



HYDROCHEMISTRY OF SURFACE AND GROUNDWATER IN PARTS OF BIRNIN KEBBI NORTHWESTERN NIGERIA

Y. Abdulganiyu^{1*}, B. S. Oresajo¹, M. AbdulKarim¹, O. A. Phillips¹, H. Ibrahim I, T. A. Abdulfatah¹, H. Yakubu¹, H. Zainab¹, M. Sadiya¹, A. Nasiru¹ and I. Mahmud²

¹Department of Geology, Federal University Birnin Kebbi, Kebbi State, Nigeria

²Department of Geology, Federal University Dutsinma, Katsina State, Nigeria

*Corresponding author's email address: charger.ca34@gmail.com

ARTICLE INFORMATION

Submitted 30 March, 2023

Revised 3 Sept, 2023

Accepted 9 Sept, 2023

Keywords:

Water type
Physico-chemical
heavy metal
Nemerow's pollution
index
contamination

ABSTRACT

A hydro-chemical investigation of drinking water sources in Birnin Kebbi Old Town and its environs, in northwestern Nigeria, was carried out to determine the potability and suitability of the groundwater for domestic and agricultural uses. Twenty-three water samples were collected from these communities, and their physical and chemical parameters, such as electrical conductivity, total dissolved solids, pH, and temperature, were evaluated. Both the chemical and heavy metal analyses were conducted at the Multi-User Laboratory, Usmanu Danfodiyo University, Sokoto. The results obtained indicated that physical parameters like TDS and EC and chemical parameters like Mg^{2+} , Ca^{2+} and HCO_3^{2-} are high, while Cr^{2+} , Fe^{2+} , Ni, and Pb^{2+} have values that are below the NSDWQ recommended limits. While Na^{2+} , Cu^{2+} , Cl^- , and NO_3^- have values far below the NSDWQ set limit, The Schoeller and Piper diagrams show the dominant water type in the study area to be Ca-Mg- HCO_3 . However, the Gibbs plot shows the dominant source of the water to be the precipitation domain due to the dissolution of carbonate rocks, while the Wilcox diagram shows that all the water samples in the study area have low salinity. Application of Nemerow's pollution index method shows that the majority of the sampling locations displayed high NPI values, especially for Ni^{2+} and Pb^{2+} . The NPI Ni^{2+} values for eleven (11) out of twenty-three samples, making up 47.83%, have NPI values that range from 7.53 to 90.01, making them unsuitable for drinking purposes. The NPI values for Pb^{2+} for six (6) samples, making up about 26.09%, have high NPI values that range from 36.37 to 172.56, depicting a high level of pollution

1.0 Introduction

Groundwater is a valuable resource in the vast, thickly populated, semi-arid and arid areas of Kebbi State, northwestern Nigeria, and where it is available, it is unreliable. Because improved water supply is one of the essentials for a healthy lifestyle, it is constrained by uncontrolled anthropogenic activities (Chen, *et al.* 2016; Chitsazan *et al.*, 2019), flow of pollution from upland to lowland, too much use of fertilizers, pesticides in agriculture (Joarder *et al.*, 2008) and to some extent by natural conditions (Zadawa and Omran, 2018). Since surface and groundwater quality has become an important water resources issue due to rapid population increase and unplanned urbanization. Pollution Index become a powerful tool for processing, analyzing, and conveying raw environmental information to decision makers, and the public (Caeiro *et al.*, 2005). Highly toxic elements, including mercury, lead, arsenic, cadmium and nickel have been established as dangerous surface and groundwater pollutants which pose great health risks, especially in rural communities that directly utilize these resources (Burke, 2016).

Boreholes and dug wells are used to abstract groundwater in addition to water from the River Dukkul, which passes through most of the study area (Figure 1). Notable earlier workers on the hydrogeology of the study area include Raeburn and Tattam (1930), Du Preez and Barber (1965), Anderson and Ogilbee (1973), Adelana *et al.* (2003), Alagbe (2006), and Kwaya *et al.* (2020) and Oteze (1976, 1991). Oteze (1976) indicated that the Kalambaina aquifer, which is

shallow and cavernous, is readily subjected to pollution from human and animal wastes. But Wali *et al.* (2020) concluded that both Illo and Gwandu formations display significant differences in their physicochemical parameters of water quality and mineral facies of rock weathering

This work is to employ hydrochemistry and Nemerow pollution index (NPI) to determine the suitability of the surface and groundwater in the study area for domestic and agricultural uses. This study employed hydrochemistry to determine the suitability of surface and groundwater in the study area, while the Nemerow pollution index (NPI) is to determine the heavy metal pollution status of the surface and groundwater in the study area.

2. Materials and Methods

2.1 Study Area

The research was carried out within Birnin Kebbi old town and several other villages, which form part of the Birnin Kebbi Sheet 49, northwestern Nigeria. The study area is part of Gwandu Formation and is accessible through Birnin Kebbi - Dukkul road, Birnin Kebbi -Zauro, Badariya - Kola road with several foot paths and untared roads. The relief of the study area consists of flat-topped hills with ironstone capping which is dominated by gullies which serves as drainage to some of the surrounding villages. Generally, the hills are less than 150 feet high, but the relief between the stream valley floor (Fadama) and the hill tops reaches 300 feet. South and east of the Sokoto Basin, crystalline rocks form a dissected upland surrounded by isolated steep sided hills (Anderson and Ogilbee, 1973). The study area is drained by River Dukku and its tributaries which provide extensive floodplains for farming activities as shown in (Fig 1) flowing northwest direction.

The study area is located within the semi-arid zone of northwestern Nigeria, with two distinct seasons characterized with rainy and dry conditions. These are characterized by a short period of rainfall that really exceeds 5 months with a yearly average precipitation of about 600 mm. The rainfall is erratic with longer dry season that lasted from October to April, characterized by high temperature, low humidity with high evapotranspiration which can exceed 2,500 mm/year. Vegetation is the savannah-type and is characterized by sparse shrub and short feathery grasses, which forms a complete ground cover during the wet season only.

The study area is part of the Nigerian sector of the lullemeden Basin in north-western Nigeria which is underlain by a sequence of semi-consolidated sedimentary rocks ranging in age from Cretaceous to Tertiary and consisting mostly of interbedded sand, clay, and limestone. The stratigraphy of the basin is made up of the Taloka, Dukamaje, Wurno, Dange, Kalambaina, Gamba and Gwandu Formations. The sediments were deposited during four main phases:

1. The Illo and Gundumi Formations are composed of grits and clays, which were deposited unconformably on the Pre-Cambrian Basement.
2. The Maastrichtian Rima Group rests unconformably on the Illo and Gundumi Formations. The group consists of mudstones and friable sandstones (Taloka and Wurno Formations), separated by the fossiliferous Dukamaje Formation.
3. The Paleocene Sokoto Group consists of the Dange and Gamba Formations (mainly shale) and is separated by the calcareous Kalambaina Formation.
4. The Post-Paleocene Continental Terminal, which is the Gwandu Formation, occurs as tabular hills or low hummocks over the dip slope of the Paleocene Formation. The study area is predominantly of the Gwandu Formation.

2.2 Data Collection and Analysis

Twenty-three groundwater and surface water samples taken from dug wells, tube wells, rivers, and boreholes were collected from different communities within the study area and subjected to hydrogeochemical analyses to determine the different physicochemical parameters present in the water samples. The APHA (1999) criteria were followed for sampling, handling and analysis. Electrical conductivity (EC), Total dissolved solids (TDS), pH, and temperature were measured in the field using a hand-held portable digital 3-in-1 conductivity metre and a pH metre, respectively. The samples were stored at a very low temperature of $< 4^{\circ}\text{C}$ and transported to the multi-user laboratory of Usmanu Danfodiyo University, Sokoto, where they were processed and analyzed for major and minor cations, anions, and oxides using an atomic absorption spectrometer (AAS). Nemerow Pollution index (NPI) was used to determine the pollution level since ground and surface water quality has become an important water resources issue due to rapid increase of population and unplanned urbanization. Sample points with their respective coordinates are displayed in Table 1.

Twenty-three samples were collected in all, with groundwater (14) taken from dug wells, tube wells and boreholes, while nine (9) surface water samples were collected from the River Dukkul in the study area (Figure 1 and Figure 2) in different communities within the study area (Table 1a). The APHA (1999) criteria were followed for sampling, handling and analysis. Prior to the sampling, the containers were rinse with water from which the samples were to be collected; in order to get representative samples, direct from the aquifer. Water was pumped out or bailout using a water drawer from the different groundwater sources for at least 10 – 15 minutes. Two samples were collected from each of the sampling points, in one sample from which the cations were to be analyzed and few drops of 1.1 molar HNO_3 was added to reduce the precipitation of some metals by reducing the pH of the water to 2. Physical parameters of electrical conductivity (EC), total dissolved solids (TDS) pH, and temperature were measured in-situ at the sampling points using a handheld 3-in-1 conductivity and pH meters, respectively. Samples were stored at a very low temperature of 4°C . The samples were taken to the multi-user laboratory of Usmanu Danfodiyo University, Sokoto, where they were processed and analyzed for major and minor cations, anions, and oxides using an atomic absorption spectrometer (AAS model AA 6300 SHIMADZU Japan). The Piper and Schoeller plots were employed for the samples to know the water types and the level of contamination and relative concentration of the anions and cations in the study area. While the Wilcox diagram and Gibbs plots were used to know the level of salinity and to define the source of the chemical species in the analyzed water samples in the study area. Statistical analyses were used to evaluate the heavy metals and the physical parameters measured in the study area using IBM SPSS 2.1 model software statistical package. Nemerow Pollution index (NPI) was used to determine the pollution level since ground and surface water quality has become an important water resources issue due to rapid increase of population and unplanned urbanization.

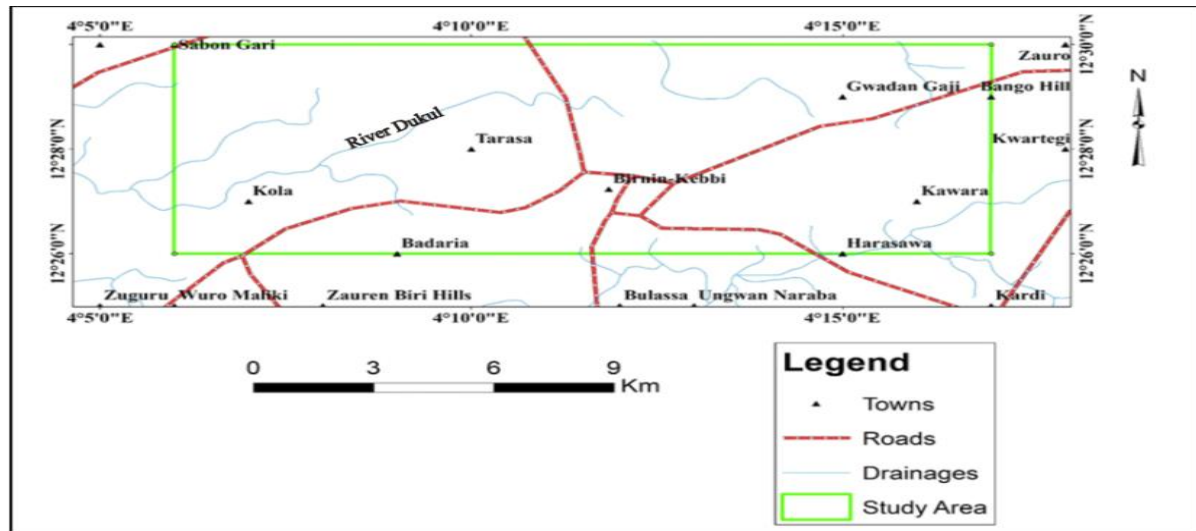


Figure 1: Drainage map of the study area.

TABLE I: Community drinking water source analyzed samples with coordinates.

Sample Number	Names of Location with their coordinates	Drinking Water Source
1	Takalau N 12° 28' 12" E 4° 11' 16"	Borehole
2	Takalau N 12° 28' 08" E 4° 11' 19"	Well
3	Takalau N 12° 28' 11" E 4° 11' 29"	Well li
4	Water Works N 12° 28' 53" E 4° 12' 2"	River Dukul
5	Gamagira N 12° 27' 57" E 4° 11' 30"	Borehole
6	Malala Quarters N 12° 28' 16.8" E 4° 11' 13.1"	Borehole
7	Fadama li N 12° 28' 46.5" E 4° 11' 22.7"	River Dukul
8	Fadama li N 12° 28' 46.5" E 4° 11' 22.7"	River Dukul
9	Tarasa I N 12° 28' 42" E 4° 10' 23"	Well
10	Dutsen Idi N 12° 28' 01" E 4° 11' 24"	Borehole
11	Tungar Buzu N 12° 29' 40" E 4° 16' 23"	Well
12	Tungar Buzu N 12° 29' 57" E 4° 16' 15"	River Dukul
13	Tarasa li N 12° 28' 33" E 4° 9' 46"	River Dukul
14	Ungwar Jodu N 12° 26' 7.8" E 4° 7' 36.3"	Well
15	Tarasa lii N 12° 28' 36" E 4° 10' 10.7"	River Dukul
16	Gamagira(Dangaladima) N 12° 28' 11" E 4° 11' 24"	Borehole
17	Tarasa N 12° 28' 44" E 4° 9' 34"	Tube Well
18	Gwadangwaji N 12° 28' 31.1" E 4° 13' 53.7"	Bore Hole
19	Water Works li N 12° 28' 53" E 4° 12' 2"	River Dukul
20	Tarasa Iv N 12° 26' 56" E 4° 10' 31"	Borehole
21	Takalau N 12° 28' 11" E 4° 11' 24"	Borehole
22	Tarasa V N 12° 28' 44" E 4° 9' 41"	River Dukul
23	Tarasa N 12° 28' 44" E 4° 9' 41"	River Dukul

Table 1b: Equation used for pollution indices computation for water samples collected from study area.

POLLUTION INDEX	EQUATIONS USED	MEANING OF SYMBOL IN EQUATION	REFERENCE
Nemerow Pollution Index (NI)	$\sqrt{\frac{(MCI/SCI)^2_{mean} + (MCI/SCI)^2_{max}}{2}}$	(MCI/SCI) _{mean} and (MCI/SCI) _{max} Are the average and maximum contaminant factors and maximum contaminant factors	Caerio et al.-(2005) Liu et al., (2015a)

3. Results and Discussion

The results of the physical parameters measured in the study area are presented in Table 2. For the 23 surface and groundwater samples analyzed, the measured temperature ranged between 33.3 and 34.2°C. pH values ranged between 0.27 (sample LI6A from DanGaladima) and 7.32 (sample 4A from the waterworks). The pH of the water in this study indicated weakly acidic to slightly alkaline water because the former samples were from a borehole located 4 m from a pit latrine, while the latter were from near the waterworks, where dry season farming with excessive fertilizers occurs. The EC measured ranges between 70 and 9692, while the TDS fluctuates between 35 and 5501. The variation observed in these physical parameters is due to uncontrolled anthropogenic activities in the study area, mainly agricultural activities and improper waste disposal. However, most of the physical parameters measured values fall within the acceptable limit of WHO (2011), as given in Table 2. The geological map of the study area is displayed in Figure 2.

The results of the major elements and oxides measured for the samples Table 3, which was used in plotting the Piper diagram, Schoeller plot, Gibbs diagram, and Wilcox diagrams. The Piper diagram was used to classify the hydro-chemical facies of the groundwater according to the dominant ions analyzed in the samples. The dominant water type in the study area is Ca-Mg-HCO₃. Figure 4 3, which can be attributed to the presence of Ca²⁺, Mg²⁺, and HCO₃²⁻, which are dissolved in the water from the breakdown and dissolution of carbonate rock, mainly limestone, which occurs in the area. However, the results of heavy metals measured for samples in the study area are shown in Table 4 and Table 5 display summary of physical parameters and heavy metals measured in the study area.

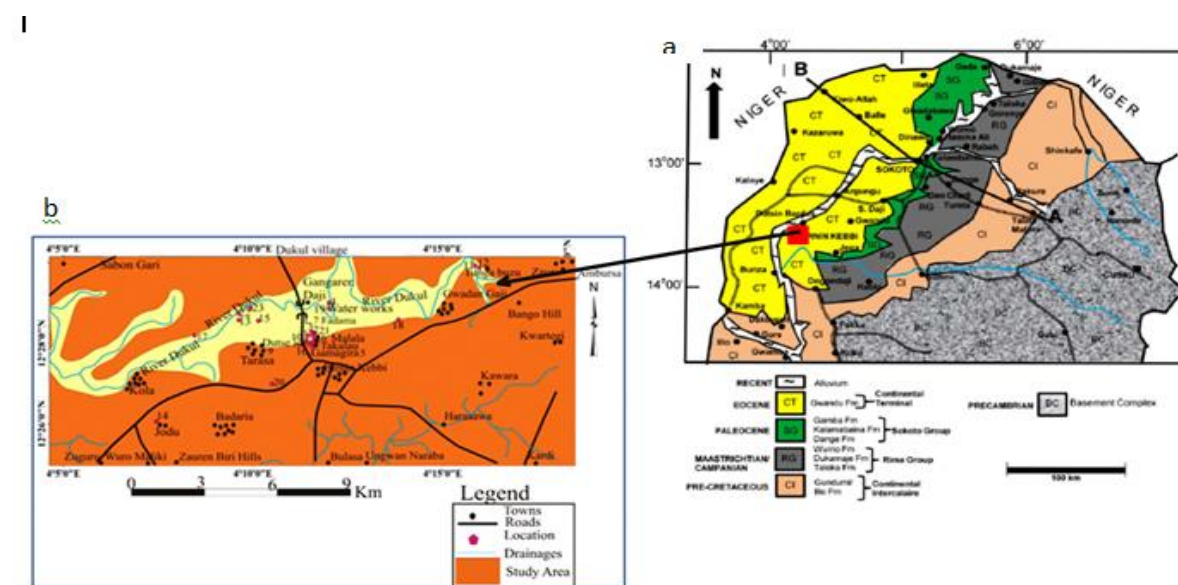


Figure 2: a. Generalized geological map of the Nigerian sector of Iullemeden Basin (Sokoto Basin) showing the study area (red). b. Geological map of the study area.

Table 2: Physical parameters for the water samples measured in the field

Sample Number	Ec	Tds	Ph	Temperature (°C)
1a	936	469	6.34	34.2
2a	590	295	5.46	33.7
3a	1638	819	6.76	34.2
4a	114	57	7.32	33.4
5a	916	458	6.94	33.3
6a	3562	1781	1.63	34.2
7a	112	56	6.09	33.5
8a	114	57	6.59	34.2
9a	114	57	7.01	33.8
10a	1244	622.4	0.59	34.2
11b	90	45	4.14	33.8
12b	112	56	6.2	33.7
13a	114	57	6.55	33.8
14a	92	46	6.36	34
15a	114	57	6.81	34.2
16a	1506	5501	0.27	33.8
17a	416	217	5.46	33.8
18a	192	96	5.19	33.8
19a	9692	4846	0.85	33.9
20b	070	035	3.52	34
21a	312	156	5.47	33.7
22a	134	67	5.51	33.7
L 23	90	45	6.08	33.8
Average	968.4348	691.1043	5.093043	33.85652
Maximum	9692	5501	7.32	34.2
Minimum	70	35	0.27	33.3

Table 3: Major elements and oxides measured in the laboratory.

Sample Number	Mg/L Ca	Mg/L Mg	Mg/L K	Mg/L Na	Mg/L P	Mg/L Co ₃	Mg/L Hco ₃	Mg/L Cl	Mg/L Nh ₄	Mg/L No ₃
1a	166	194.4**	20**	6.7	0.19	Nil	72	0.6	0.4	2.0
2a	102	87.6	5.2	3.8	0.19	Nil	60	1.1	0.4	1.2
3a	268**	67.2	26	20	0.20	Nil	92	0.7	0.8	2.4
4a	84	74.4	0.7	0.8	0.22	Nil	52	1.6	0.4	1.4
5b	64	79.2	7.4	8.3	0.21	0.2	124**	1.9	0.6	1.8
6a	112	100.8	2.4	3.3	0.20	Nil	64	0.7	0.4	1.0
7b	46	76.8	0.8	0.9	0.22	Nil	64	2.6	0.6	1.4
8b	72	54.0	0.7	0.9	0.22	Nil	80	2.1	0.4	1.2
9a	108	51.6	0.7	0.9	0.23	Nil	96	1.2	0.8	1.6
10a	68	109.2	2.2	2.5	0.19	0.2	76	0.6	0.4	1.0
11b	74	73.2	0.6	0.6	0.19	Nil	84	0.6	0.4	1.0
12b	286**	5.04	0.6	0.8	0.21	Nil	104**	1.7	0.4	1.4
13a	56	56.4	0.7	1.0	0.22	Nil	112	1.4	0.4	1.4
14a	90	51.6	1.9	0.9	0.19	Nil	68	0.5	0.4	1.0
15a	68	78.0	0.7	1.0	0.21	Nil	52	1.9	0.8	1.8
16a	286**	135.6	5.8	8.3	0.19	Nil	136**	0.5	0.4	1.0
17a	134	126.0	2.6	3.9	0.19	Nil	92	0.7	0.6	1.4
18a	72	78.0	0.8	1.7	0.19	Nil	108	0.7	0.4	1.4
19a	114	100.8	0.7	1.5	0.20	0.2	148**	3.2	0.4	2.2
20b	96	62.4	0.6	0.8	0.19	Nil	76	0.6	0.8	1.4
21a	84	73.2	7.0	1.3	0.19	Nil	96	1.0	0.4	1.2
22a	66	62.4	0.7	1.1	0.21	0.2	64	2.2	1.0	3.4
23	52	78.0	1.7	0.9	0.19	0.2	108**	0.8	0.6	3.0
Maximum	286	194.4	26	20	0.23	0.2	148	3.2	1.0	3.4
Minimum	46	5.04	0.6	0.6	0.19	0.2	52	0.5	0.4	1.0
Average	111.652	81.558	3.935	3.126	0.2017	0.2	88.174	1.257	0.5304	1.5913
Who 2011	200	150	12	50		120	100	250		50
Nswqs 2007	-	-	-	200		-	-	250		50

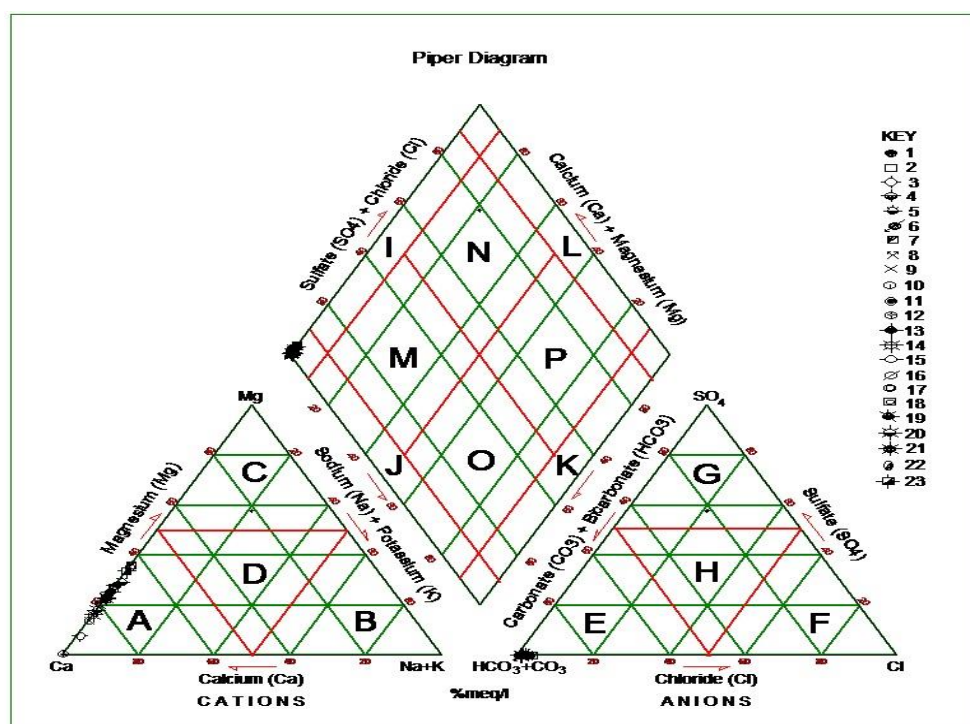


Figure 3: Type classification for water samples from the study area using the Piper trilinear diagram (Back and Hanshaw 1965). A = Calcium type, B = sodium or potassium type, C = magnesium type, D = no dominant type, E = bicarbonate type, F = chloride type, G = sulphate type, H = no dominant type I = Ca^+Mg type, J = $\text{HCO}_3^+\text{CO}_3$ type, K = Na^+K type, L = $\text{Cl}+\text{SO}_4$ type M = $\text{Ca}(\text{Mg}) \text{HCO}_3$ type, N = $\text{Ca}(\text{Mg}) \text{Cl} \text{SO}_4$ type, O = $\text{Na}(\text{K}) \text{HCO}_3$ type, P = $\text{Na}(\text{K}) \text{Cl}(\text{SO}_4)$ type.

The Piper and Schoeller plots for the samples indicate the dominance of $\text{Ca}+\text{Mg}-\text{HCO}_3$ water in the study area. The level of contamination and relative concentration of the anions and cations in the study area indicate shallow fresh groundwater that is slightly hard. The water is associated with limestone underlining the area and carbonate hardness from recent precipitation occurring at shallow depths below the surface. $\text{Ca}+\text{Mg}-\text{HCO}_3$ is formed from the dissolution of carbonate minerals, most likely from the Kalambaina limestone in the study area.

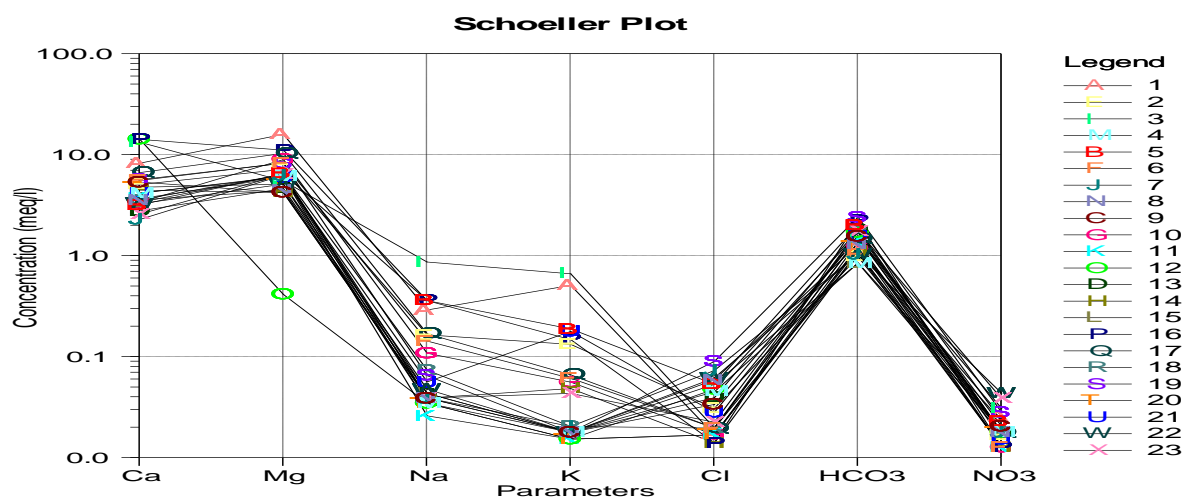


Figure 4: Schoeller Plot showing level of contamination in the analysed water sample.

The Gibbs plots (Figures 5a and b) were used to interpret and define the source of the chemical species in the analyzed groundwater samples. This plot demarcated three domains for the anions and cations, which are the precipitation, Rock, and Evaporation domains. The

dominance origin for both cations and anions in the analyzed water sample is precipitation dominance, with a few samples falling in the precipitation domain and evaporation domain.

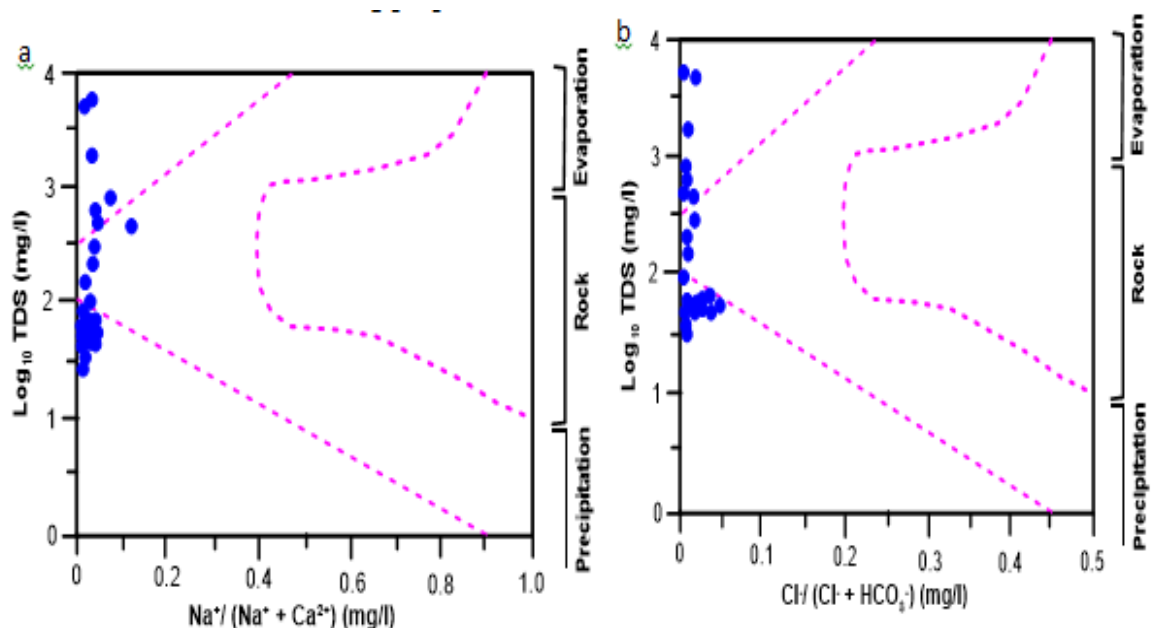


Figure 5a and b: Controlling mechanisms for groundwater quality in the study area (after Gibbs, 1970).

The Wilcox diagram (Figure 6) shows the level of salinity of water samples in the study area which is generally ranging from low to very high salinity hazard especially in samples 5 and 6.

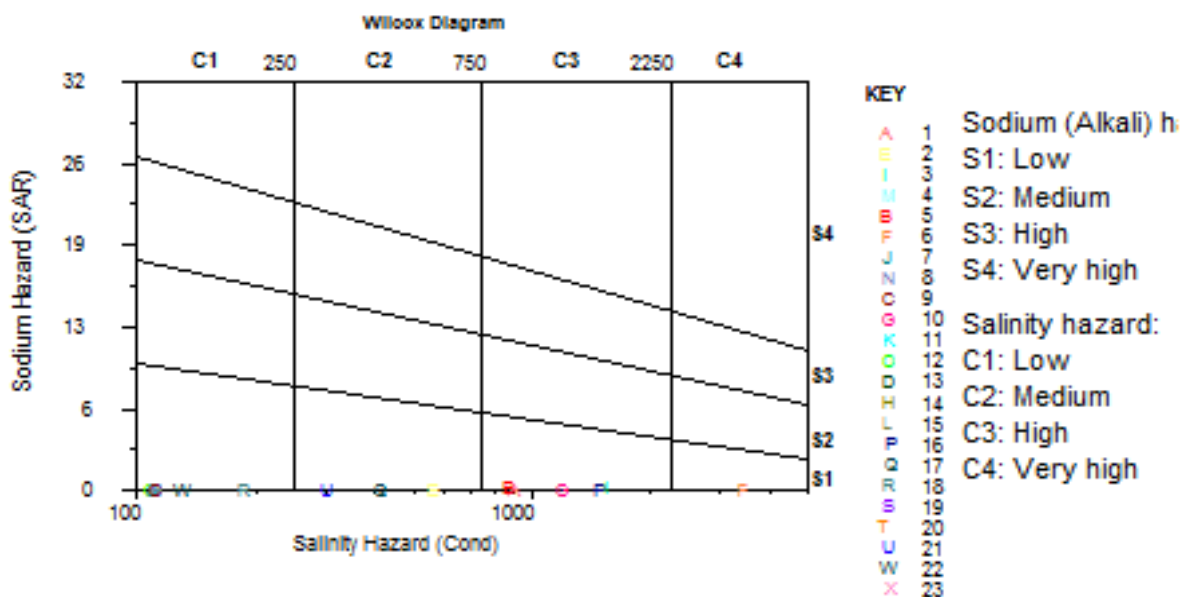


Figure 6: Wilcox diagram for all the samples in the study area.

Table 4: Heavy metals measured in the surface and groundwater

Sample Number	Cr	Fe	Cu	Pb	Ni
1A	BDL	BDL	BDL	BDL	1.8001
1B	-0.7450	-1.8240	0.2544	-0.1175	BDL
2A	-0.2941	0.0147	0.2786	-0.1992	BDL
2B	BDL	BDL	BDL	BDL	1.6278
3B	-0.3993	0.0624	0.3149	-0.1447	1.7722
4B	0.6376	0.1908	0.2871	-0.0448	1.7221
5A	0.7621	0.3156	0.2386	-0.1175	1.7555
6B	0.7256	0.3230	0.3137	-0.2173	0.1505
7	0.6333	0.3266	0.3246	-0.0312	BDL
8A	0.5775	0.3670	0.4191	0.4772	BDL
9B	0.6634	0.3817	0.6068	1.1445	BDL
10B	0.6720	0.4257	0.2701	-8.5337	BDL
11A	0.5839	0.4514	0.2737	-9.7639	0.3009
12A	2.6063	0.3450	0.3924	0.4137	0.4124
13B	-0.1589	0.3413	0.3537	0.5771	0.5629
14B	0.3134	0.4074	0.3174	1.7256	0.5629
15B	0.3564	0.9322	0.3089	-45.2956	0.5517
16A	0.9489	1.5598	-0.2798	-18.7022	0.6075
17B	0.7492	0.7230	0.2968	-33.8270	-0.1672
18B	0.4487	-4.3455	0.2750	-45.1039	-0.0279
19B	0.4830	-2.8002	0.2750	-20.3727	0.0724
20B	-0.4165	0.4367	0.3331	-45.2945	0.3009
21B	0.5088	-36.7001	0.2980	-29.5198	0.2285
22B	0.7729	-0.4844	0.3125	-45.2945	-0.3177
23	0.5925	-2.5066	0.3089	0.3637	0.3511
Average	0.459824	-1.81264	0.292957	-12.0451	0.7196

Table 5: Summary of physical parameters and heavy metals measured in the study area.

Parameter	Minimum	Maximum	Mean	Std. Deviation	Variance	Kurtosis	WHO (2011)
Cr	-.7450	2.6063	.4409	.6371575	.406	4.904	50
Fe	-36.7001	1.5598	-1.6423	7.4203392	55.061	23.262	300
Cu	-.2798	.607	.2709	.1616117	.026	5.710	2000
Pb	-45.2956	1.72	-	17.7880	316.414	-.419	3000
Ni	-.3177	1.80	.4907	.6785633	.460	-.069	70
EC	70.0000	9692.00	1317.37	2638.7740	6963128.2	7.506	1000
TDS	35.0000	5501.00	883.500	1705.7613	2909621.7	3.939	500
pH	.270000	7.32	5.1821	2.14828	4.615	.697	6.5-8.5
TEMP	33.30000	34.20	33.8702	.2606	.068	-.394	30-32

The results of the heavy metals displayed in Table 4 reveal average values for Cr^{2+} 0.459824, Fe^{2+} -1.81264, Cu^{2+} 0.292957, Pb^{2+} -12.0451, and Ni^{2+} 0.3009, respectively. These values were compared to the WHO (2011) standard in Table 5, which shows that all fall within the acceptable limit permissible for human consumption. Evaluated physical and chemical parameters revealed that water resources reveal the presence of Mg^{2+} which indicates the hardness of the water. This could be due to the presence of alkaline earth metals such as magnesium, which remarkably influence the chemistry of the water at the location. Ca^{2+} in twenty out of the twenty-three water analyzed samples comply with the WHO (2007) and NSDWQ (2007; 2015) standards, with the exception of samples from location 3B, which have 268 mg/l, while locations 12B and 16A have 286 mg/l, respectively. The presence of Ca^{2+} indicates the hardness of the water, which could be due to the presence of alkaline earth

metals such as calcium, which remarkably influence the chemistry of the water in the location. All the major oxides analyzed for all twenty-three samples fall within the WHO (2007) and NSDWQ (2007; 2015) standards except for HCO_3^{2-} . The HCO_3^{2-} for sixteen of the twenty-three samples is in tandem with the WHO (2007) and NSDWQ (2007; 2015) standards, except for samples from seven locations: 5B 124 (mg/l), 12B 104 (mg/l), 13A 112 (mg/l), 16A 136 (mg/l), and 18A 108.(mg/l), 19A 148 (mg/l), and 23 108 (mg/l), respectively. The high values of Ca^{2+} , Mg^{2+} and HCO_3^{2-} recorded in the samples could result from the breakdown and dissolution of carbonate rock, mainly limestone, which occurs in the study area. The contaminants may have migrated through tectonic and sedimentary structures, which serve as conduit pipes for rapid transmission to the groundwater system in the study area. Low-salinity Ca-Mg- HCO_3 water is the most common type in the research area.

Nemerow pollution index was used to evaluate the water quality of the study area. NPI value exceeding 1.0 indicate the presence of impurity in water and hence require some treatment before being used. Other interpretations of the Nemerow pollution index are shown in Table 6 while the result from Nemerow pollution index is displayed in Table 7.

Table 6: Standard and classes of computed pollution used in this study

Pollution Index		Standard /Class		Standard Source
Nemerow Index (Npi)	Pollution	$\text{Ni} < 1$	No Pollution	Adopted from Liu Et Al., (2015a)
		$1 \leq \text{NI} < 2.5$	Light Pollution	
		$2.5 \leq \text{NI} < 7$	Moderate Pollution	
		$\text{Ni} \geq 7$	Heavy Pollution	

Table 7: Below is Nemerow’s pollution index for water quality showing the level of contamination in the water samples Nemerow’s Pollution Index [Water Quality Index] NPI Values of Various Sampling Locations

Parameters	NSDWQ, 2015	Location 1	Location 2	Location 3	Location 4	Location 5	Location 6
PH	8.5	0.75	0.64	0.80	0.86	0.82	0.19
TDS	500	0.94	0.59	1.64	0.11	0.92	3.56
E.C	1000	0.94	0.59	1.64	0.11	0.92	3.56
Mg ²⁺	20	9.72	4.38	3.36	3.72	3.96	5.04
Na ⁺	200	0.03	0.02	0.10	0.00	0.04	0.02
Cr ²⁺	0.05	0.00	0.00	0.00	12.75	15.24	14.51
Fe ²⁺	0.3	0.00	0.05	0.21	0.64	1.05	1.08
Cu ²⁺	1	0.25	0.28	0.31	0.29	0.24	0.31
Ni	0.02	90.01	81.39	88.61	86.11	87.78	7.53
Pb ²⁺	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Cl ⁻	250	0.00	0.00	0.00	0.01	0.01	0.00
NO ₃ ⁻	50	0.04	0.02	0.05	0.03	0.04	0.02

location 7	Location 8	Location 9	Location 10	Location 11	Location 12	Location 13
0.72	0.78	0.82	0.07	0.49	0.73	0.77
0.11	0.11	0.11	1.24	0.09	0.11	0.11
0.11	0.11	0.11	1.24	0.09	0.11	0.11
3.84	2.70	2.58	5.46	3.66	0.25	2.82
0.00	0.00	0.00	0.01	0.00	0.00	0.01
12.67	11.55	13.27	13.44	11.68	52.13	0.00
1.09	1.22	1.27	1.42	1.50	1.15	1.14
0.32	0.42	0.61	0.27	0.27	0.39	0.35
0.00	0.00	0.00	0.00	15.05	20.62	28.15
0.00	47.72	114.45	0.00	0.00	41.37	57.71
0.01	0.01	0.00	0.00	0.00	0.01	0.01
0.03	0.02	0.03	0.02	0.02	0.03	0.03

Location	Location	Location	Location	Location	Location	Location	Location	Location	Location
14	15	16	17	18	19	20	21	22	23
0.75	0.80	0.03	0.64	0.61	0.10	0.41	0.64	0.65	0.72
0.09	0.11	11.00	0.43	0.19	9.69	0.07	0.31	0.13	0.09
0.09	0.11	1.51	0.42	0.19	9.69	0.07	0.31	0.13	0.09
2.58	3.90	6.78	6.30	3.90	5.04	3.12	3.66	3.12	3.90
0.00	0.01	0.04	0.02	0.01	0.01	0.00	0.01	0.01	0.00
6.27	7.13	18.98	14.98	8.97	9.66	0.00	10.18	15.46	11.85
1.36	3.11	5.20	2.41	0.00	0.00	1.46	0.00	0.00	0.00
0.32	0.31	0.00	0.30	0.28	0.28	0.33	0.30	0.31	0.31
28.15	27.59	30.38	0.00	0.00	3.62	15.05	11.43	0.00	17.56
172.56	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	36.37
0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00
0.02	0.04	0.02	0.03	0.03	0.04	0.03	0.02	0.07	0.06

Values > or = 1 indicates presence of pollution in the water sample

However, the pH NPI value varies from 0.03 to 0.86 in all sampling stations that fall within the permissible NPI range. Table 6. The TDS NPI value varies, but all fall within the permissible limit except in sampling locations L3 = 1.64, L6 = 3.56, L10 = 1.24, L16 = 11.0, and L19 = 9.69, respectively. The EC NPI value falls within the permissible range except for L3 = 1.64, L6 = 3.56, L10 = 11.24, L16 = 1.51, and L19 = 9.69. The NPI value for Mg²⁺ for only sample L12 falls within the permissible limit, with others ranging from 2.58 to 9.72. The EC NPI value falls within the permissible range except for L3 = 1.64, L6 = 3.56, L10 = 11.24, L16 = 1.51, and L19 = 9.69. The NPI values for Na⁺ all fall within the permissible range. The Cr²⁺ value for L 1, L2, L3, and L13 all fall within the permissible range, but other samples range from 6.27 to 52.13, which fall outside the NPI range. The Fe²⁺ ranges L1, L2, L3, L4, L18, L19, L21, L22, and L23 all fall within the NPI range, but other sampling locations indicate a range of 1.05 to 5.20, which is unsuitable for drinking purposes. The Cu²⁺ NPI for all samples is within the NPI range. The Ni NPI value for samples L7, L8, L9, L10, L17, L18, and L22 is within the NPI range, but others range from 7.53 to 90.01, making them unsuitable for drinking purposes. The values for Pb²⁺ all fall within the permissible NPI range except for L8, L9, L12, L13, L14, and L23, which indicate pollution. The Cl^{and} NO₃⁻ exhibit values below the NPI range of 1.

4.0 Conclusion

The hydro-chemical study of the twenty-three water samples from drinking water sources in Birnin Kebbi Old Town and its environs was conducted to determine the pollution and contamination status. Results revealed surface and groundwater with concentrations of pH, Na²⁺, Cu²⁺, Cl⁻ and NO₃⁻ and higher concentrations of TDS and EC, which are above the NSDWQ (2015) set limits. The results also show that the cations Na²⁺ and Cu ions from the locations have values less than the maximum limit recommended by NSDWQ (2015), while Mg²⁺ and Fe²⁺ have higher values with lower values for trace elements like Cr²⁺, Ni, and Pb²⁺. Also, the anions analyzed, Cl⁻ and NO₃⁻ ion have concentrations within the limits of NSDWQ (2015) recommended for drinking water. The dominance of the Ca²⁺Mg²⁺-HCO₃ facie over the other two types can be related to the geology and other geochemical processes that operate within the aquifers in the area. However, Application of Nemerow's pollution index shows that the majority of the sampling locations displayed high NPI values, especially for Ni²⁺ and Pb²⁺. The NPI Ni²⁺ values for eleven (11) out of twenty-three samples, making up 47.83%, have NPI values that range from 7.53 to 90.01, making them unsuitable for drinking purposes. The NPI values for Pb²⁺ for six (6) samples, making up about 26.09%, have high NPI values that range from 36.37 to 172.56, depicting a high level of pollution. The Nemerow pollution index for evaluating the water quality, shows some pollutants have concentrations that are above standards. The people in the study area directly rely on the available surface and groundwater

for drinking and domestic use from boreholes, river and open wells without any treatment. However, if the water is to be consumed for these purposes, proper treatment is necessary to avoid adding to the already existing health issues that affect not only older people but also children and younger people. Better management of water systems is needed for water supplies for agricultural and domestic uses in the study area.

References

- Alagbe, SA. 2006. Preliminary evaluation of hydrochemistry of the Kalambaina Formation, Sokoto Basin. *Nigeria Environmental Geology*, 51: 39–45 DOI 10.1007/s00254-006-0302-5
- Anderson, HR. and Ogilbee, W. 1965. Exploratory drilling for ground water in western Sokoto Province, Nigeria, with particular reference to artesian aquifers in the Gwandu Formation: United State Geological Survey open-file report, p. 98.
- APHA, 1999. Standard methods for the examination of water and wastewater, 20thedn. American Public Health Association, Washington DC.
- Black, W. and Handshaw, BB. 1965. Chemical Geohydrology in: *Advance in Hydrosience*, Academic Press, New York, pp. 11 – 49.
- Born, SM., Yanggen, DA. and Zaporozec, A. 1987. A guide to groundwater quality planning and management for Local Governments. Wisconsin Geological and Natural History Survey, Madison, Special Report 9:91
- Burke, F., Hamza, S., Naseem, S., Huda, SN., Azam, M. and Khan, I. 2016. Impact of Cadmium Polluted Groundwater on Human Health: Winder, Balochistan: *SAGE Open*. 6 (1), p1-8 DOI: 10.1177/2158244016634409.
- Caerio, S., Costa, MH., Ramos, TB., Fernandes, F., Silveira, N., Coimbra, A., Mederios, G. and Painho, M. 2005. Assessing heavy metal contamination in Sado estuary sediment: an index analysis approach *Ecological Indicators*, 5(2): 151-169.
- Chen, M., Qin, X., Zeng, G. and Li, J. 2016. Impacts of human activity modes and climate on heavy metal “spread” in groundwater are biased. *Chemosphere*, 152:439–445.
- Chitsazan, M., Aghazadeh, N., Mirzaee, Y. and Golestan, Y. 2019. Hydrochemical characteristics and the impact of anthropogenic activity on groundwater quality in suburban area of Urmia city, Iran. *Environment, Development and Sustainability*, 21(1):331–351.
- Davis, SN. and Dewiest, RJM. 1966. *Hydrogeology*, John Wiley and sons, Inc., Hoboken, p.463.
- Gibbs, RJ. 1970. Mechanisms Controlling World Water Chemistry. *Science*, 170: 1088-1090. doi.org/10.1126/science.170.3962.1088
- Joarder, MAM., Raihan, F., Alam, JB. and Hasanuzzaman, S. 2008. Regression Analysis of Ground Water Quality Data of Sunamganj District, Bangladesh. *International Journal of Environmental Research*, 2(3): 291.
- Kogbe, CA. 1972. Preliminary study of the geology of the Nigerian sector of the lullemeden basin. (Dessauvage TFJ. and Whiteman, AJ. (eds)). *African Geology*, Ibadan, University Press, Nigeria, pp.219–228.

Kogbe, CA. 1972. Preliminary study of the geology of the Nigerian sector of the Iullemeden basin. (Dessauvage TFJ. and Whiteman, AJ. (eds)). African Geology. Ibadan, University Press, Nigeria, pp.219–228.

Kogbe, CA. 1976. Paleogeographic history of Nigeria from Albian times. Geology of Nigeria (CA. Kogbe(ed.)), Elizabethan Publishing, Lagos Nigeria.

Kogbe, CA. 1979. Geology of the South-Eastern (Sokoto) Sector of the Iullemeden Basin Department of Geology, Ahmadu Bello University Zaria Bulletin, 32:142.

Kwaya, MY., Hamidu, H., Abdullahi, IM., Yelwa, NA., Abdulganiyu, Y., Kana, AM., Ibrahim, HA. and Grema, HM. 2020. Irrigation and drinking groundwater quality indices of Gada community and Environs, Semi-arid region, Sokoto Basin, Northwestern Nigeria. Nigerian Journal of Science, 54(1): 85-103.

Liu, S., Zhang, Y., Bi, S., Zhang, X., Li, X., Lin, M. and Hu, G. 2015. Heavy metals distribution and environmental quality assessment for sediments off the southern coast of the Shandong Peninsula China, Marine Pollution Bulletin, 100(1): 483-488.

Nigerian Standard for Drinking Water quality, 2015. Nigerian Standard for Drinking Water quality NSDWQ Nigerian Industrial Standard, Lagos, 554:1-14.

Obaje, NG. 2009. Geology and mineral resources of Nigeria. Springer Dordrecht Heidelberg London.

Oteze, GE. 1989. The hydrogeology of Northwestern Nigeria. (CA. Kogbe (eds.)), Geology of Nigeria. Rock View Publ. Co. Jos, 455-472.

Petters, SW. 1978. Maastrichtian-Paleocene foraminifera from northwestern Nigeria and their paleogeography. Acta Paleontologica Polonica, 23:131-152.

Piper, AM. 1944. A graphic procedure in the geochemical interpretation of water analyses: American Geophysics Union Transactions, 25:914-923.

Raeburn, C. and Tattam, CM. 1930. A preliminary note on the sedimentary rocks of Sokoto Province: Nigeria Geological Survey Bulletin, 13: 57-60.

UNICEF2008. Unicef Hand Book on Water Quality. United Nations Children's Fund, New York, pp. 1-191. Accessed from: https://www.unicef.org/french/wash/files/WQ_Handbook_final_signed.

Wali, SU., Alias, N. and Harun, SB. 2020. Hydro-geochemical evaluation and mechanisms controlling groundwater in different geologic environments, Western Sokoto Basin, Northwestern Nigeria, SN Applied Sciences, 2:1808 <https://doi.org/10.1007/s42452-020-03589-y>

World Health Report. 2007. A safer future: global public health security in the 21st century Emergency Preparedness ADGO, Health Security Preparedness (HSP) Editors: World Health Organization, pp. 72.

World Health Organization. 2011. Guidelines for drinking-water quality. First Addendum to 3rd edition, Geneva.,1:515. (<https://weatherspark.com/y/51486/Average-Weather-in-Sokoto-Nigeria-Year-Round.2016>).

Zadawa, AN. and Omran, A. 2018. Climate change and water security issues in Africa: Introducing Partnership Procurement for Sustainable Water Projects in Nigeria, pp 127–134. https://doi.org/10.1007/978-981-10-7748-7_6