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Evaluation of Groundwater Quality Using Multivariate Statistical Techniques, in Dashen Area, North Eastern Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. Author JMI designed the study, performed the statistical analysis, wrote the protocol. Author BAA wrote the first draft of the manuscript, managed some literature searches and performed part of the statistical analysis and Author AJDP carry out the field work survey of the study and some literature searches. All authors read and approved the final manuscript.

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ABSTRACT

The aim of this research is to assess groundwater quality of Dashen and environs for irrigational and domestic purposes using multivariate techniques. Twelve water samples were collected from boreholes and hand-dug wells. The water samples were analysed for major cations: Na^+, Ca^{2+}, K^+, Mg^{2+} and anions: Cl^-, HCO_3^-, SO_4^{2-} and CO_3^{2-}. The order of abundance of the cations concentration is in order of* Ca^{2+}> Mg^{2+}> K^+> Na^+ while those of the anions are HCO_3^-> Cl^->SO_4^{2-}>CO_3^{2-}. The important constituents that influence the water quality for irrigation such as Electrical Conductivity (EC), Total Hardness (TH), Total Dissolved Solids (TDS), Sodium Adsorption Ratio (SAR), Magnesium Ratio (MR), Percentage Sodium (%Na), Permeability Index (PI), Kelley Ratio (KR), Residual Sodium Bicarbonate (RSBC), and Soluble Sodium Percentage (SSP) were assessed and

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compared with standard values. The values of TH (21.4 – 53.3 mg/l), EC (54 – 383 µS/cm), %Na (3.0 – 9.5%), SSP (3.0 – 9.5%), MR (40.1 – 48.9%), KR (0.003 – 0.067 meq/l), RSBC (-1.6 – 1.9 meq/l) and SAR (0.01 – 0.2 meq/l) were found to be within the safe limits and thus suitable for irrigation purposes. Permeability Index (41.5 – 100.7%) and total dissolved solids (80 – 580 mg/l) range from best quality water to water involving hazards. Piper diagram classified water in the study area as Ca^{2+}- Mg^{2+}- HCO_3^- facies. The multivariate statistical analysis using PCA and HCA identified diffused form of contamination, leaching of bed rock geochemistry, salinity, natural mineralization and anthropgenic contamination, as the major processes controlling the groundwater chemistry. The overall water quality index indicates that water is suitable for human consumption.

Keywords: Groundwater quality; dashen; domestic; irrigation; boreholes; hand-dug wells.

1. INTRODUCTION

Water is the most important resources without which life would be non-existent [1]. It is because of the importance of water that its management will continue to be a major issue with impact on our lives and that of our planet earth. Groundwater is widely used for irrigation in all parts of the world including Nigeria. Because of its importance to irrigation, water quality has to be ensured such that it does not retard the productivity of plants. Water quality for irrigation depends on the concentration of major ions (cations and anions). If the groundwater is contaminated with toxic compounds (metals or pesticides, etc.) it could contaminate both the soil and the plants. The major ions when in high or low concentration may affect agricultural production [2]. Agricultural activities are the main occupation of the inhabitants of the study area, which makes it imperative to ensure the quality and safety of groundwater for irrigational purposes.

Water is life; therefore, there is need for water to be of good quality for irrigation and domestic purposes. The main sources of water supply in the study area are the seasonal streams, ponds, hand-dug wells and hand-pump boreholes. Irrigational activities are carried out without consideration of the chemistry of water as it affects agricultural productivity. Low productivity rate and stunted growth of agricultural plants are some of the problems associated with water quality used for irrigation [3]. Chemical parameters in groundwater are important tool to assess the suitability for various uses, e.g. for domestic and irrigation purposes [4,5].

The previous studies showed that the groundwater quality is influenced by both natural and anthropogenic activities [6]; groundwater contamination is due to the irrigation activities in the area [7]; the area is characterized by low sodic water and nitrate due to fertilizer application, hence, the water is largely suitable for irrigation and domestic purposes [8]; and that anthropogenic activities like river bed mining, disposal of treated and untreated waste effluents from industries along with agricultural wastes may result in deterioration of water quality [9]. This research assesses groundwater quality of Dashen and environs for irrigational and domestic purposes using multivariate techniques.

2. STUDY AREA

The study area is located between longitudes 12°06′E to 12°10′E and latitude 8°32′N to 8° 36′ N (Fig. 1) and covers an area of about 55 km^2. The area is bounded to the west by the boundary between Nigeria and Cameroon.

The study area has a tropical climate, with rainy and dry seasons. The rainy season commences from April and ends in October, the average rainfall is about 197 mm [10]. The dry season starts in November and ends in April. The area has a maximum temperature of 42.2℃ and a minimum temperature of 15℃ [10]. The vegetation in the study area is thick with tall grasses and trees, constituting the Guinea Savannah Zone. The area is a low land region characterized by outcrops around Lamsel, Bakari and Nyibango (Fig. 1). The highest elevation in the area is about 553.9 m and it is located between Bakari and Lamsel. Other parts of the study area are low lying with elevation of about 426.7 m. the drainage pattern is controlled by rock types, and the streams in the area flow from southeast towards northwest direction (Fig. 1).

3. METHODOLOGY

Topographic map (Jada SW sheet 217) was collected from the Upper Benue River Basin Development Authority Yola, Adamawa State. The topographic map was used as base map.

The topographic map was extracted and digitized using arch GIS 9.2. Geologic field mapping was carried out using traversing method.

Ten water samples were collected from hand-dug wells and boreholes (Fig. 1). The type of sampling technique employed was random sampling. One litre plastic containers were used to collect the water samples.

Samples were collected from the discharge of existing wells such as boreholes and hand-dug wells, 3 buckets of water were drawn before the sample was taken on the fourth one. The containers were rinsed with the water to be sampled before samples were taken. The coordinates of each sample point was taken before samples were collected. Samples were properly labelled immediately the sample is collected. Field parameters such as pH, EC and TDS were determined in the field using Oyster pH/Conductivity meter. Temperature was measured in the field using Technel U.S.A model PHS-25.

Plastic containers were used for the sample collection. A plastic cooler with ice block was used for sample preservation. Bicarbonate and carbonate were also determined in the field using EDTA Titrimetry (HACH digital titrator). Sodium, magnesium, calcium potassium, sulphate and chlorine were measured by UV-Visible spectrophotometry using a 2400 HACH digital spectrometer.

The chemical indices used in the evaluation of groundwater quality for irrigation in Dashen and environs include; Sodium Adsorption Ratio (SAR), Residual Sodium Carbonate (RSC), Percentage Sodium (%Na), Permeability Index (PI), Kelly Ratio (KR), Total Hardness (TH), Electrical Conductivity (EC), Total Dissolved Solids (TDS), Soluble Sodium Percentage (SSP) and Magnesium Ratio (MR). The hydraulic head was calculated by subtracting depth to water level from elevation [11]. The values obtained were subjected to GIS software using Inverse Distance Weighted to obtain the hydraulic head distribution of the study area.

The following equations were used for the calculation of chemical indices.

The SAR was computed using the equation:

$$SAR = \frac{Na^{2+}}{\left[Ca^{2+} + \frac{Mg^{2+}}{2}\right]^{½}} \quad (1)$$

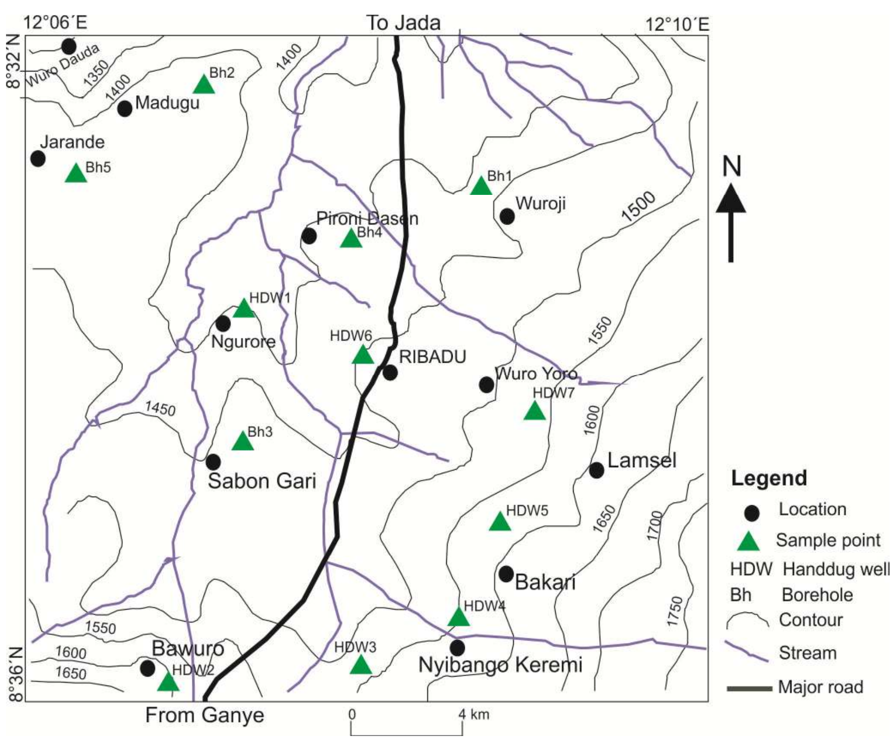

Fig. 1. Topographic map showing sample point distribution in the study area

The RSC was determined from the equation by [12] as follows:

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

The %Na was computed with respect to relative proportion of cations present in water using equation below.

$$\%Na = \frac{Na^+ + K^+}{Ca^{2+} + Mg^{2+} + K^+ + Na^+} X\,100 \quad (3)$$

Sodium measured against calcium and magnesium was considered by [13] for calculating KI as:

$$KI = \frac{Na^+}{Ca^{2+} + Mg^{2+}} \quad (4)$$

Doneen [14] evaluated the suitability of water for irrigation based on PI using the equation below:

$$PI = \frac{Na^+ + \sqrt{HCO_3^-}}{Ca^{2+} + Mg^{2+} + Na^+} X\,100 \quad (5)$$

Paliwal [15] developed an index for computing the MR using the following equation:

$$MR = \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} X\,100 \quad (6)$$

The SSP was computed using [16] equation.

$$SSP = \frac{Na^+ + K^+}{Ca^{2+} + Mg^{2+} + K^+} X\,100 \quad (7)$$

where all the concentrations of ions are expressed in meq/l

3.1 Geology and Hydrogeology of the Study Area

A detailed geologic mapping exercise was carried out using traversing method. The study area was found to be underlained by Precambrian rocks (Fig. 2). The rocks identified were the older granite which range from fine to coarse grain and highly foliated. The coarse grain granite underlay the Southwest part of the study area while the fine and medium grain granites dominate the western and northern parts of the study area (Fig. 2). Other rock types observed were mylonite and gneiss. The mylonite is localized along a northwest to southeast striking normal fault. Gneiss is foliated and it underlays the southeastern region of the study area (Fig. 2).

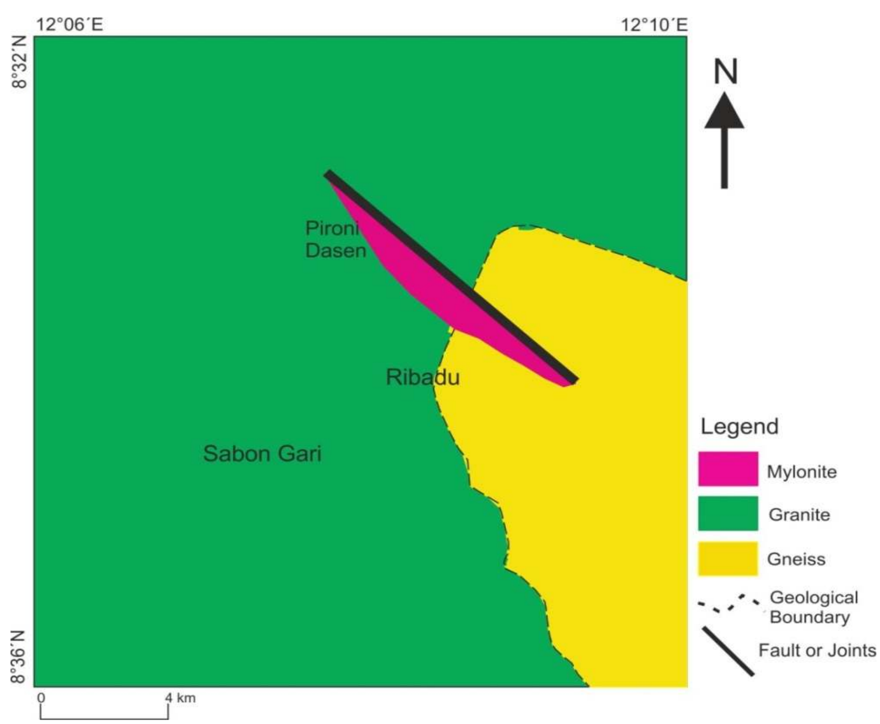

Fig. 2. Geologic map of the study area

Yields and depth of boreholes in the study area could not be obtained due to lack of data. The yields of boreholes in the area can also be comparable to borehole yields in the basement complex areas of Nigeria [17]. [18] stated that borehole yields in Nigerian basement complex rocks range from 1 l/s to 2 l/s, and up to 4 l/s in fractured zones.

Groundwater flows from Bawuro in the southwest and flows towards Sabon Gari; from Bakari towards the south and towards Sabon Gari. Other flow zones take place from Ribadu towards Sabon Gari and Wuroji, Sabon Gari and areas that lie around Nyibango Keremi (Fig. 3).

The recharge areas occur around Bakari in the southeast, Ribadu at the central portion of the study area and Bawuro in the extreme end of the southweatern part of the study area. The discharge areas occur around Wuroji in the northern part, sabongari in the western part and areas occurring between Nyibango Keremi and Bawuro in the study area.

3.2 Multivariate Statistical Analysis

The statistical analysis was applied on standardized data. This is to avoid misclassification arising from the different order of magnitude of values and variable of the parameters analysed [19].

3.2.1 Pearson correlation

Pearson correlation coefficient commonly used to measure the strength of a linear relationship between two variables of data [20]. According to [21] samples showing correlation of r>0.7 are considered to be strongly correlated, whereas r>0.5 – 0.7 shows moderate correlation. The strong correlation is an indication of common source or origin. For the water parameters in the study area the correlations between variables were computed using SPSS statistics software (Version 16.0).

3.2.2 Principal Component Analysis (PCA)

Principal component analysis (PCA) is an orthogonal linear transformation that transforms the variables to a new coordinate system. PCA provides an objective way of finding indices of variance so that the variation in the data can be accounted for as concisely as possible [22]. PCA of the variables was performed using SPSS Software to extract significant components. Factor analysis can be utilized to examine the underlying patterns or relationship for a large number of variables and summarize information

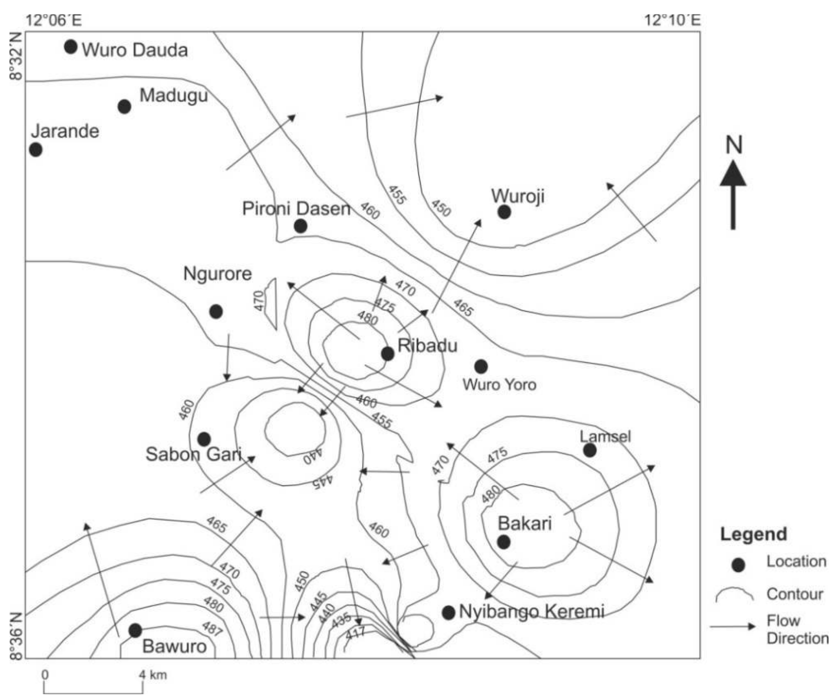

Fig. 3. Hydraulic head distribution map of the study area

in a smaller set of factors or components for prediction purposes [23]. The total number of factors generated from a typical factor analysis indicates the total number of possible sources of variation in the data [24]. [25], classify factor loadings into 'strong' (>0.75), moderate (0.75-0.50) and weak (0.50 – 0.30).

3.2.3 Hierarchical Cluster Analysis (HCA)

Cluster analysis is used to find true group of data in parameters. In clustering, the objects are grouped in such a way that similar objects fall into the same class [26]. Hierarchical clustering group the most similar observations and the levels of similarity at which observations are merged are used to construct a dendrogram. The dendrogram can be broken at different levels to yield different clusters of the data set [27]. The HCA according to [28] with Squared Euclidean distances was applied to detect multivariate similarities in groundwater quality. The Ward's method with Squared Euclidean distance as dissimilarity measure has been found to provide meaningful dendrogram of clusters measured with a rescaled distance [27]. In this study, a customized space distance was used. A low distance shows the two objects are close together, whereas a long distance indicates dissimilarity [23].

3.3 Water Quality Index Calculation

The water quality index (WQI) is used to access the influence of natural and anthropogenic activities based on the important parameters on groundwater chemistry [29,30]. To compute the WQI, the weight was assigned to the physic-chemical parameters according to the parameters' relative importance in the overall quality of water for drinking water purposes. The weight ranges from 1 to 5. The maximum weight of 5 was assigned for TDS, 4 for pH, EC, SO_4, 3 for HCO_3, TH and Cl, 2 for Ca, Na, K and 1 for Mg [6]. The relative weight is computed from the equation below.

$$W_i = w_i / \sum_{i=1}^{n} w_i \tag{8}$$

where W_i is the relative weight, w_i is the weight of each parameter, 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 [31] and multiplied by 100.

$$q_i = (C_i/S_i)x100 \tag{9}$$

where q_i is the quality rating, C_i is the concentration of each chemical parameter; S_i is the World Health Organization Standards for each chemical parameter in milligrams per litre according to the [31] 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.

$$SI_i = W_i \text{ x } q_i \tag{10}$$

$$WQI = \sum SI_i \tag{11}$$

where SI_i is the sub-index of ith parameter, qi is the rating base on concentration of ith parameter, n is the number of parameters [30].

3.4 GIS Geo Data Base

The geo-database was used to generate the spatial distribution maps of the chemical indices using the Inverse Distance Weighted (IDW) method. IDW is an interpolation technique in which interpolated estimates are made based on values at nearby locations weighted only by distance from the interpolation location [17,32]. IDW method is based on the assumption that the value of an attribute z at some unvisited point is a distance weighted average of data points occurring within a neighbourhood or window surrounding the unvisited point [33]. The unknown value is estimated by the equation;

$$\hat{Y}(S_o) = \sum_{i=1}^{n} \lambda_1 Z(S_i) \tag{12}$$

where, $\hat{Y}(S_o)$ is the estimated value for an un-visited sampled location (S_o), n is the number of measured sample points surrounding the prediction location, λ_1 is the weight for each measured point, and $Z(S_i)$ is the observed value at location (S_i). The weight λ_1 is calculated as follows:

$$\lambda_1 = \frac{d_{io}^{-\rho}}{\sum_{i=o}^{n} d_{io}^{-\rho}} \tag{13}$$

where,

$$\sum_{i=1}^{n} \lambda_1 = 1 \tag{14}$$

The weight is reduced by a factor ρ, as the distance increases, and d_{io} is the distance between the predictions S_o and each of the measured location Si. Weighting of the sampled locations highly depends on the power parameter ρ, meaning that when distance increases the weight decreases exponentially. IDW belongs to the category of local deterministic methods of interpolation [34].

4. RESULTS AND DISCUSSION

The complete data set is presented in Table 1 and the summary in Table 2. The physicochemical parameters of the groundwater quality data were statistically analysed and the results are presented in form of minimum, maximum and mean (Table 2). The order of abundance of the cations concentration is in the order of $Ca^{2+}>Mg^{2+}>K^{+}>Na^{+}$ while those of the anions are $HCO_3^{-}>Cl^{-}>SO_4^{2-}>CO_3^{2-}$.

High value of SAR means that sodium in the water may replace calcium and magnesium ions in the soil, potentially causing damage to the soil structure [35]. The SAR values in the study area (Table 3) are low range from 0.01 to 0.16 meq/l and therefore water can be used for irrigation purposes according to [36] standard. The RSC values range from -1.58 to 2.281 meq/l with an average value of 0.93 meq/l (Table 3). EC values of the study area range from 54 to 383 μS/cm with an average value of 136.92 μS/cm (Table 3). According to [6] the EC values in the study area indicate water of excellent to good quality for irrigation purposes. Sabon Gari, Bakari and Wuroji are the areas within the study area where EC is above 250 μS/cm (Fig. 4), which indicate water of good to doubtful quality for irrigation (Table 4).

The TH values in the study area range from 21.44 to 53.28 mg/l with an average value of 34.44 mg/l (Table 3). According to [37] standards, the groundwater in the study area falls in the category of soft water which is suitable for irrigation purposes (Table 4). The TDS values in the study area range from 80 to 580 mg/l with an average value of 205.83 mg/l (Table 3). Based on [38] standards the water is of best quality to water involving hazard for irrigation. The %Na values obtained in the study area range from 3.038 to 9.469%, with an average value of 6.45% (Table 3).

Fig. 4. Spatial distribution of electrical conductivity in the study area

Table 1. Measured ions and calculated parameters

ID	K^+ meg/l	Mg^{2+} meg/l	Na^+ meg/l	Ca^{2+} meg/l	$SO4^{2-}$ meg/l	$CO3^{2-}$ meg/l	Cl^- meg/l	HCO^{3-} meg/l	pH	Temp ℃	SAR %	RSC meg/l	EC µS/cm	TH meg/l	TDS meg/l	%Na %	KI meg/l	PI %	MR %	SSP %
HDW 1	0.027	1.13	0.09	1.25	0.438	0.033	0.51	3.26	4.91	29.67	0.08	0.923	83	29.12	125	4.739	0.038	77.02	47.47	4.739
HDW 2	0.101	1.16	0.18	1.54	0.431	0.053	1.18	3.43	5.1	27.81	0.16	0.783	201	31.99	297	9.469	0.067	70.62	43.03	9.469
HDW 3	0.077	1	0.01	1.35	0.45	0.047	0.42	3.07	5.9	27.96	0.01	0.762	62	28.12	97	3.489	0.003	74.57	42.45	3.489
HDW 4	0.127	1.28	0.09	1.66	0.412	0	0.37	1.98	5.6	21.26	0.07	0.957	54	32.73	80	6.841	0.03	49.42	43.45	6.842
HDW 5	0.157	1.98	0.23	2.1	0.564	0.153	1.61	6.02	6.17	26.63	0.16	2.084	326	52.79	490	8.552	0.055	62.12	48.57	8.552
HDW 6	0.149	1.42	0.05	2.03	0.519	0.097	0.49	4.28	4.49	26.98	0.04	0.929	73	35.2	107	5.536	0.015	60.62	41.08	5.536
HDW 7	0.177	1.1	0.05	1.14	0.481	0	0.48	3.57	6.73	29	0.04	1.335	77	27.31	115	9.021	0.02	84.74	48.91	9.021
BH 1	0.049	1.26	0.08	1.4	0.475	0	0.65	3.54	5.5	28.33	0.07	0.883	116	32.01	172	4.731	0.031	71.68	47.22	4.731
BH 2	0.118	1.24	0.17	1.65	0.269	0.07	0.7	5.1	5.9	27.96	0.14	2.281	139	33.69	215	9.071	0.059	79.42	42.95	9.071
BH 3	0.055	0.89	0.01	1.03	0.501	0.037	4.48	3.72	6.12	27.01	0.01	1.843	68	21.44	101	3.038	0.003	100.7	46.37	3.038
BH 4	0.133	1.39	0.1	1.88	0.346	0	0.37	1.69	6	24.66	0.08	1.58	61	35.65	91	6.573	0.029	41.49	42.61	6.573
BH 5	0.205	2.08	0.15	3.11	0.711	0.253	2.18	6.82	6.43	27.03	0.09	1.878	383	53.28	580	6.347	0.028	51.64	40.12	6.347
Average	0.115	1.33	0.10	1.68	0.466	0.062	1.12	3.87	5.738	27.025	0.079	1.353	136.917	34.444	205.833	6.451	0.032	68.670	44.519	6.451

Table 2. Summary of groundwater quality data in the study area

Parameters	Minimum	Maximum	Mean
pH	4.49	6.73	5.7375
EC (µS/cm)	54	383	136.92
TDS (mg/l)	80	580	205.83
TH (mg/l)	21.44	53.28	34.444
Calcium (mg/l)	20.54	62.2	33.557
Magnesium (mg/l)	21.32	50.01	31.832
Sodium (mg/l)	0.19	5.17	2.2817
Potassium (mg/l)	1.06	8	4.4742
Bicarbonate (mg/l)	103	416	236.25
Sulphate (mg/l)	12.91	34.11	22.388
Carbonate (mg/l)	0	7.6	1.8583
Chloride (mg/l)	12.93	76.26	27.555

Table 3. Chemical indices calculated

Locations	SAR meq/l	RSC meq/l	EC µS/cm	TH meq/l	TDS meq/l	%Na %	KI meq/l	PI meq/l	MR %	SSP %
HDW 1	0.08	0.923	83	29.12	125	4.739	0.038	77.02	47.47	4.739
HDW 2	0.16	0.783	201	31.99	297	9.469	0.067	70.62	43.03	9.469
HDW 3	0.01	0.762	62	28.12	97	3.489	0.003	74.57	42.45	3.489
HDW 4	0.07	-0.957	54	32.73	80	6.841	0.03	49.42	43.45	6.842
HDW 5	0.16	2.084	326	52.79	490	8.552	0.055	62.12	48.57	8.552
HDW 6	0.04	0.929	73	35.2	107	5.536	0.015	60.62	41.08	5.536
HDW 7	0.04	1.335	77	27.31	115	9.021	0.02	84.74	48.91	9.021
BH 1	0.07	0.883	116	32.01	172	4.731	0.031	71.68	47.22	4.731
BH 2	0.14	2.281	139	33.69	215	9.071	0.059	79.42	42.95	9.071
BH 3	0.01	1.843	68	21.44	101	3.038	0.003	100.7	46.37	3.038
BH 4	0.08	-1.58	61	35.65	91	6.573	0.029	41.49	42.61	6.573
BH 5	0.09	1.878	383	53.28	580	6.347	0.028	51.64	40.12	6.347
Average	0.08	0.93	136.92	34.44	205.83	6.45	0.03	68.67	44.52	6.45

When concentration of sodium ions is high in irrigated water, it reduces the permeability and eventually results in soil with poor internal drainage [39]. The KI values obtained range from 0.003 to 0.067 meq/l, with an average value of 0.03 meq/l (Table 3). According to KI standards by [40], the values fall within the range of water suitable for irrigation purposes. The PI values obtained in the study area range from 41.49 to 100.7%, with an average value of 68.67% (Table 3). The results were correlated with [41] standards and they fall into class I and class II, which imply that the water in the study area are from moderately suitable to unsuitable for irrigation purposes (Table 4). The Permeability Index was plotted in GIS software and the map shows that Ribadu and Nyibango Keremi has the best water for irrigation while water around Lamsel is unsuitable for irrational purposes (Fig. 5).

The MR values obtained in the study area range from 40.12 to 48.91%, with an average value of 44.52% (Table 3). Magnesium maintains equilibrium in most water and it adversely affect crop yield [42, 43]. According to [44] standards for MR, the value obtained implies that water in the study area is suitable for irrigation purposes. The MR in the study area is low in Ribadu and in area between Bawuro and Nyibango Keremi. However, the water is unsuitable for irrigation in Pironi Dasen, Bakari and Bawuro (Fig. 6). The SSP values range from 3.038 to 9.469%, with an average value of 6.45% (Table 3). The values were correlated with [38] standards for SSP; the values fall into class I, meaning the water is suitable for irrigation purposes.

Table 4. Limits of parameter indices for rating groundwater and its suitability in irrigation [6,14,35,37,39,43]

Category	SAR (meq/l)	RSC (meq/l)	EC µS/cm	TH (meq/l)	TDS (meq/l)	%Na (%)	KI (meq/l)	PI (meq/l)	MR (%)	SSP (%)	Suitability for irrigation
I	0-10	<1.25	<250	0-75	200-500	<20	<1	<25	<50	<20	Excellent
II	10-18	1.25-2.5	250-750	75-150	1000-2000	20-40		25-75		20-40	Good
III	18-26	>2.5	750-2000	150-300	3000-7000	40-80				40-80	Fair
Iv	26-100		2000-3000	>300		>80	>1	>75	>50	>80	Poor

Table 5. Correlation of chemical parameters in the study area

	pH	Temp	EC	TDS	TH	Ca	Mg	Na	K	HCO_3	SO_4	Cl	SAR	RSC
pH	1													
Temp	-0.04	1												
EC	0.30	0.11	1											
TDS	0.30	0.11	1.00**	1										
TH	0.21	-0.17	0.87**	0.87**	1									
Ca	0.11	-0.26	0.76**	0.76**	0.90**	1								
Mg	0.21	-0.19	0.85**	0.85**	0.99**	0.91**	1							
Na	0.06	-0.06	0.75**	0.75**	0.73**	0.52	0.66*	1						
K	0.44	-0.28	0.51	0.52	0.65*	0.70*	0.68*	0.37	1					
HCO_3	0.25	0.35	0.84**	0.84**	0.70*	0.62*	0.69*	0.52	0.46	1				
SO_4	0.20	0.11	0.64*	0.64*	0.55	0.56	0.60*	0.05	0.40	0.61*	1			
Cl	0.31	0.05	0.27	0.29	-0.01	0.02	0.03	-0.07	-0.08	0.36	0.43	1		
SAR	-0.06	-0.01	0.62*	0.61*	0.56	0.35	0.49	0.97**	0.22	0.38	-0.13	-0.14	1	
RSC	0.60*	-0.03	0.48	0.48	0.44	0.35	0.45	0.45	0.41	0.59*	0.07	0.47	0.338	1

***Correlation is significant at 0.01 level, *correlation is significant at 0.05 level*

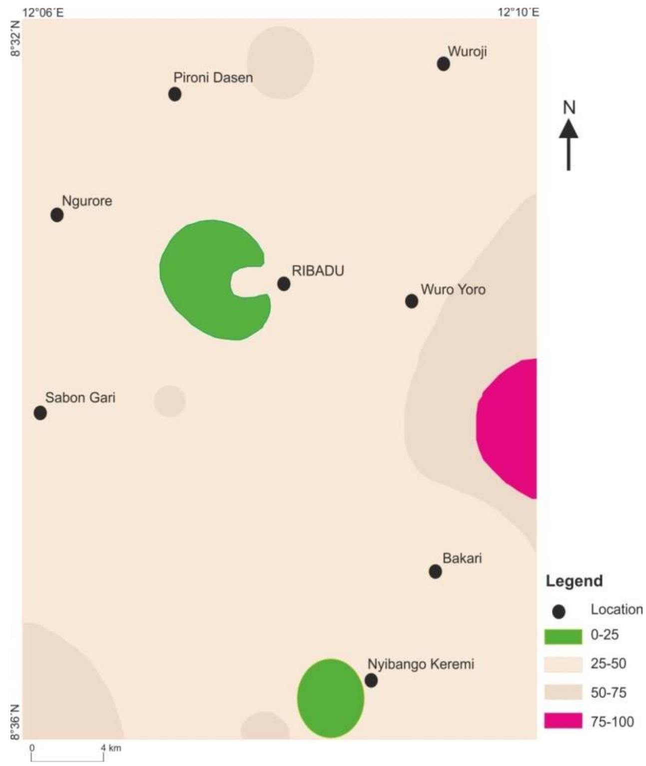

Fig. 5. Spatial distribution of permeability index in the study area

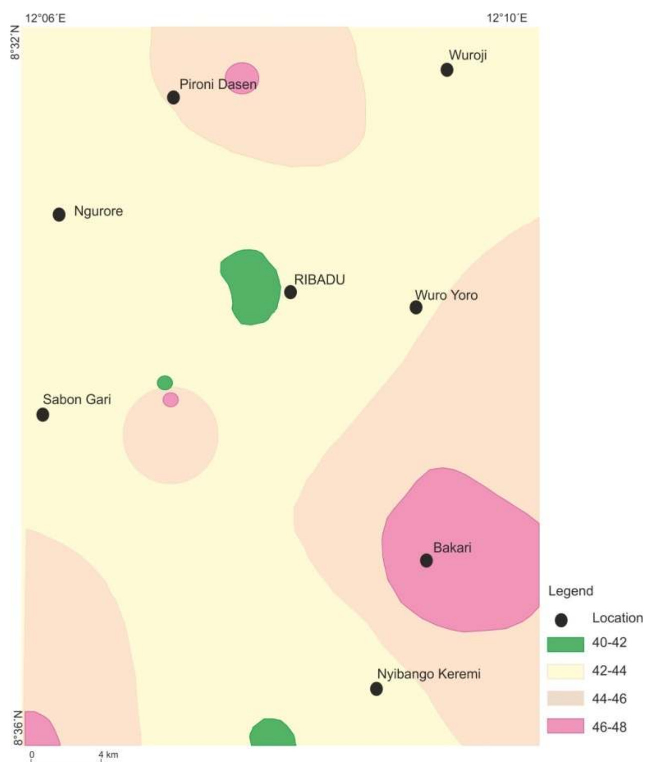

Fig. 6. Spatial distribution of magnesium ratio in the study area

4.1 Multivariate Statistical Analysis

Table 5 shows the statistical correlation for the groundwater parameters of the study area, the parameters are highly correlated. EC with TDS, TH, Ca, Mg, Na and HCO3 are highly positively correlated (Table 3), indicating mineralization is derived from the surrounding [45]. Similarly, Na and SAR are highly positively correlated (Table 4) indicating salinity of the groundwater [46].

Principal Component Analysis (PCA) on chemical data indicates four factors which explain about 87.83% of the total variance (Table 6). Factor 1 account for about 39.65% of total variance and is characterized by strong positive loading with respect to EC, TDS, TH, Ca^{2+} Mg^{2+}, HCO_3^- and SO_4^{2-}. EC and TDS has loadings of 0.818 and 0.817, and control the overall mineralization [17] while TH has loading of 0.853 and is controlled by Ca and Mg. Ca is characterized by strong positive loading as 0.874 and Mg of 0.879. The high loading of Ca and Mg may be attributed to silicate weathering. The bicarbonate has loading of 0.731 and its source could be related to CO_2 charge recharge water [47]. Sulphate having a loading of 0.868 may be derived from the decomposition of organic materials in the area since the sources of SO4 such as gypsum and anhydrite may be unlikely in the area. This underlying relationship is indicated by correlation of measured concentrations of these elements in factor 1 which ranged from r = 0.64 to 1.00 (Table 5). This factor is ascribed as rock-water interaction. This factor is a major factor influencing the water chemistry [48]. Factor 2 accounts for about 20.89% of the total variance, and exhibits strong positive loadings with respect to Na and SAR. The presence of Na in this factor may be due to cation exchange process by which Ca and Mg are replaced by Na ions [49]. The presence of Na may also be due to silicate weathering of bed rock materials. The relationship between Na and SAR is buttressed by strong correlation of 0.97. This factor can be interpreted as salinity of the groundwater [45]. Factor 3 accounts for about 15.79% of the total variance, and is characterized by strong positive loadings with respect to pH and RSC. This relationship is shown by the moderate correlation between pH and SAR as r=0.60. This implies that there is excess of sodium, carbonate and bicarbonate of the alkalinity, which result into increase in salinity of groundwater [50,51]. Factor 3 is interpreted as precipitation of Ca and Mg thereby resulting in increased salinity of the groundwater as buttressed by scattered plots of calcium bicarbonate verses RSC and Sodium bicarbonate verses RSC (Fig. 7). Precipitation of calcium bicarbonate will led to excess of sodium bicarbonate in water which influences high salinity of the water and flocculation of the soil structure, thereby resulting in low permeability of the soil. Factor 4 accounts for about 11.51% of the total variance, has strong positive loading with respect to temperature and negative moderate loading with respect to Potassium. Temperature and potassium have weak negative correlation of r = -0.28 which suggest that the two parameters have different sources. Factor 4 is interpreted as diffused form of contamination following the application of chemical fertilizer such as NPK [49].

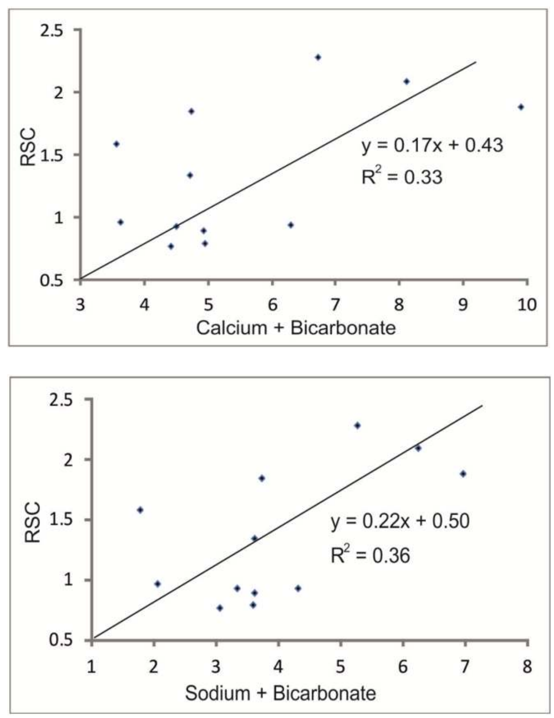

Fig. 7. Scattered diagrams of calcium bicarbonate and sodium bicarbonate verses RSC for the water samples

The hierarchical cluster analysis was used to group the water in the research area. The dendrogram analysis was performed using ward method and the result of parameters indicates two cluster groups (Fig. 8). Cluster 1 comprises of EC, TDS, Cl, Na^+ and SAR this cluster is also related to factor 2. The cluster 1 is interpreted as salinity of the groundwater [45,52]. The second cluster has close similarities with respect to Mg^{2+}, TH followed by pH and Temperature with Ca^{2+}, HCO_3^-, SO_4^{2-}, K^+ and RSC loosely bounded to the cluster. This cluster is interpreted as temporary hardness of the groundwater and precipitation leading to residual bicarbonate hazard [5,52].

The Water Quality Index (WQI) values computed for the study area is presented in Table 7. The computed WQI values indicate that the overall WQI is 30.53. According to [5,6,28], WQI <50 is excellent; 50 to 100 is good water; 100 to 200 poor water; 200 to 300 is very poor water and >300 indicates that water is unsuitable for human consumption. The WQI values obtained is less than 50 which suggest that, the water in the study area is suitable for human consumption.

The water in the study area was sampled and tested for the different major ions, the result was used to plot a piper trilinear diagram (Fig. 9) to characterize and classify the water geochemically. The classification system shows the anion and cation facies in terms of major ion percentage. The result shows that the groundwater samples fall in the field of Ca^{2+} - Mg^{2+} - HCO_3^- type of water. The Ca^{2+} - Mg^{2+} - HCO_3^- is regarded as recently recharge water and its sources are related to atmospheric precipitation and dissolution of silicate minerals [53].

Table 6. Rotation Principal Component Analysis (PCA) loading matrix

Parameters	Component			
	1	**2**	**3**	**4**
pH	0.123	-0.053	**0.831**	-0.201
Temperature	-0.02	0.035	-0.016	**0.852**
EC	**0.818**	0.449	0.255	0.17
TDS	**0.817**	0.449	0.262	0.169
TH	**0.853**	0.432	0.085	-0.202
Calcium	**0.874**	0.213	0.031	-0.295
Magnesium	**0.879**	0.348	0.102	-0.223
Sodium	0.387	**0.906**	0.064	-0.038
Potassium	**0.628**	0.109	0.262	**-0.518**
Bicarbonate	**0.731**	0.284	0.362	0.366
Sulphate	**0.868**	-0.355	0.124	0.227
Chloride	0.151	-0.225	**0.679**	0.386
SAR	0.207	**0.958**	-0.036	0.017
RSC	0.191	0.393	**0.828**	-0.065
% of Variance	39.654	20.885	15.788	11.505
Cumulative %	39.654	60.539	76.327	87.832

Dendrogram using Ward Method

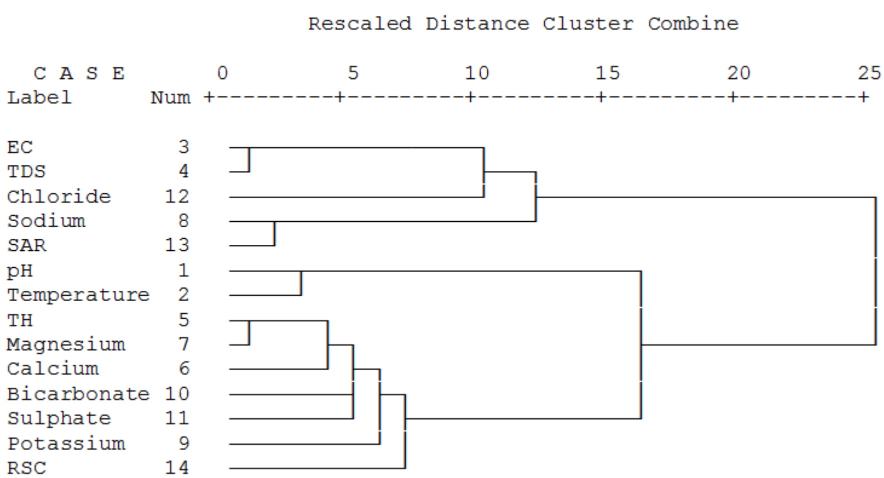

Fig. 8. Dendrogram for the groundwater grouping parameters

Table 7. Computed water quality index for Dashen Area, North Eastern Nigeria

Chemical parameters	WHO (2011)	weight (w_i)	Relative weight (W_i)	q_i	SI
pH	6.5-8.5	4	0.12121	67.50	8.18
EC (µS/cm)	500	4	0.12121	27.38	3.32
TDS (mg/l)	500	5	0.15152	41.17	6.24
TH (mg/l)	200	3	0.09091	17.22	1.57
Calcium (mg/l)	75	2	0.06061	44.74	2.71
Magnesium (mg/l)	50	1	0.03030	63.66	1.93
Sodium (mg/l)	200	2	0.06061	1.14	0.07
Potassium (mg/l)	200	2	0.06061	2.24	0.14
Bicarbonate (mg/l)	500	3	0.09091	47.25	4.30
Sulphate (mg/l)	250	4	0.12121	8.96	1.09
Chloride (mg/l)	250	3	0.09091	11.02	1.00
Total		**33**			**30.53**

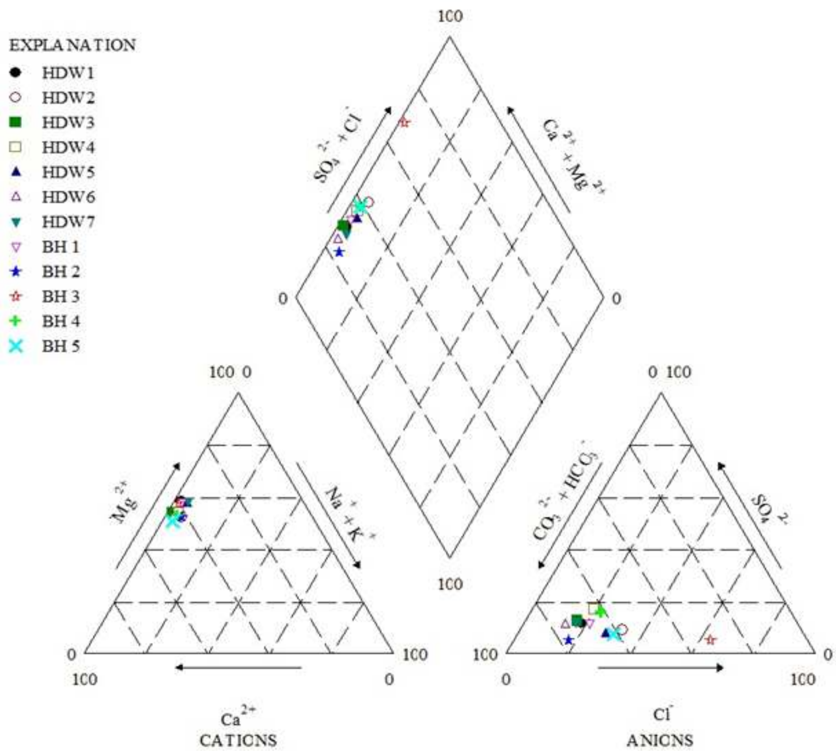

Fig. 9. Piper diagram plot of groundwater samples in the stud area

5. CONCLUSION

The groundwater quality in Dashen and environs has been evaluated for their chemical composition and suitability for irrigational purposes. The order of abundance of cations concentration is Ca^{2+}>Mg^{2+}>K^+ >Na^+ while those of the anions are HCO_3^->Cl^->SO_4^{2-}>CO_3^{2-}. SAR, RSC, Kelly Index, Magnesium Ratio, Percentage Sodium, Soluble Sodium Percentage, EC, TDS, TH and Permeability Index were the indices employed in this research. SAR, RSC, Kelly Index, Magnesium Ratio, Percentage Sodium, Soluble Sodium Percentage, EC, TH were found to be within the safe limits and thus largely suitable for irrigation purposes. The groundwater quality ranges from suitable to unsuitable based on the Permeability Index and Total Dissolved Solid. The groundwater will thus neither cause salinity hazards nor have no adverse effect on the soil properties of the study area. The multivariate statistical analysis using PCA and HCA identified diffused form of contamination, leaching of bed rock geochemistry, salinity, natural mineralization and anthropgenic contamination, as the major processes controlling the groundwater chemistry. The overall water quality index indicates that water is suitable for human consumption. The Piper Trilinear classification for groundwater samples fall in the field of Ca^{2+} - Mg^{2+} - HCO_3^- type of water. It is found from the classification of water samples based on total hardness, and most of the samples are categorized under hard and very hard.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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