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Research Paper

Investigation of Groundwater Pollution in the Central Region, Ghana

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Abstract: Investigating anthropogenic impact on groundwater quality in the Central Region of Ghana has been carried out. The groundwater type include: $CaMgSO_4$, NaCl, $CaMgHCO_3$, and Mixed water. About 82.35% of the total variance was explained by six factors. Factor 1 accounted for 36.28%, Factor 2 for 14.14%, Factor 3 for 12.43%, Factor 4 for 8.90%, Factor 5 for 5.81%, and Factor 6 for 4.79%. EC, TDS, Na^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, TH, Ca^{2+} hardness, and Mg^{2+} hardness were in factor 1. The components of factor 2 were NH_4, PO_4, NO_2, NO_3, and F^-. Turbidity, Mn, Fe, and color were in factor 3. $CaCO_3$ and H_2CO_3 made up factor 4. Factor 5 included CO_3 and pH. Only K was in factor 6. Four clusters were visible using the cluster analysis method. Turbidity, color, pH, EC, TSS, TDS, Na^+, K^+, Ca^{2+}, Mg^{2+}, Fe, NH_4, SO_4, PO_4, Mn, NO_2, NO_3, $CaCO_3$, Ca^{2+} hardness, Mg^{2+} hardness, F^-, $H_2CO_3^-$, and CO_3^{2-} were in Cluster 1. Cl^- and TH were in Cluster 2. Only TDS and only EC were in clusters 3 and 4, respectively. Generally, the groundwater quality was of ''good'' class based on WQI technique. The study found that human activities, seawater intrusion, ion exchange, rock weathering, and evaporation all have an impact on the region's groundwater quality. Anthropogenic practices that have an effect on the quality of the groundwater in the area include the use of agrochemicals on farmland, the spreading of animal waste on farms, galamsey, the lack of hygienic conditions around boreholes, and pit latrines.

Keywords: *Factor Analysis, Cluster Analysis, Correlation Analysis, Groundwater Pollution, GIS, WQI*

Introduction

Globally, about $7x10^{12}$ m^3 of groundwater is extracted annually (Jean-Claude, 1995; NGWA, 2016). This yearly groundwater extraction is used for drinking, domestic, agricultural, industrial purposes etc. Since many chemicals are dissolved into water from the atmosphere, ground surface, and through the subsurface, it does not exist in its purest form. Different rock minerals from the host aquifers dissolve into groundwater because of its relatively low flow rate. Along the flow path, specific ions may be exchanged between the groundwater and the host rocks, changing the chemistry of the groundwater. Through hydro-geochemistry, the assessment of the geology of the aquifer, recharge water, and groundwater suitability for use in a variety of ways can be done. The effects of various anthropogenic activities like mining, farming, improper industrial waste management etc. also have impacts on the chemistry of the groundwater, resulting in a complex hydrochemistry. This implies that the chemistry of groundwater and its general quality are subject to changes in space and time.

The development of technologies in mining, building, agriculture, etc. have improved many aspects of human lives, but not without cost. These activities have impacted on both the amount and quality of the available water resource. For instance, increased irrigation has increased groundwater pollution (Foster *et al.,* 2018). Groundwater overuse for such extensive irrigation objectives has result in seawater near the coastline (Hussain *et al.,* 2019). Increased agriculture, urbanization, and industrial growth have increased nitrate contamination in groundwater (Spalding & Exner, 1993; Galloway *et al.,* 2008). Lack of hygienic conditions around the boreholes has contributed to groundwater contamination (Lapworth et al., 2020). These activities have made the provision of potable water to people in developing countries a very difficult task since even the groundwater needs some level of treatment. For example, the provision of clean water to the populace is a challenge throughout Africa (Singh & Jayaram, 2022). The authors noticed that around 83% of the countries in the study are falling behind in terms of offering simple drinking water solutions. This indicates that most residents of the continent rely on water of lower quality for their water needs.

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In Ghana, drinking water quality is established by a comparison of the concentrations of the water quality parameters to the recommended values set by the Ghana Standard Authority or the WHO (Anku *et al.,* 2009). Groundwater resources play a major role in the sustainable national economic development in Ghana. Therefore, effective management and development of the natural resources have the potential to greatly contribute to the development of the country. This is because Ghanaians use groundwater for domestic, agricultural, industrial, and commercial purposes in addition to drinking (Banoeng-Yakubo *et al.,* 2009). According to estimates, 49% of the Ghanaian population resides in rural areas of the nation and relies on groundwater for drinking, domestic use, and agriculture (GSS, 2010). However, there are challenges associated with the use of groundwater resources in Ghana. People drink groundwater of unknown quality because there is ineffective groundwater quality monitoring. Meanwhile, the quality of groundwater is impacted by a variety of human activities like farming, mining, and poor waste disposal practices.

Geostatistical approaches are frequently used in hydrochemical investigations because they are useful instruments for revealing crucial details about the geographical distribution and the association between the various parameters (Yidana, 2008). Techniques used for displaying, analyzing, and interpreting hydrochemical data include Correlation Analysis, Factor Analysis (FA), and Hierarchical Cluster Analysis (HCA). The literature describes the application of the Cluster Analysis (CA) approach to determine how anthropogenic activities and natural processes affect groundwater chemistry and overall quality (Morel et al., 1996; Yidana, 2008; Banoeng-Yakubo *et al*., 2009).

The aquifer systems in the Central Region are found in both crystalline rocks and sedimentary formations (Fig. 1). As the foundation for socioeconomic development, safe water is a crucial resource for national development (Selmane et al., 2022). Groundwater accessed through boreholes and manually dug wells serves as the main source of water supply for drinking and other purposes in the Region, especially in rural communities (Osiakwan, 2021). It is essential to know the mechanisms that regulate the quality of groundwater. This is because most people drink untreated groundwater, especially those who use hand pumps to draw water from boreholes. The majority of boreholes lack treatment equipment, with the exception of a few hand pumps that have water treatment systems attached and are primarily used to treat excessive Fe and Mn concentrations.

Numerous anthropogenic activities, including galamsey, farming, and improper waste disposal, have recently had an impact on the surface water bodies in the Central Region (Osiakwan, 2021). The surface water bodies are so contaminated, in fact, that some of them are not suited for particular uses. As a result, the groundwater quality issues in the region have become major concerns. There have been studies on the groundwater quality of the region (Ganyaglo et al., 2017; Asante-Annor et al., 2018; Osiakwan *et al.,* 2021; Asare *et al.,* 2022). For example, Ganyaglo *et al*. (2012) applied Principal Component Analysis (PCA) and CA in their studies in Central Region, but their study was limited by the use of only 14 samples which did not fully covered the various geological terrain. Asare et al. (2016) applied factor analysis to study the geochemistry of part of Central Region. Ganyaglo et al. (2017) found that rock weathering is the primary source of the major ions, and that seawater intrusion had a negligible effect on the chemistry of the groundwater. According to Asante-Annor et al. (2018), the region's groundwater has become physico-chemically and microbiologically contaminated as a result of anthropogenic and geogenic activities. Osiakwan et al. (2021) used a combination of hydrogeochemical and geostatistical methods to examine the quality of the groundwater and observed similar pattern of groundwater quality in the Region.

Early studies, however, did not show the spatial variation of the various water quality parameters in the area to reveal how various anthropogenic activities are affecting the quality of the groundwater. In order to characterize groundwater's physicochemical parameters, show how they differ in various geographic locations, pinpoint the mechanisms governing hydrogeochemistry, ascertain the relationships between the various parameters, and ascertain any potential effects of anthropogenic activity in the area this study needed to be conducted. The results of this study are important for decision-makers in the region to effectively manage and protect groundwater resources especially in the area of achieving the Sustainable Development Goal number six (SDG 6).

The analysis of groundwater quality using a Geographic Information System (GIS) is now a standard procedure. This is because it makes it possible to combine data on various aspects of groundwater to facilitate effective decision-making. GIS is also used to close the communication gap between water professionals and non-professionals in order to interpret data on water quality. By using the GIS technique to examine the spatial variation of the various individual groundwater quality parameters, it is easier to comprehend the potential effects of anthropogenic activities on groundwater quality. Geostatistical and GIS-based groundwater quality investigations have the potential to reveal specific information about the groundwater resource of an area. For instance, Aral *et al*. (1996) successfully identified the affected communities, the spatial distribution of the contamination, and the extent of public exposure to contaminated water by using GIS.

Study area

The boundaries of the Central Region are defined by the latitudes 5° 05' 49" & 5° 56' 24" and longitudes 1° 49' 54" & 0° 23' 60". The region is situated in the evergreen and semi-deciduous forest zones of the dry equatorial climate region. Two predominant seasons in the region are the dry and wet seasons. With a typical annual rainfall range of 1000-2000 mm, the dry season runs from December to February while the wet seasons run from May to June as well as September to October. The range of the mean temperature is 24-30ºC which mostly occurs in March and August respectively. The majority of the communities in the region rely heavily on its groundwater resources for their water needs. This is because the reliance on transient surface water, which depends on rainfall for their replenishment, causes the communities to frequently encounter water shortages. Additionally, the majority of surface water bodies are so contaminated that some of them are unsuitable for usable certain usage (Kortatsi, 2007). Due to this, most residents now rely on boreholes fitted with hand pumps to supply their water demands.

The development of groundwater is the most reliable source of effective water supply in the region to accomplish the SDG targets due to the lack of reliable surface water sources. As part of the Small Towns Water Supply initiative, the Community Water and Sanitation Agency provided piped water to a few settlements in the region. The geological map of Central Region is presented in Fig.1. The Kibi-Winneba belt and the Ashanti belt, which are both Early Proterozoic Birimian rocks in Ghana, underlie the Central Region (Leube et al., 1990). The Cape Coast-type biotite granites/gneisses are the primary rock type in the region (Fig.1). Volcaniclastics, schists, amphibolites, sandstone, conglomerate, and shale with mafic dykes are some of the other rocks found in the region. Secondary porosity and permeability, as well as secondary structures like joints, shear zones, folds, fissures, faults, and fractures, are what primarily control the hydrogeology of the area because the region's rocks lack primary porosity and permeability.

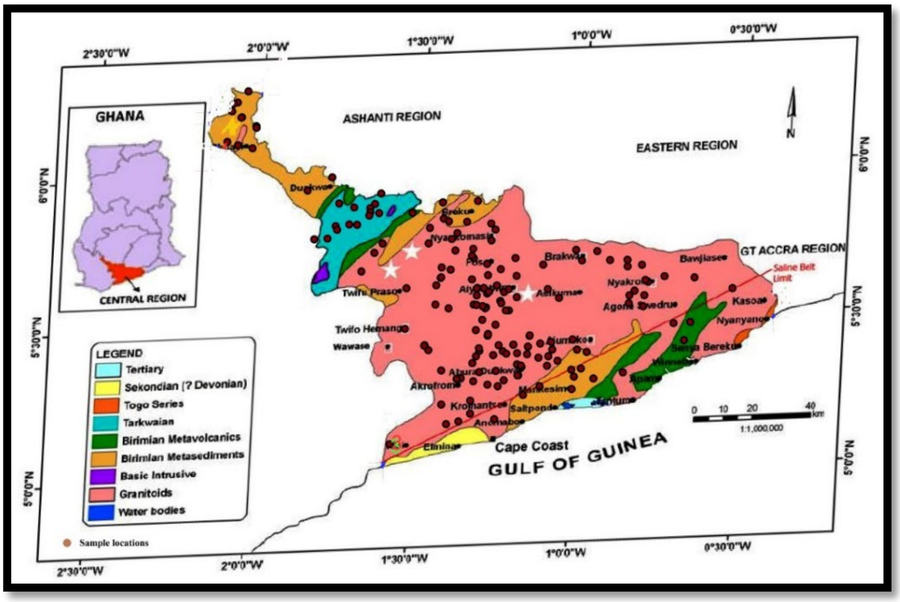


Figure 1: Geology of the Central Region showing sample locations (after Ewusi1 and Kuma, 2010)

Methodology

The Central Regional Office of Community Water and Sanitation Agency (CWSA), Cape Coast, provided the data for this study. A total of 136 borehole sample data made up of physicochemical parameters were obtained from CWSA in November 2020. The data was gathered as a result of various initiatives designed to give target populations access to potable water at different times. The GPS system was used to map the locations of the boreholes before the samples were taken from them in the beneficiary communities. Groundwater samples were taken in 500 ml high-density polyethylene sampling vials for in-lab testing. The samples were typically collected after a protracted pumping test or pumping period. Two different samples were taken for heavy metals analysis and the other physicochemical parameters. The addition of 10 ml of 69% nitric acid preserved the samples used for heavy metal analysis. The field notebook was used to record all necessary field observations and data, and the bottles were labeled to make it simple to identify the samples.

In accordance with the recommendations of WHO (2008) and APHA (1995), pH, TDS and EC were measured in-situ using a portable meter. The samples were kept in an ice chest with ice packs during transportation to the Ghana Water Company Laboratory in Cape Coast for additional analysis. The groundwater samples were examined using the APHA (1995) standards. The probe method was used to examine the physical parameters, including TDS, EC, temperature, and pH. Ion chromatography was used to examine some of the chemical parameters, including F^-, Cl^-, SO_4^{2-}, NO_3^-, NO_2^-, PO_4^-, and CO_3^2. Others, such as Fe, Mn, and Ca^{2+}, were investigated using flame atomic absorption spectrometry (AAS). Hem's (1985) formula was used to convert $CaCO_3$ mg/l to HCO_3^-. The titrimetric method was used to measure total hardness (TH), the photometric method 8006 was used to measure total hardness (TSS), the cobalt standard method was used to measure total suspended solids (TSS), the absorptiometric method was used to measure turbidity, and the electrical conductivity method was used to measure salinity. The flame photometer technique was used to analyze the ions Na^+ and K^+. Ionic balance, which was used to judge the accuracy of the data, was within the 10% range for the samples (Celesceri et al., 1998).

Application of geostatistical techniques

For the procedures to estimate sample parameters and associated error variances at uncertain locations, theoretical variograms that depend on a sill and range must be developed. In this study, thematic maps of the various parameters were made to show their spatial variations. This necessitated the development of various variograms for those parameters due to the wide range of values for the different parameters. To create the maps, all of the parameters apart from CO_3^{2-} were log-transformed.

Application of water quality index

The water quality index makes it easier for people with different professional backgrounds to understand complex water quality data (Yogendra and Puttaiah, 2008). In this study, the components in Table 1 were used to calculate the water quality index using equations (1-4):

a. Assignment of weight (w_i) to the various parameters based on their perceived impact on human health.
b. Relative weight (W_i) calculation using;

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \qquad (1)$$

c. Calculation of quality rating scale (qi) using;

$$q_i = 100 * (\frac{C_i}{S_i}) \qquad (2)$$

d. Calculation of sub-index of each parameter SI using;

$$SI_i = W_i * q_i \qquad (3)$$

e. WQI calculation using;

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

Where w_i is the assigned weight, W_i is the relative weight, n is the number of parameters, q_i is the quality rating, S_i is the WHO (2012) value in mg/l and C_i is the concentration from the laboratory in mg/l, SI is the sub-index for the various parameters and WQI is the Water Quality Index (Couillard and Lefebre, 1985).

Table 2 displays the classification of the calculated WQI values for the groundwater samples. Codes ranging from 1 to 5 were assigned to the classes, as shown in Table 2, to demonstrate the spatial variation of the various WQI classes.

Table 1: Groundwater quality parameters used for calculation of water quality indices

Parameter	**Unit**	**Weight (wi)**	**Relative weight (Wi)**	**WHO (2012)**
pH	pH unit	4	0.07	6.5-8.5
TH	mg/l	3	0.05	500.00
Ca^{2+}	mg/l	2	0.03	75.00
Mg^{2+}	mg/l	2	0.03	150.00
Na^{+}	mg/l	3	0.05	200.00
Cl^{-}	mg/l	4	0.07	250.00
TDS	mg/l	4	0.07	1500.00
F^{-}	mg/l	4	0.07	1.50
NO_2^{-}	mg/l	5	0.08	3.00
NO_3^{-}	mg/l	5	0.08	50.00
SO_4^{2-}	mg/l	4	0.07	250.00
Mn	mg/l	3	0.05	0.10
Fe	mg/l	3	0.05	0.30
PO_4^{-}	mg/l	4	0.07	0.10
Turbidity	mg/l	5	0.08	5
Colour	CPU	2	0.03	15
$CaCO_3$	mg/l	2	0.03	200
TOTAL		**59**	**1.00**	

Table 2: WQI classifications (Couillard and Lefebre, 1985)

Classification	**WQI**	**Assigned code**
Excellent	0-50	0.1-1.0
Good	50-100	1.1-2.0
Poor	100-200	2.1-3.0
Very Poor	200-300	3.1-4.0
Unsuitable	>300	4.1-5.0

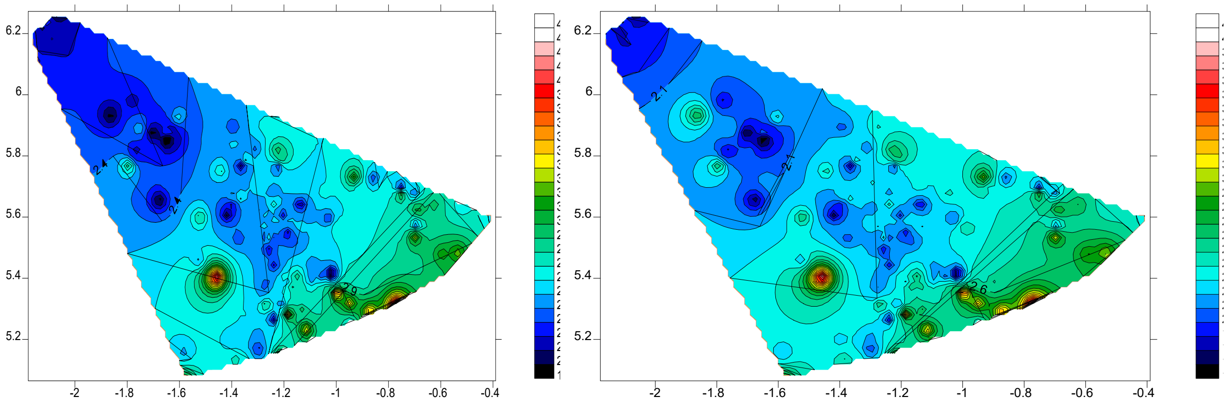
Results

Table 3 presents the statistical summary of the groundwater data used in this study. In Fig. 2 (a, b), the spatial distributions maps of EC and TDS are shown respectively. In general, the northern parts of the research area have low EC and TDS, while the southern, coastal parts have rather high levels of both. The intrusion of seawater along the shore has an impact on the high EC and TDS values in the southern part. As shown in Fig. 2 (c, d), the distributions of turbidity and color are generally high throughout the study area, with just a few isolated localities having lower values respectively. Except for the northernmost portion of the region, the TSS map depicts low amounts over the whole region (Fig. 2e). The maps in Fig. 2f, Fig. 2g, Fig. 2h, Fig. 2i, Fig. 2l, Fig. 2m, Fig. 2r, Fig. 2s, Fig. 2t, Fig. 2u and Fig. 2 for Na^{+}, K^{+}, Ca^{2+}, Mg^{2+}, Cl^{-}, SO_4^{2-}, TH, $CaCO_3$, Ca^{2+} hardness, Mg^{2+} hardness, and $H_2CO_3^{-}$ respectively demonstrate an increase in concentrations from the northern section to the southern part. The found greatest concentrations towards the southern coast indicate a potential impact of seawater intrusion on the chemistry and general quality of the groundwater. In the central and northern parts of the region, Fe concentrations are comparatively high (Fig. 2j).

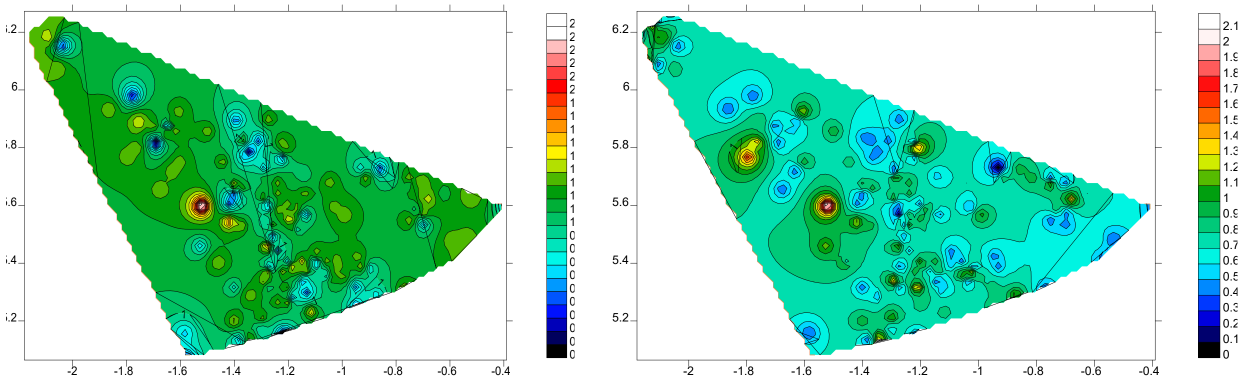
In the central part of the region, there is a comparatively high concentration of NH_4 (Fig. 2k). This finding might be explained by the use of agrochemicals in the central part of the region. The east, some southern regions, and remote areas of the north all have relatively high PO_4 concentrations (Fig. 2n). This observation may be attributed to the effects of anthropogenic activity. In remote areas near the center and southwest, the concentration of Mn is considerably higher (Fig. 2o). The southeast and the center of the region have rather high NO_2 concentrations (Fig. 2p). The northeastern part, the southern part, and certain isolated locations have significant NO_3 concentrations (Fig. 2q). The region contains scattered locations within the relatively high concentration of F^{-} (Fig. 2v). Near the northern portion of the region, a strong concentration of CO_3^{2-} is visible (Fig. 2x). The northernmost region of the region has the lowest pH values (Fig. 2y).

Table 3: Statistical summary of the groundwater data

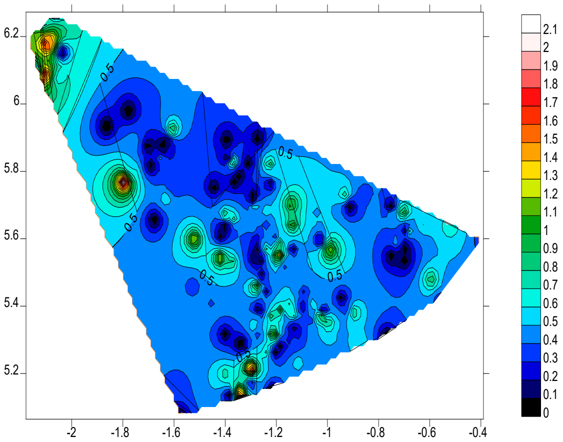
Parameter	Unit	Minimum	Maximum	Mean	Std. Deviation	WHO (2012)
Ca^{2+}	mg/l	0.800	1804.000	56.763	193.268	75.000
Ca hardness	mg/l	2.000	4509.000	142.270	483.304	200.000
$CaCO_3$	mg/l	9.800	390.000	91.944	68.914	200.000
Cl^-	mg/l	3.000	8660.000	219.009	979.322	250.000
CO_3^{2-}	mg/l	0.000	32.500	0.271	2.700	
Colour	CPU	1.000	188.000	9.701	16.858	15.000
EC	µS/cm	44.800	24900.000	893.812	2634.129	1000.000
F^-	mg/l	0.001	150.000	2.647	17.599	1.500
Fe	mg/l	0.008	56.900	0.918	4.532	0.300
H_2CO_3	mg/l	0.000	476.000	110.226	84.828	
PO_4	mg/l	0.001	61.700	0.878	5.022	0.100
K^+	mg/l	0.400	57.500	5.686	7.566	30.000
Mg^{2+}	mg/l	1.000	1286.000	31.202	124.771	150.000
Mg hardness	mg/l	0.005	5292.000	128.864	514.972	
Mn	mg/l	0.003	10.700	0.372	1.093	0.100
Na^+	mg/l	1.500	2688.000	81.532	277.760	200.000
NH_4^-	mg/l	0.001	15.000	0.131	1.232	
NO_2^-	mg/l	0.001	0.700	0.065	0.116	3.000
NO_3^-	mg/l	0.001	134.000	3.504	12.350	50.000
pH	pH unit	4.750	9.400	6.351	0.685	6.500-8.500
SO_4^{2-}	mg/l	0.001	3127.000	58.046	254.323	250.000
TDS	mg/l	26.900	13695.000	495.378	1448.120	1500.000
TH	mg/l	6.000	9200.000	272.930	955.831	500.000
TSS	mg/l	1.000	321.000	9.520	30.732	500.000
Turbidity	mg/l	0.750	484.000	22.330	38.789	5.000



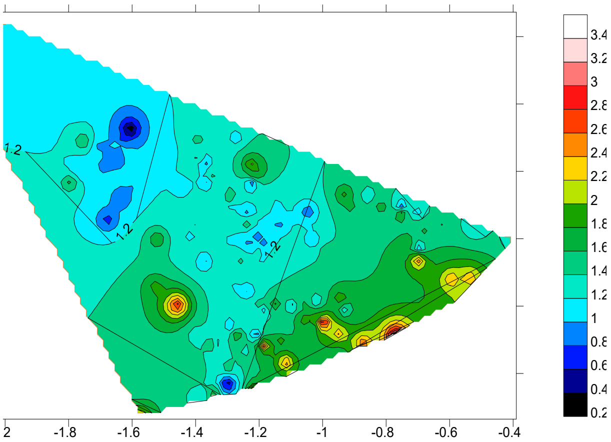
a. EC b. TDS



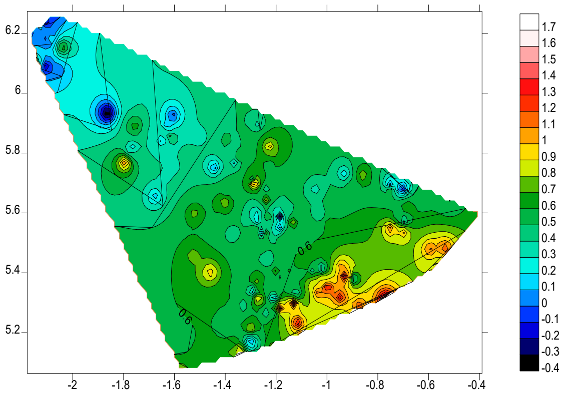
c. Turbidity d. Colour



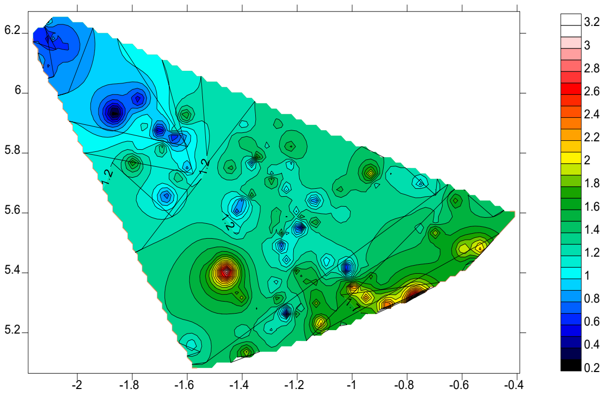
e. TSS



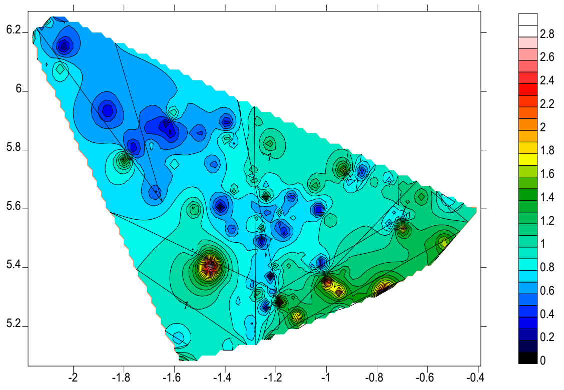
f. Na$^+$



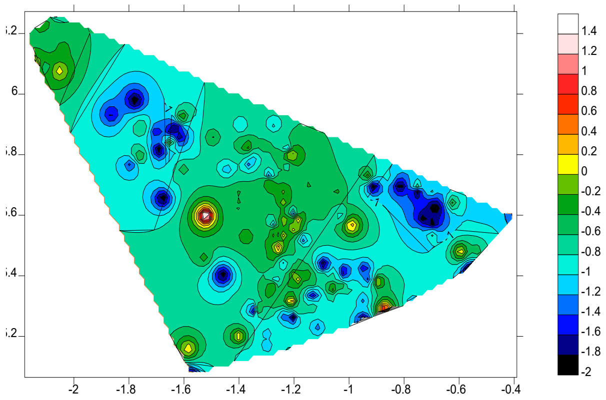
g. K$^+$



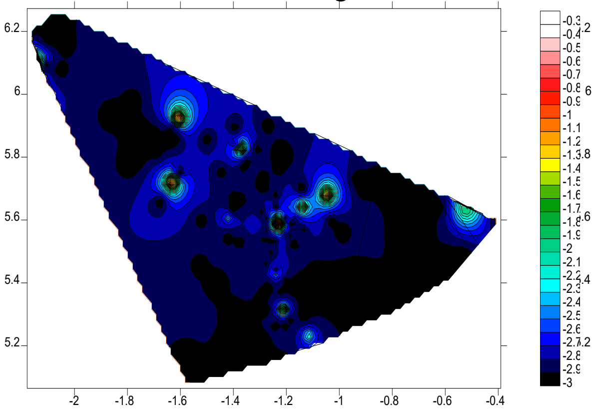
h. Ca^{2+}



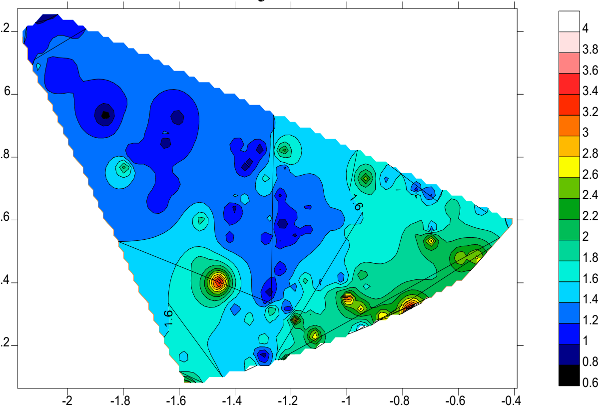
i. Mg^2



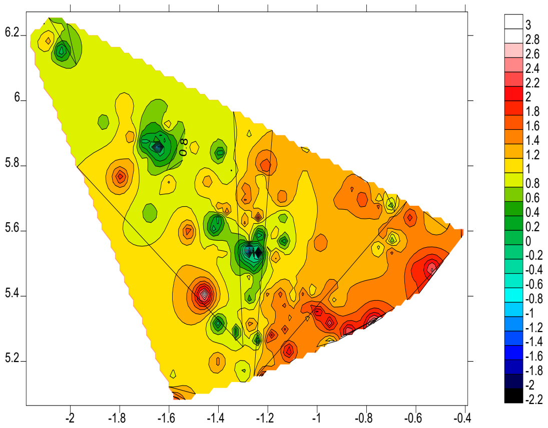
j. Fe



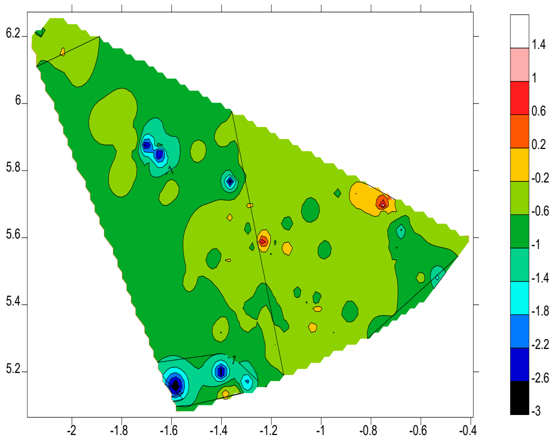
k. NH$_4$



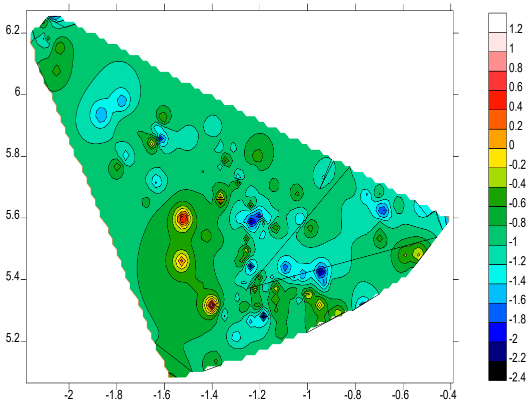
l. Cl$^-$



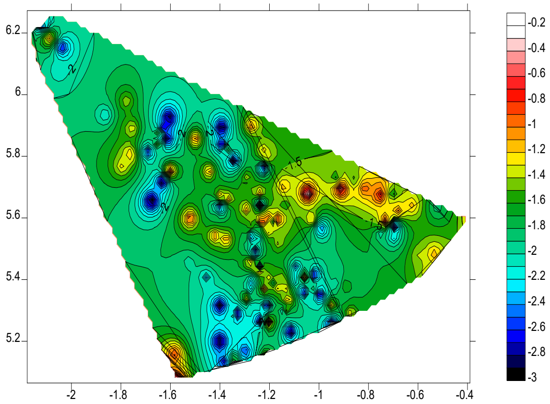
m. SO_4



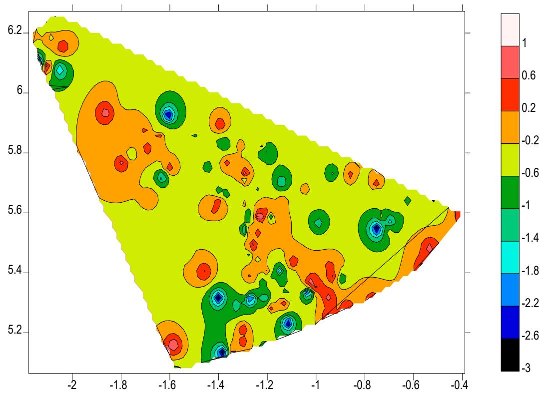
n. PO_4



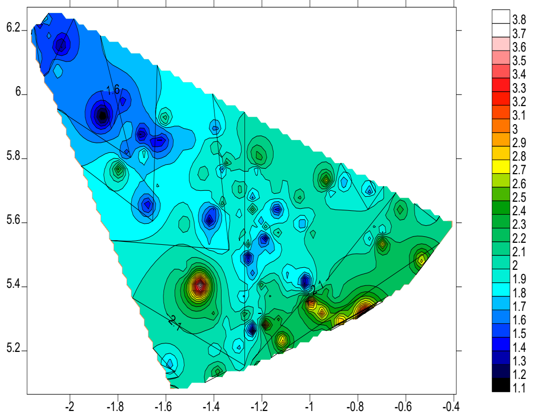
o. Mn



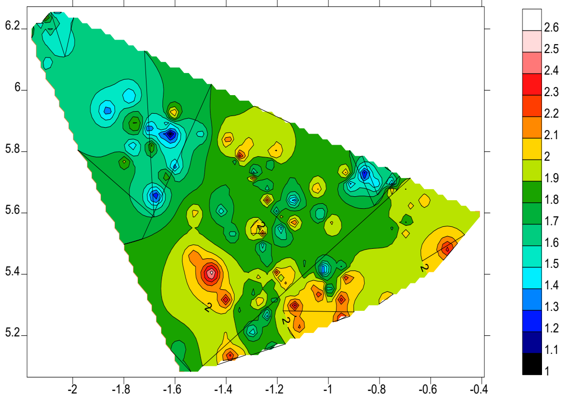
p. NO_2



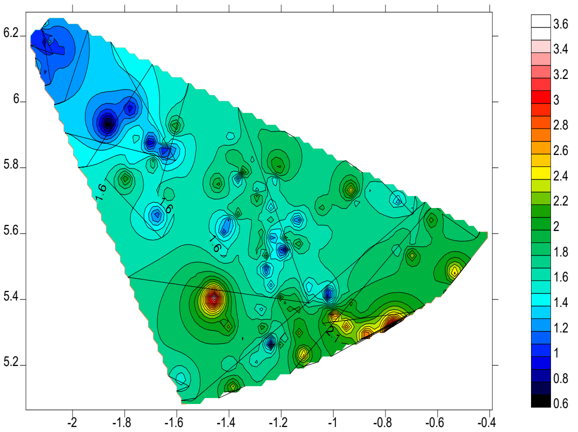
q. NO_3



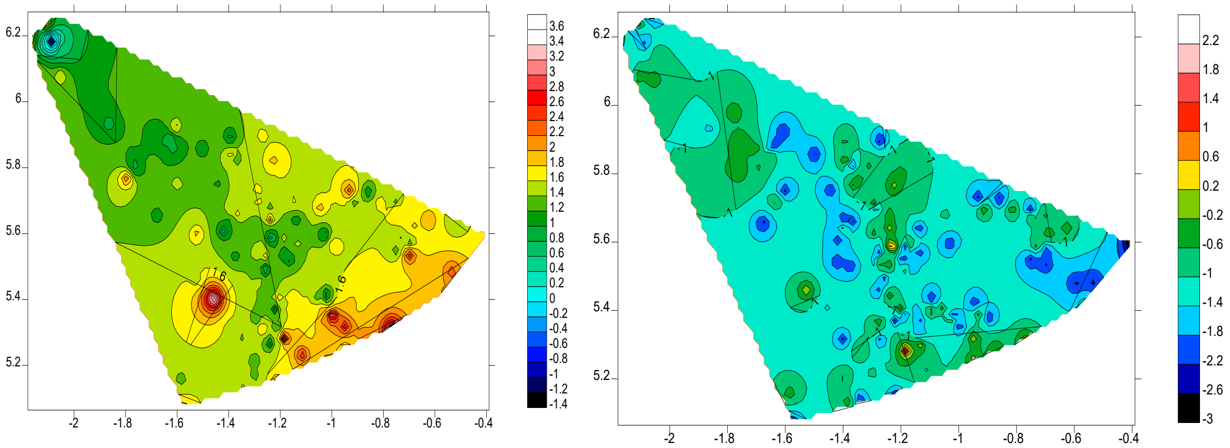
r. TH



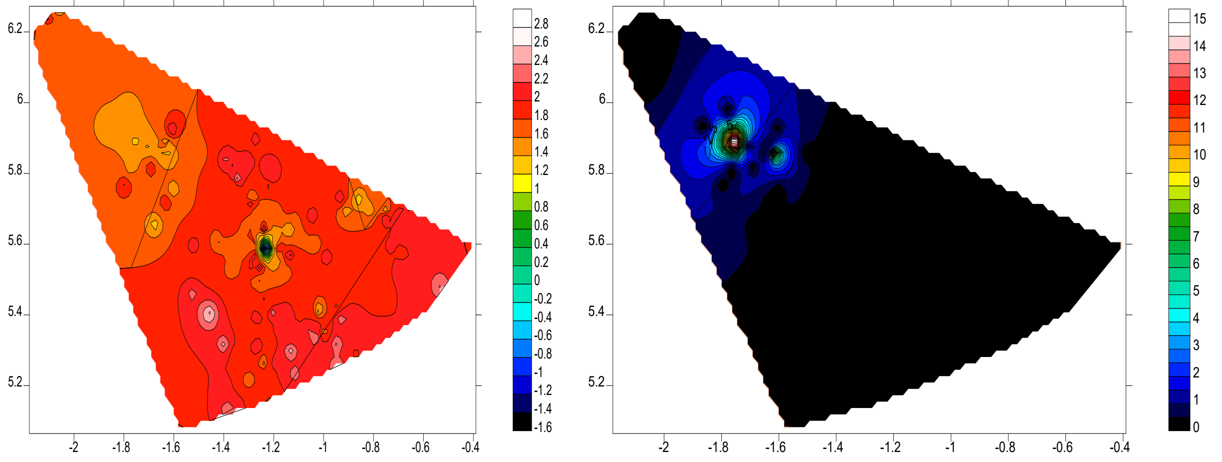
s. $CaCO_3$



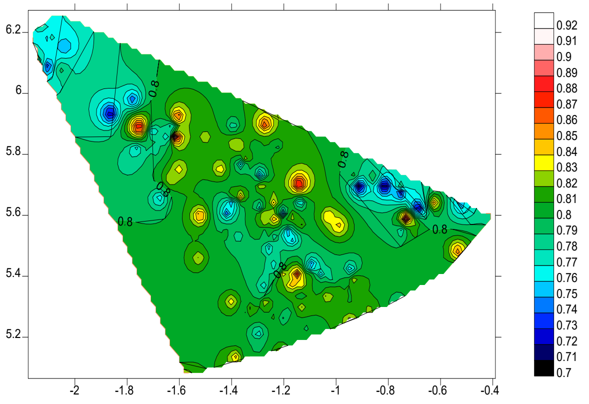
t. Ca hardness



u. Mg hardness v. F



w. H_2CO_3 x. CO_3



y. pH

Figure 2. (a-y): Spatial distribution of groundwater parameters in the study area.

Groundwater types and controlling processes

Groundwater types in the study area include $CaMgSO_4$, NaCl, $CaMgHCO_3$, and Mixed water, according to the Piper (1944) as shown in Fig. 3. The majority of the samples exhibit an excess Cl^- concentration over the Na^+ concentration, as seen by the Na^+ vs. Cl^- plot in Fig. 4. According to the Gibbs (1970) diagrams, evaporation has a minor impact on how the chemistry of groundwater whiles rock weathering mainly control the groundwater chemistry (Fig. 5 a, b). The effects of silicate weathering, carbonate weathering, and ion exchange processes are shown in the plotting of CAI I vs. CAI II in Fig. 6. Ca^{2+}+Mg^{2+} against SO_4^{2-}+$H_2CO_3^-$ is plotted in Figure 7, showing that some samples lie above, some lie on, and some lie below the equiline. This implies that silicate mineral dissolution and/or ion exchange, carbonate and/or sulphate mineral dissolution, and carbonate weathering may have an impact on the groundwater's chemistry and overall quality.

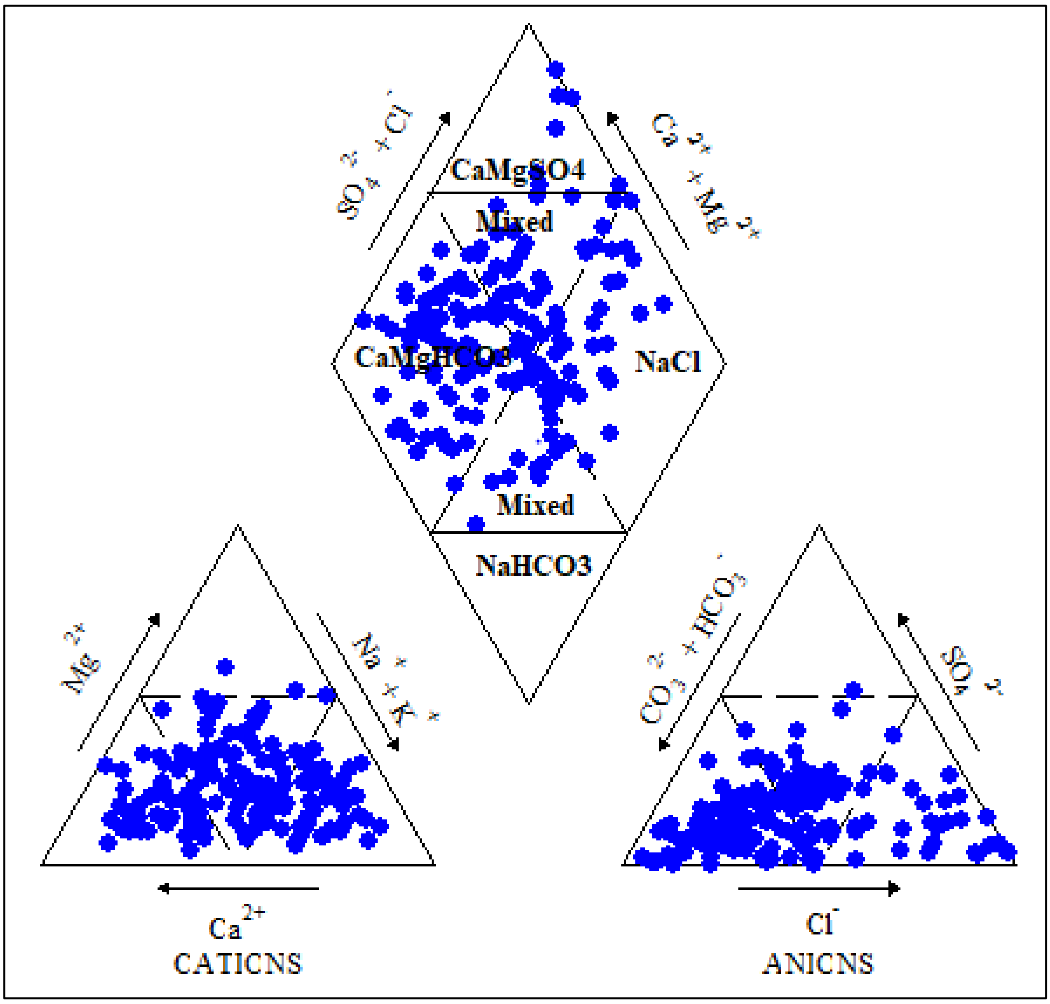
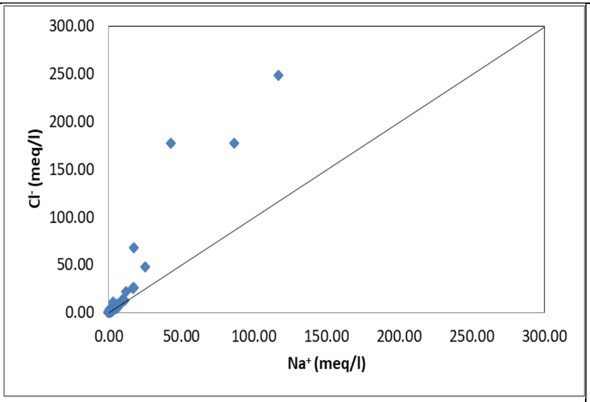


Fig. 3 Piper diagram showing groundwater



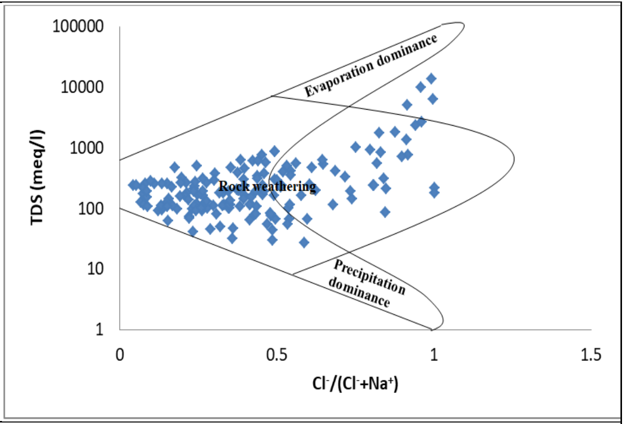


Fig. 4: A plot of Cl^- vs. Na^+

Fig. 5a A plot of TDS vs. $Cl^-/(Cl^-+Na^+)$

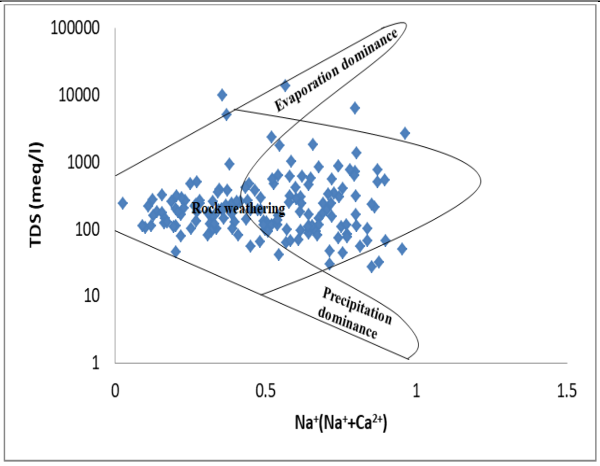


Figure 5b A plot of TDS vs. $Na^+/(Na^++Ca^{2+})$

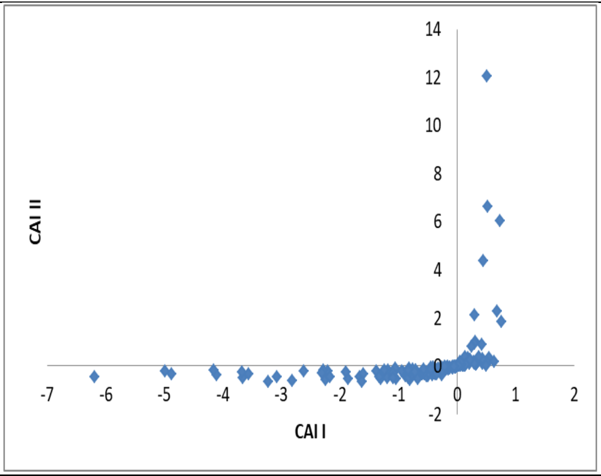


Figure 6. A plot of CAI I vs. CAI II

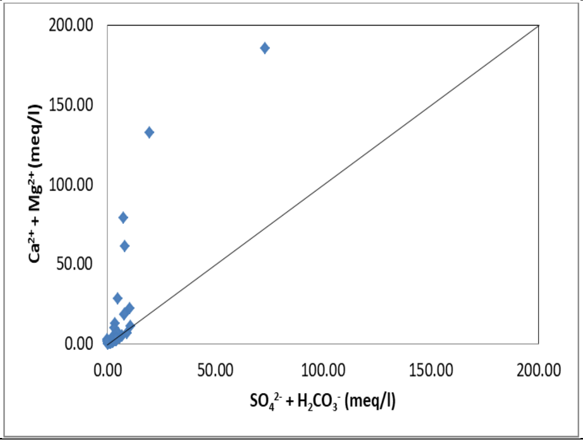


Figure 7. A plot of $(Ca^{2+}+Mg^{2+})$ vs. $(SO_4^{2-}+H_2CO_3^-)$

Geostatistical Analysis

As shown in Table 4, 82.35% of the total variance was explained by six factors. The component matrix is displayed in Table 5 and the rotated component matrix was displayed in Table 6. The Scree plot of the Eigen values for the various components is shown in Fig. 8. One or more Eigen values were taken into consideration in this study. Fig. 9 displays a component plot in rotated space to demonstrate their spatial relationship. Factor 1 accounted for 36.28%, Factor 2 for 14.14%, Factor 3 for 12.43%, Factor 4 for 8.90%, Factor 5 for 5.81%, and Factor 6 for 4.79%. EC, TDS, Na^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, TH, Ca^{2+} hardness, and Mg^{2+} hardness formed the components of factor 1. The components of factor 2 were NH_4, PO_4, NO_2, NO_3, and F^-. Turbidity, Mn, Fe, and color were all present in factor 3. $CaCO_3$ and $H_2CO_3^-$ made up factor 4. Factor 5 had pH and CO_3 and Factor 6 was made of K^+.

The HCA multivariate statistical method can be used to group hydrochemical data so that its members share traits but are different from those of other groups. One benefit of using the method is that the results are displayed as a dendrogram, which is simple to understand, and the HCA can classify water using a variety of characteristics. Additionally, it offers a fairly simple and user-friendly method of data organization. The HCA method is helpful in hydrogeochemical modeling to identify the type of aquifer system, residence time, and potential effects of anthropogenic activities that support the investigation of the properties of groundwater of the various subgroups. In this study, four clusters were revealed by the cluster analysis method (Fig. 10). Turbidity, color, pH, EC, TSS, TDS, Fe, NH_4^+, SO_4^{2-}, PO_4, Mn, NO_2, NO_3, $CaCO_3$, Ca^{2+} hardness, Mg^{2+} hardness, F^-, $H_2CO_3^-$, and CO_3^{2-} were present in Cluster 1. Cl^- and TH were in Cluster 2. Only TDS and only EC were present in clusters 3 and 4, respectively. The Correlation analysis technique was applied to determine the sources of groundwater pollution (Hussain, 2019). The technique has been applied by several authors to successfully investigate groundwater pollution (Varol and Davraz, 2014; Agyemang 2022). The correlation outcome is shown in Table 7 of the report.

Table 4: The observed Total Variance and its Explanation

		Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings	
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	9.510	38.058	38.058	9.514	38.058	38.058	9.07	36.279	36.279
2	3.560	14.232	52.290	3.558	14.232	52.29	3.535	14.138	50.417
3	3.130	12.514	64.805	3.129	12.514	64.805	3.108	12.434	62.851
4	2.000	7.994	72.798	1.998	7.994	72.798	2.225	8.901	71.752
5	1.35	5.417	78.216	1.354	5.417	78.216	1.452	5.808	77.56
6	1.04	4.138	82.354	1.035	4.138	82.354	1.198	4.794	82.354
7	1.00	3.981	86.335						
8	0.65	2.596	88.931						
9	0.63	2.498	91.429						
10	0.48	1.923	93.352						
11	0.45	1.81	95.162						
12	0.41	1.64	96.802						
13	0.29	1.159	97.961						
14	0.18	0.707	98.669						
15	0.15	0.604	99.273						
16	0.09	0.343	99.615						
17	0.05	0.2	99.815						
18	0.036	0.144	99.959						
19	0.007	0.029	99.988						
20	0.001	0.004	99.993						
21	0.001	0.004	99.997						
22	0.001	0.002	99.999						
23	0	0.001	100						
24	2.43E-05	9.72E-05	100						
25	3.64E-06	1.46E-05	100						

Table 5: Component matrix of the water quality parameters

Parameters	**Component**					
	1	2	3	4	5	6
Turb.	-0.003	-0.087	0.923	-0.215	0.023	-0.041
Col.	-0.013	-0.138	0.896	-0.159	-0.039	0.016
Ph	0.065	0.152	0.289	0.521	0.617	0.036
EC	0.974	0.031	-0.009	-0.123	0.037	0.108
TSS	-0.055	-0.057	0.089	-0.268	-0.227	0.097
TDS	0.973	0.028	-0.01	-0.125	0.037	0.108
Na	0.871	0.034	-0.021	-0.216	0.087	0.345
K	0.533	0.034	0.029	0.205	-0.034	0.709
Ca	0.962	0.011	-0.019	-0.075	0.026	-0.028
Mg	0.93	0.025	-0.012	-0.051	-0.016	-0.234
Fe	-0.011	-0.097	0.929	-0.159	-0.068	0
NH_4	-0.035	0.913	0.102	0.059	-0.047	-0.026
Cl	0.955	0.031	-0.03	-0.2	0.064	0.131
SO_4	0.828	-0.009	-0.006	0.015	-0.039	-0.449
H_2PO_4	-0.042	0.774	0.081	0.022	-0.026	-0.038
Mn	0.058	-0.129	0.654	0.163	-0.118	0.018
NO_2	-0.085	0.67	0.135	-0.032	0.003	-0.1
NO_3	-0.008	0.929	0.075	0.009	-0.102	0
TH	0.986	0.017	-0.014	-0.061	0.004	-0.141
$CaCO_3$	0.445	-0.049	0.146	0.831	-0.205	-0.036
Ca_hard.	0.963	-0.008	-0.019	-0.072	0.026	-0.03
Mg_hard.	0.93	0.023	-0.013	-0.051	-0.016	-0.234
F	0.045	0.829	0.068	0.034	-0.056	0.095
H_2CO_3	0.451	-0.194	0.123	0.808	-0.238	-0.025
CO_3	-0.037	0.009	0.09	0.05	0.876	-0.059

Table 6: Rotated Component Matrix of the water quality parameters

Parameter	**Component**					
	1	2	3	4	5	6
Turb.	0.02	0.018	0.945	-0.101	0.044	-0.046
Col.	-0.012	-0.029	0.92	-0.036	-0.005	0.009
Ph	-0.019	0.144	0.161	0.292	0.786	0.119
EC	0.96	-0.001	0.006	0.054	0.003	0.23
TSS	-0.026	-0.035	0.143	-0.174	-0.303	0.057
TDS	0.96	-0.004	0.006	0.052	0.002	0.228
Na	0.854	-0.01	0.004	-0.091	8.35E-05	0.443
K	0.392	0.017	0.001	0.236	0.002	0.789
Ca	0.954	-0.016	-0.008	0.113	0.015	0.096
Mg	0.941	0.009	-0.004	0.161	0	-0.11
Fe	-0.008	0.018	0.949	-0.023	-0.025	-0.006
NH_4	-0.019	0.922	-0.016	0.013	0.041	0
Cl	0.957	-0.008	-0.005	-0.033	0	0.243
SO_4	0.851	-0.012	-0.002	0.231	0.011	-0.332
H_2PO_4	-0.02	0.779	-0.016	-0.02	0.039	-0.021
Mn	-0.004	-0.035	0.641	0.272	0.003	0.042
NO_2	-0.046	0.682	0.056	-0.07	0.051	-0.092
NO_3	0.013	0.936	-0.034	-0.015	-0.03	0.021
TH	0.987	-0.004	-0.004	0.147	0.008	-0.011
$CaCO_3$	0.255	0.003	0.046	0.932	0.106	0.089
Ca_hard.	0.954	-0.034	-0.005	0.116	0.016	0.094
Mg_hard.	0.941	0.008	-0.004	0.161	0	-0.109
F	0.047	0.829	-0.035	0	0.008	0.124
H_2CO_3	0.259	-0.141	0.047	0.93	0.055	0.093
CO_3	0	-0.053	0.034	-0.245	0.848	-0.026

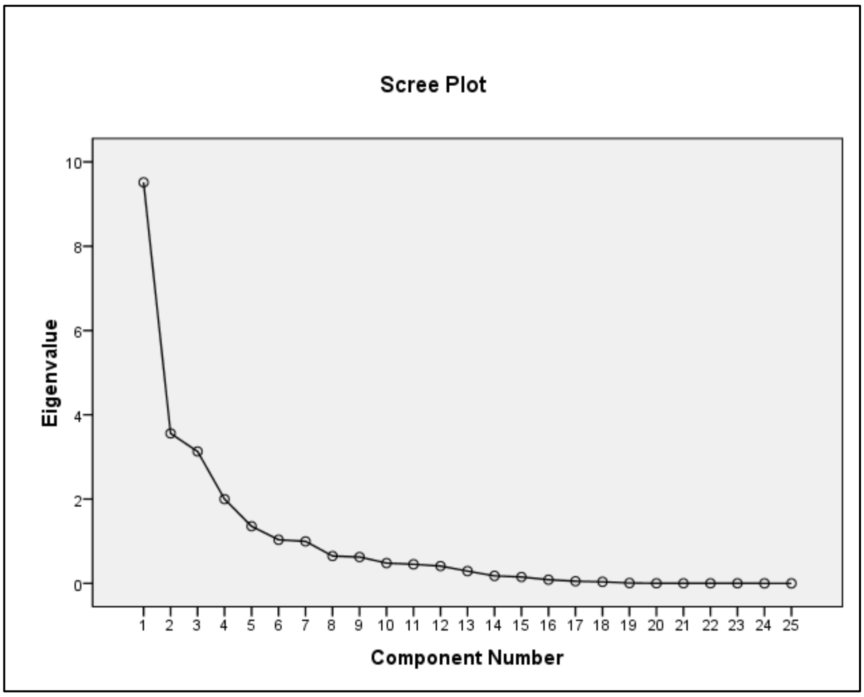


Figure 8: Scree plot showing the Eigen values of the various components

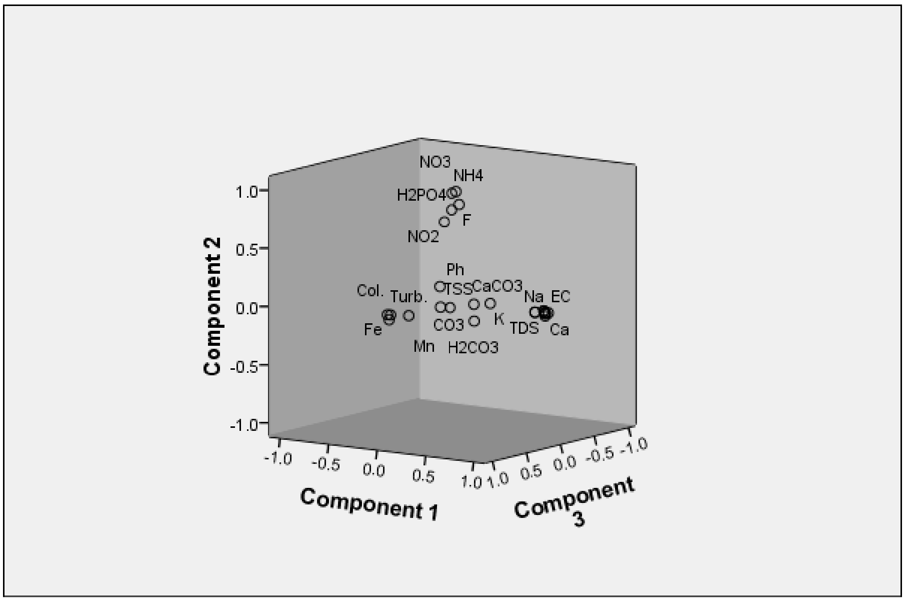


Figure 9: Plot of components in rotated space to show their spatial relationship.

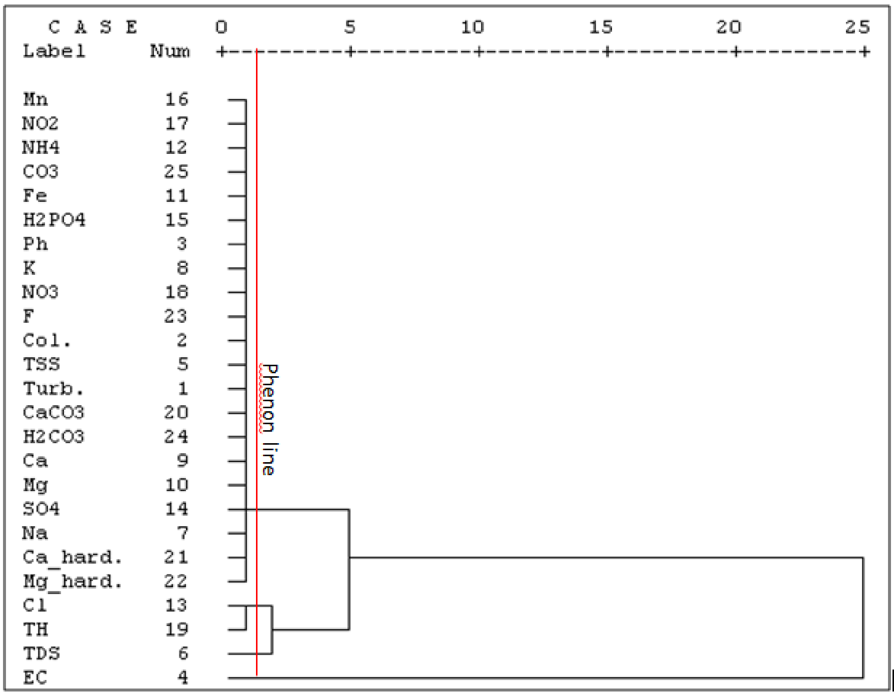


Figure 10: Dendrogram showing the clustering of groundwater parameters.

Table 7: Correlation matrix of the water quality parameters

	Turb.	Col.	Ph	EC	TSS	TDS	Na	K	Ca	Mg	Fe	NH_4	Cl	SO_4	PO_4	Mn	NO_2	NO_3	TH	$CaCO_3$	Ca_hard.	Mg_hard.	F	H_2CO_3	CO_3
Turb.	1	**0.845**	0.137	0.006	0.077	0.006	0.003	-0.026	-0.005	0.002	**0.912**	0.007	0.002	0.013	0.002	0.471	0.077	-0.025	0	-0.033	-0.004	0.003	-0.022	-0.037	0.081
Col.		1	0.125	-0.005	0.203	-0.006	-0.018	0.013	-0.029	-0.014	**0.838**	-0.043	-0.027	-0.014	-0.043	0.439	0.032	-0.055	-0.016	0.036	-0.02	-0.015	-0.043	0.04	0.061
Ph			1	0.028	-0.152	0.025	0.025	0.113	0.038	0.02	0.12	0.174	0.013	0.025	0.128	0.159	0.106	0.078	0.032	0.322	0.038	0.019	0.116	0.274	0.419
EC				1	-0.045	1	**0.927**	**0.526**	**0.968**	**0.857**	-0.006	-0.019	**0.977**	**0.721**	-0.025	0.034	-0.047	0.008	**0.95**	0.324	**0.968**	**0.857**	0.064	0.329	-0.029
TSS					1	-0.	-0.	-0.	-0.	-0.	0.03	-0.	-0.	-0.	-0.	-0.	-0.	0.02	-0.	-0.1	-0.0	-0.03	-0.	-0.0	-0.

						045	033	016	045	031	1	027	034	028	031	015	064	2	04	01	45	1	039	94	02
TDS						1	**0.927**	**0.524**	**0.967**	**0.857**	-0.007	-0.021	**0.976**	**0.72**	-0.027	0.034	-0.05	0.006	**0.95**	0.322	**0.968**	**0.857**	0.062	0.327	-0.029
Na							1	**0.594**	**0.832**	**0.736**	-0.004	-0.029	**0.963**	**0.512**	-0.032	0.04	-0.056	0.005	**0.816**	0.175	**0.831**	**0.736**	0.073	0.183	-0.023
K								1	0.446	0.367	0.004	-0.013	**0.517**	0.236	-0.008	0.023	-0.061	0.032	0.422	0.377	0.444	0.367	0.124	0.381	-0.037
Ca									1	**0.839**	-0.014	-0.008	**0.923**	**0.798**	-0.02	0.03	-0.058	0.011	**0.955**	0.364	**0.999**	**0.839**	-0.014	0.366	-0.026
Mg										1	-0.023	-0.024	**0.872**	**0.887**	-0.027	0.037	-0.075	0.01	**0.961**	0.369	**0.839**	1	0.103	0.373	-0.024
Fe											1	-0.004	-0.018	0.002	-0.002	**0.52**	0.04	-0.011	-0.02	0.014	-0.014	-0.024	-0.011	0.015	-0.014
NH4												1	-0.024	-0.024	**0.58**	-0.035	**0.526**	**0.927**	-0.018	0.022	-0.028	-0.026	**0.743**	-0.13	-0.011
Cl													1	**0.69**	-0.028	0.034	-0.067	0.01	**0.934**	0.234	**0.922**	**0.872**	0.058	0.24	-0.022
SO_4														1	-0.026	-0.009	-0.048	-0.009	**0.881**	0.388	**0.799**	**0.888**	-0.004	0.391	-0.021
PO_4															1	-0.031	0.475	**0.663**	-0.025	-0.023	-0.032	-0.029	**0.557**	-0.127	-0.006
Mn																1	-0.021	-0.052	0.034	0.221	0.029	0.036	-0.046	0.225	-0.025
NO_2																	1	**0.543**	-0.07	-0.07	-0.069	-0.076	0.405	-0.152	-0.004
NO_3																		1	0.009	0.004	-0.009	0.008	**0.719**	-0.139	-0.024
TH																			1	0.387	**0.956**	**0.961**	0.047	0.39	-0.026
$CaCO_3$																				1	0.368	0.369	0.019	**0.986**	-0.072
Ca_hard.																					1	**0.839**	-0.029	0.373	-0.026
Mg_hard.																						1	0.102	0.373	-0.024
F																							1	-0.097	-0.014
H_2CO_3																								1	-0.122
CO_3																									1

Water quality index

According to Couillard and Lefebre (1985), water is considered to be excellent to drink when the WQI value is between 0 and 50, good to drink when the value is between 50 and 100, poor to drink when the value is between 100 and 200, very poor to drink when the value is between 200 and 300, and unfit to drink when the value is above 300. Following classification, the WQI found that 6% of the groundwater samples had excellent quality, 54% had good quality, 22% had poor quality, 9% had very poor quality, and 9% were unfit for drinking. The spatial distribution of the WQI is shown using a thematic map, as shown in Fig. 11. The map revealed that the region had a dominant class of good groundwater quality. There were sporadic locations with high or low WQI values throughout the study area (Fig. 11).

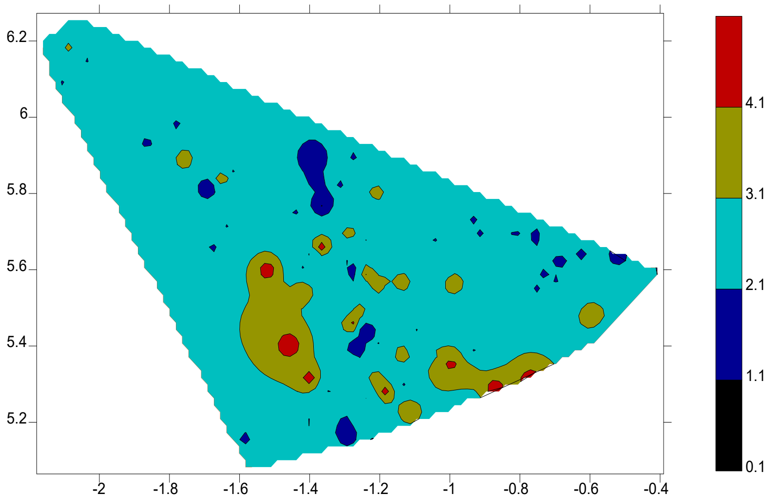


Figure 11: Spatial distribution of WQI

Discussion

Geostatistical techniques have proven to be effective in interpretation of hydrochemical data (Osiakwan et al., 2021). In this study, PCA and HCA were used to, respectively, identify the critical components that control groundwater chemistry and identify hydrochemical clusters that may be important from a geological perspective. The regional distributions of the various water quality parameters have shown how groundwater chemistry is influenced by human activity, seawater intrusion, and rock mineral dissolution. Along the coast, the majority of the metrics had extremely high values that are over the WHO (2012) recommended limits. This finding is consistent with the poor groundwater quality noted by Osiakwan et al (2021). Thematic maps of the various parameters indicate the effects of actions such as applying agrochemicals to farmlands, spreading animal dung on farms, galamsey, maintaining unhygienic conditions around boreholes, using pit latrines in some areas, etc.

Groundwater types

The dissolution of rock minerals and anthropogenic effects may have contributed to the occurrence of the $CaMgSO_4$ groundwater type (Koh et al., 2010; Tiwari and Singh, 2014). The dissolution of pyroxene, anorthite plagioclase, amphibole, and calcite may be the reason for the high Ca^{2+} ion concentration of the groundwater. The dissolution of hornblende, augite, and biotite may have had an impact on the amount of Mg^{2+} in the groundwater. Gypsum dissolution, the oxidation of sulfide-bearing minerals like pyrite and arsenopyrite, and/or human activity are all potential sources of SO_4^{2-} in groundwater. Local anthropogenic activities, such as improper waste management, the use of pit latrines, and unhygienic conditions close to the borehole, may be to blame for the rise in the level of SO_4^{2-} in the groundwater (Koh et al., 2010).

The dissolution of salt minerals like halite, which introduces equal amounts of Na^+ and Cl^- into the groundwater, may influence the occurrence of the NaCl groundwater type (Hem, 1985). However, the majority of samples contain more Cl^- than Na^+, demonstrating that the two parameters enter groundwater in various ways. The idea that the two concentrations entered the groundwater independently is supported by the absence of a clear relationship between them. The main factors affecting the occurrence of the $CaMgHCO_3$ groundwater type are ion exchange processes and/or rock weathering. According to Karnath (1989), the formation of HCO_3^- in groundwater may result from the dissolution of carbonate rocks like limestone and dolomite as well as from the reaction of water and carbon dioxide.

The $NaHCO_3$ groundwater type may develop as a result of meteoric water charged with carbonic acid dissolving Na^+ from Na-bearing minerals like albite and augite, according to Garrels and Mackenzie (1967). The creation of the $NaHCO_3$ groundwater type is caused by the dissolution of CO_2 and this

Na-rich mineral. Additionally, the exchange process where $CaHCO_3$ transforms into $NaHCO_3$ by interacting with the NaCl water type may also result in the formation of $NaHCO_3$ (Yidana et al., 2010). The final chemical makeup of groundwater is altered when two or more of different groundwater types are mixed together. Since there is no single dominant ion in mixed groundwater, it lacks any distinctive characteristics. This kind of groundwater can develop as a result of the blending of several groundwater types or the breakdown of various rock minerals in the groundwater.

Processes controlling the groundwater chemistry

The primary mechanisms that regulate the groundwater chemistry in the region were studied using the Gibbs (1970) diagram. The impact of rock weathering, which is related with moderate TDS and moderate $Cl^-/(Cl^-+Na^+)$ ratio or TDS and moderate $Na^+/(Na^++Ca^{2+})$ ratio, is shown by the graphing of TDS vs. $Cl^-/(Cl^-+Na^+)$ and TDS vs. $Na^+/(Na^++Ca^{2+})$. A few samples, however, showed signs of the potential effects of evaporation since they had high TDS, high $Cl^-/(Cl^-+Na^+)$ ratios, and high $Na^+/(Na^++Ca^{2+})$ ratios. This indicates that, even though rock weathering mostly regulates groundwater chemistry, evaporation also affects groundwater chemistry in some areas of the region.

The plot of $(Ca^{2+}+Mg^{2+})$ vs. $(SO_4^{2-}+HCO_3^-)$ was used to analyze the kind of rock weathering that mostly affects the groundwater of the region since rock weathering is the principal process affecting the chemistry of the groundwater. By using the plot of $(Ca^{2+}+Mg^{2+})$ vs. $(SO_4^{2-}+HCO_3^-)$, excess $SO_4^{2-}+HCO_3^-$ over $Ca^{2+}+Mg^{2+}$ indicates either silicate mineral weathering or ion exchange processes, whereas excess $Ca^{2+}+Mg^{2+}$ over $SO_4^{2-}+HCO_3^-$ indicates carbonate weathering (Tiwari and Singh, 2014). The study showed that the area may experience silicate mineral dissolution and/or ion exchange, carbonate and/or sulphate mineral dissolution, and carbonate weathering. A plot of CAI I vs. CAI II was used to study the effects of ion exchange on groundwater chemistry. Indicators with positive values suggest an interchange of Na^+ or K^+ in groundwater with Mg^{2+} or Ca^{2+} in the aquifer system, while those with negative values imply an exchange of Mg^{2+} or Ca^{2+} in groundwater with Na^+ and K^+ in the rocks, according to Schoeller (1965). Ion exchange is revealed by positive numbers, and reverse ion exchange is revealed by negative values. The majority of the samples in this investigation showed the dominance of reverse ion exchange.

Geostatistical Analysis

The potential processes that could affect the quality of the groundwater were deduced using HCA and FA approaches based on the connections between the elements. CA is a pattern-detection method that identifies the fundamental structure of a dataset and groups the data according to similarities (Otto, 1998). Several factors were deduced from the data set in order to conduct a factor analysis. The factors were ranked based on how much of the variation from the initial set of data they explain. A correlation matrix analysis is a bivariate technique that demonstrates how well one variable predicts the other while also identifying potential ions and chemical processes that are comparable to or identical to those in the understudied groundwater. In order to demonstrate the relationship between the metrics for water quality, the correlation technique was used in this study (McGrorya, 2020). These techniques have been used for hydrochemistry research by numerous authors from different parts of the world and are well documented in the literature (Osiakwan et al., 2021).

Factor Analysis

According to the factor analysis, Factor 1 contains the following variables: EC, TDS, Na^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, TH, Ca^{2+} hardness, and Mg^{2+} hardness. This grouping shows that weathering of rock minerals, ion exchange and human activities have impacts on groundwater chemistry. The concentrations of Na^+, Ca^{2+}, and Mg^{2+} in the groundwater are regulated by ion exchange activities or the dissolution of rock minerals, as shown by their clustering (Schoeller, 1965; Koh et al., 2010; Tiwari and Singh, 2014). The concentrations of TDS, Na^+, Cl^-, and SO_4^{2-} are grouped together, indicating the presence of rock weathering and the potential influence of anthropogenic activity. The components of factor 2 are NH_4^-, PO_4, NO_2, NO_3, and F^-. This cluster demonstrates the potential effects of anthropogenic activity on the quality of groundwater (Koh et al., 2010). The use of chemicals for galamsey activities, the use of pit latrines in some communities, the use of fertilizers, weedicides, and pesticides for farming, the lack of hygienic conditions around the boreholes, the use of poor waste disposal techniques, etc. that are prevalent in the area, among other factors, may have caused this clustering (Koh et al., 2010).

Turbidity, Mn, Fe, and color all belong to factor 3. This clustering supports the impact of rock weathering on the quality of groundwater (Tiwari and Singh, 2014). The dissolution of minerals containing Fe and Mn regulates the concentrations of the elements. The fact that Fe and Mn are clustered together with color and turbidity indicates that Fe and Mn are responsible for regulating the color and turbidity of the groundwater. $CaCO_3$ and $H_2CO_3^-$ make up factor 4. This cluster demonstrates the influence of dissolved CO_2 on groundwater chemistry and the effects of rock weathering (Karnath, 1989). Factor 5 contains pH and CO_3^{2-}, demonstrating how the concentration of CO_3^{2-} affects the pH of groundwater (Karnath, 1989). Factor 6 solely contains K^+, suggesting that human activity has an impact on the quality of groundwater (Koh et al., 2010). The dissolution of K-bearing minerals may be partially responsible for the K^+ content in the groundwater. The absence of connection with other widespread rock minerals, however, points to various distinct entry points into the groundwater system. The use of K-containing fertilizers on their farmland by the farmers may be the source of this particular route (Koh et al., 2010). The use of the Factor Analysis technique has shown the potential for ion exchange, rock weathering, and the effects of human activity.

Cluster Analysis

The application of the cluster analysis technique was used in this study to identify possible factors affecting the groundwater quality in the region. The technique revealed the effects of sewage contamination of groundwater, groundwater quality, groundwater contamination, the impact of mining and agriculture on groundwater quality, and general hydrochemical investigations (Belkhiri et al., 2010). The use of the Cluster analysis technique in the study is required because, as described in the literature, it is necessary to group samples into various hydrochemical groups that will reveal hidden information about the hydrogeochemistry and potential groundwater pollution (Belkhiri et al., 2010). This analysis combined the Ward's linkage strategy with the Q-mode hierarchical cluster analysis method to achieve its goals.

Four clusters were displayed using the method. Turbidity, color, pH, EC, TSS, TDS, Na^+, K^+, Ca^{2+}, Mg^{2+}, Fe, NH_4, SO_4, PO_4, Mn, NO_2, NO_3, $CaCO_3$, Ca hardness, Mg hardness, F^-, $H_2CO_3^-$, and CO_3^{2-} were present in Cluster 1. The grouping of the parameters shows the effects of rock weathering, potential ion exchange, and impact of anthropogenic activities on the quality of the groundwater (Schoeller, 1965; Koh et al., 2010; Tiwari and Singh, 2014). The clustering of major ions like Na, Ca, and Mg together indicates that dissolution of rock minerals is most likely their sources (Tiwari and Singh, 2014). But the ion exchange process might have an impact on the amount of Na, Ca, and Mg in the groundwater (Schoeller, 1965). Another indication of the potential impact of the rock weathering process on the groundwater chemistry is the clustering of Fe, Mn, and $CaCO_3$ (Tiwari and Singh, 2014).

However, the concentrations of TDS, K^+, NH_4, SO_4, PO_4, NO_2, and NO_3 were grouped together, suggesting the possible effects of anthropogenic activity on the quality of groundwater (Koh et al., 2010). The use of fertilizers containing K may be responsible for the concentration of K^+. The absence of hygienic conditions near boreholes, the use of agrochemicals, the use of chemicals for galamsey activities, etc. may be the influencing factor of the SO_4, NH_4, NO_2, and NO_3 concentrations (Koh et al., 2010). Cl^- and TH are present in Cluster 2, indicating the potential impact of rock weathering on the chemistry of groundwater. Only TDS and only EC are present in clusters 3 and 4, respectively, which indicate that anthropogenic activities have an impact on the chemistry and general quality of groundwater (Koh et al., 2010). The Cluster analysis technique has confirmed that geogenic processes and anthropogenic activities in the Region have impact on the chemistry groundwater.

Correlation Analysis

The use of the correlation analysis technique revealed a substantial association between turbidity, Fe, and color, suggesting that the content of Fe in the groundwater regulates turbidity. Strong correlations between color and Fe imply that the Fe concentration of the groundwater affects the color. The EC is correlated with Mg^{2+} hardness, Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, TH, and Ca^{2+} hardness, indicating that the concentrations of these parameters affect the EC of the groundwater.

Therefore, factors that regulate the levels of Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, and SO_4^{2-} indirectly affect the EC of the groundwater. As shown by the factor analysis and cluster analysis techniques, geogenic processes and anthropogenic activities may be controlling the concentrations of Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, and SO_4^{2-} in the groundwater. As a result, these factors affect the EC of the groundwater. The fact that TDS closely correlates with Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, Ca hardness, and Mg hardness suggests that the concentrations of Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, and SO_4^{2-} in the groundwater affect the TDS of the groundwater. This indicates that anthropogenic activities as well as rock weathering affect the TDS.

Strong correlations between Na and K^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, TH, Ca^{2+} hardness, and Mg^{2+} hardness indicate that the anthropogenic activities have effects on the quality of groundwater (Davalos-Pena et al. 2021). The relationship between K^+ and Cl^- shows that anthropogenic activities have an impact on the chemistry of groundwater and the overall quality of groundwater. The relationship between Ca^{2+} and Cl^-, SO_4^{2-}, Mg^{2+}, TH, Ca^{2+} hardness, and Mg^{2+} hardness suggests that the weathering of rocks has an effect on the quality of the groundwater. Mg correlates with Cl^-, SO_4^{2-}, TH, Ca^{2+} hardness, and Mg^{2+} hardness, illustrating how the weathering of rocks affects the quality of groundwater. Fe and Mn are correlated, which shows that weathering of rocks has an effect of the groundwater chemistry. The relationship between NH_4^+ and F^-, NO_2, NO_3, and PO_4 indicates that anthropogenic activities, such as applying fertilizer to farmland, maintaining unhygienic conditions around boreholes, using chemicals for galamsey activities, using pit latrines, etc., have an impact on the chemistry and general quality of groundwater.

The relationship between Cl^- and SO_4^{2-}, TH, Ca^{2+} hardness, and Mg^{2+} hardness suggests that anthropogenic activities have an impact on groundwater quality. The correlation between SO_4^{2-} and TH, Ca^{2+} hardness and Mg^{2+} hardness suggests that SO_4^{2-} may have an impact on groundwater hardness. PO_4 correlates with NO_3 and F^-, demonstrating how anthropogenic activities affect the quality of groundwater. The relationship between NO_2 and NO_3 implies that the conversion of NO_3 to NO_2 is the primary factor affecting the content of NO_2 in groundwater. NO_3 correlates with F^-, demonstrating that anthropogenic sources account for the majority of the NO_2 entering the groundwater system. A portion of the concentration is changed into NO_2 upon the introduction of NO_3. The use of the correlation analysis technique confirms the potential impact of ion exchange, rock weathering, and anthropogenic activities on the chemistry and general quality of groundwater in the region. The associations of the various parameters reveals the possible effects of mineral dissolution and anthropogenic activities on the chemistry of groundwater (Tiwari and Singh, 2014; Davalos-Pena et al. 2021).

Water quality index

The WQI technique was used in this study to evaluate the suitability of the groundwater for drinking and domestic uses as well as to identify the potential effects of anthropogenic activities on groundwater quality in the region. The study found that while the majority of the groundwater of the region was of “good” quality, the coastal regions and a few isolated localities had less poor water quality. This observation is consistent with what Osiakwan et al. (2021) discovered. The fact that the ‘‘good’’ groundwater type dominates in the region reveals how the geology affects the groundwater resource in the region. That reveals the natural quality of the groundwater as it flows through the aquifer systems in the region. The scattered localities with either high or low WQI values within the region indicate either the effects of anthropogenic activities or the effects of other natural processes aside from rock-water interactions, such as seawater intrusion. Seawater intrusion is primarily responsible for the poor groundwater quality along the coast (Asare et al., 2022; Osiakwan et al., 2021). The study identified Eduafo and Asaman with WQI values of 850.68% and 313.44% respectively as localities where groundwater likely highly polluted by Seawater intrusion.

However, anthropogenic activities are primarily responsible for the poor water quality seen in the sporadic locations away from the coast. As was already mentioned, the majority of the population in the area is rural and relies on agrochemicals like weedicides, pesticides, fertilizers, etc. for both large- and small-scale farming. Once more, the abundance of gold-bearing minerals in the area continues to draw legitimate large- and small-scale mining operations as well as galamsey activities. By exposing the subsurface rock materials to the atmosphere through mining and related activities, different chemicals are released into the groundwater through processes like acid rock drainage. Chemicals are introduced into the soil through mining and related activities, where they dissolve and enter the water table during rainfall. When surface water is contaminated by galamsey activities, groundwater may also become contaminated as a result of groundwater-surface water interactions. Most people in rural areas practice open defecation, which has an impact on groundwater quality. The use of animal dung as manure and improper domestic and industrial waste disposal pollute the environment and groundwater resources. The study identified Eduafo, Asaman, Nyamebekyere, Bosomatwe, Asempanyin, Abora, Dadieso, Mesomagor, Mankata, Afadzato, Congo 1, Gyankrom 1, Gyankrom 2, Ayigbo, Aygbo with WQI of 850.68%, 313.44%, 616.04%, 212.10%, 478.12%, 614.10%, 206.97%, 225.99%, 286.25%, 2180.01%, 216.63%, 578.73% 327.28% 2166.94% 4805.85% respectively as localities where groundwater is likely highly polluted by anthropogenic activities (Fig. 11).

Conclusion

An integration of geostatistical and GIS techniques has been applied to investigate anthropogenic impact on groundwater quality in the Central Region of Ghana. In the region, there are four different forms of groundwater: $CaMgSO_4$, NaCl, $CaMgHCO_3$, and Mixed water. About 82.35% of the total variance was explained by six factors. Factor 1 accounted for 36.28%, Factor 2 for 14.14%, Factor 3 for 12.43%, Factor 4 for 8.90%, Factor 5 for 5.81%, and Factor 6 for 4.79%. EC, TDS, Na^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, TH, Ca^{2+} hardness, and Mg^{2+} hardness were in factor 1. The components of factor 2 were NH_4, PO_4, NO_2, NO_3, and F^-. Turbidity, Mn, Fe, and color were in factor 3. $CaCO_3$ and H_2CO_3 made up factor 4. Factor 5 included CO_3 and pH. Only K was in factor 6. Four clusters were visible using the cluster analysis method. Turbidity, color, pH, EC, TSS, TDS, Na^+, K^+, Ca^{2+}, Mg^{2+}, Fe, NH_4, SO_4, PO_4, Mn, NO_2, NO_3, $CaCO_3$, Ca^{2+} hardness, Mg^{2+} hardness, F^-, $H_2CO_3^-$, and CO_3^{2-} were in Cluster 1. Cl^- and TH were in Cluster 2. Only TDS and only EC were in clusters 3 and 4, respectively.

According to this classification, the WQI showed that 6% of the groundwater samples had excellent quality, 54% had good quality, 22% had poor quality, 9% had very poor quality, and 9% were unfit for drinking. The natural groundwater quality was within the ‘‘good’’ class. The poor groundwater quality in some localities within the region was attributed to geogenic, seawater intrusion process and anthropogenic activities. Eduafo and Asaman with WQI values of 850.68% and 313.44% respectively were identified as locality of likely groundwater high pollution due to Seawater intrusion. Eduafo, Asaman, Nyamebekyere, Bosomatwe, Asempanyin, Abora, Dadieso, Mesomagor, Mankata, Afadzato, Congo 1, Gyankrom 1, Gyankrom 2, Ayigbo, Aygbo with WQI of 850.68%, 313.44%, 616.04%, 212.10%, 478.12%, 614.10%, 206.97%, 225.99%, 286.25%, 2180.01%, 216.63%, 578.73% 327.28% 2166.94% 4805.85% respectively were identified as communities of likely high groundwater pollution due to anthropogenic activities.

The study has shown that anthropogenic activities, seawater intrusion, ion exchange, rock weathering, and evaporation are factors that affect the quality of groundwater in the region. The anthropogenic activities affecting groundwater quality in the region include application of agrochemicals to farmlands, spreading animal dung on farms, galamsey, lack of hygienic conditions around boreholes, and the pit latrines. The study has demonstrated the significance of the integration of the GIS and geostatistical techniques in groundwater pollution investigation. Such an integration techniques aids in groundwater resources management and promotes the achievement of the Sustainable Development Goal Six (SDG 6), which calls for integrated water resource management.

Compliance with Ethical Standards

Ethical responsibilities of Authors: *The author has read, understood, and have complied as applicable with the statement on "Ethical responsibilities of Authors" as found in the Instructions for Authors”*

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References

Agyemang VO, (2022) "Application of geostatistical techniques in the assessment of groundwater contamination in the Afigya Kwabre District of Ghana". *App. Water Sci.* **12**, Article number: 53 (2022). https://link.springer.com/article/10.1007/s13201-022-01582-x

America Public Health Association (1995) Standard methods for the examination of water and wastewater, 19th edition, Washington, DC. https://www.scirp.org/(S(351jmbntvnsjt1aadkposzje))/reference/ReferencesPapers.aspx?ReferenceID=1883439

Anku YS, Banoeng-Yakubo B, Asiedu DK, Yidana SM, (2009). "Water Quality Analysis of Groundwater in Crystalline Basement Rocks, Northern Ghana", *Environ-mental Geology*, **58**(5), pp. 989-997. DOI: https://doi.org/10.1007/s00254-008-1578-4

Aral MM, Maslia ML, Ulirsch GV, Reyes JJ, (1996). Estimating Exposure to Volatile Organic Compounds from Municipal Water-Supply Systems: Use of a Better Computational Model. Archives of Environ. Health: An Int. J., **51**(4), 300-309. DOI: 10.1080/00039896.1996.9936029

Asante-Annor A, Acquah J, Ansah E, (2018) Hydro-geological and Hydrochemical Assessment of Basin Granitoids in Assin and Breman Districts of Ghana. J..Geoscience & Environ. Protec., **6**. DOI: 10.4236/gep.2018.69004

Asare A, Appiah-Adjei EK, Owusu-Nimo F, Ali B, (2022) Lateral and vertical mapping of salinity along the coast of Ghana using Electrical Resistivity Tomography: The case of Central Region. Results in Geophys. Sci. 12 (2022) 100048. https://doi.org/10.1016/j.ringps.2022.100048

Banoeng-Yakubo B, Yidana SM, Anku Y, (2009). "Water quality characterization in some Birimian aquifers of the Birim Basin, Ghana: *KSCE J.Civil Engin..* Volume 13, Issue 3, pp 179–187. https://link.springer.com/article/10.1007/s12205-009-0179-4

Belkhiri L, Abderrahmane B, Mouni L, (2010) A multivariate Statistical Analysis of Groundwater Chemistry Data. Int. J. Environ. Res., **5**(2):537-544, Spring 2011 ISSN: 1735-6865. https://www.researchgate.net/publication/236612300_A_multivariate_Statistical_Analysis_of_Groundwater_Chemistry_Data

Celesceri L, Greenberg AE, Eaten AD, (1998) Standard methods for the examination of water and waste water. *Am. Public Health Assoc.n*, Washington, p 134. https://www.worldcat.org/title/Standard-methods-for-the-examination-of-water-and-wastewater/oclc/40733179

Couillard D, Lefebvre Y, (1985). Analysis of Water Quality Indices. J. of Environ. Management **21**:161-179.https://scholar.google.com/scholar_lookup?title=Analysis%20of%20water%20quality%20indices&journal=Journal%20of%20Environmental%20Management&volume=21&pages=161-179&publication_year=1985&author=Couillard%2CD&author=Lefebvre%2CY

Davalos-Pena I, Fuentes-Rivas RM, Fonseaca-Montes de Oca RMG, Ramos-Leal JA, Moran-Ramirez J, Alva GM, (2021) Assessment of physicochemical groundwater quality and hydrogeochemical processes in an area near a municipal landfill site: A case study of the Toluca Valley. Int. J. Environ. Res. Public Health **18**(21):11195. doi:10.3390/ijerph182111195

Ewusi A, Kuma JS, (2010), "Calibration of Shallow Borehole Drilling Sites Using the Electrical Resistivity Imaging Technique in the Granitoids of Central Region, Ghana", *Natural Resources Research,* **20**, pp. 57-63. https://doi.org/10.1007/s11053-010-9129-6

Foster S, Pulido-Bosch A, Vallejos Á, Molina L, Llop A, MacDonald AM (2018). Impact of irrigated agriculture on groundwater-recharge salinity: a major sustainability concern in semi-arid regions. *Hydrogeo. J.*, **26**(8), 2781–2791. https://link.springer.com/article/10.1007/s10040-018-1830-2

Galloway JN, Townsend AR, Erisman JW, Bekunda M, Cai Z, Freney JR, Martinelli LA, Seitzinger SP, Sutton MA (2008). Transformation of the Nitrogen Cycle: Recent Trends, Questions, and Potential Science, **320**(5878), 889 LP – 892. DOI: 10.1126/science.1136674

Ganyaglo SY, Osae S, Akiti T, Armah T, Gourcy L, Vitvar T, Otoo IA, (2017) Application of geochemical and stable isotopic tracers to investigate groundwater salinity in the Ochi-Narkwa Basin, Ghana. Hydrol. Sci. J. **62** (8), 1301–1316. DOI: 10.1080/02626667.2017.1322207

Garrels RM, Mackenzie ET, (1967) Origin of the chemical compositions of some springs and lakes. *Advance Chemical.* Ser. 67: 222-242. Géology Minière, France. 88: 402 p. DOI: 10.1021/ba-1967-0067.ch010

Ghana Statistical Services (2010) Population and housing census. https://statsghana.gov.gh/gssmain/fileUpload/pressrelease/2010_PHC_National_Analytical_Report.pdf

Gibbs RJ, (1970) Mechanisms controlling world water chemistry. Science Journal **170**:795–840. DOI: 10.1126/science.170.3962.1088

Hem JD, (1985). Study and Interpretation of the Chemical Characteristics of Natural Water. 3rd Edition. *U.S. Geological Survey Water-Supply* Paper **2254**, 263. https://doi.org/10.3133/wsp2254

Hussain MS, Abd-Elhamid HF, Javadi AA, Sherif MM, (2019). Management of Seawater Intrusion in Coastal Aquifers: A Review. Water, 11(12) *(Advances in Groundwater and Surface Water Monitoring and Management),* **2467**. DOI: 10.3390/w11122467

Jean-Claude R, (1995). The evolution of groundwater quality in France: perspectives for enduring use for human consumption. *Sci. Total Environ. J.* **171**(1995). pp3-16. DOI: 10.1016/0048-9697(95)04695-x

Karanth KR, (1989). Groundwater assessment, Development and Management.Tata McGraw-Hill, New Delhi. https://link.springer.com/article/10.1007/s10661-010-1422-7

Koh DC, Mayer B, Lee KS, Ko KS, (2010). Land-use controls on sources and fate of nitrate in shallow groundwater of an agricultural area revealed by multiple environmental tracers. *J. Cont.n Hydrology* **118**:62–78. DOI: 10.1016/j.jconhyd.2010.08.003

Kortatsi BK, (2007). Hydrochemical framework of groundwater in the ankobra basin, Ghana. *Aquatic Geochem,* **13**: 41-74. DOI: 10.1007/s10498-006-9006-4

Lapworth DJ, MacDonald AM, Kebede S, Owor M, Chavula G, Fallas H, Wilson P, Ward JST, Lark M, Okullo J, Mwathunga E, Banda S, Gwengweya G, Nedaw D, Jumbo S, Banks E, Cook P, Casey V, (2020). Drinking water quality from rural handpump-boreholes in Africa. *Environmental Research Letters,* 15(6), 64020. DOI: 10.1088/1748-9326/ab8031

Leube A, Hirdes W, Mauer R, Kesse GO, (1990). The Early Proterozoic Birimian Supergroup of Ghana and Some Aspects of Its Associated Gold Mineralization. *Precambrian Res.* **46**, 139–165. https://doi.org/10.1016/0301-9268(90)90070-7

McGrorya E, Holianb E, Morrison L, (2020) Assessment of groundwater processes using censored data analysis incorporating non-detect chemical, physical, and biological data. *Journal of Contaminant Hydrology.* Volume 235, November 2020, 103706. https://doi.org/10.1016/j.jconhyd.2020.103706

Morel N, Bouryi V, Gomez JP, Godfraind T, (1996). Molecular selectivity of the action of calcium channel antagonists. *Arch. Int. Pharmacodyn. Ther.,* 331, 332. DOI: 10.1038/sj.bjp.0702162

National Groundwater Association News (2016) Groundwater **54**(2):150-150. https://www.ngwa.org/publications-and-news/Newsroom

Osiakwan GM, Appiah-Adjei EK, Kabo-Bah AT, Gibrilla A, Anornu G, (2021) Assessment of groundwater quality and the controlling factors in coastal aquifers of Ghana: An integrated statistical, geostatistical and hydrogeochemical approach. *J.African Earth Sci..* **184**, December 2021, 104371. https://doi.org/10.1016/j.jafrearsci.2021.104371

Otto M, (1998) Multivariate methods. In: Kellner, R., Mermet, J.M., Otto, M., Widmer, H.M. (Eds.), Analytical Chemistry. WileyeVCH, Weinheim. https://link.springer.com/article/10.1007/s10661-006-9497-x

Piper AM, (1944) A graphic procedure in the geochemical interpretation of water analyses. – *Trans. Am. Geophy.l Union,* **25**, 914–928. https://doi.org/10.1029/TR025i006p00914

Schoeller H, (1965). Qualitative evaluation of groundwater resource. In: Methods and techniques of groundwater investigation and development. *UNESCO,* pp 54-83. DOI: 10.12691/ajwr-1-4-1

Selmane T, Dougha M, Hasbaia M, Ferhati A, Redjem A, (2022) Hydrogeochemical processes and multivariate analysis for groundwater quality in the arid Maadher region of Hodna, northern Algeria. Acta Geochim (2022) **41**(5): 893–909. https://english.gyig.cas.cn/pu/papers_CJG/202209/P020220922508944108707.pdf

Singh S, Jayaram R, (2022) Attainment of water and sanitation goals: a review and agenda for research. *Sust. Water Reso. Manag.* **8**; 146 (2022). https://link.springer.com/article/10.1007/s40899-022-00719-9

Spalding RF, Exner ME, (1993). Occurrence of Nitrate in Groundwater—A Review. *J. Environ. Quality,* **22**(3), 392–402. https://doi.org/10.2134/jeq1993.00472425002200030002x

Tiwari AK, Singh AK, (2014) Hydrogeochemical Investigation and Groundwater Quality Assessment of Pratapgarh District, Uttar Pradesh. *Journal of the Geological Society of India*, 83(3):329-343p. DOI: 10.1007/s12594-014-0045-y

Varol S, Davraz A, (2014) Evaluation of the groundwater quality with WQI (Water Quality Index) and multivariate analysis: a case study of the Tefenni plain (Burdur/Turkey). *Environ Earth Sci*. doi:10.1007/s12665-014-3531-z.

World Health Organization (2008) Guidelines for drinking-water quality: incorporating 1st and 2nd addenda, **1,** Recommendations 978 92 4 1547611. https://www.who.int/publications/i/item/9789241547611

World Health Organization (2012) Edition of the Drinking Water Standards and Health Advisories Environmental Protection Agency 822-S-12-001 Washington, DC. https://rais.ornl.gov/documents/2012_drinking_water.pdf

Yidana SM, Yidana A, (2010). Assessing water quality using water quality index and multivariate analysis. *J.Environ. Earth Sci.* **59**:1461–1473. https://link.springer.com/article/10.1007/s12665-009-0132-3

Yidana SM, (2008) A multivariate statistical analysis of surface water chemistry data-The Ankobra Basin, Ghana: *J. Environ. Manag.*. **86**, 1, 80-87. DOI: 10.1016/j.jenvman.2006.11.023

Yogendra K, Puttaiah ET, (2008) "Determination of water quality index and suitability of an urban waterbody in Shimoga Town, Karnataka", Proceedings of 12th World Lake Conference, pp. 342-346.https://www.academia.edu/32049089/Determination_of_Water_Quality_Index_and_Suitability_of_an_Urban_Waterbody_in_Shimoga_Town_Karnataka