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ORIGINAL RESEARCH ARTICLE

EVALUATION OF GROUNDWATER QUALITY FOR DRINKING PURPOSES USING WATER QUALITY INDEX, IN KEFFI CENTRAL TOWN OF NASARAWA STATE

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ABSTRACT

In Nigeria, access to fresh drinking water has become serious challenges to both rural and urban areas.The aim of this study was to evaluate groundwater quality in Keffi central town of Nasarawa State for drinking purposes using the water quality index technique. Eight groundwater samples (four from both boreholes and dug wells) were collected from the study areaduring the wet season in October 2019. The water quality index is a mathematical method used to facilitate water quality explanation. The pH, Electric Conductivity, Total Dissolved Solids, Total Hardness, Calcium, Magnesium, Sodium, Chloride, Sulphate and Bicarbonate were determined according to standard methods. pH ranged from 5.7 to 7.1(mg/l), Electric conductivity ranged from 256 to 1591(μs/cm), Magnesium ranged from 2.6 to 29(mg/l), Calcium ranged from 3.7 to 34(mg/l), Sodium ranged from 22 to 56(mg/l), Chloride ranged from 8.4 to 63(mg/l), Bicarbonate ranged from 54.3 to 219.6(mg/l), Sulphate ranged from 0.1 to 32.4(mg/l), Total Dissolved Solids ranged from 95.2 to 302.94(mg/l) and Total Hardness ranged from 23.8 to 204.23(mg/l). The water quality index obtained from different locations was found to vary from 44.32 to 61.60 for boreholes and 72.55 to 97.77 for dug wells. The results for the water quality index indicated that borehole locations 2, 4, and 8were safe for human consumption, while dug well locations 3,5,6 and 7were not suitable for drinking purposes, compared with Nigerian industrial standard drinking water. The reasons for the high water quality index values of some study areas were attributed to the lithological variation and anthropogenic activities in the region. Therefore, some of the well water required treatment such as demineralization.

1.0 Introduction

Water is a transparent, tasteless, odourless, and colorless chemical substance that is the main constituent of the earth's hydrosphere and is the fluid of living organisms. The expansion of economic activities and the increasing population are leading to increased demand for water. Water has played a vital role throughout the history in the development of human civilization.

Groundwater is the water that lies beneath the earth's surface, filling the pore space between grains in bodies of sediment and elastic sedimentary rock and filling cracks and crevices in all types of rock (Abdullahi and Iheakanwa, 2013). About 98% of the World's freshwater is from groundwater and is distributed throughout the world (Tijani, 2016). Demand for groundwater has been on the increase because of rapid growth in population as well as the accelerated pace of industrialization and urbanization. The groundwater quality depends on several chemical constituents and their concentration, which are derived from geological data. Environmental and industrial solid wastes have emerged as one of the leading factors of groundwater pollution.

Available water is rendered non-portable in many parts of the country like Somalia because of the presence of heavy metals. In urban areas fresh water accessibility is more than the rural areas, because the urban areas have a lot of public water supply infrastructure for fresh water consumption. However, this statement is in contrast with the studies of Durowojo *et al.* (2022) as thy averred that in urban areas, fresh water accessibility issues are really the same with the rural areas, owing to the inadequate investigation in public water supply infrastructure that lay down pipe-bone water consumption undependable. In urban areas, fresh water accessibility issues are really the same with the rural areas, owing to the inadequate investigation in public water supply infrastructure that lay down pipe-borne water consumption undependable (Durowojo *et al*., 2022). In Keffi central, access to clean water is a major challenge to the residents. The consequence of water scarcity in some communities in the area, most especially during the middle of the dry season often results in the outbreak of water-borne diseases such as typhoid, cholera, diarrhoea, and guinea worm. With the efforts of government agencies and international agencies like Nasarawa State Ministry of Water Resources (NSMWR), United Nations International Children Emergency Fund (UNICEF), and The European Union (EU), some significant successes have been recorded in making safe drinking water available to few communities and therefore, curbing the menace of these diseases (Chiroma *et al.,* 2018).

Water quality index (WQI) provides a single number that signifies the overall water quality at a certain location based on several water quality parameters. It is an effective tools and important parameters in the evaluation and management of groundwater quality (Wu Jianhau *et al*., 2011). The objective of WQI is to transform complex water quality data into information that is understandable and useful to the stakeholders and the general public. Several indices have been developed to summarize water quality data in an easily expressible and understood format. The WQI which was first developed by Horton in the early 1970s, is a mathematical method of calculating a single value from multiple test results (Etim *et al.,* 2013).

The quality and availability of groundwater have deteriorated due to some factors such as increasing industrialization, population, and urbanization. The frequency of monitoring and assessment of water quality helps to develop management strategies to control groundwater pollution (Yao *et al.,* 2010). The water quality of any specific area can be assessed using physical, chemical, and biological parameters. If the values of these parameters occurred more than the defined limit, they become harmful to human health (Shweta *et al.,* 2013).

The traditional approaches to assessing water quality are based on a comparison of experimentally determined parameters with local or international standards. While, these procedures allow the good recognition of contamination sources and may be necessary for checking legitimate compliance, but they don't give a comprehensive vision of the spacial and temporal trends in the overall water quality (Shaif *et al.,* 2017). This work aims to evaluate the suitability of groundwater quality in Keffi central town using a water quality index for drinking purposes.

Water quality index was first proposed by Horton (Palwasha *et al*., 2020). It is a rating given to the water sample on the basis of calculated chemical parameters. WQI is a compilation of a number of variables which can be used to determine the overall quality of river and ground water

(Ashwani and Anish, 2009). Ten parameters were used for calculation of WQI as suggested by Fadhil et al. (2013). These includes: Magnesium, Sodium, Calcium, Chloride, Sulphate, Bicarbonate, pH, Total Dissolved Solids, Total Hardness, and Electric Conductivity. Water quality index (WQI) provides a single number that signifies the overall water quality at a certain location based on several water quality parameters. It is an effective tools and important parameters in the evaluation and management of groundwater quality (Wu *et al*., 2011). The objective of WQI is to transform complex water quality data into information that is understandable and useful to the stakeholders and the general public. Several indices have been developed to summarize water quality data in an easily expressible and understood format.

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2. Materials and methods

2.1 Study area

Keffi Central lies between latitudes 8° 50ˡ and 8° 52ˡN and longitude 7° 52ˡ and 7° 54ˡE (Figure1). The area is within north-central Nigeria and is characterized by wet and dry seasons. The temperature ranged from 21.3°C to 31.6°C. The area was drained River Antau, River Kodo, and River Mannu. The area falls within the North-central Nigeria basement complex, precisely within the migmatite gneiss complex. The Nigeria's basement complex consists of migmatites and migmatitic gneisses, slightly migmatized to unmigmatized paraschists with interbeds of meta and non meta Igneous rocks, also referred to as the younger metasediments or the Schist belts (Ajibade, 1976, and Turner, 1983). In the Keffi area, there are not many records of the detailed work carried out on the various units of the basement complex. Most parts of the area studied had already been mapped as underlain by the migmatites and migmatitic gneisses. The occurrence of a schist belt was only shown in parts of the area in the geological map of Nigeria produced by the geological survey of Nigeria (NGSA, 1994). Using their geochemistry and rare-earth element analysis, Onyeagocha (1986), pointed out that the granite is younger than the granite-gneiss; that Al/(Na+K+Ca) ranges from 0.92 to 1.09, indicating that the rocks are aluminium rich to aluminium excess.

The availability of groundwater would depend on the presence and extent of the weather overburden regolith and the presence of faults and fractures in the underlying bedrock

(Olayinka *et al*., 1999). Dissolution of minerals and leaching tends to increase porosity, permeability, and specific yield. However, the decomposition of secondary clay minerals tends to reverse the process (Tijani, 1994).

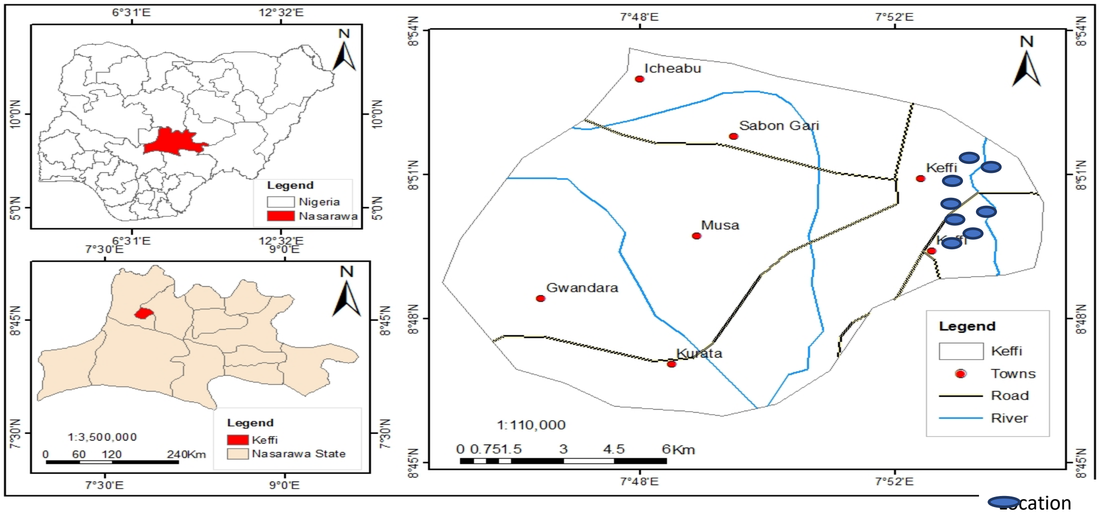

Figure 1: Map of the study area showing Groundwater sampling locations.

2.2 Sample collection

Groundwater samples were collected from8 locations of central part of Keffi town in the month of October 2019. Groundwater samples were collected in new dry clean plastic bottles after rinsed three times with the samples to be collected, using standard procedures recommended by Amadi *et al.* (2013) method. Physicochemical parameters including electrical conductivity (EC) and pH were measured in situ using HANNA EC and pH meter respectively. The collected samples were labeled, transported to The Bells University laboratory Ota, Ogun State for further analysis. The chemical parameters analyzed include: calcium, magnesium, sodium, chloride, sulphate and bicarbonate. Total Dissolved Solids (TDS) was determined according to Tripathi *et al.* (2012). Total hardness (TH) was determined using standard procedures recommended by Nematollah *et al.* (2016). In the present study water quality index were determined. All chemical concentrations were expressed in mg/l. Coordinates of each well location were identified using Global Positioning System (GPS) as shown in Table 1.

Table 1: Geographical locations of the studied Wells.

Well	Latitude	Longitude	Elevation (m)
1	$8^{0}50^{I}10.614^{II}$	$7^{0}52^{I}30.027^{II}$	309.5
2	$8°50^{I}38.074^{II}$	$7^{0}52^{I}21.110^{II}$	302.3
3	$8^{0}50^{I}42.38^{II}$	$7^{0}52^{I}12.075^{II}$	302.1
4	$8^{0}50^{I}19.37^{II}$	$7^{0}52^{I}40.056^{II}$	305.2
5	$8^{0}50^{I}59.013^{II}$	$7^{0}52^{I}28.108^{II}$	311.4
6	$8^{0}50^{I}$ 58.34^{II}	$7^{0}52^{I}58.026^{II}$	303.4
7	$8^{0}50^{I}11.022^{II}$	$7^{0}52^{I}26.528^{II}$	312.8
8	$8^{0}50^{I}39.161^{II}$	$7^{0}52^{I}24.341^{II}$	305.9

2.1. Water quality index calculation

Water quality index was first proposed by Horton (Palwasha *et al*., 2020). It is a rating given to the water sample on the basis of calculated chemical parameters. WQI is a compilation of a number of variables which can be used to determine the overall quality of river and ground water (Ashwani and Anish, 2009).The WQI Water quality index was calculated for each well location by using ten parameters namely: TDS, TH, pH, EC, Mg^{2+}, Na^{+}, Ca^{2+}, $SO^{2-}{}_{4}$, Cl^{-}, and $HCO^{-}{}_{3}$ according to Nigeria's drinking water standard for each chemical parameter. The weighted arithmetic index method as applied by Brown *et al.* (1972) and Dhirendra *et al.* (2009) was used, and presented below:

The constant of proportionality was calculated by finding the inverse of Nigeria Industrial Standard (NIS) limit for each parameter (Fadhil *et al.,* 2013). Then sum the results of the inverse, finally find the inverse of the summation of the result.

$$k = \frac{1}{\sum_{i=1}^{n} \frac{1}{Si}} \tag{1}$$

Where:

K= constant of proportionality

Si= permissible limit of Nigerian Standard for Drinking Water Quality for the i^{th} parameter

n=number of parameters

Calculating the weightage of i^{th} parameter (relative weight) Wi by using equation as shown in Table 3

The expression means the relative weight equation: The relative weight was calculated by dividing the constant of proportionality by NIS limit for each parameter (Fadhil *et al.,* 2013).

$$Wi = \frac{k}{Si} \tag{2}$$

Calculating of the quality rating scale (Qi) by the expression due to Fadhil *et al.* (2013):

$$Qi = \frac{100Ci}{Si} \tag{3}$$

In which Ci is the concentration of the i^{th} parameter Ci is the concentration for each chemical parameter in each water sample (mg/l)

Calculating water quality index (WQI) as follows (Fadhil *et al.,* 2013): Water quality index is given as:

$$WQI = \frac{\sum_{i=1}^{n} QiWi}{\sum_{i=1}^{n} Wi} \tag{4}$$

The data collected was substituted into the equations above for computation of water quality index values, with the help of statistical method.

The physicochemical parameters of Keffi central town with their NIS water quality prescribed values corresponding weightage factor (Wi), assigned with the help of equation 1 and 2 and the values are presented in Table 2.

Table 2: Relative weight for each parameter

Chemical parameters	Highest permitted value for water (I/Si)	I / S i	K	W i
Ph	8.5	0.117647		0.556733
EC	1000	0.001		0.004732
Hardness	150	0.00667		0.031548
TDS	500	0.002		0.009464
Calcium	200	0.005	4.732227	0.023661
Magnesium	20	0.05		0.236611
Sodium	200	0.005		0.023661
Bicarbonate	100	0.01		0.047322
Sulfate	100	0.01		0.047322
Chloride	250	0.004		0.018929
Total		0.211317		1.0

3. Results and Discussion

3.1 Water Quality Characteristics

The concentration of all water quality parameters of Keffi central town are presented in Table 3. The pH ranged from 5.7 to 7.1 mg/l with an average of 6.3mg/l which indicated that the ground water is slightly acidic to neutral. All the values fell below the acceptable limit being prescribed in Nigerian industrial standard (NIS 2015) for drinking water. Electrical conductivity (EC) measures the salt concentration and provides indication of ionic concentration in the water. EC varied between 256 to 1591 µs/cm with an average of 812.25 µs/cm. Only locations 5 and 7 had their EC values above the acceptable limit (>1000) of Nigerian drinking water standards. It may be attributed to high dissolution of ions in the locations (Figure 2).

The concentration of all water quality parameters of Keffi central town are presented in Table 2 The pH ranges from 5.7 to 7.1 mg/l with an average of 6.3mg/l which indicated that the ground water is slightly acidic to neutral. All the values fell below the acceptable limit being prescribed in Nigeria industrial standard (NIS 2015) for drinking water. The pH of most natural water bodies ranged from 6.5 to 8.5 while the disparity from neutral pH is as a result of free carbon dioxide or bicarbonate in the water bodies (Etim *et al.*, 2013). The lowest value of pH was recorded in borehole location 4 and 8 because they were closed to the dumpsite. The result was presented in Figure 2. Electrical conductivity (EC) measures the salt concentration and provides indication of ionic concentration in the water. EC varied from 256 to 1591 µs/cm with an average of 812.25µs/cm. In the study area only dug well locations 5 and 7 have their EC values above the acceptable limit (>1000) of Nigeria drinking water standards. Higher values of the two locations were attributed to high dissolution of ions in the region (Figure 2). A lower EC value indicated less concentration of the dissolved ions and organic matter in the water.

Table 3: Values of some water quality parameters of Keffi central.

Well	pH	EC	TH	TDS	Ca	Mg	Na	CHO_3
1	6.8	256	39.4	180	6.9	5.4	38	183
2	5.7	731	45.36	99.85	8.2	6.05	35.1	58
3	7.1	941	204.23	277.8	34	29	56	219.6
4	5.8	617	23.75	95.2	4.9	2.8	27.2	62
5	6	1085	121.36	166.5	14	21	39	75
6	6.7	854	201.59	226.7	28	22	22	125
7	6.9	1591	162.04	302.94	27	23	55	170.8
8	5.7	416	19.93	80.28	3.7	2.6	30.2	54.3

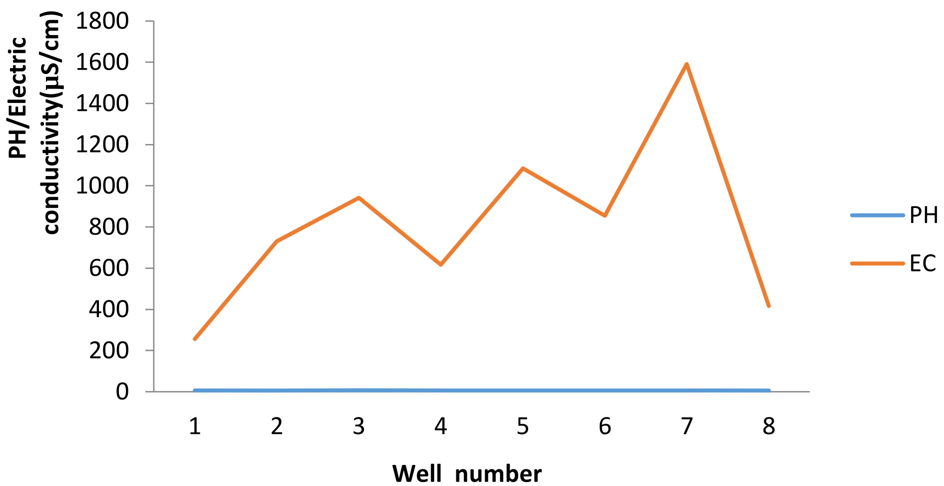

Figure 2: The values of PH and electrical conductivity for all wells.

Total dissolved solid (TDS) ranged from 80.28 to 302.9 mg/l with an average of 178.57 mg/l. This is far below the permissible limits (<500) being prescribed in (NIS 2015) for drinking water. Hence, the water is not harmful in view of these parameters, and this agrees with Afolabi and Olutomilola (2017). Hardness due to bicarbonate of calcium and magnesium is temporary hardness but hardness due chloride and sulphate of calcium and magnesium is permanent hardness. Due to permanent hardness soap consumption will be more.

Total dissolved solid (TDS) is a measure of the inorganic salts and little amount of the organic matter present in solution. TDS ranged from 80.28 to 302.9 mg/l with an average of 178.57 mg/l. This is far below the permissible limits (<500) being prescribed in (NIS 2015) for drinking water. Hence, the water is not harmful in view of these parameters, and this agrees with Afolabi and Olutomilola (2017). Again, TDS in drinking water has been associated with natural source, sewage and industrial waste water (Figure 3). Hardness due to bicarbonate of calcium and magnesium is temporary hardness but hardness due to chloride and sulphate of calcium and magnesium is permanent hardness. Due to permanent hardness soap consumption will be more. The highest TH value was observed to be 204.23mg/l at dug well location 3 and lowest value was observed to be 19.93mg/l at borehole location 8. However, the TH at dug well locations 3, 6 and 7 were found to be above the allowable limit (>150) being prescribed in NIS (2015) for safe drinking water. The reasons for the high TH values of the three samples were attributed to the lithological variation and anthropogenic activities in the area. The values indicate soft to moderately hard type of groundwater (Ashwani and Abhay, 2014). Hard water is mainly account of the unpleasant taste and reduces the ability of soap to produce lather (Figure 3).

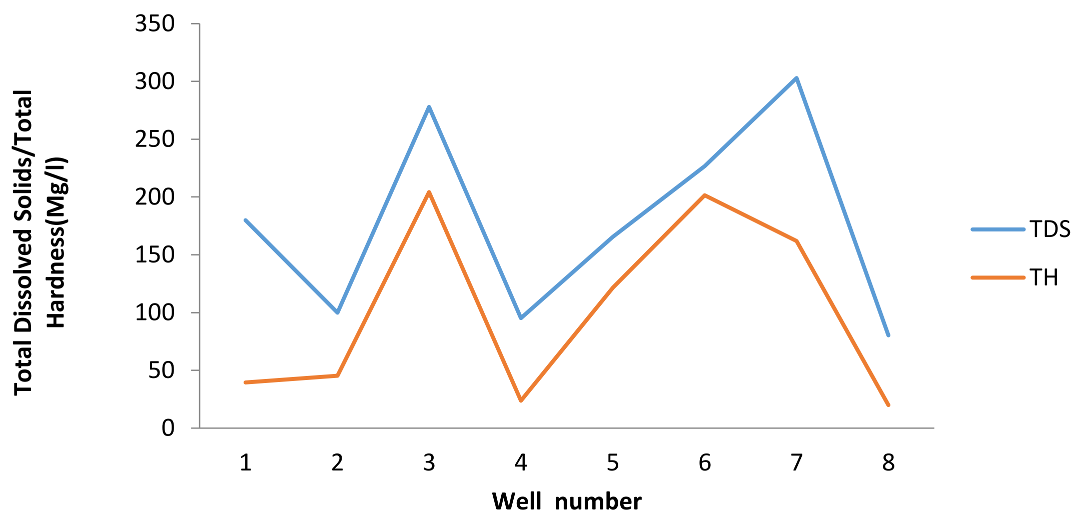

Figure 3: The values of Total dissolve solid and Total hardness for all wells

Calcium is naturally present in water. It serves in our body as muscle contractor and blood clothing. Calcium is a cation found in water which makes water hard. The concentration of calcium ranged from 3.7 to 34mg/l with a mean of 15.8mg/l. The result indicated that all the values were below the acceptable limit (<200) being prescribed in (NIS, 2015) for safe drinking water. Inadequate intake of Calcium may lead to hypertension, stroke and kidney stone (Farhad *et al.*, 2017). The concentration of Magnesium ranged from 2.6 to 29 mg/l with an average of 13.95 mg/l. This showed that all the values analyzed fell below permissible limit (<20) being prescribed in (NIS 2015) for safe drinking water. The high values of magnesium in these four samples may be as a result of dissolution of magnesium bearing mineral, example Aragonite in the location. Both Calcium and Magnesium concentrations have been originated from the dissolution of carbonate minerals such as dolomite and calcite (Figure 4). Sodium is an essential element for keeping human body in good working condition and help in maintaining blood pressure. Concentration of sodium varied from 22 to 56 mg/l with a mean of 37.8mg/l. This signified that all the values were below the acceptable limit (<200) being prescribed in (NIS, 2015) for drinking water. Also indicated little or lack of salt bearing mineral in the locations. Excess sodium in water can affect person suffering from heart and kidney problems (Gupta *et al.* 2004) as showed in Figure 4. In the study area the different of the Sodium concentration indicated weathering of feldspar bearing mineral.

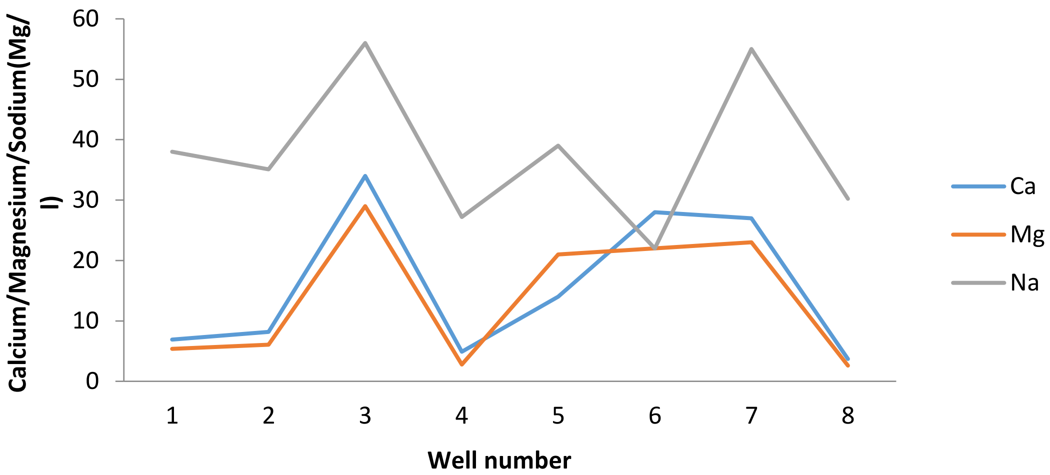

Figure 4: The values of Calcium, Magnesium Sodium for all wells

Chloride concentration in the water may be result from the evaporation of Chloride bearing mineral which are soluble to the water. Chloride concentration ranged from 8.4 to 63 mg/l with average of 2 5.59mg/l, which indicated that all locations were found to be below the acceptable limit (<250) being prescribed in (NIS, 2015) for drinking water. The low values of chloride in the study area were attributed to lack of deposition of salt spray. Most water contains Chloride and the amount present could be caused by fertilizer, air, industrial and domestic waste. In addition weathering of halite and evaporate were the major lithologic source of Chloride in the groundwater. High Sulphate (SO_4^{2-}) concentration in groundwater could be as a result of contamination of untreated industrial and domestic waste. Sulphate concentration varied from 0.1 to 32.4 mg/l with mean of 12.4 mg/l. This showed that no abnormal value was present in the water samples. This occurred because of low dissolution of sulphate bearing mineral (Gypsum) in the location. All the values fell below the acceptable limit being prescribed in (NIS 2015) for safe drinking water. Water containing high concentration of SO_4^{2-}, caused by the leaching of natural deposits of Magnesium Sulphate ($MgSO_4$) or Sodium Sulphate ($NaSO_4$) and may be undesirable because of their laxative effect.

Higher concentration of Sulphate may lead to gastrointestinal irritation especially when Magnesium and Sodium are present in drinking water resources (Farhad *et al.,* 2017). The concentration of Bicarbonate (HCO_3^-) varied from 54.3 to 219.6 mg/l with the mean of 118.46 mg/l. All the water samples in the locations were below permissible limit (<100), except borehole location 1 and dug well location 3, 6 and 7 values were higher than the permissible limit being prescribed in NIS 2015 for safe drinking water, this could be attributed to the weathering of carbonate minerals in rain water, example limestone (Figure 5). In addition, weathering of carbonate and alumino-silicate minerals with secondary contribution from dissolution of CO_2 gasses are primary source of HCO_3 in the groundwater.

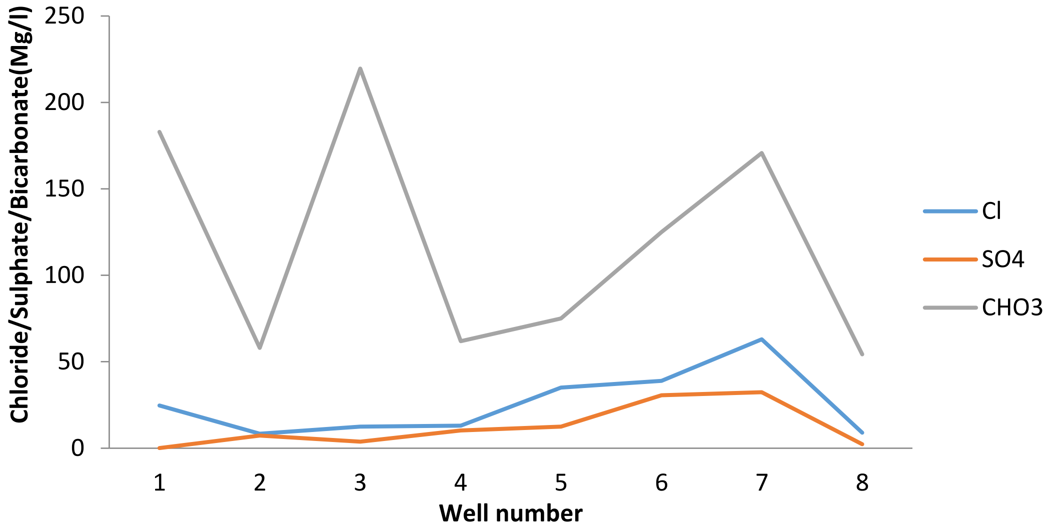

Figure 5: The values of Chloride, Sulphate and Bicarbonate for all wells

3.2 Water quality index analysis

The physicochemical parameters of Keffi central town with their NIS water quality prescribed values corresponding weightage factor (Wi), assigned with the help of equation 1 and 2 and the values are presented in Table 3. WQI were calculated from Equations 3 and 4. The WQI results are shown in Table 4. Classification of all the water samples were categorized by taking the standard water quality index bases which are shown in Table 5. Obtained results revealed that location 2, 4 and 8 met the requirement of safe drinking purpose as agreed with the standard proposed by Mishra and Patel (2001). However, location 1, 3, 5, 6 and 7 could not meet the requirement, due to the lithological variation and leachate from solid waste disposal site in the area. Therefore, the water cannot be used for human consumption. The WQI values of the 8 locations were found range from good to very poor-quality, or from 26-50 and 76-100.The statistical summary of the physicochemical parameters analyzed are showed in Table 6.

Table 4: Details of the index rate and type of water for the various samples obtained in the analysis

Location	Type	Index rate	Type of water
1	Bore well	61.60	Poor water
2	Bore well	49.64	Good water
3	Dug well	97.77	Very poor water
4	Bore well	46.17	Good water
5	Dug well	72.55	Poor water
6	Dug well	95.06	Very poor water
7	Dug well	88.19	Very poor water
8	Bore well	44.32	Good water

Table 5: Range of water quality index for drinking purpose (Mishra and Patel, 2001)

S/n	Range	Type of water
1	0-25	Excellent
2	26-50	Good
3	51-75	Poor
4	76-100	Very poor
5	>100	Unsuitable for drinking purpose

Table 6: Statistical summary of chemical data of groundwater in keffi central town (2019)

Chemical Parameter	Unit	Range	Mean	NIS(2015) HPL
pH	–	5.7-7.1	6.3	6.5-8.5
EC	µS/cm	256-1591	812.25	1000
Magnesium	mg/l	2.6-29	13.95	20
Calcium	mg/l	3.7-34	15.8	200
Sodium	mg/l	s 22-56	37.8	200
Chloride	mg/l	8.4-63	25.59	250
Bicarbonate	mg/l	54.3-219.6	118.46	100
Sulphate	mg/l	0.1-32.4	12.4	100
TDS	mg/l	95.2-302.94	178.57	500
TH	Mg/l	23.8-204.23	102.21	150

4. Conclusion

In the present study, WQI has been computed to evaluate the suitability of groundwater for drinking purpose in Keffi central town. After analysis of various physiochemical parameters, the results obtained for the WQI were found to be varied from 44.32 to 61.60 for bore holes and 72.55 to 97.77 for dug wells respectively. This indicated that location 2,4 and 8 of the water samples are safe for drinking purposed. While borehole location 1, and dug well 3,5, 6 and 7 were not suitable for human consumption. It can be said from this finding that groundwater in the study area were found to be good, poor and very poor quality respectively. Therefore, Public awareness campaign on the dangers of ground water contamination is encouraged. The high values of the water quality index at the study area was due to the higher values of electric conductivities, total hardness, Magnesium and bicarbonate as well as: anthropogenic activity, poor site sanitation and soak away.

From water quality index values, it is recommended that further improvement is required to treat the poor and very poor-quality wells (such as demineralization and water softening) for using as safe drinking purpose. In addition, bole holes should be provided for other communities within the study area. Moreover, there should be quality control standard for all the bore holes, so as to meet up with the Nigerian Industrial Standard (NIS).

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