards the Ethiope River. Local mounds also recharge the wetland and swamp that borders the south west portion of the city. Groundwater TDS is generally low at mean 42mg/l. The highest TDS of 184mg/l obtained from the relatively deep public water agency borehole suggests that water that occurs deeper in the Benin Formation may be unaffected by fluxes in the shallower regimes of the aquifer, but this potential hydro-geochemical stratification requires further investigation. Surface water in the Ethiope River is also characterized by very low ionic content and all the relevant parameters of aquatic and ecosystem health indicate that the river is in excellent condition. The major threat of contamination is posed by sawmill wastes but the data suggests that rejuvenation occurs and the effects of contamination are dissipated quite rapidly downstream. Finally, the levels of occurrence of all major chemical constituents in both ground water and surface water are well below WHO Drinking Water Quality Standards as well the Nigerian Standard for Drinking Water Quality. The exceptional high quality of groundwater and surface water in the Ethiope River catchment and relatively uniform quality recommends it for many uses including industrial processes that require consistently high quality water.

Acknowledgements

We acknowledge with gratitude the various undergraduate students of the Department of Geology, Delta State University, Abraka especially Ejiro Atenaga, who assisted in several aspects of the field work associated with data gathering. The Center for Research in Water and Environment (CREWE), Abraka, provided partial funding for the research.

References

[1]. National Population Commission, 2006 Population and Housing Census, Priority Table Volume III, Population Distribution by sex, state LGA & Senatorial District, (NPC, Abuja, Nigeria, 2010)
[2]. K. Okunomo, and F. O. Achoja, Economic Impact Assessment of African Timber & Plywood Company in Sapele, Delta State, Nigeria African Journal of General Agriculture, 6(3), 2010,159-167
[3]. O.A. Adejuwon, Rainfall Seasonality in the Niger Delta Belt, Nigeria, Journal of Geography and Regional Planning 5(2), 2012, 51-60. http://dx.doi.org/10.5897/JGRP11.096
[4]. Ministry of Economic Planning, Delta State Household and Housing Survey, (Central Office of Statistics, Asaba, Delta State, Nigeria, 2011)
[5]. E.A. Atakpo, I. A. Akpoborie and E.C. Okolie, Geoelectric Mapping of Amukpe Area, Delta State Nigeria. Nig. Jnl. Of Science and Environment, Vol.7, 2008, 73-81
[6]. McGill Engineering, Environmental Impact Assessment of proposed Independent Power Plant, Sapele. Project Report, McGill Engineering, Benin City, 2005
[7]. K.E. Aweto, Geoelectrical and geochemical evaluation of groundwater resources in Sapele metropolis, western Niger Delta, Continental J. Environmental Sciences 3, 2009, 24-32
[8]. C.O.Muwarure and U. Ufuoma, Determination of heavy metals in groundwater resources across Sapele local government area, Delta State , Nigeria, Sky Jour. Soil Science and Env. Management 2(3), 2013, 31-33
[9]. F.O. Arimoro, R.B. Ikomi and E.C. Osalor, (2007) The Impact of Sawmill Wood Wastes on the Water Quality and Fish Communities of Benin River, Niger Delta Area, Nigeria International Journal of Science & Technology 2 (1),2007, 1-12
[10]. K.C. Short, K. C. and A.J. Stauble, Outline of geology of Niger delta. Bulletin American Association of Petroleum Geologists 54 (5), 1967, 61-779.

[11]. J.B. Wright, D.A. Hastings, W.B. Jones and H.R. Williams, Geology and Mineral Resources of West Africa (George Allen & Unwin, 1985) DOI 10.1007/978-94-015-3932-6

[12]. J.R.L.Allen, Late Quaternary Niger Delta and Adjacent Areas: Sedimentary Environments and Lithofacies, Bulletin American Association of Petroleum Geologists 49 (5), 1965, 547–600.

[13]. E. Oomkens, Lithofacies relations in the Late Quaternary Niger delta complex, Sedimentology 21, 1974, 195-222.

[14]. E.C. Okolie, J.E.A., Osemeikhian, O. Ujuanbi, Determination of formation strata and groundwater potential in Sapele Metropolis and environ, Journal of Applied Sciences and Environmental Management 11(2), 2007, 181-186

[15]. E.O Atakpo, Aquifer vulnerability investigation using geoelectric method in parts of Sapele Local Government area of Delta State, Nigeria, Nigeria Journal of Basic and Applied Science 21(1), 2013, 11-19

[16]. O. Uchegbulam, and E.A. Ayolabi, Application of Electrical Resistivity Imaging in Investigating Groundwater Pollution in Sapele Area, Nigeria, Journal of Water Resource and Protection, 2014, 6, 1369-1379, http://dx.doi.org/10.4236/jwarp.2014.614126

[17]. H.O. Nwankwoala, P.O. Youdeowei and S.A. Ngah, (2009)Expanding Hydro-Geotechnical Considerations in Eia Studies: A Case Study of Ogorode – Sapele, Delta State, Nigeria, J. Appl. Sci. Environ. Manage 13(1), 2009, 67 – 71

[18]. Nigeria Geological Survey Agency, Geological Map of Nigeria, NGSA, 2004, Abuja.

[19]. Golden Software Inc. Surfer 8 Golden Software Inc. Golden, Co. USA, 2002.

[20]. Federal Ministry of Water Resources, National Borehole Programme, Amukpe Borehole No.7 Final Report, Abuja, 1982

[21]. APHA, Standard methods for the examination of water and waste water, 18th edition, American Public Health Association, Washington, D.C. 1992

[22]. H.H. Cooper, Jr. and C.E. Jacob, A generalized graphical method for evaluating formation constants and summarizing well-field history, Transactions of American Geophysical Union, 27, 1946, 526 – 534

[23]. I.A. Akpoborie, (2012). Time Series Analysis of streamflow variability in the Ethiope and Adofi Rivers, Delta State, Nigeria, in: A.S. Akpotor, et al. (Eds.) Five Decades of Oil Production in the Nigeria: Impact on the Niger Delta, (CENDS, Abraka, 2012) 275-290.

[24]. D.U. Ophori, A simulation of large scale groundwater flow in the Niger Delta, Nigeria, Environmental Geosciences,14 (4),2007, 181-195

[25]. K. Aweto, K and I.A. Akpoborie, Geo-Electric and Hydrogeochemical Mapping of Quaternary Deposits at Orerokpe in the Western Niger Delta, J. Appl. Sci. Environ. Manage.15 (2), 2011, 351 – 359.

[26]. I.A. Akpoborie and O. Efobo, Groundwater conditions and hydrogeochemistry of the shallow Benin Formation aquifer in the vicinity of Abraka, Nigeria, International Journal of Water Res & Environmental Engineering 6, 2012, 19-31

[27]. D. Chapman, Water Quality Assessments - A Guide to Use of Biota, Sediments and Water in Environmental Monitoring -Second Edition (E&FN Spon, 1996)

[28]. A.M. Piper, A graphic procedure in geochemical interpretation of water analyses, Trans. Am. Geophys Union 25, 1944, 914-923

[29]. D.A. Cates, R.C. Knox and D.A. Sabatini, The impact of ion exchange processes on subsurface brine transport as observed on Piper Diagrams, Ground Water 34(3), 1996, 532-544

[30]. I.A. Akpoborie, A.E. Uriri, and O. Efobo, Ground Water Conditions and Spatial Distribution of Lead and Cadmium in the Shallow Aquifer at Effurun- Warri Metropolis, Nigeria, Environment and Pollution, 3(3), 2014, 27-37. http://dx.doi.org/10.5539/ep.v3n3p27

[31]. E.O. Akudo, G.U. Ozulu and L.C. Osogbue, Quality Assessment of groundwater in selected waste dump site areas in Warri, Environmental Research Journal 4(4), 2010, 281-285

[32]. WHO (2011) Guidelines for drinking-water quality - 4th ed. Available at http://www.who.int

[33]. Standards Organization of Nigeria. (2007). Nigerian Standard for Drinking Water Quality NIS 554:2007.Abuja.

[34]. L.V. Wilcox LV, Classification and use of irrigation water, (U.S.D.A. Circ., 969, Washington, DC, 1955).

[35]. J.D. Hem, Study and Interpretation of the chemical characteristics of natural waters, 3RD Edition (US Geol. Survey, Water Supply Paper 2254, 1991)

[36]. L.A. Richards, Diagnosis and improvement of saline and alkali soils, Agriculture handbook, Volume 60 (US Department of Agriculture, Washington DC, 1954)

[37]. I. Szabolcs, C. Darab, The influence of irrigation water of high sodium carbonate content of soils, Proc. 8th International congress of ISSS, Transaction II,1964, 803–81

[38]. F.M. Eaton, Significance of carbonates in irrigated waters, Soil Science, 69, 1950, 127–128.