

GEOCHEMICAL CHARACTERIZATION OF GROUNDWATER IN ALKALERI AND ENVIRONS, GOMBE STATE, NORTH-EASTERN NIGERIA

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ABSTRACT

The study area witnessed expansion, growth and developmental activities which results in poor water quality supply, which necessitated this research work that is aimed at characterizing the groundwater on the basis of chemistry in Alkaleri and environs. A total of 40 water samples were taken from hand dug wells and boreholes. The physical and chemical parameters were determined using standard methods. The results of the 40 water samples analyzed revealed that only iron and Manganese exceeded the World Health Organization permissible limit for water consumption. Iron ranges from 0.21 to 1.02mg/l with the mean of 0.51mg/l and standard deviation of 0.1,7 the high concentration of iron in the samples is due to ferromagnesium minerals which are the major mineral in Basaltic and Kerri-Kerri Sandstone. Manganese ranges from 0 to 0.06mg/l with the mean value of 0.003mg/l and standard deviation of 0.009, this showed that the water has been in contact with rock for a longer time. Piper trilinear diagram was plotted and results indicated that most samples fall in the region of Ca-Mg-HCO₃ facies which is the dominant water type. The second water type is Ca-Mg-SO₄-Cl. This water type is regarded as water of intermediate composition that evolved through simple hydrochemical mixing influenced by reversed cation exchange. Principal Component Analysis and Hierarchical Cluster Analysis revealed natural mineralization, salinity of the water, weathering and rock-water interaction, temporary hardness of groundwater, caused by leaching of bed rock materials and anthropogenic contamination. The result of the Water Quality Index showed that 2.5% of the water samples revealed poor water quality of grade C, good quality water of grade B constitute. 67.5%, and Excellent Water quality of grade A constitutes 30%.

Keywords: Water quality, Groundwater, Alkaleri and environs, Hand dug wells, Boreholes

1 INTRODUCTION

Groundwater quality is mainly controlled by the range and type of human influence as well as geochemical, physical and biological processes occurring in the ground [1, 2, 3]. Groundwater quality depends, to some extent, on its chemical composition [4] which may be modified by natural and anthropogenic sources. Rapid urbanization, especially in developing countries like Nigeria, has affected the availability and quality of groundwater due to waste disposal practice, especially in urban areas. The dissolution of various materials into the groundwater are due to the erosion of rocks, the existence of evaporative and sedimentary structures and their dissolution, such as gypsum, salt, iron, etc. The

groundwater quality alteration by the dissolution materials reveals the necessity of recognizing the effects of different parts of the earth on the chemical quality of water and identifying the rate of its effectiveness over time. In general, geological formations and chemical weathering have a major role in controlling natural water composition. [5] Analyses the Physical and Chemical Parameters in Groundwater Used for Drinking around Konso Area, Southwestern Ethiopia and the result shows that most of the physical and some common ions and heavy metals were within the accepted range of the guideline recommended by WHO. [6] studied the groundwater quality and hydrogeochemistry of Toungo Area, Northeastern Nigeria. PCA, HCA and rock-water interaction diagrams identified diffused form of contamination, leaching of bed rock geochemistry, salinity, natural mineralization, anthropogenic contamination, silicate weathering and oxidation as the major processes controlling the groundwater geochemistry. [7] studied the Hydrochemical Analysis and Evaluation of Groundwater Quality in Tumkur Taluk, Karnataka State, India. From their research, they discovered that the type of water that predominates in the study area is Ca-Mg-HCO₃ type during both pre-and post-monsoon seasons of the year 2006, based on hydro-chemical facies. Besides, suitability of water for irrigation is evaluated based on sodium adsorption ratio, residual sodium carbonate, sodium percent, salinity hazard and USSL diagram. The water is safe for domestic, industrial and agricultural purposes. [8] worked on the Hydrogeochemical assessment of groundwater in Kaltungo and Environs, northeastern Nigeria. Multivariate Statistical Techniques was used to evaluate groundwater quality in Dashen Area, by [9]. The study revealed that multivariate statistical analysis using PCA and HCA identified diffused form of contamination, leaching of bed rock geochemistry, salinity, natural mineralization and anthropogenic contamination as the major processes controlling the groundwater chemistry. Water is suitable for human consumption. [10] investigated the groundwater quality in Mararaba Mubi using Factor Analysis. From the analytical results of 23 water samples from the area, the groundwater is contaminated by nitrate. Their results further revealed that the different water sources are contaminated with respect to phosphate and coliform bacteria. Principal component analysis on the chemical parameters revealed three factors (1, 2 and 3) that account for about 76.04% of the total variance. [11] pioneered a research in Fufore to determine the influence of geology and anthropogenic activities on water quality. They discovered that the water quality is unsuitable for human consumption without treatment due to bacteriological pollution. The groundwater quality is good for industrial applications while surface water may not be suitable for some industrial applications. The water quality is good for agricultural activities as SAR, EC and TDS fall below the recommended standards. [12] carried out a research on groundwater quality using water quality index and GIS in Jada, northeastern Nigeria. The results indicated that WQI values ranged from 15 to 43, and thus indicated excellent to very good groundwater quality status. [13] assess the surface and groundwater quality in Otukpo area and environs, Benue State, North Eastern Nigeria using Water Quality Index (WQI). Sixteen water samples were collected and analyzed, the result indicated good and excellent water category. [14] assess groundwater quality using WQI in parts of Varanasi district, Uttar Pradesh, India. Their results categorized the water as good, moderate, poor and very poor. Approximately more than half of the people in Nigeria depend today upon groundwater as their sources of drinking water, and have long believed that groundwater is in general, pure and safe to drink. Therefore, it is alarming to learn that groundwater would be quite polluted by many sources, and that the pollutants may be difficult to recognize even where they are toxic and potentially deadly. The inability of water supply and sanitation utilities to maintain and extend services has led typically to situations where in fact subsidized services are denied to the poor who have to rely on more costly and lower quality alternatives. A well performing utility is a necessary condition for enhancing the economic efficiency of cities and for accelerating the provision of services low-income areas. However, water utilities in Africa have limited prospects for improving their performance unless they undergo structural reform. Service delivery is not keeping pace with demand especially for fast growing number of low-income households living in informal settlements. Like any other government in any part of the world, the Nigerian Government has done well in water supply projects in the country. However, water supply projects, which is aimed at ensuring that potable water gets to all the parts of the country, have been facing a lot of setbacks.

2 THE STUDY AREA

The study area is Alkali town and environment; the area is located on the topographic map of Alkali South-west sheet 152 and lies between longitudes $10^{\circ}10'0''\text{E}$ to $10^{\circ}23'0''\text{E}$ latitudes $10^{\circ}11'0''\text{N}$ to $10^{\circ}21'0''\text{N}$ and covers an area of about 421.2km^2 (Figure 1). It is accessible through the Bauchi Gombe road and characterized by numerous foot paths. The area of study is located within the Sudan savannah climatic belt of Nigeria. It is characterized by two distinct seasons; the dry season and the wet season. The dry season (harmattan) runs from October/November to March/April with little or no rainfall. The wet season is from April/May to October. The vegetation is dominated by shrubs, short grasses and scattered trees. The topography of the area is characterized by a few hills reaching an elevation of 706m above sea level in the north-western region, underlain by crystalline basement rocks. The lowest elevation in the area is 275m above sea level and it is associated with stream channels in the north eastern region, underlain by the Tertiary Kerri-Kerri Formation (Figure 1). The mean annual rainfall is between 1000 and 1200mm for Alkali where the study area is situated while the dry season is characterized by an arid wind or tropical continental air mass originating from the Sahara Desert. During the period, there is little cloud cover and the temperature ranges from 17°C to 22°C [15]. The study area is mainly classified as a Sudan savannah region which is characterized by grasses, shrubs and trees with large trunks. The grasses dry and trees shed off their leaves during dry season and flourish again when the wet season returns.

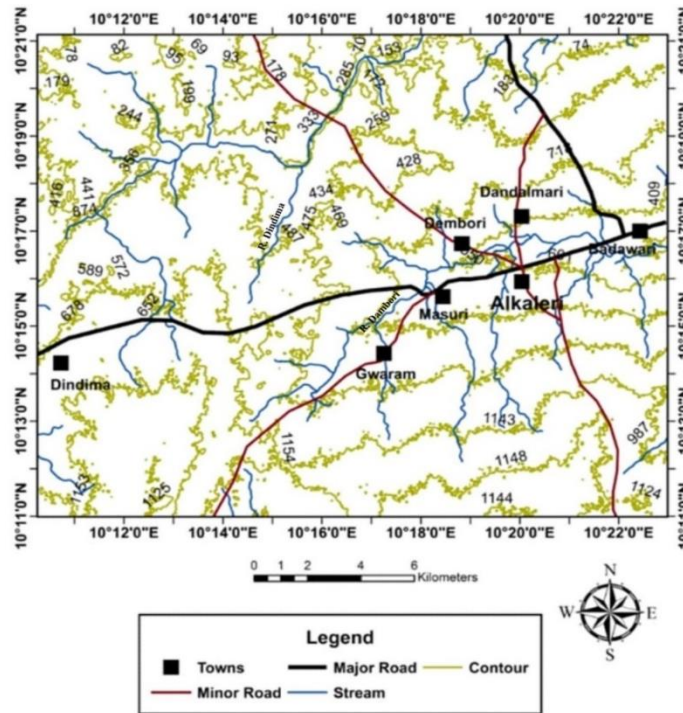


Figure 1. Topographic Map of the study area

3 METHODOLOGY

A total of 40 water samples were taken from hand dug wells and boreholes (Figure 2). The samples were systematically collected at different locations within the study area so as to get good representation of the samples. Twelve (12) samples were collected from hand dug wells and Twenty-Eight (28) samples from boreholes. The containers for sample collections were thoroughly washed with ionized water and at each sample location; they were rinsed two to three times according to [16] method using the representative groundwater samples. To avoid contamination, the containers were sealed and numbered serially from 1 to 40 to designate each sample location. The physical parameters such as temperature, pH, and total dissolve

solids (TDS), electrical conductivity EC were determined in the field. Temperature and pH were determined using pen pH and temperature meter model CT6021 exact instrument. Electrical Conductivity (EC) were determined using pen conductivity meter model CT3030 exact instruments. Carbonate and bicarbonate were determined in the field by titrimetric method using HACH digital titration model 16900 EDTA titration. The analysis was carryout at Adamawa State Ministry of Water Resources, using United State Environmental Protection Agency (USEPA) standard method for water quality analysis. During laboratory analysis, the Physical and chemical characteristics of water were determined. The groundwater samples were analyzed using the spectrophotometry HACH digital spectrophotometer model DR2040 at the Adamawa State Water Laboratory. Bacteriological analysis was also carried out at the Adamawa State Water Laboratory using membrane filtration method according to WHO [17] guidelines. At the Adamawa State Water Laboratory, pH and temperature were measured using Pen type pH and temperature meter (Model CT6021A), Turbidity (NTU) was determined using Hand held turbidity meter HACT model 210. TH (total hardness) was determined using the formula $TH=2.497(Ca^{2+}) + 4.118 (Mg^{2+})$. TDS (total dissolve solids) was determined using the formula $TDS = K_e * EC$. Where $K_e = 0.7$ is a constant of proportionality. The water samples were analyzed for the following cations and anions; Potassium (K^+), Calcium (Ca^{2+}), Copper (Cu^{2+}), Sodium (Na^+), Bicarbonate (HCO_3), Carbonate (CO_3), Magnesium (Mg^{2+}), Iron (Fe^{2+}), Manganese (Mn^-), Chloride (Cl), Nitrate (NO_3^-), Fluoride (F^-), Phosphate (PO_4^-), Zinc (Zn^-), Sulphate (SO_4^{2-}), Nitrate (NO_3), and total coliform count.

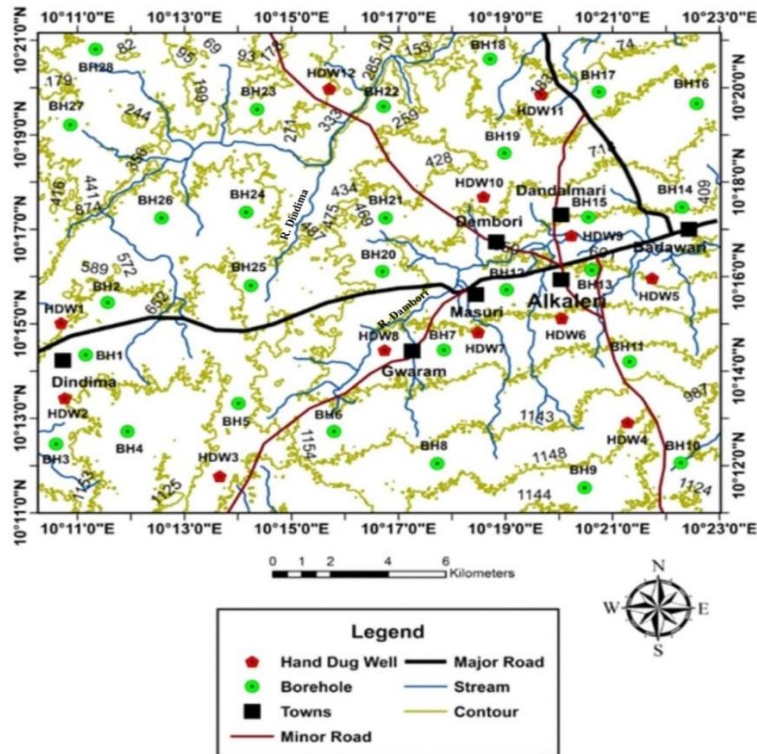


Figure 2. Topographic Map of the study area showing various point of water sample collection

4 RESULTS AND DISCUSSION

Results of physicochemical parameters of groundwater samples from the study area are presented in Table 1 while Table 2 shows the summary alongside with the WHO [17] standard. The result indicates that, temperature ranges from 22.08 to 27.22°C with mean of 26.2°C and standard deviation of 0.93. Based on this result, the water falls within the WHO permissible standard of 30 to 35°C for drinking water. pH in the area ranges from 5.42 to 7.92 with the mean value 6.23 and standard deviation of 1.064 this shows that, the water is moderately acidic to neutral water [6, 18].

Table 1. Results of Physicochemical Analysis of Water Samples from the Study Area

S/N	Sample Location	Water Source	Temp. (°C)	pH	EC µs/cm	TDS mg/l	NTU	TH mg/l	CO32 mg/l	HCO32- mg/l	NO32- mg/l	Fe2+ mg/l	Na+ mg/l	Ca2+ mg/l	Mg2+ mg/l	SO42- mg/l	Cu2+ mg/l	Zn mg/l	K+ mg/l	Po42- mg/l	F mg/l	Mn-2 mg/l	CL- mg/l
1	UnguwanaAjiya	HDW1	26.15	7.92	215	146	21.55	70.11	4.2	183	33.27	1.02	1.15	40.11	15.23	24.3	0.4	0.092	6.8	0.91	0.61	0.06	40.11
2	Gwaram	BH2	27	6.13	187	126.1	0.5	68.25	0	165	18.23	0.58	3.14	31.62	17.22	14.33	0.27	0.063	7.5	0.75	0.42	0.003	10.28
3	Kachichiya	HDW3	27.2	6.5	196	127.3	0.35	71.81	0	177	19.88	0.4	1.53	31	16.98	12.93	0.31	0.049	6.6	0.95	0.67	0.002	10.88
4	SabongarinPali	BH4	26.93	6.44	215	146	0.44	64.22	0	200	23.93	0.48	1.27	32.52	14.53	15.84	0.45	0.072	6.7	0.87	0.51	0.002	17.52
5	Ung. SarkinShanu	BH 5	27.02	6.73	219	149	0.4	59.93	0	185	27.67	0.61	0.88	37.11	19	18.15	0.41	0.092	7	1.05	0.53	0.001	16.92
6	Gunchuguni	HDW6	26.9	6.62	205	137.8	0.51	69.87	0	173	21.17	0.49	0.96	31.74	12.67	18.22	0.29	0.051	6	1	0.52	0.001	11.25
7	Kan'iyaka	BH7	26.92	6.39	210	136.5	0.61	73.31	0	179	26.93	0.61	1	35.66	17.42	18.92	0.25	0.052	6.9	1.02	0.71	0.001	11.47
8	Maimadiri	BH8	26.81	6.27	207	133	0.75	61.44	1	181	22.76	0.98	0.85	34.91	19.63	17.63	0.32	0.105	7.1	1.01	0.61	0.009	12.96
9	Ung. Kudu Alk	BH9	27.11	6.81	195	131.5	0.95	71.92	0	169	15.96	0.53	1.05	33.26	18.73	12.67	0.305	0.07	7.3	0.98	0.67	0.002	10.57
10	32Junction	BH10	26.92	6.61	301	200	0.52	64	0	271	25.93	0.73	0.91	31.2	15.87	18.77	0.33	0.081	6.5	0.86	0.63	0.004	15.44
11	Jojoto	HDW11	26.93	6.27	199	133.1	0.37	58.93	0	171	18.75	0.58	0.75	34.91	18.82	14.85	0.49	0.088	6.8	0.73	0.47	0.003	16.63
12	Londo	BH12	26.53	6.31	167	110	0.49	70.93	0	108	20.42	0.67	1.25	34.98	16.72	16.82	0.3	0.09	6.4	0.73	0.54	0.003	14.93
13	CPS Alkaleri	BH13	26.98	6.34	215	142.5	0.58	67.01	0	193	28.92	0.47	0.905	36.63	17.21	18.15	0.26	0.1	7	0.81	0.51	0.002	16.05
14	Pali	BH14	26.73	6.09	200	131.9	0.25	65.24	0	188	19.97	0.72	0.78	36.75	17.01	15.011	0.36	0.096	6.1	0.81	0.58	0.005	17.01
15	GGAC Alkaleri	BH15	27.01	6.21	220	144	0.66	68.81	0	205	26.22	0.51	0.75	35.21	16.92	17.11	0.37	0.069	7.3	0.75	0.48	0.001	16.52
16	Gagau	HDW16	26.34	6.48	218	147	0.29	74	0	203	24.98	0.61	0.81	38.44	16.91	16.95	0.28	0.081	7.2	0.85	0.45	0.002	17.84
17	Tarangadi	BH17	27.08	6.51	202	137	0.37	69.22	0	185	25.52	0.51	1	37.81	13.42	17.55	0.41	0.039	7.5	0.9	0.48	0.002	16.25
18	Federal Low-cost	BH18	27	6.42	193	126.6	0.35	66.51	0	159	21.11	0.49	1.16	35.72	15.88	16.91	0.33	0.044	6.8	1	0.53	0.001	18.35
19	Kurwala	BH19	27.22	6.18	219	143.8	0.73	73.42	0	193	21.84	0.44	1.02	29.71	15.51	15.22	0.41	0.043	6.9	0.87	0.49	0.002	17.72
20	Balyari	HDW20	26.12	6.23	297	195.5	0.61	60.92	0	261	24.99	0.52	1.001	34.16	13.93	17.92	0.49	0.077	6.8	0.93	0.59	0.001	15.68
21	Nainawa	HDW21	25.52	6.1	179	121.5	0.22	68.53	0	193	18.73	0.36	0.75	34.84	18.84	16.48	0.23	0.043	7.8	0.89	0.73	0.001	9.91
22	GwaramSabuwa	BH22	22.08	6.13	189	127.5	0.061	70.05	0	261	21.62	0.48	0.67	29.79	21.93	18.8	0.21	0.077	7.8	1.07	0.12	0	10.25
23	Mai'ari	BH23	25.22	6.22	200	131.7	0.6	70.05	1.1	201	19.66	0.69	0.73	36.3	17	16.7	0.35	0.11	6.9	1.18	0.6	0.002	12.57
24	Salihawa	HDW24	26.09	6.17	207	139.5	0.102	73.48	0	250	16.92	0.53	0.85	30.15	20.1	12.54	0.35	0.8	7.4	1.16	0.53	0.001	10
25	Turiya	BH25	25.21	6.1	196	132.5	0.201	67.25	0	179	18.83	0.46	0.57	37.81	16.93	17.81	0.28	0.072	6.7	1.12	0.49	0.001	12.85
26	Arawa	BH26	25.05	5.42	177	119.9	0.049	71.42	1	188	19.88	0.39	1	31.68	19.69	15.93	0.44	0.032	7.2	1	0.12	0.002	11
27	Takai	HDW27	26.11	6	205	134.9	0.1	68.73	0	197	24.57	0.25	0.83	40.91	16.87	14.4	0.26	0.56	6.6	1.07	0.53	0.001	10.52
28	wuroduwa	HDW28	26.51	5.87	201	134.5	0.087	69.21	0	209	20.9	0.68	1.1	35.72	16.11	14.92	0.39	0.91	7.3	0.92	0.18	0.002	11.89
29	Gokaru	BH29	26	6.18	216	144.5	0.053	67.74	0	196	18.67	0.44	0.77	37.41	18.72	11.27	0.24	0.38	7	1.07	0.4	0.001	9.27
30	Tudu	BH30	26.11	5.91	198	134.7	0.052	81.22	0	170	21.42	0.41	0.91	33.47	21.67	16.73	0.37	0.071	6.9	0.98	0.11	0	9.68
31	Dindima	BH31	25.43	5.88	215	146.9	0.19	72.55	0	222	21.7	0.5	0.98	39.15	21.77	15.91	0.27	0.011	6.8	1.15	0.44	0.001	15.91
32	Sha'iska	BH32	25.84	5.98	211	142.7	0.115	79.62	0	116	20.93	0.21	0.77	36.69	22.09	15.93	0.29	0.055	6.4	1.18	0.5	0.002	11.42
33	Kufa	BH33	25.21	6.21	193	132.5	0.061	75.54	1	185	17.54	0.58	0.7	35.61	22.54	16.9	0.41	0.066	6.8	1.05	0.48	0.002	13.52
34	Gamawa	HDW34	26.91	6.05	188	128.4	0.17	69.85	0	205	19.86	0.41	0.88	41.27	15.79	11.49	0.28	0.091	7.3	1.09	0.63	0.002	14.92
35	Felfelu	BH35	26	5.87	199	135.6	0.18	79.52	0	232	18.71	0.61	0.83	31.18	20.9	14.1	0.46	0.022	7	0.86	0.39	0.001	12.12
36	Ung. Mal. Kawu	BH36	25.77	6.01	218	146.6	0.15	66.84	0	199	22.42	0.31	0.76	39.11	19.03	16.2	0.34	0.026	7.7	1.14	0.55	0.001	15.51
37	Kwata	BH37	25.84	6.27	187	127.8	0.073	74.91	0	162	18.11	0.36	0.58	37.84	21.85	15.91	0.37	0.056	6.5	1.09	0.36	0.001	11.46
38	SabuwarKasuwa	HDW38	26.08	5.42	203	137.4	0.127	80.2	0	177	22.47	0.22	0.57	33.88	26.85	17.92	0.36	0.096	7.1	0.93	0.41	0.002	10.5
39	TashanBadara	BH39	25.91	6	209	135.4	0.09	73.11	0	219	19.53	0.33	0.59	37.85	21.42	17.93	0.26	0.07	6.7	1.23	0.61	0.002	10.67
40	Burkeke	BH40	26.08	6.1	203	139.4	0.08	67.83	0	149	23.41	0.44	0.71	37.09	15.18	12.93	0.33	0.094	7	0.98	0.52	0.001	12.87
	Minimum		22.08	5.42	167	110	0.049	58.93	0	108	15.96	0.21	0.57	29.71	12.67	11.27	0.21	0.011	6	0.73	0.11	0	9.27
	Maximum		27.22	7.92	301	200	21.55	81.22	4.2	271	33.27	1.02	3.14	41.27	26.85	24.3	0.49	0.91	7.8	1.23	0.73	0.06	40.11
	Mean		26.247	6.237	206.9	138.46	0.851	69.9375	0.208	190.1	21.7092	0.515	0.943	35.28	18.122	16.226	0.338	0.125	6.953	0.974	0.49	0.0033	14.031
	Std. Dev.		0.9295	1.064	24.78	16.122	3.3652	5.24842	0.718	31.72	4.89141	0.171	0.411	3.0893	2.9345	2.4175	0.073	0.195	0.414	0.134	0.15	0.0093	5.071

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

Parameters	Minimum	Maximum	Mean	Standard Deviation	WHO [17]
Temperature (T ^o C)	22.08	27.22	26.2468	0.92948	30 -35
Ph	5.42	7.92	6.237436	1.063838	6.5 -8.5
EC (μs/cm)	167	301	206.85	24.78373	500
TDS (mg/l)	110	200	138.4625	16.12233	500
Turbidity (NTU)	0.049	21.55	0.851025	3.36516	0 – 5
Total Hardness (TH) mg/l	58.93	81.22	69.9375	5.248418	500
Carbonate (CO ₃ ²⁻) mg/l	0	4.2	0.2075	0.718398	120
Bicarbonate (HCO ₃ ²⁻) mg/l	108	271	190.1	31.72138	500
Nitrate (NO ₃ ²⁻) mg/l	15.96	33.27	21.70923	4.891407	50
Iron (Fe ²⁺) mg/l	0.2	1.02	0.51525	0.17112	0.3
Sodium (Na ⁺) mg/l	0.57	3.14	0.9429	0.411093	200
Calcium (Ca ²⁺) mg/l	29.71	41.27	35.28	3.089297	75
Magnesium (Mg ²⁺) mg/l	12.67	26.85	18.12225	2.934504	50
Sulphate (SO ₄ ²⁻) mg/l	11.27	24.3	16.22628	2.41754	250
Copper (Cu ²⁺) mg/l	0.21	0.49	0.338125	0.072869	0 -1.5
Zinc (Zn) mg/l	0.011	0.91	0.12545	0.194664	3
Potassium (K ⁺) mg/l	6	7.8	6.9525	0.414474	12
Phosphate (Po ₄ ²⁻) mg/l	0.73	1.23	0.9735	0.133658	0 – 10
Fluoride (F) mg/l	0.107	0.73	0.4923	0.149341	1.5
Manganese (Mn ²⁻) mg/l	0	0.06	0.003325	0.009313	0 – 0.4
Chloride (CL ⁻) mg/l	9.27	40.11	14.0305	5.070966	250

4.1 Correlation of chemical parameters in the study area

Physical and chemical parameters of groundwater in the Study area were correlated and the results are presented in Table 3. According to [19], samples showing correlation coefficients of $r > 0.7$ are considered to be strongly correlated, $r > 0.5-0.7$ shows moderate correlation whereas $r < 0.5$ are considered weak. Strong correlations between the various physicochemical parameters have been observed: (1) pH shows strong correlation with Turbidity (0.73) and Cl⁻ (0.706). (2) Electrical Conductivity (EC) shows strong correlation with Total Dissolves Solid (0.989) (3) Turbidity (NTU) shows strong correlation with CO₃ (0.901), Mn (0.989) and Cl⁻ (0.845) (4) CO₃ shows strong correlation with Mn (0.918) and Cl⁻ (0.727) (5) NO₃ shows moderate correlation with SO₄. This correlation indicates that all of them have originated from the same source. Moderate correlation between EC, Manganese and carbonate indicate the contribution of these ions to the change in both alkalinity and colour of the water.

4.2 The Hydro-Geochemical Facies

The characterization of the water in the study area using piper trilinear diagram (Figure 4) indicates that most samples plotted in the region of Ca-Mg-HCO₃. The Ca-Mg-HCO₃ facies is the dominant water type and belongs to the normal alkaline group, and is related to the geology of the area [20]. The water type is young water of meteoric origin that resulted from the dissolution of aluminosilicate as a result of induced chemical weathering. The second water type is Ca-Mg-SO₄-Cl. This water type is regarded as water of intermediate composition that evolved through simple hydrochemical mixing influenced by reversed cation exchange. The Ca and Mg may be released from the influence of congruent weathering of silicate (feldspars), calcite, ions exchange processes and water mixing [21].

Table 3. Correlations Analysis of Physical and Chemical Parameters in the Study Area

	T	pH	EC	TDS	NTU	TH	CO ₃	HCO ₃	NO ₃	Fe	Na	Ca	Mg	SO ₄	Cu	Zn	K	PO ₄	F	Mn	Cl	
T	1																					
pH	.305	1																				
EC	.190	.218	1																			
TDS	.152	.218	.989	1																		
NTU	.021	.714	.074	.091	1																	
TH	-.232	-.303	-.335	-.301	-.020	1																
CO ₃	-.123	.560	-.024	-.013	.901	-.004	1															
HCO ₃	-.339	.057	.563	.572	-.042	-.277	.011	1														
NO ₃	.203	.491	.466	.457	.533	-.248	.401	.122	1													
Fe	.182	.576	.160	.136	.507	-.370	.567	-.055	.310	1												
Na	.340	.160	-.095	-.106	.102	-.109	.031	-.253	-.033	.184	1											
Ca	.045	.128	-.060	-.043	.235	-.113	.205	-.011	.286	-.035	-.290	1										
Mg	-.468	-.488	-.266	-.238	-.191	.533	-.072	-.064	-.357	-.319	-.293	-.063	1									
SO ₄	-.166	.437	.259	.249	.552	-.076	.535	.106	.665	.374	-.122	.095	-.041	1								
Cu	.229	.041	.228	.255	.143	-.150	.210	-.028	.086	.216	-.044	-.202	-.106	.071	1							
Zn	-.653	-.283	-.221	-.215	-.047	-.043	.085	.256	-.050	-.156	-.121	-.166	.155	.159	-.102	1						
K	-.274	-.167	-.172	-.145	-.064	-.010	-.039	.044	-.042	-.080	.106	-.072	.161	-.125	-.111	.189	1					
PO ₄	-.450	-.178	-.051	-.036	-.106	.240	.027	.219	-.239	-.332	-.396	.295	.345	-.076	-.304	.151	.004	1				
F	.468	.454	.240	.192	.162	-.305	.081	.069	.148	.175	.009	.233	-.339	.037	-.182	-.498	-.196	.010	1			
Mn	.037	.687	.063	.076	.989	-.051	.918	-.041	.511	.561	.103	.244	-.166	.542	.147	-.048	-.087	-.119	.170	1		
Cl	.199	.706	.222	.238	.845	-.249	.727	.007	.656	.544	.043	.325	-.368	.558	.327	-.149	-.130	-.274	.222	.840	1	

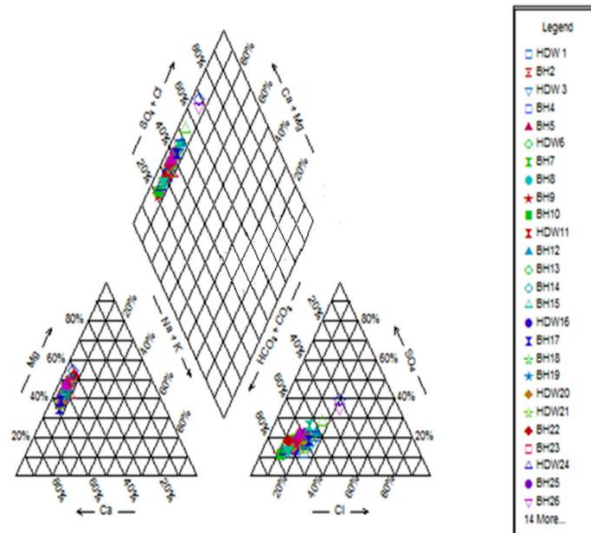


Figure 4. Piper Trilinear Plot showing different water type in the study area

4.3 Source of Dissolved Ions

The Gibbs plot is used to determine the sources of dissolved geochemical constituents and ion-exchange process in aquifer. Gibbs [22] indicated a close relationship between water composition and the hydrochemical processes involving precipitation/dilution, weathering, rock dominance, water interaction and evaporation. The plots of $\text{Na}^+/\text{Na}^++\text{Ca}^{2+}$ and $\text{Cl}^-/\text{Cl}^-+\text{HCO}_3^-$ as a function of TDS are widely employed to determine the source of dissolved chemical constituents (Figures 5 and 6 respectively). The plots indicate that majority of the samples fall in the rock dominance and weathering zone, suggesting precipitation, and induced weathering along with dissolution of rock forming minerals.

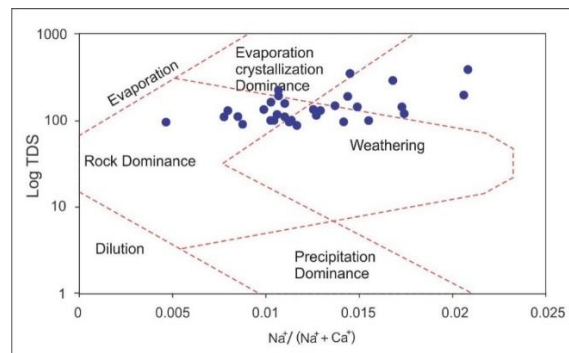


Figure 5. Plotting in Gibbs Diagram for Cations

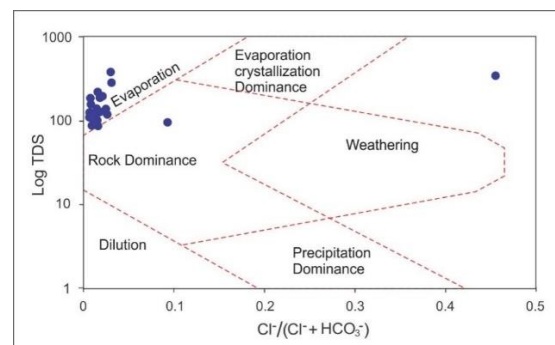


Figure 6. Plotting in Gibbs Diagram for Anions

4.4 Principal Component Analysis

Principal Component Analysis (PCA) on chemical data indicates four (4) factors which explain about 76.596% of the total variance (Table 4). The four factors are 1, 2, 3 and 4. Factor 1 account for

about 29.21% of total variance and is characterized by high loadings. PO_4^- , K, EC and pH while TH, F, and NO_3 have moderate loadings. PO_4^- and K have loadings of 0.907 and 0.844 and control the overall mineralization and appeared to be related to contamination from agricultural inputs the use of chemical fertilizers such as NPK, Potash and Manure while TH and Mg have loading of 735 and 621 which appeared to as a result of temporary hardness of water. NO_3 having moderate loading of 0.682 which could be associated with anthropogenic activities while F also having a moderate loading of 0.730 could be derived from dissolution of fluoride bearing minerals at elevated temperature. The association of these elements to this factor is as a result of diffuse contamination due to use of fertilizer in the area and temporary hardness of water. Factor 2 accounts about 14.54% of total variance and is characterized by moderate loading with respect to Cl^- , Ca, and K (0.571, 0.509, 0.492, 0.448 and 446) The presence of Ca and Cl^- to this factor may be attributed to leaching of bed rock materials, weathering and rock-water interactions. Hardness of water is caused by calcium and magnesium ions and can be tied to bed rock geochemistry [9]. Moderate loading of K could be as a result of contamination from the use of chemical fertilizers such as NPK, Potash and Manure. This is interpreted as temporary hardness of groundwater and weathering of feldspars, amphibole and pyroxenes. Factor 3 accounts for 12.541% of the total variance and exhibit moderate loadings with respect to HCO_3^- , CO_3^{2-} and Cu with high loading with respect to NTU. The possible sources of this contaminant could be anthropogenic. The interpretation of this factor could attribute to human activities that disturb land, such as construction, mining and Agriculture which leads to high sediment levels entering water bodies during rain storms and water runoff. Factor 4 account for 8.892% of the total variance and exhibit moderate loadings with respect to Na, Zinc and Cupper (0.690, 0.577 and 0.577). The moderate loading of Sodium could be derived from the weathering of sodic plagioclase feldspar (i.e., albite), atmospheric dust washed by rain water and also the through cation exchange process while that of Zinc and Cupper may be attributed to mining activities in the area in which water was contaminated as a result of the leaching of mined minerals to the groundwater bearing rocks.

Table 4. Principal Component Analysis (PCA) component matrix

Parameters	COMPONENT			
	1	2	3	4
Phosphate (PO_4^{3-})	.907	.174	-.044	.000
Potassium (K)	.844	.446	-.106	.029
Electrical Conductivity (EC)	.843	.448	-.091	.032
PH	.831	-.028	-.127	.132
Total Hardness (TH)	.735	.571	-.040	-.022
Fluoride (F)	.730	-.025	.248	-.017
Nitrate (NO_3)	.682	.020	-.185	-.231
Magnesium (Mg)	.621	.331	.294	-.105
Calcium (Ca)	-.492	.492	.155	.069
Temperature (T_c)	.315	-.672	-.506	.156
Chloride (Cl)	-.234	.509	.347	-.441
Turbidity (NTU)	.086	-.147	.809	-.075
Bicarbonate (HCO_2)	.398	-.522	.656	-.091
Carbonate $\text{C}(\text{O}_2)$.404	-.557	.640	-.081
Iron (Fe)	.123	-.204	-.547	-.361
Sodium (Na)	.236	.169	.081	.690
Zinc (Zn)	.377	-.416	-.096	.577
Copper (Cu)	-.296	.337	.428	.538
Sulphate (SO_4)	.267	-.159	-.011	-.463
Total Dissolve Solid (TDS)	-.368	.448	-.138	.159
Manganese (Mn)	-.198	.213	.019	-.269
Edgen Values	6.133	3.053	2.634	1.867
% of variance explained	29.206	14.536	12.541	8.892
% Cumulative	29.206	43.741	56.283	65.174

4.5 Hierarchical Cluster Analysis

The results of cluster analysis are presented in Figure 7 and indicate two clusters. Cluster 1 is subdivided into two sub clusters, and sub cluster 1 comprises of EC, K, TH, Cl, NO₃, PO, Zn, Fe and SO₄. This sub cluster is related to factor 1 and 2 interpreted by the leaching of bed rock materials, weathering and rock-water interactions and diffuse contamination due to use of fertilizer in the area. The sub-cluster 2 comprises of HCO₃, CO₂, Mg, F, NTU, Ca, and Cu. This sub cluster is related to factor 3 and interpreted to human activities that disturb land, such as construction, mining and Agriculture which leads to high sediment levels entering water bodies during rain storms and water runoff. The second cluster comprises of pH, Mn, TDS, Na and TC. This cluster is related to factor 1 and 4 and is interpreted as natural mineralization processes through rock-water interaction and the use of Chemical for fertilizers.

4.6 Water Quality for Drinking (Water Quality Index)

The result of the water quality index rating from the study area is presented in Table 5. From the analysis, 2.5% of the water is of poor water quality of grade C, good quality water of grade B constitutes 67.5%. The Excellent Water quality grade A constitutes 30%. From the spatial distribution map of water quality index in the study area (Figure 8) is interpreted as the green color represent the good water quality which predominated the area, the blue color represents the excellent water quality which is located in the northern and western part of the study area and the red color with less significant in the North-eastern part of the study area represent the poor water quality.

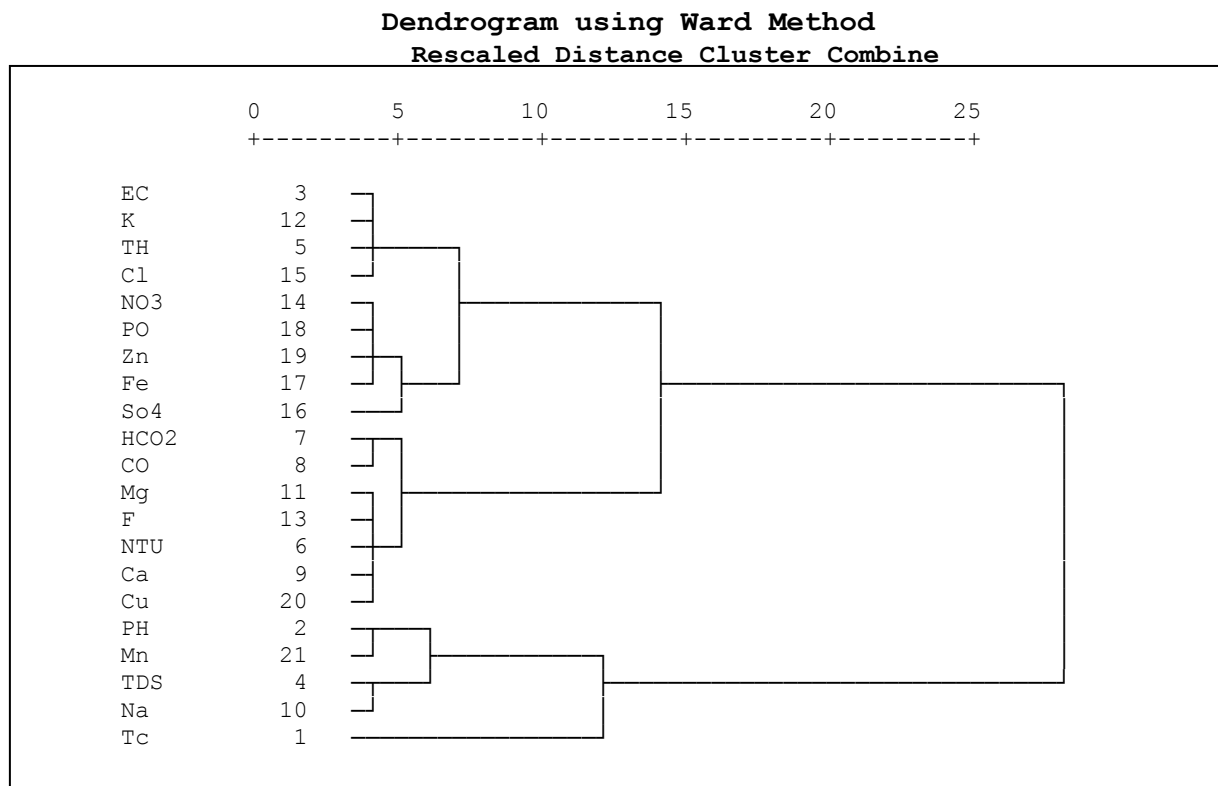


Figure 7. Dendrogram of hydrochemical data

Table 5. Water Quality Index Rating of water from the study Area

S/N	Sample Location	Sub Index of Parameters ($\sum S_{li}$)	Number of chemical Parameters ($\sum n$)	Water quality index (WQI = $\frac{\sum S_{li}-n}{\sum S_{li}-n}$)	Water Quality Status
1	Unguwan Ajiya	65.02251484	15	50.02251	Good Water Quality
2	Gwaram	44.2512052	15	29.25121	Good Water Quality
3	Kachichiya	40.6604434	15	25.66044	Good Water Quality
4	Sabongarin Pali	43.1073033	15	28.1073	Good Water Quality
5	Ung. Sarkin Shanu	49.8547578	15	34.85476	Good Water Quality
6	Gunchuguni	39.7194045	15	24.7194	Excellent water quality
7	Kan'iyaka	49.15960097	15	34.1596	Good Water Quality
8	Maimadiri	58.681921	15	43.68192	Good Water Quality
9	Ung. Kudu Alk	44.35266366	15	29.35266	Good Water Quality
10	32Junction	54.0539726	15	39.05397	Good Water Quality
11	Jojoto	44.43005804	15	29.43006	Good Water Quality
12	Londo	45.8675039	15	30.8675	Good Water Quality
13	CPS Alkaleri	77.21086217	15	62.21086	Poor Water Quality
14	Pali	45.4062141	15	30.40621	Good Water Quality
15	GGAC Alkaleri	43.66435062	15	28.66435	Good Water Quality
16	Gagau	45.9028239	15	30.90282	Good Water Quality
17	Tarangadi	45.2950479	15	30.29505	Good Water Quality
18	Federal Low-cost	43.0423816	15	28.04238	Good Water Quality
19	Kurwala	42.17370901	15	27.17371	Good Water Quality
20	Balyari	48.6513531	15	33.65135	Good Water Quality
21	Nainawa	38.71395055	15	23.71395	Excellent water quality
22	Gwaram Sabuwa	40.027484	15	25.02748	Good Water Quality
23	Mai'ari	49.4720794	15	34.47208	Good Water Quality
24	Salihawa	44.7041818	15	29.70418	Good Water Quality
25	Turiya	41.39350494	15	26.3935	Good Water Quality
26	Arawa	37.128014	15	22.12801	Excellent water quality
27	Takai	37.34674933	15	22.34675	Excellent water quality
28	Wuroduwa	27.8510592	15	12.85106	Excellent water quality
29	Gokaru	41.48246618	15	26.48247	Good Water Quality
30	Tudu	39.1339243	15	24.13392	Excellent water quality
31	Dindima	41.0270801	15	26.02708	Good Water Quality
32	Sha'iska	37.3659075	15	22.36591	Excellent water quality
33	Kufa	64.67837238	15	49.67837	Good Water Quality
34	Gamawa	38.844792	15	23.84479	Excellent water quality
35	Felfelu	46.13444696	15	31.13445	Good Water Quality
36	Ung. Mal. Kawu	39.8402332	15	24.84023	Excellent water quality
37	Kwata	38.11842414	15	23.11842	Excellent water quality
38	Sabuwar Kasuwa	35.4773661	15	20.47737	Excellent water quality
39	Tashan Badara	39.72677351	15	24.72677	Excellent water quality
40	Burkeke	41.8310863	15	26.83109	Good Water Quality

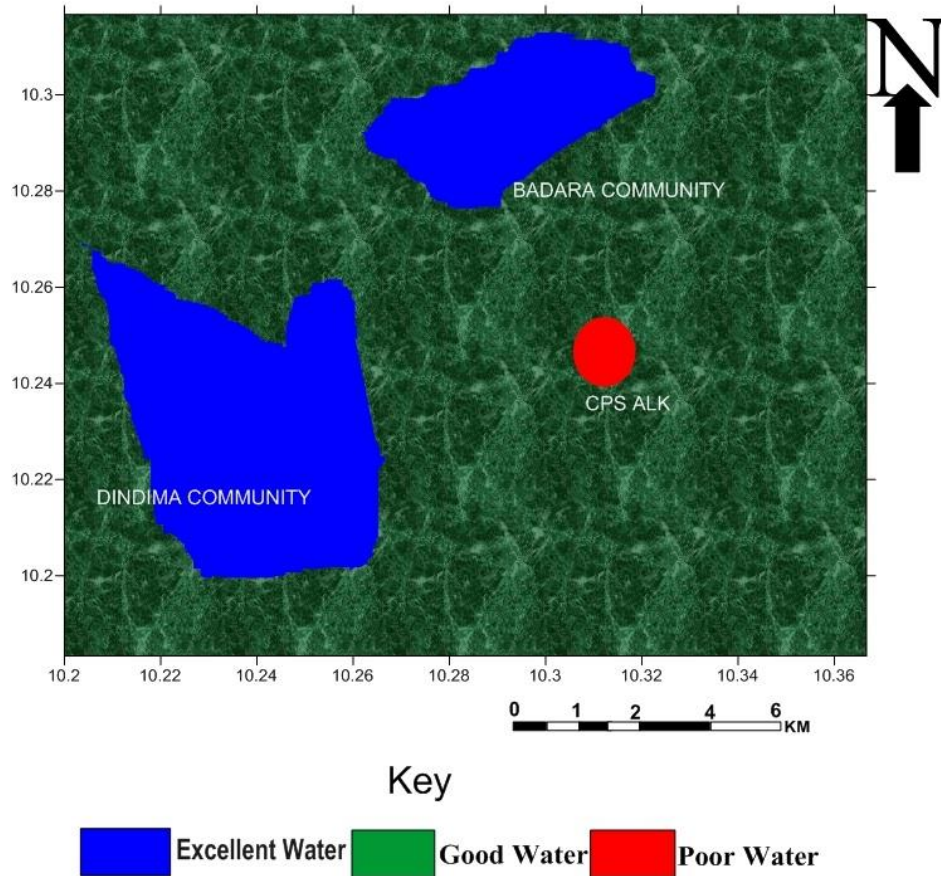


Figure 8. Spatial distribution of Water Quality Index in the Study Area

4.7 Water Quality for Agricultural Purposes

Table 6 shows computed chemical Indices for the assessment of groundwater quality for agricultural purposes. The SAR values in the study area were low, ranging from 0.0251 to 0.1588 with an average of 0.047 (Table 6). The concentration is within the excellent range according to [23] and is therefore suitable for irrigation purposes according to [24, 25, 26]. Irrigation water with high sodium adsorption ratio may require soil amendments to prevent long-term damage to the soil. Prolong exposure of irrigation water with high SAR on soil would lead to the displacement of calcium and magnesium in the soil. This in turn causes loss of soil structure, inability of the soil to form stable aggregates. This will also lead to decrease in infiltration and permeability of the soil leading to problems of crop production. RSC values in the study area shows values ranging from -3.23 to 0.987 with an average of -0.27 (Table 6). This indicates that sodium build-up is unlikely since sufficient Ca^{2+} and Mg^{2+} are in excess of what can be precipitated as carbonate whereas positive RSC indicates that sodium build-up in the soil is possible. In the study area, 75% of the water samples revealed negative RSC, indicating that Na^+ build-up is unlikely with practically no Na^+ hazard and therefore classified as fit for irrigation. %Na in the area ranged from 4.58 to 9.91 with an average of 6.4. In the area, all the water samples were within the class 1 excellent quality of <20% [24, 25, 26]. Therefore, the concentration of Na in the areas is suitable for agricultural purposes.

Table 6. Chemical Indices for the assessment of groundwater quality for Agricultural purposes

SN	Sample Location	Water source	SAR (meq/l)	RSC (meq/l)	%Na (meq/l)	PI (meq/l)	KR (meq/l)	SSP (%)	MR (%)
1	Mainau	HDW1	0.0555	-0.1151	6.438	57.41	0.0153	6.78	38
2	GRA	BH2	0.1588	-0.2898	9.91	66.25	0.0459	10.512	47.29
3	Londo	HDW3	0.0776	-0.0431	7.39	63.24	0.2261	7.808	47.43
4	Gaggau	BH4	0.0658	0.46	7.442	68.54	0.0195	7.886	42.41
5	Tarangadi	BH 5	0.0414	-0.3819	5.98	54.29	0.0112	6.288	45.75
6	Pali	HDW6	0.0515	0.209	6.908	67.31	0.0158	7.304	39
7	Kan'iyaka	BH7	0.0485	-0.27859	8.734	56.95	0.0135	9.208	44.59
8	Arawa	BH8	0.0403	-0.35297	6.12	54.48	0.0112	6.442	48.085
9	Gunchiguni	BH9	0.0514	-0.43	6.79	55.87	0.0143	7.18	48.125
10	Ung. Ajiya	BH10	0.0468	-0.0787	6.703	61.43	0.0138	7.088	45.54
11	Maimadiri	HDW11	0.0373	-0.2393	6.36	57.59	0.0107	6.718	42.77
12	Bayan Banki	BH12	0.0615	-1.351	6.53	45.27	0.0174	6.531	44.06
13	Balyari	BH13	0.0436	-0.0797	6.31	58.12	0.0121	6.65	43
14	Felfelu	BH14	0.0377	-0.1529	5.95	57.11	0.0104	5.81	43.27
15	Nainawa	BH15	0.0367	0.213	6.51	60.91	0.0103	6.89	44.17
16	Masuri	HDW16	0.0385	0.019	6.2	58.07	0.0105	6.6	42.02
17	Bagurja	BH17	0.0497	0.0413	7.27	61.71	0.0143	7.74	36.904
18	Gwaram	BH18	0.0569	-0.479	6.74	56.49	0.0162	7.11	42.301
19	Takai	BH19	0.0566	0.404	7.49	69.16	0.0171	7.96	46.24
20	Kurwala	HDW20	0.0409	-0.252	4.58	49.57	0.0096	4.76	25.28
21	Kwaimawa	HDW21	0.0359	-0.1246	6.59	56.82	0.0099	6.99	47.11
22	Gokaru	BH22	0.0321	0.987	6.49	65.23	0.0088	6.89	54.81
23	Sabonlayi	BH23	0.0353	0.121	6.09	59.16	0.0098	6.42	43.6
24	Sharfuri	HDW24	0.0411	0.9405	6.67	67.03	0.0115	7.06	52.35
25	Wuroduwa	BH25	0.0753	-0.3451	6.81	57.99	0.0207	7.16	42.45
26	S/Shanu	BH26	0.0486	-0.0847	6.64	58.48	0.0135	7.01	50.6
27	Kachallari	HDW27	0.0389	-0.1992	6.08	55.47	0.0105	6.41	40.46
28	Girgiri	HDW28	0.0545	0.321	7.02	63.75	0.0154	7.45	42.65
29	U/Malam kawu	BH29	0.0359	-0.1976	6.38	55.35	0.0097	6.16	45.14
30	Dandalhari	BH30	0.0425	-0.6637	5.88	51.78	0.0114	6.18	51.59
31	Sha'iska	BH31	0.0441	-0.1041	5.47	55.21	0.0114	5.73	47.8
32	Lafiya	BH32	0.0346	-1.746	5.12	40.75	0.0091	5.34	49.8
33	Tudu	BH33	0.0315	-3.23	5.31	53.08	0.0082	5.57	51
34	Pali	HDW34	0.0415	0.442	6.28	61.16	0.0113	6.62	38.69
35	Tumuru	BH35	0.0398	-0.015	6.16	58.13	0.0109	6.49	52.49
36	Wuro ladde	BH36	0.0467	-0.8617	6.14	49.21	0.0094	6.48	44.49
37	Mararraba	BH37	0.0261	-1.0303	4.94	46.43	0.0068	5.16	48.76
38	Jojoto	HDW38	0.0251	-0.9979	5.03	45.88	0.0064	5.26	56.63
39	Mai'ari	BH39	0.0268	-0.0613	5.12	54.09	0.0071	5.36	48.25
40	Sabongari	BH40	0.0351	-0.6571	6.35	53.01	0.0091	6.71	40.28
		Average	0.04721	-0.26711	6.423125	57.1945	0.018153	6.742875	45.129
		Min.	0.0251	-3.23	4.58	40.75	0.0064	4.76	25.28
		Max	0.1588	0.987	9.91	69.16	0.2261	10.512	56.63

5 CONCLUSIONS

That Principal Component Analysis (PCA) and Hierarchical Cluster Analysis (HCA) reveals that natural mineralization processes, salinity, weathering and rock-water interaction, hardness of water caused by calcium and magnesium ions and anthropogenic contamination are factors responsible for the modification of groundwater chemistry. That Water Quality Index (WQI) for drinking purposes exhibit poor, good and excellent quality rating for drinking purposes in the area. That Sodium Absorption Ratio (SAR), Residual Sodium Carbonate (RSC), Percentage Sodium (%Na), reveals that the water sources in the area are fit for agricultural purposes.

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