Evaluation of Groundwater Quality in Shallow Aquifers in Minna, North-Central Nigeria using Pollution Load Index

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Abstract
Water is essential to life but can serves as a means of diseases transmission when the quality is compromised. The degree of water contamination in an area can be attributed to the local geology and anthropogenic activities. This present study assesses the quality status of groundwater from hand-dug wells in Minna metropolis, North-central Nigeria using geo-statistical techniques. A total of eighteen samples were collected from hand-dug wells and taken to the laboratory for relevant physico-chemical and bacteriological analysis. Result of the analysis indicates that most of the physico-chemical parameters analyzed compete fovourably with the guideline for safe drinking water recommended by the Nigeria Standard for Drinking Water Quality and World Health Organization except the following parameters Mn, Fe, NO_3, colour and total coliform whose concentration in some location exceed their respective recommended maximum permissible limit for a safe water. The observed high concentration of Mn and Fe may be attributed to bedrock dissolution through weathering processes while the enriched concentration of NO_3 can be due to fertilizer application by farmers in the area. The presence of total coliform in water is an indication of faecal contamination due poor hygiene. The dissolution of these parameters in water generally affects the colour. The pH, indicate that the water is slightly alkaline. The dominant water type in the area as revealed by Piper diagram, Stiff and Durov diagrams is Mg–HCO^{3-}. The water quality index value indicates that the quality of the water in the area is poor while the outcome of metal pollution index revealed that the water in the area is slightly to moderately contaminated. Siting of hand-dug well far away from septic tanks, boiling of the water and good hygiene practice is recommended.

Keywords: Groundwater Quality Assessment, Water Quality and Pollution Index, Hand-dug wells, Minna, North-Central Nigeria

1. Introduction

Water is a universal solvent and natural resources tapped by man, animal and plants to meet their need on earth, either in vapour, liquid or solid form. It is one of the important needs of life that guarantee living whose quality promotes or reduces life. The quality of water can be traceable to chemical composition of precipitation, mineral composition of aquifer and confining beds through which the water moves and the chemical reaction occurring on land surface and in soil zones (Aminu and Amadi, 2014). The physical, chemical, and biological characteristic defines water quality and determines water uses either for domestic, irrigation, and industrial purposes. Quality of water has been a greatest challenge facing many developing nations such as Nigeria. However, consumption of unsafe water has been the chief cause of waterborne disease such as dysentery, typhoid, cholera and diarrhea. Studies have shown that high concentration of trace elements causes adverse health challenges in humans and animals (Nwankwoala *et al*., 2013). Water supply in Minna is grossly inadequate especially during the dry season and many people depend on hand-dug wells and boreholes for their daily water needs. Hence the need to know the pollution status of groundwater from these shallow aquifers.

2. Materials and Methods

2.1 Study Area Description

The study area is Minna, North-central Nigeria and is situated between longitude to 9°31'10.08''N to 9°41'22.32''N and latitude 6°28'13.03''E to 6°35'57.54''E (Figure 1). It is accessible through Minna-Zungeru road, Minna-Bida road, Minna-Sarkin powa road and Minna-Suleja road. The study area consists of low land, valleys and hills as shown (Figure 2).

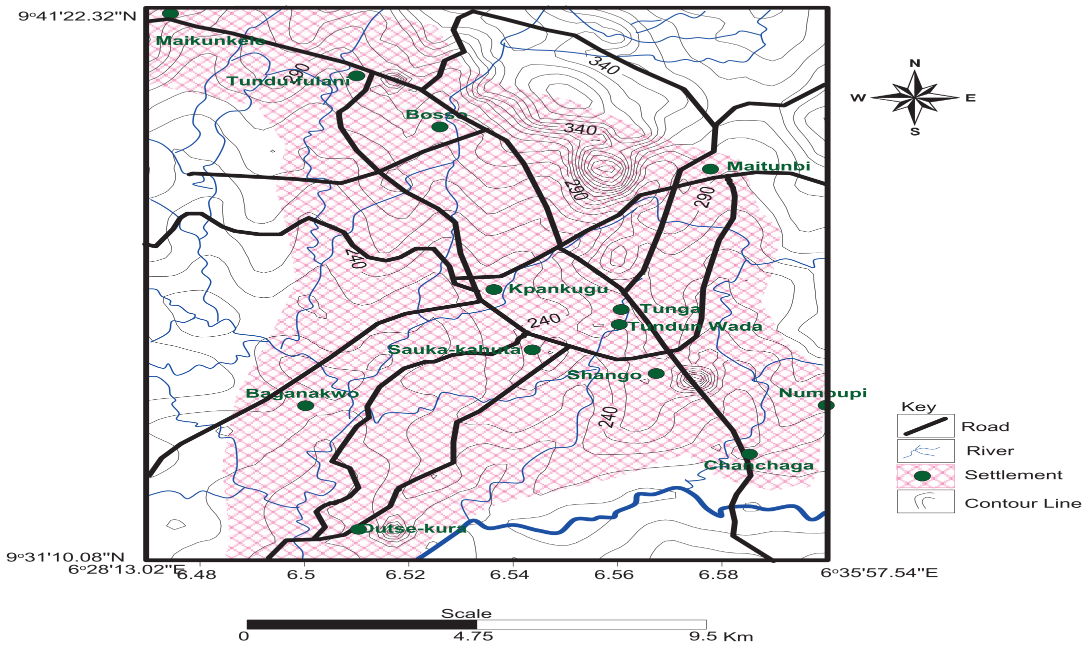

Figure 1: Topographical Map of the Study Area

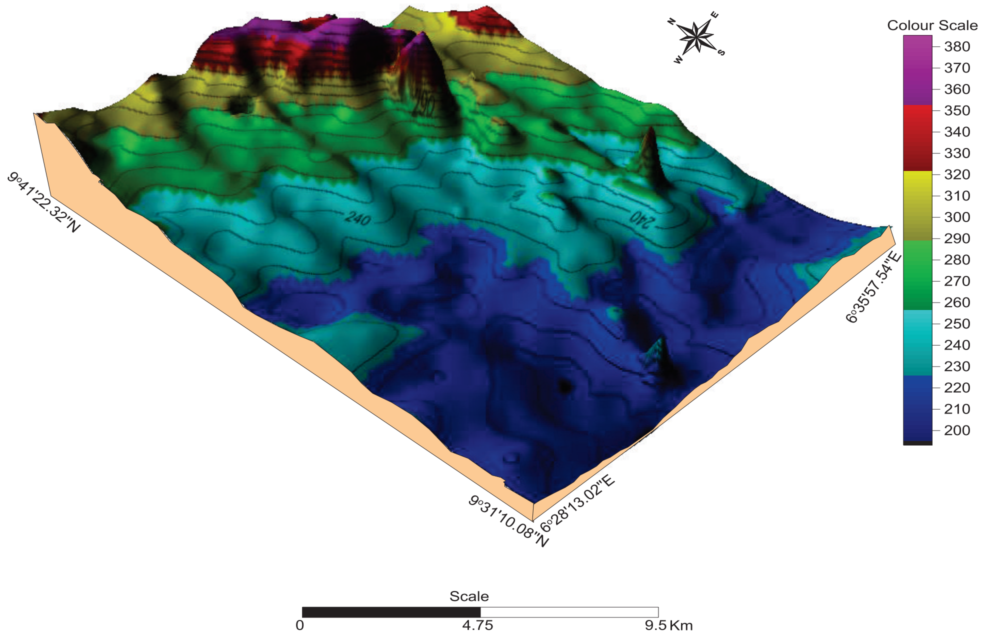

Figure 2: The relief map of the Study Area

2.2 The Geology and hydrogeology of the Study Area

The study area is part of the north-central Nigerian Precambrian basement complex rocks. The lithologic units include granites, gneisses, migmatites and meta-sediment (Adeleye, 1976). The field mapping carried out shows the existence of three rocks type: granites, schists, and gneiss with quartzite intrusion (Figure 3). The granites belong to the older granite suites occurring as Minna batholith of several high. The texture and colour of these granites vary from medium to coarse grained and light to dark colour. The area has witnessed fracturing and joint values were measured and used for the construction of rosette diagram (Figure 4). The rosette diagram for the measured outcrop joint directions show the NNE-SSW and NE-SW fractures control weathering depth and these agrees with groundwater flow direction (Figure 6).

Hydrogeologically, the study area is characterized by low permeability and poor water yield. However, secondary porosity and permeability through fracturing and weathering are common. The groundwater in the area is recharged through rainfall and the static water table varies from 10 to 35 m depending on the area.

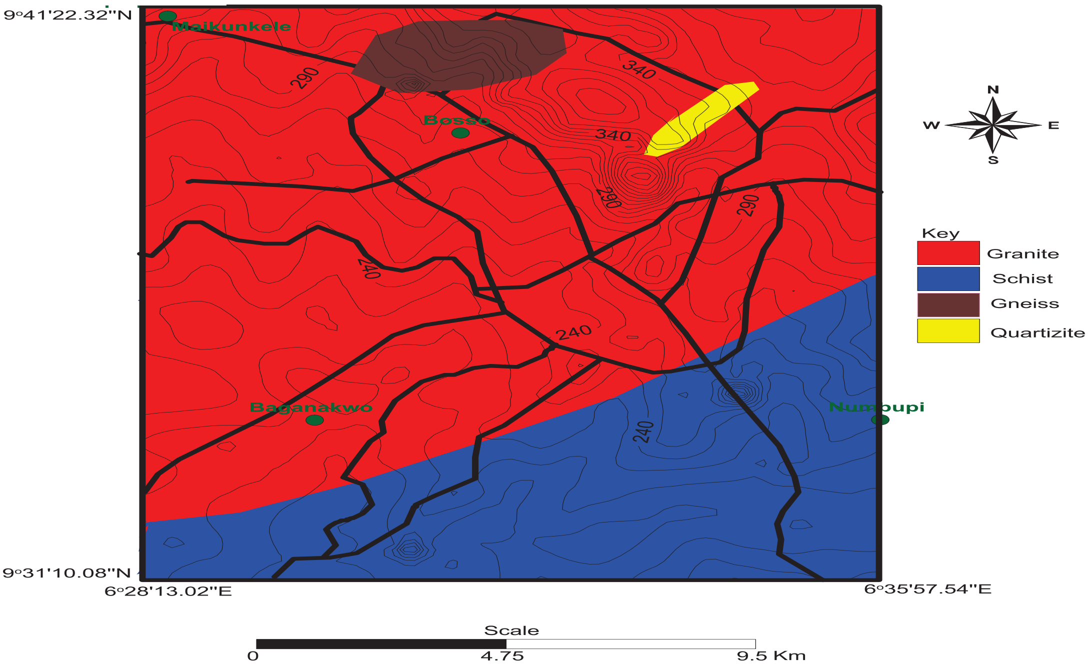

Figure 3: The Geological Map of the Study Area.

2.3 Water Sampling

Eighteen well samples were taken from different location within the study area with the aid of sterilized polythlene bottles and stored in a cooler before transferred to the laboratory for relevant chemical and bacteriological analysis. The physical parameters such as temperature, turbidity, pH, and colour were analyzed in-situ using appropriate equipment. Standard water sampling procedure according to APHA (1998) was followed. The static water level of the hand-dug wells sampled were taken using meter tape while the respective coordinates were obtained using the global positioning system. This led to the generation of the sampling location map (Figure 5) as well as groundwater flow direction (Figure 6).

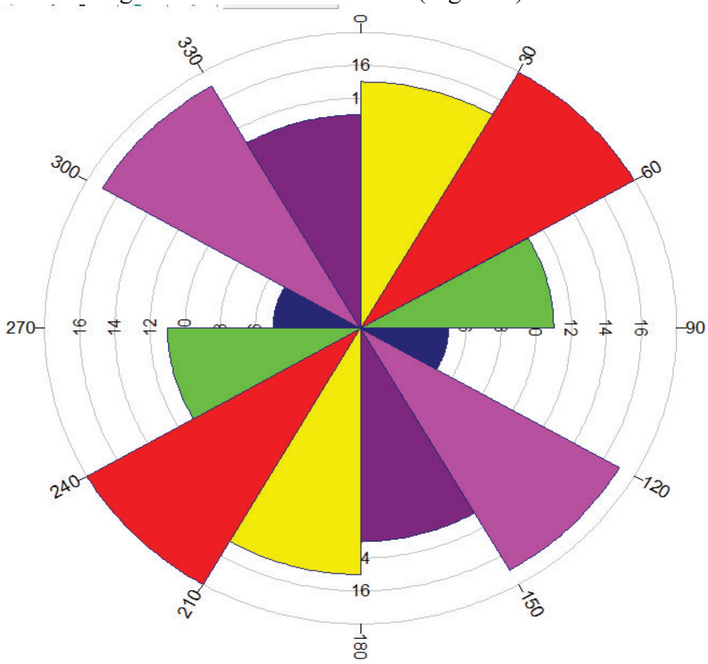

Figure 4: Rosette Diagram of the Study Area.

2.4 Laboratory Analysis

The samples were analyzed for relevaat the water quality section, Federal Ministry of Water Resources regional laboratory, Minna. Biological analysis was done by determination of total viable counts (TVC) through growth and the samples were incubated in agar medium for the period of 48hours at 35°C. Then bacteriological growth was observed by trapping of air bubble and decolourization of media and the decolorized bottles were then compared with a standard chart. In order to determine the present of E-Coliform bacteria in the water samples, 38.0 g of MacConkey broth was dissolved in 1000ml of water with an incubation temperature of about 40°C at 24 hours, which later revealed the presence of E-Coli in respect to the further decolouration of the media.

3. Results and Discussion

The statistical summary of the physical, chemical and bacteriological parameters analyzed are shown in Table 1.

3.1 Physical Parameters

The temperature ranged from 21.0°C to 26.5°C with an average value of 24.0°C (Table 1). Water for drinking purposes has a better fresh taste at lower temperature of about 15°C, but higher temperature do not imply impurities (Olasehinde, 1999). The turbidity value varied between 0.0 NTU to 16.19 NTU with a mean value is 3.8 NTU (Table 1). The turbidity values in some locations are higher than the permissible values of 5.0 NTU (WHO, 2006; NSDWQ, 2007). Turbidity can be defined as the degree of transparency in water.

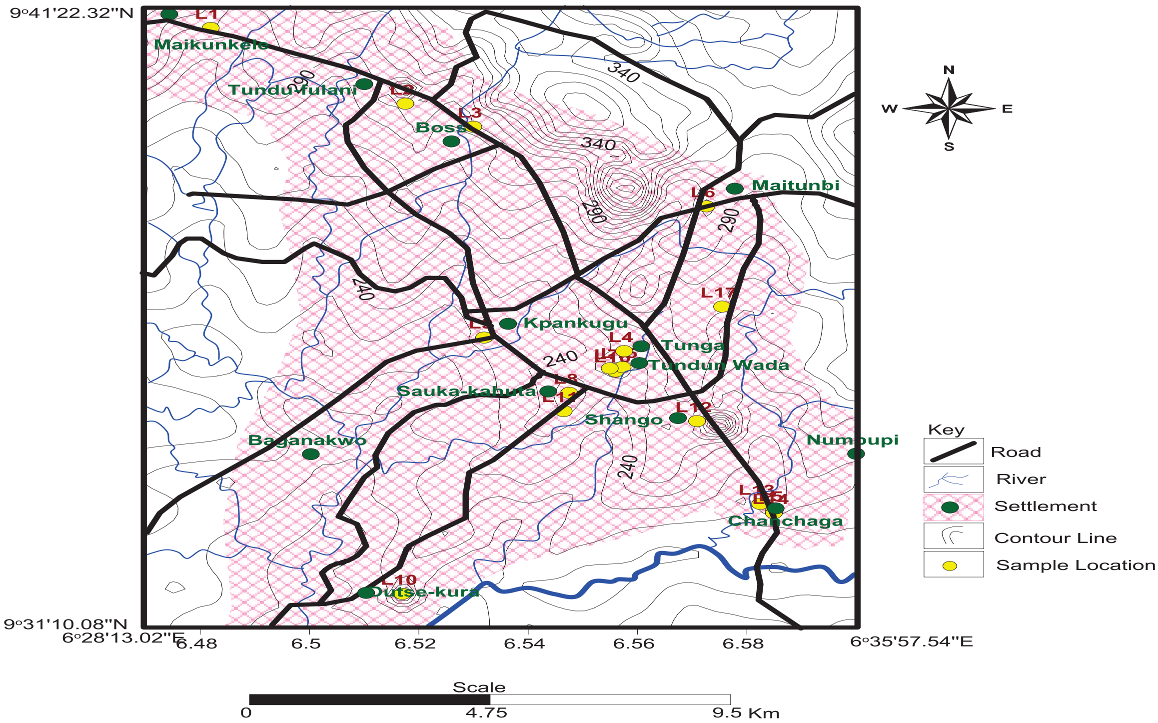

Figure 5: Sample location map of the Study Area

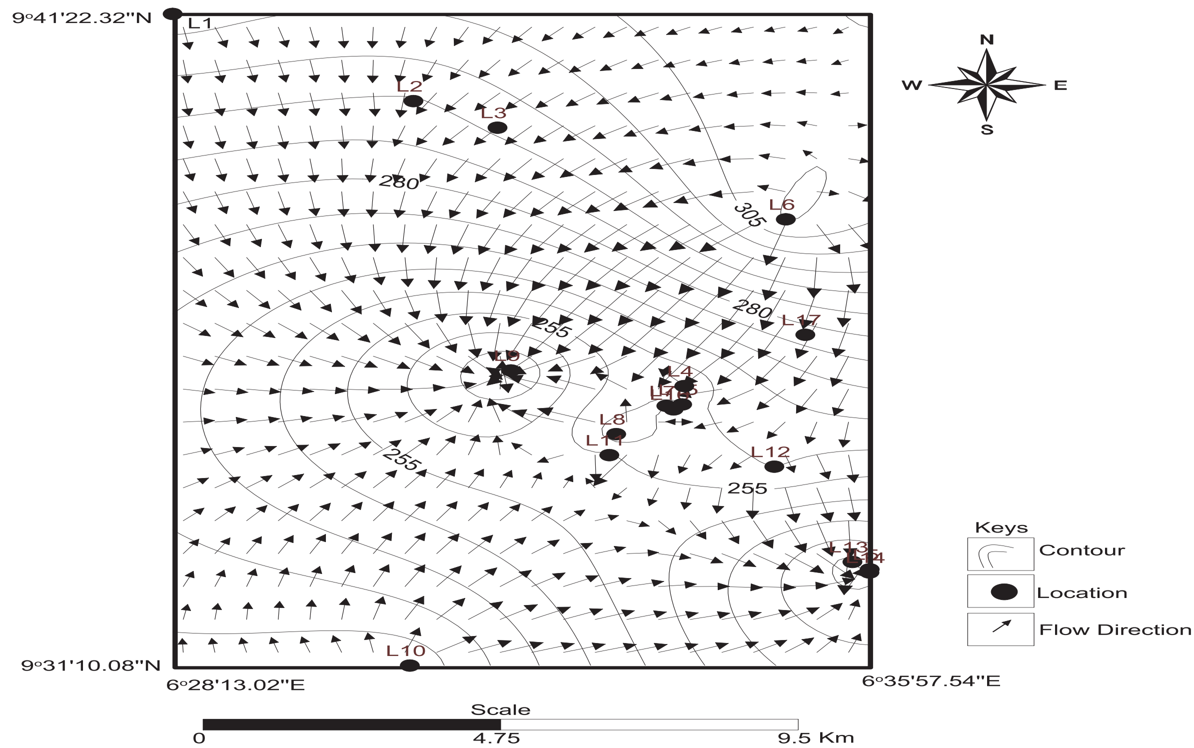

Figure 6: Groundwater flow direction of the Study Area

Clean water is related to low turbidity. However, high turbidity can be attributed to erosion and human activities such as inflow of sewage, vegetation removal and soil interruption. The value of the pH ranged from 6.4 to 8.7 with an average value of 7.8 and these value falls within the acceptable values of 6.5 – 8.5 (Table 1). The pH is good quality parameters as its values affect the rate of elemental dissolution in water. The colour value is of the order of 0.0 TCU to 550.0 TCU with mean value of 80.38 TCU as against the maximum permissible of 15.0 TCU (WHO, 2006). Colour in water may be attributed to the presence of organic matter such as humic substances, metals such as iron or highly coloured industrial wastes (Amadi *et al*., 2012; Abimbola *et al*., 1999).

3.2 Chemical Parameters

The dissolved oxygen varied from 5.71 mg/l to 6.71 mg/l with 6.33mg/l as the mean concentration value while total dissolved solid (TDS) ranged from 0.14 mg/l to 402.0 mg/l with mean value of 113.5 mg/l (Table 1). The concentration falls within the recommended permissible value of 500.0 mg/l. The amount of cations and anions that dissolved in water constitutes TDS value. The concentration of electrical conductivity ranged between 126 µs/cm to 600 µs/cm with a mean value of 169.4 µs/cm. These values are by far below the recommended maximum permissible value of 1000 µs/cm (WHO, 2006; NSDWQ, 2007). Clean water does not conduct electricity. Conductivity of water is a function of ionic constituent present in such water (Amadi, *et al*., 2013). The alkalinity ranged between 100.0 mg/l to 190.0 mg/l with mean value of 136.0 mg/l. These values are within the ranged of from basement terrain. The value of suspended solid varied from 0.0 mg/l to 362.0 mg/l with an average value of 45.38 mg/l (Table 1). The concentration are lower than the recommended permissible of 500 mg/l (WHO, 2006; NSDWQ, 2007). The concentration of total hardness ranged from 43.0 mg/l to 203.0 mg/l with a mean value of 107.5 mg/l (Table 1). The concentration of total hardness is some locations were found to be higher than the recommended maximum permissible value of 150.0 mg/l (NSDWQ, 2007). The presence of calcium and magnesium ions in water constitutes hardness. The concentration of chloride ranged between 0.0 mg/l and 37.4 mg/l with average concentration of 10.4 mg/l and these values fall below the acceptable limit of 250.0 mg/l (Table 1).

The values of calcium ranged between 12.8 mg/l and 79.2 mg/l with mean value of 43.8 mg/l. Calcium is an essential constituent for strong bone and tooth formation. The magnesium concentration ranged between 1.2 m/l and 118.8 m/l with average value of 39.6 mg/l. The concentration of bicarbonate ranged from 100.0 mg/l to 190.0 mg/l with a mean value of 116.0 mg/l while nitrate concentration ranged from 6.16 mg/l to 128.92 mg/l with an average of 33.2 mg/l (Table 1). . The nitrite concentrations ranged between 1.4 mg/l and 29.3 mg/l with a mean value of 11.038 mg/l. The concentrations of nitrate and nitrite in some area are higher than the maximum permissible limit of 50.0 mg/l and 5.0 mg/l respectively (WHO, 2006; NSDWQ, 2007). High nitrate level in drinking water leads to infant methaemoglobinaemia (blue-baby syndrome), gastric cancer, metabolic disorder and livestock poisoning (Dan-Hassan *et al*., 2012). The result of the analysis revealed that some locations have nitrate concentration above the WHO and NSDWQ guide limit of 50.0 mg/l and it is dominant in the rainy season than dry season. An oral interview conducted in the area indicates that some people use this hand-dug well as their drinking water sources. The sources of nitrate in the groundwater were attributed to bedrock dissolution due to groundwater migration and more importantly anthropogenic activities such as urban runoff, poor sanitation and leachate from waste dumpsites and agricultural chemicals such as nitrate-rich fertilizer. The concentration of sulphate varied between 8.0 mg/l to 44.0 mg/l with a mean value of 26.1 mg/l while the concentration of phosphate ranged between 0.03 mg/l to 2.1 mg/l with an average value of 0.67 mg/l (Table 1). The concentration of potassium ranged between 0.0 mg/l and 0.35 mg/l with a mean concentration of 0.069 mg/l while sodium concentration is in the order of 4.27 mg/l to 19.11 mg/l with an average value of 8.97 mg/l (Table 1). The concentration of the major ions where within the permissible limits of NSDWQ (2007) and WHO (2006) except bicarbonate and nitrate whose concentration were above the maximum permissible limits in some locations. Their enrichment in groundwater may be attributed to dissolution arising from rock/water interaction and urban pollution such as waste dump and agrochemicals (Lohani *et al*., 2008; Tamasi and Cini, 2004).

The concentration of iron ranged from 0.01 mg/l to 0.44 mg/l with mean value of 0.2 mg/l. Iron is a very essential element in human nutrition and its deficiency causes goiter. High concentration of iron in water does not have any negative effect except colouration of the water (Amadi *et al*., 2013). The concentration of copper ranged from 0.0 mg/l to 0.32 mg/l with mean of 1.02 m/l while that of zinc varied between 0.0 mg/l and 0.12 mg/l with an average value of 0.05 m/l. The concentrations of chromium ranged between 0.0 mg/l and 0.001 mg/l with a mean value of 0.0001. The concentration of manganese ranged from 0.0 mg/l to 0.06 mg/l with a mean value of 0.04 mg/l. High concentration of manganese in water can cause undesirable taste and it enhances bacterial growth (Amadi, 2011).

3.3 Bacteriological parameters

The presence of E.coli and total coliform in the water is an indication of faecal contamination. The mean concentration of E.coli and total coliform are 0.20 cfu/100ml and 40.4 cfu/100ml respectively. These bacteria are found in the intestines of humans and other warm blooded animals. Their presence may be links to the inflow of sewage from the poorly constructed septic tanks into the nearby hand-dug well. Water related illnesses such as cholera, typhoid, dysentery and diarrhea can be attributed to water contamination by these bacteria due to poor hygiene (Vinodhini and Narayanan, 2008).

3.4 Piper, Durov and Stiff Diagrams

The Piper (Figure 7), Durov (Figure 8) and Stiff (Figure 9) are methods named after the person that devised them and they outlined fundamental principles in a pictorial form which are effective in studies regarding sources of the dissolved constituents in water. The concentration of 8 major ions (Na^+, K^+, Mg^{2+}, Ca^{2+}, Cl^-, CO_3^-, HCO_3^- and SO_4^{2-}) are represented on a trilinear diagrams by grouping the (K^+ with Na^+) and (CO_3^- with HCO_3^-), thus reducing the number of parameters for plotting to 6. On these diagrams, the relative percentages of the cations and anions are plotted and the degree of mixing between waters can also be shown on the diagrams. The diagrams are useful in the classification of the hydrochemical facies/water type in an area according to their dominant ions. The water type in the study area is Mg-HCO_3^- water type.

Table 1: Statistical summary of analyzed Physico-chemical and Bacteriological parameter

Parameters	Minimum	Maximum	Mean	S.Deviation	Variance	Ranges	WHO	NSDWQ
T.Hardness	43.0	203.0	107.5	119.28	14228.50	160.0	-	150.0
Cl	0.0	37.4	10.4	15.0	225.4	37.4	200.0	250.0
Alkalinity	100	190.0	136.0	138.71	19240	90.0	-	-
Ca	12.83	79.2	43.8	38.9	1514.8	61.6	200.0	200.0
Mg	1.22	118.8	39.6	56.5	3190.3	117.6	200.0	200.0
Conductivity	126	600.0	169.4	252.6	63813.2	599.7	1000.0	1000.0
TDS	0.14	402.0	113.5	164.7	27127.7	401.9	500.0	500.0
DO_2	5.71	6.71	6.33	6.34	40.17	1.0	-	-
Temp	21.0	26.5	24.0	23.6	556.7	5.5	Ambient	Ambient
Turbidity	0.0	16.19	3.8	6.1	37.4	16.2	5.0	5.0
pH	6.4	8.70	7.6	7.7	58.8	2.3	6.5-8.5	6.5-8.5
Fe	0.01	0.44	0.2	0.2	0.1	0.43	0.3	0.3
Cu	0.0	0.32	0.12	0.1	0.01	0.3	1.0	2.0
Zn	0.0	0.12	0.05	0.1	0.003	0.1	3.0	3.0
HCO_3	100	190.0	116.0	124.9	1559.6	170.0	100.0	-
NO_3	6.16	128.92	33.2	187.3	35096.8	122.8	50.0	50.0
SO_4	8.0	44.0	26.1	30.0	902	36.0	150.0	100.0
Cr	0.0	0.001	0.0001	0.00032	0.0000001	0.001	-	0.05
NO_2	1.4	29.3	11.038	13.57	184.06	34.4	5.0	
S.Solid	0.0	362.0	45.38	127.99	16380.5	362.0	1000.0	1000.0
Colour	0.0	550.0	80.38	195.25	38123.38	550.0	15.0	15.0
PO_4	0.03	2.1	0.665	1.028	1.057	6.2	5.0	-
Mn	0.0	0.06	0.04	0.058	0.004	0.1	0.05	0.02
K	0.0	0.347	0.069	0.13	0.017	0.4	75.0	150.0
Na	4.27	19.11	8.97	9.92	98.39	14.8	150.0	200.0
E-Coli	0.0	5.0	0.20	0.45	0.2	5.0	0.0	0.0
T.Coli	0.0	100.0	40.4	53.64	2877.6	100.0	10.0	10.0

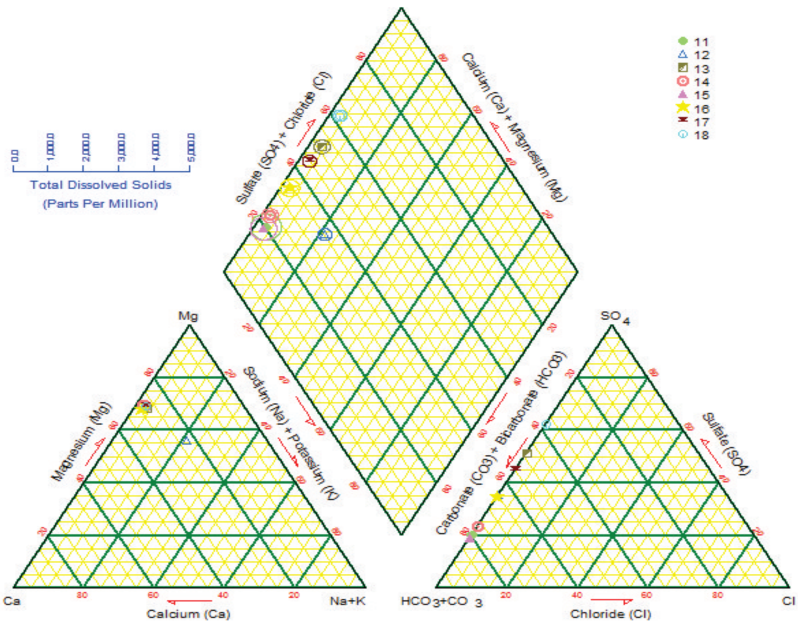

Figure 7: Piper diagram of the groundwater from hand-dug well in the study area

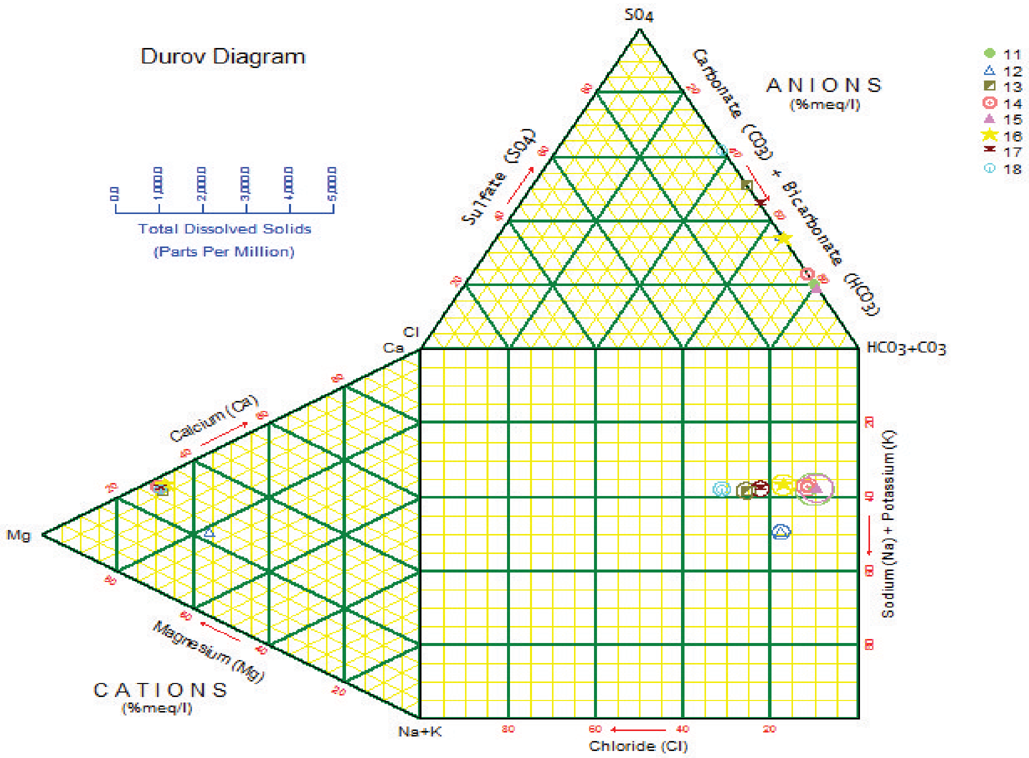

Figure 8: Durov diagram of the groundwater from hand-dug wells in the study area

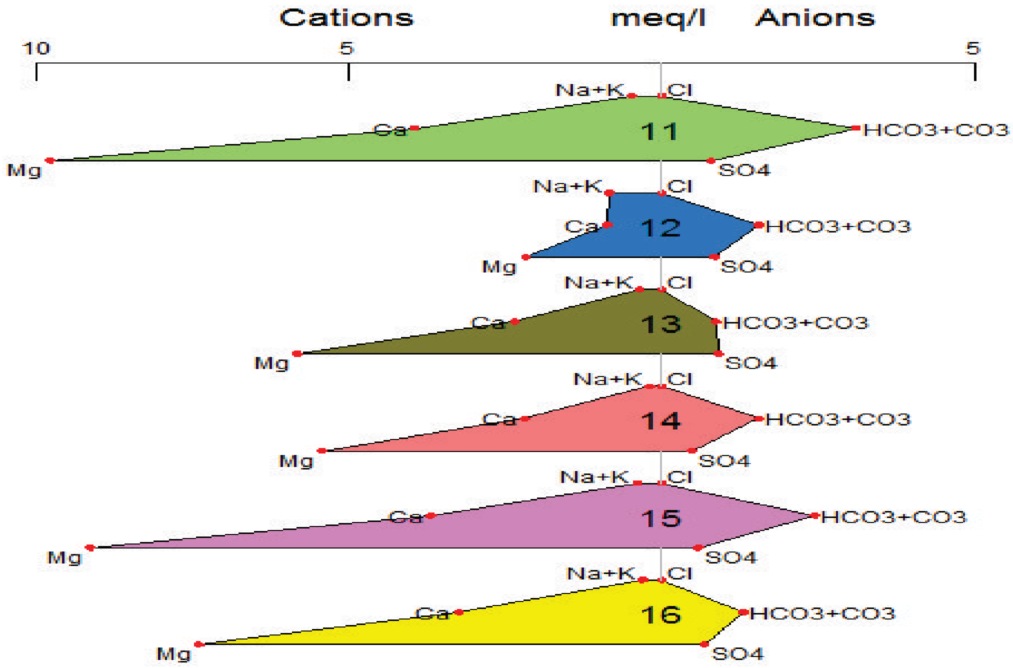

Figure 9: Stiff plots of the groundwater from hand-dug wells in the study area

3.5 Water Quality Index

This concept helps us to know the degree of water contamination in any location at a particular period. Generally, WQI are discussed for a specific and intended use of water. In the present study, the WQI evaluation is for drinking purposes is considered and permissible limit for the drinking water is 100 (Table 3). This implies that WQI values for any parameter greater than 100 is unfit for drinking.

3.6 Calculation of WQI:

The Water Quality Index (WQI) was calculated using the Weighted Arithmetic Index method (Caerio *et al*., 2005; Prasad & Kumari, 2008). The quality rating scale for each parameter qi was calculated by using this expression: $qi = (Ci/Si) \times 100$

A Quality rating scale (qi) for each parameter is assigned by dividing its Concentration (Ci) in each water sample by its respective Standard (Si) and the result multiplied by 100 Relative Weight (Wi) was calculated by a value inversely proportional to the recommended Standard (Si) of the corresponding parameter: $Wi = 1/Si$

Furthermore the water quality index (WQI) can be expressed as:

$$WQI = \sum_{n-1}^{i-n} qiWi$$

Where: Ci means Concentration in each water parameter

Where:
qi = The quality of the ith parameter
wi = The unit weight of the ith parameter
n = The number of the parameter considered

The overall water quality index (WQI) was calculated by aggregating the Quality rating (qi) with unit weight (Wi) linearly: $WQI = \sum qiWi / \sum Wi$. The overall water quality index of groundwater from hand-dug well in the study area is 128.6 which are classified as poor water (Table 3). However, 33% of the total water samples collected from study area was certified fit for domestic purposes while 67% are unfit for domestic purposes (Table 3). It can be deduced that water from hand-dug wells that are lined and covered constitute bulk of the excellent and good water while the ones very close to pit-latrines, soakaways, waste dumps and farm-lands constitute the poor to unsuitable water. The bedrock geochemistry is another determinant.

Table 2: Summary of computed water quality index values

Parameters	Ci	Si	qi	wi	$qiwi$
T.Hardness	107.5	150.0	71.67	0.0067	0.48
Cl	10.4	250.0	4.16	0.004	0.02
Ca	43.8	200.0	58.4	0.013	0.76
Mg	39.6	200.0	19.8	0.005	0.10
Conductivity	169.4	1000.0	16.9	0.001	0.02
TDS	113.5	500.0	22.7	0.002	0.05
Turbidity	3.8	5.0	76.0	0.2	15.2
pH	7.6	6.5-8.5	89.4	0.118	10.52
Fe	0.2	0.3	66.67	3.33	222.23
Cu	1.02	2.0	11.0	0.5	25.5
Zn	0.05	3.0	1.67	0.33	0.56
NO_3	33.2	50.0	66.4	0.02	1.33
SO_4	26.1	100.0	26.1	0.01	0.261
Cr	0.0001	0.05.0	0.2	20.0	4.0
S.Solid	45.37	1000.0	4.54	0.001	0.005
Colour	80.38	15.0	535.83	0.067	35.72
Mn	0.04	0.02	200.0	50.0	10000
K	0.069	150.0	0.046	0.00067	0.00031
Na	8.96	200.0	4.484	0.005	0.022
T.Coli	40.4	10.0	404	0.1	40.4

Table 3: Classification of groundwater from the hand-dug wells based on WQI

WQI Value	Category	Water Samples (%)
<50	Excellent	12
50-100	Good water	21
100-200	Poor water	35
200-300	Very poor water	18
>300	Unsuitable for drinking	14

3.7 Pollution Index

A groundwater pollutant is any substance that, when it reaches an aquifer, makes the water unclean or otherwise unsuitable for a particular purpose. Groundwater pollutant may be from a natural or anthropogenical source. Pollution index (PI) is a technique which shows the pollution status of water/soil quality parameters (Amadi *et al*., 2012). It identifies the contribution individual parameters on the overall quality of water (Amadi *et al*., 20123; (Aboud and Nandini, 2009). The pollution index (Table 4) is determined reflecting the relative importance individual quality parameter and divided by the recommended standard (Si) for the maximum and minimum values and the summation divided by two as shown below.

$$PI=\sqrt{\left(\frac{Ci}{Si}\right)^2 max+\left(\frac{Ci}{Si}\right)^2 min/2}$$

Where:

PI: Pollution index
Ci: Respective maximum and minimum concentration of quality parameters
Si: Nigerian Standard for Drinking Water Quality (NSDWQ, 2007)

The overall classification of water based on water pollution index (Table 5) revealed that Fe and Mn are slightly polluted, NO_3 is moderately polluted, colour is strongly polluted while T.coli is seriously polluted. This finding is in agreement with the water quality index. The parameters are what made the groundwater from the shallow hand-dug well poor. The enrichment of the water with Fe and Mn can be attributed to bedrock dissolution and this affects the colour of the groundwater. The presence of total coliform in the water implies that the water is contaminated with animal faeces and this impairs the colour of the water.

Table 4: Calculated Pollution Index of Groundwater from Hand-dug wells in the study area

Parameters	Calculated PI Values	Status
T.Hardness	0.98	Not pollution
Cl	0.11	Not pollution
Ca	0.76	Not pollution
Mg	0.42	Not pollution
Conductivity	0.43	Not pollution
TDS	0.82	Not pollution
Turbidity	0.29	Not polluted
pH	0.27	Not polluted
Fe	1.04	Slightly polluted
Cu	0.11	Not pollution
Zn	0.14	Not pollution
NO_3	2.83	Moderately polluted
SO_4	0.32	Not pollution
Cr	0.01	Not pollution
S.Solid	0.26	Not pollution
Colour	4.3	Strongly polluted
Mn	1.12	Slightly polluted
K	0.002	Not pollution
Na	0.098	Not pollution
Total Coliform	5.5	Seriously polluted

Table 5: Classification based Pollution Index (Caerio *et al*., 2005; Amadi *et al*., 2012)

Class	PI Values	Status
I	<1	No pollution
II	1-2	Slightly polluted
III	2-3	Moderately polluted
IV	3-5	Strongly polluted
V	>5	Seriously polluted

4. Conclusion and Recommendation

Water is a universal solvent and natural resources tapped by man, animal and plants to meet their need on earth, either in vapour, liquid or solid form. The quality of groundwater of in area is a function of its chemistry and the nature of the aquifer characteristics. The groundwater from shallow aquifers was evaluated using water quality index and pollution index. The study revealed that the water type in the area is Mg–HCO_3. The concentration of most of the parameters analyzed fall below the maximum permissible limit of WHO and NSDWQ except Fe, Mn, NO_3, colour and total coliform whose concentration in some locations exceed the maximum permissible limit. This was further confirmed when the data was treated using water quality index and pollution index both showing varying degree of pollution. Good hygiene should be encouraged and hand-dug well in the area should be well lined and covered. Future hand-dug wells in the area should be deeper and sited away from soakaways and dumpsites. Boiling of the water in locations with high bacteria count before use is advocated.

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