academicJournals

Vol. 6(1), pp. 19-31, January, 2014
DOI: 10.5897/IJWREE2013.0446
ISSN 2141-6613 © 2014 Academic Journals
http://www.academicjournals.org/IJWREE

International Journal of Water Resources and Environmental Engineering

Full Length Research Paper

Groundwater conditions and hydrogeochemistry of the shallow Benin Formation aquifer in the vicinity of Abraka, Nigeria

Irwin Anthony Akpoborie[1]* and Oghenevwede Efobo[2]

[1]Department of Geology, Delta State University, Abraka.
[2]Centre for Research in Water and Environment, Abraka.

Accepted 22 November, 2013

Shallow borehole and dug well data are used in describing groundwater conditions in the vicinity of Abraka in the Nigerian coastal plain. Drill cuttings from ten boreholes show that the Abraka area is underlain by reddish brown unconsolidated sands, followed by a succession of grey- off-white medium grained sands of the Benin Formation. Hydraulic conductivity estimated from grain size analysis of cuttings obtained from typical borehole screened horizons range from 0.12 to 0.19 msec^{-1}. Regional groundwater flow is from north east to southwest with local distortions on this regional trend resulting from ground water abstraction in densely populated areas. Maximum TDS in ground water was recorded at 28 and 85 mg/l from dug wells. The trilinear plots of major ions in water indicate a mixing of mainly sodium chloride and calcium chloride water types. The stiff diagrams are also suggestive of possible stratification of water chemistry with depth. Borehole water quality is well within WHO and Nigerian drinking water quality standards while that from dug wells contains minimal levels of fecal coliform. Ground water and surface water are determined to be suitable for irrigation. It is also shown that the quality of water in the River Ethiope, TDS 6.6 to 8.09 mg/l, *Escherichia coli* occurrence at less than an average of 50 cfu/100 ml from selected recreation sites meets WHO standards for body contact recreation.

Key words: Benin Formation, River Ethiope, Abraka, Niger Delta, groundwater, water quality.

INTRODUCTION

The Abraka area is located in the western Niger Delta and underlain by the Benin Formation that bestrides the River Niger and stretches from west of the Lagos area to the Calabar Flank in eastern Nigeria. The formation which contains prolific aquifer horizons is heterogeneous and has been studied in some detail in the Port Harcourt area by Amajor (1991) who characterized the water bearing sandy layers of its upper (300 m) horizon and described rapid horizontal and vertical variations in lithology and hydraulic characteristics. Ibe and Njemanze (1998) also identify at least three aquifer horizons that 200 m of the formation in the vicinity of Owerri, also in the are separated from each other by clay layers in the upper eastern sector. West of the River Niger, Oteze (2011) and Akujieze and Oteze (2006) have described the water bearing upper horizons of the formation and identify lateral variations in hydraulic properties in the vicinity of Benin City. Longe (2010) also reports the presence of three aquifer horizons that are separated by thin clay layers in the upper 100 m of the formation in the Shomolu area of Lagos State. There is a dearth of similar studies in the Abraka area and existing ground water conditions in the underlying Benin Formation are not well understood. *Laissez faire* exploitation of ground water

*Corresponding author. E-mail: tony.akpoborie@gmail.com

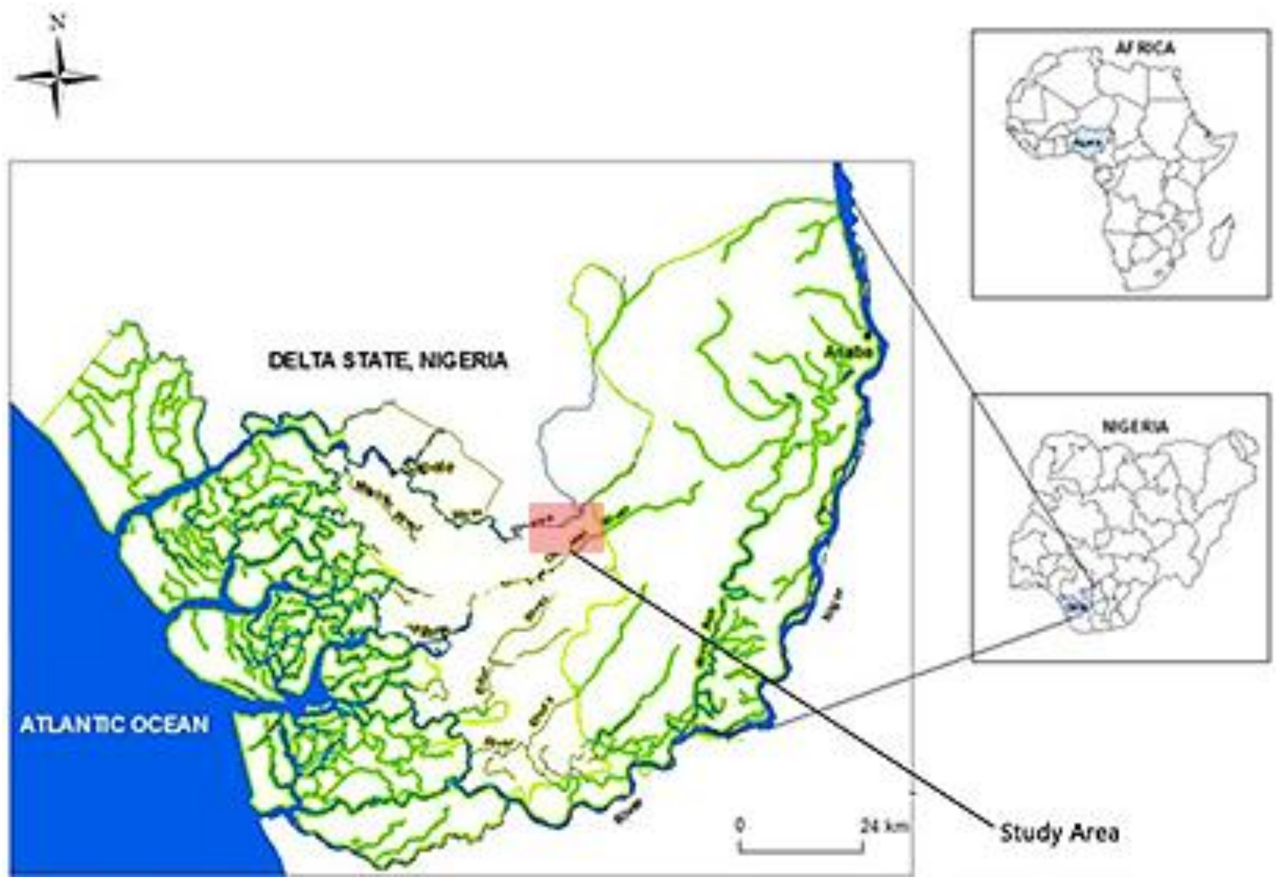

Figure 1. Map of Delta State Nigeria showing location of study area.

especially in this rapidly expanding university community that is witnessing rapid growth could potentially create problems for the ground water system in the long term. This is because in the absence of public water supply facilities to serve an estimated population of 90,000 (Oje and Origbo, 2012), all water supplies for domestic, commercial and industrial uses are obtained from privately owned boreholes that tap the shallow Benin Formation.

An appreciation of existing ground water conditions is not only desirable but a requirement for urban expansion and regional planning. The objective of this investigation is thus to gain an understanding of ground water conditions in the area, associated hydrogeochemistry, as well as determine the suitability of surface water and ground water for domestic use, irrigation, water contact recreation and industry. Furthermore, the results will add to and contribute to the expansion of current regional knowledge and understanding of this prolific, extensive and important aquifer.

STUDY AREA

The Abraka area, situated between latitude 5° 45' and 5° 50’ N and longitude 6° and 6° 15’ E is located on the south bank of the River Ethiope and is an agglomeration of several communities that are aligned linearly along the New and Old Sapele– Agbor highway (Figures 1 and 3). These communities include from the west, Oria, Ajalomi, Abraka PO, Ekrejeta, Urhuoka and Umeghe. Ajalomi, Abraka PO, Ekrejata and Urhuoka have grown in size and are now conjoined to form what is loosely referred to as Abraka Urban, the seat of all three sites of the Abraka Campus of the Delta State University. Southwards, the rural communities of Ugono, Aragba, Abraka Inland and Ughere - Uragbesa are as well, bona fide Abraka communities (Figure 3).

Physiography and climate

The Abraka area is a typical coastal plain terrain, monotonously lowland and flat with a gentle slope towards the Ethiope River. The climate is equatorial, hot (23 to 37°C) and humid (relative humidity, 50 to 70%). There is a dry season from about November to February, and a wet season that begins in March, peaks in July and October. Six -years (2000 to 2005) annual mean rainfall measured at the Delta State University weather station is

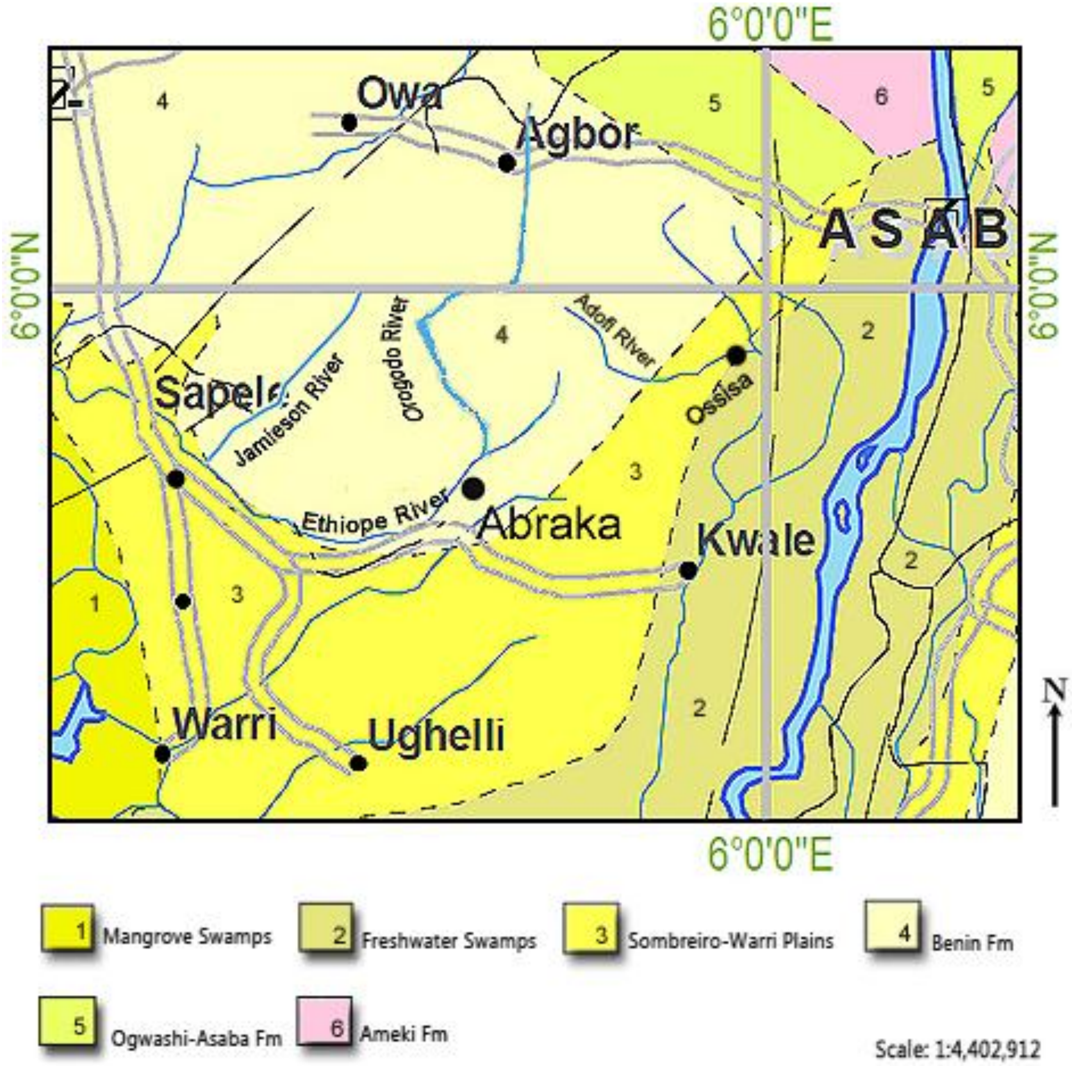

Figure 2. Regional geology of part of the Western Niger Delta showing the Abraka area (NGSA, 2006).

3317.8 mm. Vegetation is rainforest, most of which has been decimated and replaced with farmlands and secondary forest. However, lush, dense and swamp primary forest flanks the river banks.

Geology

The area is located in the Niger Delta Basin, a much studied and important petroleum province. Briefly, there is general agreement that the basin was formed as a result of an aulacogen type development that was triggered by the separation of the African and South American plates in the Jurassic. The resulting trough has been filled by a series of marine transgressions, regressions and deltas, the present Niger delta being the most recent. The basin fill has been described by Short and Stauble (1967), Reijers et al. (1996), Nwajide (2006), among many others and consists of three formations, namely, from the oldest to the youngest, the Akata Formation, Agbada Formation both of Eocene to Recent and the Miocene to Recent Benin Formation. However, west and just south of Abraka the Benin Formation is masked by the younger Holocene deposits of the Sombreiro-Warri Deltaic Plain, the Mangrove Swamp and Freshwater Swamp wetlands. These deposits which have not been assigned formal geological names because they are universally considered to be recent expressions of and a continuation of the Benin Formation are only identified by the physiographic terrains in which they occur. The aerial distribution of these delta top deposits coincides somewhat with the associated physiographic subdivisions shown in Figure 2. The inferred boundary between the Sombreiro–Warri Deltaic Plain and the Benin Formation outcrop as can be seen from Figure 2 passes through the Abraka area such that the southern

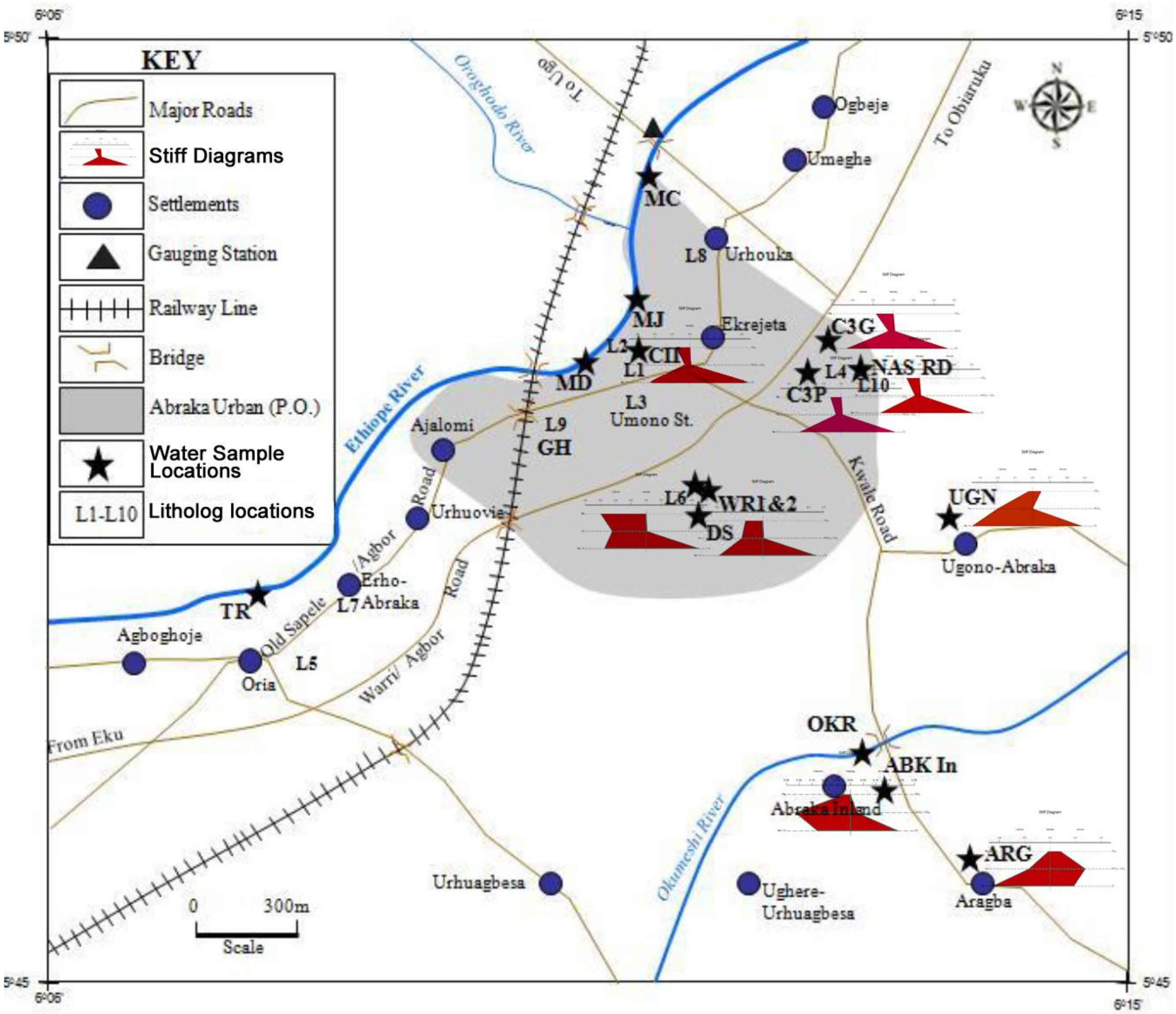

Figure 3. Borehole drill - cutting sample locations, water sample locations and associated stiff diagrams. L1(CII), Geology Lab; L2, Abraka Hall; L3, Omono Street; L4, Campus 3 New Administrative Block; L5, Oria; L7, Erho; L8, Urhuoka; L9, General Hospital; L10 (Nas Rd), Nassarawa Road; ARG, Aragba; ABK In, Abraka Inland; UGN, Ugono; CII, Geology Lab; C3G, Campus 3 Gate; C3P, Campus 3 Pool site; WR1, Winner's Road 1; WR2, Winner's Road 2; DS, Dump site; MC, McCarthy Beach; MJ, Majoroh Beach; MD, Mudi Beach; TR, The Turf; okr, Okemesi River; L6, Winner's Road (not WR1or WR2).

part of the area is underlain by Sombreiro-Warri Deltaic Plain deposits while the north rests on Benin Formation outcrop.

The Ethiope River, the most important physiographic feature in the area flows almost exclusively on the outcrop of the Benin Formation. The Benin Formation in the Abraka area is overlain everywhere by reddish brown colored ferruginized regolith that is usually no less than 2 m thick. This can be observed clearly at two locations on the Abraka – Ugo road (Figure 3). The first site is a large borrow pit located just before the bridge on the River Ethiope and from where material is being excavated for building and road construction and the second at the rail road crossing near the overpass on the Abraka – Ugo Road. At both locations, the formation is massive and deeply weathered.

METHODOLOGY

Drill cuttings were collected and described from ten sites (Figure 3) where shallow water supply boreholes were drilled for private home owners. Sieve analysis of drill cutting samples obtained from the screened and usually the lowermost horizon penetrated was undertaken at the laboratories of the Department of Geology, Delta

State University. The sampling procedure for groundwater involved the collection of replicates from six randomly located boreholes that could be accessed and three dug wells. Borehole water samples were collected after boreholes were pumped continuously for about 1 h. Surface water samples were also collected from selected recreational points along the River Ethiope, from the Okemeshi River as well as from a water filled quarry that is being used as a dump site. Sampling sites are shown in Figure 3. The set of samples designated for heavy metal analysis were stabilized *in situ* with nitric acid. Electrical conductivity and total dissolved solids were also measured *in situ* using the HACH conductivity/TDS meters, respectively. 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 to 100°C. The Pye Unicam Atomic Absorption Spectrophotometer SP 2900 was employed in the determination of the heavy metals while the HACH Spectrophotometer was employed in determining the NO_3 ion using the cadmium reduction method. Na and K ion concentrations were obtained with a Jenway Clinical flame photometer. Sulphate content was determined by turbidimetry and Ca, Mg, HCO_3 and Cl with appropriate titrimetric methods (APHA, 1992). In order to determine the presence of total and fecal coliform, 100 ml of each water sample were passed through a membrane filter consisting of uniform pore diameter of 0.45 nm following which the membrane filter was placed in a petri-dish containing Mac-Conkey Agar and Eosin-Methylene blue Agar, in duplicate with the grid side up and incubated at 35 and 45°C for 18 to 24 h, respectively. Bacteria colonies if present were counted and expressed as numbers of coliform per 100 ml of water.

Four dug wells and six boreholes (Table 1) were selected on the basis of spread for depth to water level measurements. Depth to water level in each of the boreholes and dug wells was measured with an electronic well sounder. An Ertec model GPS instrument was used to determine wellhead coordinates. Because existing maps of the area are devoid of contours, averaged elevation readings from three GPS instruments at each site were used with the sparsely distributed benchmarks to approximate the elevation of each well location. Surfer 8 (Golden Software Inc., 2002) was employed in generating water table contour lines of equal head.

RESULTS AND DISCUSSION

Lithology

Cuttings recovered from boreholes show a succession of fine grained reddish brown sands underlain by typically clean, grey - off white and fine - medium - coarse grained, angular to sub- rounded well sorted quartz sands. In addition to remarkable lithological similarity, a layering and cyclical fining upward sequence is apparent at some locations (Figure 4). The consistent absence of clays gives an indication of the potential high vulnerability of the shallow aquifer to contamination from surface sources.

Groundwater conditions

Water table conditions prevail in the Abraka area. Depth to water varies from about 4 m at Abraka Inland to 26 m at Oria. Water table head above mean sea level determined at each location is shown in Table 1 and associated water table contour lines of equal head in meters above sea level are plotted in Figure 5. Sustained groundwater abstraction in the more densely populated Abraka Urban has resulted in a depression of the water table in the town centre that stretches from Oria through Winner's Road to Ugono and towards which groundwater is flowing from virtually all directions. This has thus caused a local distortion on regional south westward groundwater flow (Akpoborie, 2011; Aweto and Akpoborie, 2011) that mirrors the seaward slope of the coastal plain. There also appears to be a mound at the Abraka Inland community that extends to Umuebu from which water is moving in all directions.

Hydraulic characteristics

Sieve analysis curves for cuttings retrieved from boreholes at Geology Laboratory, Oria, Erho, behind the General Hospital and Nassarawa Road, locations L1, L5, L7, L9 and L10 respectively in Figure 3, were plotted as shown in Figure 6. Cuttings from all ten boreholes sampled in this investigation were all remarkably similar upon visual examination in terms of textural attributes and which similarity is reflected in the curves for the five representative samples shown in Figure 6. Following Odong (2007) and Fetter (2004), hydraulic conductivity was estimated with the Hazen (1892) approximation:

$$K = C\,(D_{10})^2$$

Where K is hydraulic conductivity in cm/s, D_{10} is the effective grain size in cm, C is a coefficient that is based on the aquifer matrix.

Estimated values of K obtained with C = 6 (Uma et al., 1989) range from 0.12 to 0.17 cm/s with uniformity coefficient ranging from 1 to 1.4. It should be stressed that all sampled boreholes are located on the outcrop of the Benin Formation and that maximum depth penetrated and sampled is a shallow 18 m which makes the results of limited application especially with respect to the reputed average 2000 m thickness of the Benin Formation. However, they are interesting to the extent that in the absence of formal aquifer tests, this is the first indication of hydraulic properties of this horizon of the Benin Formation in this area.

Water chemistry

Characteristics of surface and ground water

The physical and chemical characteristics of surface water from different recreational sites located on the south bank of the Ethiope River are shown in Table 2. One sample collected from the bridge crossing on the Okumesi (Warri) River, near Abraka Inland, and another

Table 1. Depth to water level measurements.

Eastings	Northings	Location	Well type	DWL	Head
6.1369	5.731333	Aragba	Dug Well	5.1	9.01
6.125633	5.746067	Abraka Inl	Dug Well	3.9	13.22
6.137133	5.782383	Ugono	Dug Well	4.5	5.7
6.097833	5.792	Geology Lab.	Borehole	3.69	16.3
6.103472	5.778833	Winners Rd	Borehole	14.63	4.27
6.117789	5.789828	Delsu, Site 3 Pool	Borehole	16.82	12.77
6.063889	5.75825	Oria	Borehole	15.03	3.87
6.148333	5.783875	General Hospital	Borehole	13.41	10.36
6.159883	5.752183	Umuebu	Dug well	4.2	11.42
6.148333	5.846183	Morka Primary School, Obiaruku	Borehole	31.2	3.10

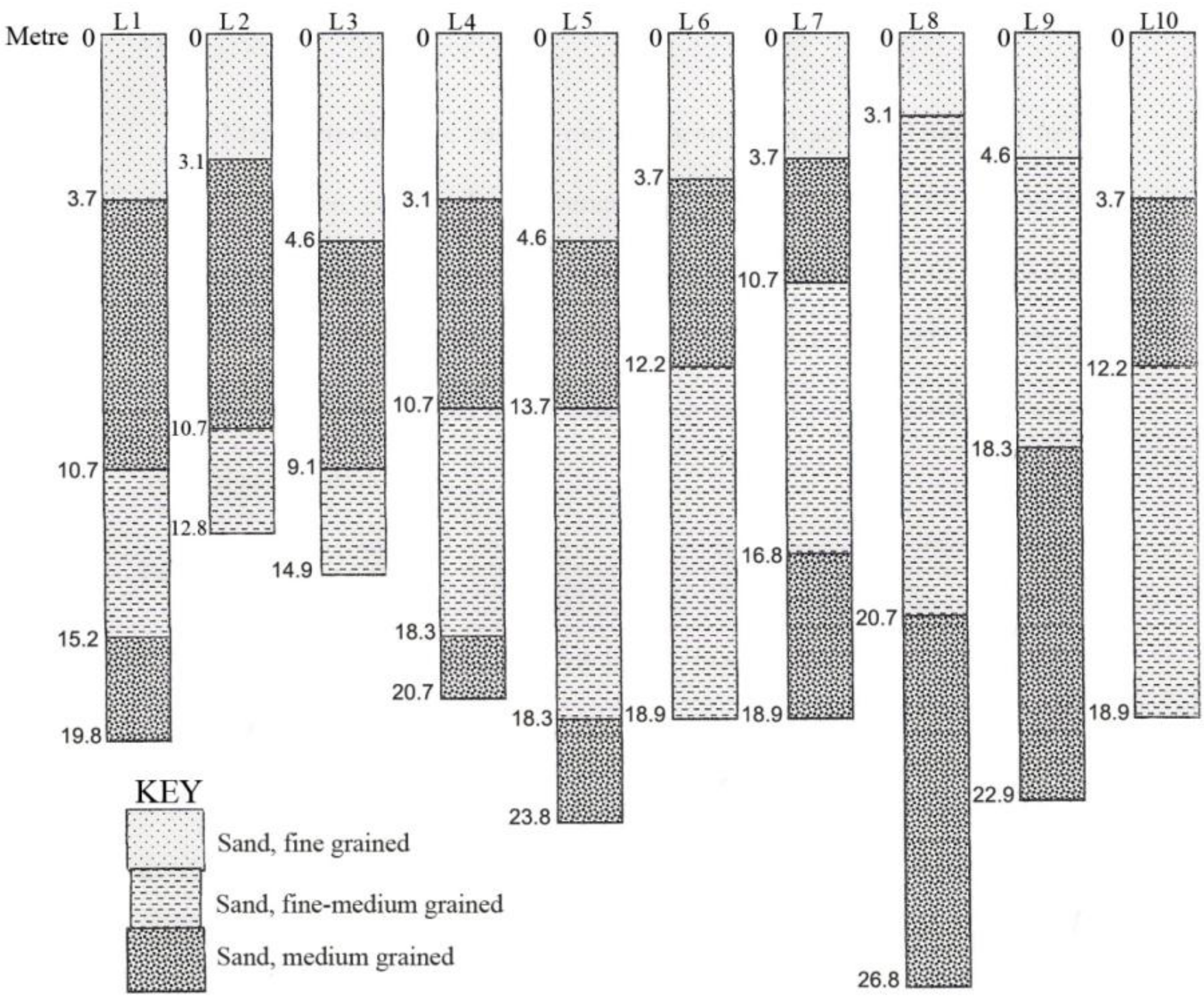

Figure 4. Lithologs from water supply wells in Abraka. L1, Geology Lab; L2, Abraka Hall; L3, Omono Street; L4, Campus 3 New Administrative Block; L5, Oria; L6, Winner's Road; L7, Erho; L8, Urhuoka; L9, General Hospital; L10, Nasarrawa Road.

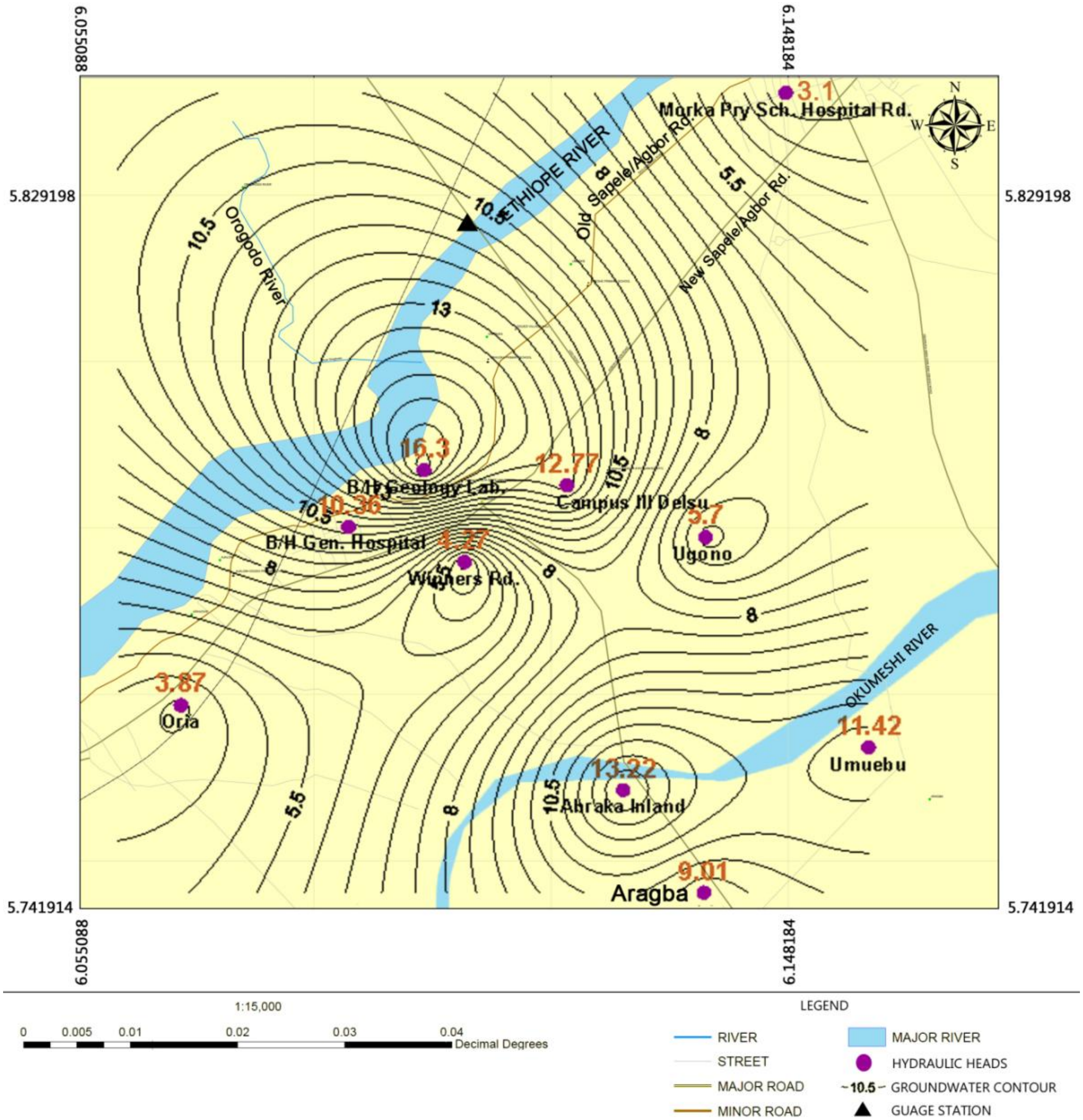

Figure 5. Water table contour lines of equal head in meters above sea level in the vicinity of Abraka.

from the Jamieson River are also included for comparison. Sampling sites except for the Jamieson River are shown in Figure 3. TDS at all sites is very low and all ions show very low levels of occurrence. However, TDS from Ethiope River is much lower at mean 7.18 mg/l than Okumeshi River water which returned a TDS value of 16.5 mg/l. Indeed, Kaizer and Osakwe (2010) in a regional comparative study of water quality from five rivers in Delta State show that the Ethiope River contains the lowest total dissolved solids. Water in both the Ethiope and Okumeshi Rivers is also slightly acidic, which as reported from previous studies (Efe, 2005; Olobaniyi and Efe, 2007; Kaizer and Osakwe, 2010) is reflective of associated gas flaring in the Niger Delta petroleum province. The physical and chemical characteristics of ground water collected from boreholes and dug wells in the Abraka area are shown in Table 3. TDS is low at mean 26.67 mg/l (standard deviation 21.3) and as expected, higher than TDS in surface water. The highest TDS at 85 mg/l was recorded from the dug well at Aragba, but water from this dug well is not represenative as it is uncovered and in the wet season regularly receives runoff from surrounding areas. Ground water is also weakly acidic at an average pH of 6.64. The acidity

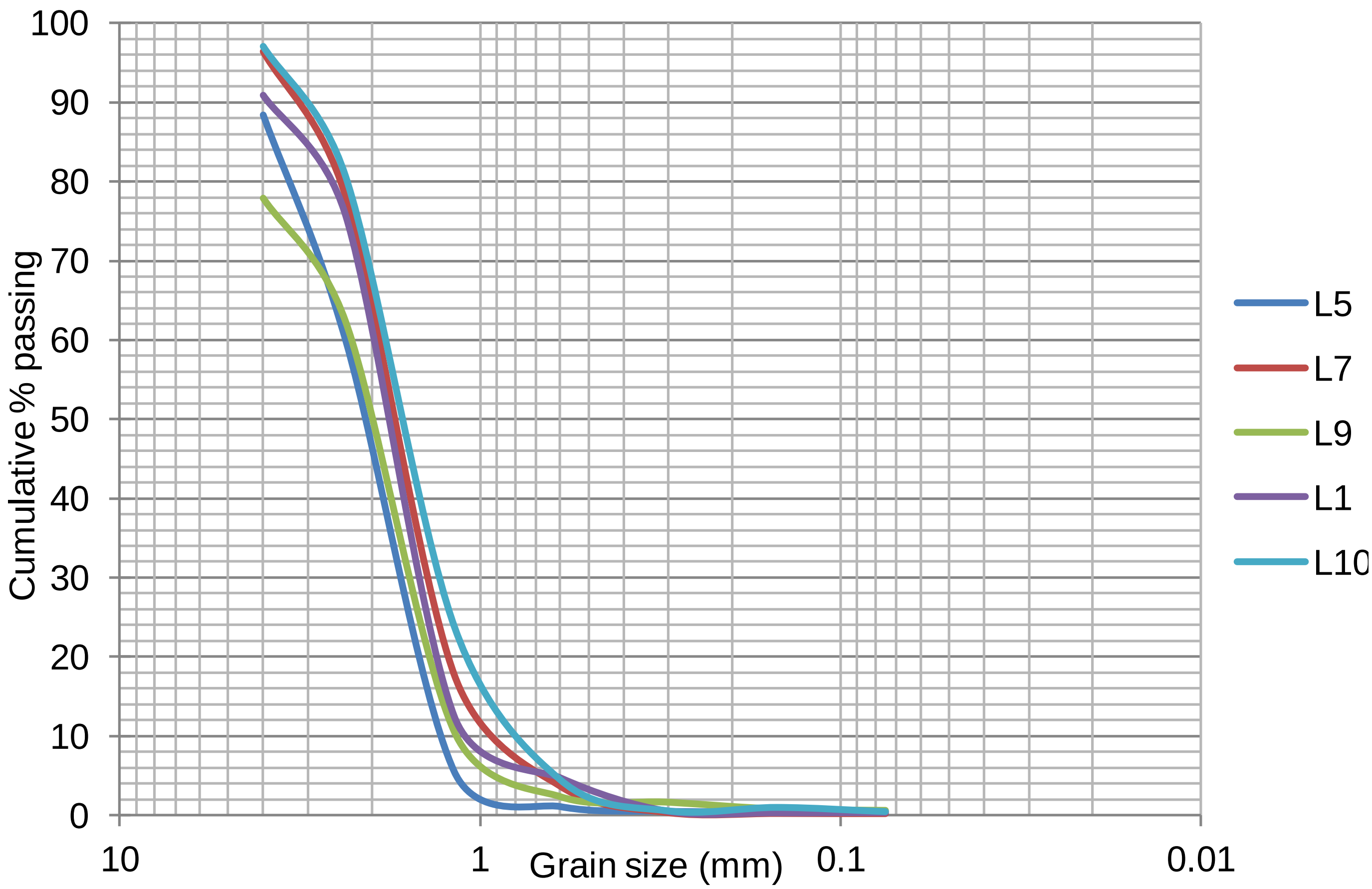

Figure 6. Typical grain size curves from screened horizons in selected boreholes in Abraka.

Table 2. Physical, chemical and microbiological characteristics of surface water from the Ethiope River and the Okumeshi River (mg/l, except where indicated), bacteria counts in (cfu/100 ml).

Parameters	Sampling points					
	MC	**MJ**	**MD**	**TR**	**OKR**	**JMR**
Temperature (°C)	27.8	28.2	27.5	27.5	28.1	-
TDS	6.62	8.09	7.21	6.83	16.5	8.91
EC (μ/cm)	12.74	15.51	13.87	13.14	33	17.85
pH	5.27	5.14	5.18	4.92	6.33	8.0
Ca	0.96	3.45	1.84	1.23	3.99	0.41
Mg	0.32	2.72	4.67	2.72	0.20	0.88
Na	1.91	2.33	2.08	1.97	0.86	0.42
K	0.51	0.62	0.55	0.53	1.46	0.10
HCO_3	1.01	3.05	0.61	0.16	2.20	0.65
SO_4	1.24	0.25	0.12	0.12	6.60	1.01
Cl	4.1	4.02	4.3	4.07	3.33	2.26
NO_3	0.00	0.65	0.26	0.18	0.20	1.25
Total bacteria	3.3×10^2	1.7×10^3	4.2×10^3	3.0×10^3	Nd	
Total coliform	11	35	45	80	Nd	0.0
Total *E. coli*	4.0×10	1.5×10	2.8×10	4.0×10	Nd	0.0
Total Salmonella	0	0	0	0	Nd	

MC = McCarthy Beach, MJ = Majoroh Beach, MD = Mudi Beach, OKR = Okumeshi River, TR = The Turf, JMR = Jamieson River, Nd = Not determined.

Table 3. Physical and chemical characteristics of groundwater (mg/l except where indicated).

Parameters	Sampling locations										
	CII	C3G	C3P	NAS Rd	WR2	WR1	UGN	ABK In	ARG	DS	SON
Temperature (°C)	28	27	28	27	28	27	27	27	28	28	
H	7.1	7.4	6.9	7.13	5.7	5.6	6.25	6.39	7.29	8.9	6.5-8.5
TDS	28	25	27	26.67	41.2	20.9	20	13	85	424	500
EC (µ/cm)	58.2	52.5	47.8	52.83	82.8	41.08	40	26	170	849	
Turbidity (NTU)	0	0.4	0.1	0.17	0.32	0.00	0.25	0.19	0.20	6.95	5
Ca	1.0	1.01	1.2	1.07	9.0	2.8	4.05	4.32	8.46	65.3	
Mg	1.8	2.1	1.5	1.8	7.3	1.4	0.26	0.30	0.41	54.6	0.2
K	3.5	3.6	2.0	3.03	4.32	2.43	4.09	0.84	9.95	74.4	
Na	7.2	8.5	9.8	8.5	10.11	5.21	5.58	2.49	20.34	109.1	
Cl	24.0	19.0	22.0	21.67	24.84	12.54	9.99	6.67	16.66	254.7	
HCO_3	1.3	1.0	1.4	1.23	5.01	3.22	<1.0	3.17	47.82	87.09	
SO_4	0	0	0.1	0.03	0.04	0.00	2.39	<1.0	10.07	9.7	200
NO_3	0	0	0	0	0.29	0.15	0.26	0.19	0.29	5.12	10
Pb	0	0.01	0	0	0	0	ND	ND	ND	0.04	0.01
Zn	0.1	0.2	0.1	0.13	0.1	0.13	ND	ND	ND	ND	3
Cd	0.01	0	0.02	0.01	0.001	0.00	ND	ND	ND	0.006	0.003
Fe	0.04	0.06	0.03	0.043	0.18	0.09	ND	ND	ND	7.65	0.3
Cr^{6+}	0	0	0	0	0.00	0.00	ND	ND	ND	0.008	0.05
Total coliform (cfu/100 ml)	0	0	0	0	6	0	8	8	8	54	
Faecal coliform (cfu/100 ml)	0	0	0	0	4	0	4	6	4	42	0

ARG, Aragba; ABK In, Abraka Inland; UGN, Ugono; CII, Geology Lab; C3G, Campus III Gate; C3P, Campus 3 Pool site; Nas Rd, Nassarawa Rd; WR1, Winner's Road 1; WR2, Winner's Road 2; DS, Dump Site; SON, Nigerian Drinking Water Standards.

is retained from that of recharging rainfall which as explained has been attributed to gas flares.

The unusually low TDS in the Ethiope River water could possibly be explained by the fact that its catchment is exclusively situated on the outcrop of the Benin Formation which is directly recharged perenially by rainfall. The Jamieson River its only tributary (Figure 2) was also sampled at its headwaters near Ugo, Edo State as part of this investigation and returned similar low TDS of 8.91 mg/l (Table 2). Reported regional variation in groundwater TDS (Olobaniyi and Owoyemi, 2004; Emeshili, 2008; Sarner PFM, 2011; SPDC, 2004, 2008) indicate that shallow groundwater from Benin Formation outcrop areas appears to be relatively lower in mineral content than that from areas where the formation is masked by younger layers.Thus, following from Domenico (1972), it does appear that while recharging, rainwater may have over time leached the upper layers of the Benin Formation of all soluble mineral matter with the resulting low total dissolved solids in shallow groundwater, it continues to dissolve mineral matter from overlying younger deposits where they occur. Because regional groundwater flow is from northeast to southwest, that is from Benin Formation outcrop areas southwestwards and contributes more than 80% to total flow of the River Ethiope (Akpoborie, 2011), it follows that river water would also be low in dissolved solids. Furthermore, this high contribution of low TDS ground water to stream flow could be partly responsible for the remarkable and unique clarity of water in the Ethiope River as well as the Jamieson River.

With respect to the microbial content, water from the boreholes in both campuses of the university at Abraka CII, C3G, C3P and Nas Rd is free of coliform bacteria. However, one borehole at Winners Road, WR2 is possibly receiving water from the heavily contaminated water in the abandoned quarry (DS, Table 3) as indicated by the relatively higher coliform count. That this contamination is limited for the time being to the immediate vicinity of the quarry is borne out by the fact that borehole WR1 which is also near the quarry but further away from it than WR2 is coliform free. Also, water in all the dug wells in rural Abraka at Ugono, Abraka Inland and Aragba contains faecal coliform which may be explained by the fact that the wells are shallow, uncovered and are often left in an unsanitary state.

Major ion geochemistry

Major ion content is used in interpretive diagrams (Hem, 1991; Piper, 1944; Keheew, 2001) to describe, classify and determine geochemical trends in ground water and has subsequently been used in several ground water

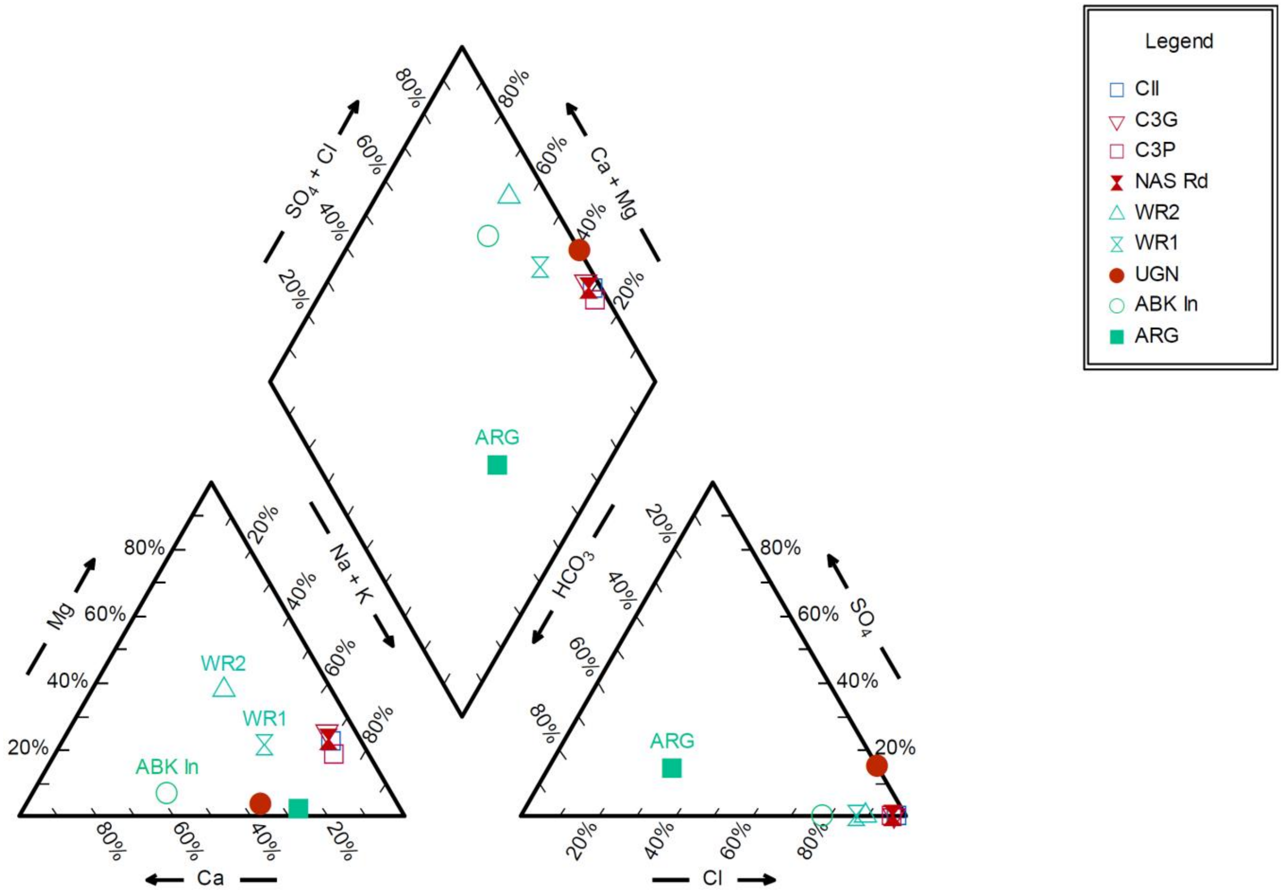

Figure 7. Piper diagram of groundwater analyses from Abraka area. ARG, Aragba; ABK In, Abraka Inland; UGN, Ugono; CII, Geology Lab; C3G, Campus 3 Gate; C3P, Campus 3 Pool site; WR1, Winner's Road 1; WR2, Winner's Road 2; Nas Rd,

studies (Arabi et al., 2010; Naseem et al., 2010; Smith and Wahl, 2003; Rafael et al., 1998). The Piper diagram plots of the chemical constituents in ground water presented in Table 3 are shown in Figure 7. All samples except Aragba (ARG) plot in the right hand quadrant of the diamond that stretches from about 20 to 60% calcium + magnesium, while sulphate + chloride are between 70 to 80% indicating a mixing trend as well as direct recharge by rainfall (Petalas and Diamantis, 1999). Ground water from both campuses of the University overlap at the 25% point on the Ca + Mg axis while Ugono plots slightly higher at 40%. Keheew (2001) classifies hydrochemical facies using the Piper plot and on the basis of which ground water from the boreholes at the university and at Ugono, UGN, may be described as the sodium chloride type while at Abraka Inland (ABK In), ground water is the calcium chloride facie. At Aragba, the water is dominated by sodium and potasium which constitute about 70% of the cations while the bicarbonate and chloride ions occur respectively at 60 and 35%; hence, the water is uniquely for this area, the sodium bicarbonate type. As has been noted however, this sample is from an unringed dug well that is always left uncovered and may not be considered representative of groundwater in the area.

The Stiff diagrams (Hem, 1989; Kehew, 2001) plotted for each sampling location and superimposed on Figure 3 confirm these facie classifications as well as further highlight the differences in shallow dug well water and water obtained from deeper in the aquifer from drilled wells. Ground water from boreholes located at the university for example presents a distinctive inverted funnel shape that may be considered representative of native ground water in Benin Formation outcrop area. At WR1, the funnel shape is mildly distorted due to relative enrichment in calcium occasioned by recharge from the nearby waste dump. At WR2, the borehole location closest to the dumpsite, ground water is already an admixture of native ground water and dumpsite water, and the funnel shape is completely distorted. In comparison to groundwater obtained from deeper in the aquifer, dug well water from shallower horizon and outside Benin Formation outcrop area at Aragba and Ugono present distintively different shapes than the university campus wells which is suggestive of possible hydrogeochemical stratification.

Suitability for domestic water supply

The depth at which water would be encountered in a well has always traditionally influenced the choice of domestic water supply source in the Niger Delta. The shallow water table at Umuebu, Aragba and Abraka Inland (Table 1), explains the preponderance of manually dug wells in these areas. Boreholes predominate at Abraka Urban and other areas located on the outcrop of the Benin Formation where the water table is deeper. The chemical parameters for both water supply sources in Table 3 are below the Nigerian guidelines for drinking water (SON, 2007). However, the presence of cadmium detected at three locations CII, C3P and NAS Rd where it occurs above the guideline value of 0.003 mg/l is worrisome and needs to be monitored because of its toxicity (Ifeagu and Ayankora, 2012). The source of cadmium enrichment in the area is unknown but its presence in stream sediments at elevated levels has been reported from nearby Ndokwa area by Emeshili (2008). Akpoborie (2011) and Aweto and Akpoborie (2011) have drawn attention to the potential problems that could be associated with continous ingestion of low TDS water in the long term especially when combined with very low levels of calcium and magnesium in drinking water supplies as reflected in the values for both ions in Tables 2 and 3.

Calcium and magnesium are essential micronutrients and their deficiency in drinking water supplies especially when dietary habits exclude foods rich in calcium and magnesium has been associated with increased risks of osteoporosis, nephrolithiasis (kidney stones), colorectal cancer, hypertension and stroke, among others (Ong, 2006; Kozisek, 2006). Enrichment of these micronutrients is therefore recommended if the water in this area is to be used as a source of raw water for public water supply schemes. Finally, gradual impairment of ground water with coliform bacteria (WR2, Table 3) by water from the abandoned quarry at Winner's Road confirms the potentially high vulnerability of the shallow and upper layers of the Benin Formation in this area to contamination as suggested by the predominantly sandy lithology.

Suitability for water contact recreation

The River Ethiope is the most prominent natural feature in Abraka area. The waters of the river are crystal clear, and the white river sands are of clean quartz grains with the result that the river is like a giant natural aquarium where fish and other organisms may be observed. This natural beauty is the main attraction for the rapid development of the hospitality industry along the river's south bank. Indeed, the river is an international tourist destination site and a gallery of spectacular pictures from some of the recreational beaches has been posted on the World Wide Web by Emiel Jegen (Jegen, 2004). In order to establish the suitability of river water for full body contact recreation, water samples from the more popular sites (Figure 3) were screened for the presence of coliform bacteria over a 30 day period in March 2011 in the middle of the dry season when the sites enjoy maximum patronage. The results which are shown in Table 2 indicate that occurrence of *Escherichia coli* is less than 50 cfu/100 ml at all sites. This level of occurrence is well below the guideline value of 126 cfu/100 ml for *E*. *coli* specified by the U.S. Environmental Protection Agency (USEPA, 2003) and affirmed by Wade et al. (2003) who reviewed the issue of using *E*. *coli* as the choice indicator of fecal contamination of bathing waters. Omo - Irabor and Olobaniyi (2007) report a mean *E. coli* occurrence of 145 MPN/100 ml in River Ethiope water with a range of 39 to 502 MPN/100 ml but do not provide results from individual sample sites thus precluding direct comparison with results shown in Table 2.

With respect to chemical quality, the World Health Organization (WHO, 2003) and the Australian National Health and Medical Research Council (NHMRC, 2008) are in agreement that health risks associated with chemical contamination during swimming are usually insignificant. The results in Table 2 indicate that the quality of water in the River Ethiope is suitable in this regard for swimming purposes.

Suitability for irrigation

The standard indices that are universally utilized to determine suitability for irrigation purposes have been determined for all samples and the results shown in Table 4 are summarized as follows:

Salinity hazard: High TDS in irrigation water affects soil efficiency, plant growth and yields. Following from Wilcox (1955) water with TDS that is less than 200 mg/l is excellent for irrigation and all water sampled in this study falls in this category.

The sodium adsorption ratio (SAR), the tendency of water to replace adsorbed calcium and magnesium with sodium was calculated as follows (Hem, 1991):

$$SAR = Na^{+} / \{[Ca^{2+} + Mg^{2+}] /2\}^{0.5}$$

Where the concentrations are expressed as milliequivalents per liter. All water sampled in this study falls within the low (< 10) SAR category (Richards,1954) and is thus suitable for irrigation.

Magnesium hazard was estimated with the Szabols and Darab (1964) relationship:

$$MH = (Mg^{2+} \times 100)/ (Ca^{2+} + Mg^{2+})$$

Table 4. Parameters for determining suitability for irrigation.

Sample site[a]	Parameter[b]				
	Facie	SH	SAR	MH	RSC
ARG	Na-HCO_3	Low	1.85	7.4	0.24
ABK INL	Ca-Cl	Low	0.312	10.3	0.0
UGN	Na-Cl	Low	0.725	9.57	N/A
CII	Na-Cl	Low	0.994	74.8	0.0
C3G	Na-Cl	Low	1.11	77.4	0.0
C3P	Na-Cl	Low	1.41	67.3	0.0
NAS Rd	Na-Cl	Low	1.16	73.5	0.0
WR1	Mg-Cl	Low	0.606	57.2	0.0
MC	Na-Cl	Low	0.476	35.5	0.0
MJ	Mg-Cl	Low	0.186	56.5	0.0
MD	Mg-Cl	Low	0.207	80.7	0.0
TR	Mg-Cl	Low	0.239	78.5	0.0
OKR	Ca-SO_4	Low	0.114	7.63	0.0

[a] ARG, Aragba; ABK In, Abraka Inland; UGN, Ugono; CII, Geology Lab; C3G, Campus 3 Gate; C3P, Campus 3 Pool site; WR1, Winner's Road 1; WR2, Winner's Road 2; DS, Dump site; MC, McCarthy Beach; MJ, Majoroh Beach; MD, Mudi Beach; TR, The Turf; okr, Okemesi River; Nas Rd, Nassarawa Rd. [b] SH, Salinity Hazard; SAR, sodium absorption ratio; MH, magnesium hazard; RSC, residual sodium carbonate.

Waters that have MH ratios > 50 are considered harmful to soils and may not be used for irrigation without appropriate treatment. The results in Table 4 indicate that water in the Abraka area has a high magnesium hazard and needs to be carefully evaluated in this regard before being utilized for irrigation.

Residual sodium carbonate (RSC) was obtained from the folowing relationship:

$$RSC = (CO_3^{+} + HCO_3^{2-}) - (Ca^{2+} + Mg^{2+})$$

Where all ionic concentrations are expressed in epm. Following the Eaton (1950) classification, RSC values from Abraka are all less than the + 1.25 threshold and may thus be safely used for irrigation.

Conclusions

This study has described for the first time aspects of the hydrogeology of the upper 20 m horizon of the Benin Formation aquifer in this part of the coastal plain and the Niger Delta. This horizon consists of a succession of fine grained reddish brown sands underlain by typically clean, grey – off white and fine – medium - coarse grained, angular to sub- rounded well sorted quartz sands. Depth to water level in the water table ranges from about 4 to 16 m. Sustained groundwater abstractions around the more densely populated Abraka Urban have resulted in a depression of the water table in the area towards which groundwater is flowing from virtually all directions in a distortion superimposed on regional southwestward groundwater flow. Hydraulic conductivity of the medium grained sands that are usually screened at an average 20 m depth in production wells is estimated from grain size analysis to range from 0.12 to 0.19 $msec^{-1}$. The major ion geochemistry indicates that groundwater is an admixture of NaCl, CaCl and $NaHCO_3$ facies and there is evidence of possible hydrogeochemical stratification. All water has very low TDS and this suggest that the perennial leaching of soluble minerals by recharging rainfall from the near surface horizon of the Benin Formation is probably responsible for the presence of minimal amounts of mineral content in water. It has also been determined that surface water and ground water are suitable for domestic use, irrigation and industrial purposes without prior treatment and that the water in this stretch of the Ethiope River is suitable for full body contact recreation.

ACKNOWLEDGEMENT

This investigation was undertaken with the aid of partial funding and resources provided by the Center for Research in Water and Environment (CREWE), Abraka and for which the authors are grateful.

REFERENCES

Akpoborie IA (2011). Aspects of the hydrology of the western Niger Delta wetlands: groundwater conditions in the Neogene (Recent) deposits of the Ndokwa area. Afr. Geosci. Rev. 18(3):25-36.

Akujieze CN, Oteze GE (2006). Groundwater Quality of Benin City Urban aquifer of the Pleistocene – Oligocene Benin Formation, Nigeria. Afr. Sci. 7(2):69-85.

Amajor LC (1991). Aquifers in the Benin Formation (Miocene Recent), Eastern Niger Delta, Nigeria: Lithostratigraphy, Hydraulics, and Water Quality. Environ. Geol. Water Sci. 17(2):85-101.E.

APHA (1992). Standard methods for the examination of water and waste water, 18th Edition, American Public Health Association, Washington, D.C.

Arabi SA, Funtua II, Alagbe SA, Zabosrki P, Dewu BBM (2010). Investigation of Groundwater quality for Domestic and Irrigation purposes around Gubrunde and Environs, northeastern Nigeria. J. Am. Sci. 6(12):664-672.

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

Domenico PA (1972). Concepts and Models in Groundwater Hydrology: McGraw Hill, 405 pp.

Eaton FM (1950). Significance of carbonates in irrigated waters. Soil Sci. 69:127-128.

Efe SI (2005). Urban Effects on precipitation amount, distribution and rainwater quality in Warri Metropolis, Ph. D. Thesis, Delta State University, Abraka, Nigeria.

Emeshili ME (2008). Quality assessment of the potability of borehole and surface waters in the Ndokwa area of Delta State, Nigeria, Unpublished Ph.D. Thesis, Delta State University, Abraka, Nigeria, 254 pp.

Fetter CW (1994). Applied Hydrogeology. Prentice-Hall, New Jersey, p.691

Golden Software Inc. (2002). Surfer 8, Golden Software Inc. Co. USA.

Hazen A (1892). Some physical properties of sands and gravels, with special reference to their use in filtration, 24th Annual Report, Massachusetts State Board of Health, Pub.Doc. 34:539-556

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

Ibe KM, Njemanze GN (1998). The Impact of Urbanization and Protection of water Resources, Owerri, Nigeria. J. Environ. Hydrol. 6:1-9.

Jegen E (2004). “Jump” available via: www.pbase.com/emieljegen/abraka&gcmd.

Kaizer AN, Osakwe, SA (2010). Physicochemical Characteristics and Heavy Metal Levels in Water Samples from Five River Systems in Delta State, Nigeria. J. Appl. Sci. Environ. Manage. 14(1)83-87.

Kehew AE (2001). Applied chemical hydrogeology: Prentice-Hall, New Jersey, p. 368.

Kozisek F (2006). Health risks from drinking demineralized water, In: Nutrients in Drinking Water. WHO, Geneva, pp. 148-163.

Longe EO (2010). Groundwater Resources Potential in the Coastal Plain Sands Aquifers, Lagos, Nigeria. Res. J. Environ. Earth Sci. Res. 3(1):1-7.

Naseem S, Hamza S, Bashir E (2010). Groundwater geochemistry of Winder Agricultural Farms, Balochistan, Pakistan and Assessment for Irrigation Water Quality. Eur. Water 31:21-32.

National Health and Medical Research Council, (2008). Guidelines for Managing Risks in Recreational Water Available via: http://www.nhmrc.gov.au

NGSA (2006). Geological Map of Nigeria, Nigeria Geological Survey Agency, Abuja.

Nwajide CS (2006). A guide for geological field trips to Anambra and related sedimentary basins in southeastern Nigeria. PTDF Chair, University of Nigeria, Nsukka.

Odong J (2007). Evaluation of empirical formulae for determination of hydraulic conductivity based on grain-size analysis. J. Am. Sci. 3(3):54-60.

Ojeh VN, Origho T (2012). Socioeconomic Development of Rural Areas in Nigeria Using the Growth Pole Approach: A Case Study of Delta State University in Abraka. Global Adv. Res. J. Geogr. Regional Plan. 1(1):007-015.

Olobaniyi SB, Owoyemi FB (2004). Quality of groundwater in the Deltaic Plain Sands aquifer of Warri and Environs, Delta State, Nigeria. Water Res. 15:39-45

Olobaniyi SB, Efe SI (2007). Comparative assessment of rainwater and groundwater quality in an oil producing area of Nigeria: Environmental and health implications. J. Environ. Health Res. 6(2):111-118.

Omo-Irabor OO, Olobaniyi SB (2007). Investigation of the Hydrological Quality of Ethiope River Watershed, Southern Nigeria. J. Appl. Sci. Environ. Manage. 11(2):13-19.

Ong CN (2006). Minerals from Drinking Water: Bioavailability For Various World Populations And Health Implications, In: Nutrients in Drinking Water, WHO, Geneva, pp. 61-74.

Oteze GE (2011). Water supply, groundwater and flood control in Benin City, Presented at the NMGS, Benin Chapter sensitization workshop on water resources management and its implications in Benin City,22nd March.

Piper AM (1944). A graphic procedure in geochemical interpretation of water analyses. Trans. Am. Geophys. Union 25:914-923

Rafael HA, Teodoro MG, Rafael MR (1998). Patterns of groundwater hydrochemistry in Apan-Tochac sub-basin, Mexico. Hydrol. Sci. J. 43(5):669-685.

Reijers TJA, Petters SW, Nwajide CS (Eds.) (1996). The Niger Delta Basin, SPDC Corporate Reprographic Services, Warri.

Richards LA (1954). Diagnosis and improvement of saline and alkali soils, Agriculture handbook, Volume 60, US Department of Agriculture, Washington DC.

Sarner PFM (2011). Environmental Impact Assessment of Oleri Water Theme Park, Sarner Pfm, Warri

Short KC, AJ Stauble (1967). Outline of geology of Niger delta. Bull. Am. Assoc. Petr. Geol. 54(5):761-779.

Smith SJ, Wahl KL (2003). Changes in Streamflow and Summary of Major-Ion Chemistry and Loads in the North Fork Red River Basin Upstream from Lake Altus, Northwestern Texas and Western Oklahoma, 1945–1999, USGS Water-Resources Investigations Report 03–4086.

SPDC (2004). Environmental Impact Assessment Of Jones Creek Field Development Plan Project, http://www.shell.com.ng/environment-society/environment-impact-assessments.html (Accessed on 12 Sept. 2013)

SPDC (2008). Environmental Impact Assessment (EIA) of Oben Gas Development Project http://www.shell.com.ng/environment-society/environment-impact-assessments.html (Accessed on 12 Sept. 2013).

Standards Organization of Nigeria (SON) (2007). Nigerian Standard for Drinking Water Quality, NIS 554:2007, Abuja, 30pp

Szabolcs I, Darab C (1964). The influence of irrigation water of high sodium carbonate content of soils, In: Proceedings of 8th international congress of ISSS, Transaction II, pp 803-810

Uma KO, Egboka, BCE, Onuoha, KM (1989). New Statistical Grain-Size Method for Evaluating the Hydraulic Conductivity of Sandy Aquifers. J. Hydrol. 108:367-386

USEPA (2003). Bacterial Water Quality Standards for Recreational Waters (Freshwater and Marine Waters) Status Report, EPA-823-R-03-008

Wade TJ, Pai N, Eisenberg, JNS, Colford, Jr. JM (2003). Do U.S. Environmental Protection Agency Water Quality Guidelines for Recreational Waters Prevent Gastrointestinal Illness? A systematic review and meta-analysis. Environ. Health Perspect. 111:1102-1109

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

World Health Organization (WHO) (2003). Guidelines for safe recreational water environments Volume 1: Coastal and Fresh Waters WHO, 20 Avenue Appia, 1211 Geneva 27, Switzerland.