Investigation of Groundwater Quality in parts of Onitsha, Southeastern Nigeria

B.A. Igbomor and A.N. Amadi*

Department of Geology, Federal University of Technology, Minna, Nigeria.

E-mail: geoama76@gamil.com*

ABSTRACT

The physico-chemical and microbial characteristics of water defines its quality. The groundwater quality in Onitsha was investigation in the present study from the point-view anthropogenic interference. The concentrations of the major ions were found to be below the recommendations by Nigeria Standard for Drinking Water Quality (NSDWQ) and World Health Organization (WHO) except chloride. High chloride content in groundwater may be an indication of urban groundwater contamination as well as proximity to marine source.

The water type in the area as revealed from Piper Diagram is calcium-chloride type. The pH of the groundwater is slightly acidic, and it explains the paucity of carbonates in the groundwater system in the area. Carbonates are easily converted to bicarbonates under acidic condition. The concentrations of iron, lead, manganese, chromium and cadmium in the groundwater were found to be 73.3%, 23.3%, 20.0%, 13.3% and 10.0% respectively higher than their maximum permissible limit by NSDWQ and WHO. The slightly acidic medium enhances the dissolution, release and migration of these metals into the auriferous system. Based on the Water Quality Index (WQI), the groundwater in the area was categorized into 5 ranging from excellent water (24%), good water (27%), poor water (17%), very poor water (24%) and water unsuitable for drinking (10%).

High concentration of chloride, iron, lead, manganese, chromium and cadmium in the groundwater in some locations are responsible for the poor water quality in the area. It can be attributed for the huge human activities going on in the area. The spatial distribution of WQI shows that wells close to dumpsites or untreated industrial effluent are deteriorated with respect to quality. Metal pollution index (MPI) indicates that iron lead and manganese show moderate pollution status while chromium and cadmium reflect light pollution. The results MPI agreed with the findings of WQI, which confirms the efficacy of these models in groundwater pollution studies.

(Keywords: groundwater, assessment, Onitsha, southeastern Nigeria)

INTRODUCTION

Groundwater is the water found in the intercalated pore spaces saturated in the subsurface below the water table. It accounts for about 98% of the world's available fresh water and is the most valuable resources for various activities of man. The chemistry of groundwater is influenced majorly by the mineralogy of the host rock, the residence time and the anthropogenic activities dominant in the area [1, 2].

In most developing countries of the world like Nigeria, due to high population in most urban centers there is increase in industrial and human activities coupled with environmental degradation and indiscriminate refuse disposal tend to make groundwater vulnerable to contamination, [3, 4, 5, 6, 7, 8, 9, 10]. Groundwater is the most sort after in most cities in Nigeria as a result of paucity of surface water and the broken down of public water supply has led to the increase in demand of groundwater due to its protective nature and indirect contact with the surface [2].

A World Health Organization (WHO) [11] report estimates that more than a billion people globally lack access to potable water and sanitation, with most of them in Sub-Sahara Africa. Drinking polluted water increases the risk of cholera, typhoid fever, hepatitis, increased blood pressure and metabolic poison [12, 13, 14] Although they are treatable and preventable, they are the number one killer disease in Africa [11]. Many chemical constituents of groundwater can potentially cause adverse human health effects, the detection of these constituents in water is often slow, difficult and expensive which limits early warning capability and affordability.

Reliance on water quality determination alone is not enough to protect public health because it is not economically feasible to test all drinking water quality parameters, thus the use of monitoring effort should be employed. The study area is a densely populated commercial nerve center in southeastern Nigeria host to many industries and markets, with serious sanitation pose by these industries and markets. The urban population depend on groundwater for drinking and domestic purposes. The objective of this paper is to discuss the physicochemical parameters based on compliance the of the groundwater in Onitsha to Nigeria and WHO standard for drinking water quality and the use of Water Quality Index (WQI) and Metal Pollution Index (MPI) to access the overall quality rating the groundwater in the study area.

MATERIALS AND METHODS

Location, Geology, and Hydrogeology of the Area

The study was carried out in Onitsha area, located in the southeastern part of Nigeria. The area extent of the study area is approximately 46.65 km^2 and bounded within Latitudes 6°6' 00'' N to 6°9'30'' N and Longitudes 6°46'00'' E to 6°50' 00'' E in the topographical map of Nigeria, sheet 300. (Figure 1). Located within the tropics with two prominent seasons. The dry and wet season, April to October is the period of rainfall with average monthly rainfall of 2000 mm. The dry season is between November to March. The mean annual rainfall is between 1,500 mm to 2,500 mm. Temperature ranges between 22^0C to 27^0C. The study area is majorly drained by Nkisi, Anambra and the Idemili rivers which are tributaries to River Niger.

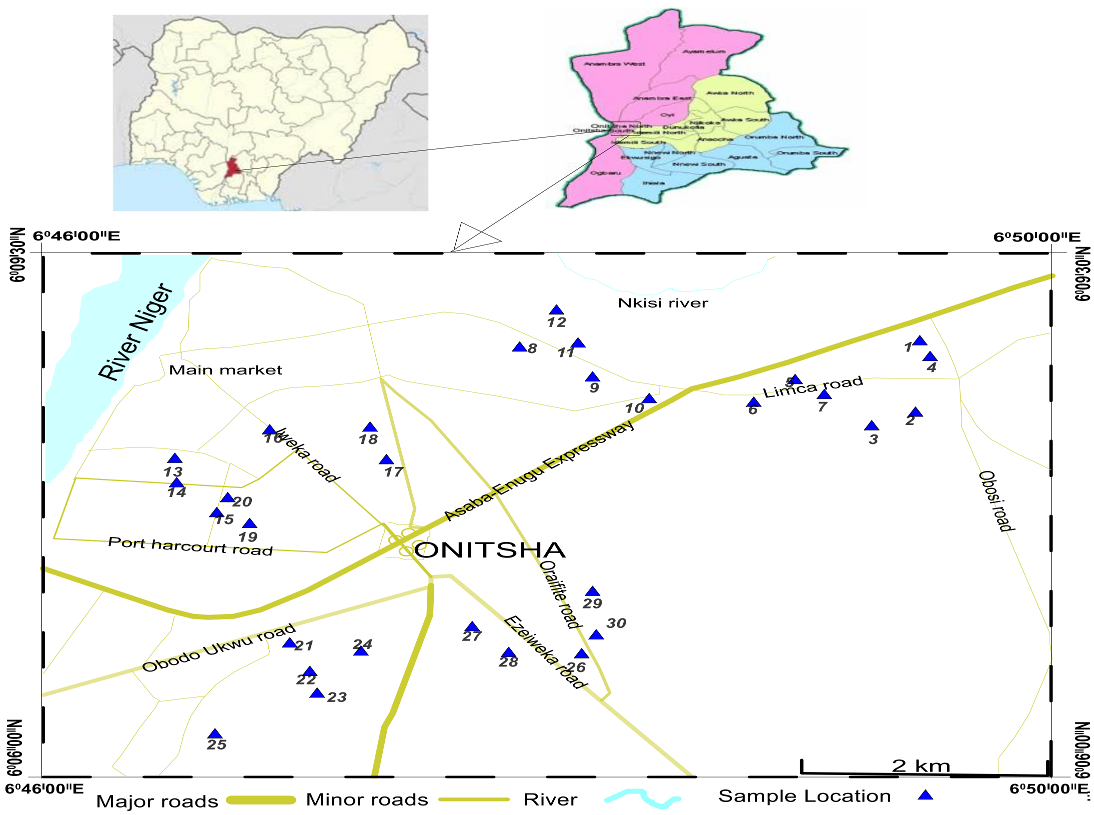

Figure 1: Map of Nigeria showing the Study Area.

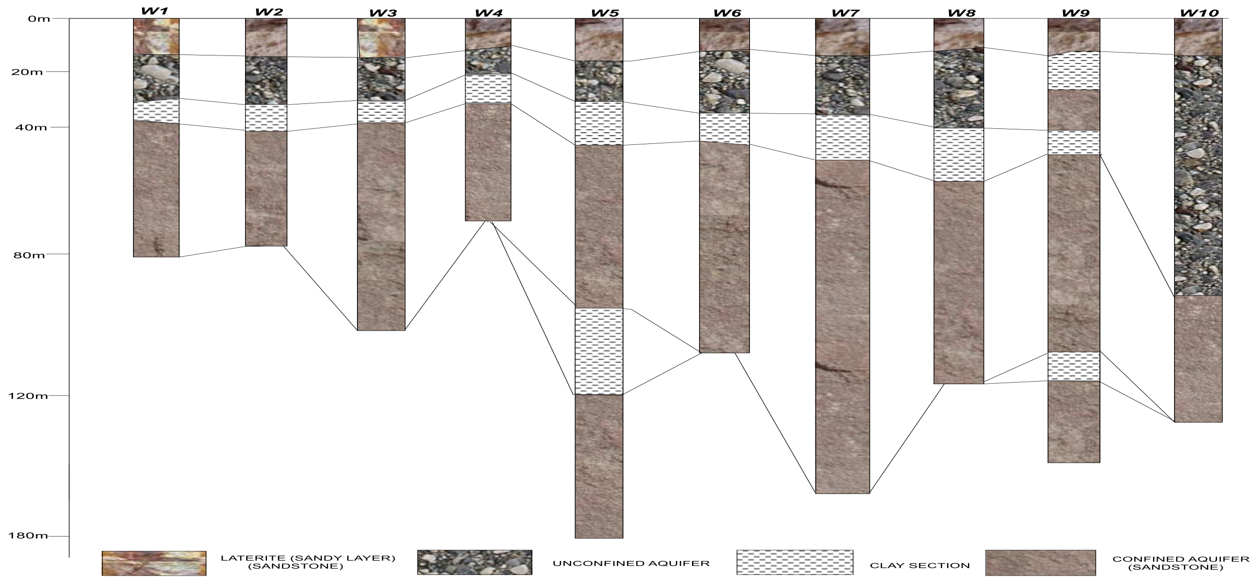

Figure 2: Lithologic Log from Wells within Onitsha [17].

Geologically Onitsha is located within the Anambra basin, it is underlain by cretaceous to recent sedimentary formations that are of varying aquifer potentials which belong to Ameki group consisting of the Nanka sand, Nsugbe sandstone and Ameki formation, [15]. The area is underlain by the alluvial plain sands, Ameki/Nanka sands and the Imo shale with different ability to hold and transmit water [16]. The area is mostly cover by lateritic soil with variable thickness, underlain by a thick course sandy horizon with lenses of medium shale to medium sand occurring with the coarse sand.

The thickness of the coarse sand range between 8 – 27 m. The coarse sand horizon is underlain with clay with a range of thickness from 6 m at southern part to 23 m in the east [17]. Below the shale and sand horizon at about 102 m is the top of a medium grained sand zone which is the main aquifer which varies in thickness from 23 m to more than 92 m. The aquifer is prolific and extends within the study area [17]. Figure 2 shows the subsurface stratigraphy and the various auriferous horizons from unconfined, semi confined to confined in the region. At the base of the unconfined aquifer lie the semi-confined and the confined upper, middle and deep auriferous horizons made up of sandstone within the Ameki Formation [17].

Sampling and Laboratory Analysis

A preliminary investigation was conducted to locate areas that of interest within the study area and establish sampling points. Samples were collected from boreholes (Figure 1) in tight capped high-quality polyethylene bottles, they are rinsed with the same water which must be taken as samples.

Electrical conductivity (EC), total dissolved solids and pH were measured using a model PHS-3D pH meter uniscope immediately after sampling and the coordinate of the borehole taking with a hand-held Global Positioning System (GPS, Model GARMIN GPSMAP 78S). The samples were immediately transferred to the laboratory. Each of the groundwater samples was analyzed for various physicochemical parameters such as pH; electrical conductivity (EC); total dissolved solids (TDS); turbidity; colour; major cation- sodium (Na^+), potassium (K^+), calcium (Ca^{2+}) and magnesium (Mg^{2+}); major anions- bicarbonate (HCO_3^-), chloride (Cl^-), and sulphate (SO_2^-). Minor constituents such as nitrate (NO_3), nitrite (NO_2), phosphate (PO_4), and ammonium nitrogen. Heavy metals such as iron (Fe), manganese (Mn), copper (Cu), arsenic (As), zinc (Zn), lead (Pb) cadmium (Cd) and nickel (Ni).

Test methods followed are the standard procedures recommended by American Public Health Association [18]. Statistical analysis was done using Statistical Program for Social Sciences (SPSS 16.0) obtain from the physicochemical parameters and the suitability of the water was examined based on percent compliance of the measured data with respect to Nigeria Standard for Drinking Water Quality [19] and World Health Organization standard [20]. The groundwater hydrochemical facie will be classified by graphic procedure [21].

Metal Pollution Index (MPI)

Metal Pollution Index (MPI) is a method of rating water quality that shows the composite influence of individual parameters on the overall quality of water [22]. The rating is a value between zero and one, reflecting the relative importance individual quality considerations. The higher the concentration of a metal compared to its allowable standard, the worse the quality of the water [23]. It has a wide application and it is used as indicator of the quality of river water [24, 25], as well as drinking water [26]. The MPI represents the sum of the ratio between the analyzed parameters and their corresponding national standard values [22, 25] as shown:

$$MPI = \Sigma[C_i/(MAC)_i]$$

Where,
MPI = Metal Pollution Index
C_i = the metal concentration in water sample,
MAC_i = the maximum allowable concentration.

Water Quality Index(WQI)

To understand the overall quality of groundwater, the WQI was used. WQI is defined as a rating reflecting the composite influence of different water quality parameters on the overall quality of water [27]. The objective of WQI is to turn complex water quality data into information that is understandable and useable by the public [23].

The Nigeria Standard for Drinking Water Quality [18] was used for the calculation of WQI. The water quality index was calculated using the Weighted Arithmetic Index method. The quality rating scale for each parameter (qi) was calculated by using the expression: qi=(ci/si)x100.

Relative weight (wi) was calculated by a value inversely proportional to the recommended standard (si) of the corresponding parameter: wi= 1/si. Overall WQI = Σ qiwi /Σwi.

The computed WQI values are classified into five categories: excellent water (WQI= 50); good water (WQI=50–100); poor water (WQI=100–200); very poor water (WQI=200–300); and water unsuitable for drinking (WQI> 300).

The Geographic Information System (GIS) was integrated to generate a map that includes information relating to water quality and its distribution over the study area. The spatial analysis was carried out using sufer 11 software. The physicochemical parameters from groundwater samples from each location were computed using WQI (Table 2). All the WQI values with their location details were included separately into the attribute table of the software to generate a spatial distribution of water quality map.

RESULTS AND DISCUSSION

The statistical summary of groundwater analysis with respect to the Nigeria Standard for Drinking Water Quality [19] and World Health Organization [20] standards are presented in Table 1.

The pH shows acidic property (4.92 to 7.11) with mean value of 5.73, pH shows the water is acidic and this can be attributed to precipitation as the major source of recharge. Water with low pH gives sour taste to water, corrode pipes and increase element mobility [28].

Electrical conductivity ranged between 44 µs/cm to 575 µs/cm with a mean value of 353.87 µs/cm, indicating low mineralization in the study area. The maximum value for total dissolved solid is 385.25 mg/l, shows the groundwater is freshwater and suitable for drinking. The turbidity and color values were <1 NTU to 2.6 NTU and <1 Pt.co to 5.4 Pt.co, respectively.

The physical parameters lie within the permissible limit for Nigeria and WHO standard for drinking water quality. The major ion analysis shows that calcium ion (Ca^{2+}) is the leading cation and chlorine ion (Cl^-) is the dominant anion in the groundwater samples from the study area.

Table 1: Statistical Summary of the Physico-Chemical Parameters.

Parameters (mg/L)	Minimum	Maximum	Mean (Ci)	NSDWQ, 2007	WHO, 2007
pH	4.92	7.11	5.728	6.5-7.5	6.5-7.5
Conductivity (µs/cm)	44	575	253.87	1000	1000
Color (Pt.Co)	0.00	1.8	0.2	15	15
Turbidity (NTU)	0.00	1.24	0.172	5	5
TDS	29.48	385.25	158.204	500	500
COD	3.2	23.1	9.703	10	-
Bicarbonate	23.4	90.1	53.327	100	-
Sodium	0.18	1.29	0.6407	200	200
Potassium	0.09	1.21	0.3683	150	-
Calcium	0.85	5.11	1.9913	200	-
Magnesium	0.13	2.41	1.165	200	-
Chloride	33.49	320	133.97	250	250
Nitrite	0.005	0.18	0.0426	0.2	0.2
Nitrate	0.305	8.2	2.0508	50	10
Sulphate	0.024	3.00	0.5302	100	250
Iron	0.172	1.165	0.5333	0.3	0.3
Manganese	0.019	0.281	0.1200	0.200	0.1
Zinc	0.142	0.721	0.3327	3.00	5.0
Copper	0.012	0.18	0.0512	1.00	0.5
Chromium	<0.001	0.081	0.0082	0.05	0.05
Cadmium	<0.001	0.0012	0.0098	0.001	0.03
Lead	<0.001	0.08200	0.0156	0.01	0.01

The range of the cation abundance was recorded as Ca>Mg>Na>K and the order for anion Cl>HCO>SO_4. The overall concentration pattern of major ions in milligram/liter are Cl>HCO>Ca>Mg>Na>SO_4>K. All major ions values lie within the permissible limit for Nigeria and WHO standard except for chlorine which was found to above the standard in some locations.

The concentration of chlorine ranged between 33.49 to 320 in some locations it is way above the 250 mg/l acceptable limit for Nigeria and WHO standard. This gives a clue the elevated concentration of chloride in some groundwater of the study area might be from waste water. The influence of waste water on groundwater quality is well-documented worldwide [29].

The study area is the commercial center of southeastern Nigeria, it is densely populated and home to many industries and markets. The waste water generated from these industries and household coupled with leakages from septic tanks can be linked to the elevated concentration of chloride in the study area. Concentrations of Nitrate and Nitrite ranged between 0.3 mg/l to 8.2 mg/l and <0.05 mg/l to 0.18 mg/l, respectively.

Other minor constituents in groundwater include phosphate, ranged between <0.05 mg/l to 0.34 mg/l and 0.11 mg/l to 0.21 mg/l for Ammonium Nitrogen, both lie within the Nigeria and WHO standard for drinking water quality.

Heavy metals iron, manganese, copper, zinc, chromium, cadmium, and lead were all detected in the water sample while nickel and mercury were found below the detection limits. Concentrations of iron varied from 0.17 to 1.17 mg/L with a mean value of 0.53 mg/l, 70% of the groundwater samples show concentration of iron above the 0.3 mg/l limit for Nigeria and WHO standard for drinking water quality.

The lateritic nature of the overlying soil and host rocks is likely to cause the elevated iron concentration in the groundwater. The interaction of rainwater during infiltration with the iron-rich sediments was primarily responsible for the high iron content in groundwater. Groundwater occurs at shallow depths in the study area under unconfined conditions in the upper part of the unconsolidated sediments, a sequences of lateritic gravel, ferruginous sand, with minor clay, has been intersected (Figure 2).

Anthropogenic activities are being carried out in the study area, but the elevated values of iron concentration can be linked to water-rock interaction which is geogenic. Manganese concentrations ranged between 0.02 mg/l to 0.28 mg/l and average of 0.12 mg/l. 20% show values greater than the desirable limit, and this may be because of manganese occur naturally along iron and this can be attributed to some localized effects. Copper and zinc ranged between 0012 mg/l to 0.18 and 0.14 to 0.72, respectively and lie within the acceptable limit for Nigeria and WHO standard. Chromium, cadmium and lead were below detection limit in most groundwater samples. However, chromium, cadmium and lead were detected in 26.67%, 13.33%, and 30% respectively, of the groundwater sample in the study area and with some higher than the desirable limit. Chromium ranged between (<0.001 mg/l to 0.081 mg/l), cadmium (<0.001mg/l to 0.013 mg/l) and lead (<0.001 mg/l to 0.082 mg/l).

The elevated concentration of these heavy metals in some locations within the study area can be attributed to the anthropogenic activities domicile in the area through effluent discharge from industries to the surrounding soils and stream channels. They can also be linked to infiltration of urban runoff into groundwater from waste disposed indiscriminately in some open dumpsite located within the study area.

The WQI of all the samples taken were calculated using the procedure explained above and presented in Table 2. The results obtained from this study indicate that the mean concentration of the following parameters: pH, COD, iron, manganese, chromium, cadmium and lead compare to their weight index and the permissible limit of [19] thereby signifying contamination. The computed overall WQI was 101.28, which implies that the water is of poor quality.

The high value of WQI obtained is as a result of the high concentration iron, manganese, COD, and traces of lead, chromium and cadmium in the groundwater and can be attributed to natural and human activities taking place in the study area. Table 3 and Figure 4 shows the classification of water quality based on WQI value and distribution of the water samples according to their respective quality rating. Based on the WQI value, water is categorized into 5 groups ranging from excellent water (24%), good water (27%), poor water (17%), very poor water (24%) and water unsuitable for drinking (10%). The WQI ranges from 31.5 to 725.2. The elevated WQI values in location 12, 13 and 14 is as a result of concentration of cadmium and lead above acceptable limit of [19].

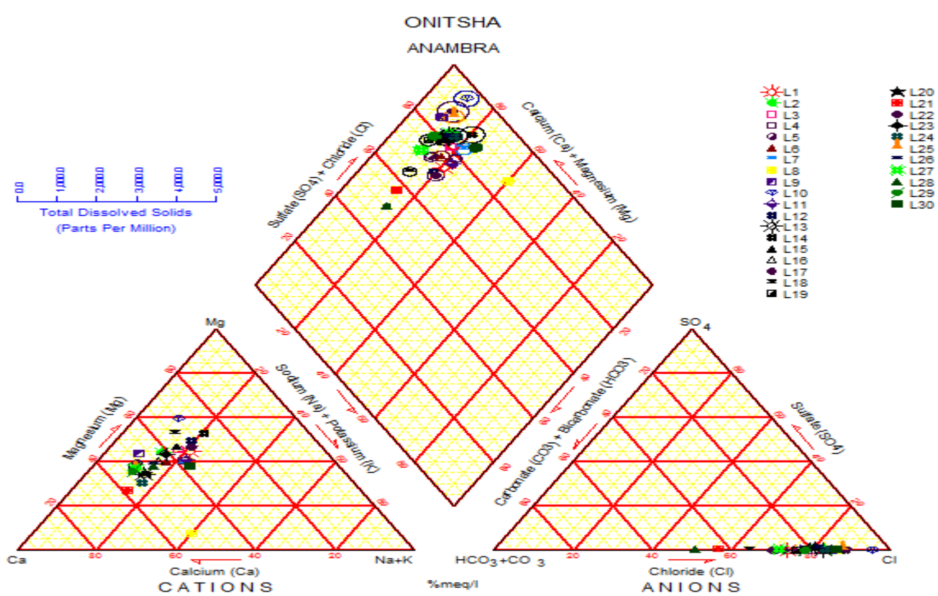

Figure 3: Piper Diagram.

Table 2: Computed WQI Values for the Study Area.

Parameters (mg/L)	Ci	Si	qi	Wi	qiwi
pH	5.728	6.5-7.5	76.27	0.1330	10.140
Conductivity (µs/cm)	253.87	1000.00	25.88	0.0010	0.0260
Color (Pt.Co)	0.2	15.00	1.33	0.067	0.0891
Turbidity (NTU)	0.172	5.00	3.40	0.200	0.6800
TDS	158.204	500.00	15.82	0.001	0.0158
COD	9.703	10.00	97.03	0.100	9.7030
Bicarbonate	53.327	100.00	53.327	0.010	0.5332
Sodium	0.6407	200.00	0.55	0.005	0.0030
Potassium	0.3683	150.00	0.5847	0.010	0.0058
Calcium	1.9913	200.00	1.050	0.005	0.0053
Magnesium	1.165	200.00	4.450	0.050	0.2225
Chloride	133.97	250.00	67.49	0.004	0.2700
Nitrite	0.0426	0.2000	21.30	5.000	106.50
Nitrate	2.0508	50.00	4.100	0.020	0.0820
Sulphate	0.5302	100.00	0.530	0.010	0.0053
Iron	0.5333	0.300	181.12	3.335	603.67
Manganese	0.1200	0.200	60.00	5.000	300.00
Zinc	0.3327	3.00	11.10	0.333	3.6963
Copper	0.0512	1.00	5.130	1.000	5.1300
Chromium	0.0082	0.0500	16.54	20.00	350.80
Cadmium	0.00098	0.001	98.00	1000	98000
Lead	0.0156	0.0100	156.00	100.00	15600

Table 3: Groundwater Quality Classification based on WQI Value.

WQI Value	Water Quality Rating	Water Samples (%)
<50	Excellent water	24
50-100	Good water	27
100-200	Poor water	17
200-300	Very poor water	24
>300	Unsuitable for drinking	10

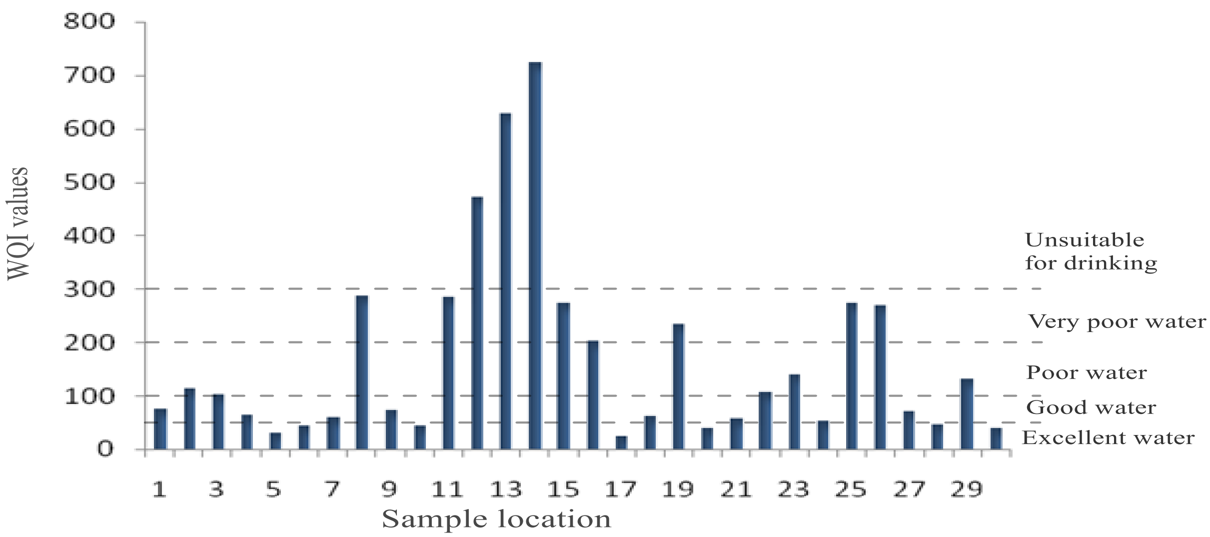

Figure 4: Water Quality Index (WQI) of Groundwater at Different Locations of the Study Area.

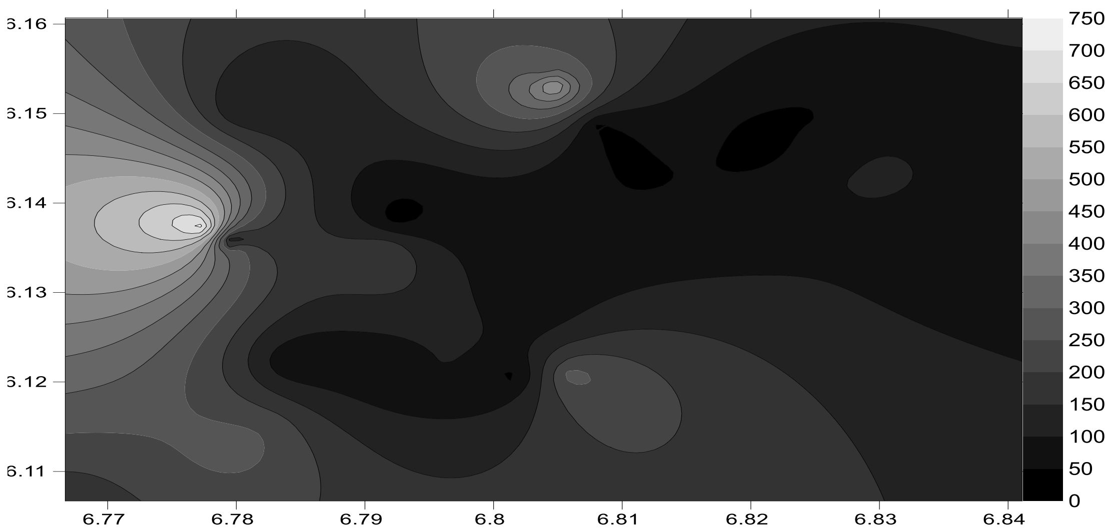

Figure 5: Spatial Distribution of Water Quality based on WQI.

The spatial distribution of WQI values (Figure 5) shows that the area is covered by good water and poor water(Table 3) and this can be attributed to iron and manganese concentration in all water sample which a naturally influenced. The elevated values of WQI covering the area with very poor water and water unsuitable for drinking (Table 3) is attributed to the concentration of heavy metals in some boreholes in proximity to dumpsites and waste water discharge points signifying water pollution and aquifer vulnerability around these locations due to anthropogenic activities taking place in the study area.

Table 4: Calculated Metal Pollution Index for the Water in the Area.

Parameter (mg/l)	C_i	MAC_i	MPI value	Rating
Iron	0.543	0.300	1.81	Moderately polluted
Manganese	0.120	0.200	0.60	Lightly polluted
Zinc	0.333	3.00	0.11	Lightly polluted
Copper	0.512	1.00	0.51	Lightly polluted
Chromium	0.008	0.05	0.16	Lightly polluted
Cadmium	0.00098	0.001	0.98	Lightly polluted
Lead	0.0160	0.01	1.60	Moderately polluted

CONCLUSION

The quality of groundwater status has been investigated in this study using physicochemical parameters, water quality index and metal pollution index. The result of the physicochemical parameters shows that the major ions concentration is in this pattern $Cl^- > HCO^- > Ca^{2+} > Mg^{2+} > Na^+ > SO_4^{2-} > K^+$ and in conformity with [19] and WHO standard except for Cl^- in some location above the recommended standard signifying improper sanitation system.

The high concentration of iron may be from leaching lateritic soil and host rock, which can also link manganese concentration to localize effects. Concentration of chromium, cadmium and lead can be linked to effluent from industries, waste from paints, electronic waste and improper disposal of battery waste, contributed to the elevated concentration of heavy metals especially around open dumps. The pH value shows an acidic property, and this contributed to the leaching and subsequent infiltration of these pollutants to the shallow aquifer.

Water quality index rate the overall water as of poor quality and heavy metals are the contributing factor. The result from the computed metal pollution index suggests that the groundwater is slightly to moderately affected with respect to heavy metal pollution and it is attributed to the sanitation problem in the area. Spatial distribution also linked area with high water quality index values around dumpsites. Most people in the study area depend on groundwater for drinking and domestic use and the toxic nature of these pollutants even at low concentration; it has become imperative to raise awareness for the overall interest of public health.

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ABOUT THE AUTHORS

Dr. Amadi A. Nwanosike is an Associate Professor at the Federal University of Technology (FUT) Minna, Nigeria. He holds a Ph.D. degree in hydrogeology and is currently serving as the Fieldwork Coordinator for the Department of Geology, FUT Minna. He is a registered and accredited Geologist with the Nigerian Council of Mining Engineers and Geoscientist (COMEG). He is a Fellow of the Strategic Institute for Natural Resources and Human Development (FRHD) and a Fellow of the Directorate of Geosciences at the International Agency for Standard and Ratings (IASR). He is a Member of Nigerian Association of Hydrogeologist (NAH), and a Member of the Nigerian Society of Mining Engineers (NSME). He is also a Member of the Nigerian Mining and Geosciences Society (NMGS). He is the current Chairman, Nigerian Mining and Geosciences Society (NMGS) Minna Chapter and the Vice Chairman, Nigerian Association of Hydrogeologist (NAH) Minna Chapter. He co-authored a reputable book titled "*Essentials of Structural Geology"* and has published many research papers in reputable journals. He has won several national and international awards and prizes including the outstanding award of the World Championship 2019 in Geosciences (groundwater quality).

Benjamin A. Igbomor, holds a B.Tech. degree in geology from the Federal University of Technology Minna. His research interests are in the areas of groundwater quality, geochemistry, environmental geology and engineering geology. His undergraduate research is on the geochemical characterization of ironstone in Bida basin north central Nigeria. He is currently undergoing his Masters degree program at the Department of Geology, Federal University of Technology (FUT) Minna, under the supervision of Dr. Amadi A. Nwanosike.

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