Aspects of the Hydrology of the Western Niger Delta Wetlands: Groundwater Conditions in the Neogene (recent) Deposits of the Ndokwa Area

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Abstract

Groundwater conditions in the thin Neogene deposits of the Sombreiro-Warri Deltaic Plain and the Freshwater Swamp physiographic environments of the Ndowa area are not well understood. Physical examination indicates that the deposits are lithologically similar to those of the Benin Formation. All deposits exhibit a fining upwards cyclical sequence of fine, medium-coarse grained and pebbly quartz and feldsphatic sands and differ from each other only in the topmost superficial cover of approximately 6-10m thickness. The configuration of the water table as deduced from measurements in dug wells show that it mirrors the general topography. Ground water movement is unidirectional from the recharge mound centered on Urhonigbe towards the south and east of the area into a major ground water sink stretching from Ogume to Aboh and beyond. The sink evidently sustains the surrounding wetlands year round. Transmissivity of the multilayered aquifer is estimated at 71m^2 per day. Differences in the chemistry of groundwater from the three physiographic regions are reflected in elevated levels of lead and cadmium at an average concentration of 0.01mg/l and 0.13mg/l respectively in the Sombreiro-Warri Deltaic Plain terrain. Furthermore, while the order of cation abundance in Benin Formation outcrop groundwater is Ca>Mg>K>Na, it is Na>K>Ca>Mg in the Sombreiro-Warri Deltaic Plain and the Freshwater Swamps. Coliform bacteria occur in all samples tested. These findings have important implications for water and environmental management of the Ndokwa area that deserve further and closer examination.

Keywords: Groundwater, Neogene deposits, wetlands, water quality, Niger Delta

Introduction

Ndokwa is part of the western Niger Delta petroleum province and many oil and gas fields (Kwale, Ebedei, Okpai) and related installations are located in the area. Generally, the area is also endowed with an abundance of water resources. However, Emeshili (2008) estimates that less than 5% of the population has access to public water supplies. The remainder depends on untreated water from streams, ponds and groundwater, which is obtained from shallow boreholes and dug wells, as a result of which waterborne diseases are common (DSHMB, 2004). The search for clean water supply sources as well as the determination of the quality of raw water supply sources has therefore attracted much attention. Okolie et al. (2006) and Oseji et al.(2005, 2006) in attempts to facilitate successful groundwater exploitation used resistivity methods to delineate the geometry of the underlying water bearing deposits in several communities within the area. Emeshili (2008) undertook chemical and microbiological analyses of stream water and ground water pumped from boreholes and stored in overhead tanks in several communities to determine potability as did Kaizer and Osakwe (2010) for selected rivers. Iwegbue (2008) and Iwegbue et al. (2007) also sought to determine the potential effects of leached crude oil spills on the soils and groundwater.

The primary objective of this study is to build on the earlier efforts by determining and describing the groundwater conditions in the Quaternary near surface deposits that affect and to a large extent control many of the phenomena that have been observed in the previous studies. In addition, because existing studies are in general devoid of appropriate maps, the primary data collected in this study is geo-referenced and plotted on a base map of the area. The resulting map would be an essential tool and base for further studies on the wetlands and lakes that dominate the eastern part of the area.

Location and Physiography

The Ndokwa area is located between Latitude 50 15N, 5005N and Longitude 6005E, 6045E, covering a total land area of about 3000 km^2 (Figure 1). The area comprises of the Ndokwa West, Ndokwa East and Ukwani Local Government Areas of Delta State, Nigeria. Ndokwa area is part of the physiographic province that is described by Odemerho and Ejemeyovwi (2007) as the Low Deltaic Plain and Freshwater Swamps, which also coincides with Allen's (1965, Table 1) Upper floodplain and Lower floodplain respectively. In Delta state, this low province rises gradually from less than 9m above sea level in the west to about 25m above sea level at its eastern boundary.

The province is further subdivided into three distinct landform assemblages. The first is the southern lower Niger flood plain that merges with the more than 25km wide combined Ase River-Niger River flood plain to the east. The fluvial landscape of these flood plains is dominated by numerous streams and oxbow lakes. The second landform is the north-central (Sombreiro-Warri) plain that contains many freshwater swamps. The third landform type occupies the north east and is distinguished from the north-central plain by the presence of low undulating ridges and a much reduced frequency in the occurrence of swamps. All three subdivisions are represented in Ndokwa: the combined Ase River-River Niger floodplain that occupies the eastern portion and stretches from Aboh to Umuzezi; the Sombreiro-Warri that runs diagonally across the area from Abbi to Umuzezi, and the low ridged plain that extends from Obiaruku through Umuaja to Nsukwa.

Ndokwa is drained by four main river systems, namely, the Adofi River to the north, which flows south and swings northeastwards to join the dominant Ase River system whose network in combination with the River Niger drains the eastern portion of the area. The head waters of the Ethiope River and Okumeshi River (Warri River) occur here and drain the northwest portion. Secondary tropical lowland forests prevail in the area because much of the original primary forest has been lost to farming and timber exploitation. Annual ten year mean rainfall is about 2600mm while the mean daily temperature is 31.2^{0}C (Nigerian Meteorological Agency, 2003).

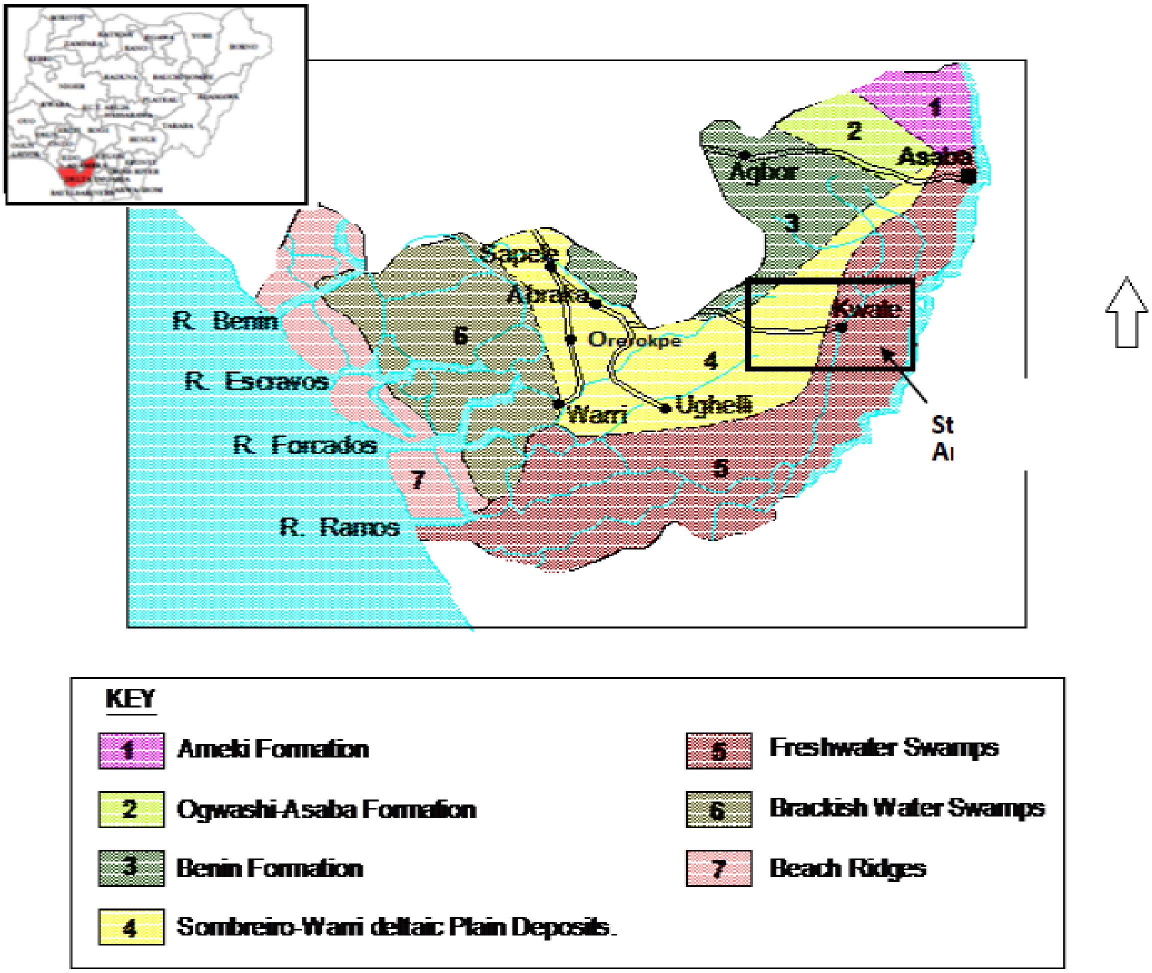

Figure 1: The study area: physiographic provinces and distribution of Recent deposits (After Akpoborie et al. 2011).

Distribution of Recent Geological Deposits

The sedimentary environments and morphological features of the Niger Delta have been described by (Short and Stauble, 1967; Allen, 1964, 1965, 1967; Oomkens, 1974; Durotoye, 1989; Odemerho and Ejemeyovwi (2007).

Specifically, the Ndokwa area is underlain by the deposits of the modern and Holocene delta top deposits that result in the various physiographic landforms described in the foregoing. The aerial distribution of the deposits thus coincides with the physiographic subdivisions and Short and Stauble's (1967, pp. 766) depositional environments. The Nigerian Geological Survey Agency retained the nomenclature in the Geological Map of Nigeria, from which Figure1 is adapted. Thus the combined Ase River/River Niger flood plain is the Freshwater Swamps, the north central plain is the Sombreiro-Warri Deltaic Plain, and both of which contain deposits that conformably overlie and mask the Benin Formation whose outcrop forms the undulating hills in the north and north east.

The deposits of the Freshwater Swamps and the Sombreiro-Warri Deltaic Plain are universally considered to be recent expressions of and a continuation of the Benin Formation. They result from the sediment laden discharges of the River Niger that is spread on the delta by its various tributaries. The sediment is generally an admixture of medium to coarse-grained sands, sandy clays, silts and clays that eventually settle in fluvial/tidal channel, tidal flat and mangrove swamp environments, a process that has been ongoing since the late Quaternary and is related to interglacial marine transgressions (Allen, 1964, Oomkens, 1974, Durotoye, 1989).

The described deposits 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). Together, the deposits also constitute the shallow aquifer that is exploited by shallow (<30m) boreholes and dug wells that serve as the primary water supply source for rural as well as many semi-urban and urban communities in Ndokwa and in the Niger Delta region in general (Amajor, 1991).

The Benin Formation, the youngest of the three important formations that constitute the sedimentary fill of the Niger Delta Basin is usually described as consisting of massive continental/fluvial sands and gravels. The older formations, which are encountered only in the subsurface in Ndokwa are the Agbada Formation of paralic sands and shales and the basal Akata Formation, which consists of holomarine shales, silts and clays. The lateral equivalents at the surface as shown in Figure 1 are the Ogwashi-Asaba Formation and Ameki Formation of Eocene-Oligocene age (Short and Stauble, 1967; Asseez, 1989).

Methodology

To achieve the study objectives, the Ndokwa area was subdivided into the three geomorphic zones. Lithologs were assembled for each province from the records of Aquix Limited, a drilling company that is actively involved in private borehole construction in the area. Seventeen dug wells were selected from communities, which are evenly distributed in the area for water level monitoring in the wet and dry seasons. Five boreholes were selected for the same purpose but located in the areas where dug wells are not available due to a lower water table. Two sets of data from pump tests conducted at Kwale were analysed with the multi layer unsteady (MLU) state computer code to determine aquifer characteristics.

To understand groundwater contribution to stream flow in the area, stream flow data collected over a six- year period by the Benin-Owena River Basin Development Authority (BORBDA, 1992) at the Ossissa gauging station at Adofi, were processed with the Time Series Analysis Module of the River Analysis Package, Version 1.01 (Grayson et al. 1996; Marsh, 2003).

With respect to water quality and groundwater geochemistry, samples were collected from the selected dug wells and boreholes and screened for the major anions, cations, and some heavy metals. Replicate water samples were collected from dug wells into sterilized polyethylene bottles. Borehole water samples were collected after the boreholes have been developed, flushed clean and pumped continuously for about one hour. 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^oC units from 0^oC to 100^oC. 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. Major 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 appropriate titrimetric, flame photometric and atomic absorption spectrometric methods (APHA, 1992).

Finally, depth to water level in each of the dug wells and boreholes were measured with an electronic water level indicator. An Ertec model GPS instrument was used to determine wellhead coordinates. Existing topographic maps of the entire area are devoid of contours, averaged elevation readings from three GPS instruments at each site were used with the sparsely distributed benchmarks established for oil exploration activities to approximate the elevation of each well location. Surfer 8 (Golden Software Inc., 2002) was employed in generating the depth to water level as well as the calculated head distribution.

Results and Discussion

Lithology of the Shallow Deposits

The lithologic logs for boreholes located at Ndemili, Etua-Etiti, Ossisa, Kwale, Aboh, Abbi and Ellu are shown in Figure 2. The sediments are predominantly fine –medium grained, medium to coarse grained and coarse grained sands deposited in a fining upwards cycle. A thin clay layer (<2m) appears to consistently occur in this succession at different depths in the depositional cycle. Boreholes are screened at the lowermost coarse grained layer. At Aboh and Ossissa on the Freshwater Swamps, the topsoil contains dead vegetation while the grey gravelly sands contain fresh feldspars and angular quartz. The deposits at Abbi and Etua–Etiti exhibit a predominantly whitish coloration with depth. The logs confirm the difficulty in distinguishing the Benin Formation proper from the overlying deposits in the subsurface. The clay bands encountered at Etua-Etiti, Ndemili and Aboh apart from being too thin at less than a meter each, are characteristically discontinuous and as such do not constitute any form of confinement to the underlying sands. The deposits with the Benin Formation thus form one continuous but layered aquifer.

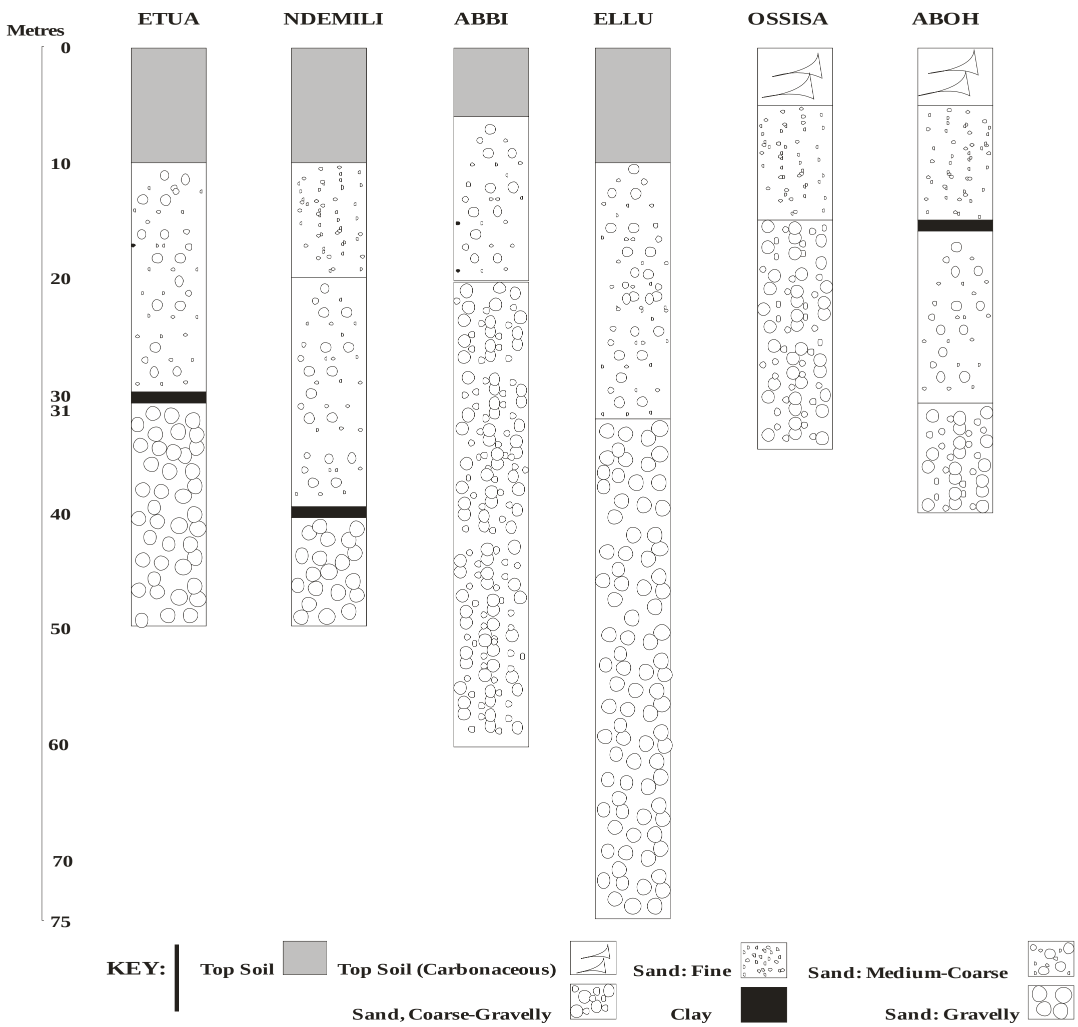

Figure 2: Lithologs from Ndokwa

Groundwater Conditions

Depth to water levels in March and July representing dry and wet seasons respectively were measured at seventeen locations in twelve communities. The results are shown in Table 1. Groundwater clearly occurs at water table conditions and seasonal water level fluctuation in 2009 was an average of 0.83m with a range of 1.61m at Ogume to 0.11m at Okpai. The configuration of the water table as contoured with the dry season data and superimposed on the geological map is shown in Figure 3.

Table 1: Groundwater Levels from Ndokwa

Locations	Latitude/ longitude	Surface elevation	Actual depth to water table for dry season	Actual depth to water table for wet season	Rise in water level within the period	Hydraulic Head for Dry Season
Ogume (Hand dug well)	N 05^{O} 45^{I} 00.4^{II} E 06^{O} 19^{I} 21.3^{II}	10	4.58	2.97	1.61	5.42
	N 05^{O} 45^{I} 18.6^{II} E 06^{O} 19^{I} 25.3^{II}	13	3.76	2.07	1.69	*9.24
Umukwata (Hand dug well)	N 05^{O} 48^{I} 17.9^{II} E 06^{O} 14^{I} 58.5^{I}	22	2.94	2.20	0.74	19.06
	N 05^{O} 48^{I} 17.4^{II} E 06^{O} 14^{I} 39.1^{II}	11	3.42	3.06	0.36	*7.58
Ebedei (Hand dug well)	N 05^{O} 49^{I} 32.0^{II} E 06^{O} 14^{I} 39.3^{II}	40	1.89	1.69	0.20	38.11
	N 05^{O} 49^{I} 34.9^{II} E 06^{O} 14^{I} 39.0^{II}	22	4.70	4.55	0.15	*17.30
Okpai (Borehole)	N05^{0} 43^{I} 33.0^{II} E06^{0} 36^{I} 02.4^{II}	18	5.36	5.29	0.11	*12.64
Aboh (Hand dug well)	N05^{0} 33^{I} 14.7^{II} E06^{0} 31^{I} 49.1^{II}	14	1.39	0.30	1.09	*12.61
Ashaka (Hand dug well)	N05^{0} 39^{I} 10.2^{II} E06^{0} 24^{I} 25.7^{II}	16	5.39	4.76	0.63	*10.61
	N05^{0} 38^{I} 50.2^{II} E06^{0} 24^{I} 14.7^{II}	23	8.35	7.74	0.61	14.65
	N05^{0} 38^{I} 44.9^{II} E06^{0} 24^{I} 07.0^{II}	12	7.33	7.00	0.33	4.67
Utagbe-Ogbe (Hand dug well)	N05^{0} 41^{I} 21.3^{II} E06^{0} 25^{I} 43.3^{II}	15	8.33	8.01	0.32	*6.67
	N05^{0} 41^{I} 25.6^{II} E06^{0} 25^{I} 46.6^{II}	17	8.04	7.68	0.36	8.96
	N05^{0} 42^{I} 07.3^{II} E06^{0} 25^{I} 58.7^{II}	16	8.01	7.70	0.34	7.99
Utagbe-Uno (Hand dug well)	N05^{0} 52^{I} 57.8^{II} E06^{0} 23^{I} 12.2^{II}	32	3.66	2.63	1.03	28.34
	N05^{0} 52^{I} 48.2^{II} E06^{0} 22^{I} 44.6^{II}	26	3.04	1.94	1.10	*22.96
	N05^{0} 53^{I} 05.7^{II} E06^{0} 23^{I} 21.4^{II}	23	2.95	2.12	0.83	20.05
	N05^{0} 53^{I} 05.0^{II} E06^{0} 23^{I} 24.3^{II}	20	2.88	2.05	0.80	17.12
Ndemilli (Borehole)	N06^{0} 01^{I} 33.0^{II} E06^{0} 17^{I} 05.3^{II}	79	23.01	-	-	*55.99
Umuaja (Borehole)	N05^{0} 56^{I} 07.6^{II} E06^{0} 14^{I} 01.9^{II}	34	15.02	14.05	0.97	*18.98
Umutu Borehole	N05^{0} 55^{I} 01.1^{II} E06^{0} 13^{I} 36.1^{II}	34	16.74	16.58	0.16	17.26
Obiaruku (Borehole)	N05^{0} 50^{I} 58.4^{II} E06^{0} 09^{I} 19.8^{II}	57	14.14	-	-	*42.86

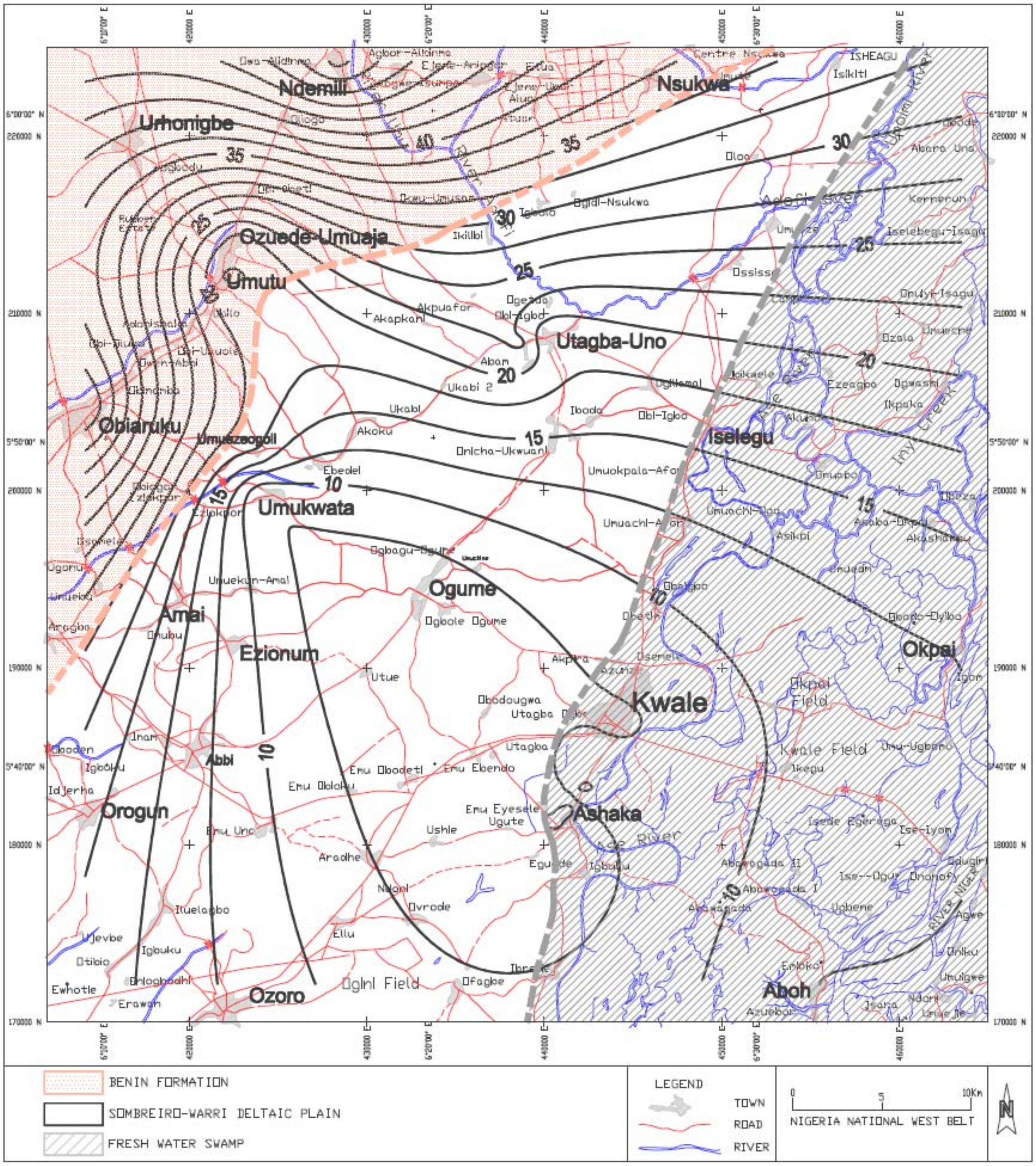

Figure 3: Physiographic terrains/recent deposits, drainage and water table contours

Ground water movement is generally from north to south. Thus recharge is more extensive at the outcrop of the Benin Formation to the north where groundwater is at a steeper gradient and from where flow is down slope, generally southwards and unidirectional. In the terrain of the overlying deposits, the ground water gradient has become virtually flat and the contours closed a characteristic of groundwater-fed wetlands. Specifically, movement is through

Urhonigbe, Ndemili and Nsukwa in the northeast, all on the Benin Formation which in this area is devoid of overlying recent deltaic deposits.

The water table contours begin to flare out in the vicinity of Umuaja-Umutu where the source of the River Ethiope is located. Movement from the recharge front is thus southeastwards towards the central area at Ogume, Kwale and Ashaka that occupy the Sombreiro-Warri Deltaic Plain. From the northwest, ground water moves south directly into the combined Ase River/ River Niger flood plain, i.e. the Freshwater Swamps. The headwater of the Adofi River that drains the northeast flank of the recharge mound is also located here. The steep ground water gradient in the recharge area flattens out on the Sombreiro-Warri Plain and flatter still on the Freshwater Swamps thus the configuration of the water table mirrors the general physiography. The resultant decrease in flow velocity would explain the dominance of perennial swamps and oxbow lakes in this wetland. Akpoborie and Osula (1999) earlier used manual hydrograph separation techniques to show that groundwater constitutes up to 72 per cent of the total annual flow of the Adofi River.

To eliminate manual errors that are naturally inherent in the manual techniques used in the earlier study, the same data from the Ossissa gauging station were reprocessed with the Time Series Analysis Module of the River Analysis Package (Grayson et al. 1996; Marsh, 2003). Figure 4 is a typical hydrograph for the 1989 year as separated by the software package. Base flow characteristics for the six years of available record are presented in Table 2. The base flow index (BFI) is the ratio of total base flow discharge for the reporting period to total discharge. The average Base flow Index for the six year period is 0.85, slightly higher than Akpoborie and Osula's (1999) estimate of 0.72.

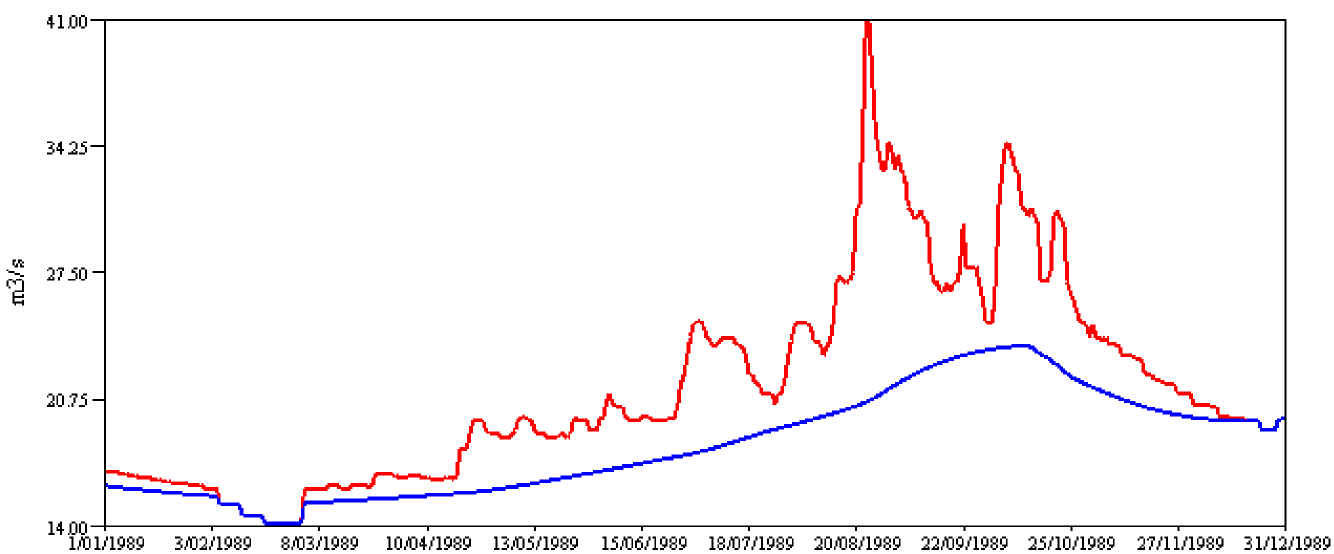

Figure 4: 1989 Stream Dischage Hydrograph for Adofi River at Ossissa, Ndokwa area with base flow indicated.

Table 2: Summary Baseflow Statistics, Adofi River at Ossissa

Statistic	1989	1990	1991	1992	1993	1994
Minimum (m^3/s)	14	16	18	15.9	24.6	25.5
Maximum (m^3/s)	41	47.5	49	46.2	53	54
Mean (m^3/s)	21.321	23.591	25.618	22.355	31.87	36.668
BFI	0.855	0.845	0.832	0.844	0.872	0.868

If the lower and more conservative estimate of 0.72 is used, it would represent an approximate annual groundwater discharge of $0.606x10^9$ m^3 and an effective annual infiltration of 1.42m spread uniformly over the effective drainage area of 425 km^2. This compares favorably with the wet season-dry season ground water level fluctuation of 1.62m measured at Ogume during the study period. Further west on the Sombreiro-Warri Deltaic plain at Okurekpo, Akpoborie et al (2000) measured annual ground water fluctuations of 5m in dug wells. Furthermore, this recharge–discharge relationship is consistent with the suggested characterization of the groundwater flow systems in the Niger Delta as one that is dominated by local alternating recharge discharge areas which when combined with low regional slopes and undulating relief make the Niger Delta region a hydrogeologically shallow watershed (Ophori, 2007; Toth, 1963) that is devoid of extensive and deep regional flow systems.

Aquifer parameters were estimated from data obtained from a pump test conducted in 1985 by Paulosa Nigeria limited in a well drilled at Kwale during the National Borehole Program. The borehole was approximately 120m deep and was completed with 170mm casing and screen. The 15m screen was placed at the bottom of the borehole. The well was pumped at 2.16m^3/hr for 15 hours. The Multilayer Unsteady state model developed by Hemke and Post (2010) was used to determine Transmissivity as 71m^2/day. Model curve matching results, Figure 5 show a good fit between observed drawdown and model predicted drawdown.

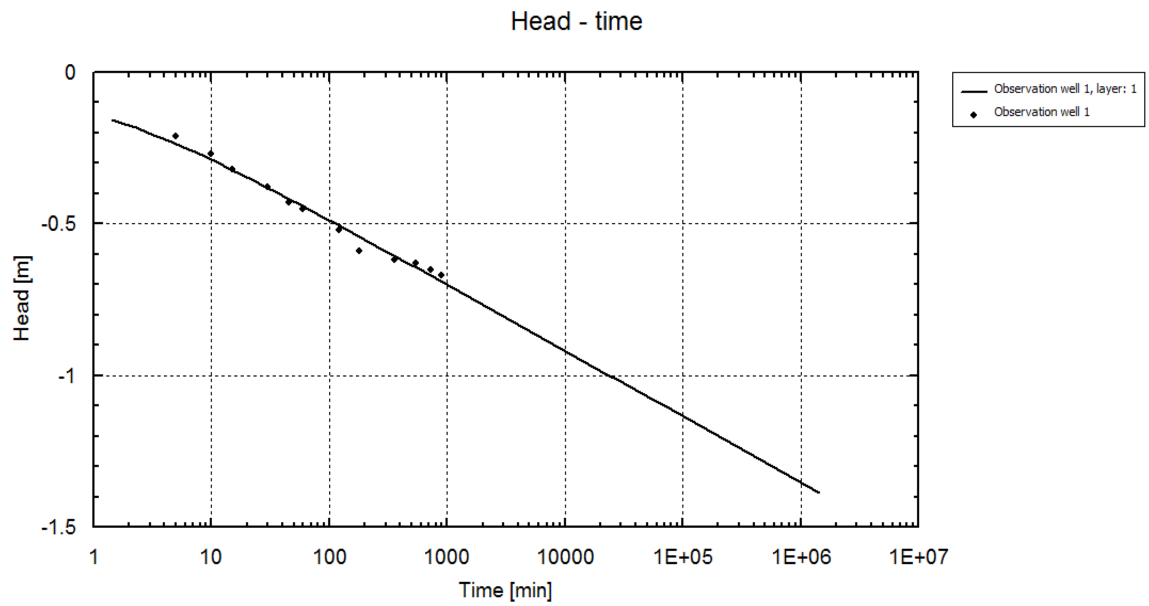

Figure 5: Time-drawdown curve from Kwale pump test.

Groundwater Chemistry

Physical and chemical characteristics of ground water in the area are summarized in Table 3. Ground water is generally soft. However, the order of abundance of the major cations in both the Sombreiro Warri- Deltaic Plain and the Freshwater Swamps is Na>K>Ca>Mg. This order is the same as that reported for shallow groundwater from Orerokpe in the Sombreiro- Deltaic Plain west of Ndokwa by Aweto and Akpoborie (2011) who suggest the dominance of water-rock interactions after recharge by rainfall in determining ground water chemistry. This would include natural softening caused by the replacement of Ca^{2+} ions by the Sodium ion. And is reinforced by the fact that in the Benin Formation outcrop and recharge area in Ndokwa where groundwater is likely more representative of pristine conditions and flow gradients are higher than at the other terrains, cation occurrence is the order Ca>Mg>K>Na (Table 3). The anions occur in the order $Cl>HCO_3>NO_3>SO_4$ in all terrains. However, the significantly higher average chloride content of 51.6mg/l appears to characterize groundwater in the Sombreiro-Warri Deltaic Plain. It is probably significant that the highest chloride content, 81mg/l was recorded from a un- ringed dug well at Utagba Uno. The only other un-ringed dug well sampled in the study at Umukwata showed an above average chloride content of 58mg/l. The observation might suggest a relationship between contamination from domestic waste and elevated chloride content (Appelo and Postma, 1993; Singh et al.2008). Aside from the higher chloride content, other contrasting differences in geochemical character appear to occur across the physiographic regions. Groundwater with lower Total Dissolved Solids (TDS) in the recharge mound to the north for example attains higher salinity at the sink in the central area where movement is significantly at lower velocity and thus longer travel time is spent in contact with the felsphatic sands. In the Ase/Niger River floodplain, dilution occurs and could be attributed to the constant flooding of the alluvial deposits and resultant recharge.

Table 3: Physical and Chemical Characteristics of Groundwater in Ndokwa

Parameters	**Physiographic Area**						
	Benin Formation		**Sombreiro-Warri**		**Freshwater Swamps**		
	Mean	**Std. Dev.±**	**Mean**	**Std Dev ±**	**Mean**	**Std Dev ±**	**SON MCL's**
pH	4.6	0.36	7.45	1.44	7.3	0.84	
TDS mg/l	18	1.42	161	48.72	109.42	16.35	
EC µs/cm	36	2.27	261.75	87.92	159	28.58	
Na^+ mg/l	0.07	0.001	12.85	5.67	9.24	2.62	
K^+ mg/l	0.12	0.0003	11.36	5.51	8.08	2.3	
Ca^{2+} mg/l	4.15	0.13	1.19	0.31	0.79	0.13	
Mg^{2+} mg/l	3.02	0.1	0.71	0.26	0.43	0.18	
Pb^+ mg/l	0.00	0.00	0.01	$4x10^{-3}$	0.00	0.00	**0.01**
Cd^+ mg/l	0.00	0.00	0.13	0.008	0.002	$2x10^{-4}$	**0.003**
Cr^+ mg/l	0.001	0.0002	0.005	0.003	0.003	$1x10^{-4}$	**0.05**
SO_4^{2-} mg/l	0.15	0.0045	0.024	0.016	0.005	0.006	
HCO_3^{2-} mg/l	0.32	0.001	2.1	0.71	1.53	0.39	
Cl^- mg/l	4.51	0.32	51.63	21.53	20.57	6.79	
NO_3 mg/l	0.25	0.05	1.18	1.08	0.22	0.063	**10**
Coliform *MPN/100*	0.00	0.00	95.5	34.57	64.0	10.50	**0**

Ground water from dug wells is generally used for domestic purposes in the rural areas of Ndokwa without prior treatment and there are concerns about health implications (Emeshili, 2008.). A significant problem as the results show is the consistent presence of coliform bacteria in all screened samples in the Sombreiro-Warri Deltaic Plain and the Freshwater Swamps, at levels above WHO (2006) and SON (2007) standards. The highest counts were recorded at Umukwata and Utagba Uno, where the sampled dug wells were unlined with the standard concrete rings that are used in the construction of most dug wells in the region. Coliform counts in Benin Formation boreholes are negligible, which is consistent with the greater depths from which water is obtained as well as the better sanitary conditions that are associated with extraction of water from sealed boreholes as opposed to exposed dug wells.

The levels of occurrence in groundwater of lead, cadmium and chromium in the three physiographic terrains were compared with the maximum acceptable limits (MCL's) set by World Health Organization (WHO, 2006) which are the same as those of the Nigerian Standards Organization (SON, 2007). As shown in Table 3, chromium occurs at levels that are well below the MCL of 0.05mg/l, with the highest occurrence of 0.005mg/l recorded for groundwater in the Sombreiro-Warri Plain terrain. Similarly, Cadmium levels in the Sombreiro-Warri Plain are approximately 43 times higher than the MCL of 0.003mg/l while Lead occurrence is at the threshold MCL of 0.01mg/l. In both the Benin Formation and Fresh Water Swamps, groundwater is lead free. Cadmium also occurs in the Fresh Water Swamps at levels that are well below the MCL while it was not detected in Benin Formation water. Excessive lead intake is associated with cancer and neurological disorders while cadmium is toxic to kidneys (WHO, 2006; SON, 2007). Akpoborie et al. (2000) have indeed drawn attention to the elevated lead and cadmium in groundwater problem from other parts of the Sombreiro-Warri Plain as have Eriyamvemu et al (2005) who established the presence of high lead and cadmium levels in vegetables in the same terrain at Aladja and Ekpan, which are west of Ndokwa. The absence of lead and presence of low cadmium levels in Freshwater Swamp wetland groundwater could as before be explained by attenuation occasioned by recharge from seasonal floods.

Conclusion

The results of this study indicate that groundwater conditions in Ndokwa are controlled to a large extent by the areal and vertical distribution of the Recent deposits that overlie the Benin Formation. Thus recharge is more extensive at the outcrop of the Benin Formation to the north where groundwater is at a higher gradient and from where flow is down slope, generally southwards and unidirectional. In the terrain of the overlying deposits, the ground water gradient has become virtually flat and the contours have closed, a characteristic of groundwater- fed wetlands. A map has been presented that depicts these conditions. In the subsurface however, the available lithologs confirm the impossibility of distinguishing between the Benin Formation and the Recent deposits. The estimated Transmissivity of $71m^2$/day is representative of the combined Recent deposits and Benin Formation as a single multi-layered aquifer.

The data indicates that chemical characteristics may be used to distinguish ground water that occurs in the three physiographic terrains. Groundwater in the exposed Benin Formation recharge area for example represents more pristine conditions and exhibits higher salinity in the areas where the Benin Formation is overlain by younger deposits. In the Sombreiro/Warri Deltaic Plain, groundwater is not potable without prior treatment because it contains coliform as well as unacceptable levels of lead and cadmium. In the Freshwater Swamps, coliform was detected but it appears that dilution from perennial floods have reduced the heavy metals to an acceptable level. There are obvious implications in these results for public water supply, health management and poverty alleviation policies especially in the rural areas where there is total dependence by communities on dug well water and streams.

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