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Hydrogeochemical Assessment of Groundwater Quality in Parts of Ohaji Egbema Eastern Niger Delta, Nigeria

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Abstract:
Groundwater resource in Ohaji Egbema, was investigated for its quality from which inferences are drawn on its usability, prevalent hydrochemical processes in the water system and probable quality degradation. Results of the field and laboratory analysis indicate a chemical attribute of low pH, total dissolved solids (TDS) and electrical conductivity (EC). Cationic concentrations including Na^{2+}, K^+, Ca^{2+}, Mg^{2+} have values ranging from 5.2 – 20.3, 2 – 8, 0.96 – 9.28, and 0 – 2.3mg/l respectively whilst Anions involve NO_3^-, Cl^-, SO_4^{2-}, HCO_3^-, with their respective values as 8.5-20.1, 8.5-24.14, 1.48-45.07 and 8.6-16.5mg/l. Selected heavy metals tested follow the order of $Mn^{2+} > Fe > Zn^{2+} > Cu^{2+}$. The water quality plots reveal a hydrogeochemical process operative within the groundwater system as relating to water-soil interaction and incorporation of leached formation water along the groundwater flow path. Illatively, other parameters suggests a low mineralized soft freshwater having a limited residence time, with an onset of degradation from biochemical related substances resulting from human activities in the area. An interplay of these processes produced a chloride water type ($Na(k)Cl$ and $Cl^- + SO_4^-$). A comparison of these results with various quality guidelines, suggests that the groundwater maybe usable in its untreated state for crop irrigation but will require pH remediation to upgrade its quality for portability and use in some industries.

Keywords: Hydrogeochemistry, Water quality, Pollution.

1.0 Introduction:
Groundwater accounts for about 98% of the world's fresh water (Buchanan, 1983; Bouwer, 2002). It serves as the major source of water for general usage in the study area. In southern Nigeria, especially in areas underlain by sedimentary formations, groundwater is usually present in abundance, this is partially because of the prevalent equatorial climate that fosters abundant rainfall hence, ensures adequate aquifer recharge coupled with the availability of suitable aquifers and impervious layers of sediments that favour the storage of the recharging water, (Olobaniyi et al; 2007). Despite its abundance, groundwater may still be unusable when its quality is considerably degraded by chemical and bacteriological contamination with increasing human population, industrialization, urbanization and the consequent increase for the demand of water for both domestic and industrial uses, the attendant increase in the implication of polluted water on man and the environment have been severally studied- (Asiwaju Bello and Akande, 2000; Onipede and Bolaji, 2004; Seo, 2004; Kurian et al, 2005). Unknown about this water resource is its vulnerability to quality degradation from surface activities. The issue of water quality and maximum permissible limits of elements in drinking water can constitute health risks and add to the variety of water related problems. Health issues arising from water sources are generating serious concern in almost all the countries of the world particularly in rural communities where agricultural practices are intensive (Tredoux et al., 2000; Colvin, 1999; Marais, 1999; Fan and Steinberg, 1996).

Groundwater contamination is nearly always the result of human activity; in areas where population density is high and human use of land is intensive, groundwater is especially vulnerable. Virtually any activity whereby chemicals or wastes maybe released to the environment either intentionally or

accidentally has the potential to pollute groundwater. When groundwater becomes contaminated, it is difficult and expensive to clean up. Whilst the effects of man's activity on the quantity of recharge into the groundwater system are more glaring, the less recognized is his impact on the quality. Thus, this work is aimed at the need for thorough assessment of the quality of water in the study area (whether human or naturally influenced) available for human consumption, agricultural and industrial purposes and thus create awareness on any anthropogenous water quality degradation practices.

1.1 Physical setting

Ohaji Egbema lies in the southwestern part of Imo state and shares common boundaries with owerri to the east, oguta to the north and ogba/Egbema/Ndoni in Rivers state in the southwest. The 2006 census estimated the study area to over 182,500 inhabitants but recently due to industrialization and urbanization, Ohaji/Egbema has witnessed a great deal of population influx.

The study area lies within latitudes 5^0 11'N and 5^0 35'N and longitudes $6^0$37' ad $6^0$57'. It covers an area of about 890km^2. The study area is largely drained by the Otammiri River and other Imo river tributaries. The study area belongs to a major physiographic region- the undulating lowland plain which bears a relationship with its geology. The low land areas are largely underlain by the younger and loosely consolidated Benin formation (Ezeigbo, H. I., 1989).

The vegetation and climate of the study area has been delineated to have 2 distinct seasons both of which are warm (Okoli I wuala, 2004), these are the dry and rainy season. The dry season occurs between November and March, while the rainy season occurs between April and October. Although over the recent decades, it appears very difficult to create a clear cut distinction between the periods we refer to as rainy season and dry season due to climate change. Despite this observed erratic nature of both rainy and dry spells, the high temperatures, humidity and precipitation of the area favour quick plant growth and hence vegetation cover of the area is characterized by trees and shrubs of the rainforest belt of Nigeria. However, human activities such as agriculture, hydrocarbon exploration and exploitation in the area have resulted in deforestation of parts of the study area.
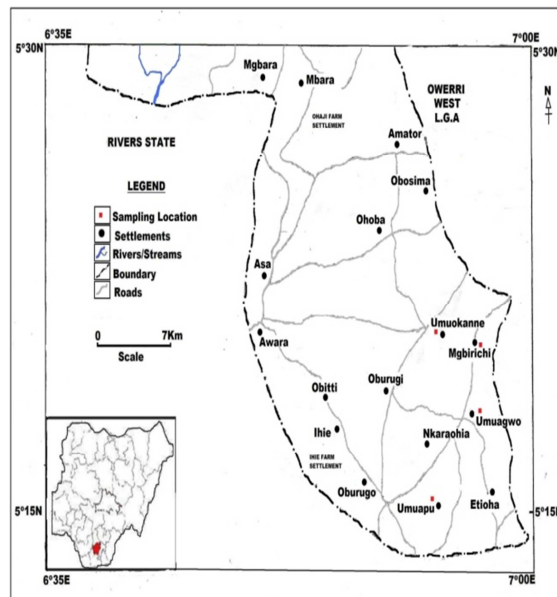

Fig. 1: Location map of the study area

1.2 Geology and Hydrogeology

The study area is located in the eastern Niger delta sedimentary basin, characterized by the three lithostratigrapgic units in the Niger delta. These units are – Akata, Agbada and Benin formation in order of decrease in age (Short and Stauble, 1965). The overall thickness of the tertiary sediments is about 10,000 meters. All boreholes in the study area tap from the youngest aquiferous Benin formation. The Miocene to Recent formation is made up of sands, which are mostly medium to coarse grained, pebbly, moderately sorted with local lenses of poorly cemented sands and clays. The sand clay intercalations in the area are indicative of a multi aquifer system. These aquifers are separated by a clayey unit whose thickness determines how thick the aquifer is in a particular borehole. The high rainfall in the area provides enough recharge for the aquifers. Other details about the geology of the Niger Delta are given by Allen (1965), Aseez (1976), Wright et al (1985), and Kogbe (1989).
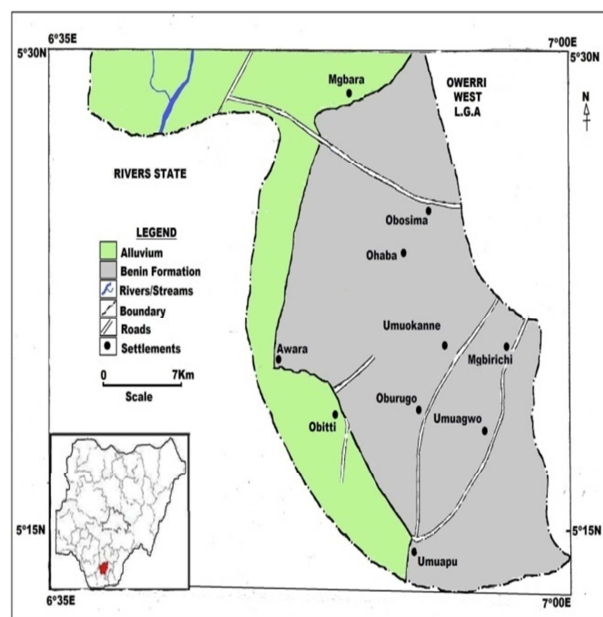
Fig.2: Geology map of the study area

2.0 Materials and Methods:

A total of 20 water sampling points within the study area were collected for analysis. These water samples comprise of 11 hand dug wells and 9 borehole wells as located in the study area. At each sampling point, the well was pumped for a minimum of 2 minutes to ensure obtaining fresh water samples, replicate water samples were collected at each point in a clean 1 litre container already rinsed out with the sample water for cationic, anionic and heavy metal analysis. Prior to collection of the water samples, the prevailing environmental condition of the town was studied. Two (2) drops of nitric acid were added to each sample to prevent formation of complexes (Schroll, 1976). Analytical procedures for physical and chemical parameters are generally in accordance with the specifications of American public health association (1998). Unstable parameters such as electrical conductivity (EC), pH, and temperature were measured in situ in the field with digitized meters. Already corked and secured samples (stored in a cooling system at about 5^0c) were transported to the laboratory for analysis within 24 hours. The field measurements and observations was followed by laboratory assessments, Atomic Absorption Spectrometry (AAS) method was used in determining the concentrations of Ca^{2+}, Mg^{2+}, K^+, Na^{2+}, Fe, Cu, Zn, Mn and Pb in the preserved water samples. SO_4^{2-}, HCO_3^-, Cl^-, NO_3^- and PO_4^{3} were determined by digital titration method.

3.0 Result and Discussion:

3.1 Hydrogeochemistry

The temperature of the groundwater in the study area range from 22^0c to 28^0c. The WHO does not recommend any limit values as ragards to water temperature, however, Ammar, Tiri, and Abdemahmane Boudoukha (2010), revealed that temperature higher than 15^0c facilitates the development of microorganisms and in the same time intensifies the organoleptical parameters such as odour and taste and activates chemical reactions. In the study area, the relatively warm temperature have probably aided chemical reactions; from the results obtained, the pH lies between 4.43 and 5.23 for borehole samples and 4.36 and 5.13 for handdug wells with a mean of 4.83 and 5.13 respectively. The groundwater here is slightly acidic to acidic with all the values falling below (NSDWQ, 2007) and (WHO, 2004) recommended values for drinking water (6.5-8.5). The low pH values indicates more hydrogen ion (H^+) availability (activity) in the study area. Consequently, the greater the availability of H^+ ions the lower the pH, the higher the electrical conductivity (EC) and total dissolved solids (TDS) in water; though, relatively high TDS in water might be due to increased residence time of the water in the aquifer allowing longer contact with the minerals. The greater the extent of its reaction with those minerals, the higher will be the content of dissolved minerals. This observation to some extent is observed by the hydrochemical result presented in tables 1&2, with EC values ranging from11 to 125.3µs/cm in handdug wells and 16.2 to 109µs/cm in boreholes.

Table 1: Physicochemical Analysis of Borehole Water samples (mg/l)

Parameters	BH1	BH2	BH3	BH4	BH5	BH6	BH7	BH8	BH9	WHO 2006
pH @ 25^0	4.67	4.46	4.43	4.95	4.75	5.07	4.93	5.23	5.02	6.5-9.0
TDS, mg/l	25.5	65.4	61.2	9.4	21.8	9.7	5.8	7.4	4.7	1500
T. Alka, mg/l	7.5	8	6.5	7.3	7	6.8	7.4	8.3	8.6	
T. Hard, mg/l	10.73	21.9	19.83	4	8	6	3.6	5.5	2.8	
Ca^{2+}	2.72	6.4	4.16	1.12	2.56	2.08	1.44	1.12	0.96	200
Mg^{2+}	0.96	1.44	2.3	0.29	0.38	0.19	0	0.67	0.1	150
Na^+	13.5	9	11.8	9.4	11	12	14.5	9.2	10.4	500
K^+	5	6	3	4	6	5	4	3	6	50
HCO_3^-	12.5	13.5	15.1	11.5	8.6	12	16.5	11.8	10.5	500
SO_4^{2-}	4.11	2.47	2.3	1.48	2.8	1.64	1.32	1.97	2.3	400
Cl^-	15.05	24.14	19.31	10.79	13.92	7.5	10.5	8.5	12.78	400
NO_3^-	15	13.5	10.5	9.8	13.4	20.1	16.3	10.4	8.5	45-50
PO_4^{3-}	0.08	0.06	0.07	0.04	0.03	0.05	0.1	0.09	0.15	10
Fe	0.25	0.2	0.02	0.03	0.02	0.75	0.4	0.2	0.1	0.3-1.0
Pb^{2+}	nil	nil	nil	nil	nil	nil	nil	nil	nil	0.05
Zn^{2+}	0.01	0.03	0.04	0.05	0.08	0.03	0.05	1	0.04	5
Cu^{2+}	0.08	0.04	0.05	0.12	0.03	0.05	0.04	0.01	0.02	0.05
Mn^{2+}	0.1	0.12	0.14	0.1	0.4	0.2	0.03	0.1	0.2	0.1
Elec. Cond.	42.5	109	102	15.7	36.3	16.2	9.67	12.63	7.8	1400

Table 2: Physicochemical analysis of Handdug Well samples (mg/l)

Parameters	HD1	HD2	HD3	HD4	HD5	HD6	HD7	HD8	HD9	HD10	HD11	WHO 2006
pH @ 25^0	4.92	4.47	4.73	4.36	4.7	5.01	4.6	5.8	5.9	5.5	5.6	6.5-8.5
TDS, mg/l	6.6	75.2	22.5	52.2	21.6	7.8	9.72	8.52	7.26	6.56	9	1500
T. Alka, mg/l	6.7	8	8.3	8.1	7.2	7.7	6.8	7.4	8.3	8.6	8	
T. Hard, mg/l	6	31.9	9.9	87	6.4	2.4	4.64	17.84	16.17	16.06	16.29	
Ca^{2+}	1.44	9.28	2.24	2.24	1.6	0.96	1.2	3.2	4.5	3.8	4.3	200
Mg^{2+}	0.58	2.11	1.06	1.06	0.58	0	0.4	2.4	1.2	1.6	1.35	150
Na^+	10	20.3	9.8	10.5	11	11.3	9.8	5.2	7	7.5	7.4	500
K^+	8	7	8	5	8	7	3.4	4.3	3.2	2	2.8	50
HCO_3^-	12.4	13.2	9.2	9.5	15.2	11.6	12.4	11.4	10.4	12.8	13.3	500
SO_4^{2-}	1.48	45.07	3.45	3.45	2.3	2.47	2	3	4	3	3.5	400
Cl^-	9.94	10.5	10.22	10.22	15.05	11.08	9.5	4	7	4.6	4.2	400
NO_3^-	18	17.4	18.6	19.5	15.4	15.7	13	10	12	10.5	12.6	50-70
PO_4^{3-}	0.2	0.02	0.08	0.04	0.06	0.07	0.7	0.6	0.9	0.05	0.08	10
Fe	0.09	0.08	0.06	0.02	0.04	0.05	0.01	0.02	0.01	0.02	0.01	0.3-1.0
Pb^{2+}	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	0.05
Zn^{2+}	0.08	0.05	0.04	0.06	0.04	0.05	0.04	0.06	0.04	0.05	0.04	5
Cu^{2+}	0.05	0.03	0.02	0.01	0.02	0.03	0.02	0.01	0.01	0.03	0.02	0.05
Mn^{2+}	0.1	0.3	0.1	0.12	0.1	0.1	0.4	0.2	0.3	0.1	0.1	0.1
Elec. Cond.	11	125.3	37.5	87	36	13	16.2	14.2	12.1	10.8	15	1400

The groundwater in the study area has TDS range of 6.6 to 7.2mg/l in handdug wells and 4.7 to 65.4mg/l in borehole. As per the TDS classification (Fetter, C. W., 1990), all the water samples are fresh water (TDS < 1000mg/l) type. Also, the total hardness (TH) measured as calcium carbonate (caco$_3$) range from 2.8 to 21.0mg/l in borehole and 2.4 to 31.9mg/l in handdug wells with the exception of sample no HD4 with a high TDS value of 87mg/l. According to McGowan, W. (2000), all samples from the study area are within the soft water category with TH as caco$_3$ less than 60mg/l. The low EC and TDS values, along with low TH values suggest a low mineralized soft fresh groundwater system with limited residence time. The concentration of the major cations of the groundwater system in the study area appear in the order of $Na^{2+} > K^+ > Ca^{2+} > Mg^{2+}$ with concentration ranges of 5.2 – 20.3, 2 – 8, 0.96 – 9.28, and 0 – 2.3, respectively whilst the anions follow the order of $NO_3^- > Cl^- > SO_4^{2-} > HCO_3^-$ (figs. 6 & 7). A few trace metals was also analyzed due to the oil and gas exploration activities in the area and follows the order of $Mn^{2+} > F > Zn^{2+} > Cu^{2+}$

3.2 Hydrochemical Facies:
The relative ionic composition of the groundwater in the study area in milli-equivalent per liter (meq/l) were calculated and employed in plotting the piper trilinear diagram in which the ions in milli-equivalent per liter are expressed in percentages of total cations and anions (Figs. 2&3), Whereas, the Schoeller diagram (Fig.4&5) as plotted using the major ion concentrations in milli-equivalent per liter (meq/l).
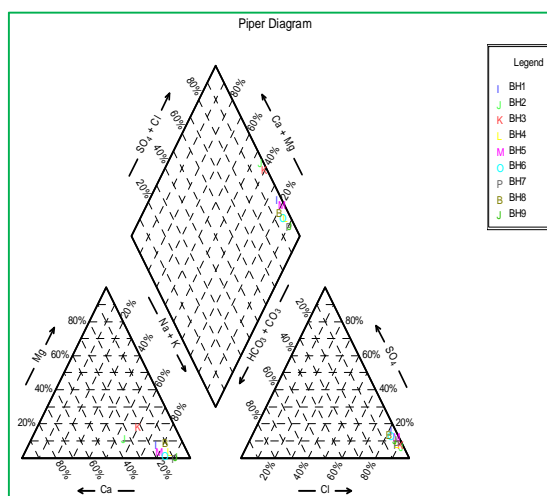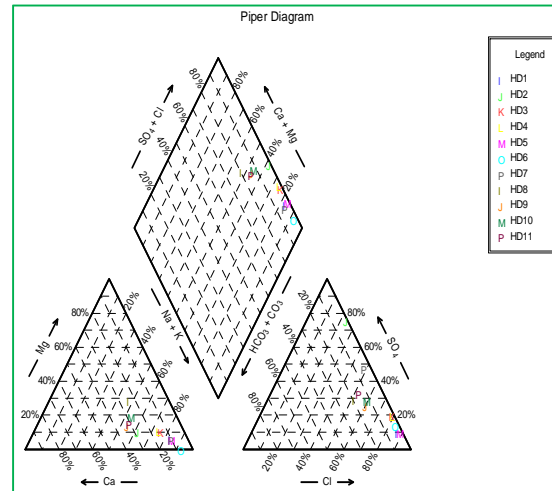

Fig. 3: PTD of borehole sample

Fig. 4: PTD of Handdug well samples

The values obtained from the analyzed samples and their plots on the Piper diagram revealed Na^+ as the dominant cation and Cl^- as the dominant anion. Based on Back, W. and Hanshaw, B (1965) water classification, the plot depicts the groundwater type in the study area as majorly Na(k)cl water type and a minor percentage as Cl + SO$_4$ water type.
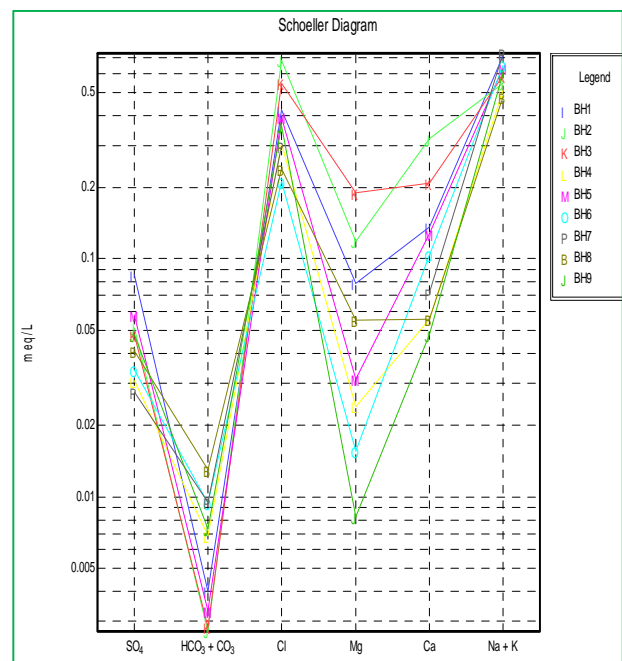

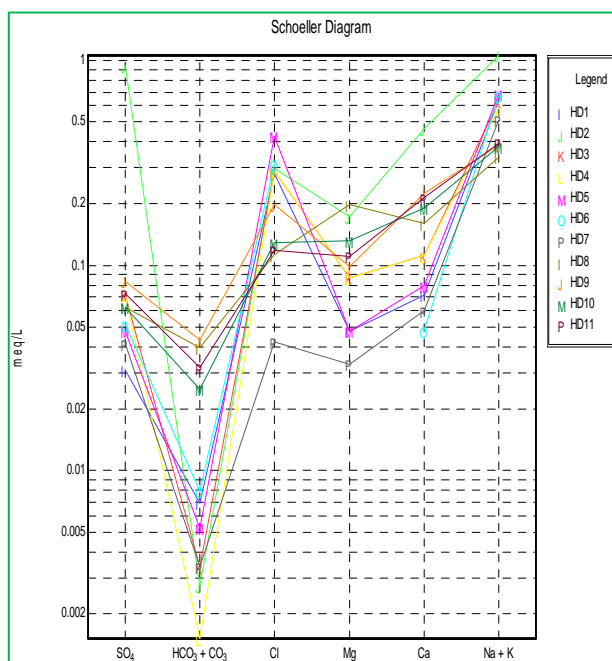**Fig. 5:** Schoeller diagram of BH samples

Fig. 6: schoeller diagram of HD sample

Furthermore, the Schoeller semi-logarithmic diagram (fig. 12) allows the major ions of many samples to be represented on a single graph; in which samples with similar patterns can be easily discriminated. Results of the Schoeller plots revealed Na^{2+} as the dominant cation and Cl^- as the dominant anion. It also reveals that the alkalis (Na + k) exceed the alkali earths (Ca + Mg) while the strong acids ($SO_4^{2-} + Cl^-$) exceed the weak acids ($HCO_3^- + CO_3$), therefore corroborating the classification of the Piper trilinear diagram.

3.3 Water Quality and Possible Sources of Pollution Domestic Uses:

Domestic (drinking and household) water criteria for this study are based on WHO (2006) standards for drinking water. All the water samples are tasteless odourless and colourless. The temperature varies from 22^0c to 28^0c with a mean value of 25^0c. The pH values range from 4.36 to 5.9 and has an average value of 4.96 interpreting the water in the study area to be slightly acidic to acidic. The pH values of all the water samples fall below the recommended value of NSDWQ and WHO standard for drinking water. The electrical conductivity (EC) values range from 11 t0 125.3µs/cm with an average value of 36.50µs/cm. all the water samples fall within WHO permissible level for EC depicting low concentration of dissolved ions in the water sample. The total dissolved solids (TDS) values in the water sample range from 4.7 to

75.2mg/l and falls within WHO (2006) recommended level and thus classifies itself as freshwater.

All samples according to McGowan, W (2000), are within the soft water category with the total hardness(TH) measured as calcium carbonate less than 60mg/l with the exception of sample HD4 with a higher TH value of 87mg/l thus classified under moderately hard water. There is no health based standard for the hardness of drinking water but the WHO has identified that water with hardness of 200mg/l or higher will produce scale and soft water with a value of 100mg/l or less will have a low buffering capacity and be more corrosive to pipes. A minimum of total hardness of 150mg/l is recommended by WHO (2004) because there is some limited evidence of relationship between hardness and cardiovascular health which may be related to the beneficial properties of magnesium and calcium in diet. Generally all the parameters were observed to be within the WHO (2004, 2006) standards for drinking water with the exception of pH values. However, a few trace metals tested showed Cu^{2+} exceeding its permissible limit in most of the borehole samples. This can be treated by the addition of coagulants and the use of reverse osmosis.

3.4 Agricultural Uses:

Water finds use in agriculture in two major ways; namely, livestock feeding and plant irrigation. Major criteria for suitability of water for irrigation purposes is as such, TDS < 1000mg/l and a reasonably low (< 10) sodium absorption ratio (SAR) values for the water (Davies and Dewiest, 1966; Driscoll, 1986; Mandell and Shiftan, 1991). Sodium concentration is important in classifying irrigation water because sodium reacts with soil to reduce its permeability and cause the soil to harden (Hamill and Bell, 1986; Todd, 1980; Hem, 1970 and Leeden et al., 1990). Alkali hazards in soils is promoted by water of high SAR values but could be reverted by water containing high proportion of calcium and magnesium (Hem, 1984). The result of this investigation reveals that the values of TDS, EC, and SAR in groundwater within the study area are < 100mg/l, < 200µs/cm and < 10 respectively. These therefore indicate suitability for all agricultural soils and most plant (crops). The major factor considered for the suitability of any water for livestock farming is the total dissolved solids. Based on the Australian standards for livestock water (Hamill and Bell, 1986),

water from the study area can be said to be suitable for livestock farming with TDS < 100mg/l. but, whilst specific water quality for individual animal may vary slightly, the non-conformity of pH values unless otherwise treated may not be suitable.

3.5 Industrial Use:

The quality guideline for industrial waters is given by the American Water Works Association (1971). These include for most industries: taste and odour (none - low), TDS (50 – 1500mg/l), total hardness as $caco_3$ (0-250mg/l), pH (6.5 – 8.3), chlorides (20-250mg/l), iron (0.1-1.0mg/l) and manganese (0-0.5mg/l). Groundwater from the study area lacks taste and odour, a comparison of the analysis results with the quality guidelines shows that the groundwater in the study area would be suitable for use in most industries after treatment for pH.

3.6 Pollution Tracer:

One very important concept which is used in pollution issues is that of a tracer concept. A tracer is a substance which is either naturally present, occurring in the water (natural tracers) or is introduced artificially to identify the flow path of water through the subsurface (artificial tracer). To further confirm the impact anthropogenous activities on the groundwater study of the area nitrate and pH are used. This two were selected based on the fact that the degradation of groundwater due to human contact (on-site sanitation and domestic/industrial effluent) could easily be traced using their relatively higher concentration and standard permissible value.

3.7 Acidity:

For pH (4.36-5.9) which falls below the recommended value for drinking water (6.5-8.5) it can be safely inferred that acid rain is the significant source in the study area. Rain and snow (the principal sources of ground water) have pH values near 5.6, if they are relatively free of pollution. However, in the study area gas flaring is currently being practiced by exploration companies in the study area and Acid rain can have pH values near 4. Ground water chemistry including pH could vary depending on the composition of the rocks and sediments that surround the travel pathway of the recharge water infiltrating to the ground water; and also on how long the existing ground water is in contact with a particular rock. The chemical composition of the bedrock tends to stabilize

(buffer) the pH of the ground water. The longer the contact time, the larger the effect of the rock chemistry on the composition and pH of the ground water. Ground water passing through carbonate-rich rocks (e.g., limestones and marbles) will usually have pH values greater than 7 as the acidic water is "neutralized." If the geology of the aquifer containing the ground water has few carbonate rocks (e.g., sandstones, metamorphic granitic schist and gneisses; volcanic rocks, etc.) the ground water will tend to remain acidic.

3.8 Nitrate:

Although, still within the permissible limit, groundwater nitrate is a global problem that is assuming serious dimensions in Nigeria. The most common contaminant identified in groundwater is dissolved nitrogen in the form of nitrate. Nitrate is becoming increasingly widespread because of agricultural activities and disposal of sewage on or below the land surface. The direct sources of nitrate in groundwater, originates as NO_3 from wastes or commercial fertilizers applied to land surface. In some other cases, nitrates by conversion of organic nitrogen or NH_4^- which occur naturally or are introduced into the soil zone by mans activities. Concentrations of nitrate in the range commonly reported for groundwater are not limited by solubility constraints. As a result of this and its anionic form, nitrate is very mobile in groundwater (Freeze and Cherry, 1979). In strongly oxidizing groundwater, NO_3^- is the stable form of dissolved nitrogen. It moves with the groundwater with no transformation and little or no retardation (Apello and Postma, 1996). Under natural conditions, the internal nitrogen cycle is virtually closed within the topsoil. However, environmental conditions exist under which natural leaching of nitrate from the soil zone takes place and natural accumulation occurs in groundwater. Precondition for nitrate accumulation relate to aspects of vegetation, rainfall, temperature, soil, geology and hydrology.

Generally, nitrate is a cause for concern in drinking water at levels greater than 10mg/l (NIS, 2007; USEPA, 2009). At concentration levels greater than this, there is an increased risk of babies developing infant methaemoglobinaemia, a disease commonly known as 'blue baby syndrome' (Canter, 1996). Clinical effects become obvious when drinking water containing nitrate in the neighbourhood of 50mg/l, other human health effect suspected to be caused or

aggravated by nitrate in take are, hypertension, the 'hot dog' headache, certain cancers, some birth defects (congenital malformations) and spontaneous abortions (Spaiding and Exner, 1993).

4.0 Conclusion:

The results from this study, indicates groundwater of low TDS and pH. Although these attributes are typical of tropical regions of high rainfall and abundant flora (Rose at al., 1979), the low pH is a cause for concern with respect to human activity induced pollution. The abundant rainfall (> 2000mm) experienced yearly in the study area ensures a continuous leaching of sediments thereby reducing its soluble components with time. This in addition to the significant dilution of groundwater resulting from abundant recharge by precipitation, and rapid circulation of water through the soil because of the high permeability and porosity probably account for the low solute concentration of groundwater in the study area. The water type encountered in the study area are Na(K)Cl and Cl+SO$_4$. The chloride type suggests water rock interaction and the dissolution of formation water accompanied by some cation exchange activities. Studies of groundwater chemistry in areas with contrasting topography have revealed that the chemical facies of groundwater could also be influenced by topographic setting (Raji and Alagbe, 2000; Adams et al., 2001). In topographic highs (hills and upslope areas), that represent areas of recharge, bicarbonate water accompanied by low TDS can be dominant. Middle slope locations often contain significant bicarbonate-chloride water. In down slope areas (valleys and plains), where groundwater is relatively static, sulphate-chloride facies with concomitant increase in TDS values are often noticed. Although categorized (study area) as part of the down slope area this study does not as such reveal such association in the groundwater chemistry. This may imply that the influence of this factor is minimal in the study area and/or has been effectively masked by the activities of other factors.

Deductions from the study indicate that the groundwater is generally suitable for irrigation purposes; nevertheless, appropriate pH remediation is needed to upgrade its quality to industrial and domestic standard. Inferences from the analysis suggest an on-set of aquifer contamination from agricultural related activities. However, the potential exists for extensive further impacts from continuous use of nitrogen-rich fertilizers such as NPK and livestock manure that ensures adequate agricultural yield plus poor sanitation habits, uncontrolled and indiscriminate disposal of wastes and other activities. Although the nitrate level in groundwater is still within the WHO maximum permissible limits, the possibility of a rise in its concentration is a potential cause for concern.

Recommendations

Sequel to this study, a few recommendations have been drawn up based on the results and findings. These include- Proper town planning, Creating awareness for groundwater quality protection, The need for improved Regulations. Among the identified needs are; Improvements in the drinking water standards, Improved handling of 'special' wastes, and tighter monitoring requirements.

Other recommendations include

Reduction in nitrogen-rich fertilizer application or the use of alternative slow-release fertilizers may help to mitigate this contamination trend (Montgomery, 1992). Water should be treated for pH possibly by the use of neutralizing filters (ground limestone or magnesia) or solutions (lime or soda ash) to raise the pH by stripping dissolved CO_2 (carbonic acid) from the water in order to make them safe for drinking. PVC materials and other non corrosive materials should be used for borehole construction in the area, because acidic waters could be very aggressive (Hem, 1985). However, further studies should be carried out to include microbial investigation, a detailed trace or heavy elements composition and air quality analysis to further ascertain the water quality and most probable source of degradation in groundwater quality of the study area and recommend necessary treatment and mitigation measures.

5.0 Acknowledgement:

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