



ASSESSMENT OF SEASONAL VARIATIONS IN GROUNDWATER QUALITY AND ITS SUITABILITY FOR AGRICULTURAL USE IN KEFFI, NORTH-CENTRAL NIGERIA

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ABSTRACT

Groundwater within the Basement Complex terrain of Keffi and its environs was assessed for seasonal variation, quality for domestic and agricultural uses. A total of sixty-three groundwater samples were collected during wet and dry seasons, and major ion constituents were analyzed. Results showed that values of the analyzed parameters during the wet and dry seasons are within WHO permissible limit, except for NO_3^- . Major cation constituents during both seasons occur in order $\text{Ca}^{2+} > \text{Na}^+ > \text{Mg}^{2+} > \text{K}^+$. In the wet season, major anions present in the groundwater occur in the order $\text{NO}_3^- > \text{HCO}_3^- > \text{Cl}^- > \text{SO}_4^{2-}$, while in the dry season it is $\text{NO}_3^- > \text{Cl}^- > \text{SO}_4^{2-} > \text{HCO}_3^-$. These major ions are released into the groundwater system owing to the rock-water interaction during weathering of the host rock. The study showed that groundwater in the area is of good to excellent quality, and hence suitable for domestic use as illustrated by the water quality index (WQI) model adopted in this study during both seasons. In terms of the agricultural indices (total hardness, TH; sodium percentage, %Na; sodium absorption ratio SAR; magnesium hazard, MH; residual sodium carbonate, RSC; permeability index, PI) evaluated in both seasons, groundwater is suitable for agricultural use. Bivariate analysis suggests that during the wet and dry seasons, anthropogenic sources contribute to the excess NO_3^- in the groundwater through the application of fertilizer and pesticide, improper disposal of refuse, and indiscriminate open defecation over time.

KEYWORDS: domestic use, Groundwater, Irrigation, Keffi, major ion, Seasonal.

INTRODUCTION

Groundwater is a necessary natural resource for human sustenance, livelihood and other fundamental needs. It is utilized for domestic, commercial, and agricultural purposes, especially in areas of the world where surface water is in short supply (Rosca et al. 2020). Groundwater is one of the most important sources of water on the planet, according to Bear (1979), although Foster (1998) found that only 22% of the world's freshwater resources are present as groundwater. The advantage groundwater has over surface water is that it has a more even and stable Spatio-temporal distribution, better water quality, and more constant temperature (Zhou et al. 2016;

Sridharan and Senthil-Nathan 2017). Vorosmarty et al. (2010) estimated that 3.4 billion people in developing nations are extremely vulnerable to the water insecurity that industrialized countries have been able to overcome through significant technological innovation, management, and investment. More than 2.8 billion people are anticipated to experience water stress or water scarcity by 2025 in 48 different nations (UNECA 1999). The issue of water quality in developing countries like Nigeria can also be classified as an economic, political, institutional, technological, operational, and water quality crisis (Sojobi 2016).

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Therefore, steps should be taken to guarantee accurate and efficient regular quality evaluation and management of the accessible groundwater resources. According to Li (2016), various hydrogeological conditions, lithological variations, and other influencing factors may contribute to the complexity of any groundwater system. Because of this, the quality of groundwater is becoming a severe concern (Rebolledo et al. 2016; Edet et al. 2023; Ekwere et al. 2023), and the challenges that may follow on a local, national, and global scale could be environmental, social, and political (Nickson et al. 2005; Azizullah et al. 2011).

The amount of dissolved chemical constituents and their physical properties determine the wide range of applications that groundwater is subjected to (Schiavo et al. 2006; Magesh and Chandrasekar 2011). Groundwater quality can be affected by both geological and human-made factors (Sheikhy-Narany et al. 2014). Hem (1985) asserts that geogenic processes can result from interactions between rock and water during recharge and discharge, mineral dissolution, and the presence of fossil water, among other factors. According to Subramani et al. (2010), because groundwater is stored in the subsurface geologic medium known as an aquifer, its interaction with the mineral constituents of the aquifer material through which it flows controls the chemical nature of the groundwater and subsequently the quality. Numerous human activities, such as mining, indiscriminate waste dumping, and agricultural practices, may also have an impact on groundwater quality. "Anthropogenic processes" refers to all of these human-made processes combined. Several investigations on the assessment of groundwater's physicochemical properties and their effect on its quality have previously been conducted in different parts of Nigeria and other countries across the world

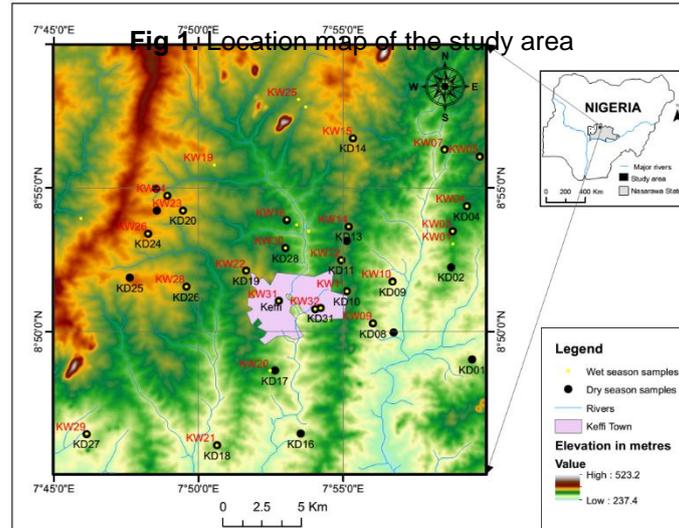
(Raji and Alagbe 2000; Edmunds et al. 2006; Ramakrishnaiah et al. 2009; Hameed et al. 2010; Musa et al. 2014; Edet 2016; Edet 2018; Edet et al. 2022; Edet and Okereke 2022; Ochelebe and Kudamnya 2022; Edet et al. 2024).

The majority of northern Nigeria is experiencing an increase in human population as well as changing lifestyles. Groundwater demand as a result has increased in tandem with this, particularly during the dry season when the water level is typically lowered (Kudamnya et al. 2021). Most wells only hold a little amount of groundwater during this period, and if it lasts for a long time, they might entirely dry out (Kudamnya and Andongma 2017). Irrigated agriculture, which relies on the use of groundwater, is the main source of income in Keffi and its environs, especially during this time of year. Therefore, using inorganic fertilizers, pesticides, and other chemicals during farming activities could have a significant impact on groundwater quality (Nag and Lahiri 2012). Additionally, blasting during mining activities has affected insitu rocks by creating discontinuities and fracture surfaces, which in turn increases the volume-area ratio and permits the initiation of chemical weathering processes inside the host rock due to rock-water contact. The major groundwater ionic constituents (Na^+ , K^+ , Ca^{2+} , Mg^{2+} , Cl^- , SO_4^{2-} , NO_3^- , and HCO_3^-) were employed to assess the appropriateness of groundwater for agricultural operations (Edet 2016; Javed et al. 2017; Koffi et al. 2017; Ghalib 2017; Edet 2018). To categorize groundwater for irrigation use, these previous studies looked at indices including total hardness (TH), sodium percentage (%Na), sodium absorption ratio (SAR), magnesium hazard (MH), residual washing soda (RSC), and permeability index (PI). Therefore, this study aims to assess; the seasonal variation of major ion constituents in the groundwater, its quality for drinking and other domestic uses, and further classify its suitability for agricultural use within the crystalline basement terrain of Keffi and its environs.

Description of the study area

Location

The study area is situated from 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 approximately 765.64 Km².



Accessibility within the study area is notable through four (4) routes, namely; the Abuja-Keffi, Keffi-Akwanga, Nasarawa-Keffi, and Keffi-Kaduna major roads. There are numerous minor roads, such as footpaths and cattle tracks, that serve as access to the hinterland and village settlements. Keffi and its surroundings have a humid tropical climate with distinct wet and dry seasons. The wet season spans six months because it begins in April and ends by October, while during dry periods, no rainfall occurs from November until March. Annual rainfall ranges between 1100–1500 mm, while the annual temperature range is between 32°C and 35°C (NIMET, 2011). Rainy months are related to the northward 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 in the north from moist maritime monsoon air masses in the south of Nigeria (Schoeneich 2010). The 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

The geologic settings of the study area are 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 that led to the emplacement of the Basement Complex in Nigeria are 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 are characterized by episodes of intense deformation and isoclinal folding, accompanied by regional metamorphism, and followed by extensive migmatization. Further, Pan-African deformation was accompanied by regional metamorphism, migmatization, extensive granitization, and gneissification that produced syn-tectonic granites and homogeneous gneisses (Abaa, 1983). However, there was the late emplacement of granitic rocks with associated contact metamorphism during the final stages of the last deformation. Faulting and fracturing indicated an advanced stage of orogeny (Gandu et al. 1986; Olayinka 1992).

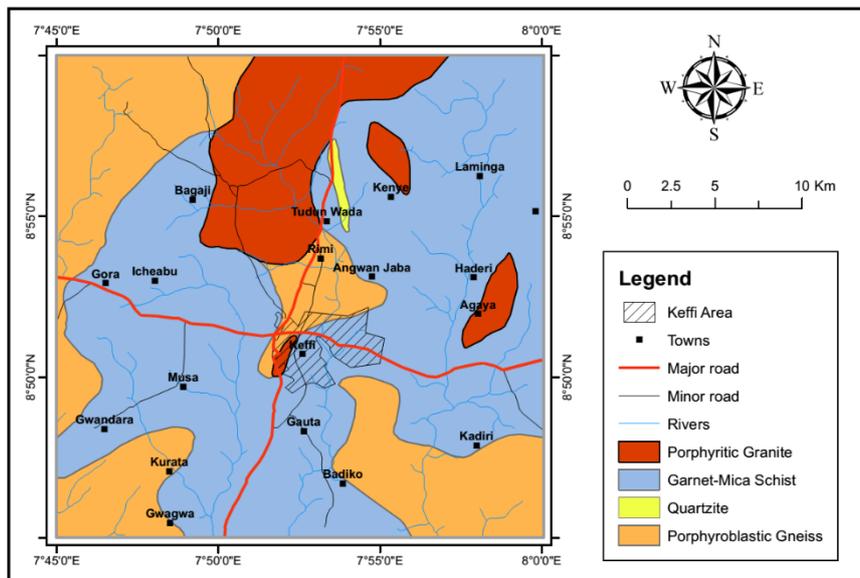


Fig 2. The geology underlying Keffi and its environs

MATERIAL AND METHODS

Data acquisition and laboratory analysis

A total of sixty-three (63) groundwater samples were collected during the wet and dry seasons 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 using 0.75-cl plastic containers, which were thoroughly rinsed with the water whose sample was to be collected. This procedure was carried out to make certain that representative groundwater samples were obtained. The sample 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 ashless WHATMAN filter paper (110 mm diameter) and labeled properly for identification, and subsequently sent to the laboratory for analysis. Volumetric methods were used to analyze major anions such as bicarbonate (HCO_3^-) and chloride (Cl^-); calorimetric methods were used to estimate SO_4^{2-} ; and an ultraviolet (UV) spectrophotometer screening method was used to analyze NO_3^- . 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 Freiberg, 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 opposite 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

The water quality index (WQI) was calculated with references to the World Health Organization (WHO) standards for each analyzed water quality parameter. The index used in this was modeled after Cude (2001), Ramakrishnaiah et al. (2009), Al-Obaidy et al. (2016) and Suvana 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 (W_r) for every parameter is performed using the equation:

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

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:

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

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:

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

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

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

"salinity hazard," a vital quality criterion for 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 the 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	$TH = 2.5Ca + 4.1Mg$ (5)	Todd (1980)
2	%Na	$\%Na = \left[\frac{(Na + K)}{(Ca + Mg + Na + K)} \right] \times 100$ (6)	
3	SAR	$SAR = \frac{Na}{\sqrt{\frac{(Ca + Mg)}{2}}}$ (7)	Haritash et al. (2014); Edet (2016); Sridharan and Senthil-Nathan (2017)
4	MH	$MH = \frac{Mg}{(Ca + Mg)} \times 100$ (8)	
5	RSC	$RSC = (HCO_3^- + CO_3^{2-}) - (Ca^{2+} + Mg^{2+})$ (9)	
6	PI	$PI = \frac{(Na^+ + \sqrt{HCO_3^-})}{(Ca^{2+} + Mg^{2+} + Na^+)} \times 100$ (10)	

*All units are in meq/l

Results

The results obtained from the physicochemical analysis of wet and dry season groundwater samples that were sourced from relatively shallow open hand-dug well and deeper boreholes are presented herein (Table 2). These data form the basis for all interpretations in the succeeding discussions.

Table 2. Major ion composition in groundwater samples during the wet and dry seasons

Wet season samples										Dry season samples									
Code	Well type	Concentration in mg/l								Code	Well type	Concentration in mg/l							
		Na ⁺	K ⁺	Ca ²⁺	Mg ²⁺	Cl ⁻	SO ₄ ²⁻	NO ₃ ⁻	HCO ₃ ⁻			Na ⁺	K ⁺	Ca ²⁺	Mg ²⁺	Cl ⁻	SO ₄ ²⁻	NO ₃ ⁻	HCO ₃ ⁻
KW04	HW	34.47	3.56	15.55	8.47	35.00	4.00	97.00	180.00	KD04	HW	39.71	5.16	18.47	8.16	37.00	2.00	0.00	2.27
KW08	HW	12.13	2.78	23.48	4.03	11.00	1.00	39.00	120.00	KD06	HW	74.24	28.46	123.20	59.40	126.00	50.00	502.00	2.33
KW09	HW	16.33	2.31	30.60	6.52	30.00	0.00	33.00	0.93	KD08	HW	21.82	3.76	32.34	4.78	13.00	13.00	0.00	6.93
KW10	HW	68.02	7.15	80.93	47.40	79.00	37.00	186.00	6.33	KD09	HW	41.31	13.59	71.44	44.59	46.00	33.00	60.00	1.93
KW12	HW	23.05	9.14	35.43	27.35	51.00	4.00	168.00	160.00	KD10	HW	25.45	4.35	26.58	3.58	45.00	7.00	45.00	1.27
KW13	HW	97.84	3.24	32.21	3.17	5.00	7.00	49.00	77.00	KD12	HW	16.05	2.33	12.56	3.98	12.00	2.00	13.00	1.00
KW07	HW	53.43	54.57	94.81	51.41	118.00	52.00	168.00	2.80	KD13	HW	9.00	4.16	10.02	3.16	9.00	1.00	24.00	1.53
KW11	HW	25.26	4.87	28.75	4.53	0.00	0.00	0.00	1.02	KD17	HW	4.45	13.31	4.84	3.57	3.00	3.00	1.00	2.87
KW14	HW	86.10	4.18	42.81	4.11	6.00	4.00	44.00	1.88	KD18	HW	13.65	4.74	25.70	5.01	31.00	2.00	30.00	2.13
KW21	HW	30.06	7.50	183.30	12.73	19.00	0.00	84.00	30.00	KD20	HW	14.27	3.65	19.95	7.33	12.00	0.00	24.00	3.93
KW23	HW	25.74	5.61	44.35	11.19	0.00	5.00	0.00	60.00	KD21	HW	13.97	4.02	21.99	8.10	31.00	2.00	30.00	1.93
KW24	HW	11.23	5.72	29.92	7.97	0.00	0.00	0.00	48.00	KD22	HW	28.88	5.97	32.54	15.10	0.00	10.00	0.00	1.00
KW26	HW	22.40	8.91	90.20	16.32	0.00	0.00	0.00	56.31	KD23	HW	6.80	3.54	4.42	3.22	12.00	0.00	24.00	0.80
KW27	HW	17.86	4.17	37.51	7.95	0.00	0.00	0.00	24.00	KD24	HW	3.42	2.60	26.77	1.42	3.00	4.00	5.00	1.80
KW28	HW	9.98	4.73	17.78	5.14	0.00	0.00	0.00	60.00	KD26	HW	10.21	2.60	4.39	4.72	14.00	0.00	52.00	1.53
KW29	HW	56.86	98.85	161.10	43.01	76.00	116.00	318.00	148.00	KD27	HW	9.78	3.52	8.37	4.71	11.00	1.00	46.00	0.80
KW30	HW	14.79	3.69	30.56	4.22	10.00	2.00	76.00	0.27	KD28	HW	48.40	2.75	63.42	18.61	32.00	42.00	150.00	3.87
KW18	HW	20.92	3.65	17.89	6.59	3.00	5.00	0.00	1.07	KD29	HW	11.80	3.49	9.31	3.44	8.00	0.00	9.00	0.93
KW20	HW	19.53	4.69	73.95	7.46	0.00	5.00	0.00	80.00	KD30	HW	206.70	21.05	106.90	50.59	265.00	108.00	339.00	4.07
KW31	HW	182.10	65.09	125.80	26.67	266.00	119.00	269.00	128.10	KD01	BH	15.17	5.61	19.35	5.03	3.00	2.00	0.00	3.00
KW01	BH	50.88	5.14	25.67	12.01	55.00	9.00	170.00	7.21	KD02	BH	78.76	7.71	47.08	36.10	184.00	19.00	76.00	0.67
KW02	BH	29.94	11.44	75.61	42.13	86.00	30.00	153.00	166.00	KD03	BH	17.68	2.55	8.56	3.93	5.00	0.00	0.00	1.93
KW03	BH	15.65	2.07	14.42	2.74	10.00	0.00	17.00	0.53	KD05	BH	20.82	6.16	14.48	15.00	46.00	2.00	108.00	0.87
KW05	BH	23.88	7.75	35.95	22.48	47.00	3.00	145.00	8.12	KD07	BH	5.31	1.63	6.61	1.63	4.00	6.00	1.00	3.07
KW06	BH	14.48	3.17	26.11	9.52	12.00	3.00	72.00	1.63	KD11	BH	35.84	7.45	22.12	22.68	86.00	2.00	192.00	1.93
KW15	BH	16.39	2.29	19.17	2.52	3.00	0.00	12.00	1.32	KD14	BH	15.12	2.05	6.71	2.37	3.00	0.00	0.00	3.13
KW16	BH	34.18	5.05	62.96	13.96	77.00	0.00	88.00	160.00	KD15	BH	10.51	1.50	10.71	1.49	4.00	1.00	0.00	1.93
KW17	BH	24.79	6.09	33.39	7.99	21.00	13.00	54.00	180.00	KD16	BH	15.78	3.08	10.45	4.77	2.00	0.00	0.00	2.60
KW19	BH	8.62	10.68	25.82	3.99	3.00	3.00	30.00	44.00	KD19	BH	7.07	4.09	24.18	3.81	0.00	10.00	0.00	2.00
KW22	BH	18.10	5.23	31.72	11.73	35.00	3.00	45.00	38.00	KD25	BH	6.30	3.52	22.05	4.43	0.00	0.00	0.00	0.87
KW25	BH	14.60	3.40	54.55	11.21	17.00	49.00	0.00	97.44	KD31	BH	25.53	2.98	41.20	7.82	20.50	15.00	0.00	2.60
KW32	BH	31.53	3.73	41.23	10.73	24.00	16.00	124.00	3.82										

Note: HW – Hand-dug wells; BH - Boreholes

DISCUSSIONS**Seasonal variation in physicochemical parameters****Seasonal variations in physical parameters**

A statistical summary of the physical parameters measured from the groundwater samples is presented in Table 3. 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 values were within the range of 5.20 to 7.15 with a mean of 6.58, while the dry season values range from 5.80 to 7.60 with an overall mean value of 6.63. During both seasons, the groundwater within Keffi and its environs is slightly acidic based on the mean pH values, although it is within the permissible limit for drinking water (6.50 to 8.50). This might be attributed to the usage of fertilizers and also poor waste disposal practices within the densely populated

parts of Keffi and its environs (Ochelebe and Kudamnya 2022). Values of EC obtained during the wet season ranged from 101.00 to 1410.00 $\mu\text{S}/\text{cm}$ with a mean of 398.44 $\mu\text{S}/\text{cm}$, while they ranged from 160.00 to 2970.00 $\mu\text{S}/\text{cm}$ with a mean of 781.29 $\mu\text{S}/\text{cm}$ during the dry season. Excessively high values of EC > 1,500 $\mu\text{S}/\text{cm}$ 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 the 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 they ranged from 117.00–1918.00 mg/l with a mean of 558.74 mg/l. Based on the mean values obtained, the physical parameters were comparable to previous studies elsewhere within north-central Nigeria by Musa et al. (2014) and Sojobi (2016).

Table 3. 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., °C	26.20	31.00	28.30	26.50	31.00	28.34	32.00
	E-C, $\mu\text{S}/\text{cm}$	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	-	

Seasonal variations in chemical parameters

The mean values for major ionic constituents are below the permissible limit of the WHO (2011) standard, except for NO₃⁻. A statistical summary of the results (Table 3) showed that in wet and dry seasons, the relative abundance of major cations present in groundwater is of the order Ca²⁺ > Na⁺ > Mg²⁺ > K⁺. Anionic constituents in groundwater samples are found in the descending order NO₃⁻ > HCO₃⁻ > Cl⁻ > SO₄²⁻ during the wet season, and in the order NO₃⁻ > Cl⁻ > SO₄²⁻ > HCO₃⁻ during the dry season. This implies that NO₃⁻ concentrations in groundwater are highest during both seasons, most likely due to anthropogenic inputs such as fertilizer application and improper waste disposal within the study area (Saranth-Prasanth et al. 2012; Mthembu et al. 2020; Ochelebe and Kudamnya 2022). Furthermore, HCO₃⁻ concentrations are highest during the wet season due to rainwater infiltration and lowest during the dry season. However, within the dry season, the effect of evaporation resulted in a high concentration of Cl⁻.

The concentration of Na⁺ is the highest amongst the cations, and this could impart a salty taste to the groundwater by combining with Cl⁻ (Ramesh and Elango 2011; Saranth-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 a mean concentration of 27.54 mg/L. K⁺ was found to occur within the range of 2.07 to 98.85 mg/l, with a mean of 11.58 mg/l for the wet season. K⁺ dry season samples ranged from 1.50 to 28.46 mg/l and had a mean of 5.85 mg/l. The values of Ca²⁺ were found to be present within the range of 14.42 to 183.30 mg/l with a mean of 51.36 mg/l for the wet season samples analyzed. During the dry season, the range of Ca²⁺ was 4.39 to 123.20 mg/l, with a mean of 27.64 mg/l. Groundwater with extremely high Ca²⁺ levels can cause abdominal pain, encrustation, and scaling (Saranth-Prasanth et al. 2012).

The concentration of Mg^{2+} present in the wet season samples ranged from 2.52 to 51.41 mg/l, with a mean of 14.29 mg/l. In the 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 are a result of rock-water interaction, which has led to their dissolution through weathering and ion exchange processes.

During the wet season, the concentration of Cl^- in groundwater ranged from 0.00 to 266.00 mg/l, with a mean of 34.34 mg/l. However, during the dry season, Cl^- levels ranged from 0.00 to 265.00 mg/l, with a mean of 34.44 mg/l. NO_3^- concentrations during the wet season ranged from 0.00 to 318.00 mg/l and had a mean of 76.28 mg/l, while the range obtained during the dry season was from 0.00 to 502.00 mg/l with a mean of 55.84 mg/l. Excess Cl^- in water can be used as a tracer for groundwater contamination (Loizidou and Kapetanios 1993), whereas NO_3^- can be used to identify anthropogenic influences (Edet 2016; Edet and Okereke 2022). During the wet season, SO_4^{2-} levels in groundwater from the study area ranged from 0.00 to 119.00 mg/l, with a mean of 15.31 mg/l. In the dry season, SO_4^{2-} ranged from 0.00 to 108.00 mg/l, with a mean of 10.87 mg/l. During the wet season, the concentration of HCO_3^- ranged from 0.27 to 180.00 mg/l, with a mean value of 59.18 mg/l. During the dry season, however, HCO_3^- concentrations ranged from 0.67 to 6.93 mg/l, with a mean of 2.18 mg/l. Except for a few locations during the wet season, the concentrations of SO_4^{2-} and HCO_3^- in most of the samples are within the WHO (2011) acceptable standard for drinking water.

Bivariate analysis (correlation matrix)

Correlation measures how well one variable predicts the other (Bahar and Reza 2010; Adamu et al. 2021). The matrix obtained at a 95% confidence limit during the study for both wet and dry season samples is hereby presented (Table 4). As shown in Table 4, pH and HCO_3^- have a 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 the oxic nature of the environment: dissolution of basement rocks takes place, resulting in groundwater with a

weakly acidic pH. During the wet season, Mg^{2+} positively correlated strongly with EC and TDS; Na^+ positively correlated strongly with K^+ , Cl^- , SO_4^{2-} , and NO_3^- , while K^+ positively correlated strongly with Ca^{2+} , Mg^{2+} , Cl^- , SO_4^{2-} , and NO_3^- .

During the dry season, Na^+ correlated strongly with K^+ , Ca^{2+} , Mg^{2+} , Cl^- , SO_4^{2-} , NO_3^- , and HCO_3^- , whereas EC and TDS correlated strongly with Na^+ , K^+ , Ca^{2+} , Mg^{2+} , Cl^- , SO_4^{2-} , NO_3^- , and HCO_3^- . Most of the ionic constituents are released into the solution phase during the process of weathering and may be responsible for the chemical break-down of minerals such as feldspars, pyroxenes, and amphiboles that are present in the basement rocks under the existing pH condition, and therefore ion-exchange may take place. Except for HCO_3^- , NO_3^- showed a strong positive correlation with all of the major ionic constituents during the wet and dry seasons. 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 the chemistry of the groundwater over time.

Seasonal water quality assessment

According to Sarath-Prasanth et al. (2012), Ghalib (2017), and Alam et al. (2020), determining the acceptability of groundwater for drinking and agricultural uses requires a thorough examination of its quality. The calculated WQI for each location is shown along with the relevant classes for both the wet and dry seasons (Tables 5 and 6). It shows that the groundwater samples examined during the wet season had WQI values that were excellent (59.37%), good (31.26%), and poor (9.37%) quality. The groundwater samples evaluated during the dry season had excellent (77.42%), good (16.13%), and poor (6.45%) water quality according to the WQI classifications. Overall, the WQI mean values computed revealed that the majority of the areas where samples were studied have "good" to "excellent" quality groundwater. Also, the groundwater under investigation had better quality during the dry season than during the wet season when compared on a seasonal basis.

Table 4. 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										
	EC	0.20	1.00									
	TDS	0.18	0.99	1.00								
	Na ⁺	0.16	0.04	0.06	1.00y							
	K ⁺	-	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 ⁺	-	0.65	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

Table 5. 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 K�re	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	Hlgh 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	Hlgh Court II	50.95	Good	-	-	-	-

Table 6. 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

Alam (2014) asserts that hydrochemical changes, which have the potential to impede plant growth, may be brought about by the dissolution of a particular salt's mineral components. Sodium is one such ion that degrades the quality of groundwater used for irrigation and agriculture, and it may be quantified

using the terms salinity hazard and sodium hazard (Alagbe 2006; Al-Shaibani 2008; Edet 2016; Ochelebe and Kudamnya 2022). Table 7 presents the study's computed irrigation water quality indices for the wet and dry seasons, along with a summary of the findings (Table 8).

Table 7. Computed groundwater indices for agriculture use

<u>Wet season</u>							<u>Dry season</u>						
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 8. 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.	$\mu\text{S/cm}$	< 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	-
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) is an important parameter in determining the salt content of irrigation water, the higher the EC, the greater its salt content (Tahmasebi et al. 2018). 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 8). When EC is in excess, it limits air and water movement in the soil during both seasons (Ravikumar et al. 2011; Ocelebe and Kudamnya 2022). Therefore, based on the EC obtained in the study area, the groundwater is largely suitable for irrigation, except at a few locations in the dry season where it is doubtful. Depending on the concentration of Ca^{2+} and Mg^{2+} , total hardness (TH) was computed to determine the salinity level of the groundwater in the study area. A high concentration of Ca^{2+} against Mg^{2+} causes hardness in water, which affects the water quality of crops (Bucks et al. 2009). The values of TH for the wet season ranged from 47.25 to 578.84 meq/l with a mean of 186.91 meq/l, while they ranged from 1.37 to

35.40 meq/l with a mean of 7.39 meq/l in the dry season (Table 7). These values during the wet and dry seasons revealed that 100% of groundwater samples analyzed are classified as "soft water," according to Sawyer and McCarthy (1967) since the hardness is < 75 meq/l (Table 8). Accordingly, and in agreement with Gopinath et al. (2015), groundwater within the study area is appropriate for domestic and industrial uses both during the wet and dry seasons in terms of TH.

In the soil, sodium replaces calcium through an ion-exchange process, destroying the soil's structure and reducing its permeability (Todd 1980; Subba-Rao 2006). This has an impact on soil drainage, which would therefore result in lower yields and slower plant growth (Ocelebe and Kudamnya 2022). Groundwater in Keffi and its environs was found to be suitable for irrigation purposes, with the exception of two locations during the wet season: KW13 (69.90%) and KW14 (60.89%), based on values of percent sodium (%Na) obtained (Table 7).

The classifications for the wet season based on data for %Na were excellent (16%), good (59%), permissible (19%), and doubtful (6%). The groundwater samples were categorized as excellent (6%), good (52%), and permissible (42%), for irrigation and agriculture in general, according to the dry season %Na data (Table 8).

According to a plot of %Na against EC (Fig. 3), the majority of the groundwater samples are "very good to

good" for agricultural use. This represents 91% and 71%, respectively, of the samples that were analyzed during the dry and wet seasons. In the wet and dry season samples, 9% and 23%, respectively, of the water classes were "good to permissible" for irrigation. Only in 6% of samples during the dry season were "doubtful to unsuitable" for irrigation. Similar variations in the trend were seen in both seasons, which can be explained by a variety of geological, climatic, soil, and anthropogenic factors, among others.

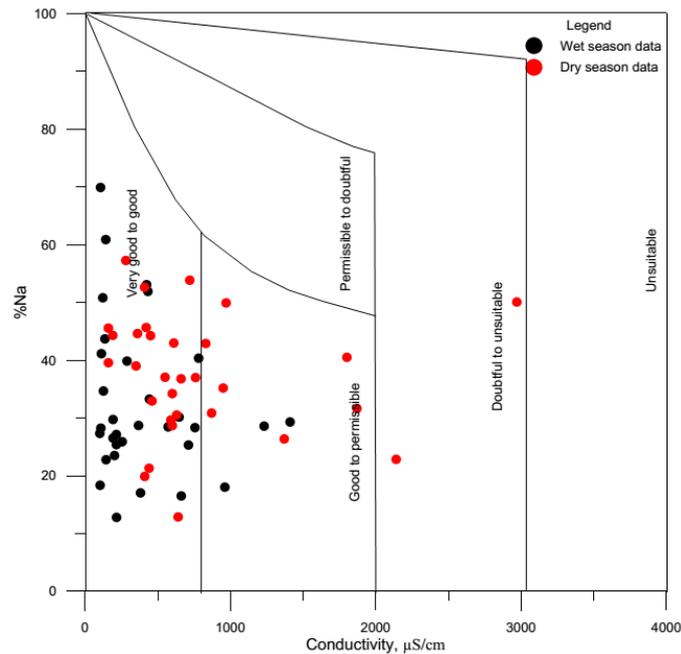


Fig 3. Wilcox plot for groundwater within the study area (after Wilcox 1955)

Sodium Absorption Ratio (SAR) is used to evaluate the appropriateness of groundwater for irrigation and is directly related to sodium absorption by soils. According to the computed seasonal SAR values, the dry season's values ranged from 0.17 to 4.13 meq/l with a mean of 1.02 meq/l, whereas the wet season's values ranged from 0.42 to 4.40 meq/l with a mean of 1.16 meq/l (Table 7). Due to the fact that all SAR values throughout the wet and dry seasons were below 10, 100% of the groundwater samples were considered to be "excellent water" and suitable for agricultural use (Table 8). A plot of SAR against EC (salinity hazard) during both seasons indicates that groundwater from the study is of the "low sodium hazard" type except for one sample in the dry season that is of the "medium sodium hazard" type (Fig. 4). The wet season groundwater samples were classified for suitability in agriculture as follows: C1S1 indicative of low salinity hazards and low sodium hazards (47%), C2S1 interpreted as medium salinity hazards and low sodium hazards (38%), and C3S1 representing high salinity hazards and low sodium hazards (15%).

During the dry season, they are classified as C2S1 for medium salinity hazards and low sodium hazards (58%), C3S1 for high salinity hazards and low sodium hazards (29%), C1S1 for low salinity hazards and low sodium hazards (10%), and C4S2 for very high salinity hazards and medium sodium hazards (3%). Therefore, the study has revealed that groundwater within Keffi and its environs, in terms of suitability for agricultural use, is classified as moderate to good (Table 9). The implication of high salinity hazard in irrigation water according to Zhou et al. (2020) is the accumulation of salts in the soil, thereby impacting secondary salinization in the soil, and thereby degrading the soil physical properties. This was also an earlier assertion by Todd (1980). Paliwal (1972) and Haritash et al. (2014) suggested that the magnesium hazard (MH) value represents the alkalinity of groundwater because equilibrium reactions result in a more alkaline soil, which reduces soil quality and crop productivity.

Water with MH > 50% is unsuitable for agricultural use because the soil becomes more alkaline (Ravikumar et al. 2011; Edet et al. 2022), while groundwater with MH < 50% has no detrimental effects on crop productivity. The study revealed that 94% of the wet season groundwater samples were suitable for irrigation and other agricultural uses, whereas only 6%

were unsuitable. Additionally, it was revealed that 77% of the samples taken during the dry season were suitable for irrigation while 23% of the groundwater samples from the study area were considered unsuitable. Furthermore, seasonal MH values showed that the wet season ranged from 10.27 to 56.00 meq/l with a mean of 30.13 meq/l, while they ranged from 8.04 to 63.93 meq/l with a mean of 38.12 meq/l in the dry season (Table 7).

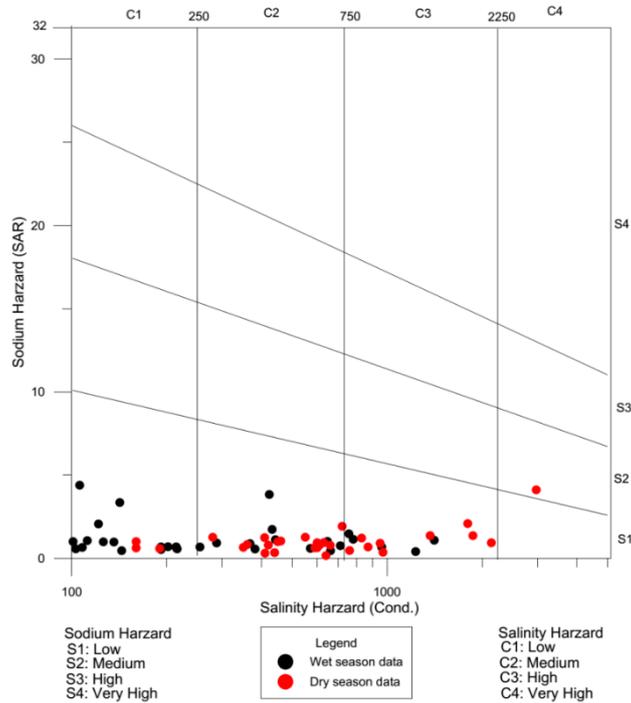


Fig 4. Classification of groundwater for irrigation (after Richards, 1954).

Table 9. 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

Groundwater contamination caused by an excess of $\text{HCO}_3^- + \text{CO}_3^{2-}$ over Ca^{2+} and Mg^{2+} is revealed by residual sodium carbonate (RSC). This is due to the potential of Ca^{2+} and Mg^{2+} precipitating, as these ions' concentration in soil water increases. As a result, calcite precipitates from the soil's solution, increasing the sodium level and causing soil dispersion. For irrigation and other agricultural uses, this is unsuitable (Emerson and Bakker 1973; Ghalib 2017). The RSC was used to analyze the bi-carbonate hazard in the water samples (Tables 7 and 8), and wet season samples were classified as "good" (88%), "doubtful," (6%), and "unsuitable" (6%), depending on their suitability for irrigation and other agricultural uses. During the dry season, however, 100% of the groundwater samples are classified as "good" for irrigation and agricultural use based on RSC. According to estimated seasonal RSC values, the dry season's values ranged from -11.00 to -0.41 meq/l with a mean of -2.31 meq/l, while the wet season's values ranged from -7.61 to 3.10 meq/l with a mean of -0.42 meq/l (Table 8). Consequently, during both the wet and dry seasons, groundwater from Keffi and its surroundings is acceptable for irrigation and other agricultural uses based on the RSC.

Prolonged irrigation water use may affect soil permeability because it is influenced by the soil's Na^+ , Ca^{2+} , Mg^{2+} , and HCO_3^- concentrations (Doneen 1964). It is possible for the concentration of ions like Na^+ in groundwater to increase to the extent where it begins to interchange with Ca^{2+} and Mg^{2+} . The permeability of soils tends to be adversely impacted by this process after continuous irrigation. Saleh et al. (1999) suggest that it causes inadequate air and water circulation as well as poor soil drainage. The wet season's Permeability Index (PI) values ranged from 17.47 to 108.24 meq/l with a mean of 49.11 meq/l, while the dry season's values ranged from 20.02 to 74.46 meq/l with a mean of 43.65 meq/l (Table 7). The wet season data were classified as "suitable" (16%), "moderate" (78%), and "not suitable" (6%), while the dry season data were classed as "moderate" (87%) and "not suitable" (13%) for agricultural purposes. These classifications were based on the values of PI calculated from the groundwater samples. An increase in the concentration of Na^+ in groundwater, which is readily available during ion-exchange processes with the Ca^{2+} and Mg^{2+} present, may slightly increase during the dry season.

Conclusion

Both natural and man-made processes have an impact on seasonal groundwater quality for domestic and agricultural purposes based on major ion constituents. Groundwater in Keffi and its environs has a computed WQI that indicates that it is typically "good to excellent" quality for consumption in the wet and dry seasons. Except for NO_3^- , concentration levels of the physicochemical parameters under analysis are within the World Health Organization's permissible limits. Both seasons had elevated NO_3^- concentration levels in the groundwater from the study area. The following are the order of major cation constituents present in samples from the wet and dry seasons: $\text{Ca}^{2+} > \text{Na}^+ > \text{Mg}^{2+} > \text{K}^+$. The major anion species in groundwater are $\text{NO}_3^- > \text{HCO}_3^- > \text{Cl}^- > \text{SO}_4^{2-}$ during the wet season, and $\text{NO}_3^- > \text{Cl}^- > \text{SO}_4^{2-} > \text{HCO}_3^-$ during the dry season. Due to the rock-water interaction at the prevailing pH conditions, ion exchange and weathering processes may be responsible for the release of these major ions into the groundwater system. During both seasons, there is a strong positive correlation between NO_3^- and Na^+ , K^+ , Ca^{2+} , Mg^{2+} , Cl^- , and SO_4^{2-} with the exception of HCO_3^- . Over time, anthropogenic activities such as indiscriminate open defecation, inappropriate waste disposal, and the application of fertilizer and pesticides all contribute to the excess NO_3^- in groundwater.

By analyzing agricultural indices such as TH, %Na, SAR, MH, RSC, and PI, it was revealed that the groundwater quality in Keffi and its environs were largely suitable for agricultural uses. Using the Wilcox Plot, the majority of the groundwater samples for the wet and dry seasons were classified as "very good to good" and "good to permissible," respectively. The groundwater samples studied have also been classified as "good" on the plot of sodium hazard versus salinity hazard.

For improving the overall water quality in the study area, the following are recommended:

- i. Adequate water management strategies that will minimize the impacts of human activities, especially indiscriminate waste disposal and open defecation, on groundwater.
- ii. There should be enlightenment campaigns through public education on the need to sustain an improved groundwater quality.
- iii. A regular but periodic assessment of groundwater quality is essential to appraise the status quality.

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 field work and first draft of the manuscript was written by “Ebenezer A. Kudamnya” and all authors read and had their input in the first drafted version of the manuscript. All authors read and approved the final manuscript.

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DATA AVAILABILITY STATEMENTS

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

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