GROUNDWATER FLOW PATTERNS AND DISTRIBUTION OF GEOCHEMICAL FACIES IN GOMBE AND ENVIRONS, NORTH EAST NIGERIA

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ABSTRACT

Groundwater is the major sources of water supply for drinking, domestic, household, agricultural, industrial, recreational, and environmental activities in Gombe and environs. The research is aimed at delineating the groundwater flow patterns and distribution of geochemical facies in Gombe area and environs, northeastern Nigeria. Analytical results of 50 groundwater samples from the study area revealed that the order of abundance of the cations concentrations are $Ca^{2+}>Mg^{2+}>K^{+}>Na^{+}$ while those of the anions are $HCO_3^{-}>SO4^{2-}>Cl^{-}>CO_3^{-}$. The plotting of groundwater samples on piper trilinear and Schoeller diagrams delineate three groundwater facies as Ca-SO_4, Mg-HCO_3, and Ca-HCO_3. Ca-SO_4 accounts for 6% of the chemical facies, Mg-HCO_3 accounts for 12%, and Ca-HCO_3 Constitute 82% of the chemical facies. Ca-HCO_3 facie is the dominant water type and is regarded as young water of meteoric origin that resulted from the dissolution of carbonates as a result of induced chemical weathering. From the recharge area groundwater flow South-West and also towards extreme North-East where it encountered groundwater of saline characteristics, and this leads to the evolution of Ca-SO_4 facie. Also Ca-HCO_3 facie in the recharge zone interacted with Na_2SO_4 where the Ca-SO_4 water type evolved through reverse cation exchange. Another recharge area is around the central portion of the study area where groundwater flows southwest and north respectively and encountered rocks with plagioclase and clay composition within the aquifer. This lead to the evolution of Mg-HCO_3. the Ca-SO_4 water type is regarded as water of intermediate composition. Principal Component Analysis on the data indicates three factors which explain about 64.93% of the total variance, and suggests temporary hardness of water, salinity of the groundwater, diffused contamination and dissolution of bedrock materials as the dominant processes responsible for the modification of groundwater chemistry.

Keywords: Groundwater flow, geochemical facies, piper diagram, water type, recharge zone and Gombe

1 INTRODUCTION

Groundwater is the most vital natural resource, which forms the core of the ecological system [1]. It has become the major source of water supply for drinking, domestic, household, agricultural, industrial, recreational, and environmental activities. Groundwater quality variation in an area mainly depend on the physical and chemical parameters that are greatly influenced by natural processes such as geological formations and anthropogenic activities. According to [2], groundwater quality also depends, to some extent, on its chemical composition which may be modified by natural and anthropogenic sources. Also WHO reported that drinking contaminated water is the cause of about 80% of all diseases in human being. Groundwater chemistry changes as it flows from recharge area towards the discharge area.

The change in the chemistry is as a result of dissolution of ions in soils, sediments and rocks as the water travels along mineral surfaces in the pores and fractures of unsaturated zone and the aquifer [3]. Groundwater constitute a wide variety of dissolved chemical constituents in various concentrations which resulted from its chemical and biological interaction with contaminants from various sources related to natural or anthropogenic sources along its flow paths. The major ions which constitute most of groundwater chemistry act as natural tracers that aid in delineating groundwater flow path, therefore the common method of delineating flow path in aquifers may be the use of major ions as natural tracers [4]. Despite how importance groundwater is, little is known about the natural phenomenon that governs its chemical composition or the anthropogenic factors that affect it [5]. Therefore, Understanding the chemical composition of groundwater will aid in the development and management of groundwater for various uses. This research is aimed at delineating the groundwater flow patterns and distribution of geochemical facies in Gombe area and environs as well as the processes that are responsible for the modification of the groundwater chemistry. Gombe and environs is the study area, it covers an area of about 136.08 km^2 located in the northeastern part of Nigeria. It is defined by longitudes 11°7'0''E to 11°14'0''E and latitudes 10°15'0''N to 10°21'0''N (Figure 1).

2 THE STUDY AREA

The study area is characterized as tropical continental climate zone. It is usually having two seasons; a rainy season, which commonly starts in May and finishes in October and the dry season, normally spans between October and April. The study area is mainly classified as a Sudan savannah region, which is characterized by grasses, shrubs and trees with large trunks. The elevation ranges from about 400 m to 600 m above sea level (Figure 1). The topography of the area is generally inlier having some igneous rocks been surrounded by sedimentary rocks. Surface drainage systems in the study area is characterized by numerous streams ended in the direction of the river basin towards the southeast. Most of the streams are seasonal overflowing their banks during rainy season.

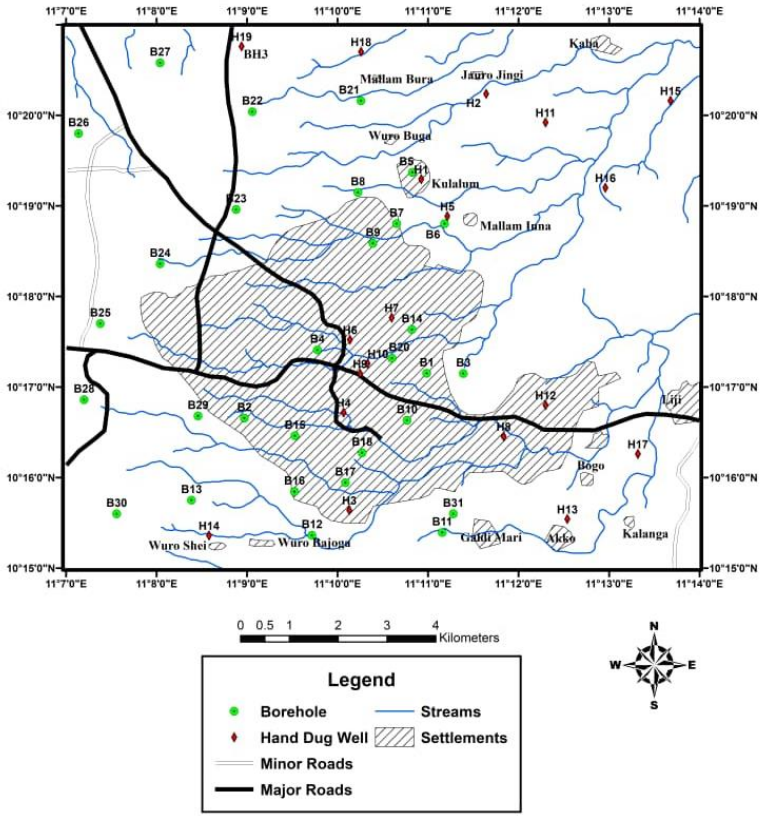

Figure 1. Map of the study area showing fifty sampling points

2.1 Geology of the Study Area

The Precambrian Basement rock and Cretaceous sediments are the two rock types found in the study area. The Basement complex rocks are characterized by Diorite and Granite whereas Bima, Yolde, Fika and Gombe Formations characterized the Cretaceous [6] (Figure 2). Tectonic activities affected the rocks types which resulted in faulting and upliftment of the rocks (Figure 2). The observed fault trend in NW-SE direction. The cross section A-B (Figure 2) shows that the oldest sedimentary unit is the Aptian-Albian Bima Formation overlying the Precambrian Basement rocks. The Bima Formation consist of poorly sorted, angular highly aekosic pebbly sandstones. In some areas the formation consists of granulestones and pebble conglomerates [7]. The Cenomanian Yolde Formation overlying the Bima Formation hitch is characterized by Sandstone and mudstone to the basal while thinly and regularly bedded bioturbated sandstone represents the upper part of the formation. Fika shales is the only member of Pindiga Formation observed in the study area. The Fika shales mostly shown shaly mudstone which are dark grey when fresh and lighter blue-green to grey colour when weathered. The youngest cretaceous unit in the study area is the maastritchian Gombe Formation. Gombe Formation comprises of pebbly coarse grained sandstone with slurred cross bedding. In the basal part of the formation are fine to medium grained and generally show tabular cross bedding which is highlighted by layers and streaks of white sandstone.

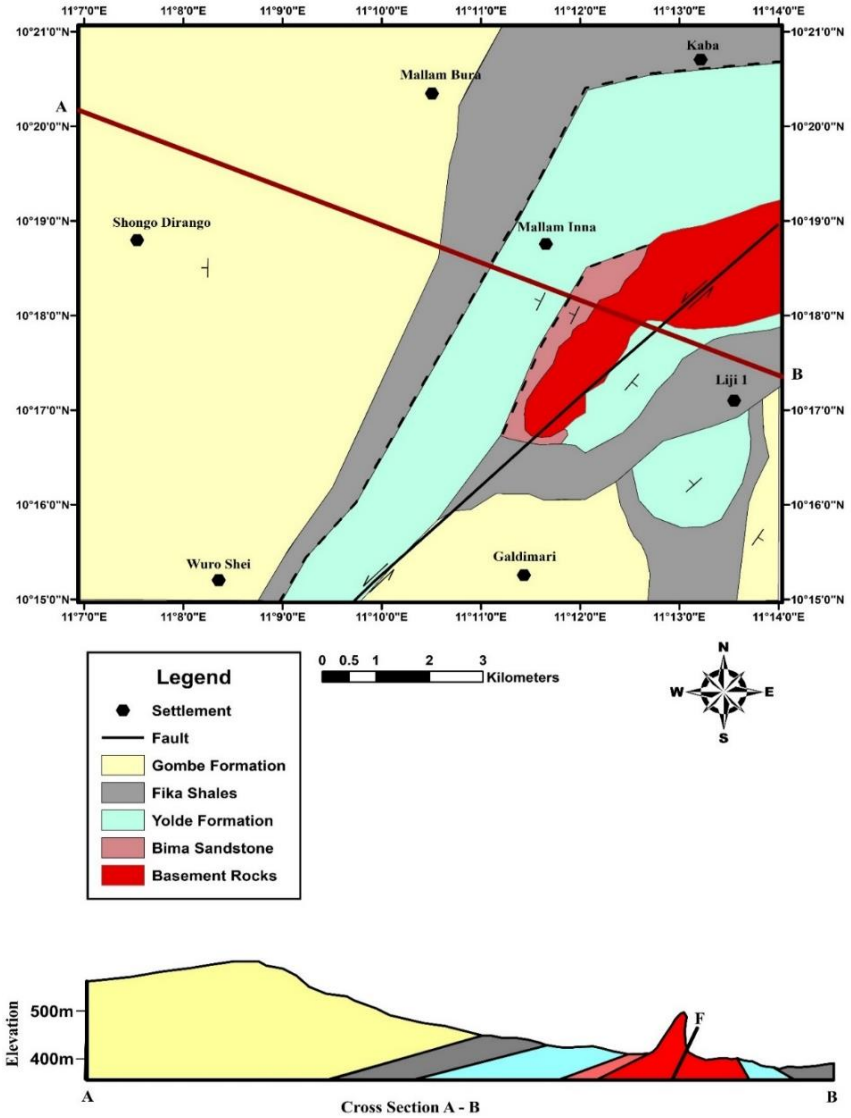

Figure 2. Geological map of Gombe and Environs the study area

2.2 Hydrogeology of the Study Area

Gombe and environ is largely underlain by sedimentary rocks of different lithology and responds in different ways hydro geologically. Bima Formation is the most productive of the sedimentary rocks; because of the coarse nature of its grains and its high degree of sorting, it can serve as a good aquifer. It can also serve as a good source of recharge. The water bearing zones of the sandstones are 20 to 50 m in depth. In the marine Cretaceous series of Yolde and Pindiga Formations, Yolde Formation has water more than the Pindiga Formation because it has thin beds of sandstones making it a better aquifer than the blue / black shales of the Pindiga Formation (Fika Shales). The Gombe sandstone mainly composed of sandstones, siltstones and shales that are poor in groundwater storage. [8] reported that the aquifer systems of Gombe are mostly medium grained sandstones and are of semi-confined to confined, that ranges in thickness from 28.3 m to 30 m with an average of 29 m.

3 MATERIALS AND METHODS

The geological mapping of the study area was done by detailed traversing, critically observing the different formations and exposures, within Gombe and environ. Also, dry river channels and footpaths, were carefully traversed. A Global Positioning System (GPS) was used to obtain the altitude readings of rock formations encountered. The boundaries between these rock units were delineated, Also GPS (Model Garmin eTrex HC Series) was used to take coordinates of geological boundaries. A topographical map was used to plot geologic data acquired in the field. A reference point was also fixed by noting a prominent feature seen in the field. This position was then marked on the base map and its GPS location was then recorded.

The groundwater samples were obtained from 50 sampling points (hand dug wells and boreholes) in June 2017 (Figure 1). The sample collection was done according to [9] method, and the coordinates of each well and boreholes were recorded using GPS (Model Garmin eTrex HC Series). The water samples were analyzed for physico-chemical parameters. Field parameters such as: pH, Temperature, Turbidity, Conductivity, bicarbonate, and Total Dissolve Solids were measured immediately after sampling, using appropriate equipment's. All other parameters such as Potassium (K^+), Calcium (Ca^{2+}), Copper (Cu^{2+}), Sodium (Na^+), Magnesium (Mg^{2+}), Chloride (Cl^-), Nitrate (NO_3^-), Fluoride (F^-), Sulphate (SO_4^2-), zinc (Zn^{2+}), lead (Pb^{2+}) and chromium (Cr^{6+}) were determined in the laboratory by spectrophotometry using HACH digital Spectrophotometer (Model DR2400, USA).

3.1 Hydraulic Head/Groundwater flow Path

Ground-water flow in an aquifer responds to real differences in potential, moving from areas of high potential to areas of low potential. Potentiometric maps are useful for any hydrological investigation because they help one to see how the potentiometric surface appears in 3D as opposed to a point measurement at a well bore. Thirty (30) hand dug wells were used to determine the hydraulic head (in meters) in the study area. The hydraulic head was determined by subtracting the static water level from the elevation of each sampling point. The static water level was measured using coaxial water level meter while the elevation was measured using GPS. The Hydraulic Head distribution map of the study area was plotted using surfer 13 software.

3.2 Geochemical Facies

AqQa statistical software package version 1.0.5 was used to develop the Piper, and Schoeller diagrams in order to determine the different geochemical facies in the study area.

3.2.1 Piper Diagram

Piper trilinear diagrams are normally prepared to classify the water chemistry of selected sources of an area [10]. Piper plots are very powerful tools for visualizing the relative abundance of common ions in water samples. This plot type is especially useful because it allows plotting multiple samples on the same plot, thus allowing for grouping water samples by groundwater facies and other criteria. A Piper plot is

comprised of three components: a ternary diagram in the lower left representing cations (magnesium, calcium, and sodium plus potassium), a ternary diagram in the lower right representing anions (chloride, sulphate, and carbonate plus bicarbonate), and a diamond plot in the middle which is a matrix transformation of the two ternary diagrams. Each sample is normalized to 100 (sum of cations = 100 and sum of anions = 100), so the relative concentrations are on percentage basis.

3.2.2 Schoeller Diagram

Schoeller diagram is a semi-logarithmic diagram of the concentrations of the main ionic constituents in water (SO_4^{2-}, HCO_3^-, Cl^-, Mg^{2+}, Ca^{2+}, Na^+ and K^+) [11, 12]. This plot displays the relative concentrations of various anions and cations from multiple samples on a single graph. The Schoeller plot is a series of line/scatter plots where the X value is the cation or anion and the Y value is the concentration values in mg/l from the raw data. Concentrations of each ion in each sample are represented by points on six equally spaced lines and points are connected by a line. The diagram gives absolute concentration, but the line also gives the ratio between two ions in the same sample. If a line joining two points representing ionic concentrations in a single sample is parallel to another line joining a second set of concentrations from another sample, the ratio of those ions in those samples are equal.

3.3 Principal Component Analysis

SPSS version 20 statistical software package covering a wide range of calculations were used for the analysis of Principal Component Analysis. The principal component analysis (PCA) is a multivariate statistical technique employed for the purpose of data reduction with a view to determining the sources of elements and their controlling factors [13]. Factor loadings were interpreted as correlation coefficients between the variables, a high positive loading was defined as greater than 0.75, and moderate loading was defined as 0.40-0.75. Loadings of less than 0.40 were considered insignificant [14].

4 RESULTS AND DISCUSSION

4.1 Hydraulic Head Distribution Map

Values of hydraulic head are presented in Table 1. Figure 3 indicates that the groundwater flow is from the central part of the study area, north of Arawa (Recharge area) towards the north eastern part around Kaba and then down towards Arawa (Discharge area). Another recharge area is from the north-western part near Shongo Dirango and flows down south. Also another Recharge area is near Kundulum due north towards main market (Discharge area) and then down south towards Kundulum and also out wards to Wuro Shie (Figure 3). Similar hydraulic head distribution was observed by [15] on Benue floodplain.

Table 1. Hydraulic head of the study area

S/No	Sample Location	Northing	Easting	Elevation (m)	Static Water Level (m)	Hydraulic Head (m)
1	Bagadaza	N10015'38.4"	E11010'07.8"	496	6	490
2	Tashan Gona	N10016'27.2"	E11011'50.2"	520	4.6	515.4
3	Mallam Inna	N10018'53.1"	E11011'12.8"	532	11	521
4	Ajiya	N10017'45.9"	E11010'36.0"	541	3.6	537.4
5	Jauro Jingi	N10020'14.2"	E11011'38.6"	523	4.5	518.5
6	Kumbiya-Kumbiya	N10017'08.8"	E11010'15.0"	543	2.2	540.8
7	Anguwan Fada	N10017'31.3"	E11010'08.3"	542	10.2	531.8
8	Kulalum	N10019'17.7"	E11010'55.5"	532	12	520
9	Bolari	N10016'43.0"	E11010'04.1"	554	2.7	551.3
10	Herwagana	N10017'15.5"	E11010'20.0"	555	2.7	552.3
11	Kasuwan Katako	N10°17'31.0"	E11°9'55.3"	439	8	431
12	Rafin Sanyi	N10°16'36.8"	E11°10'12.4"	475	7	468
13	Wuro Bajoga	N10°15'16.8"	E11°9'12.4"	470	10	460
14	Anguwan Gandu	N10°17'58.3"	E11°10'31.0"	523	8.2	514.8
15	Opposite GSU	N10°18'18.5"	E11°10'12.3"	513	10.1	502.9
16	Railway	N10°17'25.1"	E11°09'50.9"	512	12.5	499.5
17	Kagarawal	N10°17'15.0"	E11°09'45.6"	518	16	502
18	J/Fari	N10°17'10.6"	E11°09'51.2"	533	14.5	518.5
19	Pantami	N10°16'27.0"	E11°09'41.8"	540	9.8	530.2
20	Jankai	N10°16'26.0"	E11°09'42.5"	543	5.9	537.1
21	Jauro Abdul Pantami	N10°16'13.9"	E11°9'18.4"	549	2.5	546.5
22	Malam Kuri	N10°16'23.7"	E11°09"46.2"	538	4.5	533.5
23	Madaki	N10°16'11.3"	E11°09'53.0"	541	3.9	537.1
24	Real Quarters	N10°15'56.9"	E11°10'31.8"	556	7.9	548.1
25	Bomala	N10°15'43.1"	E11°10'37.3"	549	3.2	545.8
26	Dubai Quarters	N10°15'44.9"	E11°10'30.4"	546	4.8	541.2
27	Barunde	N10°15'31.1"	E11°10'38.5"	490	9.6	480.4
28	Galidimari	N10°15'48.1"	E11°11'18.7"	512	4.5	507.5
29	Hammadu Kafi	N10°16'10.7"	E11°10'59.7"	476	5.8	470.2
30	Kwata	N10°17'28.1"	E11°11'16.8"	550	2.9	547.1

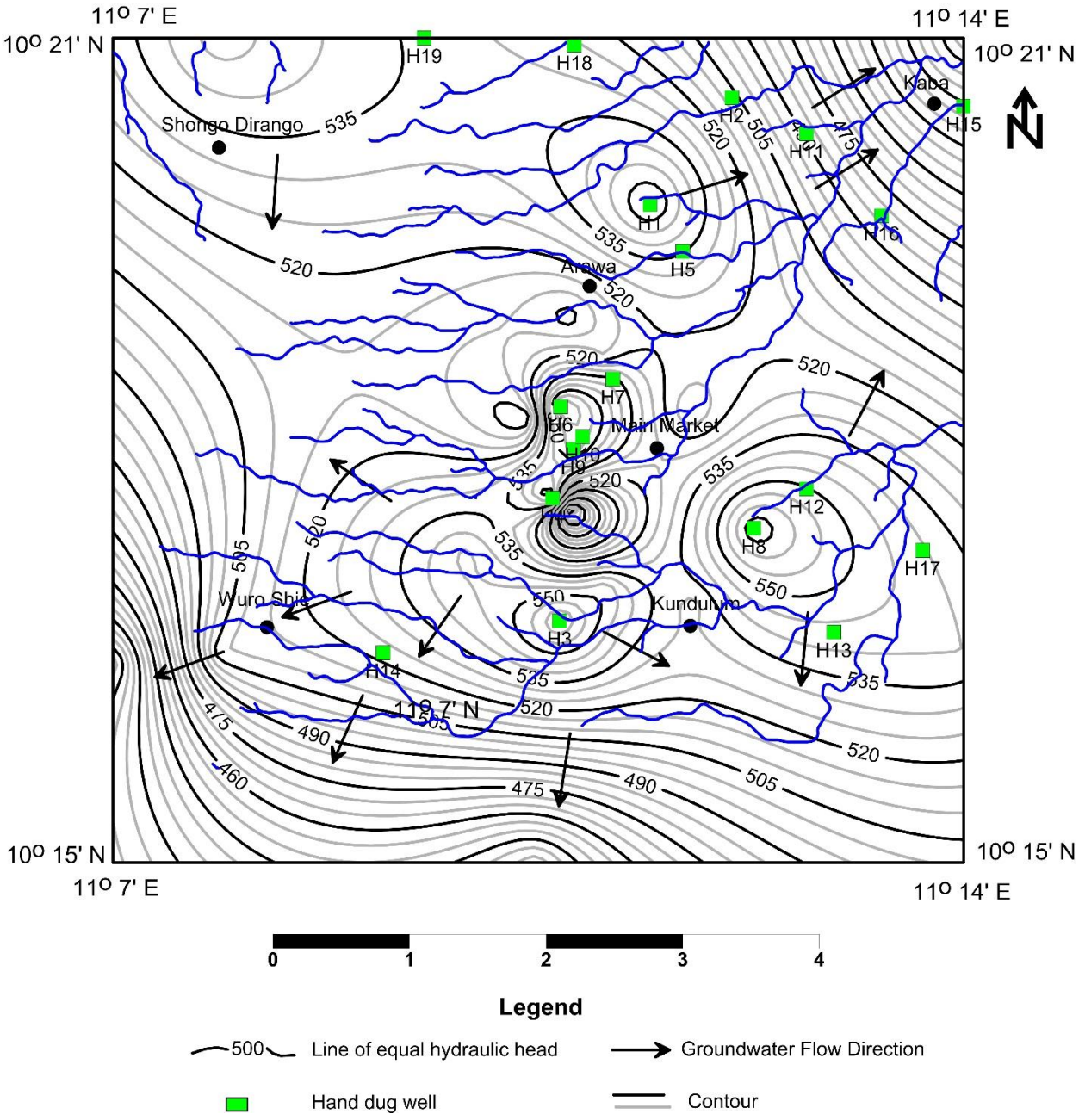

Figure 3. Hydraulic head distribution map of the study area

4.2 Geochemical Facies

Table 2 contains the values of physico-chemical results of groundwater from the study area. Based on the mean values of the chemical parameters the order of abundance of cations concentrations are as $Ca^{2+}>Mg^{2+}>K^{+}>Na^{+}$ while those of the anions are $HCO_3^{-}>SO4^{2-}>Cl^{-}>CO_3^{-}$. Major Cations ($Ca^{2+}$ Mg^{2+} K^{+} and Na^{+}) and Anions (CO_3^{2-}, HCO_3^{-}, $SO4^{2-}$and Cl^{-}) from the results were used for the plotting of Piper and Schoeller diagrams.

Table 2. Physico-Chemical Constituents of groundwater samples in the Study Area

Sample Locations	Water source	Temp (°C)	pH	EC (µs/cm)	TDS (mg/l)	Turbidity (NTU)	TH mg/l ($CaCO^3$)	Ca^{2+} mg/l	K^+ mg/l	Cu^{2+} mg/l	Na^{2+} mg/l	Mg^{2+} mg/l	Fe^{2+} mg/l	SO_4^{2-} mg/l	CO_3^{2-} mg/l	HCO_3^- mg/l	F^- mg/l	Cl^- mg/l	NO_3^- mg/l	PO_4^{2+} mg/l
ARAWA	BH1	26.83	5.92	309	205	0.11	47.54	36.84	5.33	1.09	0.96	10.11	0.83	28.01	0	118.7	0.61	20.42	10.43	1.02
WURO BIRIJI	BH2	26.73	6.44	341	226	1.053	46.62	34.42	5.6	0.8	1	11.01	0.49	28.08	1.1	220	0.5	16.88	13.2	0.94
RAILWAY	BH3	26	6.41	289	190	0.25	59.84	46	5.53	0.99	1	14.01	0.83	27	0	200	0.47	23.07	9.66	0.86
BYE PASS	BH4	26.97	6.25	268	177	0.075	54.05	41.67	5.3	1.1	0.94	12.61	0.77	26.57	0	191.11	0.67	17.63	12.08	1.04
PANTAMI	BH5	26.12	6.22	297	196	0.105	64.97	43.23	4.77	1	1.14	18.11	0.63	29.66	0	196.1	0.56	18.53	9.88	1.01
JEKA DA FARI	BH6	25.92	6.37	298	200	0.005	54.66	41.08	5.1	1.09	0.9	12.82	1.02	26.99	0	192.5	0.68	20.18	10.42	0.97
BOLARI	BH7	26	6.44	340	227	0.066	51.27	43.37	7	0.97	0.9	7.49	0.8	27.55	0	90	0.44	16.83	8.62	1
JAURO KUNA	BH8	27.01	6.23	287	190	0.108	53	43.13	4.83	0.9	0.89	8.97	0.7	26.77	0	174	0.82	21	9.18	0.83
MAIN MARKET	BH9	27.05	5.97	255	169	0.027	47.48	38.11	6.9	1.04	0.78	8.55	0.6	26.84	0	102	0.83	19.4	7.58	0.71
IDI QUARTERS	BH10	26	6.65	297	199	0.042	52.89	37.01	5.38	1.2	0.86	16.42	0.59	27.9	0	188	0.92	16.57	8.63	0.85
KUNDULUM	BH11	26.81	6.31	348	231	0.029	55.98	40	4.88	0.8	0.88	16.73	1	28.01	0	201.4	0.6	18.93	9.77	1
TAURA	BH12	26.91	6.21	311	210	0.125	52.09	38.87	4.2	0.73	0.98	12.44	0.67	28.11	0	186.4	0.33	17.67	8.73	1.1
WURO KESA	BH13	27.11	6	353	237	0.95	47.67	37.73	5.4	0.69	1	9.08	0.55	28.73	1	190.8	0.73	17.88	12	1.06
WURO JULI	BH14	26.64	6.6	314	209	0.028	59.12	39	6.1	0.78	1	19.83	0.5	27.01	0	205	0.49	16	9.07	0.88
NEW GRA	BH15	25.7	6.48	274	184	0.035	52.6	38.93	6.6	1.11	0.8	14.4	0.78	26.81	0	133	0.44	23.11	11.52	1
GABUKKA	BH16	27.03	6.18	269	179	0.091	50.24	40.83	4.9	1.1	0.84	8.87	0.43	26.11	0	109	0.5	21.43	10.55	0.9
STATE LOWCOST	BH17	27.2	6.2	317	210	0.15	53.94	42.84	4.8	0.67	0.8	11.47	0.92	27.11	0	166.73	0.61	15.93	9.4	1
T/WADA PANTAMI	BH18	26.9	6.2	273	181	0.511	49.05	39.66	6.6	0.91	0.91	9.16	0.39	27.41	0	124	0.37	19.53	7.93	0.78
WURO BOGGA	BH19	26.87	6.1	284	188	0.907	50.97	38.55	6	1.02	0/91	12.83	0.6	29	1	108.6	0.77	22	11	0.95
MKTTAKO	BH20	25.99	6.09	285	191	0.315	55.95	44.42	6.42	1.03	0.92	11.73	1	25.93	0	211.4	0.48	16.87	9.91	0.96
MALAM BURRA 1	BH21	27.1	6	217	134	1.02	59.11	37.81	6.61	0.73	2.44	21.07	0.27	23.42	2.1	193	0.39	24	23.66	0.43
MALM BURRA 2	BH22	27	6.12	212	129	0.65	62.28	40.66	6.42	1.01	2.81	21.44	0.52	24.81	2.4	187	0.48	21.1	19.48	0.59
CBN	BH23	26.81	6.33	284	251	0.55	70.17	41.92	4.93	1	2.73	27.12	0.49	24.66	1.4	198	0.64	16.5	20.48	0.81
LEGISLATIVE QUARTERS	BH24	26.12	6.17	271	241	0.41	68.84	39.73	5.1	0.67	1.66	27.91	0.44	25.92	0	191	0.44	20.1	19.68	0.75

JIYAMERE	BH25	24.93	6.16	255	149	0.112	62.91	41.1	5	0.7	1.47	23.42	0.4	26.6	0	207	0.59	16.5	19	1
SHONGO DIRANGO	BH26	26	6.53	189	118	1	73.12	44.87	4.99	0.4	1.88	31.27	0.37	26.1	0	200	0.6	20	18.97	0.63
DORAWA 2	BH27	26.53	6	200	110	0.215	53.92	37.08	6	0.51	2.93	19.79	0.22	27	0	178	0.34	17.5	20.55	1.04
NEW MILE 3	BH28	27.1	5.81	298	181	0.405	51.73	32.91	7.01	0.88	2.91	19.88	0.377	27.12	1.1	153	0.72	18.8	12.54	0.44
NEAR HOUSE OF ASSEMBLY	BH29	26.81	5.93	300	186	0.095	50.93	33.03	6.98	0.47	1.88	18.78	0.4	27.11	0	149	0.67	16.9	11.73	0.57
WURO SHIE 3	BH30	26.44	6.18	283	172	0.073	68.22	40.43	5.23	0.59	1.9	27.19	0.501	26.93	0	188	0.41	14.5	10.46	1.1
GALDIMARI	BH31	27.2	6.27	219	137	1.05	64.79	46.27	5.93	0.8	2.48	19.39	0.45	26.14	0	158	0.8	23.7	21.18	1.21
RIYAL QUARTERS	HDW1	23.67	8.1	321	210.5	0.063	64.11	39.73	8.6	0.37	1.14	23.59	0.56	28.72	1.1	107	0.9	22.97	16.73	0.43
YALANGURUZA	HDW2	24.28	7.6	331	216.5	0.095	67.51	48.91	13	0.72	1.01	17.55	0.601	26.15	0	121	0.82	30	20	1
WURO KESA 2	HDW3	24.08	7.81	301	196.7	0.205	71.08	47.88	10.4	0.39	1.34	22.88	0.4	28.09	3.2	101	0.79	29.72	38.42	0.56
ANGUWAN GANDU	HDW4	23.67	7.4	334	221	0.1	71	49	12.8	0.81	1.06	21.67	0.453	27.08	0	178.63	0.75	24.88	8.4	0.68
JAURO JINGI	HDW5	24	7.44	303	201.1	0.101	71.22	49.6	13.1	0.2	1.08	20.15	0.443	28.01	0	123.3	0.83	18.77	19.72	0.84
KUMBIYA KUMBIYA	HDW6	22.83	7.63	348	221	0.201	69.89	51.66	9.9	0.44	1.04	19.67	0.617	27.15	1.2	110.1	0.75	21.76	16.92	1.05
ANGUWAN FADA	HDW7	23.11	7.55	367.1	240	0.411	73.05	53	11.6	0.63	1.24	19	0.37	28.1	2.6	100	0.81	26.52	9.43	0.87
KUNDULUM	HDW8	23.42	7.9	309	214	0.152	66.93	44.11	10	0.6	1.31	23.42	0.411	26.15	0	188	0.51	21.67	15.62	0.77
BAYAN STADIUM	HDW9	23.92	7.48	369	244.5	0.927	57.85	37.28	9.1	0.52	1	20.85	0.49	28.1	1.4	120	0.64	19.4	14.93	0.72
HERWAGANA	HDW10	23.91	8	322	212.9	0.104	72	46.77	12.6	0.56	1.21	24.22	0.318	27.62	1	96.6	0.54	26.15	16	1.19
JAURO JINGI 2	HDW11	26.66	6.14	269	159	0.511	71.43	40.72	6.1	0.47	1.97	28.93	0.321	26.88	0	181	0.41	20.4	18.92	0.72
NASARAWO	HDW12	20.4	6.23	274	248	0.501	64.8	37.12	4.88	0.51	2.04	20.61	0.34	24.92	0	174	0.4	25	22.47	0.71
AKKO	HDW13	26	6.44	300	167	1.02	60.11	39.61	6.27	0.92	1.86	21.43	0.41	25.9	0	212	0.53	23.1	19.67	0.64
WURO SHIE 2	HDW14	25.93	6.51	260	149	0.45	59.82	30.1	5.91	1	1.09	27.11	0.48	26	2	199	0.47	19.6	11.1	1.02
KABA	HDW15	26.17	6.28	254	144	0.09	66.81	36.33	4.99	0.87	1.43	28	0.33	27.11	1.1	179	0.51	25.9	21.68	0.8
LIJI	HDW16	26.11	6.51	209	129	1.02	61.91	34.17	6.01	0.43	1.67	29.01	0.29	27.01	0	241	0.62	24.9	19.77	0.54
LIJI 2	HDW17	27	6.42	227	131	0.25	60	36.72	6.3	0.55	2.42	21.63	0.48	26.9	0	210	0.51	24.9	18	1.03
MALAM BURRA 3	HDW18	26.91	6.4	241	141	0.05	64	31.98	5.88	0.48	2.81	30.99	0.41	27.8	0	221	0.63	23.8	20.12	1
DORAWA 1	HDW19	26.84	5.98	270	167	1.005	57.21	36	7.1	0.61	1.09	19.53	0.33	27	1.2	168	0.67	21.4	24.11	0.69

4.2.1 Piper Trilinear Diagram/ Schoeller Diagram

Piper Trilinear diagram (Figure 4) and Schoeller diagram (Figure 5) indicate about three samples plotted on the region of Ca-SO_4 water type, six samples on Mg-HCO_3 region and 41 samples plotted in the region of Ca-HCO_3.

Ca-HCO_3 facies is the dominant water type in the study area and belongs to the normal alkaline group. The water type is young water of meteoric origin that resulted from the dissolution of carbonate minerals (Limestone and Gypsum) as a result of induced chemical weathering [16]. Ca can be derived from the dissolution of carbonate minerals while bicarbonate can be derived from the contribution of CO_2^- charged rainstorms and weathering process. This facie covers major portion of the study area (Figure 6).

Mg-HCO_3 facies covers extreme end of the eastern part of the area (Figure 6) as well as areas around Wuro Shei. This water type is regarded as recently recharged water and its sources are related to dissolution of alumina silicate minerals. Mg can be derived from the dissolution of silicate minerals while bicarbonate can be derived from the contribution of CO_2^-charged rainstorms and weathering process and may also come from the dissolution of dolomite in the area.

Ca-SO_4 facies represents an evolved water type. The evolution is due to rock-water interaction and reverse cation exchange reaction. Sulphate (SO_4^{2-}) are as a results of evaporates with sulphate composition [17, 18, 19]. This water type found in the western part of the study area (Figure 6) and also covers areas such as Arawa and Main market. This water type evolved due to interaction between the groundwater and gypsum found within the rock formation. The Ca from the Ca-HCO_3 replaced Na from Na_2SO_4 through reverse cation exchange. This water type is regarded as water of intermediate composition that evolved through simple geochemical mixing dominated by reverse cation exchange.

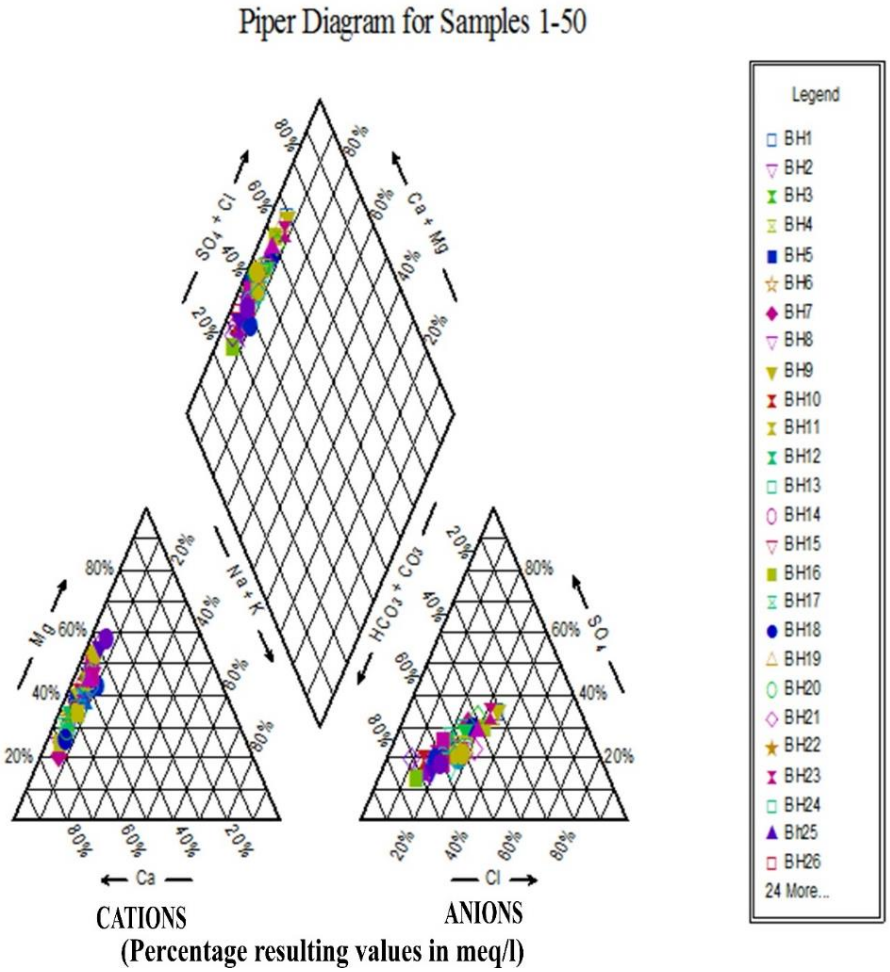

Figure 4. Trilinear diagram showing proportions of major ions for groundwater samples in the Study area

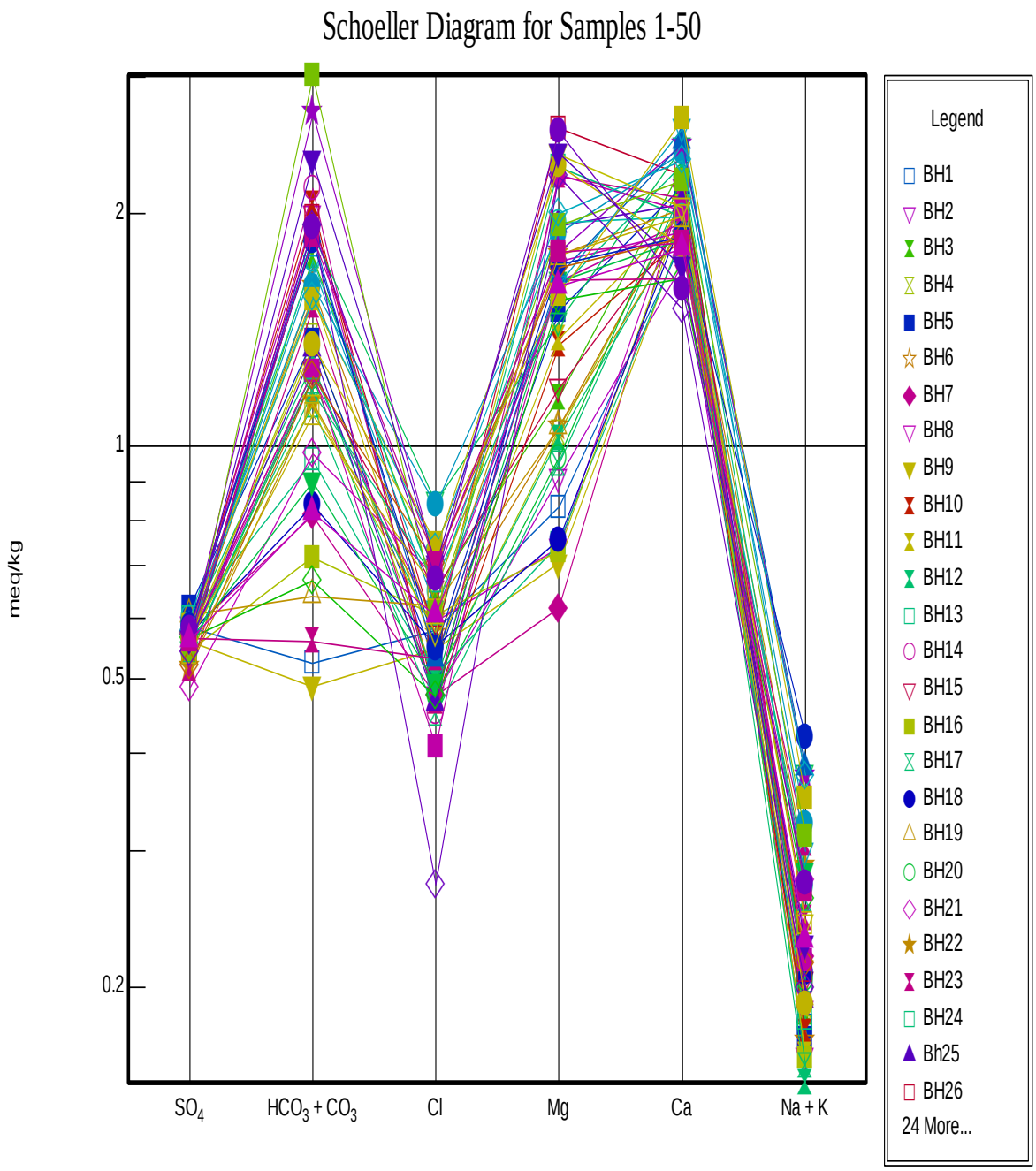

Figure 5. Schoeller Plot showing the different Water-types in the Study area

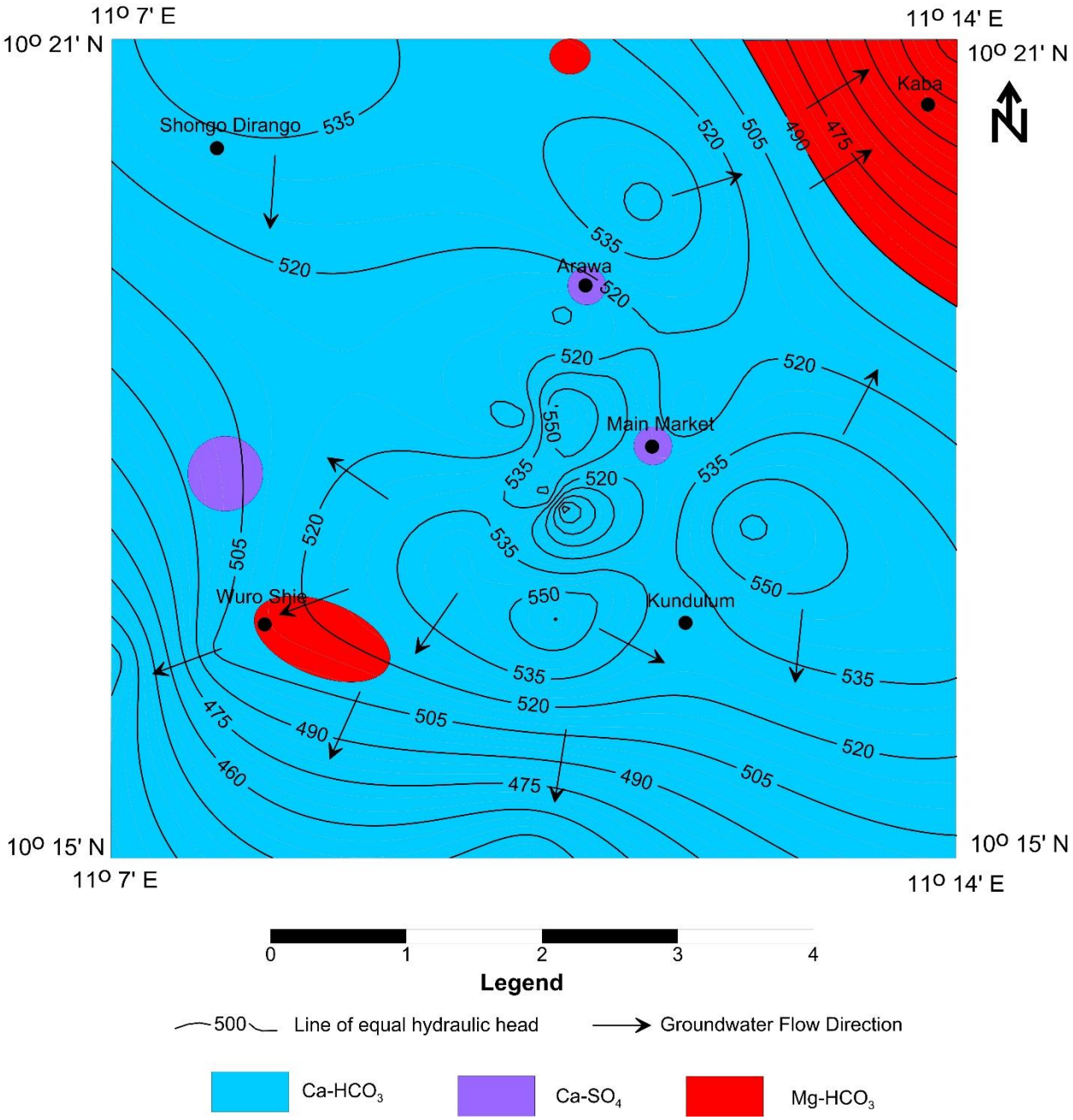

Figure 6. Groundwater flow patterns and distribution of geochemical facies

4.2.2 Chemical Evolution of Groundwater

The Durov diagram (Figure 7) is used to present groundwater chemistry [20, 21]. This was used to determine the geochemical evolution of groundwater within the study area. The results were used to identify the geochemical evolution of groundwater where it was initially recharged by the Ca-HCO_3^- water (rain water) at the recharge zone. It later went through water-rock interactions (dissolution) and mixing with pre-existing groundwater in sandstones and clayey sand materials along flow path that may be of saline nature. Geochemical evolution proceeds as indicated by groundwater flow path that may be of saline characteristics. From the recharge zone around Kundulum and Arawa areas, groundwater flow towards Wuro Shie and Kaba areas respectively, where it may have encountered rocks with plagioclase and clay composition within the aquifer. This lead to the evolution of Mg- HCO_3. The Ca-HCO_3 in the recharge zone interacted with Na_2SO_4 where the Ca-SO_4 water type evolved through reverse cation exchange. The Ca-SO_4 water type is regarded as water of intermediate composition. This water type occurs around Arawa, Main Market and adjacent to Wuro Shie (Figure 7).

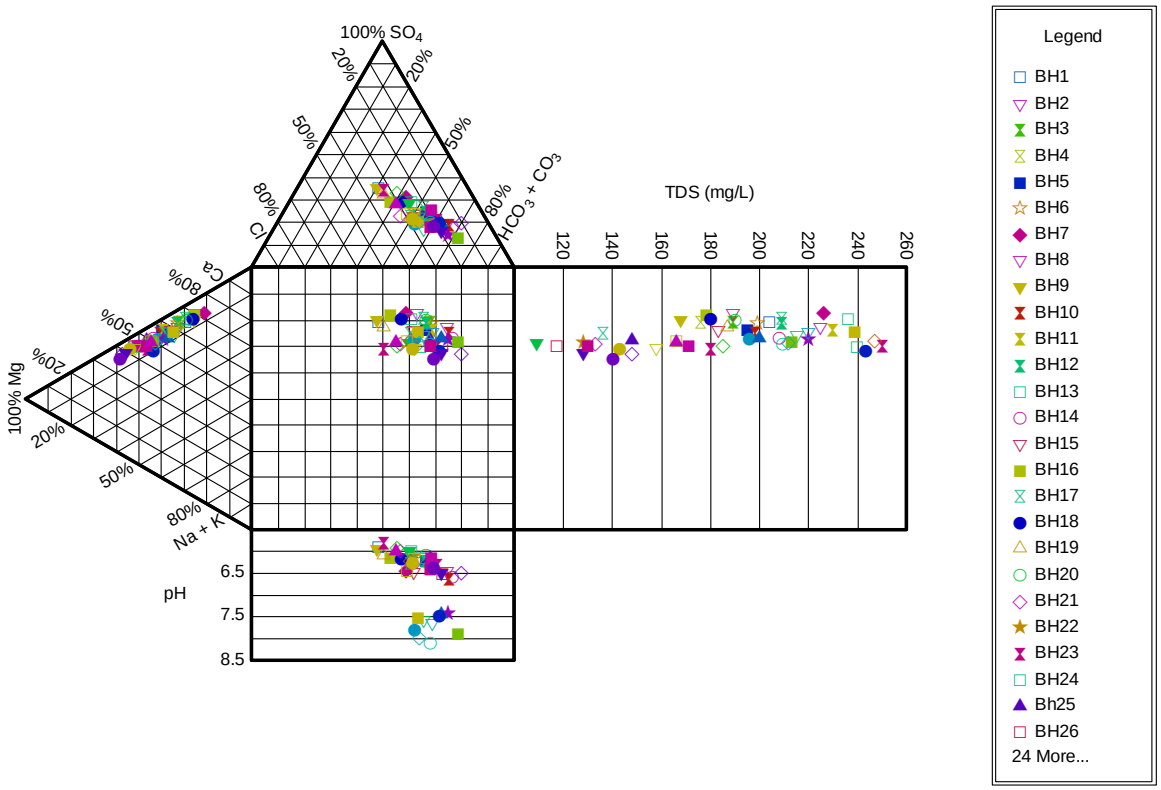

Figure 7. Plotting of water samples on Durov Diagram

4.3 Principal Component Analysis

The results of the PCA indicates three components explained most of the variance 64.9% (Table.3). Component 1 explained 25.35% of dataset variance and had high loadings for pH (.843) and TH (.807), while it had moderate loadings for Ca^{2+} (.739), K^{+} (.735), Mg^{2+} (.580) and Cl- (.462). This Component can be interpreted as temporary hardness of water contributed mainly by major ionic concentrations; calcium, Magnesium, potassium, and chloride. It occurs mainly through the weathering and dissolution of rock forming minerals in the study area [22, 23]. Component 2 describes 23.92% of the variance and had high positive loading for Fe (.778) and moderate loadings for EC (.636), TDS (.604), and PO_4^{-} (.854). This factor can be interpreted as salinity of water attributed by strong loadings of Fe and moderate loadings of Phosphate. EC and TDS controlled the overall mineralization. Component 3 exhibit 15.65% of the total variance and had moderate positive loadings for F (.673), SO4 (.509), and K (.467). This factor is interpreted as diffused form of contamination due to the application of chemical fertilizer such as NPK, potash, and manure [24, 25, 26]. The present study area has a variety of agricultural activities, particularly cropping patterns and irrigation; so that factors are mainly contribute to ionic movement to groundwater.

Table 3. Principal Component Analysis (PCA) component matrix

Parameters	Component		
	1	**2**	**3**
Temp	-0.816	0.055	-0.159
pH	**0.843**	-0.049	0.351
EC	0.414	**0.636**	0.421
TDS	0.44	**0.604**	0.256
TH	0.807	-0.394	-0.284
Ca	**0.739**	0.211	0.107
K	**0.735**	-0.144	**0.467**
Na	-0.07	-0.667	-0.468
Mg	**0.58**	-0.657	-0.418
Fe	-0.129	**0.778**	0.028
SO4	0.015	0.389	**0.509**
HCO3	-0.267	-0.083	-0.728
F	0.195	-0.039	**0.673**
Cl	**0.462**	-0.492	0.293
NO3	0.289	-0.752	-0.086
PO4	0.066	**0.618**	-0.271
Eigenvalue	**4.72**	**4.36**	**1.3**
% of Variance explained	**25.357**	**23.916**	**15.658**
Cumulative %	**25.357**	**49.273**	**64.931**

5 CONCLUSION

From the combined lines of evidences obtained from the field and laboratory investigations it is concluded that the factors responsible for the modification of the chemistry of the water were; diffused form of contamination, leaching of bedrock geochemistry, salinity, natural mineralization and temporary hardness of water. Moreover, plotting on Piper and Schoeller diagrams shows Ca-HCO_3, Mg-HCO_3 and Ca-SO_4 as the water facies. In which Ca-HCO_3 facie is the dominant water type and is regarded as young water of meteoric origin that resulted from the dissolution of carbonates minerals as a result of induced chemical weathering. Ca-HCO_3 water flows and encountered rocks with plagioclase and clay composition within the aquifer and leads to the evolution of Mg-HCO_3. Also Ca-SO_4 water type is regarded as water of intermediate composition which evolved from the interaction of Ca-HCO_3 waters with Na_2SO_4 along flow path through reverse cation exchange.

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