African Journal of Environmental Science and Technology Vol. 5(13), pp. 1152-1169, 29 December, 2011
Available online at http://www.academicjournals.org/AJEST
DOI: 10.5897/AJESTX11.011
ISSN 1996-0786 ©2011 Academic Journals

Review

Groundwater chemistry and quality of Nigeria: A status review

A. Edet*, T. N. Nganje, A. J. Ukpong and A. S. Ekwere

Department of Geology, University of Calabar, P. O. Box 3609 UPO, Calabar, Nigeria.

Accepted 21 December, 2011

The present work is a review on the quality characteristics of groundwater in Nigeria. The aim was to collate, synthesize and analyse hydrochemical data from available literature in order to evaluate the physical and chemical character, quality and determine the sources of ions. The review process covered four major groundwater sedimentary basins viz Benin, Benue, Niger Delta, Sokoto and the Crystalline Basement Complexes. The issue of saline groundwater in parts of Benue and Niger Delta Basins were given attention. In general, data show that on the average, TDS for the groundwater from the different basins was < 250 mg/l compared to the saline groundwater with average TDS as high as 15700 mg/l. The high salinity was attributed to dissolution of salts and seawater intrusion. Nitrate concentration on the average is high especially, for Sokoto Basin indicating anthropogenic pollution. Descriptive and multivariate statistics together with cross plots indicate that the major geologic controls on the groundwater chemistry are chloride dissolution, weathering (silicate and carbonate) and ion exchange. With respect to agricultural and irrigation purposes, the groundwater are excellent besides the water from the saline groundwater from Benue Basin and the coastal aquifers.

Key words: Groundwater, chemistry, quality, Nigeria.

INTRODUCTION

Nigeria is blessed with large quantity of groundwater resources. For instance, Rijswljk (1981) estimated the amount of groundwater resource in Nigeria to be 6×10^{18} m^3. The resource plays an important role in the social and economic life of the people in terms of domestic, industrial and agricultural use. However, little is done to assess and understand the quality of groundwater especially within the different aquifer systems. Most literature on groundwater quality of Nigeria is localized, small scale and scattered. Besides, no known publication to date has been highlighted on quality alongside the sources and processes responsible for the water chemistry for the entire nation as an entity.

Available literature both published and unpublished are skewed towards comparing analytical results with existing national and international standards for drinking, domestic and agricultural purposes. Besides, geologic input is not given consideration in the quality assessment while most of the works are routine and does not seek to address any geologic problem.

The present work uses published work to document for the first time the quality status of groundwater in Nigeria bearing in mind natural and anthropogenic inputs. This consisted of gathering information on the groundwater geology of Nigeria; collate the information, synthesis and analysis the physicochemical data to assess their quality and sources of the ions bearing the local geologic setting of the major groundwater basins in Nigeria. The overall objectives of this review work are three-fold as follows:

1. To describe the distribution of physicochemical parameters in order to bring the groundwater quality problem to the attention of the population.
2. To identify the major pollutants in groundwater.
3. To identify the major sources of ions in water.

The available published works on groundwater quality and chemistry of Nigeria are on specific issues and

*Corresponding author. E-mail: aniekanedet@yahoo.com.

generally localized in terms of area coverage. One widely addressed issue is on quality assessment for drinking, domestic, agricultural and industrial uses in some cities (Lagos, Orlu, Calabar, Ijebu Ode, Warri, Agila, Ede, Yenogoa, Mubi, Akure, Agbor, Igbora, Bama, Iddo,); local government areas (Calabar, Port Harcourt, Khana, Gokana, Tai-Eleme, Jemaa and Umuahia); states (Akwa Ibom, Anambra and Ondo) and some geologic terrains (parts of Sokoto Basin, Eastern and Western Niger Delta, Basement of Central Nigeria, Obudu Plateau and Oban massif). These studies are documented in the work of Longe et al. (1987), Otezie (1991), Edet (1993), Olarewaju et al. (1997), Udom et al. (1998), Ajayi (1998), Ajayi and Obot (1998), Erah et al. (2002), Ahiarakwem and Ejimadu (2002), Ogunbayo (2004), Olobaniyi and Owoyemi (2004), Ozoko (2004), Udom et al. (2004), Adediji and Ajibade (2005), Ofoma et al. (2005), Efe et al. (2005), Edet and Okereke (2005), Alagbe (2006), Udom and Amah (2006), Abulude et al. (2007), Olobaniyi et al. (2007), Olobaniyi and Efe (2007), Adekunle et al. (2007), Jatau and Bajeh (2007), Chukwu (2008a), Boboye (2008), Adebo and Adetoyinbo (2009), Babatunde et al. (2009) and Nganje et al. (2010a).

Another area of concern in literature include bacterial contamination in groundwater in Benin City and Eastern Niger Delta (Tekwa et al., 2006; Ejechi et al., 2007), determination of natural background levels for parts of Cross River Basin (Offiong and Edet, 1998a, b; Edet et al., 2003; Edet, 2004) and groundwater dating of surface and subsurface waters in Sokoto Basin (Oteze, 1993; Adelana et al., 2003; Goni, 2006).

Other works in literature were on the interaction of groundwater with the host rock in Anambra State, parts of Niger Delta, northern parts of Ibadan, Warri Metropolis, Owerri Town and the Lower Benue Trough, (Ezeigbo, 1987; Amadi et al., 1989; Abimbola et al., 2002a; Olobaniyi and Owoyemi, 2006; Edet and Ekpo, 2008; Nganje et al., 2010; Amadi et al., 2010).

Impact of human activities received some attention on the groundwater situation in Nigeria. Most of the impacts were due to poor sanitation and agricultural practices, petroleum related activities and mining. Examples of these studies as documented in literature are nitrates in shallow aquifers of Sokoto and acid mine drainage pollution in Enugu. Others are on impact of waste dumps on groundwater quality in Orita-Ibadan, Oramiriukwa River Basin-Owerri, Minna, Benin and Lagos (Uma, 1993; Ezeigbo and Ezeanyim, 2006; Abimbola et al., 2002b; Tijani et al., 2002; Ibe sr and Sowa, 2002; Chukwu, 2008b; Yerima et al., 2008; Omo-Irabor et al., 2008; Edet, 2009; Omofonmwan and Eseigbe, 2009).

Saline groundwater problem has also been given prominent attention in Cross River Basin and Niger Delta (Uma et al., 1990; Uma, 1997; Awalla and Ezeigbo, 2002; Frank-Briggs, 2005; Edet, 2009; Amadi et al., 2010; Edet and Okereke, 2001a, b; Edet et al., 2011).

From the above, as stated earlier, these studies were localized. Hence the need to assemble the available works in literature as a prelude to give an overall status of the quality of groundwater in Nigeria. In achieving this, emphasis is placed on the major sedimentary basins and the basement complex bearing in mind the local geologic setting.

Location of Nigeria

Nigeria is situated south of the Sahara Desert in West Africa. It is bordered by Niger and Chad to the north, Benin in the west, Cameroon in the east and Gulf of Guinea in the south (Figure 1). The country lies between latitude 4° 10 to 13° 48 North and longitude 2° 50 to 14° 20 East covering an estimated area of 923, 768 km^2. The climate of Nigeria varies from equatorial in the south through tropical in the central to arid to the north. Nigeria experiences consistently high temperatures throughout the year. The temperature ranges between 21 and 33°C (Iloeje, 1981). The mean annual rainfall along the coast is more than 4000 mm while it is less than 250 mm in the north with an average of 1180 mm (BGS, 2003).

GEOLOGY AND GROUNDWATER BASINS

The geology of Nigeria consists of two main lithological units. These are the Precambrian Crystalline Basement and Cretaceous-Tertiary sedimentary rocks (Figure 2). The basement complex rocks are of metamorphic-igneous-volcanic origin. The main rock types include units include: Migmatite-Gneiss Complex (migmatites, gneisses), Schist Belts (schists, quartzites, metaconglomerates, amphibolites, phyllites), Older Granites (granites) and Younger Granites (basalts, rhylolites, tuff), Oyawoye (1970).

The sedimentary basins include the northern inland sedimentary basins consisting of the Sokoto and Chad Basins while the middle belt and southern coastal basins is made up of the Nupe, Benue, Benin and Niger Delta Basins. The sedimentary sequences in these basins were broadly divided into basal non marine sandstones, siltstones, and mudstones; a middle marine shales and limestones intercalated with sandstones and siltstones and an upper sandstone sequence that is continental or paralic (Petters, 1982).

The Sokoto Basin of northwestern Nigeria is the southern sector of the Iullemenden Basin transboundary aquifer shared by Mali, Niger, and Algeria. The depth of water level in the Sokoto Basin aquifers is typically in the range 15 to 75 m (BGS, 2003), while the Gwandu aquifer has an estimated yield of 10 to 35 L/s (Akujieze et al., 2003).

The Chad Basin consist of three main aquifers: an upper aquifer at 30 to 100 m depth with yield of 2.5 to 30 L/s, a middle aquifer about 40 to 100 m thick having a

Figure 1. Map of Nigeria showing the different states and surrounding countries (http://www.mapsofworld.com/nigeria/nigeria-political-map.html).

yield of 24 to 32 L/s and a lower aquifer consisting of sands and clays at a depth of 425 to 530 m with yield of 10 to 35 L/s (Akujieze et al., 2003; BGS, 2003).

In the Benue Basin, three broad hydrogeological groups were identified in the southern Benue Basin (Uma and Onuoha, 1990; Adelana et al., 2008). These include the first hydrogeological group underlain predominantly by shaly formations. The thickness is in the range of 10 to 40 m and water levels are generally < 20 m. The second hydrogeological group consists of mainly sandy and shaly horizons with yield in the range of 3 - > 30 L/s while the lower hydrogeological group consists predominantly of sands, sandstones and clays. The upper Benue Basin has the Gombe Sandstone and Kerri Kerri Formations as the main aquifers. These aquifers consist of coarse grained and highly permeable materials. The Kerri Kerri aquifer has yield of 1.25 to 9.5 L/s (Akujieze et al., 2003).

The Nupe Basin contains significant groundwater resources with occasional artesian conditions. Good aquifers are present in the Tertiary and Quaternary sediments of the southern coastal areas (Benin and Niger Delta Basins). The water level varies between 0 and 9 m while, the specific capacities, were in the range 90 to 1400 m^3/d/m, Offodile (1992).

The groundwater storage in the crystalline basement is small. Groundwater availability is largely limited to fracture zones and areas of deep weathering (Ajayi and Hassan, 1990; Olorunfemi, 1990; Edet, 1992; Edet and

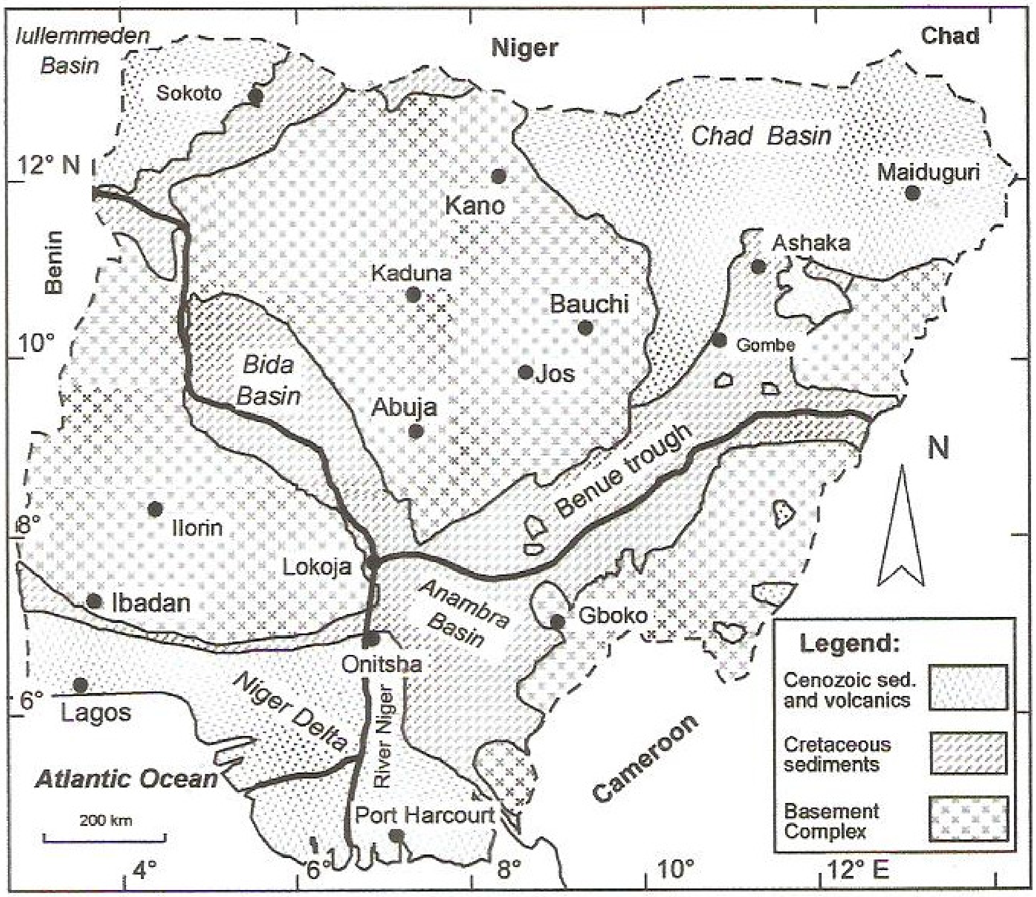

Figure 2. Generalized geological map of Nigeria including the basement complex and some sedimentary basins (Adapted from Adelana et al., 2008).

Okereke, 1997; Edet et al., 1998; Okereke et al., 1998). Generally, the principal source of groundwater is from hand dug wells. Details on the hydrogeology of Nigeria are contained in Offodile (1992), Akujieze et al. (2003), BGS (2003) and Adelana et al. (2008). A summary of the hydrostratigraphic units in Nigeria is presented in Table 1.

DATA GATHERING

In the present work, available literature were gathered and categorized on the basis of the different groundwater provinces. In categorizing these works, only literature with complete physical (temperature, electrical conductivity, total dissolved solids and pH), basic cation (sodium, potassium, calcium and magnesium) and anions (chloride, bicarbonate, sulphate and nitrate) were selected. This was in addition to iron and manganese. The data were then subjected to descriptive statistics (mean, median, minimum, maximum, standard deviation), correlation and factor analyses. In addition, cross plots were made between different ions. The cross plots together with correlation and factor analyses were used to determine the source of ions in groundwater bearing in mind the lithologic units under consideration. The data were also compared with national and international standards to assess their suitability for domestic, industrial and agricultural applications. The cross plots were made with Microsoft Excel while the multivariate statistics were made with the software STATISTICA®. The locations and sources of data for the present review work are presented in Table 2.

OVERVIEW OF GROUNDWATER QUALITY IN NIGERIA

A number of groundwater quality studies have been carried out in Nigeria, though generally on local basis with few numbers of chemical constituents. This accounts attempt to make a summary of the groundwater characteristics. BGS (2003) noted that the shallow aquifers are vulnerable to pollution from domestic, agricultural and industrial waste. Oil spillages are known to have some impact on groundwater a good example being the recent report on the environmental assessment

Table 1. A summary of the hydrostratigraphic units of Nigeria[a].

Age	Benin Basin	Niger Delta Basin	SE Benue Trough	NE Benue Trough	Chad Basin	Nupe Basin	Sokoto Basin
Quaternary	Alluvial aquifer						
	Deltaic aquifer				Chad aquifer		
Pliocene							
Miocene							
Oligocene	Benin aquifer	Benin aquifer	Benin aquifer	Kerri Kerri aquifer	Kerri Kerri aquifer	Patti aquifer	
	Ilaro aquifer		Ogwashi-Asaba aquifer				
Eocene	Akimbo/Oshosun aquifers	Agbada aquifer	Nanka sand aquifer				Gwandu aquifer
			Ameki aquitard				Kalambaina aquifer
	Imo Shale aquitard		Imo Shale aquitard				Dange aquiclude
Paleocene	Ewekoro aquifer	Akata Shale aquitard					Wurno aquifer
Maastrichtian	Nkporo Shale aquitard	Nkporo Shale aquitard	Nsukka aquitard				Dukumaje aquiclude
			Ajali Sandstone aquifer	Gombe Sandstone aquifer	Gombe Sandstone aquifer		Taloka aquifer
			Mamu aquiclude			Lokoja Sandstone aquifer	
			Nkporo Shale aquitard				
Campanian			Enugu Shale aquitard				
Santonian			Agwu aquitard	Lamja Sandstone aquifer	Fika Shale aquitard		
Coniancian	Abeokuta aquifer		Agbani Sandstone aquifer	Numanha aquifer			
			Amaseri Sandstone aquifer	Sukuliye aquifer			
			New Netim marl aquitard	Jessu aquifer			
				Gulani aquifer			
Turonian			Ekenkpon shale aquitard	Pindiga aquitard	Gongila aquifer		
			Eze Aku aquitard				
			Markurdi Sandstone aquifer				
			Agala aquifer				
			Ezillo aquifer	Yolde aquifer			
Cenomanian			Odukpani aquitard	Bima Sandstone aquifer	Bima Sandstone aquifer		
Albian			Asu River aquitard				Illo-Gundumi aquifer/aquiclude
Pre-Albian	Basement Complex	Basement Complex	Basement Complex	Basement Complex	Basement Complex	Basement Complex	Basement Complex

[a] Based on the work of Petters (1982), Offodile (1992), Akujieze et al. (2003), Adelana et al. (2008)

of Ogoni land (UNEP, 2011).

Natural water quality problems have also been noted especially, in relation to dissolution of evaporate minerals in the Benue Basin (Ekwere and Ukpong, 1994; Uma, 1998; Tijani, 2008).

Overexploitation of coastal aquifers, tidal influences and shallow wells in the coastal parts of Nigeria has led to problems with saline intrusion. This is noted around Lagos, Ondo, Delta, Bayelsa, Rivers, Akwa Ibom and Cross Rivers States.

Problems of acid mine drainage have also been reported in some areas especially, the coal mining areas in Enugu (Nganje, 2010, 2011).

A summary of groundwater for a total of 600 samples is given in Table 3. The data indicate that the average concentrations of most elements investigated are present in concentrations lower

Table 2. Location characteristics and data source.

State	Code	Age	Basin	Formation (Aquifer)	Sample size (n)	Source
Abia	AB	Oligocene	Niger Delta	Benin	27	Ukandu (2009)
Akwa Ibom	AK				75	Edet (1993), Ajayi and Obot (2006)
Bayelsa	BAY				27	Amadi et al. (1989)
Cross River	CR-1				7	Edet et al. (2009)
Delta	DEL				34	Olobanyi et al. (2001)
Lagos	LAG				12	Longe et al. (1987)
Rivers	RIV				54	Udom et al. (1999), Frank-Briggs (2003)
Imo	IM	Eocene		Ogwashi Asaba	10	Ahiarakwem and Ejimmadu (2002)
Ogun	OG-1	Paleocene	Benin	Ewekoro	7	Tijani (2003)
Ogun	OG-2	Coniacian		Abeokuta	15	Ogunbanjo (2004)
Anambra	ANAM	Eocene	Benue Trough	Nanka Sands	4	Ogbukagu and Akujieze (1990)
Enugu	ENU	Maastrichian		Enugu Shale	44	Onwuka et al. (2004)
Benue	BNE-1	Turonian		Agila	12	Ozoko (2004)
Ebonyi	EBY	Albian		Asu River	17	Awalla and Ezeigbo (2002)
Sokoto	SOK-1	Eocene	Sokoto	Gwandu	19	Uma (1993), Alagbe (2006)
	SOK-2	Eocene		Kalambina	30	Alagbe (2006)
FCT-Abuja	FCT-KD		Basement Complex	North Central	53	Etu-Efeotor (1998 a, b), Alagbe (2002)
Adamawa	ADAM			Adamawa Hills	3	Onugba and Eduvie (2005)
Ondo	ON-OY			South West	74	Ajayi (1998), Abimbola et al. (2002), Ogunbajo and Kolajo (2003), Boboye (2008)
	CR-2			Oban massif	18	Ekwere (2011)
	CR-3			Obudu plateau	27	Edet and Okereke (2005)
Akwa Ibom/Bayelsa/Rivers	AK-BAY-RIV	Quaternary	Seawater	Benin	12	Edet and Okereke (2001a, b)
Benue	BNE-2	Turonian	Saline	Markurdi Sandstone	4	Uma (1998), Uma et al. (1990), Tijani et al. (1996)
Benue	BNE-3	Albian		Awe	5	Tijani (2008)
Cross River/Ebonyi States	CR-EBY	Albian		Asu River	11	Ekwere and Ukpong (1994)

Source: Abimbola et al. (2002) and JMG {2001: 37(1)}.

than the WHO (1993) guideline values for domestic and agricultural uses. This excludes the saline groundwaters which have concentrations higher than the WHO (1993) guideline. In the next section, details of concentrations and variations within the different groundwater basins are discussed.

DISTRIBUTION OF IONS ACCORDING TO GROUNDWATER BASINS

The distribution of ions in groundwater of sedimentary and basement complex areas (excluding the saline water) indicate comparable concentrations with EC, Na, K, Mg, and Cl higher in the sedimentary area relative to the basement complex. No geographical bias to the distribution is observed but on local basis, the water tends to reflect the lithology. The distribution of ions in the sedimentary area is as follows $Na^+ > Ca^{2+} > K^+ > Mg^{2+}$ and $HCO_3^- > Cl^- > SO_4^{2-}$ and for the basement area the sequence is $Ca^{2+} > Na^+ > Mg^{2+} > K^+$ and $HCO_3^- >$

Table 3. Summary of major ions data for groundwater in Nigeria (n = 600), excluding the saline groundwater.

Parameter	Unit	Mean	Med	Min	Max	SD	WHO [1993]
Temp	°C	28.27	28.03	26.46	30.79	1.04	
pH		6.04	6.12	4.86	7.05	0.58	6.5-8.5
EC	µS/cm	270.63	225.83	30.16	635.36	181.04	1500
TDS	mg/l	164.83	131.95	10.00	413.92	131.70	1000
Hardness	mg/l	78.38	60.92	0.01	316.70	77.67	500
Na^+	mg/l	30.35	12.27	0.00	202.09	47.49	200
K^+	mg/l	8.07	3.05	0.02	52.29	12.02	30
Ca^{2+}	mg/l	20.16	13.15	1.04	55.60	17.00	200
Mg^{2+}	mg/l	9.98	5.98	0.20	46.01	11.77	150
Cl^-	mg/l	25.34	17.27	0.87	82.55	23.17	250
HCO_3^-	mg/l	71.50	44.57	4.64	237.79	67.20	380
SO_4^{2-}	mg/l	21.03	12.64	0.00	87.38	25.61	400
NO_3^-	mg/l	18.38	10.09	0.00	97.22	24.99	10
Fe	mg/l	1.28	0.32	0.04	12.01	2.87	0.3
Mn^{2+}	mg/l	0.20	0.16	0.05	0.58	0.15	0.1

SO_4^{2-}>Cl^-.

The Niger Delta Basin

The aquifers within the Niger Delta Basin are the most prolific and exploited in Nigeria. These are the Oligocene Benin and the Eocene Ogwashi/Asaba aquifers. These aquifers are composed of alternating layers of gravels, sands, silts and clays thus giving rise to a multi-aquifer system (Okereke et al., 1998; Ibe snr and Sowa, 2002). The Benin aquifer underlies the coastal states of Lagos, Ogun, Ondo, Edo, Delta, Bayelsa, Rivers, Akwa Ibom and Cross River States (Figure 1). Groundwater chemistry data for this aquifer were obtained from the work of Longe et al. (1987), Amadi et al. (1989), Edet (1993), Ajayi and Obot (1998), Udom et al. (1999), Olobaniyi et al. (2007), Edet and Okereke (2001a,b; 2002), Edet et al. (2003), Frank-Briggs (2003), Bolaji (2009) and Ukandu (2009).

From the work of these authors (Table 4), the mean groundwater temperature is between 27.35 and 29.43°C, while the mean pH is less than 7.00. The average value of total dissolved solids (TDS) is less than 150 mg/l and hardness, less than 75 mg/l of $CaCO_3$. The pH indicates acidic condition and outside the WHO (1993) acceptable limit of 6.5 to 8.5. According to Freeze and Cherry (1979) reference values, the groundwater is fresh (TDS < 1000 mg/l) and soft (Hardness < 75 mg/l). The average ions values show that for the Benin Aquifer the sequence is as follows: $Na^+ > K^+ > Ca^{2+} > Mg^{2+}$ and $Cl^- > HCO_3^- > SO_4^{2-}$ for the anions. The data indicate that the concentrations of Na, Ca, Mg, Cl and SO_4 were within the WHO (1993) acceptable limit of 200 mg/l (Na), 200 mg/l (Ca), 150 mg/l (Mg), Cl (250 mg/l) and 400 mg/l (SO_4) respectively for drinking water. The lowest values were observed from the inland state of Abia while the highest values were mainly from the coastal states of Akwa Ibom, Bayelsa, Cross River, Delta, Lagos, Ondo and Rivers due to saline water intrusion.

The water types (Table 5) in the Benin Aquifer are not uniform and consist of the following: Na^+-Cl^- (Abia and Cross River States), Ca^{2+}-Na^+-Cl^- (Delta State), Ca^{2+}-Mg^{2+}-Na^+-Cl^- (Rivers State), Ca^{2+}-Mg^{2+}-Na^+-Cl^--HCO_3^- (Akwa Ibom State), Na^+-Ca^{2+}-Mg^{2+}-Cl^--SO_4^{2-} (Bayelsa State) and Ca^{2+}-Na^+-Mg^{2+}-SO_4^{2-}-Cl^- (Lagos State). The variations are mainly due to differences in number of samples used for the review and locations of data in terms of distance from the Gulf of Guinea.

The work of Ahiarakwem and Ejimadu (2002), documented the characteristics of the Ogwashi/Asaba aquifer in parts of Imo State. The major components of the unconfined aquifer are sands, clays, shales and lignite. The groundwater here is acidic, fresh and soft. The cation concentration show that, $Na^+ > Ca^{2+} > Mg^{2+} > K^+$ while, the anion are $HCO_3^- > SO_4^{2-} > Cl^-$. The water type in this aquifer is Na^+-Ca^{2+}-Mg^{2+}-SO_4^{2-}-Cl^- (Table 5).

The Benin Basin

The Benin Basin is situated in the southwestern part of Nigeria covering most of Ondo and Ogun States extending to the Republic of Benin. Two aquifers, the Coniancian Abeokuta (Shale, Limestone) and the Paleocene Ewekoro (Limestone, Shale) aquifers were considered based on the work of Tijani (2003) and Ogunbanjo (2004).

The average groundwater temperature for the aquifers ranged from 27.97 to 28.47°C, while the mean pH is in

Table 4. Physicochemical characteristics of groundwater for some aquifers in Nigeria.

Basin	Formation (Aquifer)	Code	Temp (°C)	pH	EC (µS/cm)	TDS (mg/l)	TH (mg/l)	Na^+ (mg/l)	K^+ (mg/l)	Ca^{2+} (mg/l)	Mg^{2+} (mg/l)	Cl^- (mg/l)	HCO_3^-	SO_4^{2-}
Niger Delta	Benin	AB	29.43	4.86	30.16	14.58	3.46	2.67	0.36	1.04	0.20	5.54	33.81	0.00
		AK	27.74	6.12	86.24	52.22	60.92	9.50	2.36	13.15	6.73	28.32	18.53	3.38
		BAY	27.35	6.60	353.34	252.04	49.59	23.29	12.96	10.01	5.89	54.21	39.84	18.02
		CR-1	27.98	6.35	225.83	116.58	6.98	18.81	2.30	2.11	0.41	10.75	44.57	2.84
		DEL	28.95	5.27	53.24	21.98	13.67	4.92	1.42	3.81	1.00	8.58	4.64	1.35
		LAG		5.46		10.00	12.95	3.08	0.73	2.75	1.75	5.58	27.86	12.64
		RIV	27.74	6.20	258.31	141.99	51.78	12.69	2.24	10.74	5.98	54.78	42.07	6.13
	Ogwashi Asaba	IM		5.62		28.08	20.05	5.36	0.42	3.87	2.49	6.51	18.90	13.25
Benin	Ewekoro	OG-1	27.97	5.63	95.00	59.71	37.75	37.04	1.54	12.39	1.63	42.86	50.00	0.43
	Abeokuta	OG-2	28.47	6.80	161.07		211.78	7.86	8.32	26.27	35.07	0.87	51.67	12.69
Benue Trough	Nanka Sands	ANAM		5.50	313.25	153.75	163.33	0.00	3.05	39.50	15.50	53.25	13.50	8.00
	Enugu Shale	ENU		5.31	635.36	413.92	98.91	80.26	23.16	11.56	17.19	82.55	119.10	79.37
	Agila	BNE-1		6.61	625.38	372.53	0.01	0.25	0.02	46.40	19.29	23.42	237.79	35.75
	Asu River	EBY	28.76	6.49	539.18	283.78	316.70	97.20	20.86	50.00	46.01	59.56	192.08	87.38
Sokoto	Gwandu	SOK-1		5.89	180.82	117.84	67.06	57.84	9.31	16.99	3.97	13.71	27.09	7.50
	Kalambina	SOK-2		7.05	364.71	402.50	106.80	202.09	52.29	55.60	14.89	17.27	156.93	25.52
Basement Complex	North Central	FCT-KD	26.46	6.13	185.87	136.32	80.95	12.27	4.07	18.57	8.29	12.00	81.38	42.69
	Adamawa Hills	ADAM	30.79	6.64	334.07	320.03	119.56	27.68	9.25	30.59	10.34	8.06	183.06	5.09
	South West	ON-OY	28.07	6.57	377.36	177.72	88.72	27.88	8.46	24.30	6.71	22.59	92.98	14.96
	Oban massif	CR-2	28.62	5.91	123.68	93.39	27.44	2.63	3.62	6.23	2.84	1.89	18.43	6.09
	Obudu plateau	CR-3	27.44	5.89	199.03	127.59	107.61	3.98	2.67	37.41	3.38	19.86	47.27	58.62
	Benin	AK-BAY-RIV	27.64	6.68	4551.33	2395.44	790.16	508.02	46.58	134.09	109.18	1206.68	187.86	114.79
Saline water	Markurdi Sandstone	BNE-2	31.85	6.83	27722.00	17641.25	1271.44	6136.75	243.15	390.58	70.80	10278.75	406.05	
	Awe	BNE-3	35.70	7.06	15441.20	9119.40	660.70	3371.00	110.44	201.58	37.62	4814.60	524.10	17.17
	Asu River	CR-EBY	29.12	6.58	50203.91	33715.14	3875.83	11528.27	283.03	1216.95	200.03	20147.18	219.85	179.36
WHO (1993)				6.5-8.5	1500	1000	500	200	30	200	150	250	380	400

TH-Total hardness.

the range 5.63 to 6.80. This indicates that the groundwater in this basin is acidic. However, the water is fresh with total dissolved solid (TDS) is less than 1000 mg/l while, the hardness varies between soft and hard. The average concentration of ions was in the order: $Na^+ > Mg^{2+} > Ca^{2+} > K^+$ for the cations and $HCO_3^- > Cl^- > SO_4^{2-}$ for anions. The data in Table 4 indicate that the mean concentrations of Na, K, Ca, Mg, Cl and SO_4 are within the WHO (1993) acceptable limit for domestic purposes. The main types of water are respectively, Mg^{2+}-Ca^{2+}-HCO_3^--SO_4^{2-} and Na^+ Ca^{2+}-Cl^- for the Ewekoro and Abeokuta Aquifers.

The Benue Basin

The Benue Basin comprises four aquifers which are Nanka sands, Enugu Shale, Agala Sandstone and Asu River Group (Ogbukagu and Akujieze,1990; Okeke and Igboanua, 2003; Onwuka et al., 2004; Ozoko, 2004; Awalla and Ezeigbo, 2002).

The groundwater of Benue Basin is acidic and fresh. The hardness of the different groundwater bodies in the Benue Basin ranges from moderately hard for the Enugu Shale, through hard for the Agala Sandstones and very hard for the Asu River Group aquifer.

The average concentrations of Na^+ ranged from 0.25 for Agala Sandstone to 97.20 mg/l for Asu River Group; K^+, 0.02 (Agala Sandstone) – 23.16 mg/l (Enugu Shale), Ca^{2+}, 11.56 (Enugu Shale) – 50.0 mg/l (Asu River Group) and Mg^{2+}, 17.19 (Enugu Shale) – 46.01 mg/l (Asu River Group). In all cases, the cation values are within the WHO (1993) permissible limits for domestic purposes. The concentration of chloride vary from 23.42 (Agala Sandstone) – 82.55 mg/l (Enugu shale), while the bicarbonate concentrations range from 13.50 mg/l for Nanka Sands to 237.79 mg/l for the Agala Sandstone. Sulphates mean concentration is in the range 8.00 mg/l for Nanka Sands – 87.38 mg/l for Asu River Group. The main groundwater types are Ca^{2+}-Mg^{2+}-Cl^-, Na^+-Cl^--SO_4^{2-}, Ca^{2+}-Mg^{2+}-SO_4^{2-}-Cl^- and Na^+-Mg^{2+}-Ca^{2+}-SO_4^{2-}-Cl^--HCO_3^- respectively, for Nanka Sands, Enugu Shales, Agala Sandstones and Asu River Group (Table 5). These variations in the water types reflect the complex lithologic types in the Benue Basin.

The Sokoto Basin

The work of Uma (1993) and Alagbe (2006) were used in respect of the Eocene Gwandu (Shale, Limestone) and the Paleocene Kalambina (Limestone, Marly limestone) aquifers of the Sokoto Basin.

The groundwater in the Sokoto Basin are acidic-basic, fresh and soft (Gwandu Aquifer) to moderately hard (Kalambina Aquifer). The mean concentrations of cations are as follows: $Na^+ > Ca^{2+} > K^+ > Mg^{2+}$. The anions are in the order $HCO_3^- > SO_4^{2-} > Cl^-$. The main types of groundwater for the Sokoto Basin are Mg^{2+}-Na^+-SO_4^{2-}-Cl^- and Na^+-K^+-Cl^--SO_4^{2-} for the Gwandu and Kalambina Aquifers respectively (Table 5).

Basement complex

The mean groundwater temperature for the basement complex is uniform with mean values ranging from 26.4 to 30.79°C. The mean pH, TDS and ions values (Table 4) indicate that the groundwater is acidic and fresh while the groundwater hardness vary from soft, to hard. The concentrations of Na^+ and K^+ are in the range 2.63 to 27.88 mg/l and 2.67 to 8.46 mg/l while, Ca^{2+} and Mg^{2+} are 6.23 to 34.31 mg/l and 2.84 to 10.34 mg/l respectively. The anions are in the following ranges for Cl^-, HCO_3^- and SO_4^{2-} as 1.89 to 22.59 mg/l, 18.43 to 183.06 mg/l and 5.09 to 58.62 mg/l respectively. The dominant water types of the basement complex are Ca^{2+}-Na^+-SO_4^{2-}-Cl^- for the north central basement complex (Etu-Efeotor, 1998a, b; Alagbe, 2002), Ca^{2+}-Na^+-Cl^--HCO_3^--SO_4^{2-} for Adamawa Hills and northwestern basement complex (Onugba and Eduvie, 2005), Ca^{2+}-Na^+-Cl^--HCO_3^--SO_4^{2-}-HCO_3^- for the southwestern basement complex (Ajayi, 1998; Abimbola et al., 2002a; Ogunbanjo and Kolajo, 2004; Tijani, 2003; Boboye, 2008) and Ca^{2+}-Mg^{2+}-SO_4^{2-}-Cl^--HCO_3^- and Ca^{2+}-Mg^{2+}-SO_4^{2-}-Cl^- respectively, for the Oban massif and Obudu plateau in in southeastern basement Complex (Edet and Okereke, 2005; Edet and Ekpo, 2008; Ekwere, 2011).

Saline groundwater

The occurrence of groundwater with very high salinity has been documented in some parts of Nigeria. These occurrences were reported from the Albian Asu River Group in Cross River and Ebonyi States, Albian Awe and Turonian Markurdi Sandstones aquifers in Benue State (Benue Basin). The TDS, Na, K, Ca, Mg, Cl, HCO_3 and SO_4 concentrations are as high as 33715.14mg/l, 11528.27mg/l, 283.03mg/l, 1216.95mg/l, 200.03mg/l, 20147.18mg/l, 219.85mg/l and 179.36mg/l respectively (Table 4). These high values are unacceptable for domestic and agricultural purposes. The source of the salinity in groundwater has been attributed to dissolution of chloride minerals (Uma et al, 1990; Ekwere and Ukpong, 1994; Uma 1998; Tijani et al., 1996; BGS, 2003; Tijani 2008).

Coastal aquifers in Nigeria straddling from Lagos State in the west to Cross River State in the east (Figure 1) have been reported to be affected by sea water intrusion. Some of these are presented in the works of Amadi et al (1989), Edet and Okereke (2001a, b), Frank-Briggs (2003), Olobaniyi and Owoyemi (2006), Edet (2008, 2009, 2010), Edet and Worden (2009), Adebo and Adetoyinbo (2009), Olufemi et al., (2010) and Edet et al., (2011). The sequences of ion concentration are as follows $Na^+ > Ca^{2+} > Mg^{2+} > K^+$ for cations and $Cl^- > HCO_3^- > SO_4^{2-}$ for the anions. A summary of the chemical characteristics including some standards for the different basins are presented in Table 6.

GROUNDWATER EVOLUTION

Correlation

Correlation coefficient is a commonly used measure to assess the relationship between two variables. It is a simple measure to exhibit how well one variable predicts the other (Bahar and Reza, 2010). The correlation matrix for the different variables is shown in Table 7. The data illustrate that EC and TDS show statistically high positive

Table 5. Hydrochemical facies and quality characteristics of groundwater for some aquifers in Nigeria.

Basin	Formation (Aquifer)	Code	Facies	NO_3^- (mg/l)	Fe (mg/l)	Mn^{2+} (mg/l)	SAR	Na (%)	RSC
Niger Delta	Benin	AB	Na^+-Cl^-	0.00	0.10		0.78	72.05	0.48
		AK	Ca^{2+}-Mg^{2+}-Na^+-Cl^--HCO_3^-	2.41	0.51	0.18	0.64	31.71	-0.91
		BAY	Na^+-Ca^{2+}-Mg^{2+}-Cl^--SO_4^{2-}	0.57	2.54	0.17	1.43	46.88	-0.34
		CR-1	Na^+-Cl^-	27.24			3.79	88.71	0.59
		DEL	Ca^{2+}-Na^+-Cl^-	1.14	0.32	0.07	0.53	45.57	-0.20
		LAG	Ca^{2+}-Na^+-Mg^{2+}-SO_4^{2-}-Cl^-	1.76	12.01	0.12	0.37	28.10	0.01
		RIV	Ca^{2+}-Mg^{2+}-Na^+-Cl^-	0.17	1.37	0.15	0.70	28.56	-0.35
	Ogwashi-Asaba	IM	Na^+-Ca^{2+}-Mg^{2+}-SO_4^{2-}-Cl^-	0.94	0.33	0.05	0.56	39.98	-0.09
Benin	Ewekoro	OG-1	Mg^{2+}-Ca^{2+}-HCO_3^--SO_4^{2-}	18.93	0.04		2.84	68.48	0.06
	Abeokuta	OG-2	Na^+-Ca^{2+}-Cl^-	4.76	2.43		0.24	13.04	-3.39
Benue Trough	Nanka Sands	ANAM	Ca^{2+}-Mg^{2+}--Cl^-	2.10	0.18	0.35	0.00	3.05	-3.05
	Enugu Shale	ENU	Na^+-Cl^--SO_4^{2-}	27.50			4.26	70.79	-0.03
	Agila	BNE-1	Ca^{2+}-Mg^{2+}-SO_4^{2-}-Cl^-	17.49	0.25	0.58	0.01	0.73	-0.03
	Asu River	EBY	Na^+-Mg^{2+}-Ca^{2+}-SO_4^{2-}-Cl^--HCO_3^-	40.26	0.29		2.49	40.95	-3.19
Sokoto	Gwandu	SOK-1	Mg^{2+}-Na^+-SO_4^{2-}-Cl^-	70.72			0.52	41.02	-1.22
	Kalambina	SOK-2	Na^+-K^+-Cl^--SO_4^{2-}	97.22	0.14		2.28	65.68	-1.72
Basement Complex	North Central	FCT-KD	Ca^{2+}-Na^+-SO_4^{2-}-Cl^-	10.09	0.49		0.66	42.23	-0.28
	Adamawa Hills	ADAM	Ca^{2+}-Na^+-Cl^--HCO_3^--SO^{42-}	5.29			1.12	40.15	0.61
	South West	ON-OY	Ca^{2+}-Na^+-Cl^--HCO_3^--SO_4^{2-}-HCO_3^-	26.09	0.57	0.18	1.45	43.04	-0.25
	Oban massif	CR-2	Ca^{2+}-Mg^{2+}-SO_4^{2-}-Cl^--HCO_3^-	17.11	0.12		0.20	26.97	-0.25
	Obudu plateau	CR-3	Ca^{2+}-Mg^{2+}-SO_4^{2-}-Cl^-	14.08	0.05	0.15	0.20	14.16	-1.38
	Benin	AK-BAY-RIV	Na^+-Cl^-	3.81	3.10	0.38	7.80	53.91	-12.72
Saline groundwater	Markurdi Sandstone	BNE-2	Na^+-Cl^-				73.77	91.38	-18.77
	Awe	BNE-3	Na^+-Cl^-				58.88	92.38	-4.62
	Asu River	CR-EBY	Na^+-Mg^{2+}-Cl^-				88.40	84.82	-73.91
WHO (1993)				10	0.3	0.1			

correlation at 95% confidence limit with Na^+, K^+, Ca^{2+}, Mg^{+2+}, Cl^- and SO_4^{+2-}. These correlations indicate that the ions are derived from the same source. The high positive correlation between Na^+-Cl^-, may represent influence of saline water. The high positive correlation between Na^+-Ca^{2+}, Mg^{2+}-SO_4^{+2-} and Ca^{2+}-SO_4^{+2-} may represent ion exchange and gypsum dissolution and the relation between Ca^{2+}-HCO_3^- and Ca^{2+}-Na^+ may represent contributions from silicate and carbonate weathering. The correlation between K^+-NO_3^- may represent poor sanitation conditions including application of fertilizer.

Factor analysis

Factor analysis is a multivariate statistical method which yields the general relationship between measured chemical variables by showing multivariate patterns that may help to classify the original data. The geological interpretation of factors gives an insight into the main processes, which may govern the distribution of hydrochemical variables. Factor analysis can identify several pollution factors reasonably but the interpretation of these factors in terms of

Table 6. Overview of physicochemical and quality characteristics of groundwater for some basins in Nigeria.

Basin	pH	SEC (µS/cm)	TDS (mg/l)	Na^+ (mg/l)	K^+ (mg/l)	Ca^{2+} (mg/l)	Mg^{2+} (mg/l)	Cl^- (mg/l)	HCO_3^- (mg/l)	SO_4^{2-} (mg/l)	NO_3^- (mg/l)	Fe (mg/l)	Mn (mg/l)	TH (mg/l)	SAR	Na (%)	RSC
Niger Delta	5.89	136.27	87.93	10.77	3.05	6.24	3.35	23.67	32.23	8.04	4.73	2.41	0.10	29.39	1.18	48.00	-0.09
Benin	6.21	128.03	29.86	22.45	4.93	19.33	18.35	21.86	50.84	6.56	11.84	1.23	0.00	124.76	1.54	40.76	-1.66
Benue Basin	5.89	338.11	203.15	29.18	7.59	23.03	15.02	43.47	89.57	33.70	13.12	2.36	0.21	119.75	1.29	31.49	-0.96
Sokoto Basin	6.53	411.95	215.19	17.25	83.31	43.57	11.80	16.15	110.18	28.70	58.78	0.00	0.04	158.09	0.78	26.97	-1.36
Basement Complex	6.23	244.00	171.01	14.89	5.61	23.42	6.31	12.88	84.62	25.49	14.53	0.25	0.07	84.86	0.72	33.31	-0.31
Saline groundwater and coastal aquifer	6.79	24479.6	15717.8	5386.0	170.8	485.8	104.4	9111.8	334.5	77.8	0.95	0.78	0.09	1649.53	57.21	80.62	-27.51
WHO (1993)	6.5-8.5	1400.00	1000.00	250	10	200	100	250		400	10	0.3	0.1	< 75			
Freshwater				30.00	3.00	50.00	7.00	20.00	52.00	8.30							

Table 7. Correlation matrix between major ions.

	EC	TDS	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	HCO_3^-	SO_4^{2-}	NO_3^-
EC	1.000									
TDS	0.997	1.000								
Na^+	0.983	0.979	1.000							
K^+	0.266	0.252	0.249	1.000						
Ca^{2+}	0.875	0.870	0.833	0.266	1.000					
Mg^{2+}	0.946	0.941	0.952	0.230	0.912	1.000				
Cl^-	0.990	0.984	0.983	0.217	0.838	0.925	1.000			
HCO_3^-	0.456	0.489	0.439	0.052	0.633	0.579	0.361	1.000		
SO_4^{2-}	0.692	0.697	0.713	0.182	0.733	0.794	0.640	0.628	1.000	
NO_3^-	-0.110	-0.131	-0.103	0.662	0.073	-0.036	-0.195	0.238	0.171	1.000

actual controlling sources and processes is highly subjective (Matalas and Reiher, 1967; Bahar and Reza, 2010).

R-mode factor analysis on the combined data sets provided two factors with eigenvalue > 1 that can explain approximately 83.57% of the variability of the data (Table 8). Factor 1 has an eigenvalue of 6.644 and explains 66.44% of the total variance and shows high loadings on EC, TDS, Na^+, K^+, Ca^{2+}, Mg^{+2+}, Cl^-, HCO_3^- and SO_4^{2-}.

The high loading for EC, TDS, Na^+ and Cl^- indicates high salinity due to saline water influence.

The Na^+, Ca^{2+} and Mg^{2+} and SO_4^{2-} may reflect the contributions of other hydrochemical processes (ion exchange, gypsum dissolution, silicate and carbonate weathering). Factor 2 has an eigenvalue of 1.71 and explains 17.14% of the total variance with high loading on K^+ and NO_3^-. This reveals pollution sources attributed to the poor sanitation and application of fertilizer.

Cross plots

The Na-Cl relationship has often been used to identify mechanisms for acquiring salinity and saline intrusions (Dixon and Chiswell, 1992; Garcia et al., 2001). In addition, the simultaneous enrichment in both ions indicates dissolution of

Table 8. Varimax factor loading.

Parameter	Factor	
	1	2
EC	0.982	0.005
TDS	0.983	-0.007
Na^+	0.974	0.000
K^+	0.191	0.814
Ca^{2+}	0.914	0.180
Mg^{2+}	0.979	0.074
Cl^-	0.965	-0.086
HCO_3^-	0.565	0.301
SO_4^{2-}	0.780	0.251
NO_3^-	-0.115	0.958
Eigen value	6.64	1.71
% Total variance	66.44	17.14
Cumulative Eigen value	6.64	8.36
Cumulative % total variance	66.44	83.57

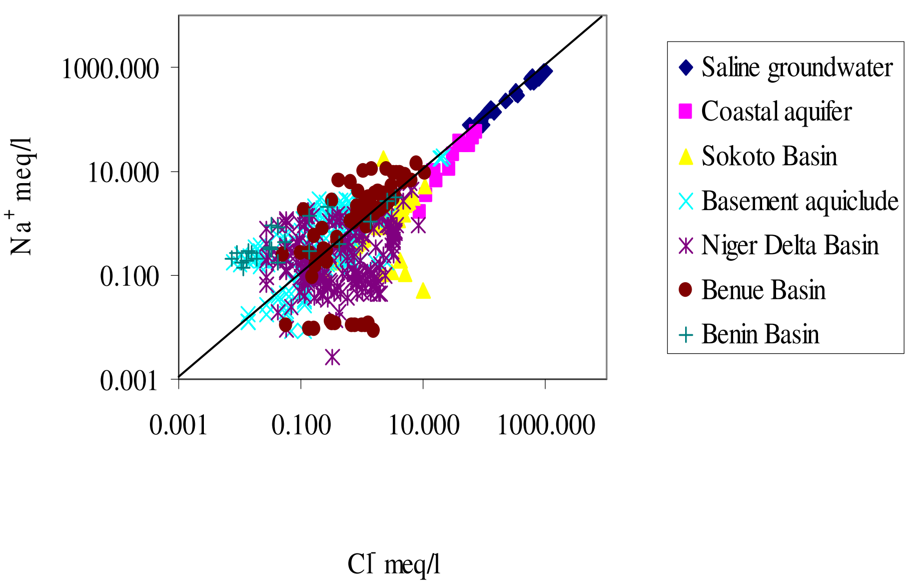

Figure 3. Plot of Na^+ versus Cl^- based on data from literature for the different basins.

chloride salts or concentration by evaporation process (Jalali, 2005). This is responsible for the relatively high Na^+ and Cl^- contents in the saline groundwater and coastal groundwater in the Benue Basin and coastal aquifers. Figure 3 shows the plot of Na^+ as a function of Cl^- based on data from literature. The dissolution of halite in groundwater releases equal concentration of Na and Cl in the solution due to dissolution of salt horizons (Uma, 1998; Uma et al., 1990; Ekwere and Ukpong, 1994; Tijani et al., 1996; Tijani, 2008) and coastal groundwater affected by sea water intrusion (Amadi et al., 1989; Edet and Okereke, 2001a, b; Frank-Briggs, 2005; Edet, 2008c, 2009, 2010; Edet et al., 2011).

The plot of Na-Cl (Figure 3) also show that some samples deviate from the expected 1:1 relation indicating that a fraction of Na is associated with another anion. A Na^+/Cl^- ratio greater than 1 reflects Na^+ released from silicate weathering reaction (Meybeck, 1987). Silicate weathering is the probable source for Na^+ in groundwater in parts of Niger Delta Basin, Benin Basin, Benue Basin and the Basement Complex. In Sokoto Basin, the ratio of $Na^+/Cl^- < 1$ meaning another source is contributing chloride to the groundwater. Generally water containing significant amount of chloride whose drainage has few salty rocks or evaporate as in Sokoto Basin, is considered to be derived from the atmosphere (Al-

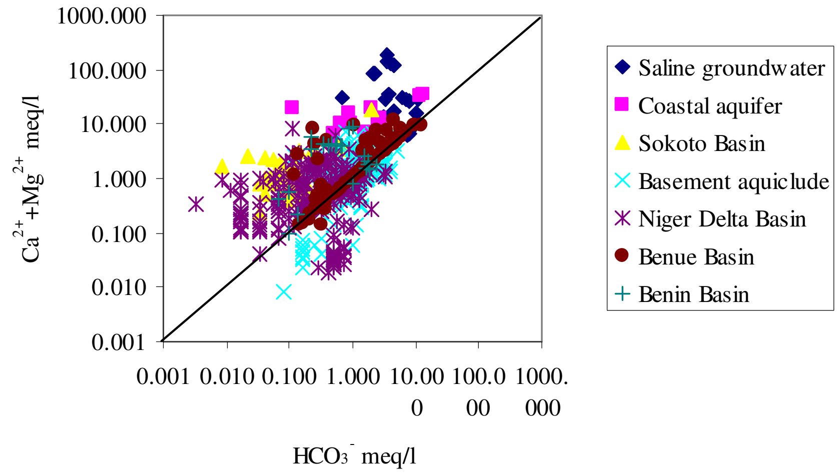

Figure 4. Plot of $Ca^{2+}+Mg^{2+}$ versus HCO_3^- based on data from literature for the different basins.

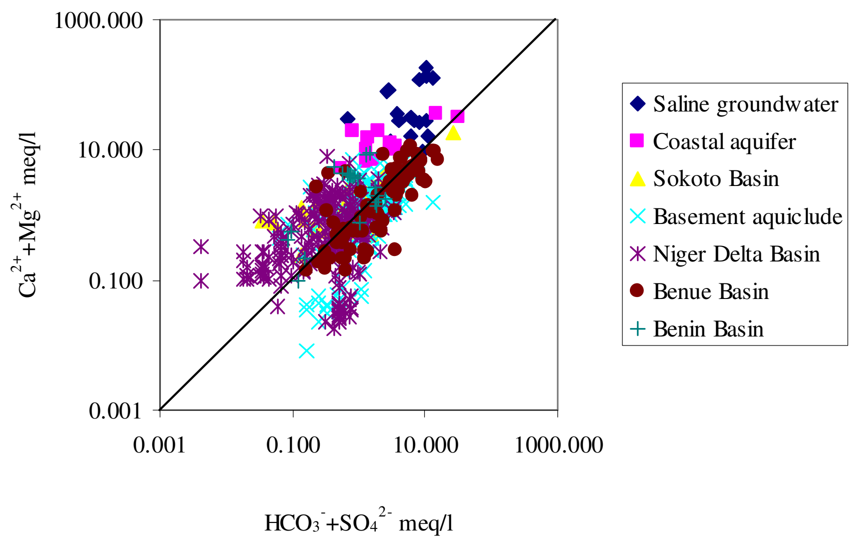

Figure 5. Plot of $Ca^{2+}+Mg^{2+}$ versus $HCO_3^-+SO_4^{2-}$ based on data from literature for the different basins.

Mikhlafi et al., 2003).

The $Ca^{2+}+Mg^{2+}/HCO_3^-$ ratio marks the upper limit of bicarbonate input from weathering of carbonate rock (Stallard and Edmond, 1983). In Nigeria, most basins show excess of $Ca^{2+}+Mg^{2+}$ over HCO_3^- indicating some extra source of Ca^{2+} and Mg^{2+}. However, $Ca^{2+}+Mg^{2+}$ was less than HCO_3^- (Figure 4), due to other sources contributing extra HCO_3^- in parts of Niger Delta Basin and the Basement Complex.

In Figure 5, a plot of $Ca^{2+}+Mg^{2+}$ versus $HCO_3^-+SO_4^{2-}$ shows that for the Niger Delta Basin, Benin Basin, Sokoto Basin Basement Complex, saline groundwater and coastal groundwater, most of the data points are above the 1:1 equiline. Further a plot of $Ca^{2+}+Mg^{2+}$ versus total cations (TC), Figure 6 shows that the plotted points for all the basins fall below the equiline reflecting an increasing contribution of Na^+ and K^+. From the above, it is clear that the groundwater chemistry is likely to be from dissolution of silicate and carbonate minerals. Thus the concentrations of major elements is controlled by the congruent weathering of carbonate and incongruent weathering of silicates (Garrels and Mackenzie, 1971; Stumm, 1992; Zhang et al., 1995; Al-Mikhlafi, 2003; Garcia et al., 2001; Jalali, 2005).

The ion exchange process is characterized by an $(HCO^-_3+ SO_4^{2-})$ excess over $(Ca^{2+}+Mg^2)$, while the reverse ion exchange is marked by an excess of $(Ca^{2+}+Mg^2)$ over $(HCO^{3-}+SO_4^{2-})$ (Cerling et al., 1989;

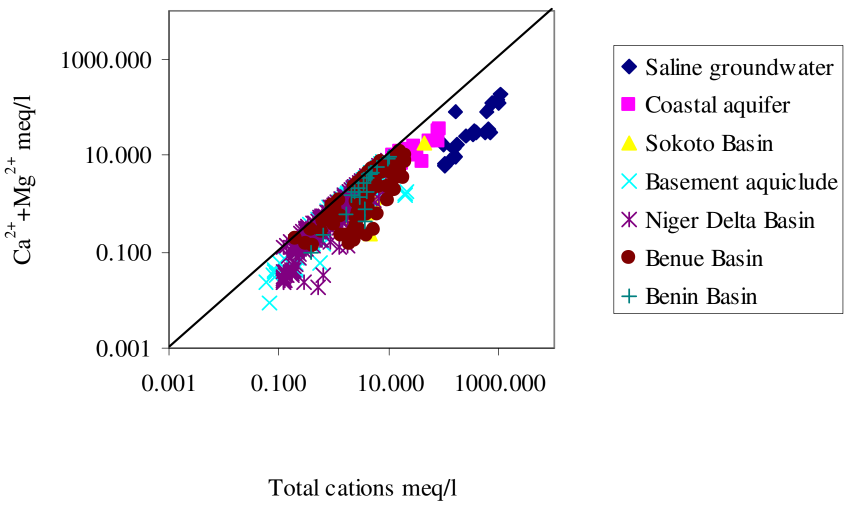

Figure 6. Plot of Ca^{2+}+Mg^{2+} versus total cation HCO_3^-+SO_4^{2-} based on data from literature for the different basins.

Fisher and Mulican, 1997). The ratio, (Ca^{2+}+Mg^{2})/(HCO^{3-} + SO_4^{2-}) > 1, in Niger Delta Basin, Benin Basin, Sokoto Basin, parts of the Basement Complex and saline groundwater indicating a reverse ion exchange process. However, for Benue Basin and parts of the Basement Complex, the ratio (Ca^{2+}+Mg^{2})/(HCO^{3-}+ SO_4^{2-}) < 1, indicating an ion exchange process. The significance here is that two processes, ion exchange and reverse ion exchange are simultaneously contributing to the water chemistry in the basement complex.

GROUNDWATER QUALITY

Here we focus on special areas of groundwater pollution due to natural and anthropogenic sources. The saline groundwater noted above from Benue and Cross River states are unacceptable for domestic uses with concentrations of indicators parameters exceeding national and international standards (Table 2). Water from the other basins is acidic, fresh and soft. High concentrations of potassium were recorded in Sokoto Basin. In some basins including Sokoto, Benue, Benin and the Basement complex, elevated levels of nitrate were recorded from some wells and boreholes.

Iron and Manganese

The occurrence of high iron and manganese in groundwater of some aquifers in Nigeria has been reported (Longe et al., 1987; Ajayi and Obot, 1998; Oteze, 1991; Edet, 1993; Amadi et al., 1989; Abimbola et al., 2002; Awalla and Ezeigbo, 2002; Ibe Sr and Sowa, 2002; Tijani et al., 2002; Udom et al., 2002; Akujieze et al., 2003; Edet et al., 2003; BGS, 2003; Olobaniyi and Owoyemi, 2004; Ozoko, 2004; Olatunji et al., 2005; Alagbe, 2006; Udom and Amah, 2006; Olobaniyi and Efe, 2007; Olobaniyi et al., 2007; Adebo and Adetoyinbo, 2009; Nganje et al., 2010). Concentrations of Fe up to 3.10 mg/l were reported for the coastal parts of the Niger Delta Basin (Edet, 1993; Ajayi and Obot, 1998; Amadi et al., 1989; Udom et al., 1999; Olobaniyi et al., 2001; Frank-Briggs, 2003; Edet et al., 2009; Ukandu, 2009). Fe concentrations up to 2.43 mg/l were found in the groundwater of Abeokuta aquifer (Ogunbanjo, 2004). Some workers found average concentrations of Fe and Mn in the range 0.18 to 0.29 mg/l and 0.35 to 0.58 mg/l for the Benue Basin (Awalla and Ezeigbo, 2002; Onwuka et al., 2004; Ozoko, 2004; Tijani, 2003). Fe concentrations of up to 12.01 mg/l were reported for the Benin Aquifer around Lagos State (Longe et al., 1987). Generally, for the Benin Aquifer, iron concentration range from 0.1 to 2.54 mg/l while manganese varies from 0.07 to 0.18 mg/l (Ajayi, 1998; Etu-Efeotor, 1998a, b; Bala and Onugba, 2001; Alagbe, 2002; Abimbola et al., 2002; Ogunbajo and Kolajo, 2003; Edet and Okereke, 2005; Onugba and Eduvie, 2005; Boboye, 2008; Ekwere, 2011). The maximum values observed for both elements in these aquifers are well over the WHO (1993) guideline values of 0.30 and 0.10 mg/l for Fe and Mn respectively.

Nitrate pollution

Elevated concentration (> 5 mg/l) of nitrate in waters is an indication that the waters are at the risk of pollution (McNeely et al., 1979; Sahinci, 1991; Atabey, 2005a, b). The levels of nitrate in waters are of particular importance for use in drinking water. Studies have shown that high nitrate in water can lead to ‘blue disease’ (methemoglobinaemia) in babies (Lahl et al., 1983; WHO, 1984), cancer (WHO, 1984, Uslu and Turkman, 1987), urinary tract diseases (Pontius, 1993, Wasik et al., 2001, Polat et al., 2007). Groundwater with nitrate pollution (> 10 mg/l) is noted for Benin Aquifer (Niger Delta Basin). The mean value of 27.27 mg/l is documented for Cross River State while the concentrations generally less than 10 mg/l characterizes Abia, Akwa Ibom, Bayelsa, Delta and Lagos and the Ogwashi/Asaba aquifer in Imo State.

High nitrate concentrations have been recorded within the different groundwater basins. For instance, the average nitrate value was as high as 58.78 mg/L for Sokoto Basin (Table 8). The average concentrations for the other basins were respectively, 4.73, 11.84, 13.12 and 14.53 mg/L for the Niger Delta, Benin, Benue Basins and the Basement complex. These values were however, not very high relative to the WHO (1993, 2006) standard of 10 mg/l for domestic purpose.

The elevated nitrate values were attributable to land use practices especially, in Sokoto Basin (Uma, 1993). Other factors responsible for high nitrate concentrations in other basins include soil leaching and nitrogenous organic waste (Ozoko, 2004), poor well completion (Edet and Okereke, 2005), improper waste disposal, handling and applications of organic and inorganic fertilizers (Alagbe
2006),

Agricultural applications

In respect of agricultural uses, groundwaters from the different basins are of low salinity and low alkalinity hazard. This indicates the usability of these waters for irrigation in most soil and crops with little danger of development of exchangeable sodium and salinity. Considering sodium percentage (%Na), the groundwater of the different basins suggest good to excellent quality and can be used for irrigation purposes (Richards, 1954).

Based on the classification of United States Department of Agriculture's Salinity using electrical conductivity and sodium adsorption ratio, SAR (Lloyd and Heathcote, 1985), the water of the Niger Delta and Benin Basins belong to the low salinity hazard-low sodium hazard (C_1-S_1) class. The SAR data for Benue Basin, Sokoto Basin and the Basement Complex fall in the C_2-S_1 class. This represents a medium salinity hazard-low sodium hazard. The saline groundwater and coastal aquifers water fall into very high salinity hazard-very high sodium hazard. The residual sodium carbonate, RSC (Ragunath, 1987) values (Table 5) indicates that the waters are suitable as irrigation water (RSC < 1.25, Eaton, 1950). Generally, the saline groundwater and coastal aquifers are not suitable for agricultural and irrigation purposes.

CONCLUSION

The review considered published data on groundwater chemistry and quality in Nigeria for some basins including the Crystalline Basement complex, Sokoto, Niger Delta, Benin and Benue Basins. In addition, data for saline and coastal groundwater were also considered. Groundwaters in these basins are acidic, fresh and generally hard. Excluding the saline groundwater, the average concentrations of sodium, calcium, magnesium, potassium, chloride and sulphate for the different basins are generally within the limits stipulated by WHO (1993) for domestic purposes. However, the average concentration of potassium is high in the Sokoto Basin. The most mineralized groundwater is found from the saline and coastal groundwater in Benue and Niger Delta Basins, while the least mineralized is the groundwater in Benin Basin. The geology is the principal factor controlling the chemistry of groundwater in term of the water types and the processes. The main processes include chloride dissolution for saline and coastal groundwater aquifers and a combination of silicate, carbonate weathering and ion exchange for the different aquifers in the various basins and the basement complex areas.

High concentrations of iron and manganese characterize all the basins. Nitrate level is high in the entire basin with the exception of the Niger Delta Basin indicating input from anthropogenic sources. In respect of agricultural uses, groundwaters from the different basins are of low salinity and low alkalinity hazard, good to excellent quality for irrigation on the basis of %Na, SAR and RSC. This thus indicates the usability of these waters for irrigation in most soil and crops with little danger of development of exchangeable sodium and salinity. However, the saline groundwater in the Benue and Niger Delta Basins are not suitable for agricultural and irrigation purposes.

In Benue and Niger Delta Basins where saline groundwater are present, all the parameters exceed the stipulated standards for drinking, domestic and agricultural purposes.

ACKNOWLEDGEMENTS

Authors thank Alexander von Humboldt, Bonn (Germany) for providing fellowship to the first author to Germany where part of this work was done. H. Madkour and two anonymous reviewers are acknowledged for their suggestions.

REFERENCES

Abimbola AF, Odukoya AM, Olatunji AS (2002a). Influence of bedrock on the hydrogeochemical characteristics of groundwater in northern part of Ibadan Metropolis, SW Nigeria. Water Resour. J., 13: 2-6.

Abimbola AF, Oke SA, Olatunji AS (2002b). Environmental impact assessment of waste dumpsites on geochemical quality of water and soils in Warri Metropolis, southern Nigeria. Water Resour. J., 13: 7-11.

Abulude FO, Obidiran GO, Orungbemi S (2007). Determination of

physicochemical parameter and trace metal contents of drinking water samples in Akure. EJEAFChe, 6(8): 2297-2303.
Adebo BA, Adetoyinbo AA (2009). Assessment of groundwater quality in unconsolidated sedimentary coastal aquifer in Lagos State, Nigeria. Sci. Res. Essay, 4(4): 314-319.
Adediji A, Ajibade LT (2005). Quality of well water in Ede Area, southwestern Nigeria. J. Hum. Ecol., 17(3): 223-228.
Adekunle IM, Adetunji MT, Gbadebo AM, Banjoko OB (2007). Assessment of groundwater quality in a typical rural settlement in southwest Nigeia. Int. J. Environ. Res. Public Health, 4(4): 307-318.
Adelana SMA, Olasehinde PI, Vrbka P (2003). Isotope and geochemical characterization of surface and subsurface waters in the semi-arid Sokoto Basin, Nigeria. Afric. J. Sci. Tech., (AJST), 4(2): 80-89.
Adelana SMA, Olasehinde PI, Bale RB, Vrbka P, Edet AE, Goni IB (2008). An Overview of geology and hydrogeology of Nigera. In Applied groundwater studies in Africa (Eds Adelana S, MacDonald A) IAH Selected papers on Hydrogeol., 13: 171-198.
Ahiarakwem CA, Ejimadu OG (2002). Geochemical properties of groundwater in Orlu area of Imo State, Southeastern Nigeria. Water Res., 13: 19-22.
Ajayi CO, Hassan M (1990). The delineation of the aquifer overlying the basement complex in western part of the Kubanni Basin of Zaria (Nigeria). J. Min. Geol., 26 (1): 117-125.
Ajayi O (1998). Quality of groundwater in the Agbabu oil sands area of the Ondo State, Nigeria. J. African Earth Sci., 27(2): 299-305.
Ajayi O, Obot AU (1998). Quality of groundwater in the Coastal Plain sands Aquifer of the Akwa Ibom State, Nig. J. Afr. Earth Sci., 27(2): 259-275.
Akujieze CN, Coker, SJL, Oteze, GE (2003). Groundwater in Nigeria-a millennium experience, distribution, practice, problems and solutions. Hydrogeol. J., 11: 259-274.
Alagbe SA (2002). Groundwater resources of river Kan Gimi Basin, north-central Nigeria. Environ. Geol., 42: 404-413.
Alagbe SA (2006). Preliminary evaluation of hydrochemistry of the Kalambaina Formation, Sokoto Basin, Nigeria. Environ. Geol., 51: 39-45.
Al-Mikhlafi AS, Das BK, Kaur P (2003) Water chemistry of Mansar Lake (India): an indication of source area weathering and seasonal variability Environ. Geol., 44(6): 645-653,
Amadi PA, Ofoegbu CO, Morrison T (1989). Hydrogeochemical assessment of groundwater quality in parts of the Niger delta, Nigeria. Environ. Geol., 14(3): 195-202.
Amadi AN, Olasehinde PI, Yisa J (2010). Characterization of groundwater chemistry in the coastal plain-sand aquifer of Owerri using factor analysis. Int. J. Phy. Sci., 5(8): 1306-1314.
Awalla CO, Ezeigbo HI (2002). An appraisal of water quality in the Uburu-Okposi area, Ebonyi State, southeastern Nigeria. Water Resour., 13: 33-39.
Atabey E (2005a). Tıbbi Jeoloji (medical geology). In: Atabey E (ed) Publications of chamber of geology engineers of Turkey. TMMOB, Ankara.
Atabey E (2005b). Tıbbi Jeoloji Sempozyum kitabı (11th medical geology symposium book) In: Atabey E (ed).1–3 Aralık 2005, Ankara, pp. 27–52.
Babatunde AI, Okolue IM, Oyelola OT, Odunlade AK (2009). Pollution of groundwater through surface input from domestic, agricultural and industrial sources in Festac Town, Lagos, Nigeria. Int. J. P. Appl. Sci., 3(2): 49-59.
Bahar MM, Reza MS (2010). Hydrochemical characteristics and quality assessment of shallow groundwater in a coastal area of southwest Bangladesh. Environmental Earth Sci., 61: 1065-1073.
Boboye OA (2008). Hydrogeochemical assessment of groundwater in Iddo area, southwestern Nigeria. J. Min. Geol., 44(2): 183-201.
Bolaji TA (2009). Hydrogeochemistry and quality index of groundwater in Port Harcourt, Nigeria. M.Sc Thesis, University of Port Harcourt, Nigeria. p. 36.
British Geological Survey (BGS) (2003). Groundwater Quality: Nigeria, p. 8.
Cerling TE, Pedrson BL, Damm KLV (1989). Sodium-calcium ion exchange in weathering of shales. Implications for global weathering budgets. Geology, 17: 552-554.
Chukwu GU (2008a). Water quality assessment of boreholes in Umuahia South Local Government Area of Abia State, Nigeria. The Pacific J. Sci. Tech., 9(2): 592-598.
Chukwu O (2008b). Analysis of groundwater pollution from abattoir waste in Minna, Nigeria. Res. J. Appl. Sci., 2(4): 74-77.
Dixon W, Chiwell B (1992). The use of hydrochemical sections to identify recharge areas and saline intrusions in alluvial aquifers, Southeast Queensland, Australia. J. Hydrol., 135: 259-274.
Eaton FM (1950) Significance of carbonates in irrigation waters. Soil Sci., 39: 123-133.
Edet AE (1992). Hydrogeology of parts of Cross River State, Nigeria: Evidence from Aero-Geological and Surface Resistivity Studies. PhD Dissertation, University of Calabar, Calabar, Nigeria, p. 316.
Edet AE (1993). Groundwater quality assessment in parts of eastern Niger delta, Nigeria. Environ. Geol., 22: 41-46.
Edet AE, Okereke CS (1997). Assessment of hydrogeological conditions in basement aquifers of Precambrian Oban massif, southeastern Nigeria. J. Appl. Geophy., 36: 195-204.
Edet AE, Okereke CS, Teme SC, Esu EO (1998). Application of remote sensing data to groundwater exploration: A case study of Cross River State, southeastern Nigeria. Hydrogeol. J., 6: 394-404.
Edet AE, Okereke CS (2001a). Monitoring seawater intrusion in the Tertiary-Quaternary aquifer system-Baseline data Online proceedings of the first International Conference on Saltwater Intrusion and Coastal Aquifers, Monitoring, Modelling and Management, Essaouira, Morroco.
Edet AE, Okereke CS (2001b). A regional study of saltwater intrusion in southeastern Nigeria based on analysis of geoelectrical and hydrochemical data. Environ. Geol., 40(10): 1278-1289.
Edet AE, Okereke CS (2002). Delineation of shallow groundwater aquifers in the coastal plain sands of Calabar area (southern Nigeria) using surface resistivity and hydrogeological data. J. Afr. Earth Sci., 35: 433-443.
Edet AE, Merkel BJ, Offiong OE (2003). Trace element hydrochemical assessment of the Calabar Coastal Plain Sands, southeastern Nigeria using statistical methods Environ. Geol., 44: 137-149.
Edet AE (2004). A Preliminary assessment of rare earth elements concentrations in an acidic fresh groundwater (Southeastern Nigeria). Appl. Earth Sci., (Trans. Inst. Min. Metall. B), 113: 100-109.
Edet AE, Okereke CS (2005). Hydrogeological and hydrochemical character of the regolith aquifer, northern Obudu Plateau, southern Nigeria. Hydrogeol. J. 13(2): 391-415.
Edet A (2008). Hydrogeochemical characteristics of groundwater in the inparts of the Niger Delta. In Proceedings 1st Postgraduate Researchers Conference on Meeting Environmental Challenges in the Coastal Regions of Nigeria 29-30 September 2008. University of Abertay Dundee, United Kingdom.
Edet AE, Ekpo BO (2008). Hydrogeochemistry of a fractured aquifer in the Ogoja/Obudu area of SE Nigeria In Applied groundwater studies in Africa (Eds Adelana S, MacDonald A) IAH Selected papers on Hydrogeol., 13:391-403.
Edet AE (2009) Characterization of groundwater contamination using factor analysis in the Niger Delta (Nigeria). J. Hydrol. Eng., 14(11): 1255-1261.
Edet A, Worden R (2009) Monitoring of Physical parameters and evaluation of the chemical composition of river and groundwater in Calabar (Southeastern Nigeria). Environ. Monitor. Assessment, 157: 243-258.
Edet AE (2010). The development of a groundwater quality index for the Niger delta region, Nigeria. In Proceedings XXXVIII IAH Congress on Groundwater Quality Sustainability, 12-17 September, 2010, AGH University of Science and Technology, Krakow, Poland.
Edet AE, Worden RH, Mohammed EA, Preston MR (2011). Hydrogeochemical processes in a populated shallow Coastal Plain Sand Aquifer southeastern Nigeria Environmental Earth Sciences DOI 10.1007/s12665-011-1175-9. 21pp
Efe SI, Ogban FE, Horsfall M, Akporhonor EE (2005). Seasonal variations of physico-chemical characteristics in water resources quality in western Niger Delta region, Nigeria. J. appl. Sci. Environ. Mgt. 9(1): 191-195.
Ejechi BO, Olobaniyi SB, Ogban FE, Ugbe EC (2007). Physical and sanitary quality of hand-dug well water from oil-producing area, Nigeria. Eniviron. Monit. Assess. 128: 495-501.

Ekwere A (2011). Hydrogeological and Hydrogeochemical framework of the Oban massif, Southeastern Nigeria. PhD Dissertation University of Calabar, Calabar, Nigeria, p. 178.
Ekwere SJ, Ukpong EE (1994) Geochemistry of saline water in Ogoja, Cross River State of Nigeria. J. Min. Geol., 30(1): 11-15.
Erah PO, Akujieze CN, Oteze GE (2002). The quality of groundwater in Benin City: A baseline study on inorganic chemicals and microbial contaminants of health importance in boreholes and open wells. Trop. J. Pharma. Res., 1(2): 75-82.
Etu-Efeotor JO (1998a). Water resources potential of the Gwagwalada area of Abuja Federal Capital Territory (Central Nigeria) Global J. Pure Appl. Sci., 4(1): 43- 52.
Etu-Efeotor JO (1998b). Hydrochemical analysis of surface and groundwaters of Gwagwalada area of Central Nigeria, Global J. Pure Appl. Sci., 4(2): 153-162.
Ezeigbo HI (1987). Quality of water resources in Anambra State. Nigeria. Nig. J. Min. Geol., 23(1 - 2): 97-103.
Ezeigbo HI, Ezeanyim BN (2006). Environmental pollution from coal mining activities in the Enugu Area, Anambra State, Nigeria. Mine Water Environ., 12: 53-62.
Fisher RS, Mulican WF (1997). Hydrochemical evolution of sodium-suphate and sodium-chloride groundwater beneath the Northern Chihuahua desert. Trans-Pecos, Texas, USA. Hydrogeol. J., 5(2): 4-16.
Frank-Briggs IB (2003). The hydrogeology of some island towns in eastern Niger Delta, Nigeria. PhD Thesis, University of Port Harcourt, Port Harcourt, Nigeria. p. 283.
Freeze RA, Cherry JA (1979). Groundwater. 2nd edn. Prentice Hall, Eaglewood, Cliff, New Jersey, USA, p. 604.
Garcia MG, Hidalgo MV, Blesa MA (2001). Geochemistry of groundwater in alluvial plain of Tucuman province, Argentina. Hydrogeol., J., 9 :597-610.
Garrels RM, Mckenzie FT (1971) Evolution of sedimentary rocks. Norton, New York.
Goni IB (2006). Tracing stable isotope values from meteoric water to groundwater in southwestern part of the Chad basin. Hydrogeol. J., 14: 742-752.
Ibe Sr, KM, Sowa AHO (2002). Hydrology of part of the Oramiriukwa River basin, southeast of Owerri, Imo State, Nigeria. Hydrogeol. J., 10: 509-521.
Iloeje NP, (1981). A New Geography of Nigeria. Longman, Nigeria, p. 201.
Jalali M (2005). Major ion chemistry of groundwaters in the Bahar area, Hamadan, western Iran. Environ. Geol., 47: 763-772.
Jatau BS, Bajeh I (2007). Hydrogeological appraisal of parts of Jema Local Government, North Central Kaduna State, Nigeria. Res. J. Appl. Sci., 2(11): 1174-1181.
Lahl U, Zeschmar B, Gabel B, Kozicki R, Podbielski A, Stachel B, Strauss S (1983). Ground-water pollution by nitrate: groundwater in water resources planning, Proceeding, International Association of Hydrological Sciences (IAHS) publication, 142: 1159–1168.
Lloyd JW, Heathcote JA (1985). Natural inorganic hydrochemistry in relation to groundwater: An introduction. Clarendon Press, Oxford, pp. 248-249.
Longe EO, Malomo S, Olorunnwo MA (1987). Hydrogeology of Lagos metropolis. J. Afr. Earth Sci., 6(2): 163-174.
Matalas CN, Reiher JB (1967). Some comments on the use of factor analysis. Water Res., 3: 213-223.
McNeely RN, Neimanis VP, Dwyer L (1979). Water quality sourcebook: A guide to water quality parameters. Indland Waters Directorate, Water Quality Branch, Ottawa.
Meybeck M (1987). Global chemical weathering of surficial rocks estimated from river dissolved loads. Am. J. Sci., 287: 401-428.
Nganje TN, Adamu CI, Ugbaja AN, Amah AE (2010a). Evaluation of hydrogeochemical characteristics of groundwater in parts of Lower Benue Trough, Nigeria. Chin. J. Geochem., 29: 398-406.
Nganje TN, Adamu CI, Ntekim EEU, Ugbaja AN, Neji P, Nfor EN (2010b). Influence of mine drainage on water quality along River Nyaba in Enugu, southeastern Nigeria. Afri. J. Environ., Sci. Tech., 4(3): 132-144.
Nganje TN, Adamu CI, Ugbaja AN, Ebieme E, Sikakwe GU (2011). Environmental contamination of trace elements in the vicinity of Okpara coal mine, Enugu, southeastern Nigeria. Arab. J. Geosci., 4: 199-205.
Ofoma AE, Omologbe DA, Aigberua P (2005). Physico-chemical quality of groundwater in parts of Port Harcourt City, eastern Niger Delta, Nigeria. Water Res., 16: 18-24.
Offiong OE, Edet AE (1998a). Water quality assessment in Akpabuyo, Cross River basin, southeastern Nigeria. Environ. Geol., 34(2/3): 167-174.
Offiong OE, Edet AE (1998b) Surface water quality evaluation in Odukpani, Calabar Flank, southeastern Nigeria Environ. Geol., 36 (3/4): 343-348.
Offodile ME (1992). An Approach to groundwater study in Nigeria. Mecon Services Ltd., Jos, Nigeria, p. 247.
Ogbukagu IKN, Akujieze CN (1990). The hydrogeology of the Lower Horizon of Nanka Sands, Anambra Basin, Southern Benue Trough in the The Evolution of the Benue Trough (Eds COfoegbu), 93-114.
Ogunbanjo MI (2004). The geochemical evolution of water resources in and around Ijebu-Ode Town, southwestern Nigeria and its environmental implications. Water Res., 15: 20-25.
Ogunbanjo MI, Kolajo OA (2004). The impact of solid waste disposal on the chemical quality of surface and subsurface water sources in parts of Ibadan metropolis, southwestern Nigeria. Water Resour., 15: 26-32
Okeke OC, Igboanua AH (2003). Characteristics and quality assessment of surface and groundwater resources of Awka Town, SE Nigeria. Water Resour., 14 : 71-77.
Okereke CS, Esu EO, Edet AE (1998). Determination of potential groundwater sites using geological and geophysical techniques in the Cross River State, southern Nigeria. J. Afr. Earth Sci., 27(1): 149-163.
Olarewaju VO, Olorunfemi MO, Alade O (1997). Chemical characteristics of groundwater from some parts of the basement complex of central Nigeria. J. Min. Geol., 33(2): 135-135.
Olatunji AS, Abimbola AF, Oloruntola MO, Odewade AA (2005). Hydrogeochemical evaluation of groundwater resources in shallow coastal aquifer around Ikorodu area, southwestern Nigeria. Water Resour., 16: 65-71.
Olobaniyi SOB, Owoyemi FB (2004). Quality of groundwater in the Deltaic Plain Sands aquifer of Warri and environs, Delta State, Nigeria. Water Resour., 15:38-44.
Olobaniyi SOB, Owoyemi FB (2006). Characterization by factor analysis of the chemical facies of groundwater in the Deltaic Plain sands Aquifer of Warri, Western Niger Delta, Nigeria. Afr. J. Sci. Tech. (AJST), 7: 73-81.
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.
Olobaniyi SB, Ogala JE, Nfor NB (2007) Hydrogeochemical and bacteriology investigation of groundwater in Agbor area, southern Nigeria, J. Min. Geol., 43(1): 79-89.
Olorunfemi MO (1990). The hydrogeological implication of topographic variation with overburden thickness in basement area of S.W. Nigeria. J. Min. Geol., 26(1): 145-152.
Olufemi AG, Utieyin OO, Adebayo OM (2010). Assessment of groundwater quality and saline intrusions in coastal aquifers of Lagos metropolis, Nigeria. J. Water Resour. Prot., 2: 849-853.
Omofonmwan SI, Eseigbe JO (2009). Effects of solid waste on the quality of underground water in Benin Metropolis, Nigeria. J. Hum. Ecol., 26(2): 99-105.
Omo-Irabor OO, Olobaniyi SB, Oduyemi K, Akunna J (2008). Surface and groundwater quality assessment using multivariate analytical methods: A case study of western Niger Delta, Nigeria. Phy. Chem. Earth, 33: 666-673.
Onugba A, Eduvie MO (2005). The hydrochemistry and environmental isotopes of the aquifer systems in the Upper Benue area, Nigeria Water Res. J., 16: 80-89.
Onwuka OS, Uma KO, Ezeigbo HI (2004). Potability of shallow groundwater in Enugu Town, Southeastern Nigeria. Global J. Environ. Sci., 3(1-2): 33-39.
Oteze GE (1991). Potability of groundwater from the Rima Group aquifers in the Sokoto Basin. J. Min. Geol., 27(1): 17-24.
Oteze GE (1993). Environmental Isotope Hydrology of the main Rima

Aquifer waters. J. Min. Geol., 25(1-2): 205-210.
Oyawoye MO (1970). The Basement complex of Nigeria. In: African Geology (Eds Dessauvagie TFG and Whiteman AJ) University of Ibadan Press, Ibadan, pp. 67-99.
Ozoko DC (2004). Geochemical and microbiological studies of the natural water systems in Agila, Benue State, Nigeria. Water Res., 15: 60-65.
Petters SW (1982). Central West African Cretaceous – Tertiary benthic Foraminifera and stratigraphy. Paloeontographica, A., 179: 1-104.
Polat R, Elc¸i AS¸ ims¸ek C, Gu¨ndu¨z O (2007). Seasonal assessment of the extent of nitrate contamination in ground water around Nif Mountain in Izmir. 7th national environmental engineering congress, live environment technology, 24–27 October 2007 Izmir, Turkey, pp. 482–489.
Pontius FW (1993). 'Nitrate and cancer: is there a link?' J. AWWA, 85(4): 12–14.
Ragunath HM (1987). Groundwater. Wiley Eastern Ltd, New Delhi, p. 563.
Richards LA (1954). Diagnosis and improvement of saline alkali soils. US Department of Agriculture, Handbook, 60: 160.
Rijswljk K (1981). Small community water supplies. IRT Technical Paper Series no. 18, Netherland.
Sahinci A (1991). Dog˘al Suların Jeokimyası (Geochemistry of natural waters). Reform Printing Office, Izmir.
Stallard RF, Edmond JM (1983). Geochemistry of the Amazon River. The influence of Geology and weathering environment on dissolved load. J. Geophy. Res., 88: 9671-9688.
Stumm W (1992). Chemistry of the solid-water interface. Wiley, New York.
Tekwa IJ, Abba MU, Ray HH (2006). An assessment of dug-well water quality and use in Mubi, Nigeria. J. Sus. Dev. Agric. Environ., 2(1): 1-5.
Tijani MN, Loehnert EP, Uma KO (1996). Origin of saline groundwaters in the Ogoja area, Lower Benue Basin, Nigeria. J. Afr. Earth Sci., 23(2): 237-252.
Tijani MN, Onibalusi SO, Olatunji AS (2002). Hydochemical and environmental impact assessment of Orita Aperin waste dumpsite, Ibadan, southwestern Nigeria. Water Res., 13: 78-84.
Tijani MN (2003). Bacteriological, chemical and lithologic controls on water quality in Sagamu area, southwestern Nigeria. Water Res., 14(2): 66-76.
Tijani MN (2008). Hydrochemical and stable isotopes compositions of saline groundwaters in the Benue Basin, Nigeria. In Applied groundwater studies in Africa (Eds Adelana S, MacDonald A) IAH Selected papers on Hydrogeol., 13: 352-369.
Udom GJ, Esu EO, Ekwere SJ (1998). Quality status of groundwater in Calabar Municipality, southeastern Nigeria. Global J. Pure Appl. Sci. 4(2): 163-168.
Udom GJ, Etu-efeotor JO, Esu EO (1999) Hydrochemical evaluation of groundwater in parts of Port Harcourt and Tai-Eleme Local Government Areas, Rivers State. Global J. Pure Appl. Sci., 5(5): 545-552.
Udom GJ, Ushie FA, Esu EO (2004). A geochemical survey of groundwater in Khana and Gokana Local Government Areas of Rivers State, Nigeria. J. Appl. Sci. Environ. Manage., 6(1): 53-59.
Udom GJ, Amah EA (2006). Quality status of groundwater in Yenegoa and its environs. J. Sci. Ind. Studies, 4(1): 45-49.
Ukandu JS (2009). Hydrochemical study of groundwater in Umuahia South Local Government Area of Abia State. M.Sc Thesis University of Port Harcourt, Nigeria, p. 50.
Uma KO (1993). Nitrates in shallow (regolith) aquifers around Sokoto Town, Nigeria. Environ. Geol., 21: 70-76.
Uma KO (1997). Salinization of shallow sandy coastal aquifers: A case study from parts of the Niger Delta region of Nigeria. IAHS, 247: 1-12.
Uma KO (1998). The brine fields of the Benue Basin, Nigeria: A comparative study of geomorphic, tectonic and hydrochemical properties. J. Afr. Earth Sci., 26(2): 261-275.
Uma KO, Onuoha KM (1990). Groundwater resources of the Lower Benue Trough, southern Nigeria. In The Evolution of the Benue Basin (Eds COfoegbu), pp.115-134.
Uma KO, Onuoha KM, Egboka CE (1990) Hydrochemical Facies, Groundwater Flow Pattern and Origin of Saline Waters in parts of the Western Flank of the Cross River Basin, Nigeria. In The Evolution of the Benue Basin (Eds COfoegbu), pp. 115-134.
United Nations Environmental Programme, UNEP (2011). Environmental assessment of Ogoniland. UNEP Publication. Executive Summary, p. 3.
Uslu O, Turkman A (1987). Water pollution and control. Publication series of Environment General Directorate of Prime Ministry of Turkish Republic 1: 251–265.
Wasik E, Bahdziewicz J, Blasszczyk M (2001). Removal of nitrates from groundwater by hybrid process of biological denitrification and microfiltration membrane. Process Biochem., 37: 57–64.
WHO (World Health Organization) (1984). Guidelines for drinking water quality. Vol. 2, Health criteria and other supporting information, WHO Publ, Geneva, p. 335.
WHO (World Health Organization) (1993). Guidelines for drinking water quality. Vol 1, Recommendations Geneva, Switzerland.
WHO (World Health Organization) (2006). Guidelines for drinking-water quality. First addendum to 3rd edn, 1, Recommendation. Geneva, p. 595.
Yerima FAK, Daura MM, Gambo BA (2008). Assessment of groundwater quality of Bama Town, Nigeria. J. Sus. Dev. Agric. Environ., 3(2): 128-137.
Zhang J, Huang WW Letolle R and Jusserand C (1995). Major element chemistry of the Huanghe (Yellow River), China-weathering processes and chemical fluxes. J. Hydrol., 168: 173-203.