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Geomorphic and Geologic Mechanisms Influencing the Occurrences and Hydrochemistry of Surface and Ground Waters of the Biu Plateau Region, North-east, Nigeria

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Abstract The study was conducted in the Biu plateau with a major objective of elucidating the geomorphic and geologic mechanisms influencing the occurrences and hydrochemistry of surface and ground waters of the area. This was achieved by analyzing surface and groundwater from rivers, lakes, wells and boreholes from different landforms of the plateau. Also, lithologic logs of boreholes and wells from different parts of the plateau were analyzed to give insight to the near surface characteristics of the area. Data on the geology and geomorphology were obtained from field mapping and complimented by secondary sources from journal articles, unpublished thesis and reports on these aspects of the plateau. The plateau with a land mass of 2635.12 Km^2 is traversed by a total of 14671 streams, with 9814 1^{st} and 3783 2^{nd} order streams totaling a length of 6879.5 Km. The drainage pattern of the plateau is dendritic in nature reflecting the uniform nature of the geology and absence of major geologic structures such as faults. The predominant major cation trends in the surface and groundwater samples is in the order of $Na^+ > Ca^{2+} > Mg^{2+} > K^{2+}$ and $Ca^{2+} > Mg^{2+} > Na^+ > K^2$. This reflects the chemical composition of rocks in the plateau which also has a relatively high Mg^{2+}, K^{2+}, Na^+ and Ca^{2+} ionic concentrations. Analysis of lithologic logs of boreholes and hand dug wells from different parts of the plateau indicated that three sources with high groundwater potentials exist in the plateau. The study also found out that the spatial variation in the surface and groundwater hydrochemistry is a reflection of water-rock interaction over space and time.

Keywords: *Biu plateau, geomorphology, hydrochemistry, surface and groundwaters*

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1. Introduction

According to the national census of 2006, the Biu plateau is a home to about 534,171 persons with a population density of 61 persons per square kilometer [1]. A baseline socio-economic survey carried out by [2] revealed that about 68% of the people on the plateau are farmers engaged in various agricultural activities. The need for agricultural and household water has placed greater demand on water resources of the plateau. A large number of communities on the plateau depend largely on surface and groundwater from rivers, streams, ponds and crater lakes, boreholes, hand dug wells and springs for their domestic and agricultural activities. Researches by [3] and [4] found out that water supply is a major problem faced by the inhabitants of the plateau. These researches identified poor knowledge of the hydrology, hydrogeology and the geomorphic setting of the plateau as some of the factors responsible. This has resulted to poor planning and utilization of water resources of the plateau.

Knowledge about geomorphologic parameters and geology of an environment provides a simple way of understanding the hydrologic behavior of different environments particularly in hard rock terrains especially volcanic plateaus [5]. It is against this backdrop that this paper is aimed at analyzing and elucidating the roles played by the interplay of geomorphic and geologic factors in the occurrences and hydrochemistry of surface and ground waters of the plateau. This is with a view to improving the knowledge on the occurrences and hydrochemistry of surface and ground waters of the plateau for its sustainable utilization.

2. Study Area

The Biu plateau is a highland area in northeastern part of Nigeria located between latitudes 10°18'N and 11°06'N and longitudes 11°49'E and 12˚25'E with and aerial coverage of about 2635.12km^2 (Figure 1). The plateau is located in Biu, Hawul and Kwaya Kusar Local Government Areas in the southern part of Borno state with extension into Gulani and Gujba Local Government Areas of southern Yobe State [6]. It is the largest area of volcanic rocks in Nigeria [7]. The plateau lies between the Upper Benue Basin to the south and the Chad Basin to the north. It has an average elevation of 700 m above the sea level which slopes gently to Bauchi planes and the Chad basin. The volcanic plateau is characterized by many spectacular geomorphic features which make the area very unique compared to its surrounding. It is characterized by series of volcanic cones, volcanic lava flow ridges, volcanic scalp slopes, craters, crater lakes and crater rims [7].

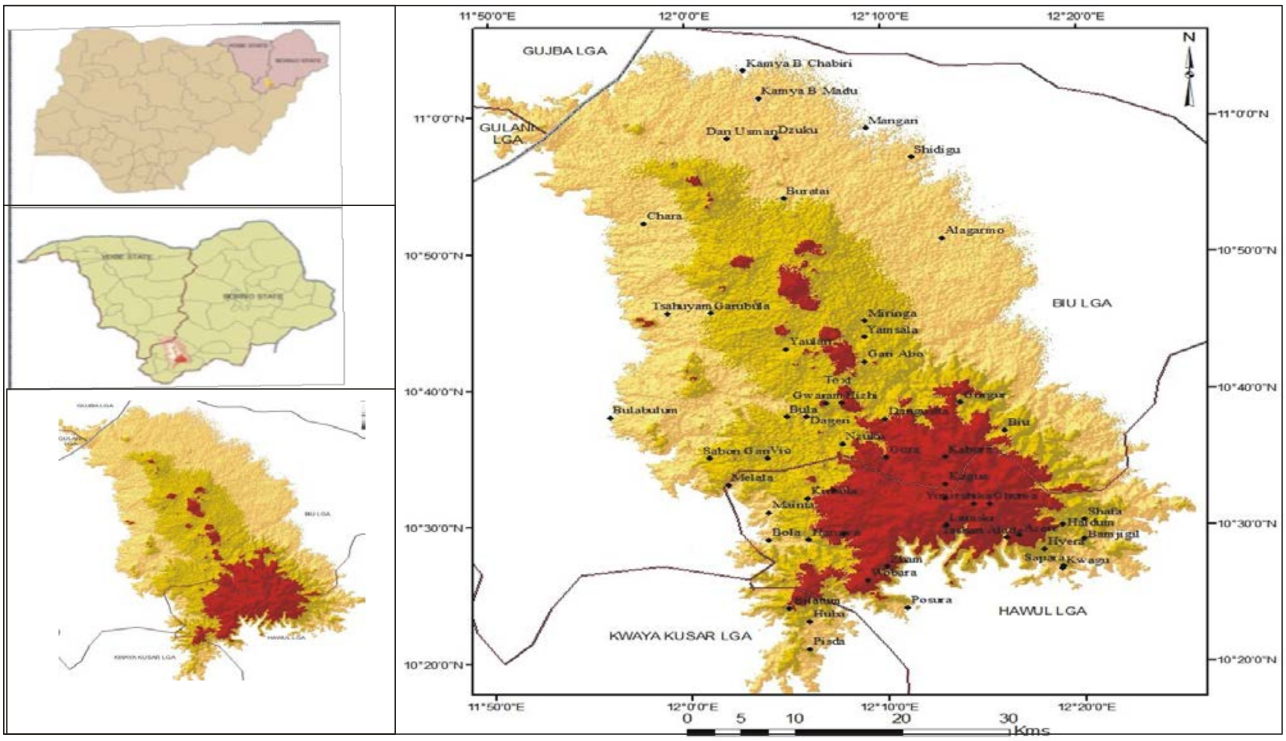

Figure 1. Location of the Study Area

3. Geologic Setting of the Plateau

Biu plateau is dominated by basaltic sequence, covering some 2635.12 km^2 reaching about 250 m in thickness and surrounded by several youthful scoria and cinder cones, exhibiting well defined craters with breached rims, from which small thin flows have issued [8]. [9] is of the view that the Biu plateau mostly occur as flood basalts in a number of flows covering nearly 85 percent of the area with its centre around Biu town. He also opined that the basalts are probably erupted through fissures and fed by dykes. The basalts in some places have been built up to a large number of successive flows. The basaltic sequence is surrounded in some places particularly North-west of Biu town by youthful scoria, cinder cones, tepra rings, exhibiting well defined craters with well breached rims [9]. This is an indication that the eruption of basaltic magma in these places was not violent. Areas west of Biu-Damaturu road (Miringa, Buratai, Zagu and Wachinbara) have hills with pyroclastic materials surrounded by it. The presence of pyroclastic materials in these areas is an indication that the eruption was violent. The various forms of volcanic materials and structures in the plateau are an indication that there was variation in viscosity of the basaltic lavas as well as differences in time, places and mode of extrusion [9]. [10] opined that two main eruptive episodes have been reported; Pliocene and Quaternary. He noted that the Biu basalts belong to the main eruptive episodes separated by an interval of weathering and erosion. The Pliocene basalts consist of an extensive thin lava flows south of Biu. The Quaternary volcanic activity is mainly concentrated along a NNW-SSW zone covering an area of about 55 km long in which over 80 volcanoes are distinguished in the northern part of the plateau.

The Biu plateau basalts are generally alkaline olivine basalts which show little variation in mineralogical characters and petrography, this could be attributed to their mode of origin [11]. In hand specimens the basalts are dark, dense, fine grained rocks in which individual olivine and pyroxene crystals can sometimes be seen. Porphyritic and vesicular varieties are common with cavities and vesicles filled with minerals such as chalcedony, zeolite, and topaz [12]. In thin section, the basalts are seen to consist of phenocryst of only olivine, sometimes olivine and pyroxene (diapsodic-augite) set in a groundmass consisting laths of labrodorite, magnetite and volcanic glass [9] and [12]. These authors also observed that whenever secondary minerals occur it is zeolite, topaz, calcite or chalcedony. Results of petrographic and geochemical studies of basalts from different parts of the plateau show some variations in mineralogy and petrology. These variations are reflection of magma chemistry, mode of eruption and the environment of cooling and crystallization. Petrologically, there are two types of basalts in the Biu plateau. The Biu type and the Miringa type basalts. The Biu type of basalts is located in and around Biu town and mostly in southern part of the

Biu plateau. The Miringa type of basalts is located around Miringa down to Buratai. The stratigraphy of the basaltic rocks of the area is made up of three types of basaltic rocks represented chronologically as massive basalts which appear to be the oldest followed by slightly vesicular basalts and the vesicular basalts which are the youngest [11]. The age variations between these basalts are due to variations in time of eruption, type and nature of magma and also the manner in which they solidify.

4. Research Method

The data for this research was obtained from two sources; primary and secondary sources of data. The primary sources of data include surface and ground water samples from rivers, lakes, wells and boreholes in different parts of the plateau for hydrochemical analysis. Also, lithologic logs of boreholes and wells from different parts of the plateau were obtained from a private drilling company involved in drilling activities in the study area for analysis. The locations of the sampled boreholes, wells, streams and lakes were obtained using a GPS. Fieldwork activities were conducted between January 2015 and September 2017. The secondary sources of data include literatures on the geological and geomorphological setting of the plateau; GIS based maps, information on geological and geomorphic setting and processes were obtained from books, journal articles, unpublished thesis and reports. Standard procedures for sampling and laboratory analysis of both surface and groundwater in accordance with APHA 1998 were employed in this research. The water and lithologic analysis were carried out at the Department of Geology, University of Maiduguri geochemistry and petrology laboratories respectively.

5. Results and Discussion

5.1. Morphology of the Plateau

The Biu plateau is a topographic divide (or watershed) between the Upper Benue to the south and the Chad Basin to the north [7]. The authors stated that the plateau is characterized by series of volcanic cones, volcanic lava flow ridges, volcanic scarp slopes, craters, crater lakes and breached crater rims. Within the plains, there are many low scarps and occasional larger escarpments which mark the end of individual flows. Boulder screes and mud flows are also associated with some flow escarpments. In the west, south and southeast, the plateau is bounded by a strongly dissected major terminal escarpment rising through 150- 300 m [13]. The boundary in the northeast is less spectacular, and in some places is marked only by a discernible low scarp of 3-6 m in height. The north plains, which extend northeast wards from this low scarp, consist of gently sloping basalt plains with a range of relief which seldom exceeds 3-6 m [14] and [15]. The dominant features of the area are the plateau and plains which according to Davies [16] can be regarded as a unit. The plateau has a scarp all around it but like the Jos plateau it slopes gradually to the north and has steep precipitous escarpments to the south (Figure 2).

The plateau has an altitude range of about 400- 900 m above sea level. Altitude of the eastern and western parts decreases down to a plain terrain. Many flat topped hills of extinct volcanoes can be observed to have well developed craters with breached rims and steep sides [17]. According to the authors, a number of volcanic cones rise above the terrain, some appear well preserved while others have their outer slopes developing free face, talus slope and pediment characteristics of the back-wearing process of normal erosion. The current landscape is essentially the result of differential weathering arising from the action of different erosive agents on a juxta-position of highly varied products of volcanicity over space and time [7].

These products as observed in many places on the plateau range from the hardest of lavas to the softest of ashes, through intermediate products of cinders and conglomerates. The most resistant of these products remain as crags while the soft ones are worn away creating a landscape that is rough, craggy and rugged in outline. Geomorphic processes modifying the volcanic structures (over time) were the physical and chemical weathering processes that set the pace for erosion in form of splash, sheet, rill and gulling. These processes are exacerbated by the socio-economic activities that tend to accelerate them. Socio-economic activities observed on the plateau include farming, mining, grazing, deforestation, environmental degradation through bush burning, network of tracts made by man and cattle, fuel wood extraction and settlement expansion.

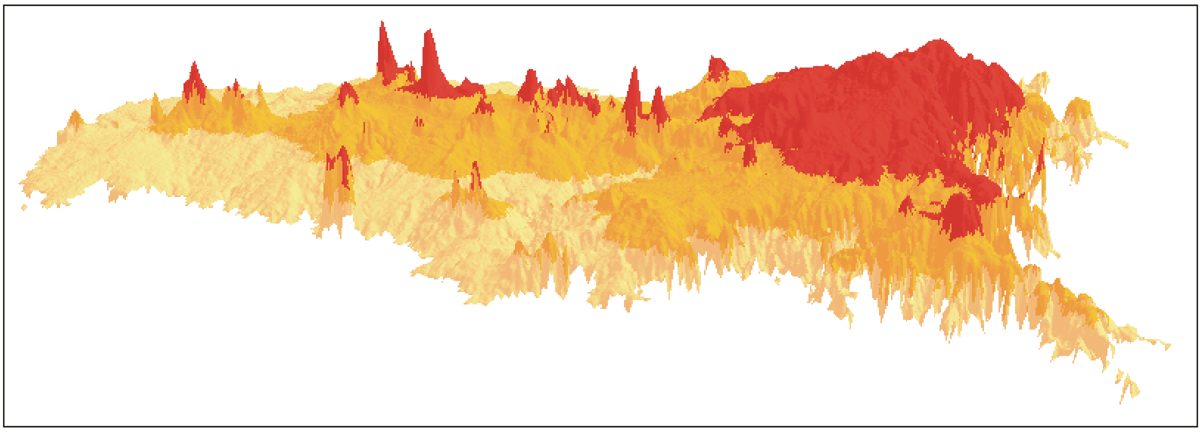

Figure 2. A 3D view of the Biu plateau (Abdullahi, Odihi and Wannah, 2015)

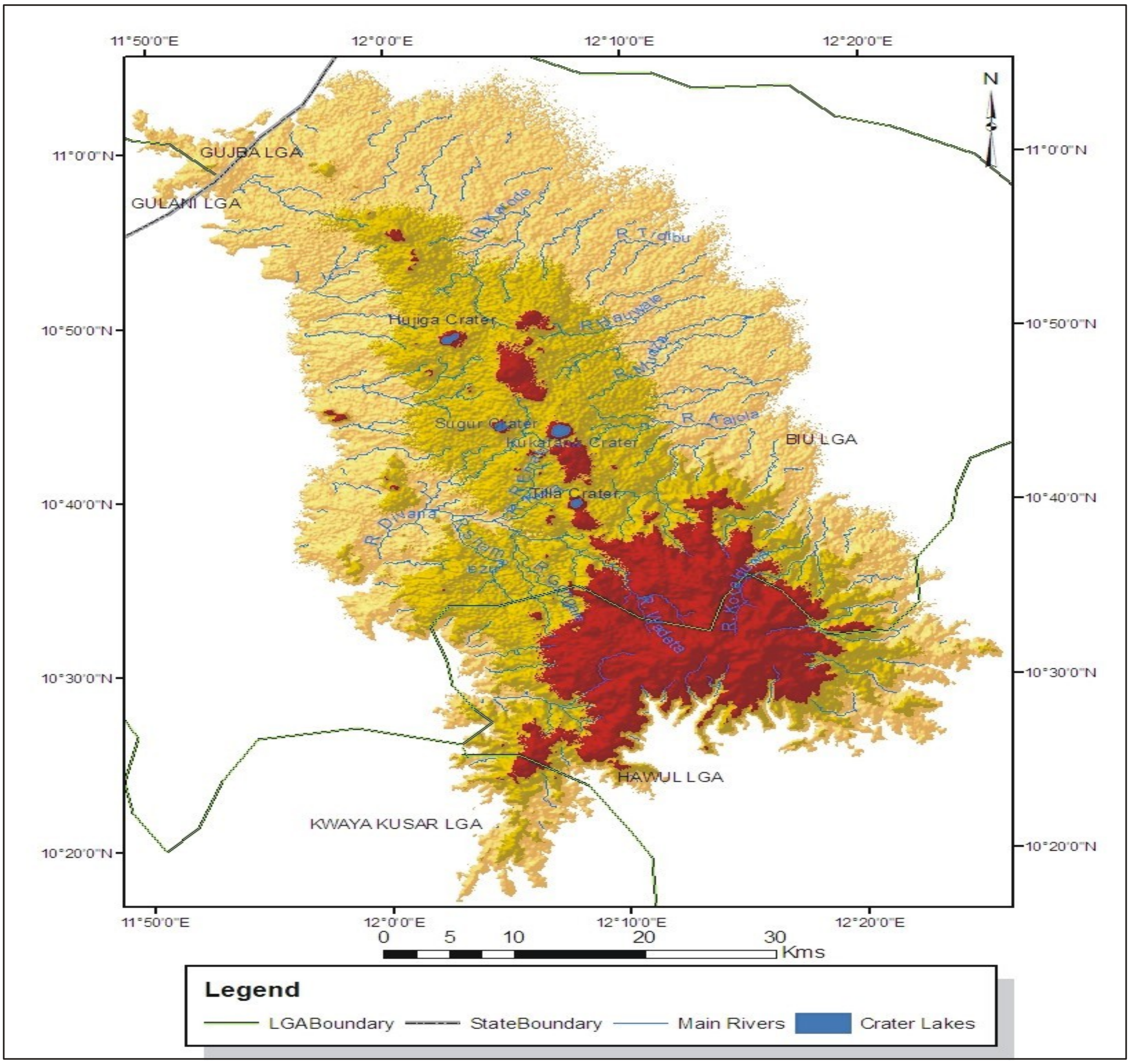

Figure 3. Drainage of the Plateau (Abdullahi, Odihi and Wannah, 2015)

5.2. Hydrology and Fluvial Processes of the Plateau

The drainage systems of the Biu plateau fall under three main catchments that originated from the Biu-Buratai watershed [16] and [15]. This watershed divides the streams that flow either northeast and discharge into the river Hawul or those which flow westward and discharge into the river Gongola (Figure 3). In the southern part, the rivers flow directly into the river Hawul that finally discharges into the River Gongola [15]. The plateau with a land mass of 2635.12 km^2 is traversed by a total of 14671 streams, with 9814 1^{st} and 3783 2^{nd} order streams totaling a length of 6879.5 km [6]. The drainage pattern of the plateau is dendritic in nature. This is a reflection of the uniform nature of the geology and lack of major geologic structures such as faults. The drainage density of the area is 2.61. This relatively low value of drainage density is an indication that the plateau has slopes that are not so steep with high vegetation cover. This hydrologic characteristic presents a unique disposition of water which forms the source of streams, lakes, ponds and groundwater recharge in the plateau. Hugiga, Kukafuna, Sugur and Tilla craters with an aerial coverage of 2.84, 3.34, 1.48 and 1.78 kilometers respectively are the only ones containing water [18]. The circular nature of the craters created as a result of volcanic activity has formed geomorphic structures which are typically basin like capable of storing large amounts of water which can be used for domestic and agricultural development when properly planned and developed for such purpose.

5.3. Some Physical and Major Elemental Composition of Surface and Groundwater in the Area

Weathering of rocks and the transport of chemical constituents by flowing water is one of the greatest agents shaping the surface of the earth [19] and runoff has been shown to be the primary variable controlling chemical weathering on land [20] and [21]. According to these authors, runoff integrates the effect of solubility of secondary and primary minerals and that basaltic rocks are among the most easily weathered rocks. Table 1 presents some physical and chemical composition of surface water samples at various locations of the plateau.

Table 1. Physical and chemical (mg/L) composition of surface water of the plateau

S/N	Temp. (°C)	pH	Turb. (NTU)	TDS	Mg^{2+}	Ca^{2+}	K^+	Na^+
1	23.6	7.7	506	241	56	101	9.3	205
2	21.4	7.7	762	355	88	154	9.6	342
3	22.6	7.3	347	148	51	109	8.2	360
4	23.4	7.2	758	335	69	77	5.4	194
5	24.1	7.4	356	640	47	109	8.7	204
6	21	7.3	347	396	44	221	7.2	218
7	22.4	7.3	216	684	45	124	6	215
8	22.1	6.8	114	604	50	90	6.2	218
9	24.1	7.2	287	221	24	88	7.1	215
10	26.8	7.4	301	604	93	91	5.5	181
11	27.3	7.1	217	912	55	182	5.2	210
12	22.1	6.9	218	746	46	124	6.1	201
13	23	8	356	111	92	160	10	317
14	23	7.4	428	984	164	125	5.2	250
15	26.5	8	804	226	50	65	7.1	281
16	28.9	7.8	264	142	86	73	6.4	293
17	30.2	7.7	738	100	114	125	5.8	360
18	22.3	8	201	127	24	88	9.1	392
average	24.16	7.46	401.11	420.89	66.56	117.00	7.12	258.67
min	21.00	6.80	114.00	100.00	24.00	65.00	5.20	181.00
max	30.20	8.00	804.00	984.00	164.00	221.00	10.00	392.00

All sampled surface waters in the study area are reddish to dark brown in colour. This implied that there were a lot of suspended and dissolved sediments in the water comprising latrites and other clay minerals. Also, it is an indication that chemical weathering predominate all other forms of weathering. This according to [22] in basaltic environments, the susceptibility of various minerals to weathering increases generally in the sequence; glass > olivine > pyroxene > amphibole > plagioclase > K-feldspar and ultimately, all these minerals alter to a mixture of allophone, iron-oxide-hydroxide and clay minerals.

The temperatures of the surface waters are slightly lower than the mean air temperature above the land surface. The surface waters temperature range between 21°C to 30°C with an average of 24.16°C. pH of the waters are alkaline/basic in nature (pH>7). Turbidity and total dissolved solids (TDS) are relatively high. The measured turbidity values (NTU) were in the range of (401 to 804) while the total dissolved solids ranged between 420 to 984. TDS of surface water in basaltic environments vary considerably and the variations indicate the degree of chemical disintegration of rocks in a water shed [22]. Higher values of turbidity and TDS similar to the ones observed in this study is an indication of higher ionic concentrations resulting from the chemical weathering of basaltic rocks [23].

The predominant major cation trend in the surface water samples is in the order of Na^+ > Ca^{2+} > Mg^{2+} > K^+ (Table 1). Na^+ concentration is extremely high (258 mg/L average) followed by Ca^{2+} (177 mg/L average). This reflects the chemical composition of rocks in the plateau which also has a relatively high Ca^{2+} Mg^{2+}, K^+ and Na^+ ionic concentrations (Table 2). Other processes such as precipitation of solids and ion exchange reactions greatly affect surface water chemistry.

Table 2. Results of major chemical composition of basalts (%) in the Biu plateau

Location	MgO	CaO	K_2O	Na_2O
Legos	8.45	14.5	1.08	0.78
Fuma	9.12	13.99	1.08	0.6
Melala	9.18	14.1	1.12	0.96
Gumyo	11.76	13.66	0.87	0.74
Vio	8.1	13.38	1.06	0.73
Burakum	8.43	14.48	0.93	0.78
Vina	9.23	13.91	1.22	0.9
Dam	7.93	13.83	1.34	1.07
Sama	8.84	13.82	1.27	0.98
Kwadiga	8.52	13.61	1.28	1.02
Minimum	7.93	13.38	0.87	0.6
Maximum	11.76	14.5	1.34	1.07
Average	8.956	13.928	1.125	0.856

Source: Obiefuna and Ngadda (2014).

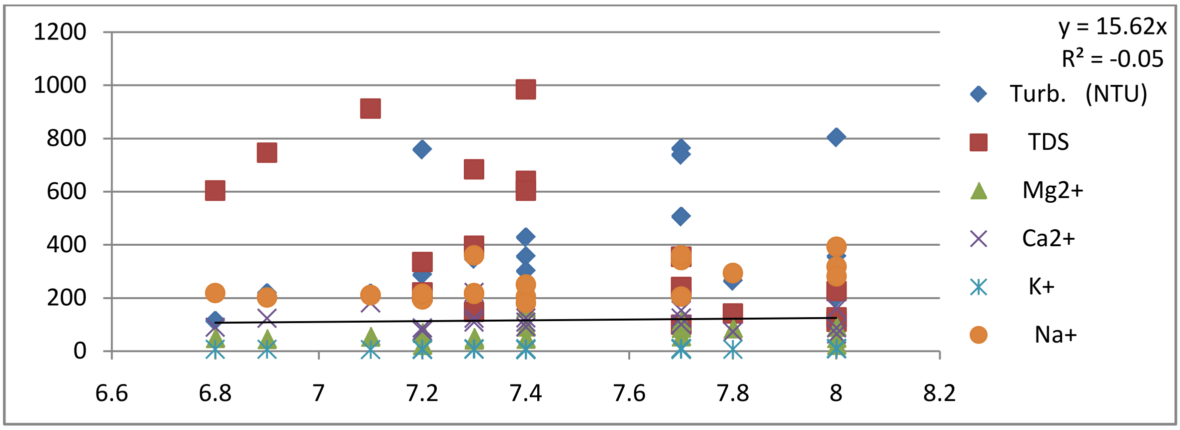

Figure 4. Relationships of measured parameters of the surface water in the study area

5.4. Groundwater Occurrences in the Plateau

The basalts making up the plateau are generally neither porous nor permeable except in areas where the rocks have primary structures or acted upon by forces where the rocks are shattered, cleaved, fissured or jointed. Although some folds, faults and joints are observed at various locations in the plateau, they are mostly localized (not of great extent) to be of significant importance in the storage and transmission of groundwater. The colluviums cover almost the entire plateau. This layer has an average thickness of 10 m, although it shows spatial variability. It is the source of a water table aquifer tapped by hand dug wells in the area. The basalt stores water either within the weathered zone or highly fractured, fissured and jointed zone which is between 15 and 20 cm thick and can provide yields of up to 1 L/s. At depth of 50-70 m heavily fissured and jointed basalt occurs which also serves as a good aquifer [24]. Groundwater flow through sequences of hard basalts characterized in the plateau is usually characterized by very low hydraulic conductivities (10^{-8}-10^{-13} m/s). This is because the pores generated by release of volatiles from the lava are not interconnected [7]. Therefore groundwater flow through sequences basalt flow is anistropic, mainly through cooling cracks and fissures.

Analysis of lithologic logs of over 60 boreholes and hand dug wells from different parts of the plateau indicated that three sources with high groundwater potentials exist in the plateau. Colluviums, weathered and fractured zones of the basalt and the basement form the aquifer systems. Parts of the fractured basalts are covered by a thin blanket of clay that often provides poor condition for infiltration and permeability. The fractured rocks in some places can be observed to have been sealed by clay sediments; the implication of this is reduced permeability. Basically, basaltic rocks tend to weather intensively and generate clay sediments which tend to fill voids created by primary and secondary structures hence affecting its ability to transmit water and form a viable aquifer. This could be one of the factors for the observed extreme variability of recharge rates and permeability in the different parts of the plateau. Another important feature of the occurrence of groundwater in the plateau is the occurrences of horizons of gravels and paleosoils formed between different lava flows during temporary cessation of volcanic activity. This together with the volcaniclastics around Miringa and other areas of the plateau forms very good aquifer systems. At a depth of 45-65 m, most of the lithologic logs are highly fractured and weathered with well-developed openings enhanced by highly connected networks of fracture system.

Groundwater in the plateau is exploitable naturally through springs and artificially through dug wells and boreholes. Springs are common on the plateau but their number, distribution and discharge are poorly understood. The observed springs have different flow directions and elevations. This characteristic according to [7] is an indication of the discontinuous nature of the groundwater source of an area.

Rainfall is the major source of recharge in the plateau which infiltrates through the soil horizons and subsequently the host rock which influences its hydrochemical signatures. Some physical and chemical (mg/L) compositions of groundwater in the plateau is presented in Table 3. The temperatures of groundwater in the plateau ranged between 30.22°C to 34°C with an average of 20°C. The predominant major cation trend in the groundwater of the area is in the order of $Ca^{2+} > Mg^{2+} > Na^{+} > K^{2}$. This trend is almost similar to that of the basaltic rocks making up the plateau (Table 2). Ca^{2+} and Mg^{2+} ions are the dominant dissolved constituents. According to [21] the enrichment of these ions and its dominance over the other cations reflect the chemical evolution mostly related to basalt water interaction. Although in most studies, good correlation between Ca and Mg on one hand and Na and K on the other were recorded, it has been observed that the concentrations of dissolved major elements in natural water are influenced by other processes such as ion exchange between soil water and clay minerals and soil organic matter [21]. In this study, a good correlation was observed between the dissolved concentrations of Mg and Ca and K and Na (Figure 5 and Figure 6).

Groundwater sampled from different parts of the plateau exhibited colourless to milkfish colours. It was further observed that deep boreholes >47 m have higher total dissolved solids (TDS) and turbidity. This could be as a result of longer residence time in the deep boreholes than it is in the shallow boreholes. pH of groundwater in the area is found to be alkaline/basic (pH>7) in nature with an average of 7.09. Spatial variation in the depth and physicochemical properties of sampled boreholes observed in the different parts (Table 3) of the plateau can be explained by the pockets or disconnected nature of the aquifer system in the area.

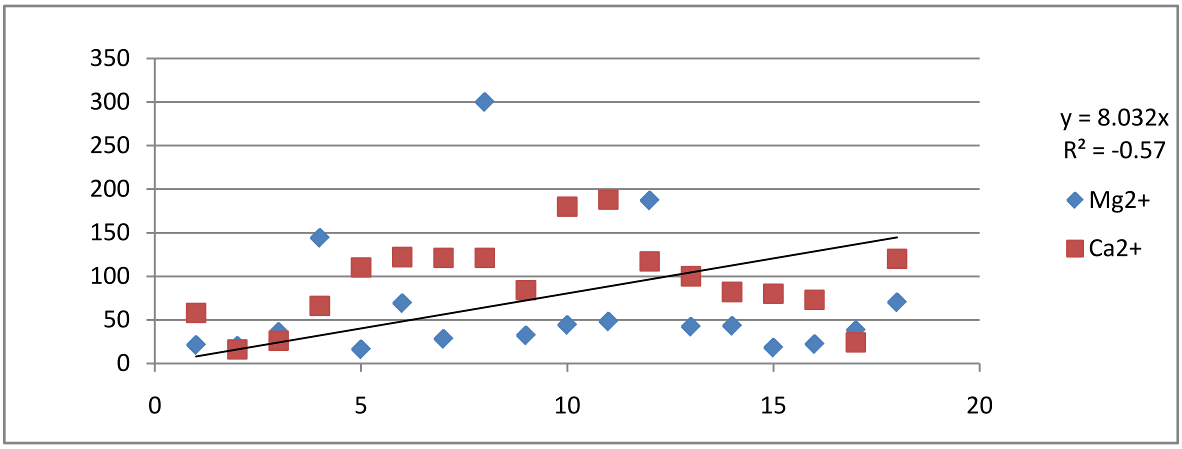

Figure 5. Relationship between Mg and Ca in the sampled boreholes of the study area

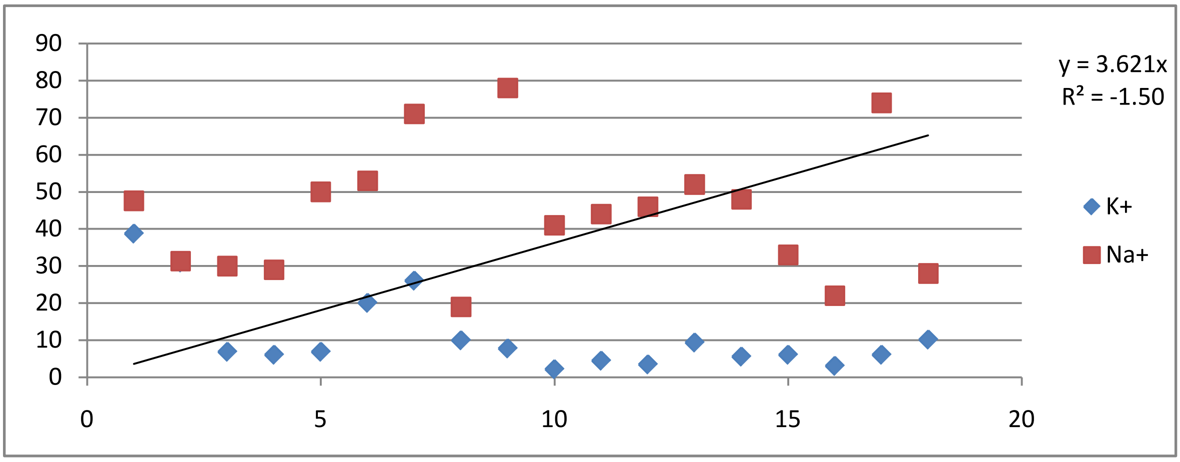

Figure 6. Relationship between K and Na in the sampled boreholes of the study area

Table 3. Depth and some physicochemical properties of sampled boreholes

S/N	Total depth (M)	Mean depth to water level (M)	Temp. (°C)	pH	Turbidity (NTU)	TDS	Mg^{2+}	Ca^{2+}	K^{+}	Na^{+}
1	41.2	15.2	34.2	7.6	10	144	21	58	38.7	47.6
2	60.3	16.4	33.4	7.2	18	690	20	16	30.9	31.3
3	61.4	14.2	20	6	19	680	36	26	6.8	30
4	41.2	11	30	7	12	430	144	66	6	29
5	50.6	7.9	28	6.8	27	210	16	110	6.8	50
6	47.7	12.4	28	7.6	19	462	69	122	20	53
7	60	15.3	27	7.4	20	848	28	121	26	71
8	45.8	6.2	31	7.8	26	590	300	121	9.9	19
9	24	6	32	6.6	15	284	32	84	7.7	78
10	82.4	14.1	34.8	7	24	148	44	180	2.1	41
11	31	12.4	34.3	7	16	472	48	188	4.4	44
12	17	7.11	29.8	7	22	332	187	117	3.4	46
13	23.2	7.6	25	6.6	26	108	42	100	9.3	52
14	16.7	6.2	29.8	6.4	16	110	43	82	5.5	48
15	15.3	7.4	34.8	7.6	18	738	18	80	6	33
16	31.4	6.2	26.4	7	11	567	22	73	3	22
17	14.8	7.4	31	7.4	19	222	38	24	6	74
18	73.2	9.3	34.4	7.7	10	483	70	120	10.1	28
average	40.96	10.13	30.22	7.09	18.22	417.67	65.44	93.78	11.26	44.27
Min	14.80	6.00	20.00	6.00	10.00	108.00	16.00	16.00	2.10	19.00
Max	82.40	15.30	34.80	7.80	27.00	848.00	300.00	188.00	26.00	78.00

6. Summary and Conclusion

Geomorphology and geology of an environment play significant roles in defining the occurrences, hydrodynamics, and hydrogeochemical characteristics of surface and groundwater system of an area. It also plays significant roles in defining the location of groundwater recharge and discharge zones, and therefore surface groundwater flow system and other related processes. The plateau is dominated by a sequence of alkaline olivine basalts which are acted upon by weathering processes. These gave room for the development of different fluvial processes giving rise to the occurrences of streams, rivers, ponds and other structures capable of storing surface water. The presence of colluviums with an average thickness of about 10 m which cover almost the entire plateau together with the highly fractured, fissured and jointed zones serves as aquifers in the plateau. The highly soluble rock minerals making up the basalts of the plateau largely determined the chemistry of surface and ground waters of the plateau.

References

[1] National Population Commission (2007), 24 (94).

[2] Amaza, P.S., Olayemi, J.K., Adejibi, A.O., Bila, Y., and Iheanacho, I. (2007). Baseline socio Economic survey report: agriculture in Borno, Nigeria. International Institute of Tropical Agriculture, Ibadan, Nigeria.

[3] Ijere, J.A. and Mailafiya, H.M. (1991). Water Resource Supply in the Biu LGA of Borno State: Problem and Prospects. In N. M. Gadzama, (eds), *Arid Zone Hydrology and Water Resources.* University of Maiduguri Press.

[4] Bwala, A.A. (2011). Domestic water resources availability and utilization in the Biu plateau Region of Borno State. Unpublished PhD Thesis, Department of Geography, Federal University of Technology, Yola.

[5] Babar and sah, I. I. (2012). Influence of Geological and Geomorphological Characteristics on Groundwater Occurrences in Deccan Basalt Hardrock Area of Tawarja River sub-Latur, India. *Research Journal of Environmental and Earth Sciences* 4(4) pp 440-447.

[6] Ikusemoran, M., Odihi, J. O. and Yelwa, M. Y. (2017). Geographical Synthesis of the Biu plateau, North Eastern Nigeria. *Academic Research International.* Vol. 8(2) Pp 18-34.

[7] Mohammed, Y., Daura, M. M, Abdullahi, J. and Usman, U. A. (2017). Origin, Geomorphology and Petrogenesis of the Biu Plateau, Borno state, Northeastern Nigeria: An overview. *Maiduguri Journal of Arts and Social Sciences (MAJASS).* Vol. 14. Pp 143-152.

[8] Wright, J. B., (1970). High pressure phases in Nigerian Cenozoic lavas- distribution and tectonic setting. *Bulleting of volcanology*, 54, P 833-847.

[9] Islam, M.R. (1986). The Petrographic Studies of Biu Plateau Northern Nigeria. *Annals of Borno Journal of Geology Volume* 4 PP. 215-226

[10] Turner, D. C. (1978). Volcanoes of the Biu Basalt Plateau, Northern Nigeria. *Journal of Mining and Geology.* 15(2), pp 49-63.

[11] Obiefuna, G. I. and Ngadda, I. S. (2014). Geochemical and Mineralogical Composition of Biu Basalts Deposits. Biu Area, NE Nigeria. *Research Journal of Environmental and Earth Sciences.* 6 (5) PP2 41-250.

[12] Usman, M. Y. (1993). The Geological Mapping and Petrographic Study of the Rocks around Kwajafa Area, Hawul Local Government, Borno state. Unpublished NISLT Final Project. PP. 12-57.

[13] Udo, R.K. (1970). Geographical Regions of Nigeria. Hienemann Publishers, Ibadan, Nigeria.

[14] Gregory, K. J. and Walling, D.E. (1973). Drainage Basin Form and Processes: A Geomorphological Approach, Edward Arnold Publishers Ltd, London.

[15] Abdullahi, J. (2015). Analysis of Volcanic Craters and their Socio-economic Importance on the Biu Plateau, North-eastern Nigeria. Unpublished PHD Thesis, Geography Department. University of Maiduguri. P 154.

[16] Davies, J.G. (1956). The Biu Book. Zaria, Gaskiya Printing Press.

[17] Abdullahi, J. Nyanganji, J. K. and Wannah B. B. (2015). Assessment of Outer and Inner Slope Profiles of Volcanic Craters on Biu the Plateau, Borno State, *Nigeria. Journal of Asian Scientific Research.* Vol. 5(5). PP.219-227.

[18] Abdullahi, J., Odihi, J. O. and Wannah, B. B. (2015). Analysis of Morphology of Volcanic Craters on the Biu Plateau, Borno State, Nigeria. *Journal of Geography, Environment and Earth Science International*. 3 (1). PP. 1-10.

[19] Gaillardet, J., Dupre, B., Laurat, P., and Allegre C. J. (1999). Global silicate weathering and CO_2 consumption rates deduced from the chemistry of large rivers: Chemical geology, Vol. Pp.3-30.

[20] White, A. F., and Blum, A.E. (1995). Effects of climate on mechanical weathering in watershed: *Geochemica et cosmochimica Acta,* Vol. 59 Pp 1729-1747.

[21] Stefansson, A., Gislason, S. R., and Arnorsson, S. (2001). Dissolution of primary basalts of basalts in natural waters II. Mineral saturation: *Chemical geology*, Vol. 172 Pp 251-276.

[22] Andri, S. and Sigurdur, R. G. (2001). Chemical weathering of basalts, Southwest Iceland: Effects of rock crystallinity and secondary minerals on chemical fluxes to the ocean. American Journal of science, Vol. 301. Pp 513-556.

[23] Dibal, H. U. and Lar, U. A (2014). The lithosructural units in selected areas of Northern Nigeria. *International Association of Hydrogeologist.*

[24] Freeze, R. A. Cherry J. A. (1979). Groundwater. Prentice-Hall Inc. New Jersey, 603 p.