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Physicochemical Characteristics and Water Quality Indices to Assess the Suitability of Groundwater Resources in some Communities of Kogi State, Nigeria

[*1]AKUDO, EO; [2]IBRAHIM, O; [3]MUHAMMAD, NM; [1]MUSA, KO; [1]AHMED II, JB; [4]AIGBADON, GO

[*1]*Department of Geology, Faculty of Science, Federal University Lokoja, Nigeria*
[2]*Department of Design & Hydrogeology, Lower Niger River Basin Development Authority, Ilorin Kwara State, Nigeria*
[3]*Universiti Sains Malaysia, Malaysia*
[4]*Department of Geology, Faculty of Physical Sciences, University of Benin, Benin City, Nigeria*

**Corresponding Author Email: ernest.akudo@fulokoja.edu.ng*
**ORCID: https://orcid.org/0000-0002-9247-7492*
Tel: +2348035371235

Co-Author's Email: ibroibrahim72@gmail.com; mnmashin1@student.usm.my; Kizito.musa@fulokoja.edu.ng; Jamilu.ahmed@fulokoja.edu.ng; godwin.aigbadon@uniben.edu

ABSTRACT: This paper aims to evaluate the physicochemical characteristics and water quality indices (WQI) to assess the suitability of groundwater resources in some communities of Kogi State, Nigeria using appropriate standard procedures. Data obtained show that pH, EC, TDS, and TSS, ranges from 6.18-7.44 (mean – 6.68; std - ± 0.53), 85.26 – 90.23 µS/cm (mean - 88.32 µS/cm; std - ± 2.06 µS/cm), 162-194 mg/l (mean - 174.75 mg/l; std - ± 10.25 mg/l), 24-30 mg/l (27.75 mg/l; std - ± 2.25 mg/l), respectively. The physical parameter results all conformed to WHO standard for ingestible water except pH which presented mild acidity/alkalinity outside the recommended threshold. The chemical parameter results all suggest that the groundwater is not polluted and suitable for consumption. The heavy metals also, showed that the water is safe except aluminum (range – 0.7 – 1.2 mg/l; mean – 0.86; std - ± 0.15), that exceeded the 0.2 mg/l benchmark specified. The computed water quality index (WQI), and heavy metal evaluation index (HEI) revealed that the water is excellent and of low risk for consumption. The groundwater facies and water type indicated that the water is Ca – $HCO_{3\ type}$ with bicarbonate dominating the water chemistry. This study further revealed that the groundwater ionic constituent is defined by rock weathering/mineral dissolution and suggest almost zero influence from anthropogenic sources. The water is also found from this research to be fit for consumption and other uses.

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Water in whichever form it occurs (either as snow, groundwater, saline water, surface water etc.,) serves crucial functions that cannot be replaced by any other resource (Abdulfatai *et al.*, 2024; Akudo *et al.*, 2010; El-Alfy *et al.*, 2018; Badmus *et al.*, 2020). Despite the occurrence of water in these various forms, the most sought after of all remains groundwater because of its suitability for ingestion, livestock farming and several industrial processes. It is the least in terms of abundance when compared to the other forms of water, yet it is most important to man (Akudo *et al.*, 2022; Aponbiede *et al.*, 2022; Hailu and Haftu, 2023;

**Corresponding Author Email: ernest.akudo@fulokoja.edu.ng*
**ORCID: https://orcid.org/0000-0002-9247-7492*
Tel: +2348035371235

Napu *et al*., 2023) In most areas, freshwater could occur as either surface water or groundwater which is often accessed by drilling boreholes (Akoteyon, 2024; Tajwar *et al*., 2023). In the developing countries like Nigeria, only those who have the means drill boreholes to access groundwater to serve their water needs since surface water facilities is either absent, in a state of disrepair or has a limited area coverage where it exists at all. With the increased urbanization, population increase, and increased need for animal husbandry, (Abugu *et al.*, 2024) more boreholes will need to be drilled in many communities to serve the highlighted purposes. In the absence of surface public water facilities in Nigeria, governments especially at local and state levels provide boreholes to serve communities water needs. The quality of such boreholes will need to be ascertained to ensure a safe and sustainable water supply to the indigenes of such communities. In Nigeria, drinking water sources have suffered a decline over time owing to anthropogenic and geogenic activities, hence requires adequate assessment to guide it exploitation and management decisions (Nwankwoala *et al*., 2023; Omoko *et al*., 2023).

In many instances, water practitioners, experts, and researchers have utilized water quality indices (WQI) to guarantee in-depth assessment of the suitability of water for intake especially by humans and livestock (Abu Salem *et al*., 2023; Aponbiede *et al*., 2022; Ekwere *et al*., 2023; Kayode *et al*., 2024; Murthy *et al*., 2024; Ochelebe and Kudamnya, 2022). These water quality indices are usually applied to results of parameters analyzed or measured in water, providing more useful information and enhancing the credibility of data pertaining to the water.

Hence, this paper aims to evaluate the physicochemical characteristics and water quality indices (WQI) to assess the suitability of groundwater resources in some communities of Kogi State, Nigeria.

MATERIALS AND METHODS

Geology and physical features of the study area: The study area is within the Northcentral Nigeria which has been thoroughly explained in terms of geology to be predominantly made of Precambrian basement rocks such as Migmatite, Gneiss, Granites and meta sediments respectively (Amigun *et al*., 2015; Ozulu *et al.,* 2021). The local geology is defined by Migmatite gneiss, hornblende gneiss, Migmatite, Granite gneiss, Quartz schist and Biotite gneiss respectively (Fig. 1). The granites present textures that are either coarse, or fine to medium-grained depending on the prevailing conditions during solidification of magma. The geomorphology of the area is undulating ranging from low-lands marking areas with weak minerals already affected intensely by weathering to highlands comprising of resistant rocks and minerals. The low-lands encourages the growth of grasses and other plants. The area is described as predominantly covered with grasses and few trees that are stunted in growth owing to the climate of the area. The climate is defined by dry season (October-April) and rainy seasons (May-september) as is the case within the Northcentral Nigeria generally. The rains are concentrated between august and September with few rains failing in the other months, while the dry season may be extended in years with reduced rainfall. The temperature is often high (up to 34 ºC) in most parts of the year and may drop to around 17 ºC during December to January, and could even rise as high as 40 ºC in the afternoon during hot seasons (Iwena, 2012).

Location, sampling, and laboratory analysis: The sampling location is located between latitude $7°30^{I}\ 0^{II}$ - $7°50^{I}\ 0^{II}$E, and longitude $6°\ 0\ ^{I}\ 0^{II}$ - $6°\ 50^{I}\ 0^{II}$N respectively. The water samples were taken from boreholes drilled in eight communities for water supply, as a means of ascertaining the status and quality of the water samples for consumption. Sampling was done following standard approach which entails allowing the tap to run for few minutes and collected with thoroughly rinsed plastic water bottle, and the physical parameters (pH, EC, TDs, TSS) recorded with a hand-held multi-meter. The samples were then analyzed in the laboratory for cations (Na+, K+, Ca^{2}+ , Mg^{2}+, F^{+}), anions (SO4 $^{2-}$, NO_3-, Cl^{-}, $CO_3\ ^{2-}$, HCO_3-), Chemical Oxygen demand (COD), Biological Oxygen demand (BOD), and heavy metals (Cr, Zn, Al, Fe, Cu, Mn), respectively. All laboratory analyses were done in compliance with standard approaches (APHA, 2005).

Computation of Water quality index (WQI) and Heavy metal evaluation index (HEI): Water quality index is an established method for comprehensively assessing the quality of water for its suitability for consumption. The WQI was computed and the water quality classified with equations 1 to 3 (Akter *et al*., 2016):

$$\text{qi} = \left(\frac{Ci}{Si}\right) * 100 \qquad (1)$$

$$\mathrm{Wi} = \frac{1}{Si} \quad (2)$$

Where qi is the ith parameter rating within a given samples number, n; Ci = the measured parameter concentration in a particular location; Si = the standard concentration of a parameter within n; Wi = the weight of the ith parameter relative to other parameters.

$$\mathrm{WQI} = \frac{\sum_i^n qiwi}{\sum_i^n wi} \quad (3)$$

For heavy metal evaluation index (HEI), the computation was done following the method reported in Nwankwoala *et al.* (2023), shown in equation 4:

$$\mathrm{HEI} = \sum_{i=1}^{n} \frac{\mathrm{HC}}{\mathrm{HMAC}} \quad (4)$$

Where HC = mean values of heavy metals of the ith parameter; HMAC = maximum allowable concentration of the ith parameter.

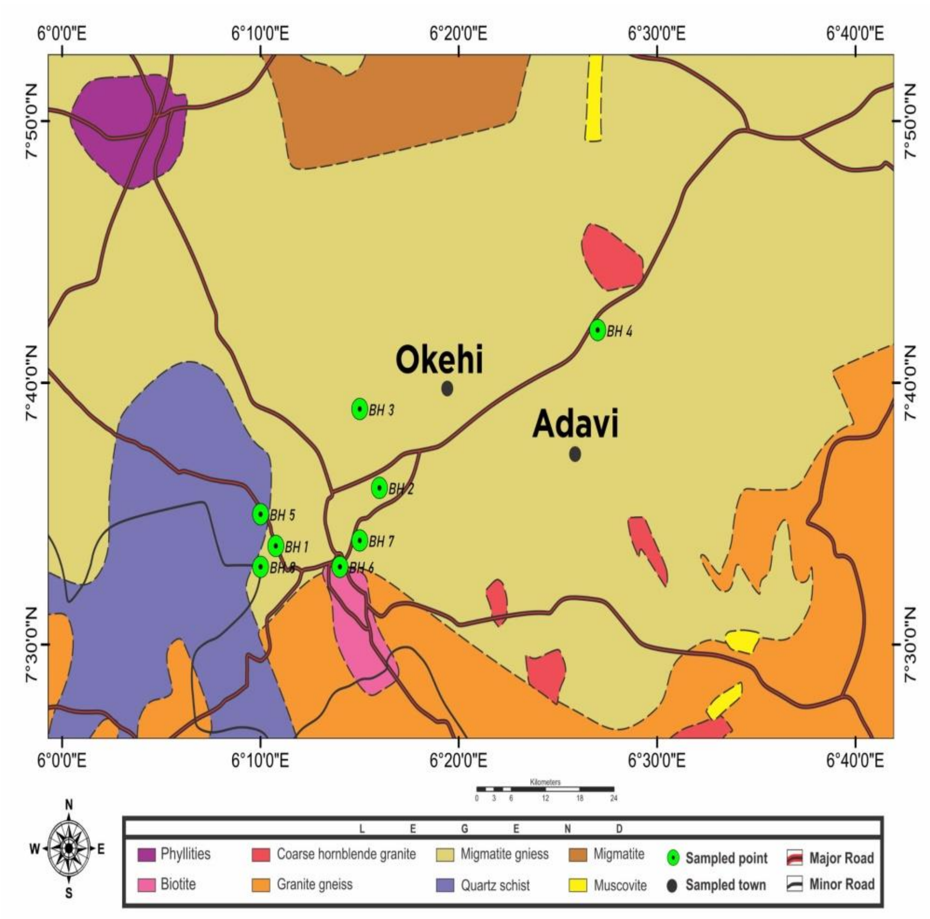

Fig. 1: Geological and sampling location map of the study area (NGSA, 2011)

RESULTS AND DISCUSSIONS

Physicochemical and Biological Parameters: Table 1 shows results of the in-situ physical parameters taken in the field and the laboratory analysis of chemical and biological parameters. The pH ranges from 6.18-7.44 (mean – 6.68) implying that the groundwater can be classified as weakly acidic to alkaline, indicating also that the water is freshwater. When compared with the World health Organization's standard for consumable water (WHO, 2022) of 6.5-8.5, all the water samples complied with the benchmark except four samples (BH 3, BH 4, BH 5, BH 6) that are polluted with respect to pH. Acidity in water could lead to corrosion of metals and metallic wares and utensils. The EC, TDS, and TSS which ranges between 85.26 – 90.23 µS/cm (mean - 88.32 µS/cm), 162-194 mg/l (mean - 174.75 mg/l), and 24-30 mg/l (27.75 mg/l) all meet the specified standard limit for potable water.

Table 1: Physicochemical and Biological parameters measured in Boreholes with descriptive statistics of the results

Parameters	BH 1	BH 2	BH 3	BH 4	BH 5	BH 6	BH 7	BH 8	Min.	Max.	Mean	STD	WHO, 2022
pH	7.32	6.64	6.18	6.26	6.24	6.24	7.44	7.08	6.18	7.44	6.68	0.53	6.5-8.5
EC (µS/cm)	90.23	85.26	89.26	87.56	90.12	85.26	89.63	89.26	85.26	90.23	88.32	2.06	1000
TDS (mg/l)	180	176	162	172	194	176	176	162	162	194	174.75	10.25	500
TSS (mg/l)	28	30	26	24	28	30	30	26	24	30	27.75	2.25	500
Na+ (mg//l)	0.9	0.8	1	1.4	1.1	0.8	1.5	1	0.8	1.5	1.06	0.26	200
K+ (mg/l)	0.7	1.1	0.8	1	0.8	1.1	0.9	0.8	0.7	1.1	0.9	0.15	12
Ca2+ (mg/l)	12.8	11.2	16	14.4	11.2	11.2	12.8	16	11.2	16	13.2	2.05	75
Mg2+ (mg/l)	7.4	8.4	8	8.4	8.8	8.4	7.8	8	7.4	8.8	8.15	0.44	50
SO4 2- (mg/l)	15	9	12	7.5	10.5	9	15	12	7.5	15	11.25	2.78	250
NO3- (mg/l)	1.2	0.8	1.1	0.7	1.2	0.8	1.2	1.1	0.7	1.2	1.01	0.21	50
Cl- (mg/l)	13	10	12	13	8	10	13	12	8	13	11.38	1.85	250
CO3 2- (mg/l)	8	6	7	6	9	6	9	7	6	9	7.25	1.28	450
HCO3- (mg/l)	70	55	50	50	50	55	65	70	50	70	58.13	8.84	250
F+ (mg)	0.04	0.03	0.05	0.04	0.07	0.003	0.04	0.05	0.003	0.07	0.04	0.02	2
COD (mg/l)	7.6	5.6	8	6.8	7.2	5.6	6.8	8	5.6	8	6.95	0.96	10
BOD (mg/l)	3.2	2.8	1.8	2.4	2.6	2.8	1.8	1.8	1.8	3.2	2.4	0.55	10

Notes: Max. – maximum; Min. - Minimum; COD - Chemical oxygen demand; BOD – Biological Oxygen demand

The range of the concentrations of the cations such as Na+, K+, Ca^{2+}, Mg2+ and Fluoride (F+) are 0.8 – 1.5 mg/l (mean - 1.06 mg/l), 0.7 -1.1 mg/l (mean - 0.09 mg/l), 11.2 – 16 mg/l (mean – 13.2 mg/l), 7.4 – 8.8 mg/l (8.15 mg/l, and 0.03 – 0.07 mg/l (mean – 0.04 mg/l) shows that they all fall within the recommended benchmark (WHO, 2022). For the anions which are SO_4 $^{2-}$, NO_3-, Cl-, CO_3 $^{2-}$, and HCO_3- the values range from 7.5 – 15 mg/l (mean - 11.25 mg/l), 0.7 – 1.2 mg/l (mean - 1.01 mg/l), 8 – 13 mg/l (mean - 11.38 mg/l), 6-9 mg/l (mean - 7.25 mg/l), respectively. The concentrations of the anions do nor also, present any challenge of pollution, since all of the values conforms with the benchmark for ingestible water. The water is also, safe with respect to COD and BOD which ranged from 5.6 – 8 mg/l (mean – 6.95 mg/l), and 1.8 – 3.2 mg/l (mean - 2.4 mg/l), having complied with the minimum requirement for potable water

Groundwater facies and Water types: The groundwater facies and water types revealed that the water can be categorized as predominantly falling within the Ca – HCO_3 zone of the piper plot (Fig. 2). This class of water suggests that alkaline earth and weak acids characterize the water ionic constituents. This also indicates that the water chemistry has been influenced by weathering and dissolution of minerals from Basement Complex rocks that act as host to the aquifers in the study area. This assertion is further corroborated from other research within the basement Complex dominated part of the Northcentral Nigeria (Ayuba and Tijani, 2021; Ekwere et al., 2023). The dominance of the cations is in the order of Ca > Mg > Na > K while the arrangement for the anions is HCO_3 > CO_3 > Cl > SO_4 (Fig. 3), respectively. Fig. 3, therefore, support the abundance of the bicarbonate ions in the water suggesting alkalinity of the water.

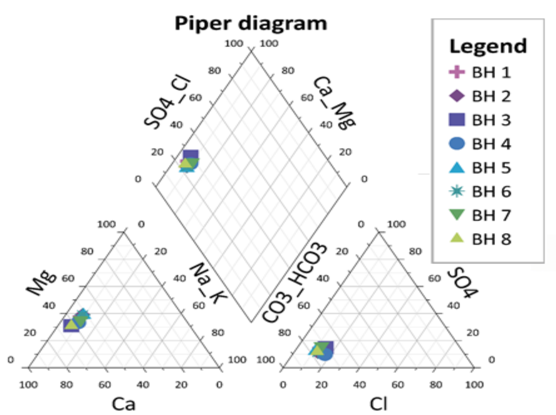

Fig. 2: Piper plot of the water types and facies

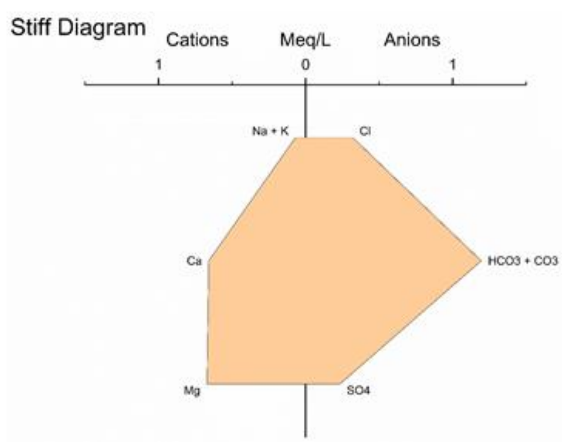

Fig. 3: Plot of the relative abundance of the cations and anions

Heavy metal concertation in groundwater: The heavy metal constituents in water are very critical determinants of status and suitability of water for intended uses. The range of the results of the analysis for heavy metals such as Cr, Zn, Al, Fe, Cu, and Mn are 0 – 0.04 mg/l (0.01 mg/l), 0.8 – 1.8 mg/l (1.26 mg/l), 0.7 – 1.2 mg/l (0.86 mg/l), 0.2 – 0.4 mg/l (0.3 mg/l), 0 – 0.15 mg/l (0.06 mg/l), and 0 – 0.2 mg/l (0.08 mg/l), respectively (Table 2). The heavy metals results indicates that all except Al fall within the specified threshold for consumable water (Table 2). The Al readings in all the boreholes surpassed the WHO, (2017) stipulated value of 0.2 mg/l for consumable water. Although much is not known about the origin of aluminum, it is thought to be from leaching of wastes and soils, and also, from industrial processes. High aluminum is not initially thought to present any concern, except recently when it is suggested that it could interfere with the nervous system and may result in Parkinson's disease (WHO, 2017).

Water quality index (WQI) and Heavy metal evaluation index (HEI): The water quality index was computed using the results of physicochemical parameters in Table 1, while the heavy metal evaluation index values were obtained using the heavy According to Akter et al. (2016), water quality index can be used to group water into excellent (WQI < 50), good (WQI ≤ 100), poor (WQI ≤ 200), very poor (WQI ≤ 300), and unsuitable (> 300), respectively. From Table 3, the WQI for all the locations are classified as excellent, thereby certifying the water as excellent for human consumption accordingly. The heavy metal evaluation index computed with the laboratory results reveal that the HEI is low and hence present very low pollution risk (Table 4). Edet and Offiong (2002), suggested that HEI < 400 is low, 400±800 is medium, while HEI > 800 is high, respectively. The HEI, therefore, aligns with the affirmation from WQI values, indicating that the water is excellent for consumption, and does not pose any risk currently

Table 2: Heavy metals measured in Boreholes with descriptive statistics of the results

Parameters	BH 1	BH 2	BH 3	BH 4	BH 5	BH 6	BH 7	BH 8	Min	Max.	Mean	STDEV	WHO, 2022
Cr (mg/l)	0.01	0.01	0	0.02	0.04	0.01	0.01	0	0	0.04	0.01	0.01	0.05
Zn (mg/l)	1.2	0.9	1.8	0.8	1.1	0.9	1.6	1.8	0.8	1.8	1.26	0.41	3
Al3+ (mg/l)	0.8	0.9	0.8	0.8	0.7	0.9	1.2	0.8	0.7	1.2	0.86	0.15	0.2
Fe2+ (mg/l)	0.4	0.35	0.3	0.2	0.3	0.35	0.2	0.3	0.2	0.4	0.3	0.07	0.3
Cu2+ (mg/l)	0.1	0.05	0	0.1	0.15	0.05	0.05	0	0	0.15	0.06	0.05	1
Mn2+	0.2	0	0.05	0.05	0.2	0	0.05	0.05	0	0.2	0.08	0.08	0.2

Table 3: Computed water quality index (WQI) results with interpretations

S/N	Sample Code	WQI Variables		WQI	Remark
		∑Wi	∑qiwi		
1	BH 1	1	20.50285	20.50285	Excellent
2	BH 2	1	18.71524	18.71524	Excellent
3	BH 3	1	18.04252	18.04252	Excellent
4	BH 4	1	18.09145	18.09145	Excellent
5	BH 5	1	18.50056	18.50056	Excellent
6	BH 6	1	18.01714	18.01714	Excellent
7	BH 7	1	20.6383	20.63830	Excellent
8	BH 8	1	19.95161	19.95161	Excellent

Table 4: Pollution evaluation index of heavy metals

Heavy metal	Hmac	HEI
Cr	0.05	2
Zn	3	8.8
Al	0.2	34.5
Fe	0.3	8
Cu	1	0.5

Conclusion: Physicochemical, biological and heavy metal analysis were undertaken to properly understand the characteristics, status and quality of groundwater from community water supply scheme boreholes in some communities in Kogi State. The data obtained from field and laboratory were used to compute for the water quality index and heavy metal evaluation index, respectively. The results of the physical parameters all conformed with required benchmark for potable water except pH which presented weak acidity/alkalinity. The chemical parameters were all satisfactory and revealed that the water is safe for intake. The heavy metal concentrations all fall within the specified guidelines for drinking water except aluminum which failed to comply with the guidelines. Although much is not known about its implication, the water is polluted with respect to Al. The computed WQI and HEI both showed that the water is excellent with low risk.

Conflict of interest: The authors have no known conflict of interest to declare.

Data Availability Statement: The associated data will be made available on reasonable requests.

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