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**Received:** December 2016**Revised and Accepted:** April 2017**ABSTRACT**

Hydrochemical patterns has been mapped and correlated with groundwater flow systems to varying degrees using hydrochemical facies. Reliable broad relationship between chemical composition and the flow distribution of groundwater were established in the process. This study examines the water quality and groundwater flow patterns present in the crystalline basement aquifer of Part of Minna in North Central Nigeria for environmental purpose. Sixteen water samples were collected from wells and analyzed for various parameters including pH, total dissolved solids (TDS), electrical conductivity (Ec),  $K^+$ ,  $Na^+$ ,  $Ca^{+2}$ ,  $Mg^{+2}$ ,  $Cl^-$ ,  $HCO_3^-$  and  $SO_4^{+2}$  using standard procedures of water analysis. The analytical results present the abundance of both physical and chemical parameters in the following order: pH (5.8 – 7.6), Ec (116.7 - 1562 $\mu$ s/m), TDS (128.6 – 1046.5 mg/l),  $Na^+$  (25.3 – 144.8 mg/l),  $K^+$  (1.1 – 39.5 mg/l),  $Mg^{+2}$  (5.6 – 30.7 mg/l),  $Cl^-$  (20.4 – 276.5 mg/l),  $HCO_3^-$  (10.0 – 21.0 mg/l),  $SO_4^{+2}$  (8.0 – 180 mg/l). Piper trilinear for the study area shows that there is a mixture of two types of water with variable concentrations of major ions. These are  $Na^+$ ,  $K^+$ ,  $Cl^-$ ,  $SO_4^{+2}$  water type and  $Ca^{+2}$ ,  $Mg^{+2}$ ,  $Cl^-$ ,  $SO_4^{+2}$  water types. This means that groundwater in the area is mainly made up of mixtures of the alkaline and alkaline earth metals and predominantly  $Cl^- - SO_4^{+2}$  water type. Comparison made from the geochemical maps indicate that high total dissolve solids occur at the discharge area and relatively the groundwater at various discharge point is older in age and has high residence time to that of recharge area. Hydrochemical data analysis revealed four sources of solutes. The processes responsible for their enrichment include: chemical weathering, leaching of the overlying sediments, domestic activities, climatic condition and the flow pattern of the aquifer. These factors have contributed to the changes of the groundwater chemistry. From the static well level measurement plot, it was revealed that the dominant trend for the groundwater movement is in the N-S, NW-SE and NE-SW directions which shows that the groundwater of the area is structurally controlled.

**Keywords:** Water Quality, Groundwater Chemistry, Hydrochemical Facies, Flow Pattern, Basement Complex.

**1.0 Introduction**

Hydrochemical patterns has been mapped and correlated with groundwater flow systems to varying degrees using hydrochemical facies. As a result reliable broad relationship between chemical composition and the flow distribution of groundwater have been established in the process. As water flow through an aquifer it

reflects a diagnostic chemical composition as a result of interaction with the lithologic framework, hydrochemical facies is used to describe the bodies of groundwater in an aquifer that differ in their degree of chemical composition. It has being found that the facies are a function of the lithology, topography, resident time, prevailing

climatic condition, solution kinetics and flow pattern of the aquifer Abdullah and Aris(2004). These factors can combine to create diverse water types that change in composition spatially and temporally. Water quality analysis and interpretation shows water-rock interaction and indicates residence time and recharge zone confirmation (Cronin et al., 2005). Thus, water quality indicators must reflect mineralization process, integrate reservoir properties and be sensitive to groundwater recharge rate and flow direction (Andre et al., 2005). The use of major ions as natural tracers has become a common method to delineate flow paths in aquifers. Generally the approach is to divide the sample into hydrochemical facies (water type), that is, groups of samples with similar chemical characteristics that can then be correlated with location. The spatial variability observed can provide insight into aquifer heterogeneity and connectivity as well as the physical and chemical processes controlling water chemistry. It can be studied in terms of anions and cations or both. For instance, Tóth (1966) used anion facies development in mapping groundwater discharge and recharge areas in Canada. Al-Agha and El-Nakhal (2004) uses both anion and cation to delineate hydrochemical facies of groundwater in the Gaza Strip, Palestine.

Amadi, Olasehinde and Yisa (2010) used both anion and cation species in mapping the groundwater facies type housed in a north-south direction of some part of the Niger Delta region. Although each system may differ in scope but all are directed towards the definition and hydrochemical facies types found in groundwater flow system.), Hydrochemical facies can be classified on the basis of the dominant ions in the facies by means of diagrams and graphs Schoeller (1965); Stiff (1951); Piper (1944). These diagrams are useful in screening and sorting large numbers of

chemical data, which makes interpretation easier. Furthermore, they can define the patterns of spatial change in the water chemistry among geological units, along a line of section or along a path line Raji and Alagbe (1997); Domenico and Schwartz (1998). This research work is to assess the hydrochemistry and groundwater flow pattern of the unconfined aquifers (hand-dug well) of the study area in order to decipher the possible groundwater chemical facies or types and the factors controlling it including the possible flow pattern of the groundwater.

### **1.1 Hydrogeology of Basement Rocks**

The area is situated within the crystalline hydro-geological province. The hydro-geological province is made up of two interconnected aquifers, namely: - the soft overburden aquifer and the partial weathered/fractured basement aquifer. The average thickness of the soft overburden in Minna and its environs is about 30m and the average yield of borehole in the aquifer is about 0.5litre per second (Adeniyi, 1985). The partially weathered/fractured basement formation is the secondary aquifer and the more reliable aquifer in this area. An average yield of 5litres per second of borehole can be gotten when carefully sited in the fractured zone. The groundwater in the area is primarily recharged by the surface precipitation and by the lateral groundwater movement. The depth to the water tables lies on the average between 3 – 15m below the surface in the crystalline basement (Adeniyi, 1985).The impermeable igneous and metamorphic rocks underlying the Minna basement complex terrain are noted as poor sources of groundwater. However, tectonic features such as fracturing, jointing and fissuring often modify the water bearing characteristics of the rocks and make them amenable to containing water in discontinuous and isolated places through the development of

secondary permeability. In addition, in this terrain permeable sandy-clayey laterite and weathered rock material overburden also serve as potentially viable water table aquifers depending on the thickness of the layers and the recharge prospects. The thickness of this overburden layer (both clayey and weathering material) may reach down to more than 15m and when aquiferous, this can sustain groundwater supply through dry wells.

In the basement terrain, groundwater is known to occur within the fractured bedrock and in overlying regolith. Some Hydrogeological investigations, including Ibe (1995) revealed that groundwater systems in such terrain are structurally controlled. Whereas those of Alagbe and Raji (1990) tend to suggest that the overburden derived from the in-situ weathering of the rocks constitutes an aquifer which in turn, is underlain by the fractured basement rocks from the aquifers in this type of geological terrain. The productivity of any aquifer however is a function of the permeability, porosity, geometry of the reservoir rock (overburden thickness and lateral extent) and nature of lithology of the formation. In essence, the weathered and/or fractured parts of the bedrock overlying the fresh crystalline basement complex are probable promising areas for groundwater exploitation in the basement complex. It is important to carry out geophysical mapping in locating and delineating the water bearing zone. Aquifer in basement terrain is not uniform and it is not continuous over a wide/small expanse of rocks, therefore, they are localized thus the use of geophysical methods in delineating this formation is of importance.

## 2.0 Methodology

The research aimed at collecting sixteen representative groundwater samples from unconfined aquifers (hand-dug wells)

Hydrogeology of area is usually controlled by such factors as geology and climate of that area. This is due to the fact that geological formations underlying the area and structures contained in them determine the types of aquifer to be encountered and how the aquifers are recharged while the climate determines the amount and rate of recharge of the aquifers (Nkereuwen, 1991; Ariyo, 2004). In basement complex environment, the aquifer is not spread like in the sedimentary region, also the number, size and area extent is limited and are separated from one another. Thickness of the weathered zone and its specific capacity is thin and narrow. The hydraulic conductivity and the bedrock are poorly developed and unpredictable from one location to another within a short distance.

Crystalline rock aquifers are considered as highly heterogeneous since their porosity is unevenly distributed through fissures and fractures. Distribution of the fracture characteristics (length and fracture centre correlation patterns) controlling heterogeneity has been shown to have no characteristic length scale. Consequently, classical equivalent porous medium hydrogeologic models cannot be applied to many of these aquifers (Berkwitz, 2002; Bonnet, Bour, Odling, Davy, Main, Cowie *et al.*, 2001; de Dreuzy, Darcel, Davy, Bour, 2004). In fractured rocks, heterogeneous water flow paths and channelling effects have been demonstrated. At a regional scale, heterogeneity has been investigated in relation with regional flow paths, discharge, geology, or agricultural practices (Chen, Tang, Sakura, Kondoh, Yu, Shi-mada *et al.*, 2004; Grassi and Cortecchi, 2005; Shapiro, Rowe, Schlosser, Ludin, and Stute, 1998; Weissmann, Zhang, La Bolle, Fogg, 2002).

tapping the basement complex aquifer of Minna and its environs in different locations of the study area, and at determined depth, Figure 1. During the exercise 16

groundwater samples was collected and the coordinate (Table 1).  
global position system was used to obtain

**Table 1: Descriptions of Water Sample Location**

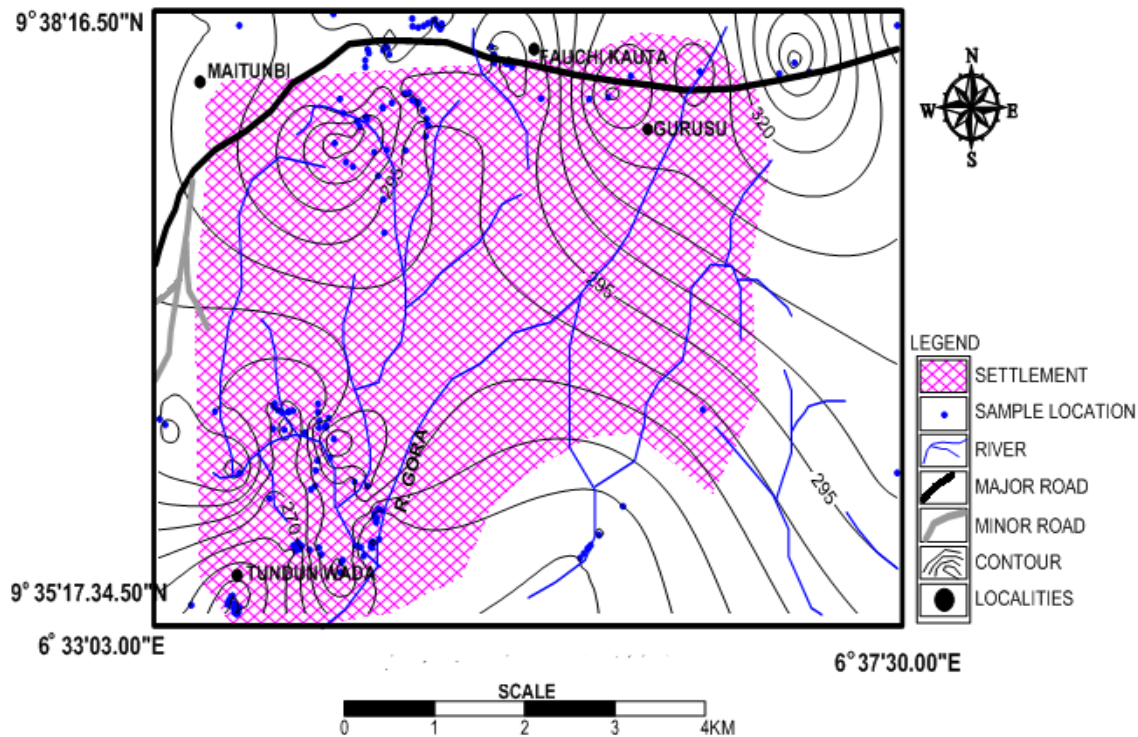
Sample Code	Sample Locations	Description	Remarks
ASM1	N09° 38'041" E006° 34' 266"	Hand- dug well at Maitumbi	Dry season sample
ASM2	N09° 38'130" E006° 34' 280"	Hand- dug well at Maitumbi	Dry season sample
ASM3	N 09° 38' 231" E 006° 34'729"	Hand- dug well at Maitumbi	Dry season sample
ASM4	N 09° 38' 253" E 06°34' 730"	Hand- dug well at Maitumbi	Dry season sample
ASM5	N 09°37' 787" E 06° 34' 269"	Hand-dug well at AngwaKadara	Dry season sample
ASM6	N 09° 38' 061" E 06° 35' 117"	Hand-dug well at Bayan Dana	Dry season sample
ASM7	N 09° 37' 997" E 06° 35' 880"	Hand-dug well at Jatai	Dry season sample
ASM8	N 09° 37 '787" E 06° 34' 269"	Hand-dug well at Gwodeyi	Dry season sample
ASM9	N 09° 36' 335" E 06° 33' 709"	Hand-dug well at Tunga	Dry season sample
ASM10	N09° 38' 041" E006° 34' 266"	Hand-dug well at Maitumbi	Dry season sample
ASM11	N 09° 36' 307" E 06° 33' 760"	Hand-dug well at Tunga	Dry season sample
ASM12	N 09° 36' 312" E 06°33' 826"	Hand-dug well at Tunga	Dry season sample
ASM13	N 09° 35' 335" E 06° 33' 208"	Hand-dug well at Tudunwada	Dry season sample
ASM14	N 09°35' 819" E 06° 34' 345"	Hand-dug well at Tudunwada	
ASM15	N 09° 35' 646" E 06° 33' 861"	Hand-dug well at Tudunwada	Dry season sample
ASM16	N09° 38' 143" E 06 °35' 32"	Hand-dug well at Bayan Dana	Dry season sample

One litre plastic rubbers was used to collect the samples, dry washed and rinsed with the water sample before filling it to capacity and then labelled accordingly. The sample from the same source was divided and submits as blind duplicate to access accuracy/precision of the laboratory. The samples were

analysed for both cations (Na, K, Ca, Mg,) and anions ( $\text{SO}_4^{2-}$ ,  $\text{HCO}_3^-$  and  $\text{Cl}^-$ ). Prior to the collection of the water samples, the physical parameters (pH, EC, TDS) were determined in the field (*in situ*) using standard equipments. After the collection, the samples were stored in a cool box and

taking to the regional water quality laboratory of Federal Ministry of Agriculture and Water Resources, Minna for

the analyses. Standard scientific methods were used to analyze the various components of the ions.



**Figure 1:** Fact Map of the Study Area

### 3.0 RESULTS AND DISCUSSION

Minimum and maximum concentration of major ions constituents of the groundwater, in addition to the physical parameters are shown in Tables 2 and 3. The pH values of groundwater were varied from (5.8 to 7.6) with a mean and standard deviation of 6.800 and 0.4858 respectively, indicating neutral nature of the water types, except in few locations where pH values is below neutrality, that is slightly acidic. Total dissolve solids (TDS) values range from (128.6 to 1046.5mg/l) with mean value and standard deviation of 462.781 and 245.8537 respectively, it revealed that the groundwater is of freshwater origin except in sample location (ASM6) where it slightly increase above 1000Mg/L it could be attributed to the nature of alluvial deposit

which are rich in soluble minerals in addition to anthropogenic effect and groundwater flow distribution. Electrical conductivity ( $E_c$ ) ranged from 192 to 1562 $\mu$ S/cm with a mean and standard deviation of 690.75 and 370.0058, with highest values at the sample location (2, 6 and 13) shown in Figure 3. The measured values of electrical conductivity are reflected in the intermediate to high concentration of salts and also in the medium grade of mineralization of these waters. Likewise, they show strong lixiviation of  $Ca^{2+}$ ,  $Mg^{2+}$ ,  $Na^+$ ,  $K^+$  cation and  $HCO_3^-$ ,  $Cl^-$ ,  $SO_4^{2-}$  anions. From (Figure 2), it becomes very glaring that among the physical parameters, electrical conductivity is the highest this has lend credence that

electrical conductivity is solely dependent on TDS, because as electrical conductivity

increase, TDS also increased.

**Table 2:** Physico-chemical parameters for water samples from Minna

Code	pH	Ec ( $\mu\text{s/cm}$ )	TDS ( $\text{mg/l}$ )	Na <sup>+</sup> ( $\text{mg/l}$ )	K <sup>+</sup> ( $\text{mg/l}$ )	Ca <sup>2+</sup> ( $\text{mg/l}$ )	Mg <sup>2+</sup> ( $\text{mg/l}$ )	Cl <sup>-</sup> ( $\text{mg/l}$ )	HCO <sub>3</sub> <sup>-</sup> ( $\text{mg/l}$ )	SO <sub>4</sub> <sup>-</sup> ( $\text{mg/l}$ )
ASM1	7	619	414.7	47.6	7.46	8.82	25.4	99.2	18	23
ASM2	7.2	1241	831.5	92.2	18.2	5.61	25.4	276.5	16	30
ASM3	6.9	825	552.7	42.5	4.26	11.2	27.1	191.4	11	15
ASM4	6.5	538	360.5	26.5	4.26	10.4	22.9	62.1	10	8
ASM5	7.3	628	420.7	27.3	2.13	4.01	30.7	69.2	10	9
ASM6	7.3	1562	1046.5	57.7	2.13	41.6	14.4	20.4	10	9
ASM7	6.8	818	548.1	81	4.26	7.21	29.7	96	21	38
ASM8	6.9	541	362.5	40.5	6.4	16.8	21.9	193.2	19	33
ASM9	6.1	312	209	32.5	3.2	20	20.9	64.2	17	23
ASM10	6.8	505	338.3	45.6	6.4	5.61	8.29	118.7	13	21
ASM11	5.8	323	216.4	54.7	1.067	15.2	19	44.3	16	11
ASM12	7.6	754	505.2	114.5	3.2	7.21	14.6	108.1	19	180
ASM13	6.6	1167	781.8	144.8	1.067	16	7.32	72.6	20	170
ASM14	7.2	192	128.6	25.3	2.13	16	5.61	85.1	15	17
ASM15	6.2	432	289.4	45.6	5.33	8.02	7.81	58.5	19	25
ASM16	6.6	595	398.6	67.8	39.5	5.61	8.78	37.2	16	18

**Table 3:** Univariate statistical overview of groundwater chemistry

Components	N	Minimum	Maximum	Mean		Std. Deviation
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic
pH	16	5.8	7.6	6.800	.1214	.4858
Ec	16	192	1562.0	690.75	91.5015	370.0058
TDS	16	128.6	1046.5	462.794	61.4634	245.8537
Na <sup>+</sup>	16	25.3	144.8	59.131	8.4479	33.7917
K <sup>+</sup>	16	1.1	39.5	6.937	2.3964	9.5858
Ca <sup>2+</sup>	16	4.0	41.6	12.456	2.2945	9.1778
Mg <sup>2+</sup>	16	5.6	30.7	18.113	2.1546	8.6184
Cl <sup>-</sup>	16	20.4	276.5	99.794	16.8780	67.5119
HCO <sub>3</sub> <sup>-</sup>	16	10.0	21.0	15.625	.9437	3.7749
SO <sub>4</sub> <sup>2-</sup>	16	8.0	180.0	39.375	13.4220	53.6878

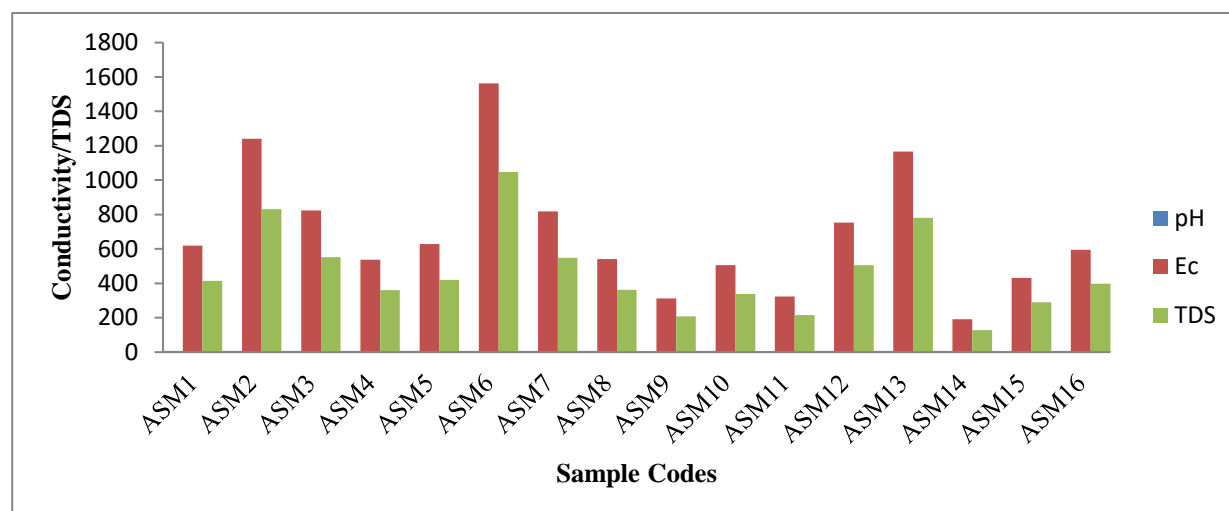


Figure 2: Plot of physical parameters (conductivity in  $\mu\text{s}/\text{cm}$  and TDS in  $\text{Mg}/\text{L}$ ) of water samples from Minna.

Generally it has being found that the chemical composition of groundwater is primarily dependent on the type of chemical reaction as well as the geochemical processes taking place within the groundwater system. In the study area analytical result presents the abundance of these ions in the following order  $\text{Na}^+ > \text{Mg}^{+2} > \text{Ca}^{+2} > \text{K}^+ \rightarrow \text{Cl}^- > \text{SO}_4^{+2} > \text{HCO}_3^-$  as shown in Figure 4. It is revealed through critical analysis that Chlorides and sodium were the dominant anion and cation respectively, in the groundwater of the study area. Concentration of  $\text{Cl}^-$  generally ranges from 20.4 to 276.5  $\text{mg}/\text{l}$  with mean and standard deviation of 99.794 and 67.5119 respectively. Subsequently, sulphate is equally found in considerable amount (8 to 180 $\text{mg}/\text{l}$ ), with mean and standard deviation value of 39.375 and 53.6878 accordingly, followed by bicarbonate (10 to 21 $\text{mg}/\text{l}$ ) with

mean and standard deviation value of 15.625 and 3.7749. In figure 3, sulphate ions were the dominant of all ions in the anionic group present in sample (ASM12 and ASM13), this may results from leaching effect of subsurface material due to the high hydraulic gradients of aquifer material in that area. On the cationic component, sodium dominates the cationic components of the groundwater range between 25.3 to 144.8 $\text{mg}/\text{l}$  with average value of 59.131  $\text{mg}/\text{l}$ , exception of sample (ASM5) were magnesium show dominancy over all the cationic group followed by magnesium range from 5.61 to 30.7  $\text{mg}/\text{l}$  with mean value of 18.113  $\text{mg}/\text{l}$ , Figure 3. Next to magnesium were calcium range from (4.01 to 41.6  $\text{mg}/\text{l}$ ) with mean value of 12.456 $\text{mg}/\text{l}$  and the last component which is potassium range from 1.067 to 39.5  $\text{mg}/\text{l}$  with mean value of 6.937  $\text{mg}/\text{l}$  Tables 2.

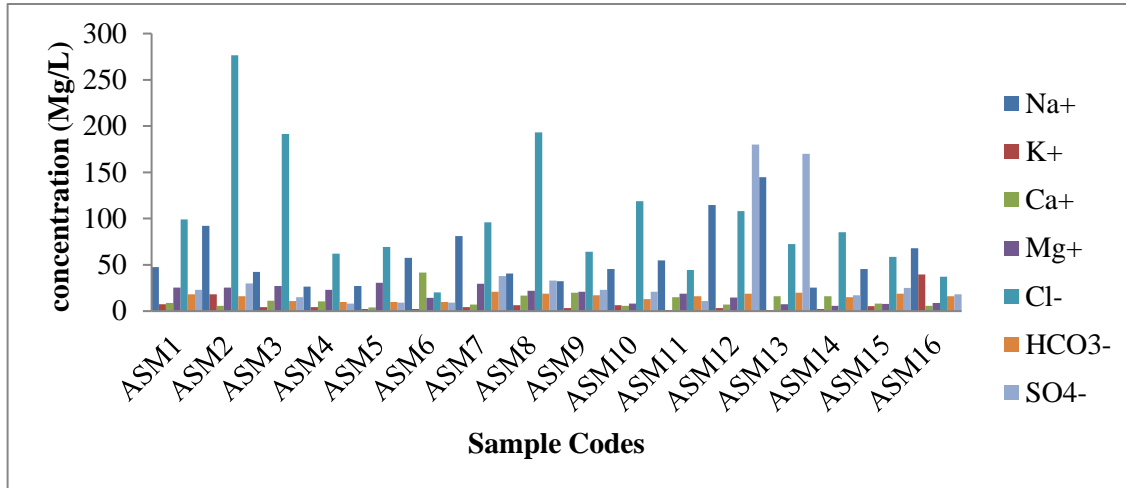


Figure 3: Graph of hydrochemical parameters of water samples from Minna.

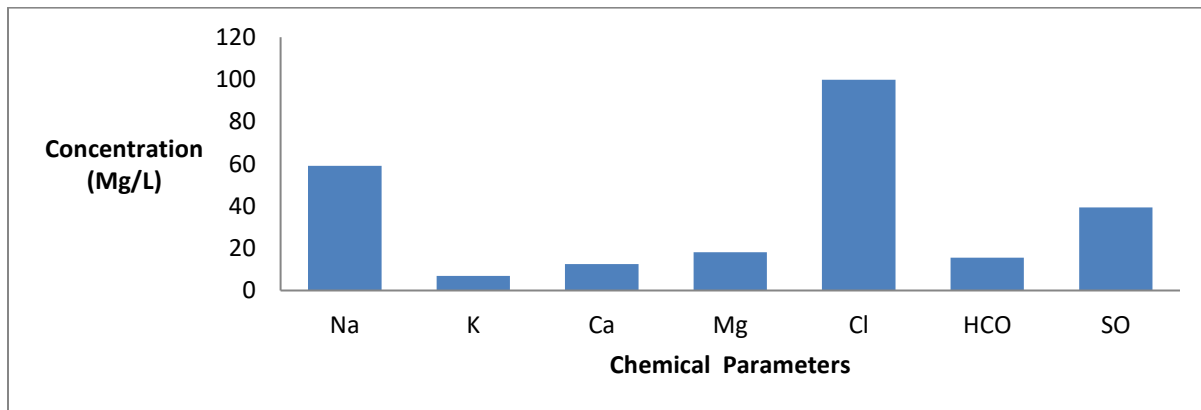
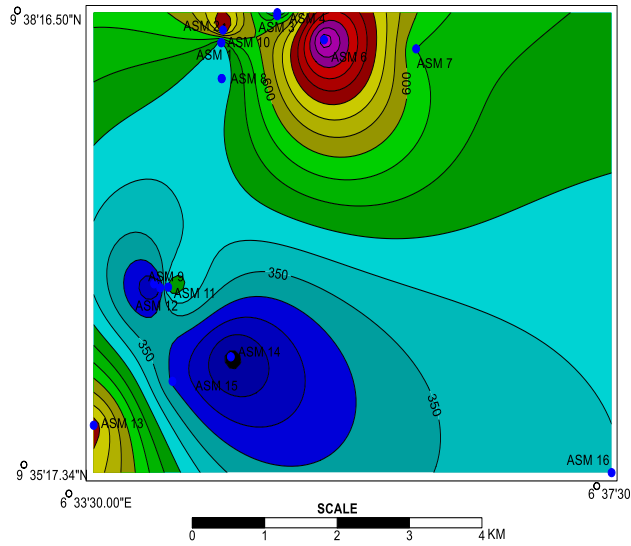


Figure 4: Average Mean Concentration of Cations and Anions over Minna.

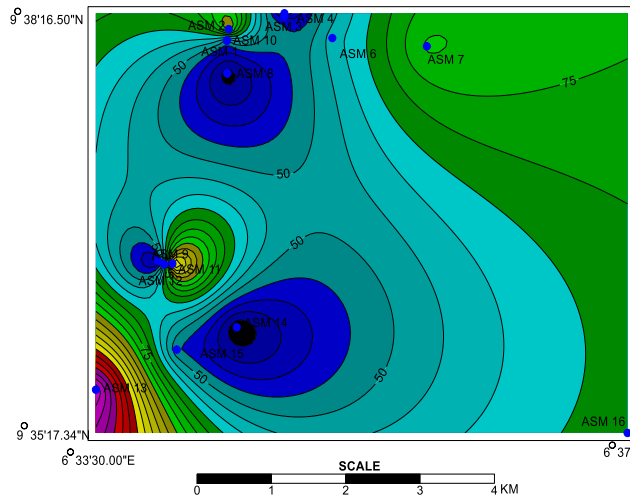
Total dissolve solids determine the rate of groundwater conductivity, as water move through an aquifer it dissolve a lot of mineral compound along its flow path, thus TDS and EC become high at discharge point (sample point 2, 6 and 13) compare to recharge points, in Figure 5. Relatively the groundwater at the various discharge point is older in age and has high resident time to that of waters at the recharge area. It was revealed through area distribution of sodium ion in figure 6 that the rock types in the vicinity of study is moderately weathered which most have result in the release of sodium ion from plagioclase feldspar within groundwater environment, greater concentration of it were found at the extreme south west part of the map, that is

sample location 13 and north west sample location 12 and 2.

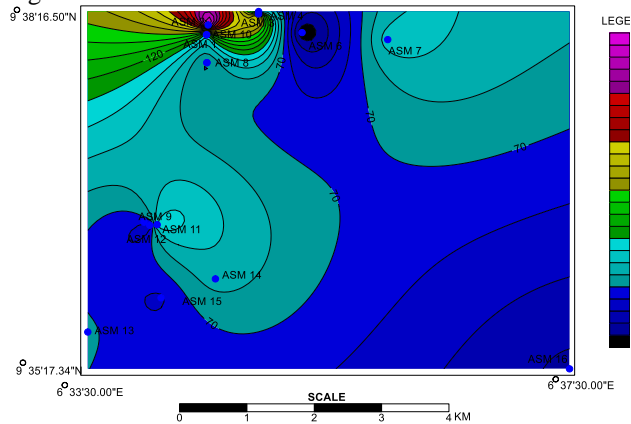
From the map showing the area distribution of chloride ion (Figure 7), the north western part of the map particularly sample location 2 shows exceptional high concentration of chloride ion couple with the fact that it shows high strength of TDS and Na<sup>+</sup> concentration this confirmed that the area is a discharge point. Though there are some other area within the study site that revealed medium concentration of chloride ion it could probably attributed to natural course of water movement and human activities around the wells.



**Figure 5: Area Distribution of Total Dissolved Solids in Minna**



**Figure 6: Area Distribution of Sodium ion in Minna.**



**Figure 7: Area Distribution of Chloride ion within Minna**

As a matter of fact the diagnostic chemical character of water solutions in hydrologic systems of the study area has been determined with the direct application of the concept of hydrochemical facies (Figures 8), which enables a convenient subdivision of water compositions of chemical processes occurring between the minerals within the subsurface rock units and the groundwater.

It has being revealed through statistical Piper trilinear diagram (Figure 8) for the study area mixture of two types with variable major ions concentrations, these are  $\text{Na}^+$  ,  $\text{K}^+$  ,  $\text{Cl}^-$  ,  $\text{SO}_4^{+2}$  water types or facies and  $\text{Ca}^{+2}$   $\text{Mg}^{+2}$   $\text{Cl}^-$   $\text{SO}_4^{+2}$  water types, the samples that are plotted in both water types is (asm16, asm15, asm14, asm12, asm13, asm10, asm11) and (asm1, asm2, asm3, asm4, asm5, asm6, asm7, asm8, asm9) respectively.

This suggests or means that groundwater in the area is mainly made up of mixtures of alkaline and alkaline earth metals and most importantly  $\text{Cl}^-$   $\text{SO}_4^{+2}$  water type. It is found through critical analysis and interpretation that on anionic component Chloride predominate followed by sulphate. Most of the samples are made up of two water types. It is a glaring fact from all practical indication that chloride and sulphate ions, as revealed are clearly the dominant anions and so there are practically no bicarbonate waters, as might be expected from the chemistry of the lateral groundwater recharge. Given the influence of the recharge in the aquifer systems of the area, the groundwater generally gives a  $\text{SO}_4^{2-}/\text{Cl}^-$  (in mg/l) ratio that is lower than that corresponding to seawater in the sampled water. This reveals that  $\text{SO}_4^{2-}$  proportion cannot be attributed to saline intrusion and that a significant proportion must come from other saline contributions that differentially enrich the water with the sulphate ion. This sulphate enrichment is accompanied by

increases in calcium and magnesium, and these suggest a common, non – marine origin for these ions.

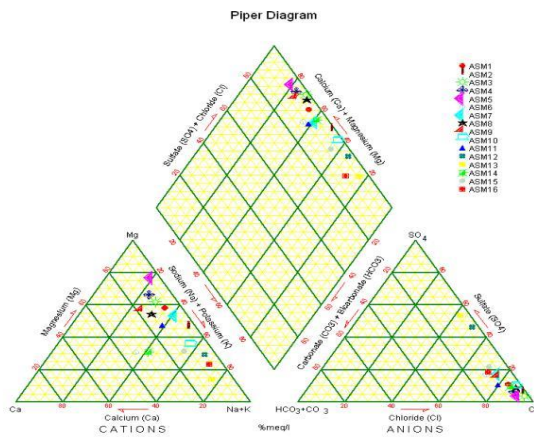


Figure 8: Hydrochemical variation diagram of different water types or facies (Piper, 1944)

### 3.1 Groundwater Movement

The effect of bedrock surface on groundwater flow may be significant, especially in a shallow alluvial aquifer. The bedrock with a set of barriers either supports or impedes the water flow system. In North Eastern part of the study area (Gurusu), the regional groundwater flow direction is toward the North and North – West, acting as discharge point within the study area.

While at Tudunwada in South-West part of the map, the regional groundwater flow recognise is North – South, SW, and somewhat East – West and SE directions. Maitumbi area (NW) part of the map forms the watershed points, though it revealed some indication of localized recharge point. The major recharge flow directions is N – S and somewhat to the North – West direction. Likewise the eastern part to the extreme western portion of the location is discharging water in different structural orientation as shown in Figures 9 and 10

The groundwater flow is interrupted in many parts along Gurusu and Tudunwada course (NE and SE) respectively due to the presence of the basement rocks at and/or near the surface. This especially clear immediately upstream around Maitumbi village, where several igneous outcrops are encountered across the tributaries of River Gora channel. This groundwater flow to some extent is reflection of surface topography and drainage patterns, indicating that the river channels are structurally controlled.

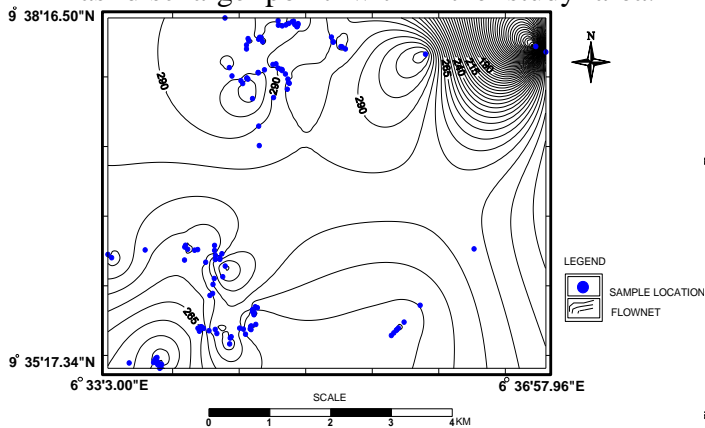


Figure 9: Vector Map of the Study Area

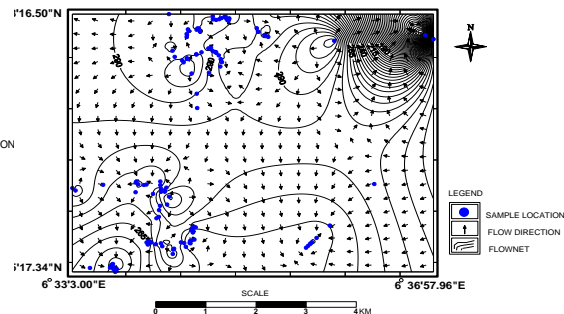


Figure 10: Flow Direction of the Study Area

#### 4.0 Conclusion

A hydrochemical analysis of groundwater is useful not only in determining the portability of groundwater, but also in understanding the hydrogeochemical characteristics of groundwater. The result revealed that the groundwater is of freshwater origin. The measured values of electrical conductivity are reflected in the low to intermediate concentration of salts and also in the medium grade of mineralization of these waters. Analytical result presents the abundance of these ions in the following order  $\text{Na}^+ > \text{Mg}^{+2} > \text{Ca}^{+2} > \text{K}^{+1} \rightarrow \text{Cl}^- > \text{SO}_4^{+2} > \text{HCO}_3^-$ . This revealed an apparent tendency for water in a flow system to shift their chemical characteristics from pure bicarbonate type toward the sulphate facies while moving to the area of upward flow. Comparison made from the geochemical maps indicate that high total dissolve solids occur at the discharge area and relatively the groundwater at various discharge point is older in age and has high residence time to that of water at the recharge area. Groundwaters in the study area are characterized by two main types of hydrochemical facies:  $\text{Na}^+ \text{K}^+ \text{Cl}^- \text{SO}_4^{+2}$  and  $\text{Ca}^{2+} \text{Mg}^{+2} \text{Cl}^- \text{SO}_4^{+2}$  water types which have tendency to dominate the Northern and the Southern parts, respectively. Prevailing climatic condition, anthropogenic effect, flow pattern of the aquifer and the lithological composition of the bedrock are the major hydro-environmental factors controlling the hydrochemistry and spatial hydrochemical evolution of groundwater in the study area. This research has shown that geospatial distribution of total dissolve solids concentration can be used to decipher groundwater flow pattern.

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