Assessment of seasonal variations in groundwater quality and its suitability for agricultural use in Keffi, Nigeria

Ebenezer Agayina KUDAMNYA (obeydelaw2013@gmail.com)
University of Calabar https://orcid.org/0000-0002-0158-7611
Aniekan Edet
University of Uyo
Azubuike S. Ekwere
University of Calabar

Research Article

Keywords: Groundwater, Keffi, Quality, Irrigation, Seasons, Agricultural

Posted Date: May 17th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1612590/v1

Abstract

Groundwater within the Basement Complex terrain of Keffi and its environs were assessed for its quality and suitability for agriculture. A total of about sixty-three groundwater samples were collected during wet and dry season, where physical and chemical parameters were measured. Results obtained show that values of analyzed parameters are within WHO permissible limit, except NO_3^-. Groundwater in the study area is of good to excellent quality. Major cation constituents during both seasons occur in order $Ca^{2+} > Na^+ > Mg^{2+} > K^+$. In the wet season, major anions in the groundwater occur in the order $NO_3^- > HCO_3^- > Cl^- > SO_4^{2-}$, while in the dry season it is $NO_3^- > Cl^- > SO_4^{2-} > HCO_3^-$. During weathering processes, dissolution may be responsible for the release of these major ions into the groundwater system owing to the rock-water interaction. Also, groundwater in the study area is suitable for agriculture based on the indices: total hardness, residual sodium carbonate, percent sodium, sodium absorption ratio, magnesium hazard and permeability index. Correlation suggests that anthropogenic sources contribute the excess NO_3^- in the groundwater through the application of fertilizer and pesticide, improper disposal of refuse and even indiscriminate open defecation over time. Majority of the groundwater samples analyzed for both season were classified as; 'very good to good' and 'good to permissible', using the Wilcox Plot. Similarly, the plot of sodium hazard against salinity hazard has classified the groundwater samples analyzed as 'good'.

Introduction

Groundwater is indispensible natural resources for the sustenance of livelihood and other basic needs of man. It's used for domestic, industrial and agricultural activities particularly in regions of the globe where surface water is scarce. One amongst the foremost sources of water globally is groundwater Bear (1979), while Foster (1998) revealed that out of the whole freshwater resources available within the earth, only 22% exists as groundwater. The advantage groundwater has over surface water is that it's a more even and stable spatio-temporal distribution, better water quality and more constant temperature (Zhou et al. 2016; Sridharan and Senthil-Nathan 2017).

According to Vorosmarty et al. (2010), an estimated 3.4 billion people in developing countries are highly liable to water insecurity which developed countries have overcome through massive technological advancement, management and investments. Further, it's projected that over 2.8 billion people in 48 countries of the globe will face water stress or water scarcity conditions by 2025 (UNECA 1999). Moreover, the matter of water quality in developing nations like Nigeria is one which can be categorized as economics, political, institutional, technological, operational, and water quality crisis (Sojobi 2016). Consequently, measures should be taken to ensure proper and effective routine quality assessment and management of the available groundwater resources. Li (2016) reveals that complexities in any groundwater system may arise from diverse hydrogeological conditions, lithological variations and other influencing factors. It is why the state of groundwater quality today has become serious issues for concern (Rebolledo et al. 2016), and also the resulting problems could also be environmental, social and political, at local, national and global levels (Nickson et al. 2005; Azizullah et al. 2011).

The various an application to which groundwater is subjected to depend upon the quantity of dissolved chemical constituents and their physical characteristics (Schiavo et al. 2006; Magesh and Chandrasekar 2011). Groundwater quality may arise from geogenic and anthropogenic processes (Sheikhy-Narany et al. 2014). According to Hem (1985), geogenic processes may arise because of rock-water interaction during recharge and discharge, mineral dissolution, fossil water, to mention but a few. They govern its hydrochemistry. This can be because groundwater is stored within the sub-surface geologic media referred to as an aquifer, and in keeping with Subramani et al. (2010), its interaction with the mineral constituents of the aquifer material through which it flows, control the chemical nature of the groundwater and hence its quality. Also, groundwater quality could also be imparted upon by various human activities like agricultural practices, mining, and indiscriminate waste disposal. These man-made processes put together are termed as *anthropogenic processes*. Several studies on the assessment of physicochemical parameters of groundwater and their impact on its quality have previously been disbursed in various parts of Nigeria and other parts of the globe (Raji and Alagbe 2000; Edmunds et al. 2006; Ramakrishnaiah et al. 2009; Hameed et al. 2010; Musa et al. 2014; Edet 2016; Edet 2018).

In most part of northern Nigeria, there's a gradual rise in population of humans, plus changing life styles. This has led to a corresponding rise in domestic and agricultural demand for groundwater especially during the dry season, when water level is typically lowered (Kudamnya, et al. 2021). During this time most wells contain little amount of groundwater, and when it is prolong, may become completely dry (Kudamnya and Andongma 2017). The predominant occupation within Keffi and its environs is agriculture, which depends on the employment of groundwater particularly during the time of year. Therefore, the employment of artificial fertilizers, pesticides and other associated chemicals during farming activities may impact greatly on the groundwater quality (Nag and Lahiri 2012). Also, blasting during mining activities have impacted discontinuities and fracture surfaces on insitu rocks, which in-turn increases the volume-area ratio that allows the initiation of chemical weathering processes within the host rock because of rock-water interaction. Major ionic constituents in groundwater (Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, NO_3^-, and HCO_3^-) were adapted to assess groundwater suitability for agricultural activities (Edet 2016; Javed et al. 2017; Koffi et al. 2017; Ghalib 2017; Edet 2018). These studies have evaluated indices like total hardness (TH), sodium percentage (%Na), sodium absorption ratio (SAR), magnesium hazard (MH), residual washing soda (RSC) and permeability index (PI) to classify groundwater for irrigation use.

Therefore, the aim of this study is to assess the groundwater quality for drinking and other domestic uses, and further classify its suitability for agricultural use within the crystalline basement terrain of Keffi and its surrounding environs.

Description Of The Study Area

Location:

The study area is situated within the latitudes 8˚ 45' N to 9˚ 00' N and longitudes 7˚ 45' E to 8˚ 00' E of the topographic sheet 208, Keffi NE (Fig. 1), covering an estimated area of about approximately 765.64 Km^2. Accessibility within the study area is notably through four (4) routes namely; the Abuja – Keffi, Keffi – Akwanga, Nasarawa – Keffi and Keffi - Kaduna major roads. Other numerous minor roads also are present, like footpaths and cattle tracks that also function as access into the hinterlands areas and village settlements.

Keffi and its environs belong to the humid tropical climate, with characteristic distinct wet and dry seasons. The wet season spans a period of six months because it begins within the month of April and ends by October, while during dry periods, no rainfall occurs from the month of November until March. Annual rainfall ranges between 1100–1500 mm while annual temperature range is between 32ºC – 35ºC (NIMET, 2011). Rainy months are related to the northwards movement of the Inter-Tropical Discontinuity (ITD), while the southward migration of the Inter-tropical Discontinuity (ITD) is related to the dry and dusty seasons. The Inter-Tropical Discontinuity line separates dry continental air masses within the north from moist maritime monsoon air masses within the south of Nigeria (Schoeneich 2010). Vegetation is typical of the guinea savannah belt of Nigeria, characterized by thickets of open, broad-leaved savannah woodland vegetation with short to medium grasses. However, land cultivation, bush burning, tree felling and grazing activities have greatly modified the natural vegetation cover. Rain-fed farming and irrigation are practiced intensively within the study area

Geology

Geologic settings of the study area is characterized by the presence of crystalline rock suites typical of the north-central Basement Complex of Nigeria that lie between the West African and Congo Cratons, south of the Tuareg Shield (Black 1980; Ugwuonah et al. 2017). Typical rock types observed within the study area include; porphyritic granite, garnet-mica schist, quartzite and porphyroblastic gneiss (Fig. 2).

Studies by early workers (Oyawoye 1964; McCurry 1971 and Ajibade et al. 1976) have all elucidated that the events which led to the emplacement of the Basement Complex of Nigeria is polycyclic. Also, not fewer than four major orogenic cycles of deformation, metamorphism and remobilization occurred within the basement rocks, such as the Liberian (2,700 Ma), Eburnean (2,000 Ma), Kibaran (1,100 Ma) and Pan-African (600 Ma) cycles (Obaje 2009). Previous studies have also emphasized that the foremost three cycles characterized by episodes of intense deformation and isoclinal folding, accompanied by regional metamorphism, and was followed by extensive migmatization. Further, Pan-African deformation was accompanied by regional metamorphism, migmatization and extensive granitization, and gneissificaton that produced syn-tectonic granites and homogeneous gneisses

(Abaa 1983). However, there was late emplacement of granitic rocks with associated contact metamorphism during final stages of the last deformation. Faulting and fracturing indicated advance stage of the orogeny (Gandu et al. 1986; Olayinka 1992).

Material And Methods

Data acquisition and laboratory analysis

A total of about sixty-three (63) groundwater samples were collected during wet and dry season from the study area. Out of these, thirty-two (32) are wet season groundwater samples, while thirty-one (31) are dry season groundwater samples. At each sampling point, groundwater samples were collected by means of 0.75cl plastic containers which were thoroughly rinsed with the water whose sample was to be collected. This procedure was carried out in order to make certain that representative groundwater sample were obtained. The samples bottles were then labeled for easy identification.

Physical parameters comprising temperature (T), pH, electrical conductivity (EC) and total dissolved solids (TDS) were measured in-situ by means of a portable HANNA Instrument multi-parameter probe with model no. HI9813. The samples taken were then filtered using the ash-less WHATMAN filter-paper (110 mm diameter) and labeled properly for identification, and subsequently sent to the laboratory for analysis. Major anions like bicarbonate (HCO_3^-) and chloride (Cl^-) were analyzed by volumetric methods; SO_4^{2-} was estimated using the calorimetric method and NO_3^- were analyzed using an ultra violet (UV) - spectrophotometer screening method. The major cations were analyzed using the induced coupled plasma multi-spectrophotometer (ICP-MS). All samples were analyzed at the Institute of Hydrogeology and Biosciences, Technical University of Frieberg-Germany.

Data interpretation

Groundwater quality assessment is predicated on comparisons with WHO (2011) standard for domestic purposes. Also statistical analysis was performed in other to present an apposite interpretation of these data, by obtaining the minimum, maximum and mean values. Furthermore, Pearson’s Correlation Matrix was employed to analyze the data set using the software MINITAB 16.

Evaluation of potable water quality index (WQI) and irrigation water quality

WQI was calculated with references to the World Health Organization (WHO) standards for each analyzed water quality parameter analyzed. The index used in this was modeled after Cude 2001; Ramakrishnaiah et al. 2009; Al-Obaidy et al. 2016; Survana et al. (2020). The WQI is computed as follows:

i. Assigning different weightage (W) to water quality parameters measured, according to their significant influence on overall water quality.

ii. Next, the computation of relative weightage (Wr) for every parameter is performed using the equation:

$$W_r = \frac{W}{\sum W_i} \qquad (1)$$

Where: i represents the quantity of parameter considered for the calculation of WQI.

iii. Then water quality rating scale (Q_i) for every parameter was determined using the equation:

$$Q_i = \left(\frac{C_i}{S_i}\right) \times 100 \qquad (2)$$

Where: C_i represents the concentration of parameters and S_i represents the water quality for every parameter according to the World Health Organization standard.

iv. Lastly, sub-indices (SI_i) and cumulative WQI are evaluated by:

$$SI_i = W_r \times Q_i \qquad (3)$$

$$WQI = \sum SI_i \qquad (4)$$

Classification of WQI after Batabyal and Chakraborty (2015) was employed in this study, with the classes; unsuitable (WQI > 300), very poor (200 < WQI < 300), poor (100 < WQI < 200), good (50 < WQI < 100), and excellent (WQI < 50).

To assess and evaluate the suitability of groundwater within Keffi and its environs for irrigation, indices including total hardness (TH), sodium percentage (%Na), sodium absorption ratio (SAR), magnesium hazard (MH), residual sodium carbonate (RSC) and permeability index (PI) were computed. The term salinity hazard, a vital quality criterion on crop productivity is a measure of the electrical conductivity of water, while sodium hazard is measured as the ratio of sodium to calcium and magnesium ions in water. Some equations for computation of these irrigation water quality indices are presented in Table 1.

Table 1
Irrigation water quality indices adopted within the study

s/no.	Index	Formulae	Source
1	TH	$TH = 2.5Cs + 4.1Mg (5)$	Todd (1980)
2	%Na	$\%Na = \left[\frac{(Na + K)}{(Ca + Mg + Na + K)}\right] \times 100 (6)$	Haritash et al. (2014); Edet (2016); Sridharan and Senthil-Nathan (2017)
3	SAR	$SAR = \frac{Na}{\sqrt{\frac{(Ca + Mg)}{2}}} (7)$	
4	MH	$MH = \frac{Mg}{(Ca + Mg)} \times 100 (8)$	
5	RSC	$RSC = (HCO_3^- + CO_3^{2-}) - \left(Ca^{2+} + Mg^{2+}\right) (9)$	
6	PI	$PI = \frac{(Na^+ + \sqrt{HCO_3^-})}{(Ca^{2+} + Mg^{2+} + Na^+)} \times 100 (10)$	

*All units are in meq/l

Results And Discussion

Physical parameters

Statistical summary of the physical parameters measured from the groundwater samples are presented in Table 2. The values of physical parameters revealed that most of them lie below the permissible limit of the WHO (2011) standard. During the wet season, pH value were within the range 5.20 to 7.15 with the mean of 6.58, while the dry season values range from 5.80 to 7.60 and overall mean value of 6.63. During both season, groundwater within Keffi and its environs are slightly acidic on the basis of the mean pH values, although it lies within the permissible limit for drinking water (6.50–8.50). This might be attributed to the usage of fertilizers and also poor waste disposal practices (Saranth-Prasanth et al. 2012) within the densely populated parts of Keffi and its environs. Values of EC obtained during the wet season ranged from 101.00–1410.00 µS/cm with mean of 398.44 µS/cm, while it ranged from 160.00–2970.00 µS/cm with mean of 781.29 µS/cm during the dry season. Excessively high values of EC > 1,500 µS/cm observed in a number of the samples indicate the presence of highly soluble ions released from the dissolution of rocks and minerals as a result of rock weathering process under the prevailing pH condition. The concentrations of TDS during the wet season ranged from 57.00–940.00 mg/l with a mean of 265.03 mg/l, while during the dry season it ranged from 117.00–1918.00 mg/l with a mean of 558.74 mg/l. Based on the mean values obtained, the physical parameter were comparable to previous studies elsewhere within the north-central Nigeria by Musa et al. (2014) and Sojobi (2016).

Table 2
A statistical summary of physical and chemical parameters from groundwater

Parameters		Wet season			Dry season			WHO (2011)
		Min.	Max.	Mean	Min.	Max.	Mean	
Physical	pH	5.20	7.15	6.58	5.80	7.60	6.63	6.50–8.50
	Temp., ºC	26.20	31.00	28.30	26.50	31.00	28.34	32.00
	E.C, μS/cm	101.00	1410.00	398.44	160.00	2970.00	781.29	1500.00
	TDS. mg/l	57.00	940.00	265.03	117.00	1918.00	558.74	1000.00
Chemical in mg/l	Na^+	8.62	182.10	34.72	3.42	206.70	27.54	200.00
	K^+	2.07	98.85	11.58	1.50	28.46	5.85	12.00
	Ca^{2+}	14.42	183.30	51.36	4.39	123.20	27.64	75.00
	Mg^{2+}	2.52	51.41	14.29	1.42	59.40	11.69	50.00
	Cl^-	0.00	266.00	34.34	0.00	265.00	34.44	250.00
	SO_4^{2-}	0.00	119.00	15.31	0.00	108.00	10.87	250.00
	NO_3^-	0.00	318.00	76.28	0.00	502.00	55.84	50.00
	HCO_3^-	0.27	180.00	59.18	0.67	6.93	2.18	100.00
WQI		24.27	190.03	56.54	21.84	160.80	42.49	-

Chemical parameters

The mean values for major ionic constituents are below the permissible limit of WHO (2011) standard, except for NO_3^-. Statistical summary of the results (Table 2) showed that in wet and dry seasons, the relative abundance of major cations present in groundwater is of the order $Ca^{2+} > Na^+ > Mg^{2+} > K^+$. During the wet season, anionic constituents within the groundwater samples occur in the descending order $NO_3^- > HCO_3^- > Cl^- > SO_4^{2-}$, while they are present within the order $NO_3^- > Cl^- > SO_4^{2-} > HCO_3^-$ during the dry season. This suggests that concentration of NO_3^- in the groundwater is highest during both seasons, which are likely due to contributions from anthropogenic inputs like the application of fertilizer and inappropriate waste disposal within the study area. Further, HCO_3^- is the second highest concentration due to the infiltrating rainwater during the wet season and hence least during the dry season. However within the dry season, the effect of evaporation resulted in the high concentration of Cl^-.

The concentration of Na^+ is highest amongst the cations and this could impart a salty taste on the groundwater by combining with Cl^- (Ramesh and Elango 2011; Sarath-Prasanth et al. 2012). Na^+ is present within the range from 8.62 to 182.10 mg/l, with a mean value of 34.72 mg/l for the wet season samples. During the dry season, Na^+ ranged from 3.42 to 206.70 mg/l, with mean concentration of 27.54 mg/l. K^+ was found to occur within the range of 2.07 to 98.85 mg/l, with mean of 11.58 mg/l for the wet season. K^+ dry season samples ranged from 1.50 to 28.46 mg/l and a mean of 5.85 mg/l. The values of Ca^{2+} were found to be present within the range 14.42 to 183.30 mg/l with mean of 51.36 mg/l for the wet season samples analyzed. During the dry season, the range of Ca^{2+} was 4.39 to 123.20 mg/l, and a mean of 27.64 mg/l. Very high Ca^{2+} in groundwater can cause abdominal ailment, encrustation and scaling (Saranth-Prasanth et al. 2012). The concentration of Mg^{2+} present for the wet season samples ranged from 2.52 to 51.41 mg/l, with mean of 14.29 mg/l. In dry season, Mg^{2+} ranged from 1.42 to 59.40 mg/l, with a mean of 11.60 mg/l. Ca^{2+} and Mg^{2+} in groundwater is as a result of rock-water interaction which has led to the dissolution of the more soluble calcium in subsurface through weathering and ion exchange processes.

Of the anions present, the concentration of Cl^- in groundwater during the wet season ranged from 0.00 to 266.00 mg/l, with a mean of 34.34 mg/l. In the dry season however, Cl^- ranged from 0.00 to 265.00 mg/l, with a mean of 34.44 mg/l. NO_3^- concentration during the wet season ranged from 0.00 to 318.00 mg/l and a mean of 76.28 mg/l, while the range obtained during dry season occur from 0.00 to 502.00 mg/l with a mean of 55.84 mg/l. Excess Cl^- in water may indicate a tracer for groundwater contamination (Loizidou and Kapetanios 1993), while NO_3^- may indicate anthropogenic influences (Edet 2016). SO_4^{2+} in groundwater from the study area during the wet season ranged from 0.00 to 119.00 mg/l and mean of 15.31 mg/l. In the dry season, SO_4^{2} ranged from 0.00 to 108.00 mg/l, with mean of 10.87 mg/l. The concentration level of HCO_3^- ranged from 0.27 to 180.00 mg/l, with a mean value of 59.18 mg/l in wet season. However in the dry season, the concentration of HCO_3^- ranged 0.67 and 6.93 mg/l, with mean value of 2.18 mg/l. The concentration SO_4^{2+} and HCO_3^- are within the acceptable standard for drinking water according to WHO (2011) in most of the samples, aside from some locations during the wet season where they exceed the permissible limits.

Correlation matrix

Correlation measures how well one variable predicts the other (Bahar and Reza 2010; Adamu et al. 2021). The matrix obtained at 95% confidence limit during the study for both wet and dry season samples are hereby presented (Table 3). The Table 3 revealed that pH and HCO_3^- show poor correlation with EC, TDS, Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-} and NO_3^- in both wet and dry seasons. This could be attributed to dissolution of the basement rocks which releases more HCO_3^- into solution, while the resulting pH of groundwater increasingly tends towards a weak acid. Also during wet season, Mg^{2+} showed a strong positive correlation with EC and TDS; Na^+ showed strong positive correlation with K^+, Cl^-, SO_4^{2-} and NO_3^-, while K^+ showed a strong positive correlation with Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-} and NO_3.

Table 3
Correlation matrix for the analyzed samples during the wet and dry seasons

	Parameters	pH	E.C.	TDS	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	SO_4^{2-}	NO_3^-	HCO_3^-
WET SEASON SAMPLES	**pH**	1.00										
	E.C.	0.20	1.00									
	TDS	0.18	**0.99**	1.00								
	Na^+	0.16	0.04	0.06	1.00y							
	K^+	-0.16	0.39	0.40	**0.53**	1.00						
	Ca^{2+}	-0.11	0.23	0.23	0.42	**0.66**	1.00					
	Mg^{2+}	0.12	**0.58**	**0.57**	0.34	**0.64**	**0.59**	1.00				
	Cl^-	0.05	0.30	0.30	**0.76**	**0.66**	**0.50**	**0.64**	1.00			
	SO_4^{2-}	-0.05	0.37	0.39	**0.66**	**0.90**	**0.63**	**0.64**	**0.77**	1.00		
	NO_3^-	0.03	0.31	0.31	**0.58**	**0.74**	**0.56**	**0.76**	**0.78**	**0.75**	1.00	
	HCO_3^-	0.07	0.01	0.02	0.16	0.27	0.21	0.22	0.31	0.32	0.30	1.00
DRY SEASON SAMPLES	**pH**	1.00										
	E.C.	0.18	1.00									
	TDS	0.16	**0.98**	1.00								
	Na^+	0.05	**0.83**	**0.75**	1.00							
	K^+	-0.07	**0.65**	**0.59**	**0.68**	1.00						
	Ca^{2+}	0.22	**0.74**	**0.72**	**0.78**	**0.82**	1.00					
	Mg^{2+}	0.07	**0.80**	**0.76**	**0.78**	**0.87**	**0.91**	1.00				
	Cl^-	-0.01	**0.79**	**0.73**	**0.93**	**0.69**	**0.73**	**0.82**	1.00			
	SO_4^{2-}	0.16	**0.87**	**0.79**	**0.93**	**0.73**	**0.88**	**0.80**	**0.81**	1.00		
	NO_3^-	-0.04	**0.60**	**0.50**	**0.71**	**0.85**	**0.83**	**0.84**	**0.74**	**0.74**	1.00	
	HCO_3^-	0.19	0.27	0.24	0.24	0.12	0.26	0.07	0.08	0.34	0.11	1.00

Na^+ showed strong positive correlation with K^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, NO_3^- and HCO_3^-; EC and TDS show strong positive correlation with Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, $SO_4^{2-}$and NO_3^- in the dry season. Most of the ionic constituents are released into the solution phase during the process of weathering and may be responsible in the chemical break-down of mineral such as feldspars, pyroxenes and amphiboles that are present in the basement rocks under the existing pH condition, and therefore ion-exchange may be take place.

It was observed that NO_3^- showed strong positive correlation with all the major ionic constituents during wet and dry seasons except HCO_3^-. Thus, it suggests there are anthropogenic contributions that may arise from agricultural practices (fertilizer and pesticide application), improper disposal of refuse and even indiscriminate open defecation dominant within the study area. These may impact on the chemistry the groundwater over time.

Water quality assessment

The evaluation of groundwater quality is incredibly important for the determination of its suitability for drinking and agricultural purposes (Sarath-Prasanth et al. 2012; Ghalib 2017; Alam et al. 2020). The computed WQI with their corresponding classes during wet and dry periods in all locations are presented (Tables 4 and 5). It reveals that values of WQI computed for the groundwater samples analyzed during the wet season were classified as: excellent (59.37%), good (31.26%) and poor (9.37%) quality. During the dry season, WQI classes obtained for the groundwater samples analyzed were excellent (77.42%), good (16.13%) and poor (6.45%) water quality. Overall, the mean values of WQI computed showed that groundwater of the study area has *'good'* to *'excellent'* quality in most of the locations from were samples were analyzed. In terms of seasonal comparison, groundwater within Keffi and its environs showed better quality during the dry season.

Table 4
Computed WQI of groundwater samples analyzed

Wet season				Dry season			
Sample ID	**Locality**	**WQI**	**Class**	**Sample ID**	**Locality**	**WQI**	**Class**
KW01	Ang, Jama'a Dadi	62.08	Good	KD01	Bokoko	32.29	Excellent
KW02	Gora	45.03	Excellent	KD02	Mahuta	160.80	Poor
KW03	Hadari	31.99	Excellent	KD03	Haderi	30.35	Excellent
KW04	Ang. Rimi Mada	79.42	Good	KD04	Agwan Rimi-Mada	69.13	Good
KW05	Bazaria	80.58	Good	KD05	Bazaria	38.46	Excellent
KW06	Ang. Pa I	44.15	Excellent	KD06	Laminga	26.87	Excellent
KW07	Laminga	115.60	Poor	KD07	Old Barracks	26.54	Excellent
KW08	Gunduma 1	29.01	Excellent	KD08	Angwan Jarimai	33.16	Excellent
KW09	Ang. Jarimai	36,46	Excellent	KD09	Agwan Kera	33.41	Excellent
KW10	Ang. Kera	64,20	Good	KD10	Agwan Káre	32.65	Excellent
KW11	Ang. Kare	38.22	Excellent	KD11	Agwan Jaba	33.01	Excellent
KW12	Ang. Jaba	31.92	Excellent	KD12	Angwan Tudu	31.05	Excellent
KW13	Jigwada II	44.16	Excellent	KD13	Angwan Taimako	26.02	Excellent
KW14	Ang. Taimako	29.77	Excellent	KD14	Agwan Pa II	25.69	Excellent
KW15	Ang. Pa II	31.32	Excellent	KD15	Jigwada	32.09	Excellent
KW16	Jigwada I	190.03	Poor	KD16	Angwan Toni	31.22	Excellent
KW17	N. S. U. K.	36.29	Excellent	KD17	Gauta	70.53	Good
KW18	HIgh Court I	24.27	Excellent	KD18	Kawo	26.06	Excellent
KW19	Bagaji	38.34	Excellent	KD19	Tilla	147.16	Poor
KW20	Gauta	159.88	Poor	KD20	Angwan Mangoro-Gataku	27.79	Excellent
KW21	Kawo	57.70	Good	KD21	Andeha-Gataku	67.12	Good
KW22	Tilla	92.79	Good	KD22	Angwan Zaria-Gataku	23.02	Excellent
KW23	Ang Mang.-Gataku	25.18	Excellent	KD23	Tudun Mada	50.86	Good
KW24	Andeha-Gataku	59.60	Good	KD24	Salamu	24.48	Excellent
KW25	Gunduma II	35.95	Excellent	KD25	Gidan Zakara	68.16	Good
KW26	Salamu	24.28	Excellent	KD26	Agada	21.84	Excellent
KW27	Gidan Zakara	65.11	Good	KD27	Gwandara	23.61	Excellent
KW28	Maraban Agada	57.31	Good	KD28	Angwan Ninzon	22.22	Excellent
KW29	Gwandara	43.87	Excellent	KD29	Low-Cost (Agwan Mada)	26.23	Excellent
KW30	Ang. Ninzo	39.30	Excellent	KD30	High-Court I	24.90	Excellent
KW31	Ang. Mada (Low-cost)	44.61	Excellent	KD31	High-Court II	31.50	Excellent
KW32	HIgh Court II	50.95	Good	-	-	-	-

Table 5
Summary of WQI classes for groundwater within the study area

Parameter	Values	Remark	Number		Percentage (%)	
			Wet	Dry	Wet	Dry
WQI	< 50	Excellent	19	24	59. 37	77.42
	50–100	Good	10	5	31.26	16.13
	101–200	Poor	3	2	9.37	6.45
	201–300	Very poor	-	-	-	-
	> 300	Unsuitable	-	-	-	-
Total			**32**	**31**	**100**	**100**

Groundwater suitability for agriculture

According to Alam (2014), hydrochemical changes may be introduced through the dissolution of mineral constituents of a particular salt which are capable of causing an adverse impact on the plant growth. One of such that impairs groundwater quality for irrigation and agricultural purposes is sodium, and it can be measured in-terms of salinity hazard and sodium hazard (Alagbe 2006, Al-Shaibani 2008 and Edet 2016). Irrigation water quality indices computed for the study during the wet and dry seasons are presented (Tables 6), while a summary of the results were further presented (Table 7).

Table 6
Computed groundwater indices for agriculture use

Wet season							Dry season						
Sample ID	**TH**	**%Na**	**SAR**	**MH**	**RSC**	**PI**	**Sample ID**	**TH**	**%Na**	**SAR**	**MH**	**RSC**	**PI**
KW01	113.44	50.82	2.08	43.54	-0.17	57.05	KD01	4.11	36.81	0.79	30.00	-1.33	43.23
KW02	361.93	18.06	0.68	47.88	2.41	34.56	KD02	18.05	40.52	2.10	55.83	-5.31	40.38
KW03	47.25	43.71	0.99	23.85	-0.49	47.61	KD03	2.39	52.65	1.26	43.08	-0.72	62.32
KW04	73.63	51.92	1.75	47.31	2.87	108.24	KD04	5.06	53.86	1.94	42.14	-1.56	57.83
KW05	182.16	25.35	0.77	50.76	0.19	29.98	KD05	6.87	35.21	0.92	63.07	-1.94	35.82
KW06	104.30	25.42	0.62	37.54	-0.49	29.21	KD06	35.40	26.40	1.37	44.28	-11.00	24.01
KW07	448.00	29.34	1.10	47.20	-0.46	22.50	KD07	1.37	37.02	0.48	28.90	-0.41	65.52
KW08	75.16	28.49	0.61	22.05	1.13	95.04	KD08	5.65	34.25	0.95	19.59	-1.89	43.51
KW09	103.16	27.16	0.70	25.99	-0.98	30.06	KD09	23.95	22.87	0.94	50.71	-7.20	21.87
KW10	396.88	28.36	1.49	49.12	-0.04	30.11	KD10	4.52	42.91	1.23	18.17	-1.60	45.87
KW11	90.36	40.37	1.16	20.62	-1.05	42.26	KD11	10.41	37.07	1.28	62.83	-2.94	38.35
KW12	200.89	23.53	0.71	56.00	3.10	52.23	KD12	2.91	44.26	1.01	34.31	-0.94	50.00
KW13	93.40	69.90	4.40	13.96	-0.08	87.84	KD13	2.32	39.58	0.64	34.21	-0.73	47.75
KW14	123.72	60.89	3.37	13.66	-1.77	63.04	KD14	1.64	57.27	1.28	36.80	-0.48	74.46
KW15	58.19	39.86	0.93	17.81	-0.73	45.82	KD15	1.84	43.00	0.80	18.66	-0.63	57.00
KW16	214.50	27.36	1.02	26.77	0.63	53.77	KD16	2.91	45.57	1.02	42.94	-0.87	55.79
KW17	116.17	34.69	1.00	28.29	1.94	82.19	KD17	1.81	49.94	0.37	54.87	-0.49	56.32
KW18	71.74	41.15	1.07	37.78	-0.33	44.46	KD18	4.90	29.67	0.65	24.32	-1.66	34.11
KW19	80.83	28.62	0.42	20.30	-0.24	61.47	KD19	4.30	21.33	0.35	20.62	-1.49	26.74
KW20	215.19	18.38	0.58	14.26	-1.77	38.71	KD20	4.96	30.88	0.69	37.72	-1.53	39.41
KW21	509.69	12.82	0.58	10.27	-7.61	17.47	KD21	5.48	28.72	0.65	37.78	-1.73	33.13
KW22	127.39	26.55	0.70	37.87	0.00	47.27	KD22	9.15	32.96	1.05	43.34	-2.85	33.58
KW23	156.68	28.73	0.89	29.38	-0.31	49.64	KD23	1.64	44.32	0.69	54.56	-0.47	52.52
KW24	107.43	22.81	0.47	30.51	-0.05	52.16	KD24	3.82	12.91	0.17	8.04	-1.42	20.02
KW25	182.21	16.54	0.47	25.30	-0.20	44.37	KD25	4.24	19.91	0.32	24.88	-1.45	22.63
KW26	292.17	17.06	0.57	22.97	-2.24	28.38	KD26	2.14	45.67	0.81	63.93	-0.58	57.30
KW27	126.29	25.92	0.69	25.89	-0.82	42.51	KD27	2.63	39.03	0.67	48.12	-0.79	43.88
KW28	65.50	29.76	0.54	32.28	0.52	81.75	KD28	14.19	31.66	1.37	32.60	-4.63	34.66
KW29	578.84	30.17	1.03	30.56	-2.08	28.69	KD29	2.32	44.63	0.84	37.85	-0.73	50.50
KW30	93.60	28.27	0.66	18.54	-1.17	28.22	KD30	30.40	50.09	4.13	43.82	-9.43	50.03
KW31	423.56	53.09	3.85	25.90	-1.98	57.16	KD31	7.78	30.54	0.96	23.83	-2.66	34.57
KW32	147.00	33.29	1.13	30.02	-1.11	37.61	-	-	-	-	-	-	-

Table 7
Irrigation water quality classes for groundwater in the study area

Indices	Units	Class range	Classification	No. of samples		Percentage, %	
				Wet	**Dry**	**Wet**	**Dry**
Electrical Conductivity, E.C.	μS/cm	< 250	Excellent	16	3	50	10
		250 – 750	Good	11	18	34	58
		750–2000	Permissible	5	8	16	26
		2000–3000	Doubtful	-	2	-	6
		> 3000	Unsuitable	-	-	-	-
Total Hardness, TH	meq/l	< 75	Soft	32	31	100	100
		75–150	Moderately hard	-	-	-	-
		150–300	Hard	-	-	-	-
		> 300	Very Hard	-	-	-	-
Sodium Absorption Ratio, SAR	-	< 10	Excellent	32	31	100	100
		10–18	Good	-	-	-	-
		18–26	Doubtful	-	-	-	-
		> 300	Unsuitable	-	-	-	-
Percent Sodium, %Na	%	< 20	Excellent	5	2	16	6
		20–40	Good	19	16	59	52
		40–60	Permissible	6	13	19	42
		60–80	Doubtful	2	-	6	-
		> 80	Unsuitable	-	-	-	-
Magnesium Hazard, MH	%	< 50	Suitable	30	24	94	77
		> 50	Unsuitable	2	7	6	23
Residual Sodium Carbonate, RSC	meq/l	< 1.25	Good	28	31	88	100
		1.25–2.50	Doubtful	2	-	6	-
		> 2.50	Unsuitable	2	-	6	-
Permeability Index, PI	%	> 75	Suitable	5	-	16	-
		75 – 25	Moderate	25	27	78	87
		< 25	Not Suitable	2	4	6	13

Electrical Conductivity (EC)

EC is a method of determining the salt content of irrigation water. The higher the EC, the greater is its salt content. The wet season data computed for EC showed the following classification; excellent (50%), good (34%), permissible (16%), while in the dry season they were; excellent (10%), good (58%), permissible (26%) and doubtful (6%) for agriculture (Table 7). Therefore on the basis of EC obtained the study area, the groundwater are largely suitable for irrigation, except few locations in the dry season where it is doubtful.

Total hardness (TH):

Depending on the concentration of Ca^{2+} against Mg^{2+}, TH was computed to determine the salinity level of the groundwater in the study area. High concentration of Ca^{2+} against Mg^{2+} causes water hardness which affects the water quality to crops (Bucks et al. 2009). The obtained values for the wet season ranged from 47.25 to 578.84 meq/l with mean of 186.91 meq/l, while they are ranged from 1.37 to 35.40 meq.l with a mean of 7.39 meq/l in the dry season (Table 6). The values obtained for TH during the wet and dry season revealed that 100% of groundwater samples analyzed are classified as '*soft water*', since its hardness is < 75 meq/l (Table 7). Hence groundwater within the study area during wet and dry season in terms of TH is suitable for domestic and industrial purposes, in agreement with Gopinath et al. (2015).

Percent sodium (%Na):

Sodium through ion-exchange process replaces calcium in the soil, thus destroying the soil structure and thereby reducing its permeability (Subba-Rao 2006). This may affects the soil drainage and consequently may lead to low yield and reduction of plant growth. Values of %Na obtained revealed that groundwater within Keffi and its environs were found to be suitable for irrigation purposes except at two locations; KW13 (69.90%) and KW14 (60.89%) during the wet season (Table 6). Wet season data computed for %Na showed the following classes; excellent (16%), good (59%), permissible (19%) and doubtful (6%). The dry season %Na data computed showed that groundwater samples were classified as follows; excellent (6%), good (52%) and permissible (42%) for irrigation and agriculture in general (Table 7).

A plot of %Na against EC (Fig. 3) reveals that majority of the groundwater samples are *'very good to good'* for agricultural purposes. This accounts for 91 and 71% of the analyzed samples during the wet and dry seasons respectively. About 9% and 23% of the wet and dry season samples respectively were *'good to permissible'* water class for irrigation. Groundwater in the dry season was *'doubtful to unsuitable'* for irrigation purposes in only about 6% of samples. There is similarity in the trend observed for both seasons, and it may be attributed to geological factors, soil types, sample size, anthropogenic activities and climatic factors, to mention but a few.

Sodium Absorption Ratio (SAR):

SAR is directly related to the absorption of sodium by soils, and is used to assess the groundwater suitability for irrigation. Seasonal SAR values estimated showed that wet season ranged from 0.42 to 4.40 meq/l with mean of 1.16 meq/l, while they are ranged from 0.17 to 4.13 meq.l with a mean of 1.02 meq/l in the dry season (Table 6). During the wet and dry season, 100% of the groundwater samples analyzed were classified as *'excellent water'* respectively, suitable for agricultural use because all the values for SAR < 10 (Table 7).

A plot of SAR against EC (salinity hazard) during both seasons, indicates that groundwater from the study area were *'low sodium hazard'* type except for one sample in the dry season sample that is '*medium sodium hazard'* type (Fig. 4). The wet season groundwater samples were classified for suitability in agriculture as thus; C1S1 indicative of *low salinity hazard - low sodium hazard* (47%), C2S1 interpreted as *medium salinity hazard - low sodium hazard* (38%) and C3S1 representing *high salinity hazard – low sodium hazard* (15%). However in the dry season, they are classified as; C2S1 indicating *medium salinity hazard - low sodium hazard* (58%), C3S1 is interpreted to have *high salinity hazard - low sodium hazard* (29%), C1S1 indicates *low salinity hazard - low sodium hazard* (10%) and C4S2 is interpreted as *very high salinity hazard - medium sodium hazard* (3%). Therefore, the study has revealed that groundwater within Keffi and its environs in-terms of suitability for agricultural use are classified as moderate to good (Table 8).

Table 8
A summary of groundwater suitability for agricultural use

Class	Number		Percent (%)		Water quality
	Wet	Dry	Wet	Dry	
C1S1	15	3	48.39	9.38	Good
C1S2	-	-	-	-	Moderate
C1S3	-	-	-	-	Poor
C1S4	-	-	-	-	Very poor
C2S1	12	18	38.71	56.25	Good
C2S2	-	-	-	-	Moderate
C2S3	-	-	-	-	Poor
C2S4	-	-	-	-	Very poor
C3S1	5	9	16.13	28.13	Good
C3S2	-	-	-	-	Moderate
C3S3	-	-	-	-	Poor
C3S4	-	-	-	-	Very poor
C4S1	-	-	-	-	Good
C4S2	-	1	-	3.13	Moderate
C4S3	-	-	-	-	Poor
C4S4	-	-	-	-	Very poor

Magnesium Hazard (MH):

MH is the measure of how much alkaline the groundwater contains. Also, it creates a more alkaline soil during equilibrium reactions thereby reducing the soil quality and crop yield (Paliwal 1972 and Haritash et al. 2014). Groundwater with MH < 50% have no adverse effect on crop yield and if MH > 50%, the water is unsuitable for agricultural purpose. From the study, wet season groundwater samples reveal that 94% are suitable, while only 6% were unsuitable for irrigation and other agricultural uses. Further, the dry season samples have revealed that 77% are suitable, while 23% of the groundwater samples were classified as unsuitable for irrigation within the study area. Furthermore, seasonal SAR values estimated showed that wet season ranged from 10.27 to 56.00 meq/l with mean of 30.13 meq/l, while they are ranged from 8.04 to 63.93 meq.l with a mean of 38.12 meq/l in the dry season (Table 6).

Residual Sodium Carbonate (RSC):

RSC assesses when groundwater it is imparted by excess concentration of HCO_3^- + CO_3^{2-} over Ca^{2+} and Mg^{2+}. This is because Ca^{2+} and Mg^{2+} may precipitate as water in the soil becomes more concentrated with these ions. Thus is precipitates calcite from solution in the soil, and thereby increasing sodium in solution resulting in soil dispersion. This is unsuitable for irrigation and other agricultural purposes (Emerson and Bakker 1973). Bi-carbonate hazard in the water samples were investigated in-terms of the RSC (Tables 6 and 7), and wet season samples were classified for irrigation and other agricultural purposes thus; ‘good’ (88%), ‘doubtful’ (6%) and ‘unsuitable’ (6%). However during the dry season, 100% of the groundwater samples classified as ‘good’ on the basis of RSC for irrigation and agricultural purposes. Seasonal RSC values estimated showed that wet season ranged from − 7.61 to 3.10 meq/l with mean of -0.42 meq/l, while they are ranged from − 11.00 to -0.41 meq.l with a mean of -2.31 meq/l in the dry season (Table 6). Therefore, groundwater from Keffi and its environs based on the RSC are suitable for irrigation and other agricultural purposes during the wet and dry season.

Permeability Index (PI):

Soil permeability may be affected by pro-long use of irrigation water as it is influenced by Na^+, Ca^{2+}, Mg^{2+}, and HCO_3^- contents of the soil (Doneen 1964), The concentration of ions like Na^+ may become high in groundwater, such that it begins to exchange for Ca^{2+} and Mg^{2+}. This process tends to adversely affect the permeability of soils after long-term irrigation practice. According to Saleh et al. (1999), it results in poor drainage of soils, including insufficient air and water circulation. Seasonal values showed that wet season ranged from 17.47 to 108.24 meq/l with mean of 49.11 meq/l, while they are ranged from 20.02 to 74.46 meq.l with a mean of 43.65 meq/l in the dry season (Table 6). Based on the values of PI computed from the groundwater samples, the wet season data were classified as; *'suitable'* (16%), *'moderate'* (78%), *'not suitable'* (6%), while in the dry season they were classified as; *'moderate'* (87%) and *'not suitable'* (13%) for agricultural purposes. The slight increase during the dry season may be attributed to increase in the concentration of Na^+ in groundwater that is readily available during ion-exchange processes with the Ca^{2+} and Mg^{2+} present.

Conclusion

Groundwater quality evaluation for domestic and agricultural purposes within Keffi and its environs are influenced by natural and anthropogenic processes. Computed WQI of groundwater within Keffi and its environs revealed that it is generally of good to excellent quality for use. The levels of analyzed physical and chemical parameters lie within the permissible limit of the World Health Organization, with the exception of NO_3^-. There is high concentration of NO_3^- in groundwater within the study area during both seasons. Major cation constituents from wet and dry season samples occur in order $Ca^{2+} > Na^+ > Mg^{2+} > K^+$. The major anions in the groundwater during the wet season occur in the order $NO_3^- > HCO_3^- > Cl^- > SO_4^{2-}$, while they occur in the order $NO_3^- > Cl^- > SO_4^{2-} > HCO_3^-$ in the dry season. Ion-exchange and weathering processes may be responsible for the release of these major ions into the groundwater system due to the rock-water interaction at the existing pH condition. During both seasons, there is a strong positive correlation between NO_3^- and Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-} except HCO_3^-. Thus, anthropogenic sources contribute the excess NO_3^- in the groundwater through fertilizer and pesticide application, improper disposal of refuse and even indiscriminate open defecation over time.

Groundwater quality within Keffi and its environs was found to be largely suitable for agricultural purposes by evaluating indices such as TH, %Na, SAR, MH, RSC and PI. Most of the analyzed groundwater samples for wet and dry seasons were classified as 'very good to good', and 'good to permissible' respectively using the Wilcox Plot. Similarly the plot of sodium hazard against salinity hazard has classified the groundwater samples analyzed as good.

Adequate water management strategies that will reduce the impact of human activities on groundwater and soil, public awareness and routine assessment of groundwater quality are recommended for improving the overall water quality in the study area.

Declarations

Funding

The authors declare that no funds, grants, or other support were received during the preparation of this manuscript.

Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

Author Contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by "Ebenezer A. Kudamnya", "Aniekan Edet" and "Azubuike S. Ekwere". The first draft of the manuscript was written by "Ebenezer A. Kudamnya" and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

References

Figures

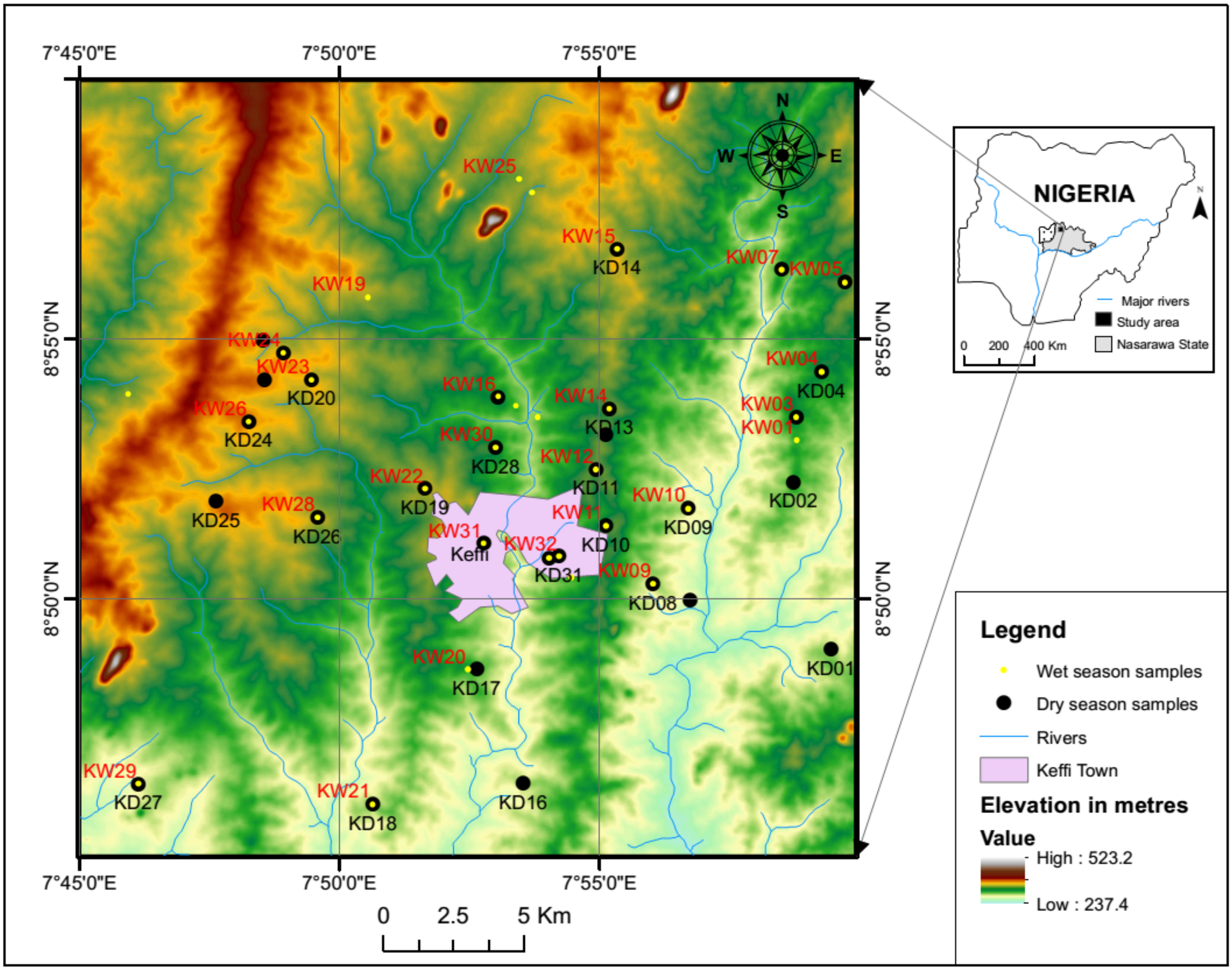

Figure 1

Location map of the study area

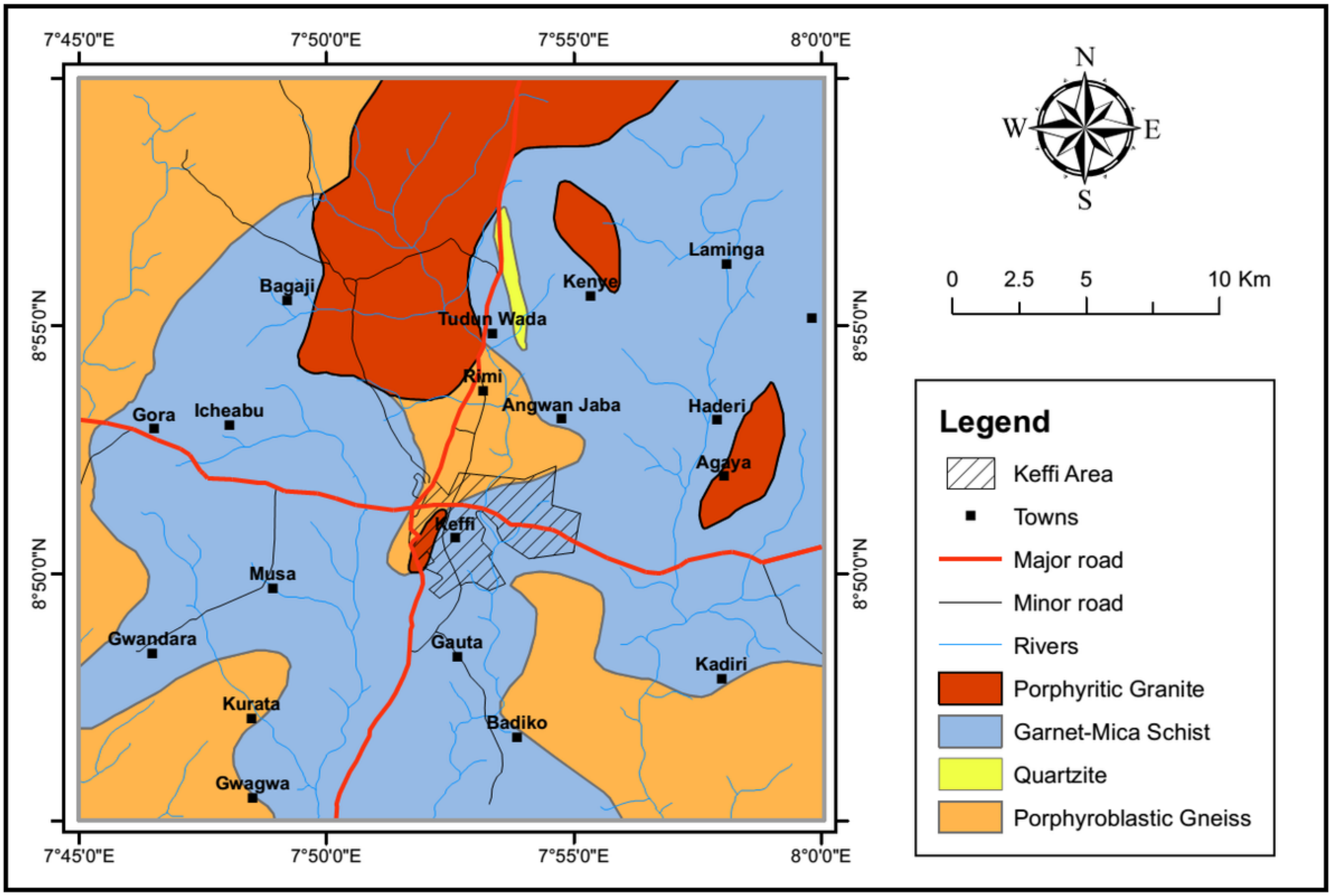

Figure 2

The geology underlying Keffi and its environs

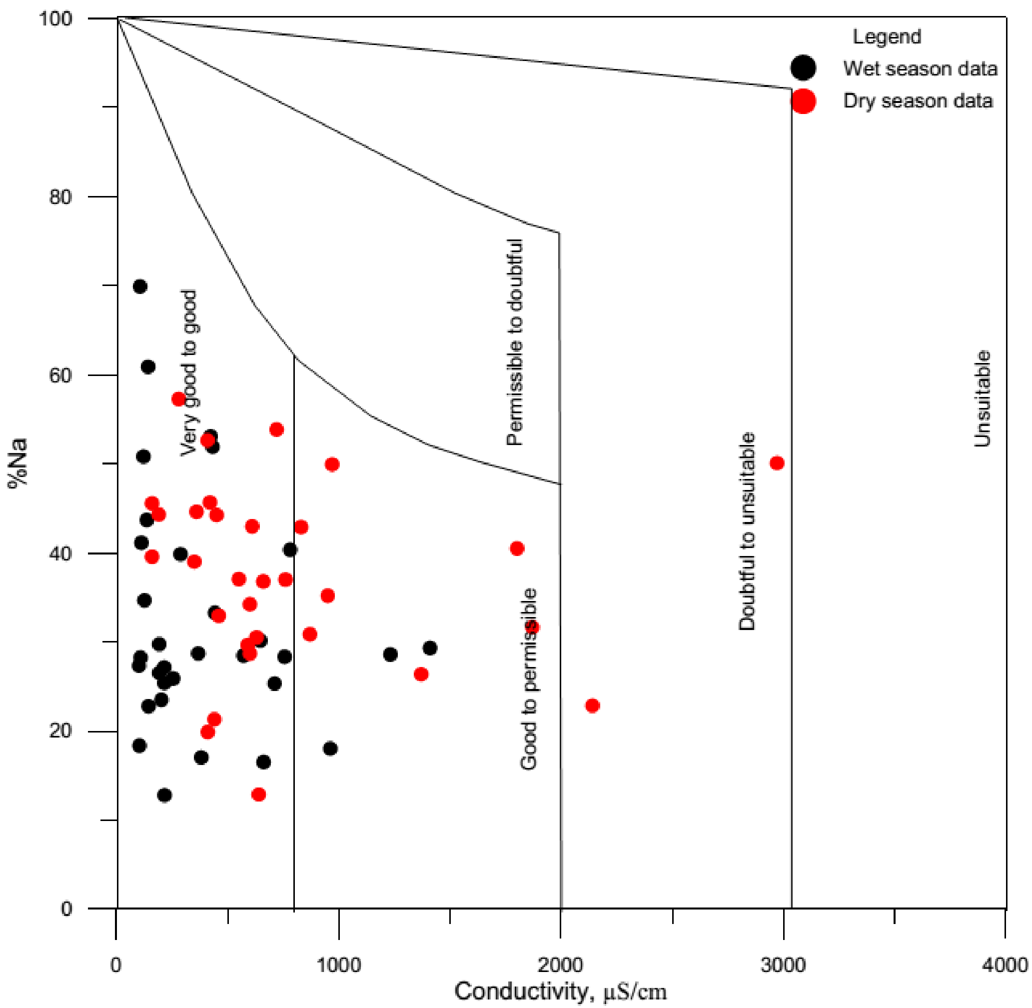

Figure 3

Wilcox plot for groundwater within the study area (after Wilcox, 1955)

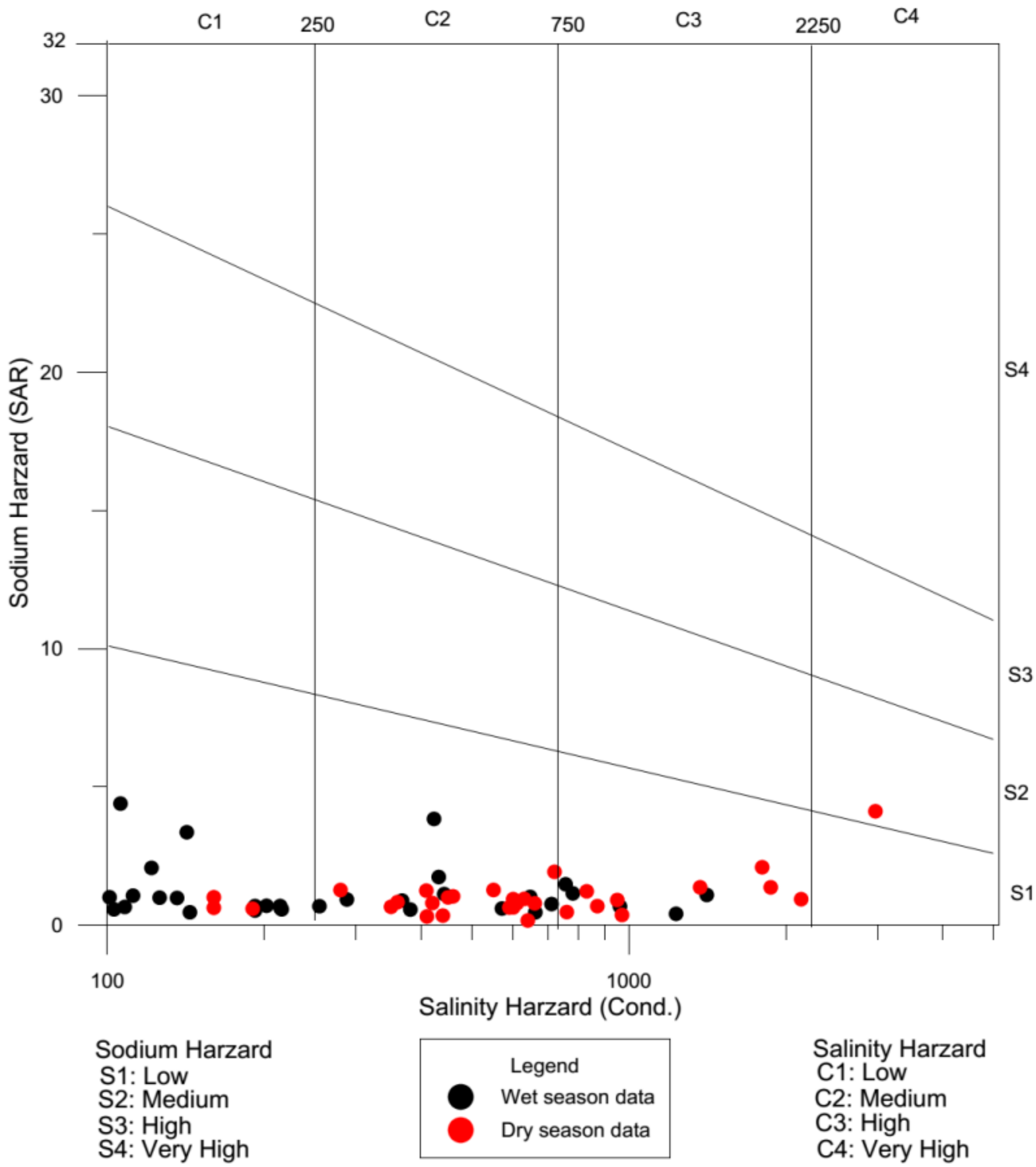

Figure 4

Classification of groundwater for irrigation (after Richards, 1954).