Hydrogeochemical Assessment of Groundwater Quality in Federal Housing Estate, Lugbe, Abuja, Nigeria

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Abstract

Groundwater quality is influenced by the local geology through which it migrates as well as the domiciled anthropogenic activities in the area and it is a function of time. The quality status of groundwater from shallow aquifers within Federal Housing Estate Lugbe, Abuja was investigated using physical, chemical and bacteriological parameters. A total of 35 groundwater samples from shallow aquifers within the depth range of 10 m to 30 m were collected in the month of October, 2015. Prior to the sampling, physical parameters were determined insitu using relevant instrument. The water sampling and analysis were done in accordance with the APHA standards. The results of the laboratory analysis revealed that the concentration of the major cations and anions falls within the permissible limit of World Health Organization and Nigerian Standard for Drinking Water Quality. The hydrochemical facies analysis revealed that water type in the area is Ca-HCO_3-facies. However, concentration of nitrate, iron, copper, zinc and lead in few locations within the study area were slightly higher than their respective maximum allowable limit. This may be attributed to urban pollution arising from dumpsite, soakaways, fertilizer application as well as chemical weathering and bedrock dissolution. Bacteriological, the groundwater in Federal Housing Lugbe is very poor and need boiling before use as faecal bacteria do not withstand high temperature. The siting of well close to soakaways should be discontinued and good sanitary practice in the area is advocated.

Keywords: *Assessment, Groundwater Quality, Federal Housing Estate, Lugbe, Abuja, Nigeria*

Introduction

The quality of groundwater is a function of its chemical composition and is greatly influenced by the local geology and anthropogenic activities domiciled in the area. Improper waste management which is common in most developing countries such as Nigeria has greatly affected the groundwater resources in terms of quantity and quality. Every effort should be made to safeguard the quality of groundwater because one cannot restore the quality of a contaminated groundwater by removing the pollutants from source (Amadi *et al.*, 2013a). It is not good for man to negatively affect the source of water through his activities on the surface of the earth in order to guarantee the availability of groundwater to meet our water needs both now and in the future. Human activities on the environment bring disorder on the supply of water, quality and creates unhealthy environment for man (Egharevba *et al.*, 2010). Amadi *et al* (2012a) drew attention on the human need for groundwater in the world and the implication on human health if contaminated. The quality of groundwater is mainly controlled by the range and type of human influence as well as geochemical, physical and biological processes occurring in the ground (Tijani *et al.*, 2004; Nouri *et al.*, 2008; Sekabira *et al.*, 2010). The need to regularly monitor water quality in the overall interest of the general public basically informed this study.

Description of the Study Area

The area lies between longitude 7°20'45"E to 7°25'10"E and latitude 8°55'35"N to 9°05'10"N on Kuje Sheet 207 Northeast and was studied on a scale of 1:50,000 (Fig. 1). The area has good road network and the drainage system are dilapidated. The area is characterized by the gently undulating terrain comprising of gently rising hills and valley. The study area falls within the Basement Complex rocks of North-Central Nigeria with the main rock units as granites, granite-gneiss and gneiss. The rocks are generally weathered into reddish sandy clay-to-clay materials with high content of mica flakes, capped by laterite. Basement complex rocks do not inherently make good aquifers, but their hydrogeologic characteristics can only be enhanced when the rocks are fractured or weathered (Ajibade and Woakes, 1983; Dan-Hassan, 2013; Ofodile, 2002).

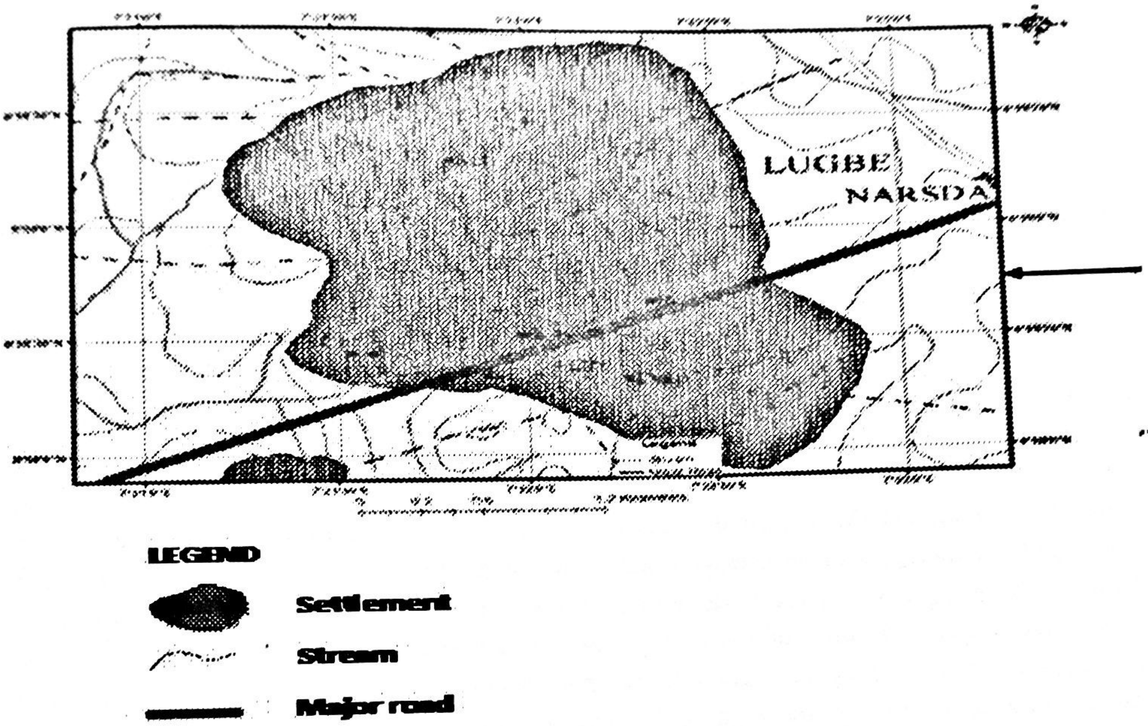

Fig. 1: Map of the study area

Materials and Methods

A total of 35 groundwater samples from shallow aquifers within the depth range of 10 m to 30 m were collected in the month of October, 2015. At every location, a glass container was used to collect water sample for the cation analysis while a plastic container was used for the anion analysis. The samples in the plastic containers were sealed with a drop of trioxonitrate (v) acid (HNO3) to ward off atmospheric interference, homogenize the water samples and to prevent the growth of algae or microbial organism as well as to prevent the metallic ions from adhering to the walls of containers. Samples were properly covered and put into a cooler containing ice while in the field and finally preserved in a refrigerator at 0 °C in order to prevent loss of ions where possible from reactions within the collected samples. Physical parameters temperature, pH and colour were measured in the field using portable HACH meters. Samples were analysed using the APHA (2008) standard method. Anions were determined using titration method while cations were determined using AAS. The microbial analysis was determined using incubation method. In order to know the dominant water type and probable source, Piper and Schoeller plots were used in the classification.

Results and Discussion

The statistical results of the physico-chemical and bacteriological analysis of groundwater samples are contained in Table 1. The pH ranged between 4.40 and 7.60 with a mean value of 6.2 while temperature of the groundwater ranged from 26.10 °C to 31.80 °C with an average value of 29.40 °C. The pH is an indicator of water quality and the extent of pollution. The pH values in some location are slightly acidic. Low pH enhances chemical reaction in water as well as dissolution and mobility of metals in water. Temperature is an important water quality parameter which plays a major role in the solubility of materials in water. The mean pH of the groundwater falls below the acceptable range of 6.50-8.50 recommended by Nigerian Standard for Drinking Water Quality (NSDWQ, 2007). Many biochemical processes in water are influenced by changes in pH and temperature and chemical substances dissolve more readily in water under low pH and high temperature conditions (Ibe *et al.*, 1992; Amadi and Nwankwoala, 2013; Okunlola *et al.*, 2015; Nwankwoala *et al.*, 2015; Okunlola *et al.*, 2016; Singh *et al.*, 2008). Total dissolved solids (TDS) indicate the general nature of water quality. Its concentration in groundwater ranged between 6.00 mg/l to 980.00 mg/l and a mean concentration of 255.00 mg/l while the concentration of electrical conductivity (EC) varied from 8.00 mg/l to 1340.00 mg/l with an average value of 301.80 mg/l (Table 1). The EC and TDS are valuable indicators of the amount of materials dissolved in water. The wide range observed in EC and TDS are signatures of the large scale urbanization taking place in the area. The biochemical oxygen demand (BOD) is a measure of the amount of oxygen required to oxidize organic matter by bacterial action.

The study of BOD gives an idea of the oxidizable matter actually present in water sample and allows pollution load evaluation to be established (Amadi *et al.*, 2013b). The concentration of BOD ranged between 2.00 mg/l to 8.40 mg/l with a mean value of 5.60 mg/l. The values are within the recommended limit of water for domestic use (WHO, 2010). The concentration of chloride in the groundwater ranged between 0.60 mg/l to 98.20 mg/l with an average value of 26.6.00 mg/l while sulphate concentration varied from 0.10 mg/l to 94.4 mg/l with a mean value of 11.8 mg/l (Table 1). These values are below their respective maximum permissible limit of 250.00 mg/l and 100.00 mg/l chloride and sulphate (NSDWQ, 2007). High chloride and sulphate concentration in groundwater may be anthropogenically induced through sewage, industrial waste or fertilizer application or geogenically via chemical weathering and bedrock dissolution as well as salt intrusion (Olasehinde *et al.*, 2016; Amadi *et al.*, 2016).

Table 1: Statistical Summary of the physico-chemical and Bacteriological Analyses

Parameters (mg/l)	Groundwater Range	Mean	NSDWQ, (2007)
Temp. °C	26.10 – 31.18	29.40	Ambient
pH	4.40 – 7.60	6.20	6.50 – 8.50
EC, µS/cm	8.0 – 1340.00	301.80	1000.00
TDS	6.0 – 980.00	260.40	500.00
Calcium	2.0 – 118.00	32.60	200.00
Magnesium	0.2 – 47.40	10.20	200.00
Sodium	1.0 – 70.50	22.80	250.00
Potassium	0.2 – 75.00	18.50	100.00
Bicarbonate	2.0 – 320.00	80.20	150.00
Chloride	0.6 – 98.20	26.60	250.00
Sulphate	0.10 – 94.40	11.80	100.00
Nitrate	0.20 – 65.00	18.60	50.00
Iron	0.01 – 0.8	0.34	0.30
Copper	0.03 – 0.45	0.18	1.00
Zinc	0.01 – 0.34	0.11	3.00
BOD	2.0 – 8.40	5.60	6.00
Manganese	0.01 – 0.28	0.14	0.20
Lead	0.01 – 0.56	0.015	0.01
T. coliform	10.00 – 248.00	130.00	10.00
E. coli	0.00 – 84.00	36.00	0.00
Sal. typhi	0.00 – 55.00	11.00	0.00

EC-electrical conductivity, TDS-total dissolved soilds, T.coliform-total coliform

The concentration of nitrate ranged between 0.02 mg/l to 65.00 mg/l with a mean value of 18.6 mg/l while the concentration of phosphate varied from 0.80 mg/l to 14.60 mg/l with an average value of 5.12 mg/l (Table 1). Nitrate values in some locations were slightly higher than the maximum permissible limit of 50.00 mg/l (NSDWQ, 2007). High nitrate level in drinking water causes infant methaemoglobinaemia (blue-baby syndrome), gastric cancer, metabolic disorder and livestock poisoning. The sources of nitrate and phosphate in the groundwater can be attributed to anthropogenic activities such as on-site sanitation, waste dumpsites and fertilizer application (Dan-Hassan *et al.*, 2012; Amadi *et al.*, 2015). In this study, the sodium ion content ranged between 1.00 mg/l to 70.50 mg/l with a mean content of 22.80 mg/l while potassium varied from 0.20 mg/l to 75.00 mg/l with an average value of 18.5 mg/l (Table 1). These concentrations are within the allowable limit of 200.00 mg/l and 100.00 mg/l for sodium and potassium respectively (NSDWQ, 2007). Studies have revealed that sodium is a major risk factor in drinking water. In epidermiological studies, a direct correlation between hypertension and sodium level in drinking water has been observed while the noxious effects of Na on blood vessels have been known for years (Pascual *et al.*, 2004). Though high sodium content in water may not be harmful to living matter due to the non-toxic nature of the metal, balance among other nutrient elements may affect the soil used for agricultural purposes (Nwankwoala and Amadi, 2013; Okunlola *et al.*, 2014).

The concentration of calcium varied between 2.00 mg/l to 118.00 mg/l with a mean value of 32.60 mg/l while magnesium concentration ranged from 0.2 mg/l to 47.40 mg/l with an average value of 10.20 mg/l. These values are within the permissible limit of 200.00 mg/l (NSDWQ, 2007). Calcium is necessary in animals for the formation of strong tooth and bone and its high concentration in water does not have any negative impact on health. The presence of calcium and magnesium in water is responsible for water hardness and conductivity. Studies have shown that magnesium in water is better and more quickly absorbed than dietary Magnesium. Epidemiological data in man and experimental data in rats have demonstrated that the intake of water containing sufficient amount of magnesium can prevent arterial hypertension and correlated ionic and nervous disturbances (Singh *et al.*, 2008; Amadi *et al.*, 2014). The concentration of iron in the groundwater ranged from 0.01 to 0.80 mg/l with a mean value of 0.34 mg/l while the concentration of zinc varied between 0.01 mg/l and 0.34 mg/l with an average value of 0.11 mg/l (Table 1) against the maximum recommended value of 0.30 mg/l and 3.0 mg/l, respectively (NSDWQ, 2007). Iron is an essential nutrient that is vital to the processes by which cells generate energy. High iron content in water does not constitute any health problem; rather it affects the colour and taste of the water (Amadi *et al.*, 2012b). Because iron can exist in different ionic states, iron can serve as a cofactor to enzymes involved in oxidation-reduction reactions.

Lead is defined by the United States Environmental Protection Agency (USEPA) as potentially hazardous to most forms of life, and is considered toxic and relatively accessible to aquatic organisms (USEPA, 1997). The lead concentration in the groundwater ranged between 0.001 to 0.56 mg/l with an average value of 0.015 mg/l (Table 1). The values were far higher than the maximum permissible limit of 0.01 mg/l (NSDWQ, 2007). High concentration of lead in the groundwater may be attributed to the various anthropogenic activities domiciled in the area. Studies have shown that lead is naturally available in all environmental media (atmosphere, biosphere and hydrosphere) varying concentrations. It is carcinogenic and affects several organs of the human body, including the nervous system, the blood system, the kidney, the cardiovascular system and the reproductive system. Prenatal exposure of lead was also demonstrated to produce toxic effects in the human fetus, including reduced birth weight, disturbed mental development, spontaneous abortion and premature birth. Such risks were significantly greater at blood lead level of 15 μg/l and more (WHO, 2010). The concentration of Cu ranged between 0.03 to 0.45 mg/l with an average concentration of 0.18 mg/l. and the value are below the maximum permissible limit recommended value of 1.00 mg/l (NSDWQ, 2007). The higher value in parts of the area indicates an anthropogenic addition from industrial effluents and dumpsites. Gastrointestinal disorder in human can be due to elevated copper concentration in drinking water (USEPA, 1997). The concentration of Manganese ranged from 0.01-0.28 mg/l with an average value of 0.14 mg/l (Table 1). Some locations have values higher than the WHO and NSDWQ acceptable limit of 0.2 mg/l. Decomposition and subsequent leaching of industrial effluent are probable sources of groundwater enrichment in Mn. Manganese is essential for plants and animals, and are used in products such as batteries, glass and fireworks (Aboud and Nandini, 2009). The concentration of Escherichia coli (E.coli) ranged between 0.00-110.00 cfu/100ml with an average value of 36.00 cfu/100ml while total coliform (TC) varied from 10.00-248.00 cfu/ml and a mean value of 36.00 cfu/ml (Table 1). The concentration of salmonella typhi is in the order of 0.00 cfu/100ml to 55.00 cfu/100ml with a mean value of 11.00 cfu/100ml. Their presence in groundwater is an indication of faecal contamination. The practice of unlined pit-latrine and soakaway in shallow aquifer exposes the groundwater to faecal contamination and good sanitary system is advocated for the area due to the vulnerability of its aquifer system.

Hydrochemical Facies Classification

Piper Diagram

This method was devised by Piper to outline certain fundamental principles in a graphic procedure which appears to be an effective tool in separating analytical data for critical study with respect to sources of the dissolved constituents in water. Piper diagram consists of three parts: two trilinear diagrams along the bottom and one diamond-shaped diagram in the middle. The trilinear diagram illustrates the relative concentration of cations (left diagram) and anions (right diagram) in each sample. The concentration of 8 major ions (Na^+, K^+, Mg^{2+}, Ca^{2+}, Cl^-, CO_3^{2-}, HCO^-_3 and SO_4^{2-}) are represented on a trilinear diagram by grouping the K^+ with Na^+ and the CO_3^{2-} with HCO^-_3, thus reducing the number of parameters for plotting to 6. On the Piper diagram, the relative concentration of the cations and anions are plotted in the lower triangles, and the resulting two points are extended into the central field to represent the total ion concentrations. The degree of mixing between freshwater and saltwater can also be shown on the Piper diagram. The Piper diagram (Fig. 2) can also be used to classify the hydrochemical facies of the groundwater samples according to their dominant ions. The water type in the area is Ca-HCO_3-facies, indication of fresh shallow water from a basement complex terrain.

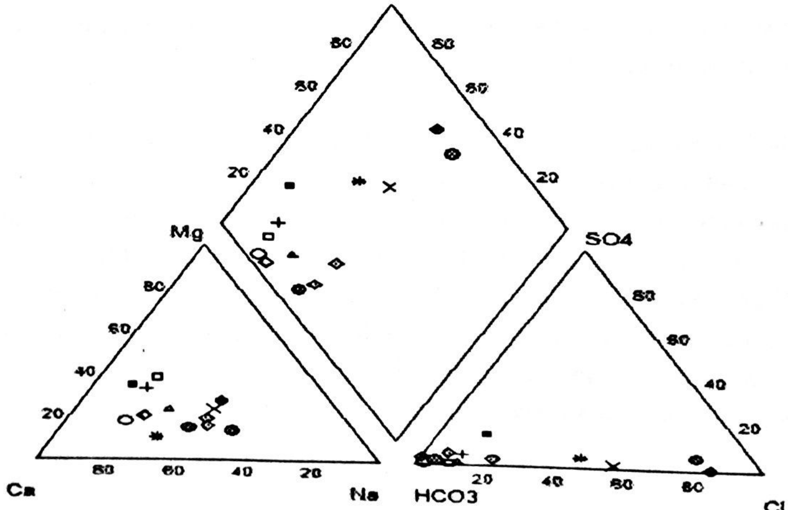

Fig. 2: Piper Diagram for the Study Area

Schoeller-Plots

These semi-logarithmic diagrams were developed to represent major ion analyses in meq/l and to demonstrate different hydrochemical water types on the same diagram (Fig. 3). This type of graphical representation has the advantage that, unlike the trilinear diagrams, actual sample concentrations are displayed and compared. The schoeller plot allows for comparism among parameter in attempts to quantify the water source and type. Based on the Piper diagram (Fig. 2) and schoeller plot (Fig. 3), It can be established that the dominant cations and anions in the groundwater from shallow aquifer in Lugbe are calcium and bicarbonate respectively. Studies have attributed calcium-bicarbonate water type as characteristics of groundwater from shallow basement aquifer (Adelana and Olasehinde, 2003; Dan-Hassan *et al.*, 2012; Nwankwoalao *et al.*, 2014).

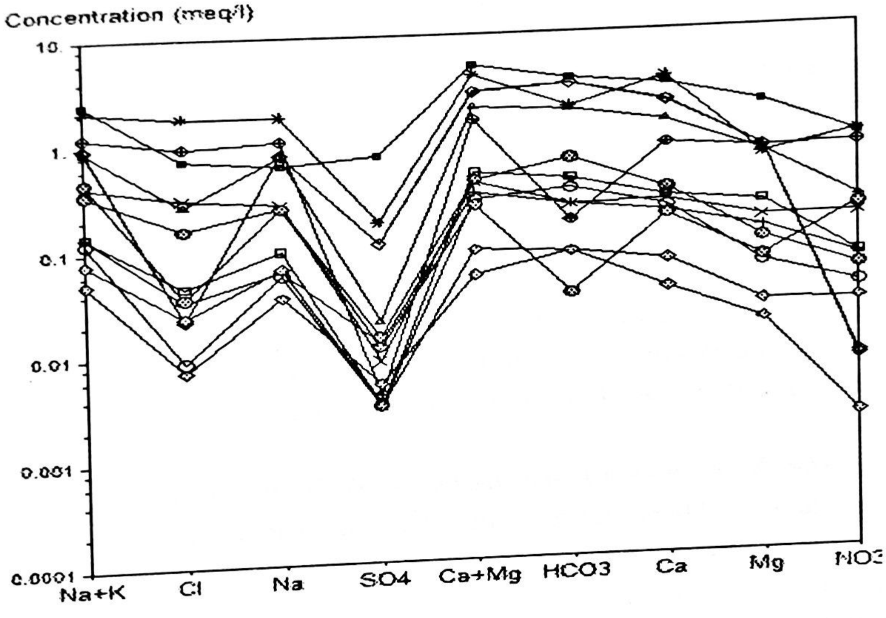

Fig. 3: Schoeller Plot for the area

Conclusion

Results of the laboratory analysis indicate the the concentration of the major cations and anions are within the permissible limit recommended by Nigerian Standard for Drinking Water Quality. The hydrochemical facies analysis revealed that water type in the area is Ca-HCO_3-facies, indication of fresh shallow water from basement complex terrain. The concentration of nitrate, iron, copper, zinc and lead in few locations were slightly above their respective maximum allowable limit. This may be attributed to urban pollution arising from dumpsite, soakaways, fertilizer application as well as chemical weathering. Bacteriological, the groundwater in Federal Housing Lugbe is poor due to faecal contamination of the water due to poor hygiene. Due to the poor bacteriological conditions of the groundwater, boiling of water before drinking is advocated as most bacteria do not withstand high temperature. The need to sensitize the people on the importance of personal hygiene and good sanitation is recommended. Enforcement of environmental laws aimed at protecting groundwater resources is advocated.

Reference

Aboud, S. J. and Nandini, N., (2009). Heavy metal analysis and sediment quality values in urban lakes. *American Journal of Environmental Science*, 5(6), 678 – 687.

Adelana, S.M.A. and Olasehinde, P.I. (2003). High Nitrate in water supply in Nigeria.

Implications for human health. "Water Resources" *Journal of the Nigerian Association of Hydrogeologists (NAH)*, 14, 1 – 11.

Ajibade, A.C. and Woakes J.B. (1983). Structural Relationship in Schist Belts of Northwestern Nigeria. In P.O. Oluyide, W.C. Mbonu, A.E. Ogezi, I.G. Egbuniwe, A.C. Ajibade and A.C. Umeji (Eds.). *Precambrian Geology of Nigeria*, (pp. 103-110). Kaduna, Geological Survey of Nigeria.

Amadi, A. N., Nwankwoala, H. O., Olasehinde, P. I., Okoye, N. O., Okunlola, I. A. and Alkali, Y. B. (2012a). Investigation of aquifer quality in Bonny Island, Eastern Niger Delta, Nigeria using geophysical and geochemical techniques. *Journal of Emerging Trends in Engineering and Applied Sciences*, 3(1), 180 – 184.

Amadi, A.N., Olasehinde, P.I., Okosun, E.A., Okoye, N.O., Okunlola, I.A., Alkali, Y.B.and Dan Hassan, M. A. (2012b). A Comparative Study on the Impact of Avu and Ihie Dumpsites on Soil Quality in Southeastern Nigeria. *American Journal of Chemistry, 2 (1): 17-23.*

Amadi, A. N. and Nwankwoala, H. O. (2013a). Evaluation of Heavy Metal in Soils from Enyimba Dumpsite in Aba, Southeastern Nigeria Using Contamination Factor and Geo-Accumulation Index. *Energy and Environment Research*, 3(1), 125 – 134. doi:10.5539/eer.v3n1p125.

Amadi A. N., Dan-Hassan M. A., Okoye N. O., Ejiofor I. C. and Aminu T. (2013b). Studies on Pollution Hazards of Shallow Hand-Dug Wells in Erena and Environs, North-Central Nigeria. *Environment and Natural Resources Research*, 3(2), 69 – 77.

Amadi, A. N., Ameh, I. M., Ezeagu, G. G., Angwa, E. M. and Omanayin, Y. A. (2014). Bacteriological and Physico-chemical Analysis of Well Water from Villages in Edati, Niger State, North-central Nigeria. *International Journal of Engineering Research and Development*, 10(3), 10 – 16.

Amadi, A. N., Okunlola, I. A., Dan-Hassan, M. A., Aminu T. and Ola, O. (2015). Evaluation of Groundwater Quality in Shallow Aquifers in Minna, North-Central Nigeria using Pollution Load Index. *Journal of Natural Sciences Research*, 5(8), 45 – 56.

Amadi, A. N., Olasehinde, P. I., Agwuncha, S. C., Nwankwoala, H. O., Shaibu I. and Okoye, N. O. (2016). Investigating the Quality Status of Groundwater in parts of Eastern Niger Delta for Irrigation Purposes. *Development Journal of Science and Technology Research*. 5(2), 81 – 87.

APHA, (1998) Standard methods for examination of waterand waste water (20th. Ed.). Washington DC: AmericanPublic Health Association.

Dan-hassan, M.A. (2013). Some Aspect of Hydrogeology of FCT, Abuja, Nigeria. An Unpublished Ph.D. Thesis, Federal University of Technology, Minna, Nigeria.

Dan-Hassan, M.A., Olasehinde, P.I., Amadi, A.N., Yisa, J. and Jacob, J.O., (2012). Spatial and Temporal Distribution of Nitrate Pollution in Groundwater of Abuja, Nigeria. *International Journal of Chemistry 4 (3)*, 39-48.

Egharevba, N. A., Amadi, A. N., Olasehinde, P. I. and Okoye, N. O., (2010). Seasonal variation in the physico-chemical and bacteriological characteristics of perched aquifer water from Zaria, North-Central Nigeria. *International Journal of Chemical Sciences*, 3(1), 100 – 107.

Huang, K. and Lin, S., (2003). Consequences and implication of heavy metal spatial in sediments of Keelung River drainage basin, Taiwan. *Chemosp*. 53, 1113–1121, doi: 10.1016/S0045-6535(03)00592-7.

Ibe, K. M., Sowa, A. H. O. and Osondu, O. C., (1992). Environmental contamination and other anthropogenic impacts on Otamiri and Nworie rivers in Owerri, Nigerian. *Journal of Mining and Geology*, 28(1), 87-91, ISSN: 1116 – 2775.

Nouri, J., Mahvi, A. H., Jahed, G. R. and Babaei, A. A., (2008). Regional distribution pattern of groundwater heavy metals resulting from agricultural activities. *Environmental Geology*, 55(6), 1337-1343.

NSDWQ, (2007). Nigerian Standard for Drinking Water Quality. Nigerian Industrial Standard, NIS:554, 1-14.

Nwankwoala, H. O. and Amadi, A. N., (2013). Hydro-geochemical Attributes and Quality Status of Groundwater in Port Harcourt, Eastern Niger Delta. World Journal of Science and Technology Research, 1(7), 151 – 167.

Nwankwoala, H.O., Amadi, A.N., Oborie, E. and Ushie, F.A. (2014). Hydrochemical Factors and Correlation Analysis in Groundwater Quality in Yenagoa, Bayelsa State, Nigeria. *Applied Ecology and Environmental Sciences*, 2(4), 100 – 105, doi:10.12691/aees-2-4-3.

Nwankwoala, H. O., Nwaogu, C., Bolaji, T. A., Uzoegbu, M. U., Abrakasa, S. and Amadi, A. N., (2015). Geochemistry and Quality Characterization of Effon Psammite Ridge Spring Water, Southwestern Nigeria. Journal of Geology and Geophysics, 4(6), 229 – 237.

Offodile, M. E. (2002). Groundwater study and development in Nigeria. *Mecon Geology and Engineering Service Limited*, Jos, Nigeria, (2nd Ed.), 239-244.

Okunlola I. A., Amadi A. N., Idris-Nda A., Agbasi K. and Kolawole L. L. (2014). Assessment of Water Quality of Gurara Water Transfer from Gurara Dam to Lower Usuma Dam for Abuja Water Supply, FCT, Nigeria. *American Journal of Water Resources,* 2(4), 74 – 80,

Okunlola, I. A., Amadi, A. N., Olashinde, P. I., Maspalma, S. S. and Okoye, N. O. (2016). Quality Assessment of Groundwater from Shallow Aquifers in Hong Area, Adamawa State, Northeastern Nigeria. *Ife Journal of Science,* 18(1), 267 – 283.

Pascual, B., Gold-Bouchot, G., Ceja-Moreno, V. and Del Ri'o-garci'a, M., (2004). Heavy metal and hydrocarbons in sediments from three lakes from san Miguel, Chiapas, Mexico. Bull. *Environmental and Contamination and Toxicology*,73, 762–769.doi:10.1007/s00128-004- 04910.

Sekabira, K., Oryem-Origa, H., Basamba, T. A., Mutumba, G. and Kakudidi, E., (2010). Assessment of heavy metal pollution in the urban stream sediments and its tributaries. *International Journal of Environmental Science and Technology*, 7(3), 435-446.

Singh, A. K., Mondal, G. C., Kumar S., Singh, T. B., Tewary, B. K. and Sinha, A., (2008). Major ion chemistry, weathering processes and water quality assessment in upper catchment of Damodar River basin. *Indian Environmental Geology*, 54(4), 745-758.

Tijani, M. N., Jinno, K. and Hiroshiro, Y., (2004). Environmental impact of heavy metal distribution in water and sediment of Ogunpa River, Ibadan area, southwestern Nigeria. *Journal of Mining and Geology* 40(1), 73–83.

World Health Organisation, (2010). Assessment of fresh water quality–Global environmental monitoring system (GEMS). *A report on the related environmental monitoring*, World Health Organization, Geneva, 357-362.