HYDROGEOCHEMICAL ASSESSMENT OF SUBSURFACE WATER AT UGHELLI METROPOLIS, WESTERN NIGER DELTA, NIGERIA.

Uzoegbu, M. U. and Uchebo, A.U.

Department of Geology, College of Physical and Applied Sciences, Michael Okpara University of Agriculture, Umudike, PMB 7267, Umuahia, Abia State.

[1]GSM: 08030715958; Email: mu.uzoegbu@mouau.edu.ng

ABSTRACT

Groundwater is an important water resource for drinking and irrigation purposes in Ughelli, Delta State. The groundwater sources are used with little attention to their quality status in addition to increased threat of anthropogenic contamination in view of rapid growth in population and oil exploitation activities. The objectives of this study were to determine the physico-chemical characteristics and heavy metals content of groundwater, its hydrogeochemical controls and suitability for drinking and irrigation. Twelve groundwater samples were collected from the Ughelli. Field measurements of physical parameters were preceded by chemical analyses of the samples for major ions concentrations and bacteriological content. The groundwater has pH ranging from 3.57 to 6.43 implying that the groundwater sources are acidic. Electrical conductivity (<25 µS/cm) and total dissolved solids (<31 mg/l) were low for all most of the water sources, suggesting low-mineralized freshwater. The order of abundance in anionic and cationic content is of the order; K > Mg > Ca > Na > Zn > Fe >NH_3 > Mn > NH_4 > Cu > Al > Pb > Cd and F > PO_4 > SO_4 > NO_3 > Cl > NO_2 > Cr. Besides pH, EC, TSS, Mn, Mg, Ca, NO_2, NH_3, NH_4, Cu, BOD, P and Fe (in some or all locations), all other measured parameters fall within WHO guidelines for drinking and domestic purposes. Irrigation quality indices (Electrical Conductivity (EC), Total Dissolved Solids (TDS), Sodium Adsorption Ratio (SAR), Magnesium Adsorption Ratio (MAR), Kelly's Ratio (KR) and Soluble Sodium Percentage (SSP)) revealed that the analyzed groundwater were poorly to fairly suitable for irrigation.

Key words: Ground water, Hydrogeology, Geochemistry, Bacteriology, Drinkability, Ughelli, Niger Delta.

INTRODUCTION

Ughelli is located within latitudes 05˚ 26' "N to 05˚ 30' N and longitudes 05˚53' E to 05˚57' E (Fig. 1). The area lies within the oil rich province of Nigeria. Groundwater as the name implies is found below the ground in the rock interstices. In the sedimentary basins of the Niger Delta, groundwater is found within coastal plain sands of the Benin formation. However, in the basement complex of Nigeria, groundwater occurs in faults, joints, fractures and contact zones with contrasting, permeability as well as in the overlying weathered overburden. Groundwaters usually have a high recharged to well during the raining reason.

It is now clear that the methods for investigating the occurrence and movement of groundwater had improved; better means for its extraction and conservation have been developed. More so, research has now contributed to a better understanding of the subject of groundwater hydrology once veiled in mystery has expanded over the years. The distribution of groundwater depends on many factors, the most important being climate, topography and hydrogeologic conditions. The rate at which groundwater flows through an aquifer is mostly determined by the gradient of the flow, the size and extent of the grain sixe pres and its water connections. An aquifer may be

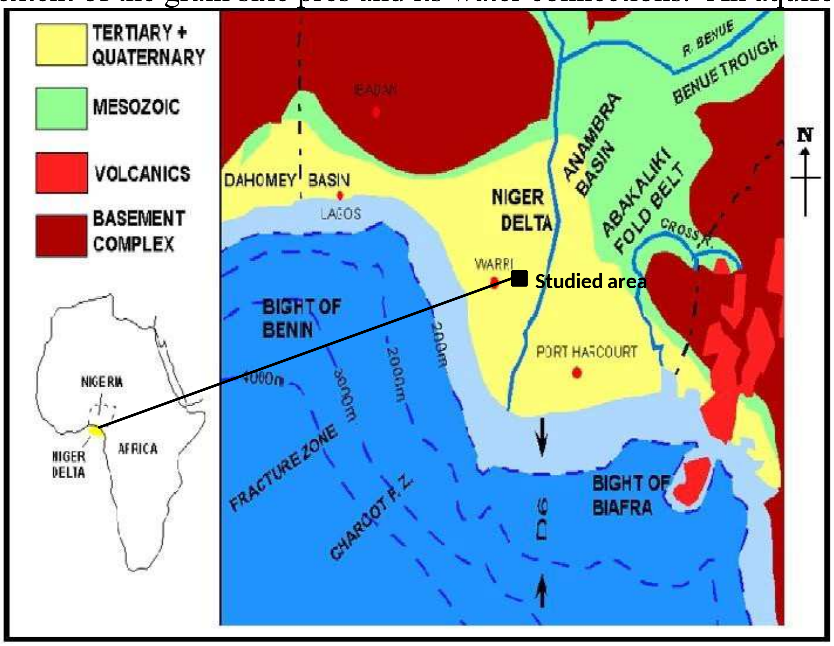

Fig. 1: Map showing the studied area (in set; map of Africa showing location of Nigeria).

considered valuable for water supply, if the water – bearing rocks or soil have adequate porosity as well as high permeability.

Groundwater is often used for agricultural, municipal and industrial purposes through the construction of extraction wells. Groundwater is also widely used for drinking and irrigation. According to Udom et al. (1999), about 53% of the world population depends on groundwater as a source of drinking water.

Groundwater is the most important gift of nature from beneath the ground, and has been exploited for everyday use since the earliest times. Although the precise nature of its occurrence was not necessarily understood, methods of bringing the water from the subsurface to the surface have been developed and successful. Groundwater is the most important and useful component and forms about two thirds of the freshwater resources of the world. In the Niger Delta, the demand for groundwater which is the major source of water for domestic and industrial uses is on the increase due to unprecedented increase in population as a result of improved standard of living and the astronomical expansion and development of the oil and gas companies and their allied establishments (Akpokodje, 1989; Nwankwoala and Udom, 2011).

The area under investigation in this study is fast growing in terms of population and business activities. However, there is an increased demand for potable water in the study area as a result of urbanization and industrialization to cater for industrial and domestic needs. These have impacted on the growing demand for portable water. It is important to initiate a proper groundwater resource and exploration program. This paper deals with the examination of the physic-geochemical and biological attributes of groundwater in Ughelli, to determine the suitability of the groundwater resources for drinking and domestic uses and finally, determine the suitability of the groundwater resources for irrigation purposes.

GEOLOGY OF THE STUDIED AREA

The Niger Delta Basin covers most areas of Rivers, Bayelsa, Edo and Delta States of Nigeria. Its areal extent is about 75,000km2 and consists predominantly of Cretaceous to Recent clastic sediment piles of about 8000m thick that rest unconformably on the sialic basement complex (Fig. 2). The Delta consists of broad riverine areas through which the River Niger enters the Atlantic Ocean, dividing into numerous rivulets, which fan out into the sea. It also includes a number of tidal creeks separating small islands of less than 10m above sea level (Offodile, 2002). The geological sedimentary sequence of the Niger Delta is made up as follows: The Ameki Formation, the Ogwash- Asaba Formation, the Benin Formation, and the Somebreiro Deltaic Plains Sand.

The Ameki Formation was deposited during the regression of the sea in early Eocene. Its lower unit consists of fine to coarse sandstone with intercalations of calcareous shale and thin limestone, while the upper unit consists of coarse cross-bedded sandstones and sandy clay (Reyment, 1965). The Ogwashi-Asaba Formation (Miocene) overlies the Ameki Formation and extends from just west of the Siluko River on the eastern flank in the Okitipupa area with a steady widening outcrop towards Onitsha. The formation consists dominantly of clays, sands, grits and seams of lignite alternating with gritty clays. Within the Ogwashi-Asaba Formation, the lignites are confined to a narrow belt of about 16 km wide 241 km long trending northwest-southeast from the Niger in the west of the Nigeria-Cameroun frontiers, east of Calabar.

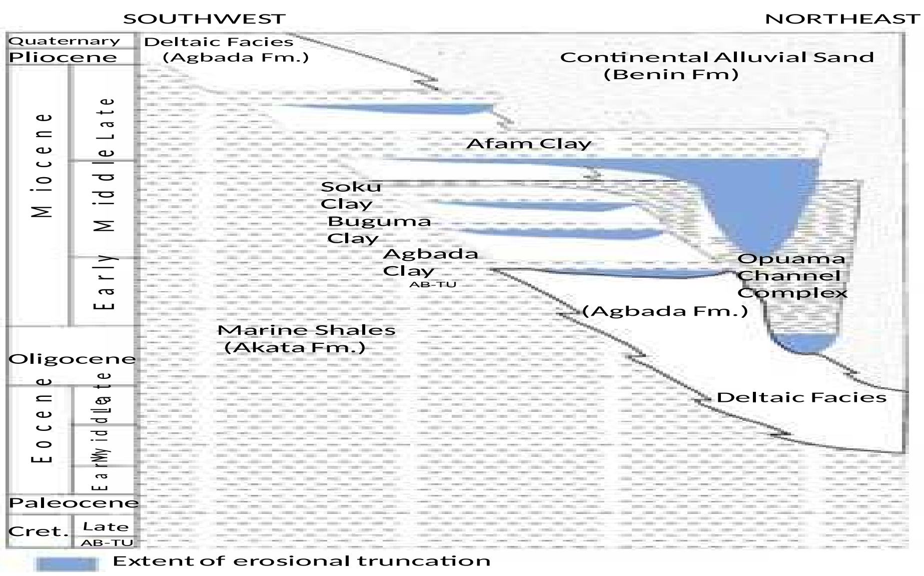

Fig. 2: Stratigraphic column showing the three formations of the Niger Delta. Modified from Shannon and Naylor (1989) and Doust and Omatsola (1990).

The Benin Formation is Oligocene to Pleistocene in age. This formation outcrops in the north east of the coastal belt in the Niger Delta and dips at a low angle in the southwest. The sediments consist, generally, of lenticular unconsolidated, dominantly sandy formations. Lenticular clays and shales occur particularly in the eastern areas where they confine small but moderately high yielding aquifers. The 90-150m confining clay beds encountered in the Niger Delta area, (Brass, Bonny and Opobo) disappear in the regions, north of the area, and adjacent to the Benin Formation area (Bodo, Okirika and Port Harcourt) (Offodile, 2002).

The thickness of the Benin Formation is variable, but generally exceeds 2000m. The Somebreiro Deltaic Plains Sands is late Pleistocene to Holocene in age. It occupies most of the area of the present delta and stretches narrowly eastwards along the coastline. The sediments consist of medium to coarse –grained unconsolidated sands forming lenticular beds with intercalation of peaty matter and lenses of soft silty clay and shale. These beds dip at varying angles towards the sea, forming units, which represent series of old deltas (Offodile, 2002). The gravelly beds of the formation could be up to 9m thick.

The major aquiferous formation in the studied area is the Benin Formation. It is about 2100m thick at the basin centre and consists of coarse-medium grained sandstones, thick shales and gravels. The upper section of the Benin Formation is the quaternary deposits which is about 40 – 150m thick and comprises of sand and silt/clay with the later becoming increasingly more prominent seawards (Etu-Efeotor and Akpokodje, 1990). The formation consists of predominantly freshwater continental, friable sands and gravel that have excellent aquifer properties with occasional intercalations of claystone/shales. According to Etu-Efeotor (1981), Etu-Efeotor and Akpokodje (1990), Offodile (2002), Udom et al (2002), the main source of recharge is through direct precipitation where annual rainfall is as high as 2000 – 2400mm. The water infiltrates through the highly permeable sands of the Benin Formation to recharge the aquifers. Groundwater in the study area occurs principally under water table conditions. Multi-aquifer systems occur in the study area and the upper aquifers are generally unconfined (Etu-Efeotor, 1981; Offodile, 2002; Amadi, 2004; and Udom, 2004).

MATERIALS AND METHODS

A total of twelve water samples were collected and analyzed in the laboratory using standard procedures. The groundwater samples were obtained directly from the water pump after allowing the water to run for at least five minutes and each sample bottle and its cap rinsed three times with the water sample. Water samples for the determination of cations were stabilized by adding few drops of diluted HCl after collection. Samples for heavy metal analysis were collected in new 500ml plastic containers and preserved by acidifying with a few drops of HNO_3 acid to achieve a pH of ≤ 2. The samples used for anions analysis were preserved in a refrigerator prior to analysis to exclude microbial activity. To maintain the integrity of the water samples, physico-chemical parameters sensitive to environmental changes such as pH and electrical conductivity were measured and recorded in-situ using portable digital meters.

The water samples were analyzed for different parameters such as pH, electrical conductivity (EC), total alkalinity (TA), total dissolved solids (TDS), salinity, inorganic ions/salts and heavy metals (As, Cu, Ni, Fe, Pb, Zn, Cr, Cd, Mn) in Zetta Allied Digital Energy Limited (ZADEL) Laboratory, Elelenwo, Port-Harcourt. Table 3.1 shows a summary of the methods employed in analyzing the samples. See Appendix A for detailed description of the various methods.

Heavy metals were determined using an Atomic Absorption Spectrophotometer (AAS) as described in APHA 3111B and ASTM D3651. This involves direct aspiration of the sample into an air/acetylene or nitrous oxide/acetylene flame generated by a hollow cathode lamp at a specific wavelength peculiar only to the metal programmed for analysis. For every metal investigated, standards and blanks were prepared and used for calibration before samples were aspirated. Concentrations at specific absorbance displayed on the data system monitor for printing. Limit of detection is <0.001mg/l. All the metals determined from the water samples are; As, Cu, Ni, Fe, Pb, Zn, Cr, Cd and Mn and were reported in mg/L (water samples).

The set of samples for bacteriological analysis were subjected to total bacteria count and coliform count. Nutrient agar medium was used to obtain plate count of living bacteria (viable cell count). The procedure involved mixing 1 ml of water sample with liquefied agar at 40 °C in a Petri dish. The agar sets to a jelly, thus fixing the bacteria cell in position. The plate was then incubated under appropriate condition (24 hours at 37 ºC for bacteria organism from animal or man). At the end of the incubation, the individual bacteria would have produced colonies visible to the naked eyes and the number of colonies was assumed to be a function of the viable cells in the original sample. Coliform count was achieved using a lactose medium inoculated with serial dilution of the sample. The appearance of acid and gas after 24 hours at 37 °C was taken as positive indication of the presence of coliform bacteria; results were expressed as number of colonies per 100 ml.

RESULTS AND DISCUSSION

The average water quality parameters for all groundwater samples in this study are presented in Table 1 and 2 while the statistical summary of the physico-chemical data compared with World Health Organization (WHO, 2006) is as presented in Table 3.

The pH of the groundwater samples ranges from 4.03 - 6.43 with a mean value of 4.59, signifying acidic water. The average pH value exceeds WHO (2006) permissible values of 6.5-8.5 set aside for drinking water. Consumption of such acidic water could have adverse effects on the digestive and lymphatic systems of human. The EC and TDS values were low and ranges from 7.82 – 23.44 µS/cm and 4.69 – 30.6 mg/L respectively suggesting low-mineralized freshwater. Only groundwater from L4 shows EC and TDS of 975µS/cm and 780mg/L, suggesting highly mineralized water. Apart from L4, EC and TDS for all groundwater samples were within the WHO recommended limits (500 µS/cm) while at L4, the EC exceeded WHO standard. Water containing more than 1000 mg/L of TDS is considered unfit for drinking (WHO, 2006).

Generally, besides Turbidity, pH, EC, TSS, Mn, Mg, Ca, NO_2, NH_3, NH_4, Cu, BOD5, P and Fe (in some locations), all other measured parameters fall within the WHO desirable and maximum permissible limits for drinking purposes. The turbidity values for most of the groundwater sources are within the WHO (2006) recommended limit of < 4 NTU (Table 3, Fig. 4). However, high turbidity values in magnitude greater than the WHO limit were recorded in L3 and L5. High turbidity is usually associated with high levels of disease causing micro-organisms such as bacteria and parasites. Montgomery (2003) noted that high turbidity values even in the absence of faecal indicator bacteria indicate a breach of sanitary integrity. Increase in turbidity may be caused by large amount of silt, microorganisms, plants, fibers, chemicals, etc. The most frequent causes of turbidity in groundwater are plankton, and soil erosion from logging, mining, and urbanization operations. Therefore, water from these sources (L3 and L5) would not be suitable for drinking and most domestic purposes (WHO, 2006).

Table 1: Physical characteristics of groundwater samples.

Physical parameters/ units	WHO (200ı)	1	2	3	4	5	ı	7	8	9	10	11	12
Temperature (°C)	Ambient	26.60	26.90	27.00	26.70	26.70	26.50	25.40	25.80	25.70	25.50	25.60	25.80
pH	6.5-8.5	4.37	4.21	5.24	6.43	4.68	4.35	4.03	4.81	3.57	4.07	4.40	4.86
Turbidity (NTU)	5.00	0.81	2.77	5.13	3.56	12.99	1.37	3.52	1.70	4.36	0.85	1.09	1.17
Conductivity (uS/cm)	500	11.51	12.93	7.82	975	10.53	10.53	23.44	13.75	51.00	16.48	18.19	11.12
Dissolved Oxygen	14.00	9.40	8.60	8.80	12.30	10.50	8.30	11.00	7.00	15.00	8.00	9.00	5.00
Total Dissolved Solids	1000	6.91	7.76	4.69	780	6.318	6.318	14.06	8.25	30.60	9.89	10.91	6.67
Total Suspended Solids	0.01	0.00	0.05	0.46	0.04	0.35	0.06	1.05	0.97	1.23	0.13	0.66	0.16
Total Hardness	500	8.56	8.56	9.22	15.90	8.56	7.12	17.10	17.10	17.10	14.60	17.10	17.10
Total Alkalinity	400	6.79	6.67	7.32	7.82	7.00	6.78	6.52	7.09	6.08	6.56	6.12	7.12
Salinity (ppt)	4.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 2: Geochemical characteristics of groundwater samples.

Parameters/ units	WHO (2006)	1	2	3	4	5	6	7	8	9	10	11	12
Cations													
Manganese (mg/l)	0.05	0.12	0.26	1.24	0.48	2.36	0.08	0.09	0.13	1.09	1.14	1.08	0.63
Magnessium (mg/l)	100	5.13	5.01	5.80	102	4.60	3.80	8.60	9.00	9.10	8.60	9.60	9.50
Calcium (mg/l)	50	3.43	3.55	3.42	51.90	3.96	3.32	8.50	8.10	8.00	6.00	7.50	7.60
Potassium (mg/l)	200	12	14	14	63	13	12	12	15	25	10	14	13
Total Iron (mg/L)	0.30	0.68	0.90	3.60	0.98	4.50	0.29	0.76	1.10	2.16	2.33	2.04	1.02
Ammonia (mg/l)	1.00	0.90	0.80	0.60	0.80	0.90	0.70	0.60	0.70	0.80	0.90	1.00	1.20
Ammonium (mg/l)	0.50	0.40	0.50	0.23	0.41	0.53	0.30	0.35	0.30	0.42	0.51	0.61	0.76
Aluminium (mg/l)	0.20	0.10	0.10	0.20	0.20	0.22	ND	0.12	0.09	0.06	ND	ND	0.04
Zinc (mg/l)	5.00	1.30	1.30	0.90	2.30	2.13	1.10	2.13	1.50	1.60	3.20	1.70	1.34
Lead (mg/l)	0.004	ND	ND	0.013	ND	0.001	ND	ND	ND	ND	ND	ND	ND
Sodium (mg/ l)	200	2.01	2.60	3.10	17.20	1.20	1.00	2.00	1.50	0.86	2.06	2.49	1.04
Cadmium (mg/l)	0.003	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Copper (mg/l)	0.50	0.40	0.30	0.60	0.60	0.66	0.50	0.46	0.56	0.50	0.51	0.63	0.55

Anions												
Chromium (mg/l)	-	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Sulphate (mg/l)	200	25.0	22.0	15.0	43.0	4.00	2.00	4.00	4.00	10.0	3.00	19.0	3.00
Phosphate (mg/l)	200	18	16	12	163	195	144	869	329	246	187	180	216
Chloride (mg/l)	250	3.50	4.40	4.16	25.30	2.04	1.05	3.50	2.30	1.30	3.13	3.80	1.40
Fluoride (mg/l)	1.30	ND	ND	ND	0.36	ND	ND	ND	ND	ND	ND	ND	ND
Nitrate (mg/l)	45	1.50	12.80	3.60	2.30	5.70	2.40	3.60	4.10	6.60	2.40	5.70	71.30
Nitrite (mg/l)	0.1	0.188	0.156	0.101	0.137	0.171	0.169	0.124	0.223	0.139	0.019	0.03	0.116
Biological													
THC (CFU/100ml)	3	TNTC	TNTC	TNTC	TNTC	TNTC	TNTC	TNTC	TNTC	TNTC	TNTC	TNTC	TNTC
TCC (CFU/100ml)	0	TNTC	TNTC	TNTC	TNTC	TNTC	TNTC	TNTC	TNTC	TNTC	TNTC	TNTC	TNTC
FCC (CFU/ml)	0	TNTC	TNTC	TNTC	TNTC	TNTC	TNTC	TNTC	TNTC	TNTC	TNTC	TNTC	TNTC
BOD5 @ 25 C		7.44	7.37	7.8	7.78	7.73	7.74	7.5	5.5	1.14	7.08	7.11	2.03

TNTC- too numerous to count
ND- not detected

The level of TSS obtained from groundwater sources in the area is higher than the WHO 2006 stipulated limit (0.01 mg/ L) except L1 which has a lower TSS than WHO stipulated limit (Table 3, Fig. 4). Total suspended solids (TSS) in water affect the aesthetic appeal of bathing water. Water that is high in TSS is more of an aesthetic than a health hazard. Total hardness values for groundwater in the area are within WHO (2006) recommended limit (500 mg/L) (Table 3, Fig. 4). WHO (2004) classifies hardness of water into several categories. On that basis, most of the groundwater sources could be described as soft water while L4 could be described as moderately hard water.

DO levels in groundwater depend on the physical, chemical, and biological activities of water bodies (Gopalkrushna, 2011). DO range obtained from groundwater samples is within WHO (2006) stipulated limit (14 mg/L), indicating aerobic and a healthy state of Ughelli groundwater (Table 3, Fig. 4). Groundwater at L9 has DO level above WHO standard. BOD_5 test is useful in determining the relative waste loading and its higher degree therefore indicates the presence of large amount of organic pollutant and relatively higher level of microbial activities with consequent depletion of oxygen content. Alkalinity level are within WHO recommended limit of 400 mg/L.

Chloride content in groundwater from all the zones is lower than the limit (250 mg/L) set by WHO 2006 for drinking water. Low levels of Na^+ and Cl^- in the groundwater sources are an indication of the absence of intrusion of sea water. Chloride level higher than 10 mg/L is a result of anthropogenic source of pollution by sewage, septic systems, landfill, or fertilizers (Bahar and Reza, 2010). The mean concentration of nitrate (except L12) is within WHO permissible limit of 45 mg/L (Table 3, Fig. 6). The concentration of nitrites (except L11) exceeds WHO standard. Also, the mean concentration of NH_3 (except L12) and ammonium (except L11 and L12) in the groundwater samples are within the WHO, (2006) permissible limits of 0.5 mg/L and 1.0 mg/L respectively. Na and K levels are below the WHO recommended limit of 200 mg/L. Levels of Mn in all the water samples exceeds the WHO recommendation of 0.05 mg/L (Table 3, Fig. 5). The concentration level of magnesium in all the samples are generally low and within WHO (2006) standard of 100 mg/L for drinking water except L4 which records values higher than the WHO standard. Apart from L4 with Calcium content exceeding WHO recommended limits, all other samples have Ca content within WHO (2006) limits of 50 mg/L. Sulphate, Pb, Zn, Al and F have concentrations within WHO recommended guidelines.

Table 3: Statistical parameters for physico-chemical characteristics of groundwater samples in the area.

Physical parameters/units	MIN	MAX	MEAN	STANDARD DEVIATION	WHO (2006)
pH	3.57	6.43	4.59	0.73	6.5-8.5
Turbidity (NTU)	0.805	12.99	3.28	3.39	5.00
Conductivity (uS/cm)	7.82	975	96.86	276.78	500
Dissolved Oxygen	5	15	9.41	2.58	14
Total Dissolved Solids	4.69	780	74.36	222.32	1000
Total Suspended Solids	0.001	1.228	0.43	0.44	0.01
Total Hardness	7.12	153.9	24.67	40.91	500
Total Alkalinity	6.08	7.82	6.82	0.49	400
Manganese	0.08	2.36	0.73	0.69	0.05
Magnessium	3.8	102	15.06	27.46	100
Calcium	3.32	51.9	9.61	13.49	50
Nitrate	1.50	71.3	10.17	19.49	45
Nitrite	0.019	0.223	0.13	0.06	0.1
Ammonia	0.60	1.20	0.83	0.17	1.00
Ammonium	0.23	0.76	0.44	0.15	0.50
Aluminium	0.04	0.22	0.13	0.07	0.20
Zinc	0.90	3.20	1.71	0.64	5.00
Chloride	1.05	25.3	4.66	6.60	250
Copper	0.30	0.66	0.52	0.10	0.50
Lead	0.001	0.013			0.004
Sodium	0.86	17.20	3.09	4.50	200
BOD_5 @ 25 C	1.14	7.80	6.35	2.32	
Sulphate	2.00	43	12.83	12.57	200
Phosphate	12.00	869	214.58	227.92	200
Potassium	10.00	63.00	18.08	14.63	200
Total Iron (mg/L)	0.29	4.50	1.70	1.28	0.30

The level of phosphate in groundwater samples at L7, L8, L9, and L12 are above WHO limit of 200 mg/l (Table 3, Fig. 6). Apart from L6, the groundwater sources in the area are high in iron content, with most areas exceeding the WHO limit (Table 3, Fig. 5).

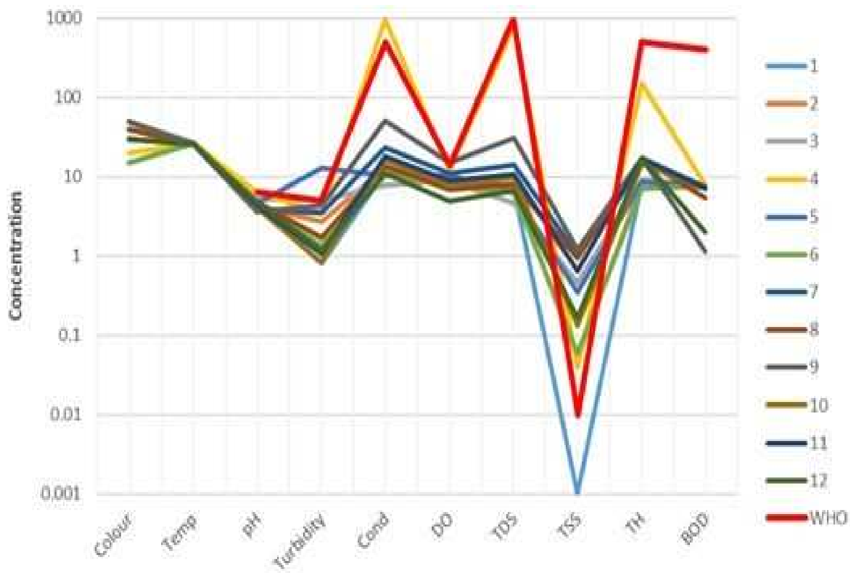

Fig. 3: Physical and biological characteristics of groundwater sources in the study area compared with WHO, 2006 standard.

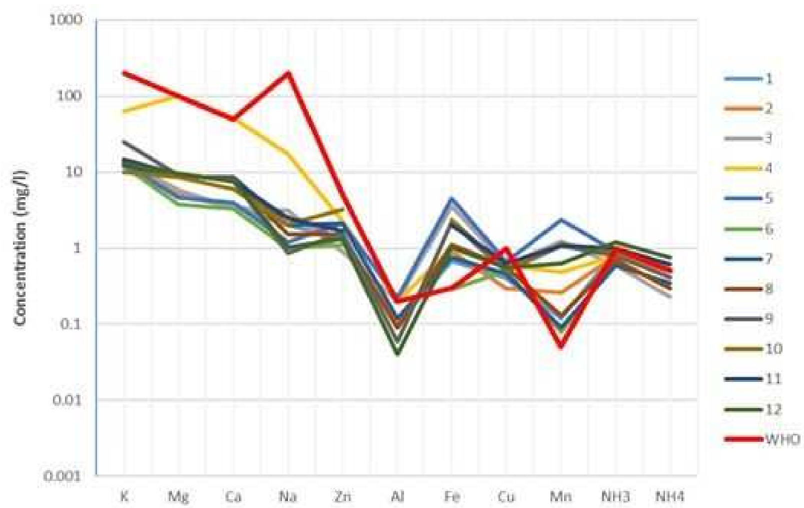

Fig. 4: Cations in groundwater from the study area compared with WHO (2006) standard.

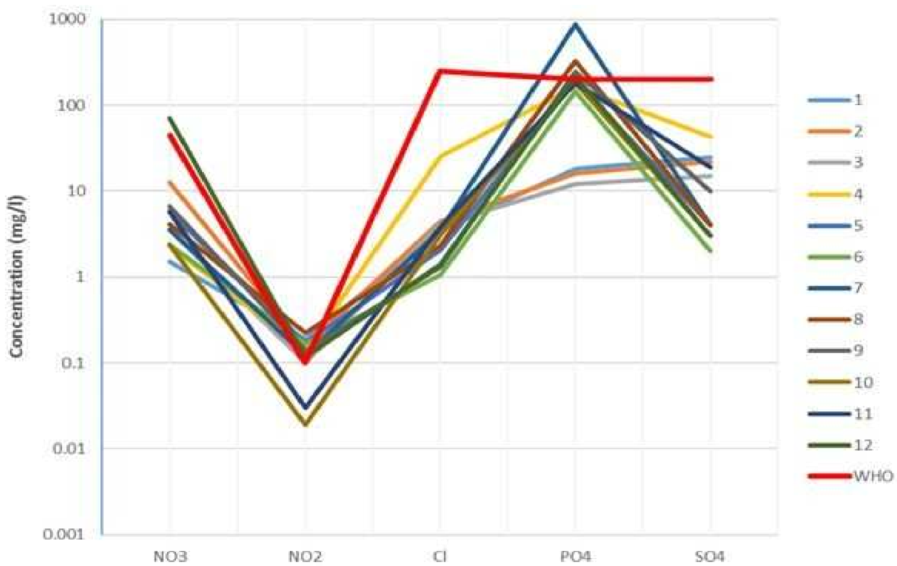

Fig. 5: Anions in groundwater sources from the study area.

Water for agricultural purposes should be good for both plant and animals. Good quality of water for irrigation is characterized by acceptable range of:

1. The Soluble Sodium Percentage (SSP)
2. The Magnesium Adsorption Ratio (MAR)
3. The Kellys Ratio (KR)
4. The Total Dissolved Solids (TDS)

The results of the different irrigation indices for rating irrigation water quality are presented in Table 4 and summarized in Table 5. Table 6 present some of the limits of some parameter indices for rating surface water quality and its sustainability in irrigation.

Table 4: Different parameter indices for rating groundwater quality and its suitability for irrigation

LOCATION	KR (Meq/l)	SPP (%)	MAR (%)	SAR
L1	0.36	79.80	47.30	5.73
L2	0.46	82.21	45.85	7.39
L3	0.52	81.73	50.43	8.58
L4	0.17	55.77	54.11	11.76
L5	0.21	79.91	41.07	3.37
L6	0.21	81.43	40.71	3.07
L7	0.17	65.29	37.77	3.94
L8	0.13	69.65	40.00	2.97
L9	0.07	78.70	40.56	1.70
L10	0.21	66.21	46.24	4.49
L11	0.22	69.46	43.44	4.97
L12	0.09	66.62	42.86	2.07

Table 5: Summary statistics of different indices of groundwater

Parameter	Min	Max	Mean	Standard deviation
KR (Meq/l)	0.07	0.52	0.23	0.14
SSP (%)	55.77	82.21	73.07	8.66
MAR (%)	37.77	54.11	44.20	4.77
SAR	1.70	11.76	5.00	2.96
EC	7.82	975	96.86	276.78
TDS	4.69	780	74.36	222.32

Table 6: Limits of some parameter indices for rating groundwater quality and its sustainability in irrigation (Ayers and Westcot, 1985).

Category	EC (µmhos/cm)	RSC (meq/L)	SAR	SSP (%)	Sustainability for Irrigation
I	< 117.509	< 1.25	< 10	<20	Excellent
ii	117.509 -	1.25 – 2.5	10-18	20-40	Good
iii	508.61	> 2.5	16-26	40-80	Fair
iv	> 503.61	-	>26	>80	Poor

Sodium Adsorption Ratio (SAR)

The sodium adsorption ratio gives a clear idea about the adsorption of sodium by soil. It is the proportion of sodium to calcium and magnesium, which affect the availability of the water to the crop. Salinity and toxicity problems of irrigation water are attributed to SAR (Bahar and Reza, 2010). It is defined by US Salinity Laboratory Staff that sodium – rich water may deteriorate the physical structure of the soil (pore Clogging). The values of SAR for the groundwater samples ranged from 1.70 to 11.76 (Table 4) with mean and standard deviation of 5±2.96 (Table 5). Salinity classification was done using a quality diagram given by the U. S. Salinity Laboratory. The diagram has 16 classes, with reference to SAR as an index of sodium hazard and EC as an index of salinity hazard.

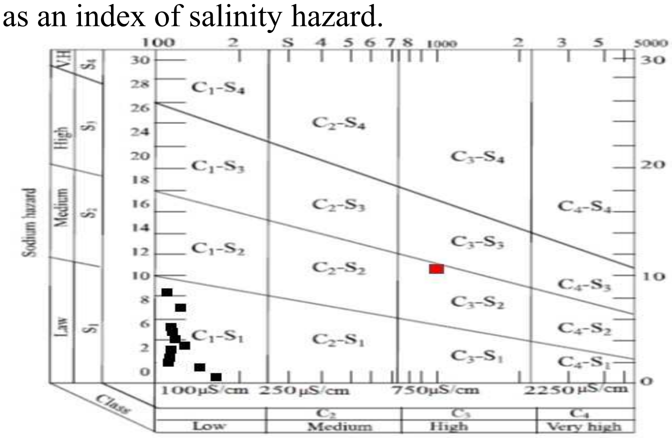

Fig. 6: Classification of the analyzed water sample with respect to sodium adsorption ration and salinity hazard.

By plotting the obtained results in the diagram (Fig. 6), all the groundwater samples was categorized into “C1-S1” (low salinity-low sodium hazard), an indication that such water can be safely used for irrigation purposes. Only sample L4 plotted in the field of “C3-S2” (high salinity-moderate sodium hazard), an indication that the water is unsafe for irrigation purposes.

Soluble Sodium Percentage (SSP)

Sodium percent is an important factor for studying sodium hazard. It is also used for adjudging the quality of water for agricultural purposes. High percentage sodium water for irrigation purpose may stunt the plant growth and reduces soil permeability. The soluble sodium percentage values of groundwater samples in the study area ranges between 55.77 and 82.21% (Table 4-5) indicating low alkali hazards and fair (Class III) to poor (Class IV) irrigation quality (Table 6).

Magnesium Adsorption Ratio (MAR)

Magnesium content of water is considered as one of the most important qualitative criteria in determining the quality of water for irrigation. Generally, calcium and magnesium maintain a state of equilibrium in most waters. More magnesium in water will adversely affect crop yields as the soils become more saline (Bahar and Reza, 2010). The values of the magnesium adsorption ratio of groundwater samples in the present study varies from 37.77 to 54.11% (Table 4-5) indicating that only sample L3 and L4 are above the acceptable limit of 50% (Ayers and Westcot, 1985). The waters are therefore, considered unsuitable for irrigation purposes based on this analysis. This is because high magnesium adsorption ratio causes a harmful effect to soil when it exceeds 50%.

Kelly’s Ratio (KR)

The kelly’s Ratio (KR) values of the study area ranged between 0.07 and 0.52 meq/L (Table 4-5). These indicate that the KR values for the groundwater samples however fall within the permissible limit of 1.0 meq/L and are considered suitable for irrigation purposes.

Total Dissolved Solids (TDS)

Salts of calcium, magnesium, sodium, potassium present in the irrigation water may prove to be injurious to plants. When present in excessive quantities, they reduce the osmotic activities of the plants and may prevent adequate aeration. The TDS value of the study area ranges from 4.69 to 780 mg/L (Table 4-5). All the groundwater sources are generally less than 1000 mg/L and can be classified as excellent irrigation water according to Bahar and Reza (2010).

Correlation statistical analyses

Interrelationships between the parameters were determined through correlation analysis applying Pearson correlation. It is a simple measure to exhibit how well one variable predicts the other (Bahar and Reza, 2010). Thus, the correlation measures the observed co-variation. Pearson’s Correlation Coefficient is usually signified by r (rho), and can take on the values from –1.0 to 1.0. Where -1.0 is a perfect negative (inverse) correlation, 0.0 is no correlation, and 1.0 is a perfect positive correlation. The variables having coefficient value (r) > 0.5 or < –0.5 are considered significant. The result of correlation analysis performed on the groundwater samples is presented in Table 7.

Table 7: Pearson correlation for physiochemical parameters in groundwater sources from the studied area.

	Colour	Temp	pH	Turbid	Cond	DO	TDS	TSS	TH	Alk	Mn	Mg	Ca	NO3	NO2	NH3	NH4	Al	Zn	Cl	Cu	Na	BOD	SO4	PO4	K	Fe
Colour	1																										
Temp	-0.28	1																									
pH	-0.26	0.479	1																								
Turbid	0.433	0.372	0.122	1																							
Cond	-0.31	0.252	.777**	0.027	1																						
DO	0.292	0.029	-0.09	0.381	0.384	1																					
TDS	-0.31	0.257	.782**	0.026	1.000**	0.377	1																				
TSS	.791**	-.582*	-0.39	0.126	-0.25	0.411	-0.26	1																			
TH	-0.28	0.181	.777**	-0.01	.996**	0.356	.996**	-0.21	1																		
Alk	-0.22	0.57	.908**	0.186	.614*	-0.21	.620*	-0.46	.603*	1																	
Mn	0.376	0.098	0.007	.753**	-0.11	0.206	-0.11	0.066	-0.12	-0.06	1																
Mg	-0.3	0.205	.785**	-0.002	.998**	0.351	.998**	-0.23	1.000**	.613*	-0.12	1															
Ca	-0.26	0.131	.759**	-0.01	.990**	0.365	.990**	-0.16	.998**	.581*	-0.13	.996**	1														
NO3	-0.04	-0.17	0.07	-0.16	-0.133	-0.52	-0.13	-0.17	-0.096	0.139	-0.03	-0.1	-0.08	1													
NO2	-0.09	0.408	0.111	0.221	0.027	0.055	0.028	0.036	-0.003	0.332	-0.33	-0.004	-0.003	-0.07	1												
NH3	-0.37	-0.22	-0.01	-0.14	-0.049	-0.36	-0.05	-0.35	-0.021	-0.1	0.251	-0.02	-0.02	.694*	-0.3	1											
NH4	-0.19	-0.3	-0.09	-0.04	-0.071	-0.3	-0.07	-0.23	-0.037	-0.2	0.29	-0.04	-0.03	.710**	-0.4	.934**	1										
Al	0.043	0.637	0.578	.686*	0.411	0.249	0.415	-0.26	0.374	0.568	0.538	0.387	0.345	-0.52	-0.13	-0.39	-0.38	1									
Zn	0.017	-0.44	-0.01	0.111	0.299	0.208	0.297	-0.01	0.324	-0.07	0.295	0.317	0.337	-0.21	-0.47	0.134	0.236	0.356	1								
Cl	-0.31	0.307	.798**	0.007	.982**	0.338	.983**	-0.3	.977**	.625*	-0.12	.981**	.966**	-0.18	-0.02	-0.09	-0.09	0.474	0.293	1							
Cu	0.208	-0.09	0.467	0.42	0.235	0.024	0.237	0.185	0.262	0.291	.620*	0.258	0.27	0.022	-0.24	0.147	0.093	0.534	0.188	0.186	1						
Na	-0.31	0.312	.813**	0.003	.984**	0.328	.985**	-0.3	.979**	.640*	-0.12	.983**	.968**	-0.17	-0.03	-0.09	-0.1	0.478	0.278	.999**	0.213	1					
BOD	-0.3	0.453	0.297	0.142	0.168	-0.08	0.175	-0.42	0.133	0.273	-0.03	0.148	0.101	-.606*	-0.04	-0.42	-0.39	.746*	0.15	0.292	-0.004	0.282	1				
SO4	-0.39	0.478	.593*	-0.1	.754**	0.356	.755**	-0.35	.731**	0.382	-0.17	.742**	.708*	-0.24	0.015	-0.002	-0.06	0.342	-0.03	.821**	-0.09	.810**	0.292	1			
PO4	0.47	-.655*	-0.24	0.034	-0.058	0.183	-0.06	.627*	-0.011	-0.22	-0.21	-0.04	0.037	-0.02	-0.01	-0.29	-0.09	-0.15	0.335	-0.09	0.027	-0.1	-0.08	-0.38	1		
K	-0.2	0.232	.709**	0.063	.975**	0.504	.973**	-0.11	.970**	0.534	-0.07	.970**	.969**	-0.13	0.074	-0.07	-0.09	0.34	0.222	.938**	0.237	.942**	0.012	.747**	-0.07	1	
Fe	0.52	0.185	0.037	.763**	-0.176	0.18	-0.18	0.147	-0.189	0.017	.950**	-0.18	-0.2	-0.15	-0.26	0.019	0.052	0.622	0.187	-0.16	.590*	-0.15	0.073	-0.18	-0.2	-0.14	1

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Most of the parameters displayed significant correlation among each other indicating high interactions of the chemical constituents in groundwater. Strong positive correlation exists between EC, TDS, Ca, Cl, Mg, Na, SO_4, K, TH and pH (Table 4.6). Correlation is significant at the 0.01 and 0.05 level (2-tailed). Also significant positive correlation exist between BOD_5 and Al (r = 0.746); Fe, Mn and Turbidity (r= 0.753 to 0.95); Colour and TSS (r = 0.791); Temp and Alk (r = 0.57), Alk, Mg, Ca, Cl, Na and K (r= 0.534 to 0.999); PO_4 and TSS (r = 0.627); NH_3 and NH_4 (r = 0.934); Colour and Fe (r = 0.52). Significant negative relationship exists between Temp and PO_4 (r = 0.655); Temp and TSS (r = -0.582); DO and NO_2 (r = 0.52); NO_3 and Al (r = 0.52) (Table 7). The relatively high positive correlation between some chemical parameters signifies a common origin or progressive enrichment of both parameters. Also, the negative correlation between some chemical parameters indicates evidences of water mixing from different sources.

CONCLUSION

This study has assessed the hydrogeochemistry, quality and suitability of groundwater in Ughelli, Delta state, southeastern, Nigeria. The pH of the groundwater samples signifies acidic water. The EC and TDS values of the groundwater suggests low-mineralized freshwater. Only a single location (L4) shows highly mineralized water. Generally, besides Turbidity, pH, EC, TSS, Mn, Mg, Ca, NO_2, NH_3, NH_4, Cu, BOD, P and Fe (in some locations), all other measured parameters fell within the WHO guidelines for drinking.

Irrigation assessment using SAR, SSP, MAR, KR, EC and TDS indicated that the groundwater from the area are within fair to poor irrigation water class with low salinity hazard (except L4) and are quite suitable for some types of crops on selected soils. The groundwater sample at L4 is seriously deteriorates in quality, and hence, is extremely unsuitable for both drinking and for irrigation purposes.

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