

Hydrogeochemical Evaluation of Groundwater Quality in the Yola Arm, Upper Benue Trough, Northeastern Nigeria



Victor Vitalis, Bello Abubakar Dauda, Bitrus Kwaji

Abstract: Groundwater constitutes the principal source of potable water in Pariya and its environs within the Yola Arm of the Upper Benue Trough, Northeastern Nigeria. However, increasing population pressure, agricultural practices, and inadequate sanitation pose growing threats to its quality. This study evaluates the hydrogeochemical characteristics and suitability of groundwater for drinking using integrated hydrochemical and multivariate statistical approaches. Twenty-three groundwater samples were collected from boreholes and hand-dug wells and analyzed for major physicochemical and microbiological parameters following standard procedures. Hydrogeochemical interpretation employed the Water Quality Index (WQI), Piper trilinear diagram, Principal Component Analysis (PCA), and Hierarchical Cluster Analysis (HCA) to identify water types and the dominant processes controlling groundwater chemistry. The groundwater is slightly acidic to neutral, with pH values ranging from 5.88 to 7.10. Electrical conductivity (210–312 $\mu\text{S}/\text{cm}$) and total dissolved solids (136–243 mg/L) indicate low to moderate mineralization. Major ions generally fall within World Health Organization (WHO) permissible limits. Turbidity ranges from 0.03 to 13.14 NTU, with only one sample exceeding the recommended threshold. In contrast, coliform bacteria exceed acceptable limits in approximately 70% of the samples, revealing widespread microbial contamination linked to poor sanitation and surface infiltration. WQI values range from 32.41 to 202.61, classifying 86.9% of the samples as suitable for drinking (Grade B), while 4.3% are poor (Grade C), 4.3% abysmal (Grade D), and 4.3% unsuitable (Grade E). Piper plots reveal dominant Ca-Mg-HCO_3 and $\text{Ca-Mg-SO}_4\text{-Cl}$ facies, indicating that groundwater chemistry is primarily controlled by carbonate and silicate weathering, mineral dissolution, and reverse ion exchange. PCA and HCA identify natural mineralisation, rock-water interactions, Na-alkalinity, and localised fertiliser inputs as the principal factors influencing groundwater composition. The results demonstrate that groundwater in the study area is generally suitable for irrigation and domestic use; however, microbial contamination necessitates disinfection before consumption. Strengthening sanitation infrastructure, regulating fertiliser application, and implementing periodic groundwater monitoring

are essential to safeguard public health and ensure sustainable groundwater management in the Yola Arm.

Keywords: Groundwater Quality, Pariya, Yola Arm, Upper Benue Trough, Water Quality Index

Nomenclature:

WQI: Water Quality Index
PCA: Principal Component Analysis
HCA: Hierarchical Cluster Analysis
EC: Electrical Conductivity
TDS: Total Dissolved Solids
WHO: World Health Organization
TH: Total Hardness

I. INTRODUCTION

Groundwater is one of the most precious natural resources, exploited worldwide. The demand for natural resources is growing rapidly as groundwater is increasingly used for domestic, agricultural, and industrial purposes. The annual extraction of Groundwater is found to exceed recharge from natural resources. The assessment of Groundwater quality is important for socio-economic growth and development (Ishaku et al., 2016). The chemical composition of water is an important factor to be considered before it is used for domestic or irrigation purposes (Abdullahi et al., 2025) [5]. The importance of groundwater quality for human health has recently attracted significant attention. In the developing World, 80% of all diseases are directly related to poor drinking water and unsanitary conditions (Shuaibu et al., 2024) [2]. On the other hand, water composition may concentrate salts in soils or water to the point that crop yield is affected. This means that failing to evaluate water quality before human consumption, domestic use, and perhaps Irrigation purposes may lead to health problems and low agricultural productivity. In recent times, the impact of leachate on groundwater and other water sources has attracted significant attention due to the high volume of waste generated and the poor management of waste, which poses a serious threat to groundwater quality and other water sources [4]. However, despite widespread awareness of the importance of using quality water for consumption, agriculture, and industry, adequate attention has not been given, especially in developing countries like Nigeria.

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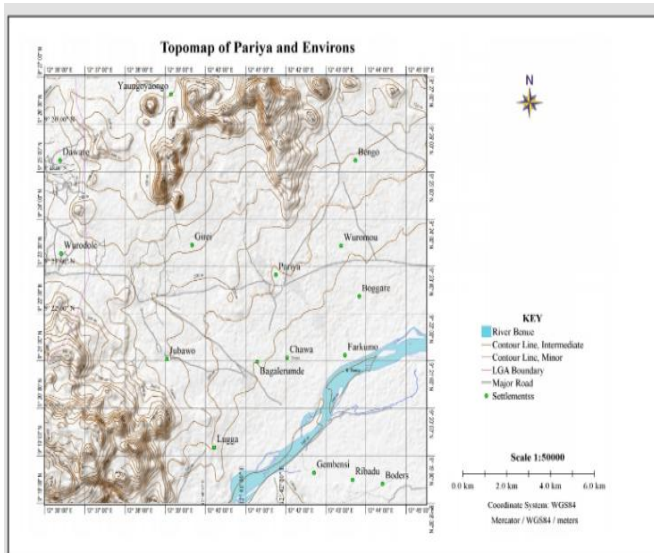
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II. MATERIALS AND METHODS

A. Location and Accessibility

The area under study is in Pariya and environs, Yola Arm, Upper Benue Trough, Northeastern Nigeria. It is situated within latitudes $9^{\circ} 18' 00'' - 9^{\circ} 25' 00''$ N and longitudes $12^{\circ} 37' 00'' - 12^{\circ} 44' 00''$ E (Fig. 1) and covers an area of about 174 km².



[Fig.1: Topographic Map of the Study area (After Federal Survey of Nigeria, 2006)]

B. Methodology

i. Groundwater Sampling

Twenty-three groundwater samples were collected from hand-dug wells, boreholes, and streams across the study area. The locations of these water sources were recorded using a GPS device. Samples were collected in plastic containers that were rinsed correctly with the water to be collected. Field measurements such as temperature and pH were taken on site using a Pen pH and Temperature Meter (Model CT6021). Carbonate and bicarbonate levels were determined in the field using a titration method with a HACH Digital Titrator (Model 16900). Electrical conductivity (EC) and total dissolved solids (TDS) were measured using a Pen Conductivity Meter (Model CT3030) and a Pen TDS Meter (Model CT3061), respectively. In the laboratory, the samples were analysed for major cations and anions using a HACH Digital Spectrophotometer (Model 3900). The ions tested included potassium (K^+), calcium (Ca^{2+}), sodium (Na^+), magnesium (Mg^{2+}), iron (Fe^{2+}), chloride (Cl^-), nitrate (NO_3^-), zinc (Zn^{2+}), sulfate (SO_4^{2-}), lead (Pb^{2+}), and hydrogen sulfide (H_2S).

ii. Water Quality Index (WQI)

The water quality index (WQI) is used to assess the influence of natural and anthropogenic activities on key groundwater chemistry parameters (Kumar *et al.*, 2015). To compute the WQI, weights were assigned to physicochemical parameters based on their relative importance in determining the overall quality of drinking

water. The weight ranges from 1 to 5 [8]. The maximum weight of 5 was assigned to TDS, 4 to pH, EC, and SO_4 , 3 to HCO_3 , TH, and Cl, 2 to Ca, Na, and K, and 1 to Mg (Vasanthavigar *et al.*, 2010). The relative weight is computed from the equation below.

$$W_i = \frac{w_i}{\sum_i w_i} = 1 \quad \dots (1)$$

where W_i is the relative weight, w_i is the weight of each parameter, and n is the number of parameters. The quality rating scale for each parameter is computed by dividing its concentration in each water sample by its respective standards (WHO, 2023) and multiplying by 100.

$$q_i = (C_i/S_i) \times 100 \quad \dots (2)$$

where q_i is the quality rating, C_i is the concentration of each chemical parameter, and S_i is the World Health Organization Standards for each chemical parameter in milligrams per litre according to the (WHO, 2023) guidelines.

For computing the final stage of WQI, the SI is first determined for each parameter. The sum of SI values gives the water quality index for each sample.

$$S_{li} = W_i \times q_i \quad \dots (3)$$

$$WQI = \sum S_{li} \quad \dots (4)$$

Where S_{li} is the sub-index of the i th parameter, q_i is the rating based on the concentration of the i th parameter, and n is the number of parameters (Kumar *et al.*, 2015).

iii. Hydro-Geochemical Facies (Water Type)

The Piper diagram is a graphical method of groundwater classification using a trilinear diagram that contains the concentration of major cations (Ca^{2+} , Mg^{2+} , Na^+ , K^+) and anions (Cl , SO_4^{2-} , HCO_3^- , CO_3^{2-}) (Piper, 1944). Separate ternary plots show the cations and anions. The apexes of the cation plot are calcium, magnesium, and sodium plus potassium. The apexes of the anion plot are sulfate, chloride, and carbonate, plus hydrogen carbonate anions. The two ternary plots are then projected onto a diamond shape. In the diagram, a water sample is presented with three points, one in each triangle and one in the diamond. The software package Rockware Aq.QA (Freeze & Cherry, 1979) was used to develop the piper diagrams for classifying water types.

iv. Principal Component Analysis (PCA)

Principal component analysis (PCA) is a multivariate statistical technique used for data reduction to determine the sources of variation and their controlling factors (Ishaku *et al.*, 2016). PCA is defined as an orthogonal linear transformation that transforms the variables to a new coordinate system such that the most significant variance by any projection of the variables



comes to lie on the first coordinate (called the first principal component), the second most significant variance on the second coordinate, and so on (Abdullahi et al., 2025). PCA aims to construct new variables, called principal components, from a set of original variables. The total number of factors generated from a typical factor analysis indicates the total number of possible variations in the data. The first factor has the largest Eigenvector sum and accounts for the greatest variation in the data. The last factor is the least important process contributing to the chemical variation. Factor loadings were interpreted as correlation coefficients between the variables; a high positive loading was defined as greater than 0.75, and a moderate loading was determined as 0.40-0.75. Loading of less than 0.40 was considered insignificant (Abdullahi et al., 2025). The multivariate statistical technique, therefore, relates variables into principal associations (factors) based on their mutual correlation coefficients, and these associations may be interpreted in terms of mineralisation, lithology, and environmental processes (Onoyima et al., 2025) [3]. The principal component is thus given by the equation below.

$$Z_{ij} = a_{i1}X_{1j} + a_{i2}X_{2j} + a_{i3}X_{3j} + \dots + a_{in}X_{nj} \quad (5)$$

Where z = component score, a = component loading, x = measure value of variable, I = component number, j = sample number, and n = the total number of variables.

v. Hierarchical Cluster Analysis

Cluster analysis groups variables into clusters based on similarities or dissimilarities, so that each cluster represents a specific process in the system (Abdullahi et al., 2025). It is a technique that identifies natural groupings among objects to reveal the hidden structure in the dataset. In HCA, clusters are formed sequentially, starting with the most similar pair of variables and progressing in steps. A short distance indicates that the two objects are identical or close together, whereas a considerable distance indicates dissimilarity (Abdullahi et al., 2013). The cluster analysis formula is given as

$$d_{ii}^2 = \sum_k^m 1(Z_{ik} - Z_{jk})^2 \quad (6)$$

Where d_{ii} = the Euclidean distance, Z_{ik} the values of variable K for object I ; Z_{jk} = the values of variable k for object j , and m = the number of variables.

III. RESULTS AND DISCUSSION

A. Physico-Chemical Characteristics of Groundwater

Groundwater temperature ranges from (24.05–27.16°C) and falls within the WHO (2011) limit, indicating thermal suitability for drinking and domestic use. The pH values (5.88–7.10) suggest slightly acidic to neutral conditions, which are generally safe for consumption. Electrical conductivity (210–312 $\mu\text{S}/\text{cm}$) reflects a moderate ion concentration, implying good water quality. Turbidity

values range from 0.31 to 13.14 NTU, with an average of 6.72 NTU. Although the mean slightly exceeds the WHO standard of 5 NTU, only one sample (HDW10) surpasses this limit, suggesting localised contamination. The elevated turbidity may result from suspended particles, pollutants, or seasonal influences, warranting further investigation. All measured physical parameters fall within the WHO permissible limits, indicating that the groundwater is fit for domestic purposes. All major cations (Ca, Mg, Na, K) and anions (SO_4^{2-} , Cl^- , HCO_3^- , CO_3^{2-}) fall within the WHO (2011) permissible limits, indicating overall good groundwater quality. Calcium, magnesium, and total hardness values show that the water is moderately challenging but suitable for domestic use. Iron (Fe) concentration exceeded the limit only in sample HDW10, implying localized mineral enrichment or contamination. Nitrate, sulfate, and chloride concentrations are low, confirming minimal agricultural or industrial influence. However, coliform counts exceeded WHO standards in about 70% of the samples, suggesting microbial contamination and emphasizing the need for proper disinfection before consumption.

Table I: Physico-Chemical and Microbiological Characteristics of Groundwater Samples from the Study Area

S/N	Water source	Temp.(⁰ C)	pH	EC (μs/cm)	TDS Mg/l	NTU M g/l	CO ₃ ² Mg/l	HCO ₃ Mg/l	TH Mg/l	Mg ²⁺ Mg/l	Ca ²⁺ Mg/l	K ⁺ Mg/l	Fe ²⁺ Mg/l	PO ₄ ²⁺ Mg/l	CL Mg/l	SO ₄ ²⁻ Mg/l	NO ₃ Mg/l	Na ⁺ Mg/l	Zn Mg/l	Pb Mg/l	H ₂ S Mg/l	Coliform count
1	HDW-1	27.16	6.82	225	152	0.39	1.20	167	89.13	4.92	27.18	8.14	0.112	1.21	12.81	11.07	16.91	1.13	0.224	0.00	0.11	3
2	BH-2	24.16	6.32	220	154	0.092	0.00	162	89.21	5.92	27.1	8.12	0.115	1.31	11.31	11.01	16.23	1.15	0.324	0.00	0.00	2
3	BH-3	26.78	6.93	221	147	0.984	0.00	171	95.17	5.16	30.09	7.96	0.109	1.40	7.17	12.1	10.12	1.007	0.18	0.00	0.00	2
4	HDW-4	26.78	6.12	215	147	0.982	1.12	151	95.17	5.16	33.19	8.66	0.062	1.60	7.29	12.1	14.52	1.021	0.223	0.00	0.00	5
5	BH-5	25.77	6.58	234	156	0.312	0.00	170	97.73	5.17	31.13	7.00	0.118	1.50	6.95	12.42	11.2	0.984	0.121	0.00	0.00	2
6	BH-6	24.77	6.21	210	146	0.031	0.00	154	93.73	5.77	31.13	0.98	0.854	1.40	9.95	12.42	15.2	0.984	0.421	0.00	0.023	3
7	HDW-7	27.07	7.1	242	161	1.05	1.00	163	92.55	5.36	29.66	7.88	0.178	1.42	11.62	11.47	18.96	1.101	0.112	0.00	0.002	4
8	BH-8	25.07	5.84	242	161	1.05	1.00	163	85.55	6.36	27.66	7.22	0.123	1.52	11.22	11.47	17.46	1.132	0.113	0.00	0.00	5
9	BH-9	25.15	6.2	263	136	0.121	0.00	119	79.53	6.10	24.14	7.22	0.170	1.47	15.26	27.11	15.27	1.17	1.154	0.002	0.00	0
10	HDW-10	26.98	5.98	312	243	13.14	2.53	206	97.95	6.84	35.34	7.92	3.765	1.32	33.01	24.17	39.69	5.18	1.01	0.004	0.22	4
11	BH-12	24.05	5.37	222	183	0.052	0.00	121	89.5	5.91	26.84	6.82	0.081	0.00	30.14	15.48	15.1	1.12	1.104	0.011	0.00	0
12	BH-14	24.1	5.22	236	154	0.64	0.00	153	92.51	6.87	27.91	7.02	0.151	1.39	29.55	9.87	16.02	1.97	0.943	0.00	0.24	2
13	HDW-17	26.34	6.48	298	198	1.07	1.10	201	55	6.99	31.12	6.99	0.206	1.20	3.16	11.18	19.1	1.09	0.148	0.001	0.001	56
14	BH-18	25.08	5.98	310	208	0.58	0.00	172	101.5	6.10	31.33	7.00	0.097	1.31	7.13	12.17	12.83	1.007	0.160	0.00	0.00	3
15	BH-19	25.17	5.98	224	148	0.493	0.00	169	96	6.77	29.84	6.17	0.110	1.49	8.17	11.98	11.92	1.05	0.170	0.00	1.03	2
16	BH-20	25.34	6.38	21	168	1.01	0.00	101	97.55	5.99	28.12	7.10	0.102	0.83	13.16	11.08	16.1	1.09	0.148	0.003	0.00	6
17	BH-24	25.08	5.88	220	177	0.045	0.00	162	76.5	6.10	26.83	7.86	0.092	1.31	9.43	12.27	14.83	1.08	0.123	0.00	0.00	1
18	BH-25	25.44	6.5	230	154	0.87	0.00	159	99.15	6.17	30.14	6.17	0.088	1.37	7.14	12.53	13.42	1.008	0.05	0.00	0.00	4
19	BH-26	25.00	6.34	253	170	0.72	0.00	142	0.15	5.93	29.81	7.10	0.105	1.18	8.16	13.46	12.18	1.02	0.101	0.001	0.00	3
20	BH-27	25.17	6.21	224	148	0.086	0.00	169	86	6.47	27.44	7.04	0.110	1.49	8.17	11.98	15.92	1	1.232	0.003	1.03	1
21	BH-28	25.23	6.81	214	145	0.064	0.00	130	87.6	5.82	27.15	7.20	0.183	1.62	12.27	10.13	15.05	0.05	0.234	0.000	0.00	1
22	BH-29	26.02	6.18	274	181	0.55	0.00	147	98.89	5.84	29.77	7.00	0.112	1.22	7.97	11.97	12.07	1.45	0.104	0.00	0.00	2
23	BH-30	25.01	6.12	237	175	0.094	0.00	126	93.51	5.74	27.02	7.60	0.023	0.13	14.88	8.34	22.84	0.96	1.561	0.003	0.00	0

B. Groundwater Quality for Drinking (Water Quality Index)

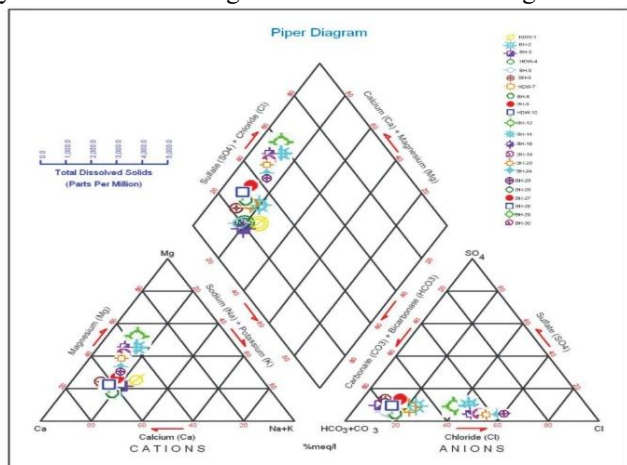
The WQI results for the study area are summarised in Table 2. The analysis indicates that 86.9% of the groundwater samples fall within the “Good” category (Grade B, WQI 26–50), including BH-2, BH-3, HDW-1, BH-5, and BH-19. A small proportion, 4.3%, was classified as “Poor” quality (Grade C, WQI 51–75), represented by BH-6 (WQI 55.05). Similarly, 4.3% of the samples were found to be of “Very Poor” quality (Grade D, WQI 76–100), exemplified by BH-30 (WQI 80.37). Only one sample, HDW-10, representing 4.3% of the total, was deemed “Unsuitable for Drinking” (Grade E, WQI >100) with a WQI of 202.61.

Table II: Groundwater Quality Index Rating of Water from the Study Area

SN	Water Source	Easting	Northing	WQI	Rating	Grade
1	HDW-1	E12°38'20"	N09°22'14"	34.06	Good water quality	B
2	BH-2	E12°38'50"	N09°22'28"	33.34	Good water quality	B
3	BH-3	E12°41'22"	N09°22'48"	34.93	Good water quality	B
4	HDW-4	E12°41'40"	N09°22'56"	39.89	Good water quality	B
5	BH-5	E12°41'16"	N09°22'53"	34.55	Good water quality	B
6	BH-6	E12°41'7.7"	N09°23'27"	55.05	Poor Quality Water	C
7	HDW-7	E12°41'29.64"	N09°22'31.05"	32.93	Good Quality Water	B
8	BH-8	E12°41'40.15"	N09°22'21.01"	32.41	Good Quality Water	B
9	BH-9	E12°41'56"	N09°22'35"	33.95	Good water quality	B
10	HDW-10	E12°42'41"	N09°21'56"	202.61	Unsuitable for drinking	E
11	BH-12	E12°43'9.3"	N09°23'3.6"	33.69	Good water quality	B
12	BH-14	E12°41'50"	N09°22'56"	38.25	Good Quality Water	B
13	HDW-17	E12°41'59"	N09°20'24"	35.42	Good Quality Water	B
14	BH-18	E12°41'08"	N09°20.43"	49.39	Good Quality Water	B
15	BH-19	E12°40'2.9"	N09°19.44"	33.18	Good water quality	B
16	BH-20	E12°40'54"	N09°20'30"	33.96	Good water quality	B
17	BH-24	E12°42'55"	N09°21'26"	33.52	Good water quality	B
18	BH-25	E12°44'23"	N09°23'07"	32.84	Good Quality Water	B
19	BH-26	E12°44'22"	N09°23'09"	33.22	Good Quality Water	B
20	BH-27	E12°40'28"	N09°18'24"	37.28	Good water quality	B
21	BH-28	E12°41'12"	N09°19'20"	34.28	Good water quality	B
22	BH-29	E12°40'18"	N09°21'33"	32.69	Good water quality	B
23	BH-30	E12°42'17"	N09°22'13"	80.37	Inferior water quality	D

C. Groundwater Hydro-Geochemical Facies

The characterization of the water in the study area using a piper trilinear diagram (Figs. 2) indicates that all samples plotted in the region of Ca-Mg-HCO₃, and Ca-Mg-SO₄-Cl. The Ca-Mg-HCO₃ facies is the dominant water type, belongs to the normal alkaline group, and is related to the area's geology (Onoyima et al., 2025). It is associated with young meteoric water of recent recharge origin. This facies typically develops through the dissolution of aluminosilicates induced by chemical weathering and reverse cation exchange.



[Fig.2: Piper's Trilinear Diagram for Groundwater]

D. Scatter Diagrams for groundwater

i. Calcium and Magnesium

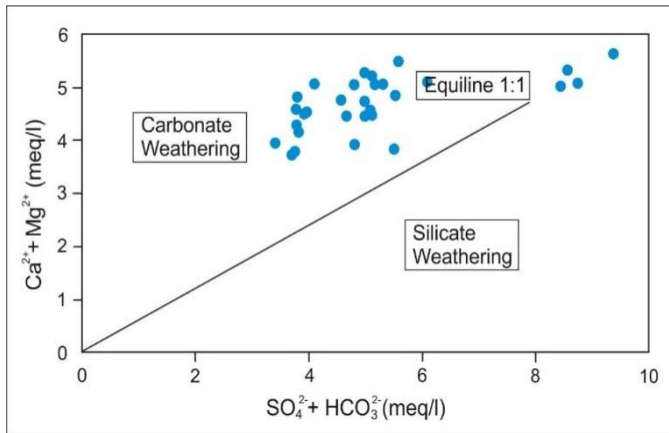
In the scatter diagram (Figure 3), 100% of the samples plot above the 1:1 line, indicating carbonate weathering. Carbonate weathering may be caused by atmospheric water charged with CO₂, which, in turn, forms carbonic acid. This accelerates the dissolution of carbonate rocks such as dolomite, limestone, and gypsum along the groundwater flow path. The result is the release of Ca²⁺ and Mg²⁺ from the carbonate weathering into the groundwater system through recharge (Artimes et al., 2011).

ii. Sodium and Chloride

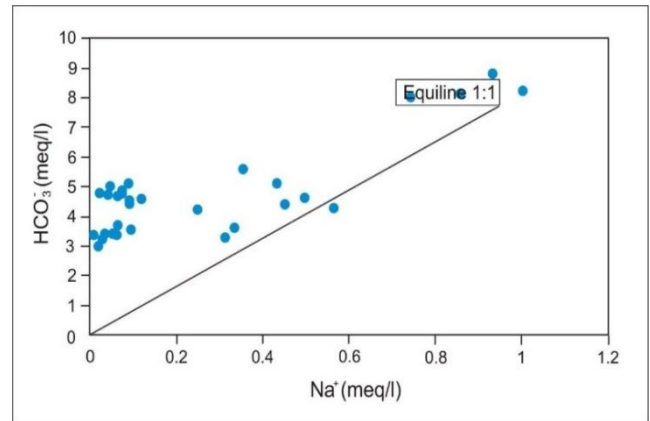
When halite dissolution is the dominant hydrogeochemical process, sodium and chloride generally exhibit a near-linear relationship along a 1:1 equiline (Elumalai et al., 2023) [1]. Deviations from this ratio, particularly where chloride exceeds sodium, suggest additional chloride inputs from non-halite sources, such as carbonate weathering and associated geochemical processes (Shuaibu et al., 2024) [6]. In Fig. 4, 86.67% of the samples plot above the 1:1 equiline, indicating a relative enrichment of Cl⁻ over Na⁺. This trend reflects a substantial influence of carbonate weathering and related water-rock interactions on the groundwater chemistry (Elumalai et al., 2023). Furthermore, in the Na-Ca (Fig. 5) and Na-Mg (Fig.) scatter plots, all samples lie above the 1:1 equiline, indicating a relative depletion of Na⁺ in solution. Such distributions are characteristic of cation-exchange processes, in which Na⁺ in groundwater is adsorbed onto aquifer materials and replaced by Ca²⁺ and Mg²⁺ (Shuaibu et al., 2024; Rajmohan & Elango, 2003).

iii. Bicarbonate and Sodium

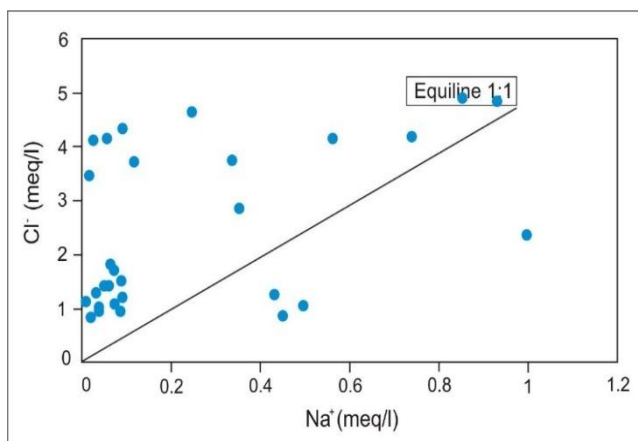
The Na vs. HCO₃⁻ plot (Fig. 7) shows that approximately 70% of the samples occur above the 1:1 equiline, implying comparatively lower HCO₃⁻ concentrations relative to Na⁺. This pattern suggests that sodium enrichment is not primarily governed by carbonate dissolution but is influenced by other geochemical processes such as silicate weathering and ion exchange (Elumalai et al., 2023) [7]. Similarly, the SO₄²⁻ vs. Cl⁻ plot (Fig. 8) indicates that 66.67% of the samples lie above the 1:1 equiline, reflecting relatively lower chloride concentrations. Elevated sulfate levels in groundwater are commonly associated with the oxidation of reduced sulfur species and the dissolution of sulfate-bearing minerals (Shuaibu et al., 2024). Collectively, these ionic relationships highlight the combined roles of weathering reactions and ion-exchange processes in controlling the hydrochemical evolution of the groundwater system.



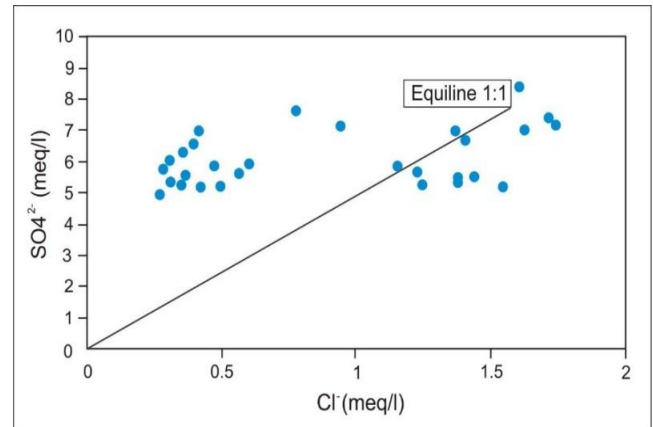
[Fig.3: Scatter Diagram of (Ca + Mg) vs (SO4 + HCO32-)]



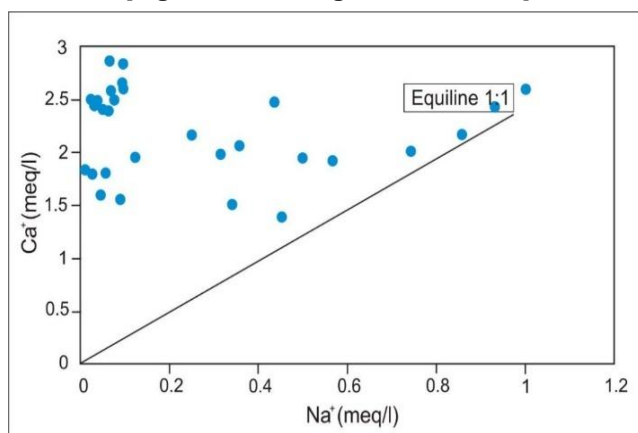
[Fig.7: Scatter Diagram of Na vs HCO3]



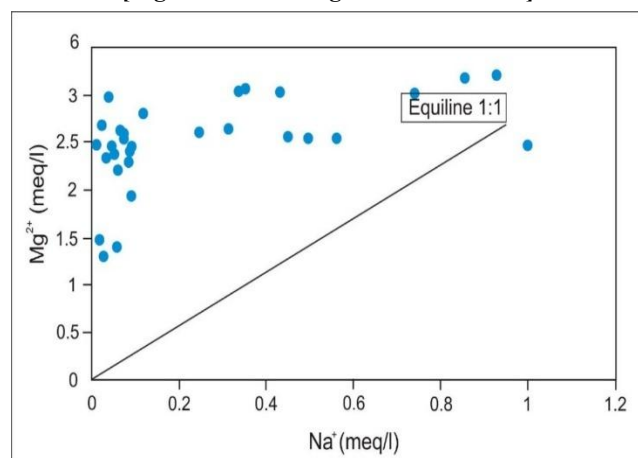
[Fig.4: Scatter Diagram of Na vs Cl]



[Fig.8: Scatter Diagram of SO4 vs Cl]



[Fig.5: Scatter Diagram of Na vs Ca]



[Fig.6: Scatter Diagram of Na vs Mg]

E. Multivariate Statistical Analysis

i. Principal Component Analysis for Groundwater

Principal Component Analysis (PCA) on chemical data indicates four factors that explain about 75.90% of the total variance (Table 3). For factor loadings, a high loading was defined as greater than 0.75, and a moderate loading was determined as 0.40-0.75. Loadings of less than 0.40 were considered insignificant (Abdullahi et al., 2025). The four factors are 1, 2, 3, and 4.

Factor 1 accounts for about 30.16% of total variance and is characterized by moderate loadings. pH, EC, TDS, Mg, NO₃, SO₄ and TH while Na, Mg, and HCO₃ have high loadings. EC and TDS have loadings of 0.614 and 0.611, respectively, and control the overall mineralisation (Ishaku et al., 2011). The bicarbonate has a high loading of 0.812, and its source may be related to CO₂ charge-recharge water (Onoyima et al., 2025). Mg has a high loading; as such, it may be derived from the weathering of mafic minerals. The high pH is related to natural mineralisation. Sodium can be derived from the weathering of plagioclase feldspar, atmospheric dust washed by rainwater, and cation exchange. Low loadings of NO₃ and K rule out the possibility of diffuse contamination from the application of chemical fertilisers such as NPK (Abdullahi et al., 2025). This factor appears to be related to natural mineralisation processes accompanied by increased Na alkalinity.

Factor 2 accounts for about 16.76% of the total variance, Moreover, exhibits moderate positive loadings for EC, TDS, Na, SO₄, and NO₃,



while Cl shows a high positive loading of 0.896. This relationship is evident in the high correlation between TDS and Na ($r = 0.906$). EC and TDS have loadings of 0.719 and 0.715, and control the overall mineralization. The presence of Na in this factor may be due to a cation exchange process by which Na replaces Ca and Mg during the silicate weathering of bedrock materials. This factor accounts for the water salinity and the chemical parameters in the study area.

Factor 3 accounts for 13.269% of the total variance and exhibits high loadings with respect to Ca and moderate loadings with respect to SO₄ and TH. Ca has a loading of 0.912, and the high loading may be attributed to its abundance in the earth crust or as the byproduct of the weathering of feldspars, amphibole, and pyroxenes. Hardness of water is caused by calcium and magnesium ions and can be tied to bedrock geochemistry (Olasehinde et al., 2015).

Factor 4 accounts for 11.472% of the total variance and exhibits moderate loadings of K and Fe. Moderate K can be attributed to fertiliser application. Factor 3 could be interpreted as a redox reaction involving the reduction of ferric iron and the diffused form of contamination following the application of chemical fertilisers such as NPK.

ii. Hierarchical Cluster Analysis

The results of the cluster analysis are presented in Figure 9, indicating two distinct clusters. Cluster 1 is subdivided into two sub-clusters, and sub-cluster 1 comprises EC, Mg, Na, and HCO₃. This sub-cluster is related to factor 2 and interpreted as temporary salinity controlled by Cl. The sub-cluster 2 comprises T⁰, H₂S, Fe, Mn, Cl, and NO₃. The cluster is associated with factor 4 and is interpreted as a reduction in ferric iron and a diffuse form of contamination following the

application of chemical fertilisers such as NPK. The second cluster comprised TDS and K. This cluster is related to factors 1 and 3 in the principal component analysis and interpreted as natural mineralization processes accompanied by increased Na alkalinity and rock-water interaction.

iii. Correlation Analysis

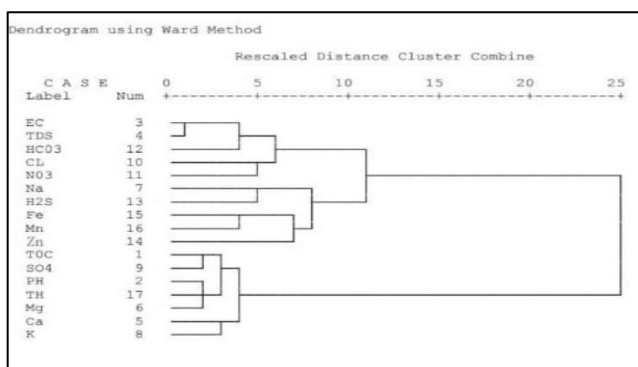
According to (Shuaibu et al., 2024), Samples showing correlation coefficients of $r > 0.7$ are considered to be strongly correlated, $r < 0.5$ are deemed weak, whereas $r > 0.5-0.7$ shows moderate correlation. The strong-to-perfect correlation between the chemical parameters indicates a common source.

Table III: Principal Component Analysis (PCA) Component Matrix

Parameters	Component			
	1	2	3	4
Temperature	0.828	0.033	0.151	-0.234
Ph	0.918	-0.034	-0.063	-0.164
EC	0.614	0.513	-0.164	0.071
TDS	0.611	0.519	-0.151	0.059
Calcium	-0.067	0.052	0.912	0.08
Magnesium	0.813	-0.156	-0.18	0.134
Sodium	0.793	0.47	-0.071	-0.033
Potassium	0.007	-0.257	-0.03	0.656
Sulfate	0.480	0.453	0.438	-0.194
Chloride	-0.015	0.896	0.099	0.064
Nitrate	0.22	0.425	-0.119	0.234
Bicarbonate	0.812	0.241	0.154	-0.186
Hydrogen sulphide	0.078	0.879	0.134	-0.094
Zinc	0.318	0.033	-0.694	0.415
Iron	-0.451	0.259	0.247	0.625
Total Hardness	0.637	0.047	0.698	0.084
% of Variance	30.16	16.76	13.269	11.472
Cumulative %	31.385	50.128	64.417	74.829

Table IV: Correlation of Chemical Parameters in the Study Area

	T°C	Ph	EC	TDS	Ca	Mg	Na	K	SO ₄	Cl	NO ₃	HCO ₃	H ₂ S	Zn	Fe	Mn
Temp.																
pH	0.731															
EC	0.504	0.609														
TDS	0.508	0.605	0.999													
Ca	-0.003	-0.166	-0.094	-0.082												
Mg	0.566	0.844	0.469	0.459	-0.333											
Na	0.668	0.644	0.907	0.906	-0.081	0.511										
K	-0.238	-0.136	-0.116	-0.127	-0.053	0.142	-0.056									
SO ₄	0.550	0.400	0.385	0.393	0.276	0.238	0.559	-0.158								
Cl	-0.047	0.022	0.382	0.386	0.088	-0.04	0.336	-0.071	0.396							
NO ₃	0.241	0.087	0.239	0.239	0.024	0.058	0.274	0.015	0.240	0.322						
HCO ₃	0.888	0.780	0.674	0.677	0.061	0.589	0.813	-0.181	0.630	0.188	0.302					
H ₂ S	0.094	0.099	0.380	0.385	0.083	0.021	0.417	-0.167	0.527	0.854	0.308					
Zn	0.048	0.271	0.319	0.302	-0.546	0.393	0.222	0.19	-0.124	-0.076	0.470					
Fe	-0.353	-0.353	-0.178	-0.179	0.253	-0.375	-0.282	0.138	-0.074	0.230	-0.002					



[Fig.9: Dendrogram for Groundwater Grouping Parameters]

IV. CONCLUSION

From the field and laboratory investigations conducted in this study, the following conclusions can be drawn: The Pariya area lies within the Upper Benue Trough (Yola arm) and is underlain by the Bima Sandstone and alluvial deposits. Water Quality Index (WQI): The WQI assessment for drinking purposes indicates that most water sources fall within the “good” quality category (grade B), with few locations exhibiting “poor” to “inferior” quality (grades D and E). Hydrochemical Facies: Piper

trilinear diagram reveals two dominant water types—Ca-Mg-HCO₃ and Ca-Mg-SO₄-Cl—indicating the influence of aluminosilicate dissolution and reverse cation exchange. Multivariate Analysis: Principal Component Analysis (PCA) and Hierarchical Cluster Analysis (HCA) reveal that the major controlling factors of water chemistry include natural mineralization processes, Na-induced alkalinity, temporary salinity, weathering, rock-water interactions, water hardness due to Ca²⁺ and Mg²⁺, and redox reactions involving Fe²⁺/Fe³⁺ transformations. Additionally, diffuse contamination from the use of chemical fertilizers such as NPK contributes to minor variations in water chemistry.

V. RECOMMENDATION

Continuous monitoring of groundwater quality is recommended to detect potential contamination from anthropogenic activities, especially agricultural runoff and domestic waste disposal. Efforts should be made to promote sustainable groundwater management practices that minimise pollution risks. Future studies should integrate isotopic and geostatistical techniques to better understand recharge processes and the spatial variability of groundwater quality across the Yola Arm. Public awareness programs should also be encouraged to educate local communities on the importance of protecting groundwater resources.

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REFERENCES

1. Elumalai, V., Rajmohan, N., Sithole, B., Li, P., Uthandi, S., & van Tol, J. (2023). Geochemical evolution and the processes controlling groundwater chemistry using ionic ratios, geochemical modelling, and chemometric analysis in the Umlathuze catchment, KwaZulu-Natal, South Africa. *Chemosphere*, 312, 137179. DOI: <https://doi.org/10.1016/j.chemosphere.2022.137179>
2. Shuaibu, A., Kalin, R. M., Phoenix, V. R., & Lawal, I. M. (2024). Geochemical evolution and mechanisms controlling groundwater chemistry in the transboundary Komadugu–Yobe Basin, Lake Chad region: An integrated approach of chemometric analysis and geochemical modelling. *Journal of Hydrology: Regional Studies*, 49, 102098. DOI: <https://doi.org/10.1016/j.ejrh.2024.102098>
3. Onoyima, C. C., Okpanachi, C. B., & Akoji, J. N. (2025). Hydrogeochemical characterization and groundwater quality assessment of Mariri Aquifer, Kano, Nigeria. *Journal of Agriculture and Environment for International Development*, 119(1), 469–486. DOI: <https://doi.org/10.36253/jaeid-17814>
4. Aliyu, M., Haruna, A. I., Maigari, A. S., Abubakar, A., & Sadiq, I. M. (2024). Groundwater quality assessment for residential and irrigation purposes: A case study of Futuk and environs, Northern Benue Trough, Nigeria. *FUDMA Journal of Sciences*, 8(3), 450–461. DOI: <https://doi.org/10.33003/fjs-2024-0803-2582>
5. Abdullahi, I. M., Abubakar, L., Saidu, G., & Yusuf, H. (2025). Hydrogeochemical characterization of groundwater using WQI and multivariate statistical analysis in Binji town and environs, Sokoto Basin, Nigeria. *Applied Water Science*, 15, 33. DOI: <https://doi.org/10.1007/s13201-025-02358-9>
6. Shuaibu, A., Kalin, R. M., Phoenix, V. R., Lawal, I. M., & Abdullahi, A. (2024). Hydrogeochemistry and Water Quality Index for groundwater sustainability in the Komadugu–Yobe Basin, Sahel Region. *Water*, 16(4), 601. DOI: <https://doi.org/10.3390/w16040601>
7. Kanu, O. P., Ugwoha, E., Udeh, N. U., & Amah, V. (2023). Groundwater quality assessment in Aba using WQI and GIS techniques. *Asian Journal of Environment & Ecology*, 22(4), 1–12. DOI: <https://doi.org/10.9734/ajece/2023/v22i4503>
8. Iwar, R. T., Utsev, J. T., & Hassan, M. (2021). Assessment of heavy metal and physicochemical pollution loadings of River Benue water using WQI and multivariate statistics. *Applied Water Science*, 11, 124. DOI: <https://doi.org/10.1007/s13201-021-01456-8>

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