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Hydrochemical Characteristics of Groundwater at Northeast Atbara Town, Nile River State, Sudan

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Abstract – **This paper emphasized on the hydrochemistry of ground water as it is vulnerable resources to many environmental risks and is essential to sustainable development. The main objectives in this study are to evaluate quantitatively the concentration of chemical species and determine the causes and sources of chemical hazards in the study area. Generally, there are two types of water-bearing formation in the study area namely; the alluvial deposits and Cretaceous sedimentary formation. Numbers of groundwater samples were collected and analyzed for hydrochemistry, using the standard laboratory methods. ArcGIS software is used for spatial data visualization. Aquachem and SPSS softwares were used for chemical facies classification and statistical analyses respectively. Most of chemical species concentration of groundwater are within the permissible limits of local and international (WHO) standards with the exception of small pockets at the center and southeast of the study area where high ion concentrations and salinity hazards were detected. Spearman's correlation reflects significance correlation of total hardness with bicarbonate , sulfate & magnesium and TDS with magnesium & bicarbonate and sulfate with chloride and Calcium with potassium. Four hydrochemicalfacies were perceived in the area namely; Ca-Na-Mg-HCO_3, Na-HCO_3, Na-Ca-HCO_3-Cl, Na-Mg-Cl-HCO_3-SO_4 -water types**

Keywords - **Chemical Species, Groundwater, Hardness, Ion-Concentration, Leaching Process, Salinity.**

I. Introduction

Groundwater flow influences hydrochemical patterns as a result of leaching mechanism from recharge to the discharge areas of the aquifer system. In all represented cases, groundwater is the main geological agent for transmitting, accumulating, and discharging salt. Leaching processes vary from one location to another [1,2&3]. Motion of groundwater along its flow paths below the ground surface increases the concentration of the chemical species [4]. Groundwater chemistry could reveal important information on the geological history of the aquifers and the suitability of groundwater for domestic, industrial and agricultural purposes. Groundwater typically has a large range in chemical composition [5,6&7]. Hydrochemical characteristics of the groundwater system has become more meaningful integral part of hydrogeology and important indication of the geological history of the enclosing rocks and direction of groundwater movement[8]. Water hydrochemistry proved to be essential in understanding the origin of chemical composition of groundwater and flow mechanism and the distribution of ground water types that controlled by the properties of rock through which it has passed[9]. Care must be taken to distinguish what is the natural background in relation to change of the water quality, which has taken place in response to intensive exploitation, agricultural development and industrial activities. Therefore, the groundwater should be protected from, pollution or any degradation. This paper emphasized on the hydrochemistry of ground water as it is vulnerable resources to many environmental risks and is essential to sustainable development.

II. The Study Area

Study area lies between latitudes 17˚ 34’ -18˚ 00’ N and longitudes 33˚ 55’ – 34˚ 43’ E covers an area of about 673 Km^2 (Fig. 1). It is extremely flat, gently dipping to the northwest. Sand dunes and low ridges with thin blanket cover of scatter cobble, pebbles and boulders characterize the undulated surface of the area. The area lies in semi desert climate with long summer and low rainfall intensity (84 mm/year) and cold dry winter. River Nile and Atbara river and seasonal wades (e.g. WadyMukabrab) are the main drainage system [10].

The main geological units are composed of Basement Complex (Pre-Cambrian), upper Cretaceous Sedimentary Formation (Nubian sandstone), HudiChert (Oligocene) and Quaternary superficial deposit (Fig. 2) in ascending chronological order [10].

The basement complex is composed of highly deformed metasedimnts and multi metamorphosed gneisses and schist, characterized by different types of structure and fracture systems. The Basement rocks are unconformable overlain by Cretaceous sedimentary formation of continental origin [11&12]. Cretaceous sedimentary formation is mainly composed of sandstone, conglomerates intercalated by gravel, grits, iron-shale and mudstone [10]. These formations appear as an escarpment and isolated scattered inselbergs. Along river Atbara the Cretaceous sedimentary formations are characterized by thick layers of mudstone (300 m). HudiChert (Tertiary) formation occurs as fossileferrous (Gastropods) boulders mixed with quartz pebbles of gravelly and breccias form, consisting of cherty deposits or as bedded strata. The HudiChert rock overlying the Nubian sandstone formation covering large area in the southeast of the area at eastern bank of Atbara river near Elnikhela villages. Superficial deposits include dark clays and silt of the river terraces and unconsolidated layers of gravel, sand, silt and clays with kanker nodules as well as extensive sand dunes at southern part of the River Atbara . The top surface blanket in the study area consist of fluvial and lacustrine facies. There are two aquiferous zones in the study area namely; alluvial (recent deposits) and Cretaceous sedimentary (Nubian sandstone) aquifers. The former one consists of pebbles, gravels, sands, silts and clays as well as kanker nodules in the most-top of the aquifer zone. It is an unconfined with high permeability and good water quality.

The Cretaceous sedimentary aquifer, forming the lower aquifer zone, is characterized by good hydraulic properties and fresh water quality, except at the central part of the study area where poor hydraulic conductivity and bad water quality were encountered, confirming the poor interaction between surface water and ground water. The aquifers are partially hydraulically interconnected. The thickness of water potential zones vary between 90 to 220 m

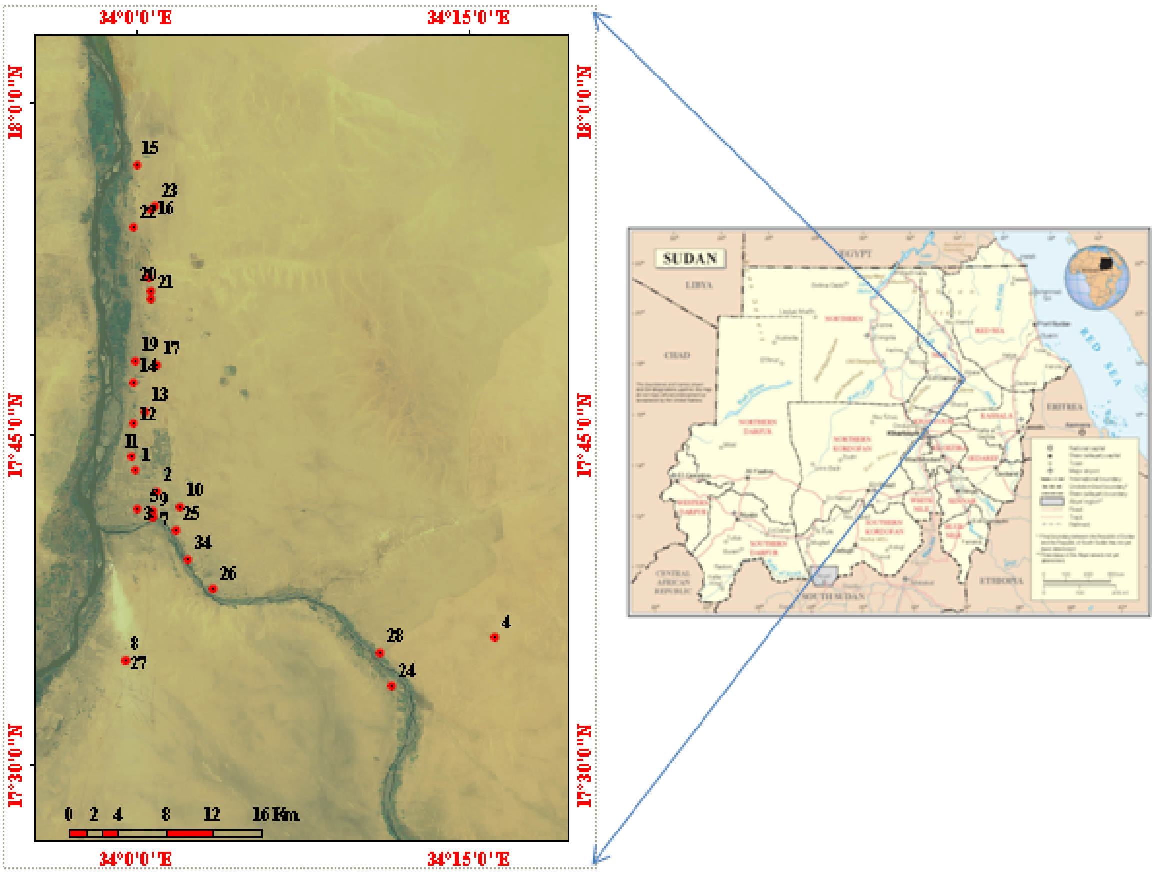

Fig.1. Location map of the study area with well sites

II. Methodology

The collected groundwater samples were analyzed for the major ion chemistry in the Water Research Central Laboratories (WRCL), using the standard methods. Electric conductivity (EC) and hydrogen ion concentration (pH) were measured immediately at the field site, using portable Orion EC- and pH -meters. Total dissolved solids (TDS) were measured by sample evaporation techniques. Bicarbonate (HCO-3) was estimated by titration with HCl acid. Total hardness (TH) and calcium (Ca^{2+}) were analyzed titrimetrically. Sodium (Na^{+}) was analyzed by flame photometry. Chloride (Cl^{-}) was estimated by titration with AgNO3. The analytical precision for the measurements of cation-anion is indicated by ionic balance error, which is observed to be within the stipulated limit of 5%. All values were in milligram per liter (mg\l) unless otherwise indicated. The hydrochemical characteristics of groundwater in the study area were summarized in table 1**.** ArcGIS software was used for spatial data visualization. Aquachem and SPSS softwares were used for chemical facies classification and statistical analyses respectively.

III. Physicochemical Characteristics of Groundwater

Electrical conductivity (EC) is an important water quality factor and it is a good indicator for water salinity. It ranges between 275.3 to 1054 with mean value of 574.3 µS/cm. Hence, water quality is seemed to be fresh with few pockets indicating high EC values and may be ascribed to the mudstone layers and kanker nodules at shallow depths. Concentration of the *total dissolved solids*(TDS) in the study area ranges between 192 to 684.8 mg/l with mean value of 373.31 mg/l. High salinity was detected at shallow depths and small pockets at south east of study area (Wells No.; **4, 24, 26** and **28**, Figure1). This can be explained as a result of leaching process of the infiltrated rainwater, mudstone layers and weathering product of shallow basement rocks.

Generally,*total hardness*(TH) ranges between 62 to 179.2 mg/l with a mean value of 171.43 mg/l. High values of hardness were recorded at the south east part of the area along Atbra river (Wells No. **4, 24, 26** and **28**, Figure1). This may ascribed to the presence of metasediments (Marble) and dolomitic rocks within the aquifer material.

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Major cations and anions

Major cations and anions (Na^{+}, K^{+}, Ca^{2+} Mg^{2+}, HCO_3-, CO_3^{2-}, SO_4^{2-} and Cl^{-}) were determined (Table 1). *Calcium* concentration ranges between 1.0 to 377.08 mg/l with man value of 135.57 mg/l (Table 1). Calcium concentration reflects relatively high values at the south east(wells No. 4, 24 & 28 Figure1) and the central part of the area along Atbara river (Wells No. 10& 25; Figure1) and may be attributed to the presence of meta sediments(marble) and cancerous sandstone of Cretaceous Sedimentary Formation.

Sodium concentration ranges from 24 to 202.97 mg/l with mean value of 86.2 mg/l. Relatively high values were visualized in the North(Well No. 16 Figure1) and southeastern part of the area (well No.24 Figure 1) which may be ascribed to ion-exchange processes and mudstone lenses within aquifer material. *Magnesium and potassium* (K) concentrations range from 4.91-77.92 mg/l and 1.32-17.72 mg/l with mean values of 29.97 and 4.94 respectively and they are within the permissible limits of water standards (table 1). They show usual distribution in fresh groundwater environments. The major ion chemistry data revealed that Ca and Na are the most predominant cationic constituents followed by Mg. *Bicarbonate*(HCO_3) is predominant anion in most groundwater samples and ranges from 51 to 476 mg/l (Table 1). Very high bicarbonate concentrations were recorded at the north (Well No. 16), central part (Wells No. 2, 26 & 34 Fig.1) and as small pockets at southeast along River Atbara (Wells No. 24 Figure 1). This is attributed to presence of dolomitic deposits and ion-exchange within calcareous sedimentary deposits in the aquifer. *Sulfate* (SO_4), contributes the major part of permanent hardness and it ranges between 2 to 142 mg/l with mean value of 27.07 (Table 1). High values of sulfate (SO_4) were perceived at the central part of the area (Well No. 2, Fig. 1). This is ascribed to the dissolution of gypsum and other Sulphide deposits. *Chloride* concentration ranges between 4 to 195 mg/l with mean value of 33.34 mg/l (Table 1) and it is within the permissible limits of local and international water standards. For the major anions (SO_4, Cl, and HCO_3), the bicarbonate and sulfate are found to be the most predominant anions followed by chloride.

Table 1: Chemical analysis data of groundwater in the study area

Well No.	pH	EC µS/cm	TDS	TH	HCO_3^-	CO_3^{--}	Cl^-	SO_4^{--}	Na^+	K^+	Mg^{+2}	Ca^{+2}
			mg/l									
2	8.4	441.5	287	312	239.12	44.4	195.25	142	161	1	44.7	51.2
4	7.4	521.8	339.2	86	102.48	12.2	32	2	58.47	12.27	19.89	230.45
6	7.9	715.1	464.8	234	183	1	76.7	63	42	1	39.36	28
8	8.4	275.7	179.2	120	56.12	7.32	10	12	69.69	7.73	11.21	25.25
10	7.6	600.6	390.4	118	70.76	4.88	12	4	71.75	10.58	35.61	377.08
16	8.3	715.1	464.8	179.2	475.8	6.6	62.48	37	201.3	1	20.7	37.6
18	7.5	773.8	503	238	422	1	31	42	73	1	47	46
20	6.9	463.1	301	62	183	1	35.5	21	105.8	1	4.91	16.8
24	8.3	1054	684.8	140	90.28	9.76	26	6	202.97	17.76	35.84	245.2
25	7.8	403.7	262.4	148	78.08	7.32	4	4	34.7	10.7	40	346.73
26	7.1	627.7	408	198	280.6	1	34.1	38	54	1	24.9	38.4
27	7.6	295.4	192	110	51.24	9.76	16	10	24.28	1.32	2.15	18.2
28	7.5	738.5	480	158	87.84	2.44	8	8	40.3	3.77	31.3	365.21
29	8.1	390.2	253.6	100	70.76	9.76	10	2	116.24	3.2	23.58	164.83
30	7.6	403.7	262.4	160	82.95	9.76	10	4	84.19	9.76	25.63	176..27
31	7.5	398.2	258.8	140	82.96	12.2	10	4	93.43	4.33	13.3	197.22
32	7.5	713.8	464	278	305	1	28.4	75	40	1	46.1	36
33	7.3	905.8	588.8	270	122	12.2	22	4	99.58	4.47	77.92	346.66
34	8.01	474.9	308.7	206	256.2	1	9.94	36	65	1	25.4	4
Mean	**7.72**	**574.3**	**373.31**	**171.43**	**170.54**	**8.08**	**33.34**	**27.05**	**86.20**	**4.94**	**29.97**	**135.57**
Std. Dev.	**0.44**	**211.1**	**137.18**	**69.77**	**127.01**	**9.84**	**43.56**	**35.43**	**52.49**	**5.04**	**17.71**	**140.84**
Minimum	**6.90**	**275.3**	**179.20**	**62.00**	**51.24**	**.00**	**4.00**	**2.00**	**24.28**	**1.00**	**2.15**	**1.00**
Maximum	**8.40**	**1054**	**684.80**	**312.00**	**475.80**	**44.40**	**195.25**	**142.00**	**202.97**	**17.76**	**77.92**	**377.08**

Table 2: Spearman's correlation coefficient matrix of analyzed ions. Bold values are significant correlations at a level <0.05.

	EC	TDS	TH	HCO_3^-	Cl^-	SO_4^{--}	Na^+	K^+	Mg^{+2}	Ca^{+2}
EC	1									
TDS	**1**	1								
TH	0.469	0.469	1							
HCO_3^-	**0.610**	**0.610**	**0.646**	1						
Cl^-	0.351	0.351	0.262	**0.610**	1					
SO_4^{--}	0.262	0.262	**0.645**	**0.677**	**0.570**	1				
Na^+	0.154	0.154	-0.023	0.184	0.305	-0.088	1			
K^+	-0.109	-0.109	-0.486	-0.681	-0.498	-0.810	0.021	1		
Mg^{+2}	**0.612**	**0.612**	**0.756**	0.377	0.092	0.257	0.005	-0.044	1	
Ca^{+2}	0.353	0.353	-0.070	-0.191	-0.196	-0.439	0.056	**0.520**	0.382	1

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The correlation coefficient matrix between the analyzed ions, were calculated using linear regression analysis (Table 2). As a result the correlation between total hardness (TH) with HCO_3, SO_4 and Mg showed significance correlation (TH-HCO3, r = 0.646; TH-SO4, r = 0.645 and TH-Mg, r = 0.756; with p <0.05); reflects an indication of both temporal and permanent hardness of groundwater. Within the major cations the TDS is only significantly correlated with Mg (TDS-Mg, r=0.612 with p< 0.05) and only significantly correlated with bicarbonate (TDS-HCO3, r=0.610 with p< 0.05) within the major anions. Calcium is significantly correlated with potassium (Ca-K, r=0.52 with p < 0.05). Sulfate is significantly correlate with chloride (r = 0.570) indicating dissolution of these ions from pyritic rocks within the basement rocks at shallow depths of the saturated zones.

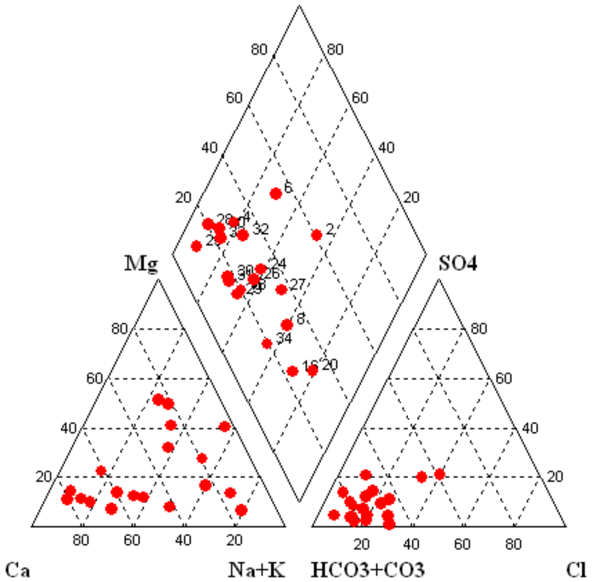

Fig.2. Piper diagram of groundwater samples in the study area

The Piper plot has been a traditional method of classification in the study of hydrochemistry [13&14]. Piper method has limited usage because of the selection of available parameters (Ca, Mg, Na, K) HCO_3, Cl, and SO_4) and an arbitrary choice of classification limits [15]. Ionic concentrations in the study area were plotted in a Piper diagram (Figure2)[16&17]to evaluate the geochemical characteristics of the sampled groundwater. Accordingly, groundwater is classified as Ca-Na-Mg-HCO_3, Na-HCO_3, Na-Ca-HCO_3-Cl, Na-Mg-Cl-HCO_3-SO_4 -water types . However, the classification based on the limits within the Piper diagram (Figure2), generated a markedly different grouping or zonation from the results of the analyses. Groundwater is significantly dominated by alkaline–earth cations (Ca^{2+} and Mg^{2+}) over alkali (Na^+ and K^+) reflecting the geochemical media, metasediments terrain. Weathering of this rocks results in the release of Calsium and magnesium from dolomite and magnesite into the environment. On the other hand, the position of the groundwater in the anions triangle indicates dominance of HCO^-_3 and CO^{--}_3.

IV. Conclusion

Most of chemical species concentration of groundwater in the study area are within the permissible limits of local and international (WHO) standards with the exception of small pockets at the center and southeast of the study area where high ion concentration and salinity hazards were detected. Correlation between total hardness (TH) with HCO_3, SO_4 and Mg showed significance correlation reflects a prevalence of both permanent and temporal hardness. Sulfate is significantly correlated with chloride indicating dissolution of these ions from pyritic rocks within the basement at shallow depths in the saturated zones. Calcium is significantly correlated with potassium (Ca-K, r=0.52 with p < 0.05)

Four hydrochemicalfacies were detected in the area namely;Ca-Na-Mg-HCO_3, Na-HCO_3, Na-Ca-HCO_3-Cl, Na-Mg-Cl-HCO_3-SO_4 -water types.

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