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Geostatistical analysis for characterization of groundwater quality in Igbokoda coastal aquifer of Dahomey Basin

Thompson Henry Tolulope Ogunribido*

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Author Affiliation:
Department of Earth Sciences, Adekunle Ajasin University, Akungba – Akoko, Ondo State, Nigeria

***Corresponding Author**
Department of Earth Sciences, Adekunle Ajasin University,
Akungba – Akoko, Ondo State,
Nigeria
Email: thompson.ogunribido@aaua.edu.ng

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ABSTRACT

Thirty-one samples of groundwater were collected in the study area and the samples collected were carried to Adekunle Ajasin Research laboratory where each sample was analyzed for 27 parameters. Anions concentrations were determined by titration while heavy metals by Atomic Absorption Spectrophotometer and sodium and potassium by flame photometer. Descriptive, correlation coefficient, cluster, and factor analyses were the geostatistical methods used for the interpretation of the data. The aim is to determine the spatial variability of groundwater samples and their chemical evolution. The results showed that the major pollutants in the groundwater samples were Mg2+ and Cl- due to saltwater intrusion from the Atlantic Ocean, iron, oil, and grease. Cluster analysis classified water into 3 groups; fresh, intermediate, and polluted water due to their geochemical and location characteristics. There were 4 factor analyses; factor 1 indicated high loading of magnesium and chloride. Magnesium and chloride were responsible for the groundwater pollution and are likely to be due to saltwater intrusion. Factor 2, showed a high loading of calcium and calcium hardness. Observed temporary hardness was caused by calcium hardness. Factor 3, exhibits a high loading of sodium and potassium which may be due to saltwater intrusion. Factor 4, showed high loading of manganese and zinc and low loading of sulphate. Manganese and zinc might be derived from ores. Some of the groundwater samples are good for drinking but those in locations 3, 4, 5, 20, 21, 21, 23, and 28 which were polluted should be treated or discarded to avoid public health hazards.

Keywords: Factor analysis, cluster analysis, hydrogeochemical, Dahomey basin, groundwater

1. INTRODUCTION

Groundwater is an essential component of the natural environment and its quality is a matter of serious concern today. The variation in the quality of water is essentially the combination of both anthropogenic and natural contributions (Chen–Wuing et al.,

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2003). Factor and cluster analyses are the main tools for analyzing and classifying large numbers of samples collected in surveys and evaluating human impacts on water quality and ecosystem. Monitoring of water quality is essential due to the effects of anthropogenic factors on groundwater quality and the results generated from monitoring may be large and complicated to interpret. Drawing meaningful conclusions may also be difficult.

The use of factor and cluster analyses in the interpretation of complicated data matrices increases our knowledge about the study area's ecological features and groundwater quality. These methods enable the identification of potential sources that could have an impact on water environmental systems and provide a useful tool for the efficient management of water resources and pollution problems

Location and Geology of the study area

The study area lies within latitudes 6o 1′ N and 6o 6′ North of the Equator and longitudes 4o 43′ E and 5o 58′ East of the Greenwich Meridian, covering coastal aquifers in two local government areas. The two local governments are Irele and Okitipupa in central parts of the Dahomey basin, Southwestern Nigeria (Figure 1). Dahomey Basin is underlain by clastic sediments which rest unconformably on the crystalline Basement Complex. From the southeast of Ghana, to Togo and the Republic of Benin, to the southwestern Nigeria is the Dahomey basin which was separated from the Niger Delta by the Okitipupa Ridge, a subsurface basement high. According to Omosuyi, (2001), the major rock types were shale and sandstones, while the minor rock types were limestone and unconsolidated sediments, and their age ranged from Albian to recent.

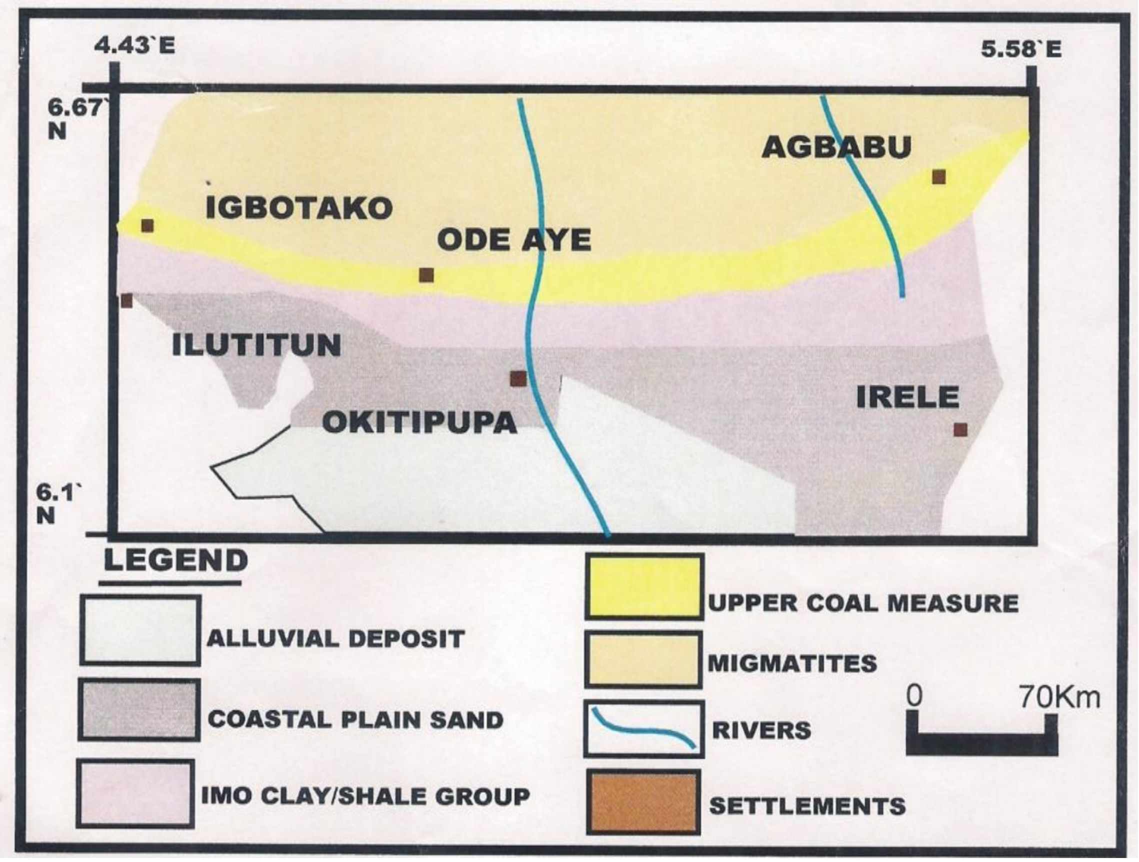

Figure 1 Geological map of the study area (Modified after)

According to Omatsola and Adegoke, (1981), the Dahomey basin consist of several horst and graben. The Abeokuta group, Oshosun Formation, and alluvial deposits are the rock types in the study area. The Abeokuta Group is the cretaceous rock type that overlies the Basement complex and is also the oldest and most abundant. Abeokuta is consisting of conglomerates, sandstones, sandy limestone, clays, and shale. Age is from Neocomian to Paleocene (Omatsola and Adegoke, 1981). The Akinbo Formation; overlies the Araromi Formation. It consists of a clayey shale sequence. The shale sequence is glauconitic gray shale.

The Akinbo Shale is characterized by greenish-grey, thickly laminated, and very richly fossiliferous shale. Oshosun/Ilaro Formation: This is made up of sandstone, mudstones, glauconites, and, phosphates. Their age is Eocene. The structure of the sandstone is massive, yellowish, poorly consolidated, cross-bedded which is fine to medium-grained and poorly sorted. Alluvial deposit/ Benin Formation: this is the youngest geologic formation in the Dahomey basin, the age is recent. Benin consists of soft, very poorly sorted clayey sands, pebbly sands, sandy clays, and rare thin lignite.

2. MATERIALS AND METHOD

Samples were collected from 31 groundwater using clean 2-liter plastic bottles which were previously washed with 2% HNO3 and were then rinsed with the water from the sampling points. Before the collection of each sample, GPS was used to measure their location. A digital conductivity meter was used to measure pH, EC, and TDS in the field. The standard methods recommended by the American Public Health Association APHA, (1992) were used to examine 27 parameters from each sample, including Na+, K+, Ca2+, Mg2+, HCO3, Cl, and SO42- among others. Cations and heavy metals concentrations were analyzed using an atomic absorption spectrophotometer, sodium, and potassium by flame photometer, and anions by titration. Geostatistical methods (Descriptive, correlation, factor, and cluster analyses) were used for the interpretation of the hydrogeochemical data. A cluster was applied for the grouping of 31 different groundwater using the ward's linkage method.

A scheme that measure similarities by Euclidean distance together with the Ward method for linkage produces the most distinctive groups where each member within group is more similar to its fellow member than to any member outside the group. The type of factor extraction utilized was factor analysis, and the eigenvalues were the percentage of variation explained by each factor; each parameter had a variance of 1, and the overall variance for the entire data set was 25. Varimax rotation, an orthogonal rotation method that reduced the number of variables that had high loading on each factor, was applied to the factors. When the loading on the Varimax rotation is greater than 0.75, it is considered strong and indicates that a significant amount of the variance is explained by the factor. When the loading is between 0.50 and 0.75, it is considered moderate, and when it is between 0.30 and 0.50, it is weak and indicates that little to no variance is explained, making the attribute less significant (Reghunath et al., 2002).

3. RESULTS AND DISCUSSION

The results of physical parameters are presented in Table 1, compound and anion constituents in Table 2, and metallic constituents of the groundwater samples in Table 3 as shown below:

Table 1 Physical parameters for groundwater

Location	Town	Longitudes	Latitudes	pH	Ec	TDS	Temp	Soil Type
1	Ode – Irele	N06o29.028′	E004o52.486′	8.39	130	90	29.4	Sandy clay
2	Ode – Irele	N06o29.065′	E004o52.336′	8.38	270	190	29.7	Sandy clay
3	Ode – Irele	N06o29.658′	E004o51.272′	8.21	10	01	28.7	Sandy clay
4	Ode – Irele	N06o29.554′	E004o52.142′	8.34	290	200	28.3	Sandy clay
5	Ode – Irele	N06o40.620′	E004o50.828′	8.34	200	140	28.3	Lateritic
6	Ode – Irele	N06o40.109′	E004o50.334′	8.35	190	130	28.9	Clayed soil
7	Ode – Irele	N06o37.222′	E004o49.664′	8.34	150	160	29.0	Clayed soil
8	Agbabu	N06o35.524′	E004o49.343′	8.34	140	100	28.7	Clay soil
9	Agbabu	N06o35.177′	E004o49.839′	8.34	230	160	29.0	Clayed soil
10	Agbabu	N06o36.284′	E004o49.829′	8.33	30	20	28.7	Clayed
11	Okitipupa	N06o30.466′	E004o47.051′	8.34	50	30	28.6	Clayed
12	Okitipupa	N06o30.268′	E004o46.893′	8.34	30	20	28.3	Clayed
13	Okitipupa	N06o30.022′	E004o46.725′	8.70	50	30	28.8	Clayed soil

14	Igbodigo	N06o27.994′	E004o45.065′	8.67	40	30	28.9	Sandy soil
15	Ayeka	N06o29.531′	E004o47.353′	8.34	120	90	28.8	Sandy soil
16	Ayeka	N06o29.528′	E004o47.117′	8.35	210	150	29.0	Sandy soil
17	Ikoya	N06o30.478′	E004o41.611′	8.34	70	50	29.1	Sandy soil
18	Ikoya	N06o30.587′	E004o41.402′	8.08	230	160	28.7	Sandy soil
19	Abusoro	N06o29.318′	E004o42.257′	8.04	80	90	27.8	Sandy soil
20	Oda-Aye	N06o34.789′	E004o44.514′	8.18	10	10	29.0	Sandy soil
21	Oda-Aye	N06o35.345′	E004o44.597′	8.23	30	20	29.3	Sandy soil
22	Agbaje	N06o33.034′	E004o47.541′	8.60	30	20	28.6	Sandy soil
23	Agbaje	N06o33.108′	E004o47.491′	8.51	100	70	28.3	Sandy soil
24	Igbotako	N06o33.859′	E004o38.547′	8.58	40	20	28.9	Sandy soil
25	Igbokato	N06o34.608′	E004o38.321′	8.47	60	40	28.9	Clayey soil
26	Iju-Odo	N06o33.149′	E004o39.025′	8.34	40	30	28.7	Sandy clay
27	Iju-Odo	N06o32.981′	E004o38.826′	8.39	30	20	28.7	Sandy clay
28	Ilutitun	N06o31.889′	E004o38.555′	6.73	870	590	30.1	Sandy
29	Ilutitun	N06o31.608′	E004o38.059′	8.39	130	90	29.4	Clayey
30	Ilutitun	N06o31.924′	E004o38.357′	8.38	270	190	29.7	Clayey
31	Ilutitun	N06o31.370′	E004o38.167′	8.21	10	01	28.7	Clayey

Table 2 Compound and anion constituents of Groundwater in rainy Season

S/N	**HCO3-**	**Total Alkalinity CaCO3**	**Cl-**	**Turbidity NTU**	**NO3 -**	**PO42-**	**SO42-**	**Oil and Grease**	**Calcium Hard as CaCO3**	**Total Hardness**
1	18.3	18.3	67.36	0.12	0.09	0.06	0.12	1.02	4.00	16.05
2	30.5	30.5	77.99	0.27	0.01	0.6	0.26	0.4	9.00	31.81
3	30.5	30.5	39.0	0.06	0.09	0.36	0.27	0.77	9.00	18.69
4	36.6	36.6	77.99	0.02	0.01	0.51	0.22	0.73	51.0	78.97
5	54.9	54.9	70.9	0.02	0.01	0.04	0.42	0.85	18.9	29.34
6	24.4	24.4	88.63	0.14	0.02	0.06	0.44	0.68	3.80	26.32
7	12.2	12.2	81.54	0.13	0.06	0.21	0.06	0.68	20.0	33.59
8	30.5	30.5	60.27	0.02	0.01	0.08	0.2	0.52	8.00	13.4
9	86.93	86.93	67.36	0.02	0.05	0.08	0.27	1.41	30.00	42.26
10	122	122	60.27	0.11	0.02	0.12	0.27	0.77	3.00	11.73
11	134.2	134.2	3.56	0.06	0.15	0.01	0.1	0.94	8.00	12.67
12	42.7	42.7	31.91	0.01	0.00	0.06	0.31	1.25	12.0	17.78
13	48.8	48.8	39.0	0.01	0.01	0.15	0.17	0.85	10.0	14.46
14	30.5	30.5	39.0	0.01	0.01	0.09	0.01	0.63	12.0	17.54
15	42.7	42.7	56.72	0.01	0.70	0.06	0.21	0.74	20.0	35.53
16	30.5	30.5	53.18	0.01	0.04	0.05	0.33	0.78	28.0	46.02
17	18.3	18.3	46.09	0.01	0.04	0.72	0.09	0.74	7.00	5.89
18	48.8	48.8	81.54	0.02	0.10	0.32	0.67	1.56	12.0	19.22
19	42.7	42.7	70.9	0.02	0.02	0.42	0.66	1.51	6.00	9.63
20	30.5	30.5	56.72	0.01	0.02	0.46	0.29	1.46	10.00	15.47
21	30.5	30.5	49.63	0.01	0.01	0.44	0.19	1.53	12.00	18.68
22	36.6	36.6	35.45	0.01	0.01	0.06	0.11	0.61	6.0	10.6

23	54.9	54.9	46.09	0.01	0.03	0.06	0.51	0.55	11.0	17.34
24	30.5	30.5	46.09	0.01	0.03	0.07	0.29	0.64	6.00	9.63
25	30.5	30.5	49.63	0.02	0.03	0.23	0.41	0.63	7.00	11.75
26	18.3	18.3	49.63	0.02	0.02	0.13	0.07	0.75	4.00	7.06
27	42.7	42.7	56.72	0.02	0.01	0.08	0.23	1.81	6.00	9.38
28	256.2	256.2	666.46	0.22	0.19	0.39	0.47	0.65	9.00	86
29	18.3	18.3	67.36	0.12	0.09	0.06	0.12	1.02	4.00	16.05
30	30.5	30.5	77.99	0.27	0.01	0.6	0.26	0.4	9.00	31.81
31	30.5	30.5	39.0	0.06	0.09	0.36	0.27	0.77	9.00	18.69

Table 3 Metallic constituents of Groundwater in rainy Season

S/N	**Mg2+**	**Ca2+**	**Na+**	**K+**	**Zn2+**	**Total Fe**	**Cr6+**	**Pb2+**	**Cd2+**	**As3+**	**Ni2+**	**Cu2+**	**Mn2+**
1	10.45	1.6	9.25	6.04	0.12	0.007	0.021	.00	0.001	.002	0.01	0.09	0.31
2	19.2	3.61	7.3	4.29	0.31	0.009	0.017	.001	0.001	.001	0.01	0.1	0.22
3	6.08	3.61	7.44	2.98	0.4	0.004	0.016	.002	0.003	.001	0.01	0.11	0.54
4	7.53	20.44	4.67	1.97	0.41	0.009	0.02	.001	.003	.002	0.01	0.19	0.51
5	4.13	7.21	5.98	2.59	0.33	0.010	0.02	.002	.002	.001	0.01	0.17	0.52
6	7.29	15.23	6.06	2.2	0.18	0.008	0.02	.001	.001	.001	0.01	0.1	0.32
7	5.59	8	11.06	6.73	0.2	0.013	0.02	.00	.003	.002	0.01	0.81	0.26
8	2.19	3.21	5.23	2.01	0.15	0.005	0.02	.001	.001	.003	0.01	0.81	0.3
9	0.24	12.02	10.21	3.96	0.21	0.001	0.02	.001	.002	.003	0.01	0.09	0.19
10	7.53	1.2	4.11	1.39	0.21	0.01	0.02	.003	.002	.001	0.01	0.11	0.31
11	1.46	3.21	3.99	1.26	0.23	0.01	0.02	.00	.001	.001	0.01	0.1	0.22
12	0.97	4.81	8.23	2.12	0.18	0.001	0.02	.001	.003	.001	0.01	0.08	0.2
13	0.45	4.01	8.62	1.76	0.23	0.002	0.02	.001	.002	.001	0.01	0.1	0.2
14	0.73	4.81	10.33	3.16	0.16	0.004	0.02	.003	.002	.003	0.01	0.1	0.26
15	7.53	8.00	7.99	3.63	0.18	0.01	0.02	.002	.001	.002	0.01	0.09	0.21
16	6.8	11.22	6.18	2.16	0.17	0.00	0.02	.001	.003	.002	0.01	0.09	0.29
17	6.08	2.81	4.3	1.23	0.22	0.001	0.02	.003	.001	.002	0.01	0.11	0.4
18	2.41	4.81	9.98	3.23	0.18	0.00	0.02	0.0	.003	.001	0.01	0.08	0.22
19	1.22	2.41	7.21	2.13	0.25	0.00	0.01	.002	.003	.001	0.00	0.1	0.31
20	1.46	4.01	9.99	3.73	0.23	0.001	0.01	.002	.003	.002	0.01	0.11	0.32
21	4.37	2.31	10.16	3.17	0.15	0.002	0.02	.001	.002	.001	0.01	0.09	0.28
22	2.19	2.41	9.27	3.1	0.32	0.009	0.01	.002	.002	.001	0.01	0.15	0.52
23	1.94	4.4	7.29	1.99	0.31	0.001	0.01	.001	.001	.001	0.01	0.21	0.53
24	1.22	2.41	5.87	1.73	0.18	0.006	0.01	.001	.001	.001	0.01	0.12	0.42
25	1.94	2.81	9.21	2.01	0.3	0.003	0.01	.001	.003	.001	0.01	0.13	0.51
26	1.46	1.6	8.99	2.3	0.17	0.002	0.02	.00	.001	.002	0.01	0.1	0.38
27	0.97	2.41	11.03	3.98	0.19	0.005	0.02	.00	.002	.003	0.01	0.11	0.31
28	73.39	3.61	9.32	4.25	0.31	0.001	0.02	.003	.003	.001	0.01	0.11	0.5
29	10.45	1.6	9.25	6.04	0.12	0.007	0.021	.00	0.001	.002	.01	0.08	0.2
30	19.2	3.61	7.3	4.29	0.31	0.009	0.017	.001	0.001	.001	0.00	0.1	0.17

Descriptive Statistics

Basic statistics were carried out to give initial information about the water quality data. Groundwater data in the study area were subjected to factor and cluster analyses, and descriptive statistics. Table 4 below shows the details of descriptive statistics in the study area

Table 4 Descriptive statistics of the groundwater

S/N	Parameters	Minimum	Maximum	Mean	Standard deviation	Coefficient of variation
1	HCO3- mg/L	12.20	256.20	48.26	47.25	97.9
2	Cl- mg/L	3.56	666.46	75.93	111.11	146
3	SO42- mg/L	0.01	0.67	0.27	0.16	59.3
4	Oil mg/L	0.40	1.81	0.89	0.37	41.6
5	Ca2+hard	3.00	51.00	11.76	9.82	83.5
6	T hard mg/L	5.89	86.00	23.66	18.75	79.2
7	Mg2+ mg/L	0.24	73.39	71.18	13.20	18.5
8	Ca2+ mg/L	1.20	20.44	5.06	4.34	85.8
9	Na+ mg/L	3.99	11.06	7.85	2.10	26.8
10	K+ mg/L	1.23	6.73	3.05	1.41	40.3
11	Zn2+ mg/L	0.12	0.41	0.24	0.95	396
12	Cu 2+ mg/L	0.08	0.81	0.15	0.14	93.3
13	Mn2+ mg/L	0.17	0.54	0.34	0.47	138
14	pH	6.73	8.70	8.30	0.20	2.4
15	EC µS/cm	10	290	137.9	0.39	0.3
16	TDS mg/L	01	590	95.03	9.5	10.0
17	Temp oC	27.8	30.1	28.9	0.56	2.0
18	NO3- mg/L	0.01	0.26	0.06	0.02	23

Anions hydrogeochemistry

Bicarbonate: The highest concentration of bicarbonate was 256.2 mg/L and the lowest was 12.2 mg/L, the mean concentration was 48.26 mg/L and the standard deviation was 47.25. There was no bicarbonate pollution, since drinking limit is 1000 mg/L.

Total alkalinity: Total alkalinity was measured with respect to calcium carbonate. Total alkalinity ranged between 18.3 mg/L and 256.2 mg/L, the mean concentration was 48.26 mg/L and the standard deviation was 47.25.

Chloride: Chloride anion was more pronounced in the deeper borehole than the hand-dug wells in the study area. A borehole in location 28 (Agbabu) recorded the highest concentration of 666.46 mg/L in this study. The lowest chloride concentration for groundwater was 3.56 mg/L. High concentrations of chloride might be due to saline water intrusion.

Turbidity: The concentration of the turbidity in the groundwater ranged between 0.01 NTU and 0.27 NTU. The mean concentration was 0.06 NTU; this was within the recommended limit of the drinking water standard.

Nitrate: The concentration of nitrate ranged between 0.01 mg/L and 0.70 mg/L and the mean concentration was 0.37 mg/L; this was a very low concentration. Here nitrate does not serve as a contaminant and therefore cannot cause health hazards since is below the 50 mg/L drinking water limit.

Phosphate: The concentration of phosphate was generally low. It ranged between 0.01 mg/L and 0.72 mg/L. Phosphate sources may be associated with agricultural practices in the study area.

Sulfate: Even though sulfate was one of the major anions present in natural water. The concentration of sulfate in groundwater in the study area was relatively low. The lowest concentration was 0.01 mg/L and the highest was 0.66 mg/L while the mean was 0.27 mg/L.

Oil and grease: Oil and grease may be due to oil spillage or decay of organic plants and animals. The highest concentration was 1.81 mg/L and the lowest was 0.4 mg/L. Oil and grease concentration was relatively low. The mean concentration was 0.91 mg/L; this also was a low concentration.

Calcium hardness: This was responsible for the temporary hardness in water. Calcium hardness concentration ranged between 3.80 mg/L and 30 mg/L. The mean concentration was 12.2 mg/L and the highest concentration which was 30 mg/L is below 100 mg/L drinking water standard.

Total hardness: Total hardness was relatively higher than the calcium hardness in the groundwater samples. The lowest concentration was 7.06 mg/L and the highest concentration was 46.02 mg/L.

Cations hydrogeochemistry

Nickel: Nickel concentration ranged from 0.0 mg/L to 0.01 mg/L, the mean concentration was 0.01 mg/L. Nickel concentration was below the drinking water standard of 0.02 mg/L (SON, 2007).

Magnesium: The highest concentration of magnesium was 73.39 mg/L in location 28 and the lowest was 0.45 mg/L while the mean was 6.7 mg/L. The drinking water standard for magnesium is 50 mg/L. Since the water sample in location 28 was above the drinking standard, therefore is not good for drinking purposes.

Calcium: Calcium is very essential for the development of bones. WHO, (2017) drinking water standard for calcium is 200 mg/L. The highest concentration was 20.44 mg/L and the lowest was 1.6 mg/L, all these values are within the drinking water limit.

Sodium: Over 200 mg/L is considered high and may cause corrosion of the water supply system particularly when that water is warm and alkaline. Sodium concentration ranged between 3.99 mg/L and 11.06 mg/L in the study area.

Lead: Lead concentration higher than 0.01 mg/L may be associated with lead poisoning (SON, 2007; WHO, 2017). Lead in the study area groundwater samples ranged between 0.0 mg/L and 0.003 mg/L and the mean was 0.00 2 mg/L.

Arsenic: Arsenic's highest concentration was 0.003 mg/L, lowest concentration was 0.001 mg/L and the mean concentration was 0.002 mg/L. Arsenic higher than 0.01 mg/L may cause black foot diseases (SON, 2007).

Cadmium: Cadmium concentration higher than 15 mg/L has been reported to cause nausea and vomiting in human beings. Cadmium in the groundwater ranged between 0.001 mg/L and 0.003 mg/L and the mean concentration was 0.002 mg/L.

Copper: The lowest concentration of copper was 0.08 mg/L and the highest concentration was 0.81 mg/L and the mean concentration was 0.16 mg/L. Copper concentration above 2 mg/L may cause gastrointestinal disorders.

Manganese: Manganese was another heavy metal tested for during the investigation. The lowest manganese concentration was 0.17 mg/L and the highest concentration was 0.54 mg/L. Manganese concentrations in locations 3, 4, 5, 20, 21, and 23 are higher than the drinking water standard of 0.5 mg/L. Groundwater in such locations may cause staining of laundry, hence they are to be discarded.

Factor analysis

The interpretation of hydrogeochemical data from groundwater samples, which were collected from some locations, was hampered because it is difficult to visualize and evaluate the geochemical relationships that may exist using normal histograms and Piper's trilinear diagrams. The purpose of factor analysis is to interpret the structure within the variance-covariance matrix of a Geo - statistical data collection which can be used for summarizing the data with minimal loss of information (Mahmud et al., 2007; Shrestha and Kazama, 2007; Machado et al., 2008; Yilmaz et al., 2010; Reghunat et al., 2002; Belkhiri et al., 2010; Ogunribido, 2011). Factor analysis reduces the overall complexity of the data by taking advantage of inherent interdependences. The geological interpretation of factors in the study area gives insight into the main processes that govern the distribution of hydrogeochemical variables.

The first step was to standardize the raw data, and then data in the correlation matrix were re-arranged in a manner that better explained the structure of the underlying system that produced the data. One part of the output from a factor analysis is a matrix of factor loading. Factor loading is the degree to which every variable correlates with a factor and the basis for imputing a label to different factors (Mahmud et al., 2007). A rule of thumb frequently used is that the absolute value of a factor loading greater than 0.3 is considered significant. The terms 'strong', 'moderate', and 'weak' as applied to factor loadings, refer to absolute loading values of > 0.75, 0.75 – 0.5, and 0.5 – 0.3 respectively (Chen–Wuing et al., 2003). R – Mode factor analysis was used to understand the hydrogeochemical association and processes controlling the groundwater in the study area. Factor analysis reduces the overall complexity of the data by taking advantage of inherent interdependences (Figure 2).

Factor Analysis for Groundwater

Factor 1

Factor 1 exhibits 37.39% of the total variance of 82.91% with high loading of Mg2+, Cl-, EC, TDS, and HCO3-, with moderate loading of total hardness and temperature (Table 5). Electrical conductivity is a useful parameter of water quality for indicating salinity hazards (Abida et al., 2009). Magnesium and chloride ions were responsible for high TDS value, hence high electrical conductivity. The temperature might be responsible for the fast dissolution of minerals; thereby Mg2+, Cl-, and HCO3- were released into the water. Total hardness might be responsible for temporary hardness in the water. Mg2+and Cl-, may be associated with seawater intrusion.

Factor 2

Factor 2 represents 16.73% of the total variance of 82.91% and is the second major factor with high loading of calcium hardness and Ca2+, and moderate loading of total hardness. The correlation coefficient (r= 0.67 to 0.82) among calcium hardness, calcium, and total hardness was very high (Table 5). Calcium hardness was responsible for the hardness of the water.

Factor 3

Factor 3 which explains 12.48% of the total variance, includes the high loading of Na+ and K+ and the low loading of oil and grease. The high loading of Na+ and K+ may be due to saltwater intrusion by which Ca2+ and Mg2+ were replaced by Na+ and K+ ions. The low loading of oil and grease which indicates an alkaline environment shows the role of dissolved CO2- in the groundwater system as a result of water action between the groundwater and oil and grease. Na+ and K+ may also be due to the dissolution of K- feldspathic minerals.

Factor 4

Factor 4 represents 10.01% of the total rotated variance of 82.91%, with high loading of Mn2+ and Zn2+ and low loading of SO42-. The presence of Mn2+ and Zn2+ may be due to ores of these minerals in the host rock, though there are no mining activities in the study area. The presence of SO42+ may be due to atmospheric precipitation rather than extraction from seawater (Olobaniyi and Owoyemi, 2006). Manganese and zinc were responsible for the contamination of the groundwater.

Table 5 Rotated varimax matrix for groundwater

Variables	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Mg2+	0.98	-0.06	-0.04	0.07	-0.11
Cl-	0.96	-0.03	0.12	0,15	0.05
Ec	0.93	0.27	0.06	0.07	0.04
TDS	0.91	0.30	0.11	0.07	-0.05
pH	-0.88	0.04	0.11	0.07	-0.27
HCO3-	0.79	-0.08	-0.23	0.05	0.23
T hard	0.70	0.68	-0.04	0.11	-0.08
Temp	0.63	-0.18	0.23	-0.39	-0.41
Ca2+ hard	0.01	0.95	0.01	0.09	-0.01
Ca 2+	0.02	0.94	-0.11	0.05	-0.01
Na+	0.03	-0.11	0.90	-0.13	0.15
K+	0.24	0.20	0.82	-0.24	-0.27
Mn2+	0.11	-0.4	-0.11	0.86	-0.05
Zn2+	0.15	0.20	-0.17	0.74	-0.05
Oil	-0.18	0.01	0.39	-0.27	0.79
SO42-	0.26	0.07	-0.07	0.36	-0.27
Cu2+	-0.09	0.14	0.26	0.19	-0.52
Total	6.355	2.844	2.121	1.701	1.072

% of variance	37.39	16.73	12.48	10.01	6.31
Cumulative	37.39	54.12	66.59	76.60	82.91

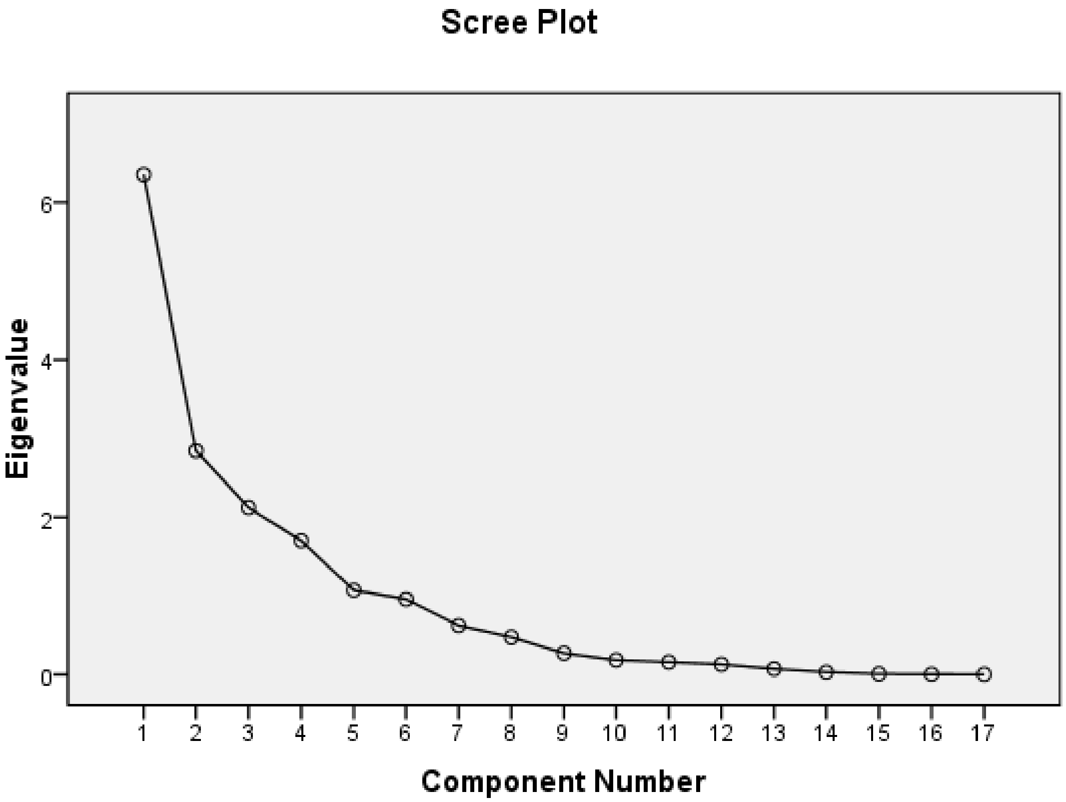

Figure 2 Scree plot for groundwater in rainy season

Factor 5

Factor 5 accounted for 6.31% of the variance with high loading oil and grease and moderate loading of SO42-. The presence of oil and grease may be due to decayed organic plants and animals or as a result of oil spills in the environment. SO42 may be due to atmospheric precipitation.

Cluster analysis for groundwater

Cluster analysis is a technique for grouping objects based on the characteristics they possess (Shrestha and Kazama, 2007). In clustering; the objects are grouped such that similar objects fall into the same class. Cluster analysis was used here to determine if the samples can be grouped into statistically hydrogeochemical groups that may be significant in the geologic context. Several studies used this technique to successfully classify water samples (Yilmaz et al., 2010; Pejman et al., 2009; Chenini and Khemiri, 2009; Hussain et al., 2008; Belkhiri et al., 2010; Ayenew et al., 2009).

Comparison based on multiple parameters from different samples was made and the samples were grouped according to their "similarity" to each other (Figure 3), in the present study Q – mode hierarchical cluster analysis was used to classify the samples into distinct hydrogeochemical groups. The dataset was treated by Ward's method of linkage with squared Euclidean distance as a measure of similarity. These clusters include sampling sites with similar characteristics features and natural backgrounds that are affected by sources of similar type/ strength. Cluster analysis suggests three groups for groundwater in the study area (Figure 3):

Group 1

Group 1 is composed of wells 2, 30, 4, 5, 16, 18, 6, 9, and 7 and this represent 29.1 % of the groundwater samples. The mean electrical conductivity value of this group is 270µS/cm, which is a characteristic of medium-contaminated water. This group was chloride-dominated; however, bicarbonate and magnesium ions were also present in the water.

Group 2

Group 2 consists of wells 1, 29, 8, 15, 19, 23, 17, 25, 3, 31, 20, 12, 22, 21, 24, 14, 27, 26, 13, 10 and 11. The dominant ion was chloride, though bicarbonate was also present in the water samples. This type of water has a mean concentration of electrical conductivity of 135µS/cm. It represents 67.7% of the groundwater samples.

Group 3

Cluster 3 was made up of water samples from well 28 only, which represent 3.2 % of the groundwater samples in the rainy season. The mean electrical conductivity for this group was 870µS/cm. This group of water was characterized by high calcium hardness and chloride-dominated. Cluster 3 was characterized by the biggest Euclidean distance to the cluster in groups 1 and 2. The dendrogram (Figure 3) clarifies the abnormality of the observation of well 28 which receives contaminant as a result of saline water intrusion. This could be attributed to higher mean electrical conductivity in this group.

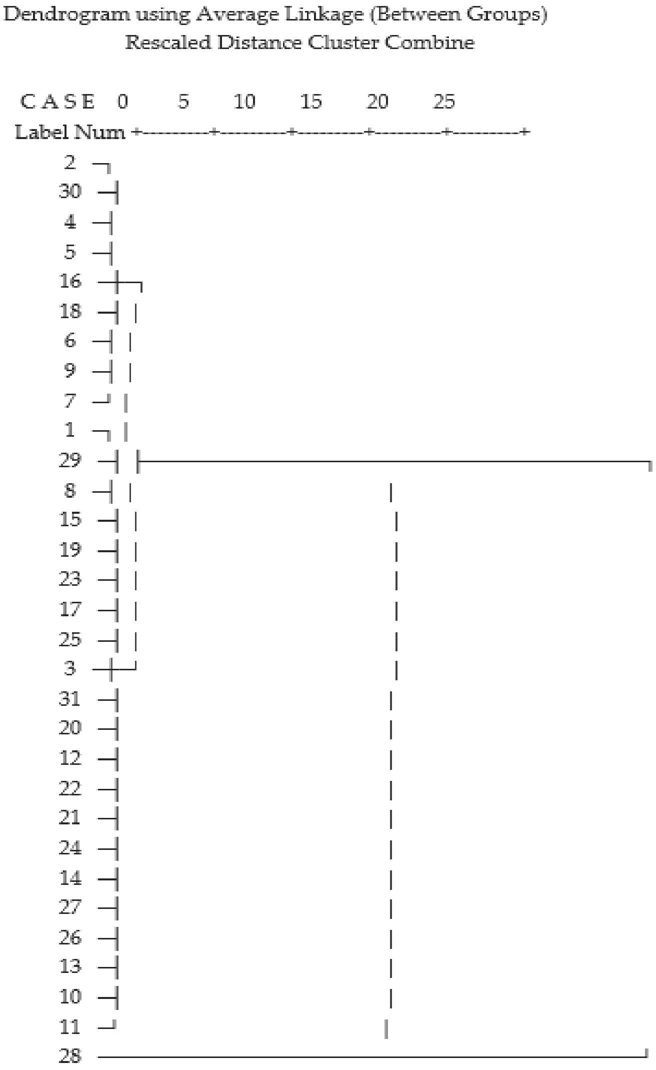

Figure 3 Dendrogram for groundwater

Correlation coefficient

There is a strong positive correlation coefficient between magnesium (r =0.95) and chloride ions in the groundwater samples, Electrical Conductivity (r =0.99) and Total Dissolved Solids (Table 6), pH (r = 0.91), and chloride. Magnesium and chloride ion increases the ions present in the groundwater samples, thereby increasing the total dissolved solids present in the water. The pH values slightly increase due to the acidic nature of chloride ions in solution.

Table 6 Correlation Matrix of Groundwater in the study area

	HCO3-	Cl_	SO42-	Oil	Ca2+hard	T hard	Mg2+	Ca2+	Na+	K+	Zn2+	Cu2+	Mn2+	pH	Ec	TDS	Temp
HCO3-	1																
Cl_	.77	1															
SO42-	.25	.28	1														
Oil	-0.01	-0.11	0.25	1													
Ca2+ hard	-0.02	-0.01	-0.01	0.01	1												
T hard	0.49	0.67	0.17	-0.20	0.69	1											
Mg 2+	0.71	0.95	0.17	-0.27	-0.05	0.67	1										
Ca2+	0.06	0.01	0.11	-0.08	0.82	0.64	0.04	1									
Na+	-0.10	0.15	-0.06	0.42	-0.09	-0.03	0.05	-0.19	1								
K +	-0.09	0.23	-0.22	0.11	-0.10	0.21	0.30	-0.07	0.65	1							
Zn2+	-0.17	0.16	0.23	-0.33	0.28	0.35	0.22	0.20	-0.24	-0.18	1						
Cu2+	0.15	-0.01	-0.20	-0.26	0.12	0.03	-0.07	0.08	-0.01	0.20	-0.10	1					
Mn2+	0.14	0.25	0.20	-0.28	0.07	0.16	0.7	0.06	-0.18	-0.28	0.51	0.03	1				
pH	-0.74	-0.91	-0.41	-0.11	0.02	-0.58	-0.85	0.03	-0.09	-0.17	-0.19	0.05	-0.18	1			
Ec	0.67	0.90	0.32	-0.21	0.25	0.83	0.89	0.28	-0.03	0.27	0.20	0.07	0.14	-0.78	1		
TDS	0.64	0.88	0.32	-0.20	0.27	0.83	0.88	0.29	0.05	0.31	0.18	0.09	0.12	0.78	0.99	1	
Temp	0.25	0.52	-0.25	-0.24	-0.18	0.33	0.66	-0.17	-0.25	0.54	-0.15	-0.08	-0.21	-0.37	0.53	0.51	1

Anthropogenic factors

Water rock interaction and human activities controlled the hydrogeochemical activities in the study area. The TDS values were plotted against the major ions as shown in Figures 4 to 10 Decrease of potassium, sodium, calcium, magnesium, sulfate, and chloride ions concentrations with increasing TDS (Figures 4, 5, 6, 7, 8, and 9) supports saltwater intrusion into the coastal aquifers from ocean water. The increase of bicarbonate with increasing TDS (Figure 10) supports the anthropogenic input of bicarbonate mainly from domestic waste. These samples of groundwater, indicate they might have come from the transition zone.

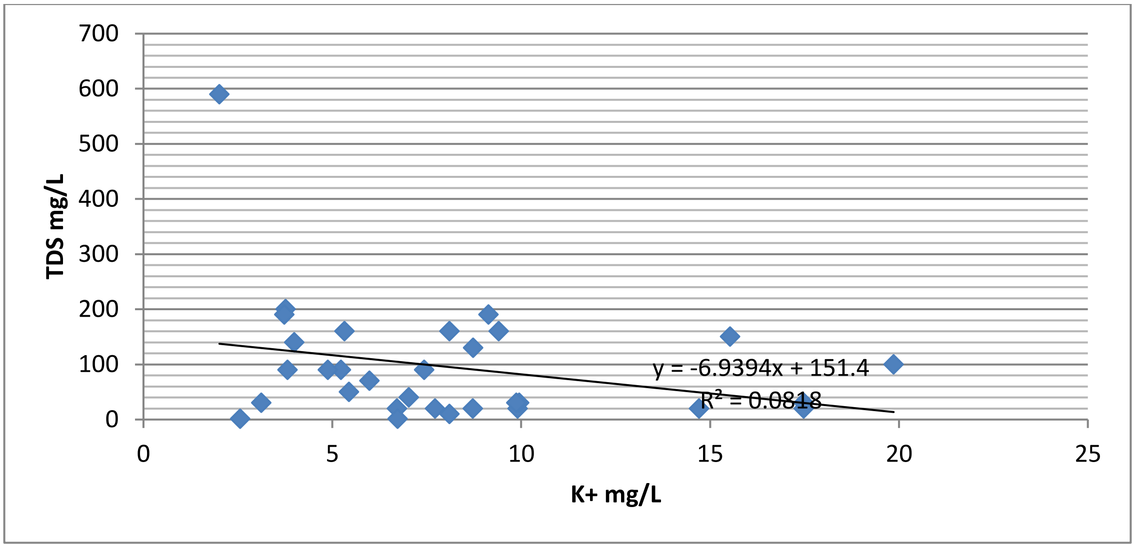

Figure 4 Graph of TDS and K+

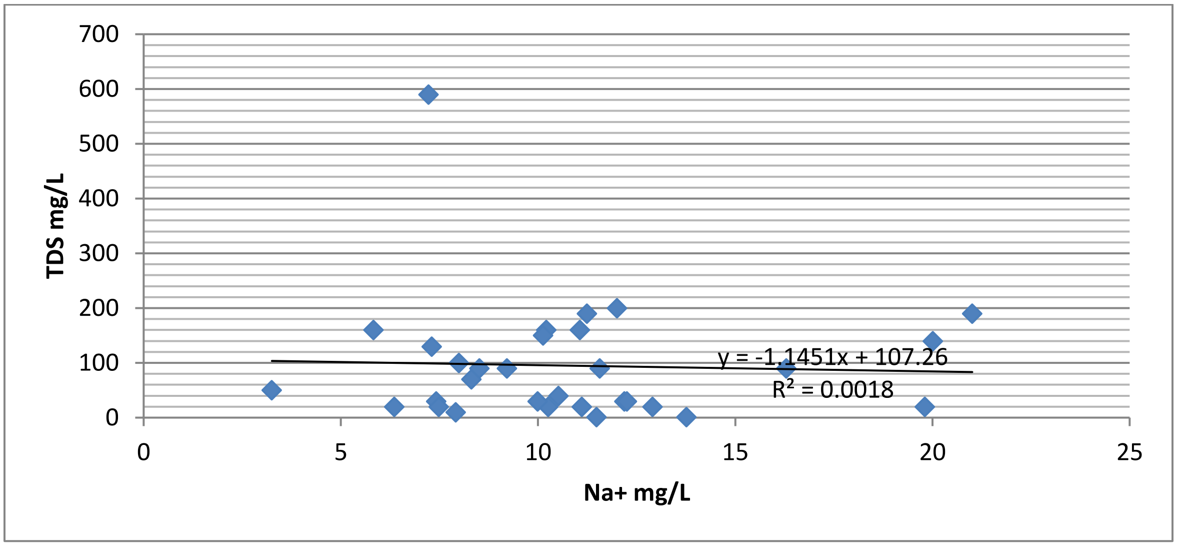

Figure 5 Graph of TDS and Na+

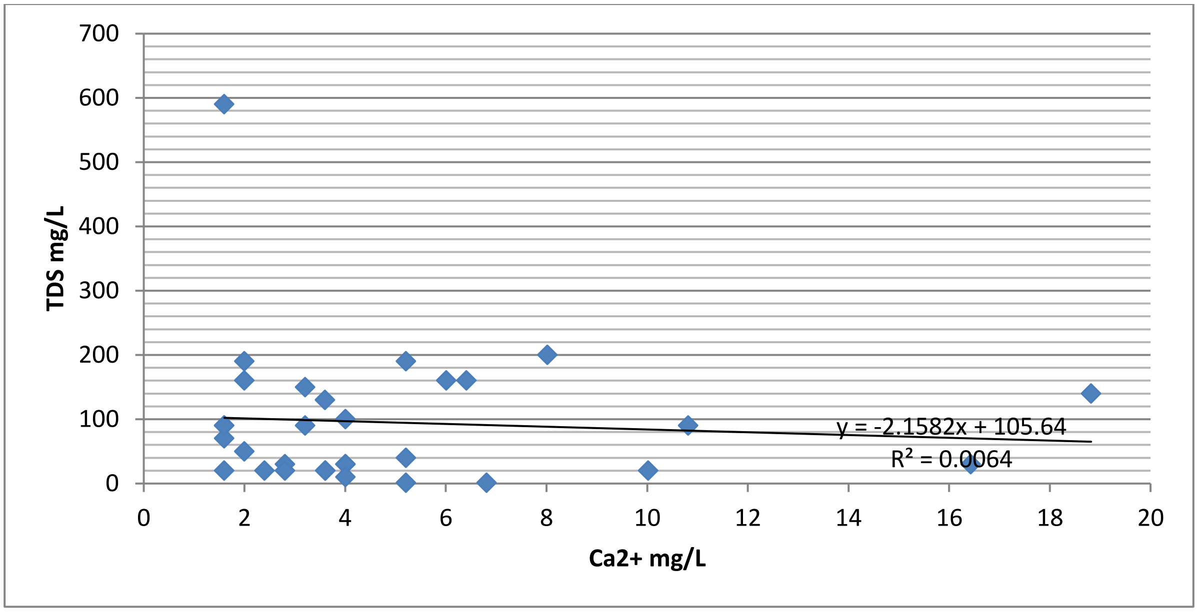

Figure 6 Graph of TDS and Ca2+

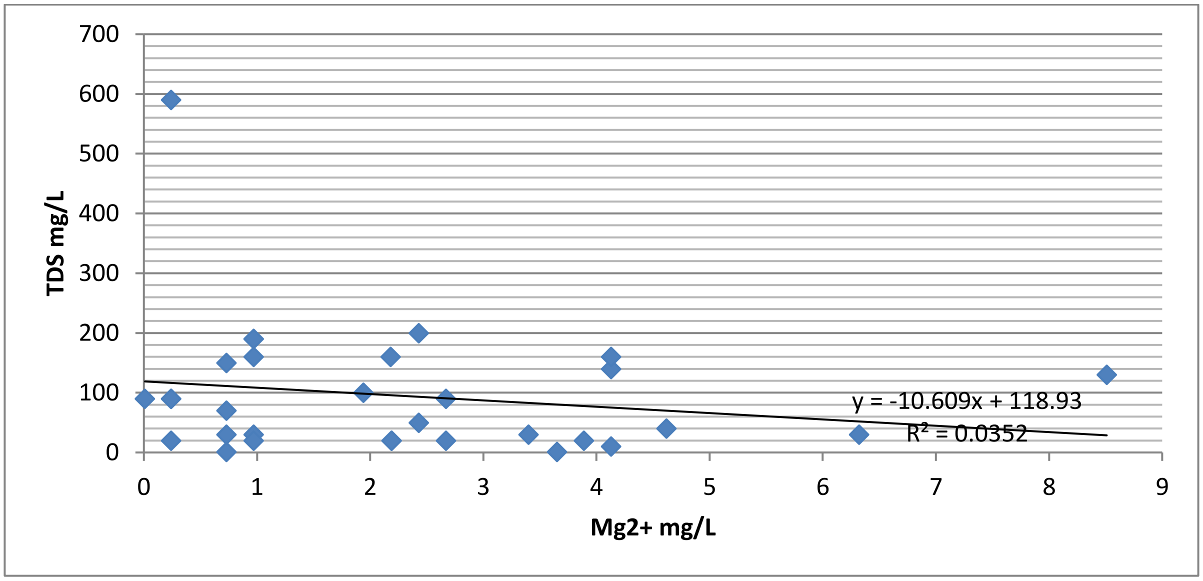

Figure 7 Graph of TDS and Mg2+

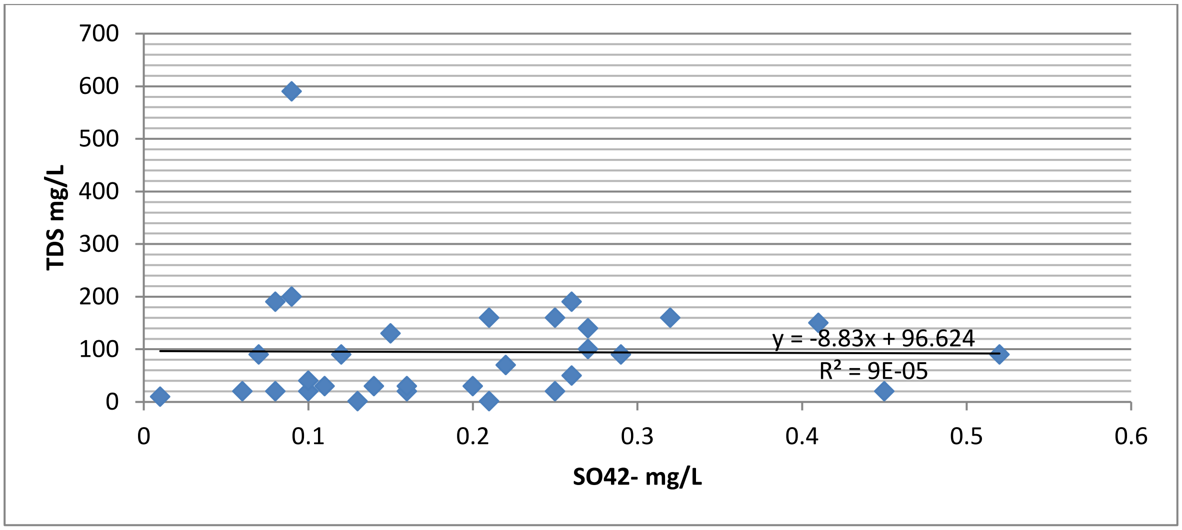

Figure 8 Graph of TDS and SO42-

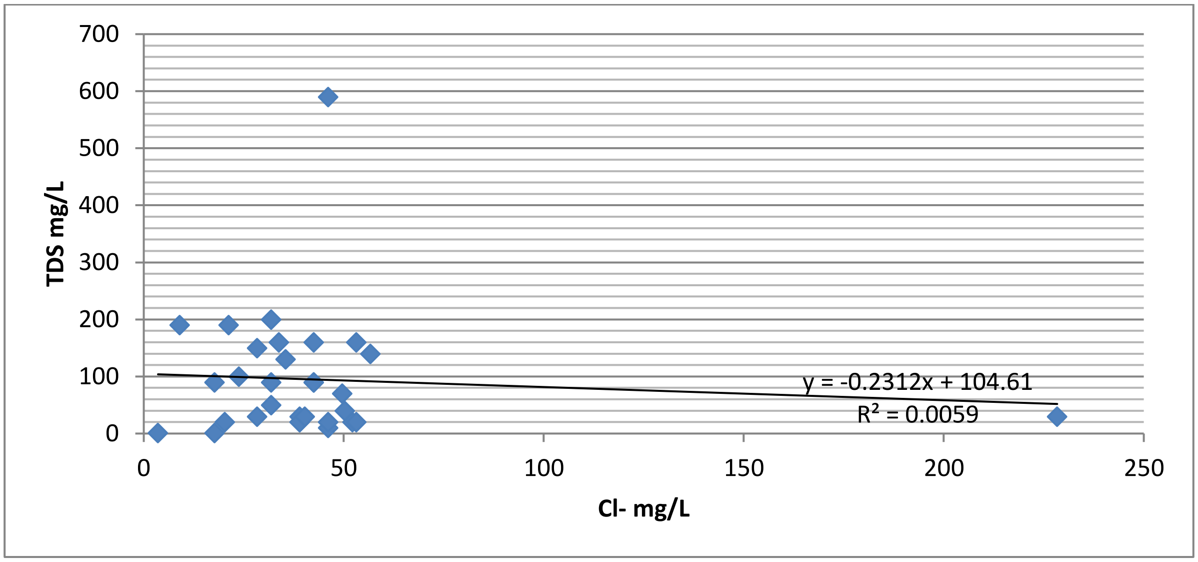

Figure 9 Graph of TDS and Cl-

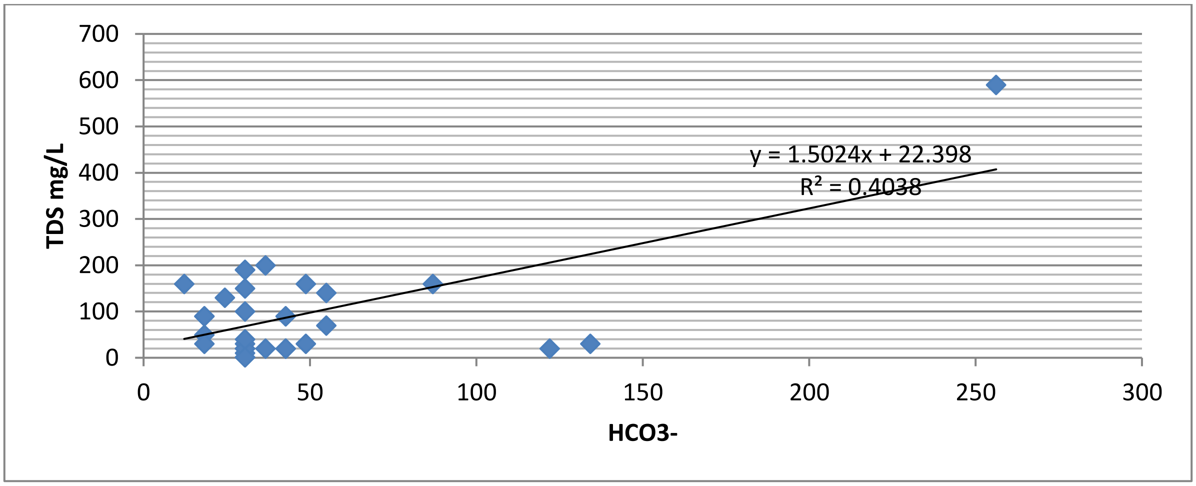

Figure 10 Graph of TDS and HCO3-

5. CONCLUSIONS

The study has examined the quality of groundwater in coastal aquifers of Dahomey Basin in Nigeria. The groundwater data was analyzed using geo- geostatistical techniques to determine the spatial variability of groundwater and to identify major variables affecting the quality of groundwater in the study area. Cluster analysis resulted in grouping groundwater samples into three main clusters of fresh, intermediate, and polluted water. The correlation coefficient showed high correlations between Mg and Cl ions (r = 0.95). Factor analysis also shows a high loading of Mg and Cl ions, suggesting Mg and Cl ions are responsible for the pollution of the groundwater samples, which was due to saltwater intrusion into the aquifers from the Atlantic Ocean

Ethical approval

Not applicable.

Conflicts of interests

The authors declare that there are no conflicts of interests.

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Data and materials availability

All data associated with this study are present in the paper.

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