



## Mapping of Groundwater Facies using anion Geochemistry in Angware Area, JOS Northcentral Nigeria

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### Abstract

The use of anion geochemistry in mapping groundwater facies in Angware area was discussed. The objective of this work is to specially use only anion species to identify the facies present in the groundwater and the processes responsible for the modification of water chemistry in the area. 20 water samples were collected and analyzed using DR 2000 spectrophotometer and titrimetric method. The results indicated that pH range from 5.8 – 7.6 with an average of 6.5 while  $\text{HCO}_3^-$ ,  $\text{SO}_4^{2-}$  and  $\text{Cl}^-$  reveal values ranging from 19.6 mg/l – 318.4 mg/l, 0.1 mg/l – 6.0 mg/l and 1.1 mg/l – 28.4 mg/l with mean values of 74.8 mg/l, 1.4 mg/l and 7.5 mg/l, respectively.  $\text{CO}_3^{2-}$  was not detected in all the samples due to acidic to neutral pH condition. Based on the mean values, the anions were in the order of abundance as  $\text{HCO}_3^- > \text{Cl}^- > \text{SO}_4^{2-}$ . The study identified Bicarbonate-Chloride-Sulphate facies as the only facies-type which is an indication of recently recharged groundwater with limited rock-water interaction. The plot of  $\text{Cl}^-/\text{Cl}^- + \text{HCO}_3^-$  against LogTDS revealed precipitation induced chemical weathering along with dissolution of rock forming minerals.

**Key words:** Facies-type, mapping, groundwater, geology, weathering, angware.

### Introduction

Facies are identifiable parts of different nature belonging to any genetically related body or system<sup>1,2</sup>. Hydrogeochemical facies are distinct zones that have cation and anion concentrations describable within defined composition category. The chemical composition of groundwater is influenced by factors such as composition of precipitation, mineralogy of the aquifers, climate, topography and anthropogenic activities<sup>3,4</sup>. These factors can combine to create diverse water types that change in composition spatially and temporarily<sup>5,4</sup>. The use of major ions as natural tracers has become a common method to delineate flow paths in aquifers<sup>6</sup>. Generally, the approach is to divide the samples into hydro chemical facies which is groups of samples with similar chemical characteristics that can then be correlated with location. The observed spatial variability can provide insight into aquifer heterogeneity and connectivity, as well as the physical and chemical processes controlling water chemistry. The overall implication of this is that hydro geochemical facies of groundwater changes in response to its flow path. This also implies that mineralogical composition can exert important control on the final water chemistry<sup>7</sup>. So the quality of water is likely to change day by day from different sources<sup>8</sup>. Earlier studies on the characterization of groundwater facies and chemical evolutionary history utilized graphical<sup>9,10</sup>. These schemes were useful in visually describing differences in major ion chemistry in groundwater and classifying water compositions into identifiable groups<sup>11</sup>, which are usually of similar genetic history<sup>12</sup>. Domenico<sup>13</sup> specifies that hydrochemical facies can be studied in terms of anions or

cations or both, and Back<sup>6</sup> proposed a classification guide for defining different facies. Chebotarev<sup>14</sup> used anion species only and concluded that the composition of groundwater varies from bicarbonate at outcrops to sulphate water at intermediate depths to chloride at greater depths of continuous flow. The objective of this work is to specially use only anion species to identify the facies present in the groundwater and the processes responsible for the modification of water chemistry in Angware area.

**Geology of the Area:** The study area is Angware in Jos north central local government area. It is located between latitudes 9°58'N to 10°00'N and longitudes 9°05'E to 9°08'E, and covers an area of about 19.4Km<sup>2</sup> (figure 1). Water supply to the people of the area is from hand-dug wells, boreholes and surface water obtain from streams and ponds. These sources of water supply have questionable quality due to anthropogenic activities such as agricultural activities and indiscriminate waste disposal practice. The population of the area is about 2500<sup>15</sup>. The area falls within the Savannah wood land<sup>16</sup> with mean annual rainfall ranging from 1250 mm to 2500 mm<sup>17</sup>. The area is largely drained by River Saradam. The altitude of the area ranges from 100 m to 1500 m<sup>17</sup>.

The Plateau province is underlain by the younger granite suite, which includes granites, syenites and rhyolites<sup>16</sup> and met sediments and volcanic rocks of different petrology<sup>17</sup>. The study area lies within the Plateau province, and is underlain by the undifferentiated migmatites, hornblende-biotite granite porphyry and rhyolites (figure 2). The areas underlain by the undifferentiated migmatites are relatively flat, low lying and occur in massive forms. They are characterized by leucocratic

and melanocratic banding caused possibly by metamorphism. The mafic minerals are characterized by fine crystals while the felsic minerals have larger crystals. The phenocrysts of the feldspars range from 0.3 cm to 0.5 cm. The undifferentiated migmatites form the dominant rock types and covers extensive areas. Minerologically, the rocks consist of quartz, feldspars and mafic minerals. The hornblende-biotite granite porphyry occurs as elongate ridge with a relatively high topography of about 1234 m in the southern part of the study area. It is exposed in the north-eastern and northern parts of the study area. Minerologically, the rocks consist of hornblende, biotite, quartz and feldspars. The feldspars range in size from 1 cm to 1.6 cm and quartz phenocrysts range from 0.1 cm to 0.6 cm. The biotites are fine grain in texture and form the groundmass. The rhyolites outcrop in the northern part of the study area. It is extrusive in nature, and characterized by fine grain texture. It occurs at an elevation of about 1034 m. Figure 3 indicates that regional groundwater flow takes place from the recharge area at Saradam in the south, and flows towards Dan Kurma and Zangam in the southwest. Another flow zone takes place from Shere Jankasa in the northwest and flows towards the northern part of the study area. A minor recharge zone occurs between Rafin Sanyi and Lenge areas in the north and flows towards the north-eastern part. The major discharge area occurs between Anguwan Saradam and Angware areas. Shoeneich and Aku<sup>18</sup> identified two groundwater zones into fractured aquifer and soft overburden aquifer with yield exceeding 10 m<sup>3</sup>/hr. The soft overburden aquifer consists of clay lenses, sandy clay and gravels with effective porosity ranging from 2.0 to 2.5<sup>18</sup>. Bulus<sup>19</sup> carried out geophysical investigation in the area and discovered that most of the fractures vary between the depth ranges of 5 m to 25 m and are isolated fractures with average weathered overburden thickness of 19.4 m.

## Material and Methods

Twenty (20) water samples were collected consisting of 14 samples from the hand-dug wells and 6 samples from boreholes (figure 1). The samples were collected from existing wells use for water supply according to Chilton<sup>20</sup> method. All samples were filtered through 0.45 µm membrane filter immediately after sampling. Before the collection of the samples, pH determined in the field using pH meter (Wagtech), the sample containers were rinsed thoroughly with the water to be analyzed according to Matini et al<sup>21</sup> method. The chemical parameters consisting of SO<sub>4</sub><sup>2-</sup> was analyzed using flame photometer (ELE International), spectrophotometer (Model DR2000, USA). HCO<sub>3</sub><sup>-</sup>, CO<sub>3</sub><sup>2-</sup> and Cl<sup>-</sup> were analyzed using titrimetric method. The water samples were analyzed at the Acts laboratory, Canada. The results in milligram per litre were converted to milli equivalent per litre. The resulting values of HCO<sub>3</sub><sup>-</sup> + CO<sub>3</sub><sup>2-</sup> and Cl<sup>-</sup> + SO<sub>4</sub><sup>2-</sup> were then expressed as percentages of all anions. The resulting percentages were correlated with Back<sup>6</sup> standards to define the facies present in the groundwater. The direction of facies was then fitted into the facies types in the anion diamond shape proposed by Domenico<sup>13</sup> (figure 4). To determine the

processes influencing the groundwater chemistry LogTDS was plotted against Cl<sup>-</sup>/Cl<sup>-</sup> + HCO<sub>3</sub><sup>-</sup> according to Gibbs<sup>22</sup> procedure.

## Results and Discussion

The results of anions expressed in milligram per litre are presented in table 1 and table 2 contains the concentrations of anions expressed in milliequivalent per litre. Table 1 indicates that pH values range from 5.8 -7.6 with an average of 6.5 indicating acidic to neutral condition. Most samples indicate acidic condition with 4 samples (Hw5, Hw6, Hw9 and Hw10) reveal neutral conditions. Bicarbonate concentrations range from 19.6 mg/l to 318.4 mg/l with a mean value of 74.8 mg/l. The presence of HCO<sub>3</sub><sup>-</sup> is influenced by the pH conditions of the groundwater system. Below pH of 8.2, HCO<sub>3</sub><sup>-</sup> forms CO<sub>3</sub><sup>2-</sup> by addition of H<sup>+</sup>. The maximum pH recorded from all the samples was 7.6 and this favours the formation of HCO<sub>3</sub><sup>-</sup>. Carbonate ion range from 0.04 mg/l to 0.08 mg/l with mean value of 0.04 mg/l. Carbonate ion was detected at low concentrations in all the samples. The low concentration of carbonate ion could be to the acidic to neutral pH conditions. The pH condition therefore does not favour the formation of CO<sub>3</sub><sup>2-</sup> at high concentrations by the dissociation of HCO<sub>3</sub><sup>-</sup>. Davis and Dewiest<sup>23</sup> indicates that dissociation of HCO<sub>3</sub><sup>-</sup> to form CO<sub>3</sub><sup>2-</sup> occurs largely above pH of 8.2, below this pH, most of CO<sub>3</sub><sup>2-</sup> add H<sup>+</sup> to form HCO<sub>3</sub><sup>-</sup> through the following equation; H<sup>+</sup> + CO<sub>3</sub><sup>2-</sup> = HCO<sub>3</sub><sup>-</sup> (1)

Chloride concentrations range from 1.1 mg/l to 28.4 mg/l with an average of 7.5 mg/l. The detection of chloride in all the samples is favoured by the conservative nature of chloride. Sulphate reveals values ranging from 0.1 mg/l to 6.0 mg/l with mean value of 1.4 mg/l. Although sulphate occurs in all the samples, the concentrations were low, and this could probably be due to sulphate reduction. According to Domenico<sup>13</sup> that sulphate reduction accounts for diminishing concentrations of sulphate in groundwater. Based on mean values of the anions, the anions occur in order of abundance as HCO<sub>3</sub><sup>-</sup> > Cl<sup>-</sup> > SO<sub>4</sub><sup>2-</sup>.

**Hydrogeochemical facies:** Using the Back<sup>6</sup> standards in table 3 indicates the dominance of Bicarbonate-Sulphate-Chloride facies as the only facies-type (table 4) embedded in the groundwater of the study area. Based on Chebotarev<sup>14</sup> well-known sequence which states that groundwater composition evolves towards the composition of sea water through the following equation;

Travel path →  
HCO<sub>3</sub><sup>-</sup> → HCO<sub>3</sub><sup>-</sup> + SO<sub>4</sub><sup>2-</sup> → SO<sub>4</sub><sup>2-</sup> + HCO<sub>3</sub><sup>-</sup> → SO<sub>4</sub><sup>2-</sup> + Cl<sup>-</sup> → Cl<sup>-</sup> + SO<sub>4</sub><sup>2-</sup> (2)  
Increasing age →

Chebotarev<sup>14</sup> further states that the composition of groundwater varies from bicarbonate at outcrops to sulphate at intermediate depths to chloride at greater depths. It can be concluded from the above consideration that the dominance of Bicarbonate-Sulphate-Chloride type facies identified in the groundwater of the study are indicates recently recharge groundwater with short

rock-water interaction and occurs at shallow depth. When the facies is fitted into the anion diamond field of Domenico<sup>13</sup> (figure 4) indicates no facies change in the groundwater (figure 5) which further buttress that the groundwater occurs at shallow depth and experienced limited mixing with the host rock.

**Sources of variation in the Hydro geochemistry of groundwater from the study area:** The plots of  $Cl/Cl + HCO_3^-$  against  $\log TDS$  indicates that the sample points plotted in the region of rock dominance and weathering zone (figure 6) suggesting precipitation induced chemical weathering along with dissolution of rock forming minerals.

## Conclusion

The following conclusions can be drawn from this study as follows; the presence of  $HCO_3^-$  in the groundwater is due to acidic to neutral pH condition. Low concentration of  $SO_4^{2-}$  could be attributed to sulphate reduction. The low concentration of  $CO_3^{2-}$  could be attributed to acidic to neutral pH condition. The results of the anions indicated that the anions were in the order of abundance as  $HCO_3^- > Cl > SO_4^{2-}$  based on their mean values.  $CO_3^{2-}$  was not detected due to acidic to neutral pH condition. The study identified Bicarbonate-Chloride-Sulphate facies-type which is an indication of recently recharged groundwater with short rock-water interaction. The plot of  $Cl/Cl+HCO_3^-$  against  $\log TDS$  revealed precipitation induced chemical weathering along with the dissolution of rock forming minerals.

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**Table-1**  
**Anion concentrations and pH values for groundwater samples**

Sample location	Sample No.	pH	HCO <sub>3</sub> <sup>-</sup> mg/l	CO <sub>3</sub> <sup>2-</sup> mg/l	SO <sub>4</sub> <sup>2-</sup> mg/l	Cl <sup>-</sup> mg/l
Rafin Sanyi	BH1	6.4	89.6	0.06	1.5	10.6
Angware	BH2	5.8	63.3	0.08	1.0	7.2
Angware	BH3	6.2	62.2	0.07	1.0	7.2
Angware	BH4	5.8	73.2	0.05	1.0	8.1
Shere Jankasa	BH5	6.1	312.7	0.06	1.0	28.4
Gurgu	BH6	5.9	40.1	0.06	1.0	6.1
Rafin Sanyi	Hw1	6.1	68.2	0.07	0.5	7.1
Angware	Hw2	6.5	65.4	0.08	3.5	7.2
Angware	Hw3	6.9	64.6	0.08	1.0	7.5
Shere Jankasa	Hw4	6.1	318.4	0.07	1.0	28.4
Zangam	Hw5	7.6	64.1	0.07	1.0	7.6
Zangam	Hw6	7.6	67.5	0.08	0.1	6.5
Zangam	Hw7	6.1	41.6	0.07	0.5	4.3
Gurgu	Hw8	6.1	28.7	0.08	1.5	3.5
Saradam	Hw9	7.5	24.1	0.06	6.0	1.6
Saradam	Hw10	7.6	19.6	0.07	1.7	1.3
Saradam	Hw11	6.7	21.4	0.05	1.5	1.1
Saradam	Hw12	6.8	24.4	0.04	1.0	1.3
Dan Kurma	Hw13	6.3	24.4	0.06	1.0	2.4
Lenge Lenge	Hw14	Nil	21.6	0.06	1.2	2.6

**Table- 2**  
**Anions concentrations in meq/l for groundwater samples**

Location	Sample No.	SO <sub>4</sub> <sup>2-</sup>	CO <sub>3</sub> <sup>2-</sup>	HCO <sub>3</sub> <sup>-</sup>	Cl <sup>-</sup>	Total
Rafin Sanyi	BH1	0.03123	0.0019998	1.468544	0.29892	1.8006938
Angware	BH2	0.02082	0.0026664	1.037487	0.20304	1.2640137
Angware	BH3	0.02082	0.0023331	1.019458	0.20304	1.2456511
Angware	BH4	0.02082	0.0016665	1.199748	0.22842	1.4506545
Shere Jankasa	BH5	0.02082	0.0019998	5.125153	0.80088	5.9488528
Gurgu	BH6	0.02082	0.0019998	0.657239	0.17202	0.8520788
Rafin Sanyi	Hw1	0.01041	0.0023331	1.117798	0.20022	1.3307611
Angware	Hw2	0.07287	0.0026664	1.071906	0.20304	1.3504824
Angware	Hw3	0.02082	0.0026664	1.058794	0.2116	1.2938804
Rafin Sanyi	Hw4	0.02082	0.0023331	5.218576	0.80088	6.0426091
Zangam	Hw5	0.02082	0.0023331	1.050599	0.21432	1.2880721
Zangam	Hw6	0.002082	0.0026664	1.106325	0.1833	1.2943734
Zangam	Hw7	0.01041	0.0023331	0.681824	0.089526	0.7840931
Gurgu	Hw8	0.03123	0.0026664	0.470393	0.0987	0.6029894
Saradam	Hw9	0.12492	0.0019998	0.394999	0.04512	0.5670388
Saradam	Hw10	0.035394	0.0023331	0.321244	0.03666	0.3956311
Saradam	Hw11	0.03123	0.0016665	0.350746	0.03102	0.4146625
Saradam	Hw12	0.02082	0.0013332	0.399916	0.03666	0.4587292
Dan Kurma	Hw13	0.02082	0.0019998	0.399916	0.06768	0.4904158
Lenge lenge	Hw14	0.024982	0.0019998	0.354024	0.07332	0.4543278

BH=Borehole, Hw=Hand-dug well

**Table- 3**  
**Classification of hydro geochemical facies**

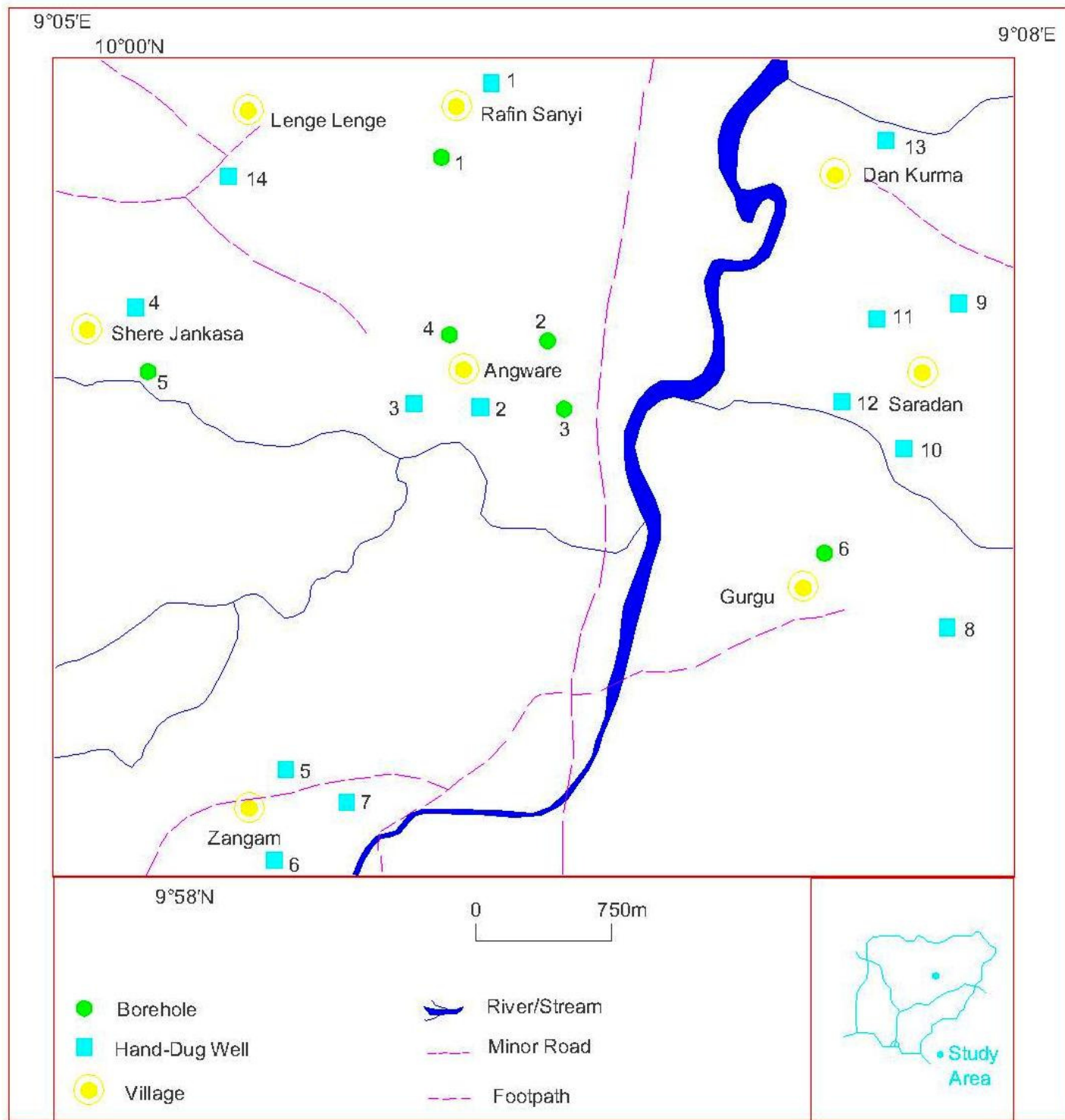
	Percentage of Constituents, epm			
	Ca + Mg	Na + K	HCO <sub>3</sub> <sup>-</sup> + CO <sub>3</sub> <sup>2-</sup>	Cl + SO <sub>4</sub> <sup>2-</sup>
<b>Cation facies:</b>				
Calcium-Magnesium	90-100	0< 10		
Calcium-Sodium	50-90	10< 50		
Sodium-Calcium	10-50	50< 90		
Sodium-Potassium	0-10	90-100		
<b>Anion facies:</b>				
Bicarbonate			90-100	0< 10
Bicarbonate-Chloride-Sulphate			50-90	10< 50
Chloride-Sulphate-Bicarbonate			10-50	50<90
Chloride-Sulphate			0-10	90-100

(Back, 1966)

**Table- 4**  
**Values of HCO<sub>3</sub><sup>-</sup> + CO<sub>3</sub><sup>2-</sup> and Cl + SO<sub>4</sub><sup>2-</sup> as percentages of all Anions for groundwater samples**

Location	Sample No.	HCO <sub>3</sub> <sup>-</sup> + CO <sub>3</sub> <sup>2-</sup>	Cl + SO <sub>4</sub> <sup>2-</sup>	Facies type
Rafin Sanyi	BH1	81.665	18.335	Bicarbonate-chloride-sulphate
Angware	BH2	82.290	17.710	Bicarbonate-chloride-sulphate
Angware	BH3	82.029	17.971	Bicarbonate-chloride-sulphate
Angware	BH4	82.819	17.181	Bicarbonate-chloride-sulphate
Shere Jankasa	BH5	86.187	13.813	Bicarbonate-chloride-sulphate
Gurgu	BH6	77.368	22.632	Bicarbonate-chloride-sulphate
Rafin Sanyi	Hw1	84.172	15.828	Bicarbonate-chloride-sulphate
Angware	Hw2	79.570	20.430	Bicarbonate-chloride-sulphate
Angware	Hw3	82.037	17.963	Bicarbonate-chloride-sulphate
Rafin Sanyi	Hw4	86.402	13.598	Bicarbonate-chloride-sulphate
Zangam	Hw5	81.745	18.255	Bicarbonate-chloride-sulphate
Zangam	Hw6	85.678	14.322	Bicarbonate-chloride-sulphate
Zangam	Hw7	87.255	12.745	Bicarbonate-chloride-sulphate
Gurgu	Hw8	78.452	21.548	Bicarbonate-chloride-sulphate
Saradam	Hw9	70.031	29.987	Bicarbonate-chloride-sulphate
Saradam	Hw10	81.788	18.212	Bicarbonate-chloride-sulphate
Saradam	Hw11	84.988	15.012	Bicarbonate-chloride-sulphate
Saradam	Hw12	87.470	12.530	Bicarbonate-chloride-sulphate
Dan Kurma	Hw13	81.954	18.046	Bicarbonate-chloride-sulphate
Lenge lenge	Hw14	78.363	21.637	Bicarbonate-chloride-sulphate

BH= Borehole, Hw= Hand-dug well



**Figure-1**  
Location map of the study area

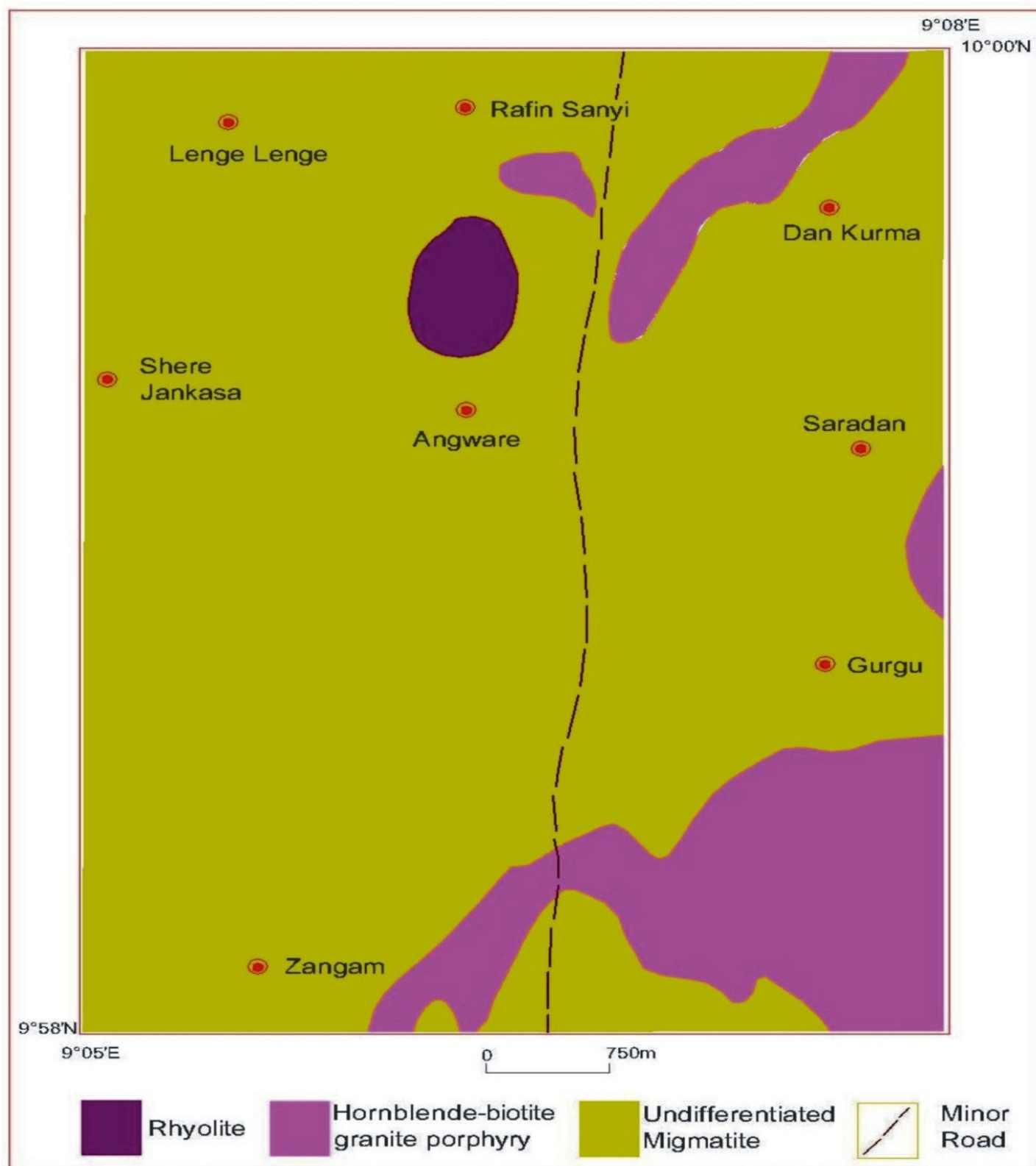
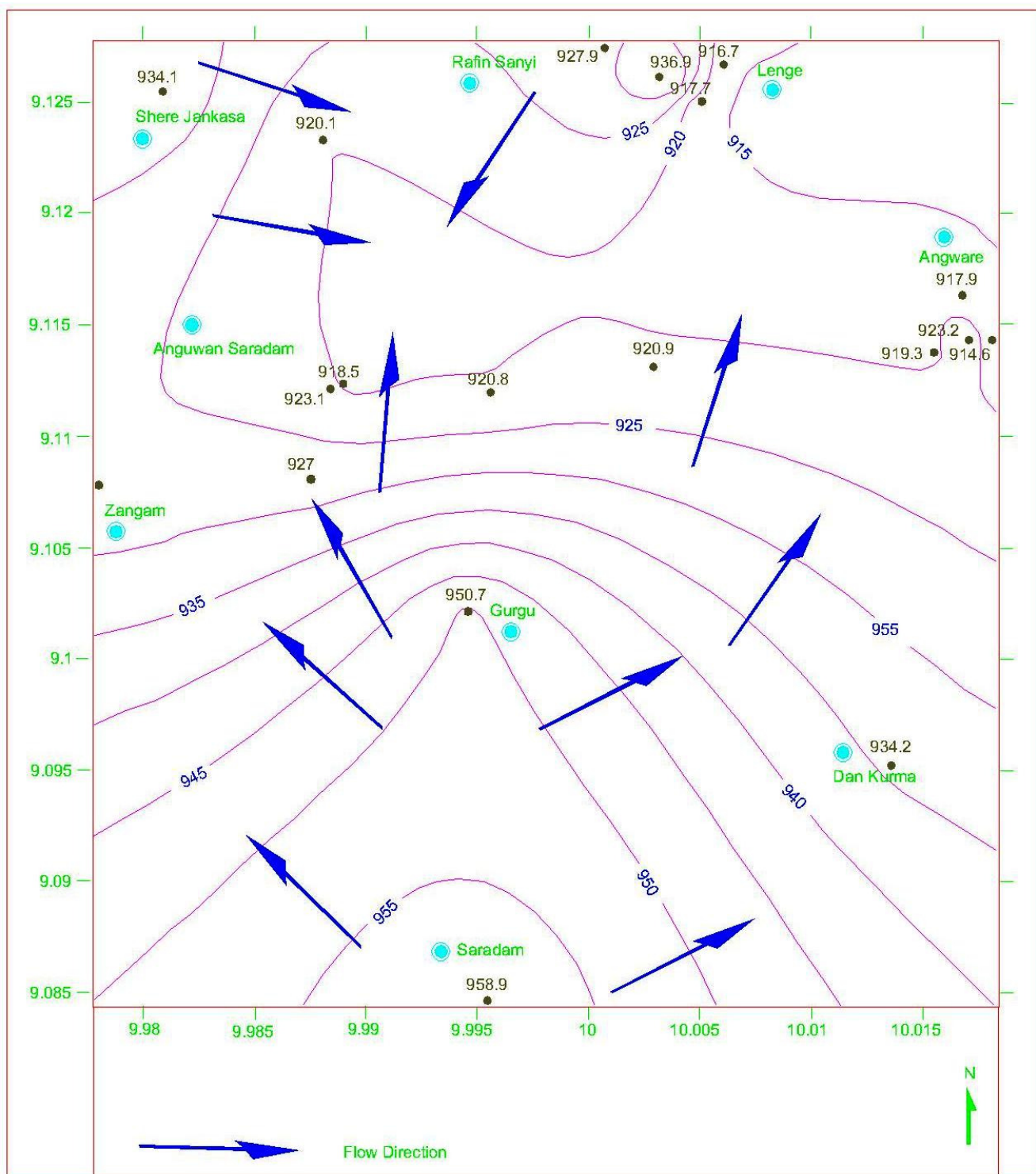
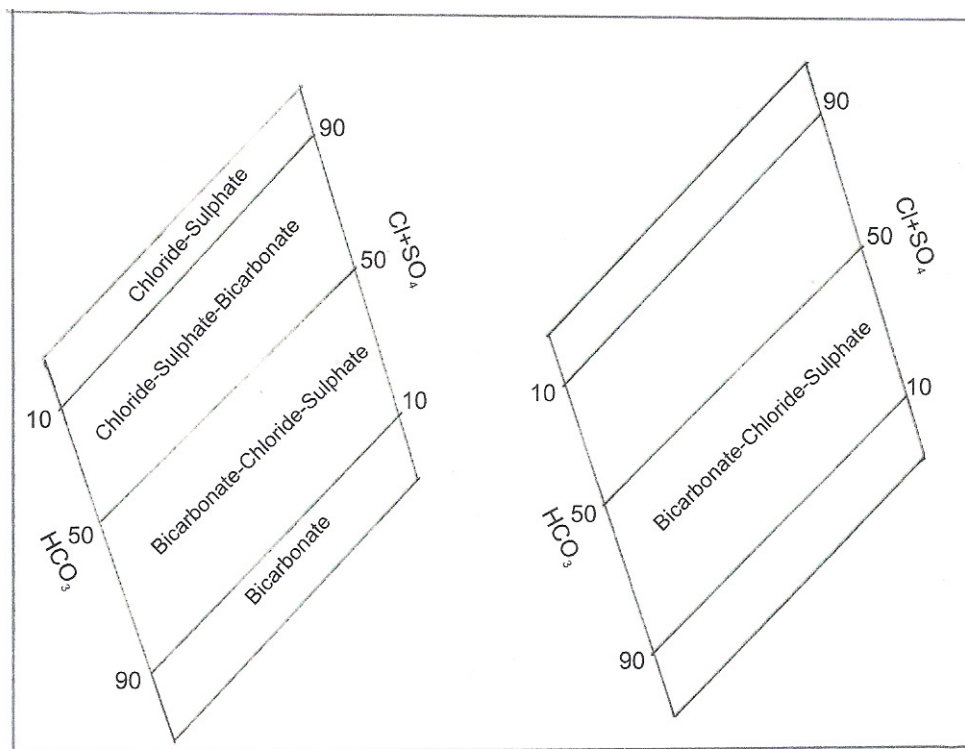


Figure-2  
Geologic map of the study area



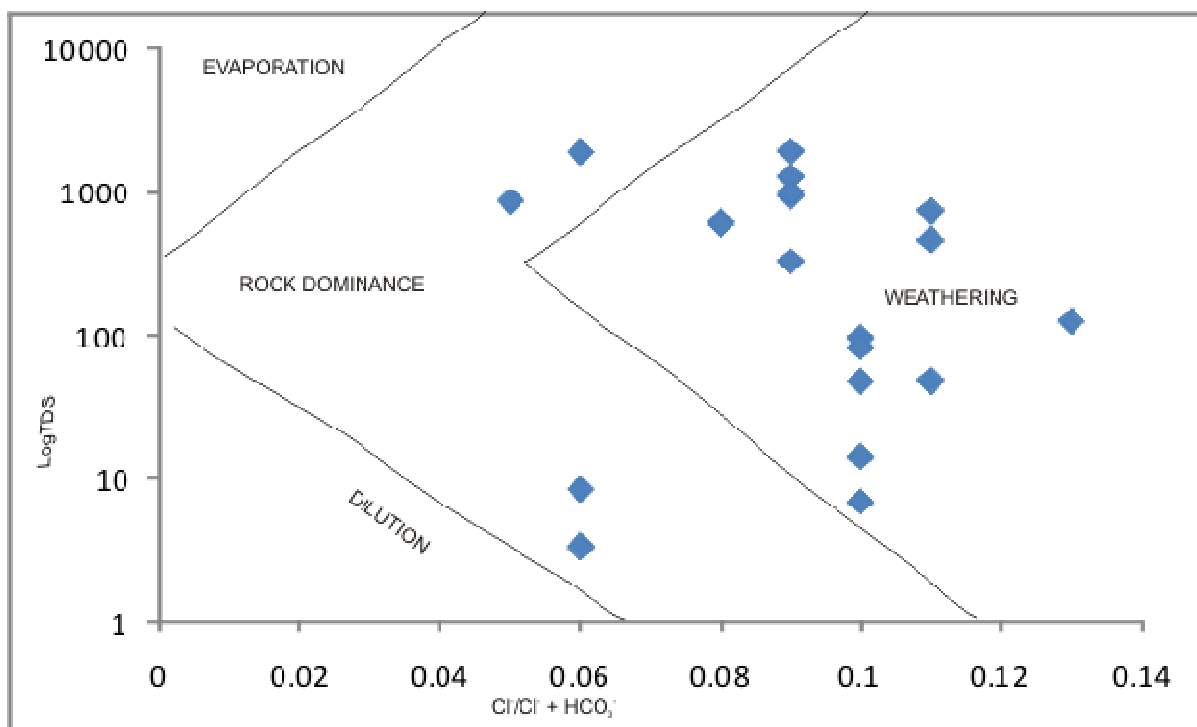
**Figure-3**  
**Hydraulic head distribution in unconfined aquifer**





**Figure-4**  
 Nomenclature for hydrogeochemical  
 Facies

**Figure-5**  
 Anion facies in groundwater of  
 the study area



**Figure-6**  
 Plot of log TDS versus  $Cl/(Cl + HCO_3^-)$  of groundwater in the study area