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Hydrochemical Characteristics and Quality Assessment of Surface and Groundwater Resources Around Nasarawa-Eggon Coal Mining Site Northcentral Nigeria Using Multivariate Statistical Analysis

Iwuoha, P.O.¹, Okeke, O.C.¹, Onyekuru, S.O.¹, Okoro, E.M.^{2*}, Obioha, Y.E.¹ and Ubechu, B.O.¹

¹Department of Geology, Federal University of Technology Owerri, Owerri, Nigeria

²Department of Geology, University of Nigeria Nsukka, Enugu, Nigeria

Abstract

Access to clean and safe potable water is vital for the well-being of communities in Nasarawa-Eggon, located in northcentral Nigeria. However, water resources in the area face quality degradation due to acidic discharges from abandoned coal mines and other anthropogenic activities. This study investigates the hydrochemical characteristics and quality of surface and groundwater around the Nasarawa-Eggon coal mining site, with the aim of evaluating their suitability for drinking and irrigation purposes using multivariate statistical techniques. A total of seventeen water samples were collected from ponds, streams, and boreholes and analyzed for key water quality indicator parameters. Hydrochemical facies were identified using Piper and Gibbs diagrams, revealing dominant water types including CaCl, Mixed CaMgCl, and HCO₃ types. The Gibbs plot indicated that rock weathering and mineral dissolution are the primary geochemical processes influencing water chemistry in the area. To assess relationships among water quality parameters and their potential sources, multivariate statistical methods such as Pearson correlation and hierarchical cluster analysis were employed. Water quality indices (WQI) for both drinking and irrigation were computed using standard evaluation models. Results from the Canadian Council of Ministers of the Environment Water Quality Index (CCME-WQI) classified the drinking water quality as *good*, with groundwater exhibiting the highest quality. For irrigation suitability, the Sodium Adsorption Ratio (SAR) indicated that 58.8% of the samples are of *excellent* quality, while 41.2% are *good*. Overall, the study underscores the impact of both natural processes and coal mining activities on the hydrochemical evolution of water in the area. It also demonstrates the utility of multivariate statistical techniques as effective tools for evaluating water quality and tracing pollution sources in mining-impacted environments.

Keywords

Hydrochemistry,
Water quality,
Multivariate
Statistics,
Coal mining,
Nasarawa-Eggon

INTRODUCTION

Clean fresh water is essential for the healthy living of all mankind. Access to potable drinking water have been difficult for the local inhabitants of Nasarawa-Eggon communities in the northcentral part of Nigeria due to the presence of abandoned coal mines which discharges loads of acid mine drainages (AMD) into the nearby surface water (streams, rivers, and ponds) and groundwater sources, thereby impairing the water quality for drinking, irrigation, domestic and other purposes (Şener et al., 2017; Wang and Zhang, 2018; Iticescu et al., 2019; Varol, 2020). Anthropogenic activities from artisans and local miners also introduce pollutants and contaminants that worsens the quality of water resources in the area, making them unfit for human consumption.

Water quality degradation due coal mining activities is a major global environmental issue that needs to be addressed urgently (Pesce and Wunderlin, 2000; Amangabara and Ejenma, 2012; Dinka et al., 2015; Wu et al., 2018; SDG Report, 2022). The issue of water poverty still remains a pressing concern in Nigeria. At present, only about 30 % of the populace in the northern part of the country can access safe drinking water and sanitation facilities (Ihezue and Obaniyi, 2023). Taiwo et al. (2012) earlier reported that about 27 % of the citizens living in the far northern and northcentral part of Nigeria were exposed to health risks associated with waterborne diseases like diarrhea, dysentery, hepatitis and cholera due to dependence on rivers, streams, ponds, rainwater, and dams as their source of drinking water. This has resulted in millions of deaths yearly, particularly among children under the

age of five (Oguntoke et al., 2009; Raji and Ibrahim, 2011; Ihezue and Obaniyi, 2023). Due to lack of detailed water quality studies in the area, the severity and extent of the contamination of the water bodies from mining activities, natural and other anthropogenic sources remain largely uncertain. In view of this and other challenges, the need therefore arises for a comprehensive hydrochemical characterization and water quality assessment to ascertain the impact of coal mining sites on the surface water and groundwater systems in the Nasarawa Eggon area and environs.

The effect of coal mining activities in parts of northcentral Nigeria, particularly in Nasarawa state, has not gone unnoticed. Iiyas et al. (2021) carried out assessment of metal accumulation in plant and soil in Eggon community mining site, Nasarawa, Nigeria. They showed that indigenous herbaceous plant species possess great potentials as phytoextractor and phytostabilizer to remediate or restore soils impacted by heavy metals due to mining activities in the area. Physicochemical and heavy metal content assessment of water quality in Keana and Nasarawa-Eggon areas was conducted by Aremu et al. (2024). The findings revealed lower pH levels for water bodies in Nasarawa-Eggon (with mean pH value of 5.74) than water sources in the Keana area (with mean pH value of 7.74). Their study provided additional into water quality variations in those areas which is essential for ensuring the healthy living of the inhabitants, and safe use of the water resources for domestic, agricultural and industrial activities. Kana (2022) carried out heavy metal assessment of groundwater quality in part of Karu, central Nigeria. The

study showed that groundwater contamination in the study area emanated from anthropogenic activities and poor waste disposal management.

The present study utilizes multivariate statistical techniques to examine the hydrochemical characteristics and quality of surface and groundwater systems around the Nasarawa-Eggon coal mining site in the northcentral part of the Nigeria, with the view to assess the impact of the abandoned coal mine on water quality in the area. This is necessary to ascertain the contaminant levels within the neighborhood harboring the mining site, in order to address the challenges and potential health dangers associated with surface and groundwater contamination due to coal mining and other anthropogenic activities in the study area.

2 Location and Geology of the Study Area

The study area is located in the northcentral part of Nigeria between longitudes 8°32'15"E and 8°33'15"E, and latitudes 8°41'30"N and 8°42'30"N (Fig. 1). It is accessible through the Makurdi - Jos Road that runs through the northwestern part to the southeastern portion of figure 1. Nasarawa-Eggon and adjoining areas fall within the tropical savannah climate which is defined by the wet and dry seasons (Ezekiel and Dominic, 2014). The area is

characterized by mean temperature of 15.6 °C and 26.7 °C, with an annual rainfall ranging of 1450 mm (wet season) and 1317 (dry season) mm. Rainfall starts from the month of April followed by a noticeable temperature decrease, and ends around October every year. Dry season is experienced from the month of December to February, known as the harmattan season (NSG, 2001; Ayiwulu, 2012).

The underlying geology of the region comprise mainly of the Lafia Formation, which form part of the Cretaceous deposits of the Middle Benue Trough. It is comprised of clays, claystones, flaggy mudstones, red loose sands, and ferruginized sandstones. These sediments of the Lafia Formation represent fluvial depositions under continental conditions (Obaje, 2009; Ebele et al., 2025; Adikwu et al., 2025).

The tectonic development of Benue Trough is associated with the Early Cretaceous separation of the African and South American Continents along a rift-rift-rift (RRR) junction. The trough resulted as the failed arm (or aulacogen) of the triple junction, leading to the opening of the South Atlantic (Ofoegbu, 1985; Benkhelil, 1989; Obaje, 2009). The hydrology and hydrogeology of the study area is influenced by the structure, stratigraphy, and tectonics of the Benue Trough.

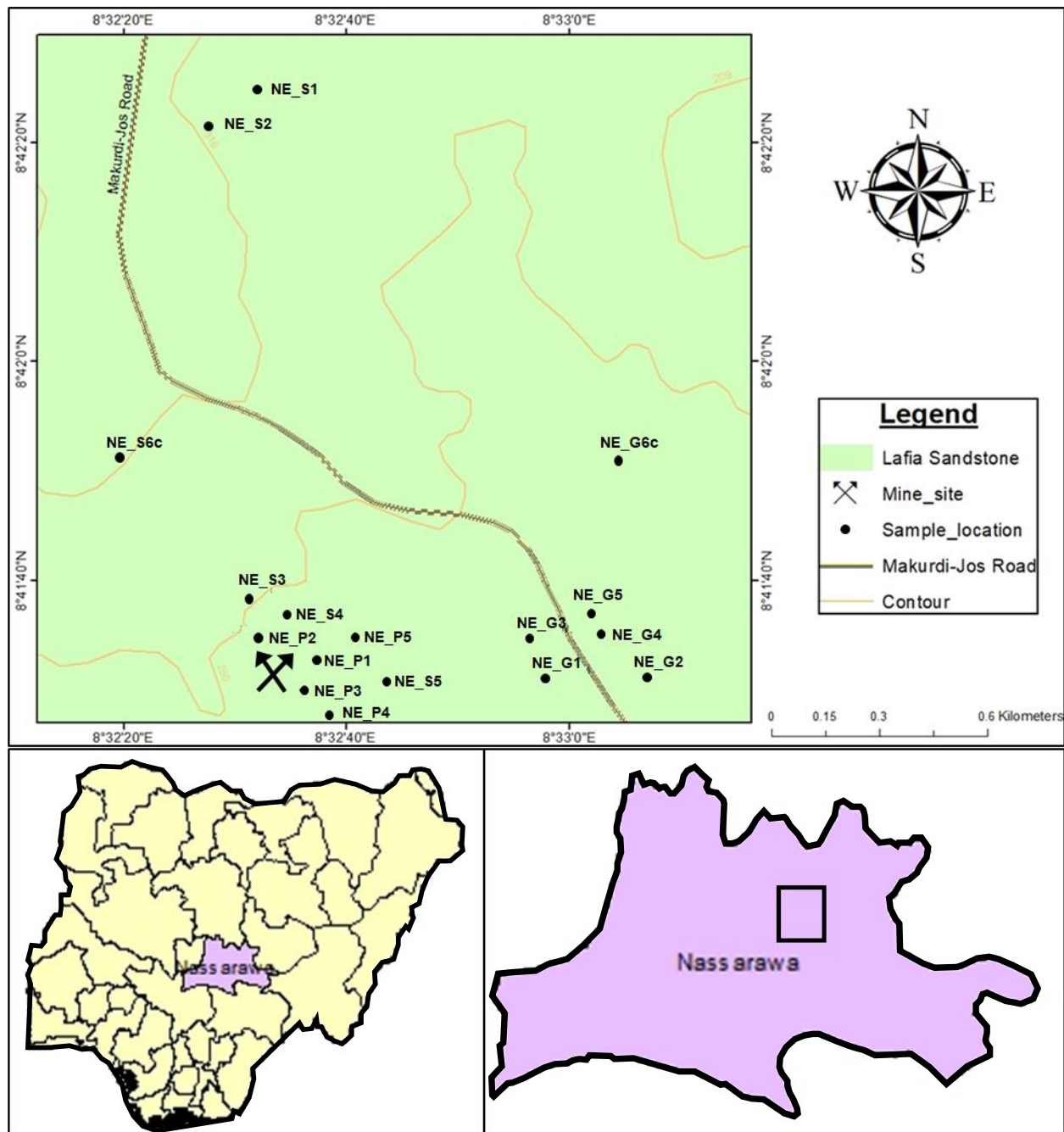


Fig. 1. Map of the study area.

3 Materials and Methods

3.1 Sample Collection and Analysis

Water samples used for the analysis were collected from ponds, streams, and groundwater bodies from different locations within Nasarawa-Eggon (NE) and adjoining areas, with a major focus on the abandoned mining site in the study region (Fig. 1). A total of seventeen (17) water samples from ponds (5), streams (6), and boreholes (6) were collected for laboratory analysis using standards methods. Polyethylene bottles (100 mL) were used in collecting the samples to prevent any form of changes that might affect the final results. The bottles were labeled according to whether it contained water sample collected from a mining pond, stream, or groundwater system. Thus, samples from ponds were labeled as NE_P1, NE_P2, and so on, streams samples were labeled as NE_S1, NE_S2, and so on, while groundwater samples labeled as NE_G1, NE_G2, etc.

The physicochemical parameters analyzed for this study include pH, electrical conductivity (EC), total dissolved solids (TDS), total acidity (TA), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), iron (Fe^{2+}), zinc (Zn^{2+}), chloride (Cl^-), nitrate (NO_3^-), bicarbonate (HCO_3^-), and sulfate (SO_4^{2-}). These parameters were selected because they form the main water quality indicators described by the Nigerian Standard for Drinking Water Quality (NSDWQ, 2015) and World Health Organization guidelines for drinking water quality (WHO, 2024). The pH value of the water samples was measured in-situ using a pH meter following the standard propounded by the American Public Health Association (APHA, 2005), while the values of

the remaining parameters were recovered from results of the laboratory analysis conducted at the soil and plant analysis/biochemistry laboratory situated at Nasarawa State University, Keffi.

3.2 Data Analysis Techniques

The obtained values of the physicochemical parameters from fieldwork and laboratory analyses were subjected to further assessment to understand the hydrochemical characteristics and geochemical behavior of the water bodies in the study area. These were carried out using appropriate software packages available from vendors, for detailed evaluation and interpretation of the available data (Zidan et al., 2020; Saqr et al., 2024).

3.2.1 Descriptive Statistics

Descriptive statistical values including the mean and standard deviation of all the parameters were calculated using the MS Excel and Origin Pro software. This methodology enabled the determination of the water quality status and trends of the different concentrations of the water quality indicators (Muijs, 2022; Dzhanghi and Atangana, 2024).

3.2.2 Hydrochemical Characterization

The chemical composition of the water bodies was analyzed using the Piper plot which enables identification of the patterns and processes that classifies the different hydrochemical facies on the basis of the relative abundance of major cations and anions (Piper, 1944). The Piper diagram categorizes the water types, thereby providing in-depth knowledge of the features and composition of the analyzed water samples (Khadka and Ramanathan, 2013; Chalaune et al., 2020).

The Gibbs diagram was utilized to determine the main geochemical processes that controlled the water chemistry, like precipitation, evaporation - crystallization, and rock weathering (Gibbs, 1970; Prasanna et al., 2011). The strength of the Gibbs plot lies in its ability to distinguish various source mechanisms using the TDS and ionic ratios, which is key to unravel the origin of dissolved solutes in the water bodies (Gibbs, 1970; Paudel et al., 2024).

3.2.3 Multivariate Statistical Analysis

Multivariate statistical approach such as Pearson correlation matrix and cluster analysis was used to identify the spatial and temporal trends among the water quality set from the Nasarawa-Eggon area and their possible sources. This was done using statistical software packages available from vendors. The use of multivariate statistical methods enabled the interpretation of intricate data matrices for enhanced understanding of the water quality and ecological condition of the study area (Kazi et al., 2009). This method also aids in the identification of potential factors that control the overall chemistry of the water system, making it a viable tool for solving water quality related problems (Kazi et al., 2009).

The Pearson correlation matrix was deployed to determine the degree of relationship between two variables. This statistical analysis techniques measures how the variance of the analyzed parameters is inter-related with one another (Liu et al., 2003; Maiolo and Pantusa, 2021). The terms "strong", "moderate", and "weak" factor loadings was applied in this study using the method of Liu et al. (2003). Hierarchical cluster analysis (HCA) is a multivariate technique that have shown

usefulness in the analysis and interpretation of complex water quality dataset (Lei, 2014; Liu et al., 2021). This approach aids in the identification of pollution sources, and quantification of the spatio-temporal variations in water quality (Lei, 2014; Sharma et al., 2021; Dzhanghi and Atangana, 2024).

3.2.4 Water Quality Index (WQI)

Water quality index (WQI) is a significant criterion in matching water demand and supply, and is the most effective method of measuring water quality (Akter et al., 2018; Atta et al., 2022; Madhavan et al., 2023). It is commonly based on a comparison of the physicochemical, bacteriological, and metallic parameters with established water quality guidelines (Tian et al., 2019). WQI integrates numerous physical, chemical and biological parameters into a single number and can represent a comprehensive picture of the water quality level (Bordalo et al., 2006; Sanchez et al., 2007), thereby giving the overall quality of the water bodies in a specific area (Tian et al., 2019; Uddin et al., 2021, 2023).

The Canadian Council of Ministers of the Environment water quality index (CCME-WQI) model was used in this study to assess water quality for drinking purposes (Dao et al., 2020; Sabry Al-Mashhadany, 2021; Kaur et al., 2022; Mohseni et al., 2023). The CCME-WQI comprise of three primary components (Uddin et al., 2021): (i) scope (F1 - which defines the percentage of variables that have values outside the range of desirable levels), (ii) frequency (F2 - which is determined by ratio of value outside the desirable levels), and (iii) amplitude (F3 - which represents the average

deviation of unsuccessful test values from their corresponding reference value). Component F1 and F2 was calculated using equations (1) and (2), respectively.

$$F_1 = \left(\frac{\text{number of failed parameters}}{\text{total number of parameters}} \right) \times 100 \dots \dots \dots (1)$$

$$F_2 = \left(\frac{\text{number of failed tests}}{\text{total number of tests}} \right) \times 100 \dots \dots \dots (2)$$

The F3 values was calculated utilizing the following steps. The relative deviation of an unsuccessful test from the objective is termed an excursion and calculated following equations (3a) and (3b):

When i th test value didn't exceed the particular objective value:

$$\text{Excursion}_i = \left(\frac{\text{failed test value}_i}{\text{objectives}_i} \right) - 1 \dots \dots \dots (3a)$$

When i th test value failed below the objectives (guidelines) value, the excursion was calculated using equation (3b):

$$\text{Excursion}_i = \left(\frac{\text{objectives}_i}{\text{failed test values}_i} \right) - 1 \dots \dots \dots (3b)$$

After that, the normalized sum of excursion (nse) was calculated using equation (4):

$$nse = \left(\frac{\sum_{i=1}^n \text{excursion}_i}{\text{total number of tests}} \right) \dots \dots \dots (4)$$

where, n is the total number of tests.

Finally, F3 was calculated using equation (5), where nse scales the normalized sum of the excursions from objectives to produce a range between 0 and 100:

$$F_3 = \left(\frac{nse}{0.01nse+0.01} \right) \dots \dots \dots (5)$$

Once all components were obtained, the index value was calculated using equation (6):

$$\text{CCME - WQI} = \left(\sqrt{\frac{F_1^2 + F_2^2 + F_3^2}{1.732}} \right) \dots \dots \dots (6)$$

The divisor 1.732 normalizes the resultant values to a range between 0 and 100, where 0 indicates the worst status of water quality and

100 denotes the best excellent status of water quality (CCME, 2017). Details of the classification schemes of the CCME-WQI model are provided Table 1.

Table 1. Water quality scale for different indices.

Category number	Water quality rank	CCME-WQI
1	Excellent	95 - 100
2	Good	80 - 94
3	Fair	60 - 79
4	Marginal	45 - 59
5	Poor	0 - 44

3.2.5 Irrigation Indices

For irrigation purposes, the water quality was assessed using the sodium adsorption ratio (SAR), percent sodium (Na%), Kelley's ratio (KR), magnesium hazard ratio (MHR), and Residual sodium carbonate (RSC). The expressions for each of the indices are given in the following equations (Prasanna et al., 2011; Zhang et al., 2019; Acharya et al., 2020).

$$\text{SAR} = \frac{\text{Na}^+}{\sqrt{\frac{\text{Ca}^{2+} + \text{Mg}^{2+}}{2}}} \dots \dots \dots (7)$$

SAR (meq/L) is used for measuring the alkali threat in irrigation (Richards, 1954). Based on SAR categories, water quality suitability for irrigation purposes is classified as 'Excellent' for values less than 10 meq/L, 'Good' for values within the range of 10 - 18 meq/L, 'Fair' for values ranging from 18 - 26 meq/L, and 'Poor' for values greater than 26 meq/L (Richards, 1954).

$$\% \text{Na} = \left(\frac{\text{Na}^+ + \text{K}^+}{\text{Ca}^{2+} + \text{Mg}^{2+} + \text{Na}^+ + \text{K}^+} \right) \times 100 \dots \dots \dots (8)$$

It is good for evaluating the effect of Na concentration on soil structure and

permeability (Wilcox, 1955). The % Na range for irrigation suitability can be categorized as follows: 'Unsuitable' > 80, 'Doubtful' 60 - 80, 'Permissible' 40 - 60, 'Good' 20 - 40, and 'Excellent' < 20 (Wilcox, 1955).

$$KR = \frac{Na^+}{Ca^{2+}+Mg^{2+}} \dots\dots\dots(9)$$

It is good for assessing the effect of Na hazard on water quality (Kelley, 1963). The water quality suitability for irrigation purposes based on KR is categorized as 'Unsuitable' when the value is greater than 1, and 'Suitable' when the value is less than 1 (Kelly, 1963).

$$MHR = \left(\frac{Mg^{2+}}{Ca^{2+}+Mg^{2+}} \right) \times 100 \dots\dots\dots(10)$$

The magnesium hazard ratio is used to ascertain the feasible threat from Mg in agriculture (Raghunath, 1987). For irrigation suitability, MHR is classified as 'Unsuitable' when the value is greater than 50, and 'Suitable' when the value is less than 50 (Kaddah, 1975).

$$RSC = (CO_3^{2-} + HCO_3^-) - (Ca^{2+} + Mg^{2+}) \dots\dots\dots(11)$$

For evaluating the impact of HCO_3^- and CO_3^{2-} on the groundwater quality due to irrigation (Ghobadi et al., 2020). The values are categorized as follows: Suitable (<1.25), Marginal (1.25-2.50), and Unsuitable (>2.50).

4 Results and Discussion

4.1 General Hydrochemistry of the Study Area

The hydrochemical analysis results of the water samples is presented in Table 2, while Table 3 is a summary of the descriptive statistics of the analyzed physicochemical parameters including minimum, maximum, mean, and standard deviation of each

parameter from the allowable limits as prescribed by the NSDWQ (2015) and WHO (2024). Based on estimated standard deviation, all the parameters were found to be within the permissible limits for drinking water except calcium whose deviation value was noticed to be about six times more than the acceptable standard by NSDWQ and WHO (Table 3). The results of the analyzed physicochemical parameters for each of the water samples revealed values that were within acceptable limits for drinking water. However, the groundwater sample NE_G2 yield EC, TDS, Ca^{2+} , and Cl^- values beyond the prescribed limits by NSDWQ and WHO (Table 2). Other samples that yielded parameters with values outside the acceptable drinking water standards include NE_P4 (Fe^{2+}), NE_G1 (Fe^{2+}), and NE_G5 (Ca^{2+}). The observed high values of these parameters in some of the water samples may be attributed to water - rock interactions resulting in the dissolution of these ions from the host rock, as water flows through them. Hence, the physicochemical characteristics of the water samples are a direct reflection of the hydrochemical alterations of the surrounding environment, which exert a major control on the spatial distribution of the analyzed parameters (Fig. 2) (Li et al., 2016; Mohammed et al., 2022).

The pH values of the surface water (pond and stream) samples range between 5.2 and 5.9, while that of the groundwater samples range from 5.3 to 6.6. This indicates a slightly acidic water type for the study area. The spatial distribution map of pH showed high values towards the eastern, southeastern, and northeastern parts, while low values characterized every other part of the study

area. The EC values of the water samples ranged from 150 to 1240 $\mu\text{S}/\text{cm}$. The spatial distribution map of the EC values showed a direct relation to that of the TDS, which is the major indicator of the presence of dissolved solids and the overall mineral concentration in both surface and groundwater bodies. The estimated TDS for the study area showed values ranging from 90 to 620 mg/L. Like EC map, high values of TDS are observed in the northeastern portion of the study area (Fig. 2).

The TA concentration values varied from 15 to 120, while the Mg^{2+} and Ca^{2+} contents fluctuated from 3.025 to 12.026 mg/L and 3.923 to 4453 mg/L, respectively. The high Ca^{2+} concentrations in the study area may have resulted from the dissolution of carbonate rock materials. The spatial distribution map of Ca^{2+} showed a similar trend with that of Cl^- , with high values occurring at the northeastern part of the maps. The estimated Cl^- values range from 10.64 to 411.22 mg/L, while Na^{2+} concentrations varied from 21.25 to 23.46 mg/L.

The Na^{2+} distribution map showed a gradual decrease in concentration towards the northern and southeastern portions of the study area. This might be attributed to the weathering and dissolution of silicate and halite rock materials in the area (Hem, 1985; Howladar et al., 2017). Fe^{2+} and Zn^{2+} values ranged from 0 to 1.342 mg/L and 0 to 2.217 mg/L, respectively. The spatial distribution maps of these two ions showed a similar trend,

with a gradual decrease in concentration towards the eastern part of the study area. The HCO_3^- content of the water samples varied from 10 to 40 mg/L, while NO_3^- and SO_4^{2-} concentrations ranged from 6.06 to 24.96 mg/L and 6.46 to 7.43 mg/L, respectively. On the spatial distribution maps, higher HCO_3^- values were noted at the northern and southeastern parts; NO_3^- map showed a generally low concentration values, except the southeastern part where some higher values were observed, while the SO_4^{2-} map displayed a gradual increase in concentration towards the southeastern part of the study area.

The dissolution of calcite and dolomite minerals or ion exchange may be responsible for the presence of HCO_3^- in the water bodies. The observed low values of NO_3^- may suggest lack of agricultural activities in the study area due to deteriorated or environmentally degraded lands resulting from intense mining activities. The SO_4^{2-} concentration may be contributed from the leaching of soil (mine tailings) or percolation of acid mine drainages (AMD) into the shallow groundwater systems (Yidana et al., 2018; Mohammed et al., 2022).

The order of cation dominance in the majority of the samples is $\text{Na}^+ > \text{Ca}^{2+} > \text{Mg}^{2+}$, suggesting that the hydrochemistry of the study area was largely influenced by the water interactions with the host geological formations. The general trend of anion dominance in the water samples is $\text{Cl}^- > \text{HCO}_3^- > \text{SO}_4^{2-}$.

Table 2. Physicochemical properties of surface water and groundwater in the study area.

Name	pH	EC	TDS	TA	K ⁺	Ca ²⁺	Mg ²⁺	Na ⁺	Fe ²⁺	Zn ²⁺	Cl ⁻	NO ₃ ⁻	HCO ₃ ⁻	SO ₄ ²⁻
NE_P1	5.9	250	125	60	0.661	4.089	4.601	21.75	0.441	1.696	17.73	6.25	10	7.03
NE_P2	5.5	250	125	80	0.661	4.007	4.128	21.74	0.619	1.674	35.45	6.4	20	6.46
NE_P3	5.7	250	125	70	0.677	4.481	4.241	21.73	0.611	1.774	39	6.06	10	7.23
NE_P4	5.2	190	95	90	0.68	5.8	5.36	22.09	1.018	1.651	21.27	8.93	20	6.87
NE_P5	5.8	180	90	50	0.68	3.924	3.901	22.27	0.582	1.133	39	6.34	20	7.04
NE_S1	5.3	346	173	100	0.761	5.039	4.229	21.25	0.423	2.217	21.27	24.9	30	7.42
NE_S2	5.8	320	160	90	0.756	5.808	4.884	22.56	0.492	1.175	28.36	11.93	20	6.9
NE_S3	5.8	320	160	80	0.837	8.04	6.032	23.21	0.628	2.145	21.27	11.8	20	6.8
NE_S4	5.9	220	110	70	0.841	4.421	4.204	23.2	0.794	0.413	10.64	8.93	20	6.87
NE_S5	5.6	330	165	90	0.845	4.608	3.768	23.18	0.453	1.174	21.27	6.42	20	6.46
NE_S6c	5.6	300	150	15	0.842	11.75	6.786	23.46	0	0	21.27	24.96	40	7.43
NE_G1	5.8	590	295	80	0.734	7.673	6.967	22.46	1.342	0.148	131.17	11.1	20	7.04
NE_G2	5.3	1240	620	120	0.183	4416	3.025	22.02	0.35	0.009	411.22	7.86	20	7.03
NE_G3	6	200	100	80	0.771	6.51	5.206	22.16	0.049	0.055	21.27	7.84	30	6.84
NE_G4	6.2	150	90	60	0.0778	4.765	3.267	22.19	0	0.02	85.08	6.46	30	6.8
NE_G5	6.3	200	100	45	0.779	4.453	3.262	22.2	0	0.067	131.17	6.4	10	6.84
NE_G6c	6.6	250	125	45	0.774	148.4	12.026	22.52	0	0	14.18	7.6	10	7.08

* NE = Nasarawa-Eggon; P = Pond; S = Stream; G = Groundwater

Table 3. Descriptive statistics of the analyzed parameters.

Parameter	Min	Max	Mean	SD	Standard
pH	5.2	6.6	5.78	0.37	8.5
EC	150	1240	328.59	255.32	1000
TDS	90	620	165.18	127.06	500
TA	15	120	72.06	24.75	500
K ⁺	0.0778	0.845	0.68	0.22	100
Ca ²⁺	3.924	4453	535.2	1468.07	200
Mg ²⁺	3.025	12.026	5.05	2.14	200
Na ⁺	21.25	23.46	22.35	0.62	200
Fe ²⁺	0	1.342	0.46	0.38	1
Zn ²⁺	0	2.217	0.9	0.85	5
Cl ⁻	10.64	411.22	62.98	97.4	200
NO ₃ ⁻	6.06	24.96	10.01	5.95	50
HCO ₃ ⁻	10	40	20.59	8.27	250
SO ₄ ²⁻	6.46	7.43	6.95	0.27	250

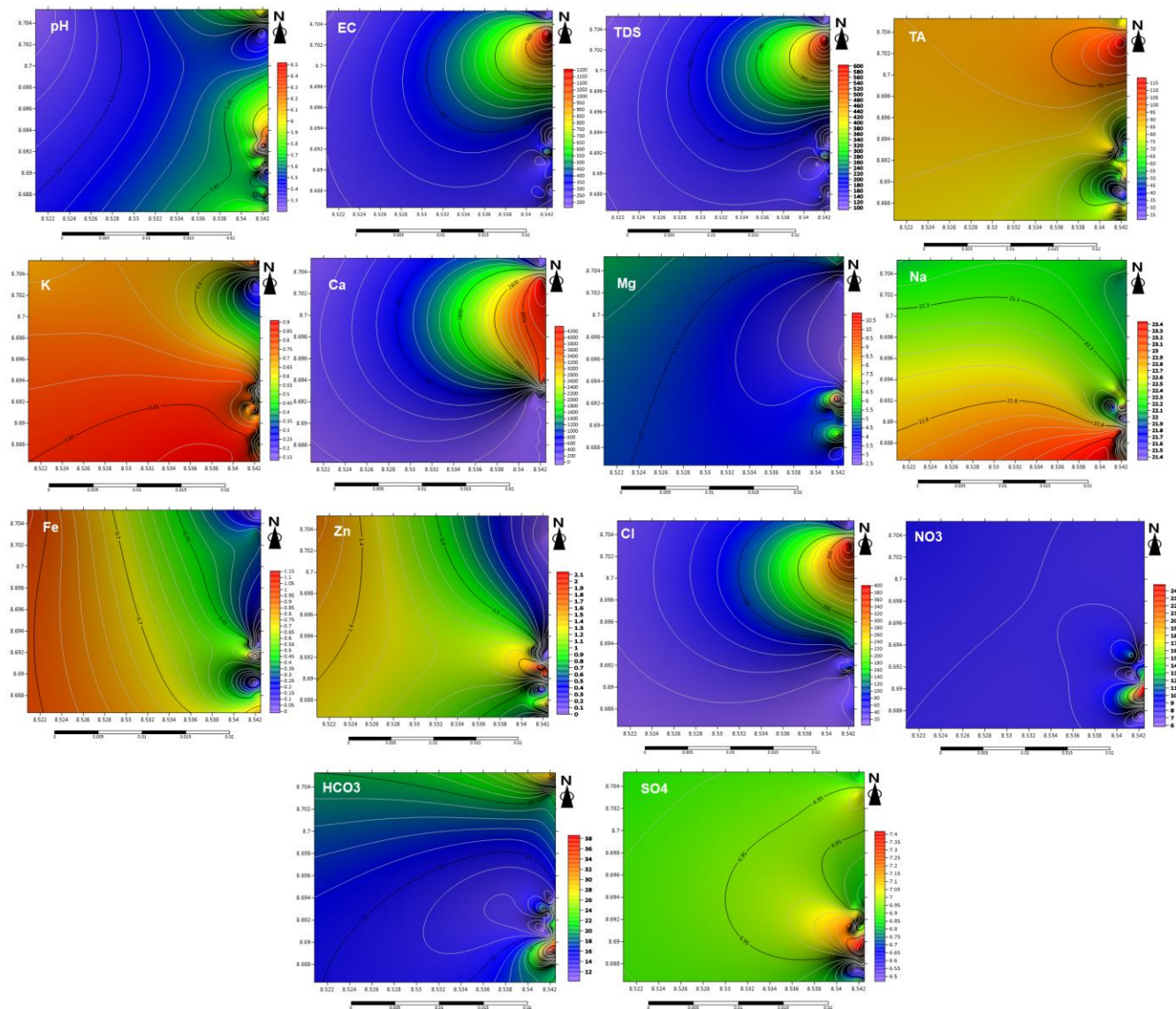


Fig. 2. Spatial distribution maps of the physicochemical parameters.

4.2 Hydrogeochemical Facies and Mechanisms Influencing Water Chemistry in the Study Area

The Piper diagram was employed in this study to identify the chemical structure of the surface water and groundwater systems in the study area, and also gave insights into the origin and distribution of the different water classes (Piper, 1944; El Osta et al., 2022). The dominant cations and anions present in the water bodies were resolved using the Piper's trilinear plot to establish the different hydrogeochemical facies in the study area (Fig. 3). The Piper plot is utilized to mathematically represent the relative percentages of cation (Ca^{2+} , Mg^{2+} , Na^+ , and K^+) and anion species (HCO_3^- , SO_4^{2-} , and Cl^-) to their total amount present in the water. Thus, it is a convenient technique for visualizing the status of the water quality, make inferences on the different water facies, establish the chemical processes controlling the water quality, and express how the various ions present in the water system are interrelated (Uddin et al., 2023).

The Piper diagram displays the percentage concentrations of the major cations (Na^+ , Mg^{2+} , and Ca^{2+}) and anions (SO_4^{2-} , HCO_3^- , and Cl^-) in two triangles, from which the plots are extended into the diamond in the center in of the two triangles. Water rich in $\text{Ca}^{2+} + \text{Mg}^{2+}$ and $\text{Cl}^- + \text{SO}_4^{2-}$ species, indicating permanent hardness, plot at the top of the diamond. The left corner of the diamond indicates region of temporary hardness where water samples rich in Ca^{2+} , Mg^{2+} , and HCO_3^- are plotted. The lower part of the diamond is assigned to alkali

bicarbonate (Na^+ and HCO_3^-) water types, saline water (Na^+ and $\text{Cl}^- + \text{SO}_4^{2-}$) will plot at the right portion of the diamond. The result of Piper diagram in this study revealed the preponderance of Mg^{2+} and Ca^{2+} cations, while the dominant anion is Cl^- . Most of the pond and groundwater samples plotted within the CaCl water type which may be attributed to the interactions between the water and the host carbonate rocks, with contributions from the dissolution of dolomitic mineral materials. Some of the stream samples plotted within the Mixed CaMgCl water type, while others plotted within the HCO_3^- and CaCl types. This further supports the dissolution of carbonates and dolomitic rocks as a major controlling mechanism of the water chemistry in the study area.

The correlation between the hydrogeochemical constituent and the formation processes of the surface water and groundwater bodies was further investigated using the Gibbs plots (Gibbs, 1970). The Gibbs diagram showed that chemistry of surface water and groundwater systems in the study area were mainly influenced by natural processes of rock weathering, controlled by rock-water interactions. Mineral dissolution is likely the primary natural mechanism influencing the presence of primary salts in the water bodies. As revealed from the Gibbs analysis, other factors that may control the hydrochemical characteristics of the study area include the background geology, and acidic discharges from artisanal mining activities (Li et al., 2022).

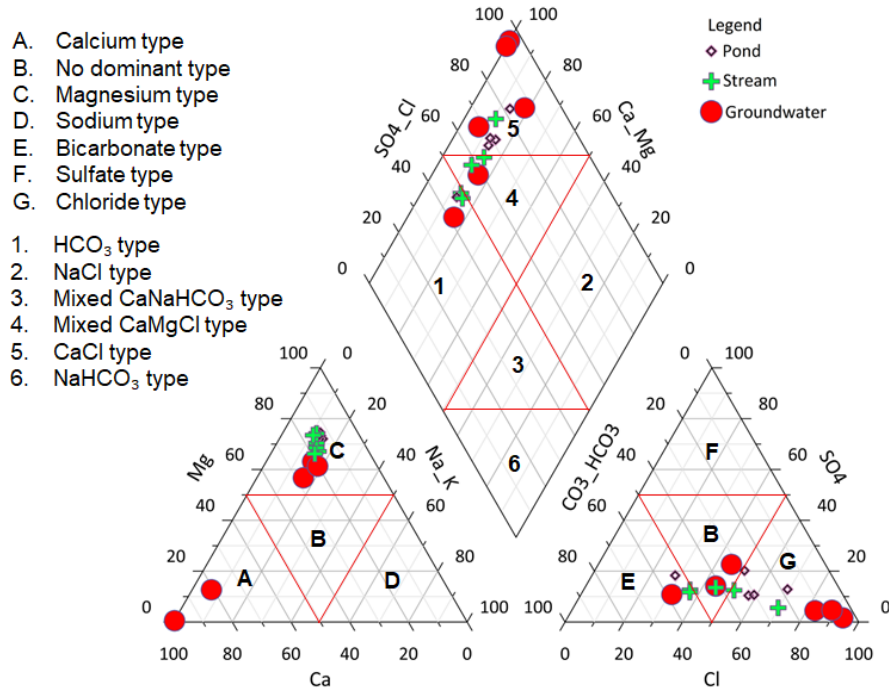


Fig. 3. Piper trilinear plot showing the classification of water types in the study area.

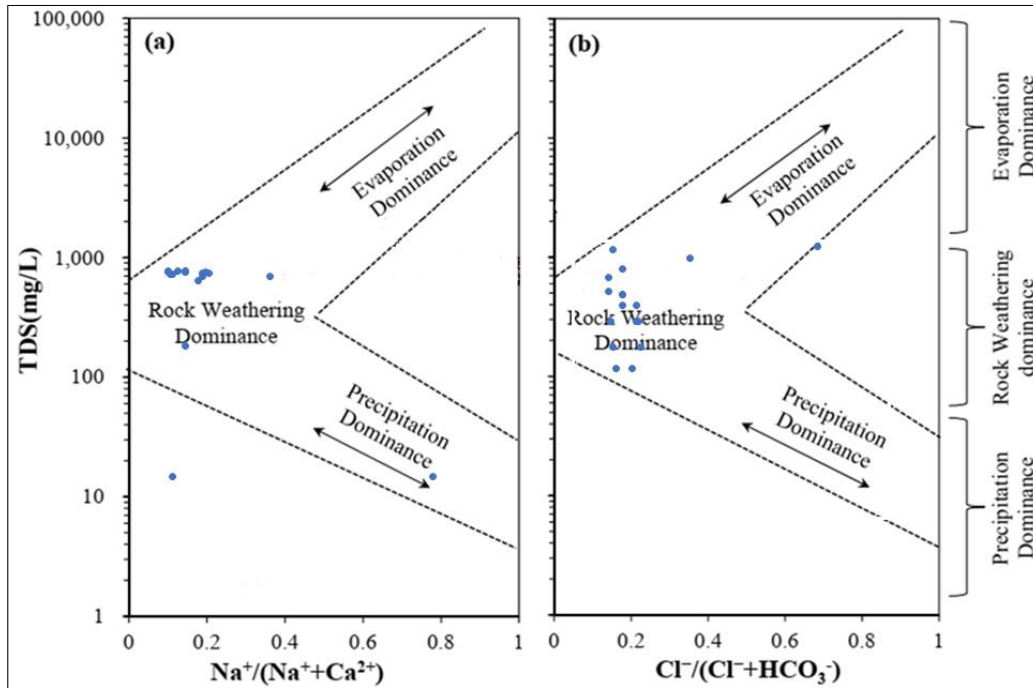


Fig. 4. Gibbs plot showing the mechanism controlling the water chemistry of the study area.

4.3 Multivariate Statistics

4.3.1 Pearson Correlation Matrix

The result of the Pearson correlation analysis is presented in Table 4. The correlation matrix is invaluable in revealing the linear relationship between the physicochemical parameters, and their influence on the overall water hydrochemistry. The correlation coefficient value of +1 or -1 connotes an entire connection between two variables (Singh and Kumar, 2011). In this study, correlation coefficient value greater than 0.7 was described as strongly correlated, and values within 0.4 to 0.7 is moderately correlated. From Table 4, it

can be observed that EC showed a strong positive correlation with TDS and Cl^- . A strong positive association also exist between TDS and Cl^- , suggesting a high contribution of these ions to the salinity of the water bodies. Ca^{2+} is also strongly correlated with Cl^- . EC showed a moderate correlation with TA and Ca^{2+} ; TDS also showed moderate correlation with TA and Ca^{2+} , and NO_3^- was moderately correlated with HCO_3^- and SO_4^{2-} , suggesting the contributions of these parameters to the slightly acidic nature of both the surface water and groundwater systems in the study area.

Table 4. Pearson Correlation between Water Quality indicators in the study area.

	pH	EC	TDS	TA	K^+	Ca^{2+}	Mg^{2+}	Na^+	Fe^{2+}	Zn^{2+}	Cl^-	NO_3^-	HCO_3^-	SO_4^{2-}
pH	1													
EC	-0.39275	1												
TDS	-0.38621	0.9996	1											
TA	-0.57161	0.55311	0.55216	1										
K^+	0.05088	-0.43044	-0.45293	-0.25885	1									
Ca^{2+}	0.03383	0.5732	0.57327	0.14956	-0.33995	1								
Mg^{2+}	0.42994	-0.1199	-0.12664	-0.36322	0.36513	-0.3165	1							
Na^+	0.19766	-0.06862	-0.07089	-0.34718	0.36912	-0.14586	0.27525	1						
Fe^{2+}	-0.47664	0.1393	0.13107	0.4223	0.19157	-0.28926	-0.06347	-0.02634	1					
Zn^{2+}	-0.50123	-0.2335	-0.24231	0.34053	0.27175	-0.39246	-0.21474	-0.32732	0.40536	1				
Cl^-	-0.20175	0.89323	0.89917	0.41203	-0.64185	0.80089	-0.29401	-0.18	-0.03035	-0.40861	1			
NO_3^-	-0.36141	0.05719	0.05305	-0.1147	0.28641	-0.18453	0.17154	0.13123	-0.0844	0.10909	-0.159	1		
HCO_3^-	-0.32665	0.00515	0.01358	-0.06736	-0.09634	-0.26284	-0.1029	0.24161	-0.20611	-0.19192	-0.07364	0.67123	1	
SO_4^{2-}	-0.089	0.14067	0.13721	-0.27315	0.05216	-0.01742	0.26632	-0.16754	-0.11277	-0.04376	0.04506	0.6519	0.22383	1

4.3.2 Hierarchical Cluster Analysis (HCA)

Dendrogram showing the result of the hierarchical cluster analysis (HCA) of the analyzed water quality indicators is presented in figure 5. HCA is an effective approach for classifying water samples into various categories of water quality or hydrochemical facies (Daughney et al., 2012; Mohammed et al., 2022; Uddin et al., 2023). The HCA technique was employed in this study to identify parameters with similarities in their origin which may indicate water quality sources in study area. A total of four (4) clusters were identified. The first cluster (C1) comprises of

pH, Mg^{2+} , K^+ , and Na^+ , suggesting origin from anthropogenic sources. The second cluster (C2) is made up of NO_3^- , HCO_3^- , and SO_4^{2-} , indicating these parameters were sourced from the weathering and dissolution of carbonates and sulphate-bearing rocks, or may have originated from anthropogenic sources such as mining and agricultural activities (Nethononda et al., 2019; Sharma et al., 2022). The third cluster (C3) suggested that the EC, TDS, Cl^- , and Ca^{2+} originated from the same natural sources involving the weathering and dissolution of halite materials and carbonate rocks. The fourth cluster (C4) included TA,

Fe^{2+} , and Zn^{2+} , indicating anthropogenic contamination related to acid mine drainages

(AMD) from abandoned mines and illegal mining activities in the study area.

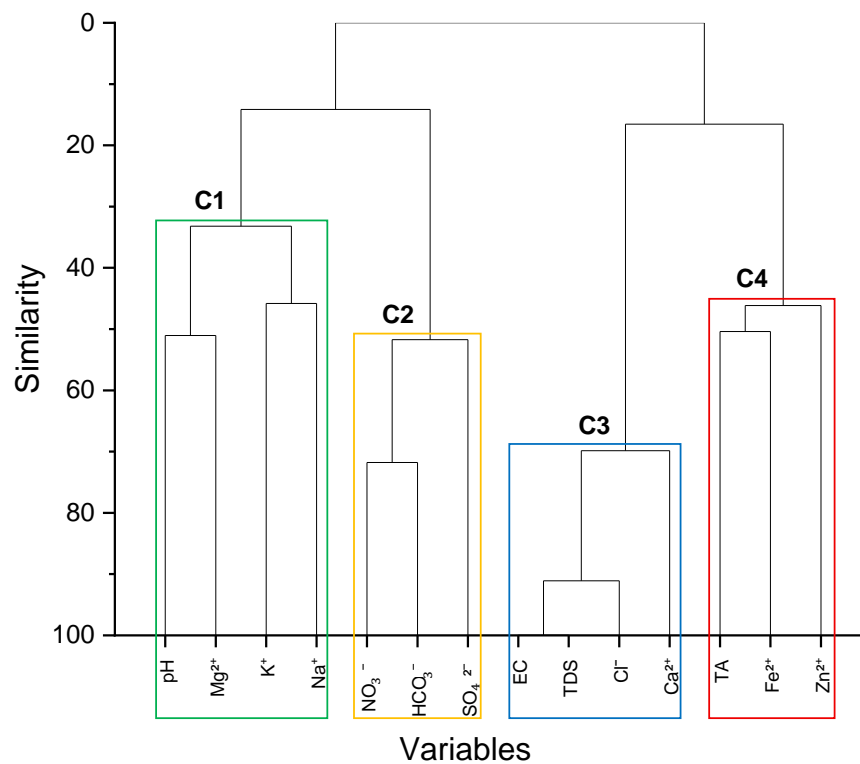


Fig. 5. Dendrogram showing the hierarchical clustering of the analyzed water quality indicators.

4.4 Water Suitability Evaluation

4.4.1 Water Quality for Drinking Purposes

The result of the water quality index (WQI) evaluation for drinking purposes is presented in Table 5. The CCME-WQI model was employed in determining the WQI values in the study area because of its ease of application and flexibility in selecting the necessary water quality parameters (Uddin et al., 2021). The NSDWQ (2015) and WHO (2024) standard limits were used as reference values for computing the WQI of the study area. Figure

6 is the statistical summary of the CCME-WQI for the surface water (pond and stream) and ground water samples used in this study, while Table 5 present the details of the CCME-WQI results. The water quality in the study area was categorized to be good, with the groundwater systems having the best quality. The quality of the water bodies is characterized to be protected with only a minor degree of threat or impairment (CCME, 2017).

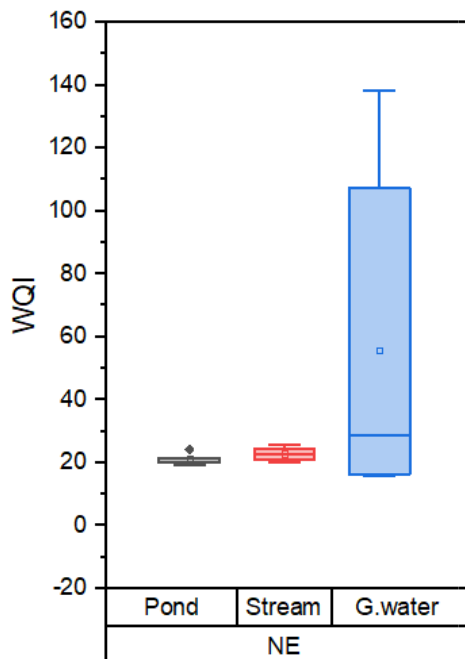


Fig. 6. Box plot showing variations in water quality index in the study area

Table 5. Estimated Average CCME-WQI value of the study area.

Location	F1	F2	F3	CCME-WQI
NE	7.14	2.38	13.46	91.09

CCME-WQI	Ranking	Water Quality Characteristics
95 - 100	Excellent	Water quality is protected with a virtual absence of threat; condition very close to natural and pristine levels
80 - 94	Good	Water quality is protected with only a minor degree of threat or impairment; conditions rarely depart from desirable levels
65 - 79	Fair	Water quality is usually protected but occasionally threatened or impaired; conditions sometimes depart from desirable levels
45 - 64	Marginal	Water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels
0 - 44	Poor	Water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels

4.4.2 Water Quality for Irrigation Purposes

The result of the irrigation water indices for the study area is presented in Table 6. The local inhabitants of Nasarawa-Eggon communities use the ponds, streams, and groundwater in the area for agricultural activities. However, poor water quality often poses a threat for irrigation activities and may cause harmful health effects on human beings

and livestock. The suitability of irrigation water can be ascertained by finding out the amount of sodium that is dissolved in it with regard to other major cations, in the vicinity of toxic elements in the surface water or groundwater (Sadashivaiah et al., 2008). Detailed interpretation of the various irrigation index values as obtained in this study is provided below.

Table 6. Results of the irrigation water quality indices evaluated in this study.

S/N	Code	SAR	MHR	%Na	KR	RSC
1	NE_P1	10.43433	52.94591	72.05878	2.502877	3.653625
2	NE_P2	10.77943	50.7437	73.35931	2.672403	5.130916
3	NE_P3	10.40559	48.62417	71.98111	2.491401	3.637927
4	NE_P4	9.351443	48.02867	67.10875	1.979391	3.771505
5	NE_P5	11.25882	49.85304	74.57352	2.846006	5.401917
6	NE_S1	9.871449	45.63013	70.3699	2.292836	5.52978
7	NE_S2	9.757187	45.67901	68.56034	2.109989	3.980546
8	NE_S3	8.750084	42.86526	63.08403	1.649375	3.070637
9	NE_S4	11.17181	48.74203	73.5964	2.689855	5.008696
10	NE_S5	11.32687	44.98567	74.14895	2.767431	5.155205
11	NE_S6c	7.706106	36.60984	56.73001	1.265645	3.423608
12	NE_G1	8.301455	47.5888	61.30465	1.534153	2.900273
13	NE_G2	0.468456	0.068454	0.499929	0.004983	0.009509
14	NE_G3	9.155774	44.43496	66.18466	1.891431	4.452031
15	NE_G4	11.07288	40.6748	73.49157	2.762699	6.497759
16	NE_G5	0.470308	0.0732	0.513011	0.004982	0.007226
17	NE_G6c	2.514467	7.496291	12.67908	0.140376	0.20271

(i) SAR: Table 7 presents the classification of the SAR values obtained in the analyzed water samples. The estimated SAR values ranged from 0.468456 to 11.32687, with 58.8 % of the samples showing excellent water quality,

while 41.2 % of the samples were found to be good for irrigation purposes. The result indicates that the water bodies are characterized by low to moderate sodium content.

Table 7. SAR classification in the study area.

Parameter	Range (meq/L)	Class	Sample No.	Percentage (%)
SAR	< 10	Excellent	NE_P4, NE_S1, NE_S2, NE_S3, NE_S6c, NE_G1, NE_G2, NE_G3, NE_G5, NE_G6c	58.8
	10 - 18	Good	NE_P1, NE_P2, NE_P3, NE_P5, NE_S4, NE_S5, NE_G4	41.2
	18 - 26	Permissible	-	-
	> 26	Unsuitable	-	-

(ii) % Na: Table 8 displays the categories of the estimated % Na values for the study area. The % Na of the analyzed samples ranged from 0.499929 to 74.14895. About 76.47 % of the

samples belonged to the "doubtful" category, 5.9 % fell within the "permissible" class, while 17.65 % of the samples ranked as "excellent" water quality for irrigation purposes.

Table 8. % Na water quality criteria for irrigation.

Parameter	Range (%)	Class	Sample No.	Percentage (%)
% Na	< 20	Excellent	NE_G2, NE_G5, NE_G6c	17.65
	20 – 40	Good	-	-
	40 – 60	Permissible	NE_S6c	5.9
	60 – 80	Doubtful	NE_P1, NE_P2, NE_P3, NE_P4, NE_P5, NE_S1, NE_S2, NE_S3, NE_S4, NE_S5, NE_G1, NE_G3, NE_G4	76.47
	> 80	Unsuitable	-	-

(iii) KR: The result of KR index determination in the study area showed that 17.64 % of the samples were classified as suitable, while 76.47 % of the samples were categorized as unsuitable for irrigation (Table 9). KR values greater 1 than suggests the presence of Na

dissolved in excess in water, which could potentially result in impairment of the soil properties (Rao, 2018). Hence, water samples with KR values less than 1 are suitable for irrigation activities (Uddin et al., 2023).

Table 9. KR classification in the study area.

Parameter	Range (meq/L)	Class	Sample No.	Percentage (%)
KR	< 1	Suitable	NE_G2, NE_G5, NE_G6c	17.64
	> 1	Unsuitable	NE_P1, NE_P2, NE_P3, NE_P4, NE_P5, NE_S1, NE_S2, NE_S3, NE_S4, NE_S5, NE_S6c, NE_G1, NE_G3, NE_G4	76.47

(iv) MHR: The determined MHR values range from 0.068454 to 52.94591 (Table 6), with 88.23 % of the samples falling within the "safe" class, while 11.76 % categorized as unsafe (Table 10). High magnesium content in

water used for irrigation poses a potential Mg^{2+} hazard which can result in elevated soil pH, and subsequent decrease in crop yield due to poor soil productivity (Singh et al., 2013; Tanvir Rahman et al., 2017).

Table 10. MHR Classification in the Study Area.

Parameter	Range (%)	Class	Sample No.	Percentage (%)
MHR	< 50	Safe	NE_P3, NE_P4, NE_P5, NE_S1, NE_S2, NE_S3, NE_S4, NE_S5, NE_S6c, NE_G1, NE_G2, NE_G3, NE_G4, NE_G5, NE_G6c	88.23
	> 50	Unsafe	NE_P1, NE_P2	11.76

(v) RSC: The computed RSC values range from 0.007226 to 6.497759, with 88.23 % of the samples categorized as safe and 11.76 % classifying as permissible for irrigation activities (Table 11).

5 Conclusions

Assessment of the hydrochemical characteristics and quality of surface water and groundwater resources within Nasarawa-Eggon coal mining site of northcentral Nigeria was carried out in this study using multivariate

statistical techniques. The conclusions are summarized as follows:

- The analyzed physicochemical parameters were observed to fall within allowable drinking water thresholds, except calcium which showed marked deviation from the

permissible value. The observed high contents of the analyzed parameters in some of the water samples are the resultant effect of water - rock interactions and dissolution of the ions

from the country rock. Thus, the physicochemical properties of the water samples are an indication of the overall hydrochemistry of the study area.

Table 11. RC Classification of the Study Area.

Parameter	Range	Class	Sample No.	Percentage (%)
RSC	< 1.25	Safe	NE_P3, NE_P4, NE_P5, NE_S1, NE_S2, NE_S3, NE_S4, NE_S5, NE_S6c, NE_G1, NE_G2, NE_G3, NE_G4, NE_G5, NE_G6c,	88.23
	1.25 – 2.50	Marginally safe	-	-
	> 2.50	Permissible	NE_P1, NE_P2	11.76

- The identified hydrogeochemical facies in the study area based on Piper plot include the CaCl type, Mixed CaMgCl type, HCO₃ type, and CaCl type. These water types reflect the interactions between the water and the host rock composed mainly of carbonate, dolomite, and halite minerals. Gibbs diagram revealed that the water chemistry was largely influenced by the natural processes of rock weathering and dissolution.
- From the Pearson correlation analysis, EC showed a strong positive correlation with TDS and Cl⁻. Similarly, TDS and Cl⁻ shared a strong positive correlation, and Ca²⁺ is also strongly correlated with Cl⁻. EC showed a moderate correlation with TA and Ca²⁺; TDS also showed moderate correlation with TA and Ca²⁺, and NO₃⁻ was moderately correlated with HCO₃⁻ and SO₄²⁻. The hierarchical cluster analysis revealed four clusters, indicating that the analyzed parameters in the water bodies may have originated from natural or anthropogenic sources.
- The drinking water quality characteristics based on CCME-WQI model categorized the water bodies in the study area as good, with the groundwater systems having the best quality.
- Sodium adsorption ratio (SAR) classified 58.8 % of the water samples to have excellent quality, while 41.2 % of the samples were categorized as good for irrigation purposes.
- The study demonstrated the robustness of multivariate statistical methods in assessing the impact of coal mining activities on the hydrochemical characteristics and water quality variations in Nasarawa-Eggon coal mining site and adjoining areas.

References

- Acharya, A., Sharma, M.L., Bishwakarma, K., Dahal, P., Chaudhari, S.K., Adhikari, B., Neupane, S., Pokhrel, B.N. and Pant, R.R., 2020. Chemical Characteristics of the Karmanasha River Water and Its Appropriateness for Irrigational Usage. *J. Nepal Chem. Soc.*, 41, 94 - 102.
- Adikwu, S.O., Ibeneme, S.I., Njoku, I.O., Jika, H.T., Okenu, S.C. and Okoro, E.M., 2025. Exploratory Assessment of Lead-Zinc Mineralization in Bangalela area Central Benue Trough Nigeria Using Integrated Ground Geophysical Data. *Pure Appl. Geophys.*, <https://doi.org/10.1007/s00024-025-03731-0>
- Akter, S., Saifullah, A.S.M., Meghla, N.T., Uddin, M.J. and Diganta, M.T.M., 2018. Seasonal variation of phytoplankton abundance and water quality parameters in Jamuna River. *J. Sci. Technol.* 8, 107-123.
- Amangabara, G.T. and Ejenma, E., 2012. Groundwater quality assessment of Yenagoo and environs Bayelsa State, Nigeria between 2010 and 2011. *Resour. Environ.*, 2(2), 20 - 29.
- APHA (American Public Health Association), 2005. Standard methods for the examination of water and wastewater, 21st edn. American Public Health Association, Washington, DC.
- Aremu, M.O., Ishaleku, Y.Y., Zando, C., Babangida, A.S., Adeka, M.U., Mohammed, M.A., Ayakeme, E.B. and Muhammad, H.I., 2024. Physicochemical and Heavy Metal Content Assessment of Water Quality in Keana and Nasarawa-Eggon Local Government Areas, Nasarawa State, Nigeria. *FULafia Journal of Science & Technology*, Vol. 8, No. 1, pp. 37 - 45.
- Atta, H.S., Omar, M.A.S. and Tawfik A.M., 2022. Water quality index for assessment of drinking groundwater purpose case study: area surrounding Ismailia Canal, Egypt, *J. Eng. Appl. Sci.*, 69, 1-17. <https://doi.org/10.1186/s44147-022-00138-9>.
- Ayiwulu, E., 2012. The nature of water scarcity and domestic water demand in Nasarawa Eggon Town of Nasarawa State. Dissertation, University of Jos.
- Benkheilil, J., 1989. The origin and evolution of the Cretaceous Benue Trough (Nigeria). *Journal of African Earth Sciences*, 8, 251-282.
- Bordalo, A.A., Teixeira, R., and Wiebe, W.J., 2006. A water quality index applied to an international shared river basin: The case of the Douro River. *Environmental Management*, 38, 910 - 920.
- Canadian Council of Ministers of the Environment, Canadian water quality guidelines for the protection of aquatic life: CCME Water Quality Index, User's Manual - 2017 Update, in: *Canadian Environmental Quality Guidelines*, 1999, Canadian Council of Ministers of the Environment, Winnipeg, 2017.
- Chalaune, T.B., Dangol, A., Sharma, J. and Sharma, C.M., 2020. First results on physico-chemical status and bathymetry of lakes in Ramaroshan Wetland, Far-West Nepal. *Nepal J. Environ. Sci*, 8, 17-27.
- Dao, V., Urban, W. and Hazra, S.B., 2020. Introducing the modification of Canadian

water quality index, *Groundw Sustain Dev* 11, <https://doi.org/10.1016/j.gsd.2020.100457>.

Daughney, C.J., Raiber, M., Moreau-Fournier, M., Morgenstern, U., van der Raaij, R., 2012. Use of hierarchical cluster analysis to assess the representativeness of a baseline groundwater quality monitoring network: comparison of New Zealand's national and regional groundwater monitoring programs. *Hydrogeol. J.*, 20 (1), 185 - 200.

Dinka M.O., Loiskandl, W. and Ndambuki, J.M., 2018. Hydrochemical characterization of various surface water and groundwater resources available in Matahara areas, Fantalle Woreda of Oromiya region. *Journal of Hydrology: Regional Studies*, 3, 444 - 456.

Dzhang, T.R. and Atangana, E., 2024. Evaluation of the impact of coal mining on surface water in the Boesmanspruit, Mpumalanga, South Africa. *Environmental Earth Sciences*, 83:159. <https://doi.org/10.1007/s12665-024-11431-6>

Ebele, J.E., Onuoha, K.M., Mode, A.W., Oha, I., Okeugo, C.G. and Okoro, E.M., 2025. Geophysical investigation of subsurface features influencing mineralization in Minna area of Nigeria using aeromagnetic and airborne radiometric data. *Environmental Earth Sciences*, 84:106

El Osta, Masoud, M.M., Alqarawy, A., Elsayed, S. and Gad, M., 2022. Groundwater Suitability for Drinking and Irrigation Using Water Quality Indices and Multivariate Modeling in Makkah Al-Mukarramah Province, Saudi Arabia, Vol. 14, <https://doi.org/10.3390/w14030483>. *Water* (Switzerland).

Ezekiel, A. and Dominic, A.A., 2014. Sources, demand and problems of domestic water in Nasarawa Eggon Town, Nigeria. *Pollution*, 1(1): 55-65.

Gibbs, R., 1970. Mechanisms controlling world water chemistry. *Science*, Vol. 170, no. 3962, pp. 1088 - 1090.

Ghobadi, A., Cheraghi, M., Sobhanardakani, S., Lorestani, B. and Merrikhpour H., 2020. Hydrogeochemical characteristics, temporal, and spatial variations for evaluation of groundwater quality of Hamedan-Bahar Plain as a major agricultural region, West of Iran, *Environ. Earth Sci.*, 79, 1-16, <https://doi.org/10.1007/s12665-020-09177-y>.

Hem, J.D., 1985. Study and Interpretation of the Chemical Characteristics of Natural Water, 2254. Department of the Interior, US Geological Survey.

Howladar, M.F., Deb, P.K. and Muzemder, A.S.H., 2017. Monitoring the underground roadway water quantity and quality for irrigation use around the Barapukuria Coal Mining Industry, Dinajpur, Bangladesh, *Groundw. Sustain. Dev.* 4, 23-34. <https://doi.org/10.1016/j.gsd.2016.11.002>.

Ihezue, E. and Obaniyi, F., 2023. World Water Day 2023: Accelerating Efforts towards Achieving SDG 6 in Nigeria. Centre for the Study of The Economies of Africa (CSEA), Available at: <https://cseaafrica.org/world-water-day-2023-accelerating-efforts-towards-achieving-sdg-6-in-nigeria/>

Ilyas, S., Sabo, A. and Akomolafe G.F., 2021. Assessment of Metal Accumulation in Plant and

- Soil at Eggon Community Mining Site, Nasarawa, Nigeria. *Journal of Research in Forestry, Wildlife & Environment*, Vol. 13(3), pp. 11 - 21.
- Iticescu, C., Georgescu, L.P., Murariu, G., Topa, C., Timofti, M., Pintilie, V. and Arseni, M., 2019. Lower Danube water quality quantified through WQI and multivariate analysis. *Water* 11, 1305.
- Kaddah, M.T., 1975. Irrigation with Saline Water. *Soil Sci. Soc. Am. J.*, 39, pp. 1973.
- Kana, A.A., 2022. Heavy metal assessment of groundwater quality in part of Karu, Central Nigeria. *Water Practice & Technology* Vol 17 No 9, 1802. doi: 10.2166/wpt.2022.102
- Kaur, M., Das, S.K. and Sarma, K., 2022. Water quality assessment of Tal Chhapar Wildlife Sanctuary using water quality index (CCME WQI), *Acta Ecol. Sin.*, <https://doi.org/10.1016/j.chnaes.2021.09.017>
- Kazi, T.G., Arain, M.B., Jamali, M.K., Jalbani, N., Afridi, H.I., Sarfraz, R.A., Baig, J.A. and Shah, A.Q., 2009. Assessment of water quality polluted lake using multivariate statistical techniques: A case study. *Ecotoxicology and Environmental Safety*, Vol. 72, No. 2, pp. 301 - 309.
- Kelley, W.P., 1963. Use of saline irrigation water. *Soil Sci.*, 95, 385-391.
- Khadka, U.R. and Ramanathan, A.L., 2013. Major ion composition and seasonal variation in the Lesser Himalayan Lake: Case of Begnas Lake of the Pokhara Valley, Nepal. *Arab. J. Geosci.* 6, 4191-4206.
- Lei, L. 2014. Assessment of water quality using multivariate statistical techniques in the Ying River Basin, China. Master's thesis, University of Michigan, United States.
- Li, P., Wu, J., Qian, H., 2016. Hydrochemical appraisal of groundwater quality for drinking and irrigation purposes and the major influencing factors: a case study in and around Hua County, China. *Arab. J. Geosci.*, 9(1), 1-17.
- Li, J., Yang, G., Zhu, D., Xie, H., Zhao, Y., Fan, L. and Zou, S., 2022. Hydrogeochemistry of karst groundwater for the environmental and health risk assessment: the case of the suburban area of Chongqing (Southwest China), *Geochemistry* 82, 125866. <https://doi.org/10.1016/j.chemer.2022.125866>
- Liu, C.W., Lin, K.H. and Kuo, Y.M., 2003. Application of factor analysis in the assessment of groundwater quality in a blackfoot disease area in Taiwan. *Sci. Total Environ.* 313, 77-89.
- Liu, H., Yuan, H., Wang, S., Zheng, L. and Liao, M., 2021. Spatiotemporal dynamics of water body changes and their influencing factors in the seasonal lakes of the poyang lake region. *Water*, 13, 1539.
- Maiolo, M. and Pantusa, D., 2021. Multivariate analysis of water quality data for drinking water supply systems. *Water* 13(13):1766. <https://doi.org/10.3390/w13131766>
- Madhavan, S., Kolanuvada, S.R., Sampath, V., Roy, P.D., Moorthy, P., Natarajan, L. and Chokkalingam, L., 2023. Assessment of groundwater vulnerability using water quality index and solute transport model in Poiney sub-basin of south India, *Environ. Monit. Assess.* 195, 1-15. <https://doi.org/10.1007/s10661-022-10883-2>

- Mohammed, M.A.A., Szabo, N.P. and Szucs, P., 2022. Multivariate statistical and hydrochemical approaches for evaluation of groundwater quality in north Bahri city-Sudan. *Heliyon* 8, e11308.
- Mohseni, U., Patidar, N., Pathan, A., Raaj, S., Kachhawa, N., Agnihotri, P., Patel, D., Prieto, C., Gandhi, P. and Durin, B., 2023. Groundwater Quality Assessment Using CCME WQI and GIS Technique for Ujjain City, India, vol. 2022, EGU General Assembly, Vienna, pp. 36. <https://doi.org/10.5194/egusphere-egu22-3643>.
- Muijs, D., 2022. *Doing Quantitative Research in Education with IBM SPSS Statistics*; Sage Publications: Thousand Oaks, CA, USA, pp. 1 - 100.
- Nethononda, V.G., Elumalai, V. and Rajmohan, N., 2019. Irrigation return flow induced mineral weathering and ion exchange reactions in the aquifer, Luvuvhu catchment, South Africa. *J. Afr. Earth Sci.* 149, 517 - 528.
- NSDWQ (Nigerian Standard for Drinking Water Quality), 2015. Nigerian Industrial Standard. pp. 1 - 28.
- NSG, 2001. Nasarawa state government official gazette. Lafia: Ministry of Information.
- Obaje, N.G., 2009. *Geology and mineral resources of Nigeria*. Lecture Notes in Earth Sciences 120. doi.org/10.1007/978-3-540-92685_6_2.
- Ofoegbu, C.O., 1985. A review of the geology of the Benue Trough. Nigeria. *J. Afric. Earth Sci.* 3 (3), 283-291.
- Oguntoke, O., Aboderin, O.J. and Bankole, A.M., 2009. Association of water-borne diseases morbidity pattern and water quality in parts of Ibadan City, Nigeria. *Tanzania Journal of Health Research*, Vol. 11, No. 4, pp. 189 - 195.
- Paudel, G., Pant, R.R., Joshi, T.R. and Saqr, T.R., 2024. Hydrochemical dynamics and water quality assessment of the Ramsar-Listed Ghodaghodi Lake Complex: Unveiling the water-environment nexus. *Water*, Vol. 16, No. 3373, pp. 1 - 23.
- Pesce, S.F. and Wunderlin, D.A., 2000. Use of water quality indices to verify the impact of Córdoba City (Argentina) on Suquí'a River. *Water Research*. 34 (11), 2915-2926.
- Piper, 1944. "A graphic producer in the geochemical interpretation of water analysis," *Am. Geophys. Union*, pp. 914 - 928.
- Prasanna, M.V., Chidambaram, S., Gireesh, T.V. and Ali, T.V.J., 2011. A study on hydrochemical characteristics of surface and sub-surface water in and around Perumal Lake, Cuddalore district, Tamil Nadu, South India. *Environ. Earth Sci.*, 63, 31-47.
- Raghunath, I.I.M., 1987. *Groundwater*, second ed., Wiley Eastern Ltd., New Delhi, India, pp. 344-369.
- Raji, M.I.O. and Ibrahim, Y.K.E, 2011. Prevalence of waterborne infections in Northwest Nigeria: A retrospective study. *Journal of Public Health and Epidemiology*, Vol. 3, No. 8, pp. 382 - 385.
- Rao, N.S., 2018. Groundwater quality from a part of prakasam district, Andhra Pradesh,

- India, *Appl. Water Sci.* 8 (2018) 1-18, <https://doi.org/10.1007/s13201-018-0665-2>.
- Richards, L.A., 1954. *Diagnosis and Improvement of Saline and Alkali Soils*. *Agron. J.*, 46, 290.
- Sabry Al-Mashhadany, M.H., 2021. Application of the CCME water quality index to evaluate the groundwater quality of shouira village for drinking and domestic purposes in Nineveh governorate, in: *IOP Conference Series: Earth and Environmental Science*, IOP Publishing Ltd, <https://doi.org/10.1088/1755-1315/722/1/012029>.
- Sadashivaiah, C., Ramakrishnaiah, C.R., Ranganna, G., 2008. Hydrochemical analysis and evaluation of groundwater quality in Tumkur Taluk, Karnataka State, India. *Int. J. Environ. Res. Public Heal.*, 5 (3), 158-164.
- Sánchez, E., Colmenarejo, M.F., Vicente, J., Rubio, A., García, M.G., Travieso, L., Borja, R., 2007. Use of the water quality index and dissolved oxygen deficit as simple indicators of watersheds pollution. *Ecological Indicators*, 7, 315 - 328.
- Saqr, A.M., Nasr, M., Fujii, M., Yoshimura, C. and Ibrahim, M.G., 2024. Delineating suitable zones for solar-based groundwater exploitation using multi-criteria analysis: A techno-economic assessment for meeting sustainable development goals (SDGs). *Groundw. Sustain. Dev.*, 25, 101087.
- Sener, S., Sener, E. and Davraz, A., 2017. Evaluation of water quality using water quality index (WQI) method and GIS in Aksu River (SW Turkey). *Science of the Total Environment* 584, 131-144.
- Sharma, T., Bajwa, B.S. and Kaur, I., 2022. Hydro-geochemical characteristics and quality appraisal of aquifers using multivariate statistics and associated risk assessment in Tarn-Taran district, Punjab, India. *Environ. Sci. Poll. Res.* 1-23.
- Singh, Y. and Kumar, M., 2011. Application of statistical methods to analyze groundwater quality. *J. Earth Sci. Geotechnical Eng.* 1 (1), 1792 - 9660.
- Singh, C.K., Shashtri, S., Rina, K. and Mukherjee, S., 2013. Chemometric analysis to infer hydro-geochemical processes in a semi-arid region of India. *Arabian J. Geosci.*, 6, 2915 - 2932. <https://doi.org/10.1007/s12517-012-0597-3>.
- Taiwo, A.M., Olujimi, O.O., Bamgbose, O. and Arowolo, T.A., 2012. *Surface water quality monitoring in Nigeria: Situational Analysis and Future Management Strategy*, Water Quality Monitoring and Assessment, Dr. Voudouris (Ed.). <http://www.intechopen.com/books/water-quality-monitoring-and-assessment/surface-water-quality-monitoring-in-nigeria-situational-analysis-and-futuremanagement-strategy>.
- Tanvir Rahman, M.A.T.M., Saadat, A.H.M., Islam, M.S., Al-Mansur, M.A. and Ahmed, S., 2017. Groundwater characterization and selection of suitable water type for irrigation in the western region of Bangladesh. *Appl. Water Sci.*, 7, 233-243, <https://doi.org/10.1007/s13201-014-0239-x>.
- The Sustainable Development Goals Report 2022.

Tian, Y., Jiang, Y., Liu, Q., Dong, M., Xu, D., Liu, Y. and Xu, X., 2019. Using a water quality index to assess the water quality of the upper and middle streams of the Luanhe River, northern China. *Science of The Total Environment*, Vol. 667, pp. 142 - 151.

Uddin, M.G., Nash, S. and Olbert, A.I., 2021. A review of water quality index models and their use for assessing surface water quality, *Ecol. Indicat.* 122, 107218. <https://doi.org/10.1016/j.ecolind.2020.107218>.

Uddin, M.G., Diganta, M.T.M., Sajib, A.M., Hasan, M.A., Moniruzzaman, M., Rahman, A., Olbert, A.I. and Moniruzzaman, M., 2023. Assessment of hydrogeochemistry in groundwater using water quality index model and indices approaches. *Heliyon* 9, e19668.

Varol, M., 2020. Use of water quality index and multivariate statistical methods for the evaluation of water quality of a stream affected by multiple stressors: A case study. *Environmental Pollution* 266, 115417.

Wang, X. and Zhang, F., 2018. Multi-scale analysis of the relationship between landscape patterns and a water quality index (WQI) based on a stepwise linear regression (SLR) and geographically weighted regression (GWR) in the Ebinur Lake oasis. *Environ. Sci. Pollut. Res.*, 25, 7033 - 7048.

WHO (World Health Organization), 2024. Guidelines for drinking water quality: small water supplies.

<https://creativecommons.org/licenses/by-nc-sa/3.0/igo>

Wilcox, L.V. 1955. *Classification and Use of Irrigation Waters*; US Department of Agriculture: Washington, WA, USA.

Wu, C., Wu, X., Qian, C. and Zhu, G., 2018. Hydrogeochemistry and groundwater quality assessment of high fluoride levels in the Yanchi endorheic region, northwest. China. *Appl. Geochem.*, 98, 404-417.

Yidana, S.M., Bawoyobie, P., Sakyi, P. and Fynn, O.F., 2018. Evolutionary analysis of groundwater flow: application of multivariate statistical analysis to hydrochemical data in the Densu Basin, Ghana. *J. Afr. Earth Sci.* 138, 167-176.

Zidan, A., Abdalla, M., Khalaf, S. and Saqr, A., 2020. Kinetic Energy and Momentum Coefficients for Egyptian Irrigation Canals. *Bull. Fac. Eng. Mansoura Univ.*, 41, 1 - 16.

Zhang, D., Lu, D., Yang, B., Zhang, J., Ning, Z. and Yu, K., 2019. Influence of natural and anthropogenic factors on spatial-temporal hydrochemistry and the susceptibility to nutrient enrichment in a subtropical estuary. *Mar. Pollut. Bull.*, 146, 945 - 954.