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GROUNDWATER QUALITY ASSESSMENT IN THE RIVER ATBARA ALLUVIAL SEDIMENTS, EASTERN SUDAN

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Abstract: According to the standard rates for water testing, 45 wells were sampled and analyzed to evaluate and assess the groundwater chemistry, classify the hydrochemical facies, and identify the sources of salinity in the study area. The main constituents determined included Sodium, Potassium, Chloride, Sulfate, Magnesium, Calcium, Nitrate, and Bicarbonate. Electrical conductivity, Total Dissolved Solids, Total and Excess Alkalinity, and pH were measured on-site during field trips. Using Piper's diagram, chemical information was utilized to identify the groundwater's chemical facies. Despite most chemical concentrations being within the Sudanese Standards and Metrology Organization (SSMO) and World Health Organization (WHO) standard limits, salinity hazards were observed in the middle part of the study area, such as in Shaoat Sherg, Almugatah Shreg, and Umm Oud villages, attributed to the concentration of sodium and chloride in basaltic rocks. The dissolved solids in the study area ranged between 200 to 800 mg/L. The values of calcium ranged between 6.4 to 90 mg/L. The magnesium ion concentration ranged between 4.8 and 90 mg/L. The sodium concentration ranged between 7 and 420 mg/L. The concentration of chloride ranged between 6 and 1098 mg/L. Potassium ranged between 1.2 and 46 mg/L. The concentration of bicarbonate ranged between 78 and 793 mg/L. The sulfate concentration ranged between 0.5 and 508 mg/L. The nitrate (NO_3^-) concentration was found to be very small. Based on Piper's diagram, the samples resulted in 60% being mixed groundwater type and 40% being Na-HCO_3, Na-Cl, and Ca-Mg-HCO_3 groundwater types. Most samples were deemed good for human and agricultural use. Only nine were found to be above the recommended values, with reference to SSMO (2002) and WHO (2008) standards.

Keywords: *Major constituents, water examination, total dissolved solids, groundwater types*

1. Introduction

Groundwater plays a critical role in maintaining river and stream flows during dry periods and in supporting wetland ecosystems. It is a vital source of drinking water globally (Brassington, 2007). Groundwater is considered the safest and cleanest form of water, with access to clean water recognized as a human right and a fundamental requirement for development (Reinhard, 2006). The suitability of groundwater for human consumption, agricultural, and industrial activities is determined by its water quality, which in turn depends on the chemical composition and concentration of elements within the Groundwater (Pebesma, 1996). Analyzing the chemical components of groundwater is an essential aspect of assessing groundwater resources. Various activities that rely heavily on water depend on the chemical characteristics of groundwater. The study of water chemistry offers crucial insights into the formations bearing water, and the occurrence, movement, recharge, and discharge possibilities of groundwater. Additionally, unusual chemical constituents in groundwater may provide important hints about the presence of hidden ore deposits (Technical Committee Reports, 1996). The investigation of water chemistry in the current research is significant for understanding the chemical evolution of groundwater, aiming to grasp spatial and temporal variations in groundwater chemistry better, thereby enabling the efficient management of groundwater resources for domestic, industrial, and agricultural purposes. Some borehole samples reflected water quality that was unfit for domestic use. The current study involves determining and describing the main dissolved chemical components in groundwater and relating these constituents to water usage. Water samples from the study area were collected and analyzed. Therefore, identifying elements that exceed acceptable ranges and understanding the reasons behind high concentrations play a central role in this research. Investigating water chemistry and hydro-geochemical processes related to hydro-geologic settings is crucial for the sustainable utilization of groundwater resources in the study area.

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2. Study Area

The area under study is located in the eastern part of Sudan, specifically within the Gedaref and Kassala states, positioned between the towns of Wad Elhelew and Khashm El Girba. It is bounded by latitudes 14.134171° N to 14.961005° N and longitudes 35.536335° E to 35.962209° E, covering an area of 3100 square kilometers (Figure 1). The region is traversed by the

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Malaysian Journal of Science 43(1): 34-43 (Mar 2024)

seasonal River Setit and Upper Atbara River, which originate in the Ethiopian highlands and converge at Eltomat village, south of Showak city.

The climate of the study area is characterized by long, hot summers and short, cold winters (Saeed, 1969). Winter temperatures (January) range from a maximum average of 37.5°C to a minimum average of 15.2°C, while summer temperatures (April) can reach up to 43.5°C, with minimum averages around 27°C. Annual rainfall varies between 420 – 1170 mm. The highest evaporation rate occurs in April, reaching 22.3 mm/day, while the lowest is in August, at approximately 3.1 mm/day.

Vegetation in Kassala State is largely influenced by rainfall and the flooding of the River Gash, with common crops including bananas, citrus, and vegetables. Natural vegetation, comprising bushes and trees like Acacia species alongside short-lived grasses during the rainy season, covers the remaining alluvial strips. Currently, large areas in Gash are dominated by Miscats trees (Zeinelabdein et al., 2017). In contrast, Gedaref state has seen its natural vegetation altered by mechanized farming, growing crops such as sesame, sorghum, and millet (Mirghani, 2002). Rain-fed plantations represent the primary land use and human activity in the area.

In semi-arid regions, estimating water resources is challenging due to limited hydrological information and scarce topographic data (Edmund et al., 1992). The study area is split into two distinct parts; the first is near the Rivers Atbara and Setit, marked by rugged topography and a unique land feature known as the Karab (Kerib) formation. The second part encompasses the plain areas, gently sloping westward on the eastern bank and eastward on the western bank of Rivers Atbara and Setit, with a general slope across the plain from southeast to northwest.

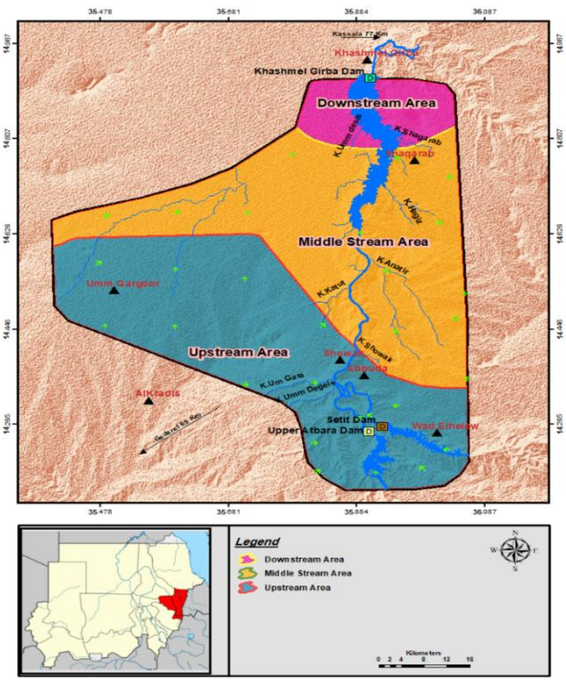

Figure 1. Location and sectors of the study area showing the study area is divided into three sectors; Upstream area, Middle area and Downstream area.

3. Geology and Hydrogeology

Hussien et al. (1989), Ibrahem et al. (1992), Hussein and Adam (1995), and Fadull et al. (1999) conducted geological surveys in the study area. The hydrogeological units of the area are represented by Basement rocks (Pre-Cambrian), Sedimentary rocks (Cretaceous), Basalts (Cenozoic), River Atbara and Setit sediments (Late Tertiary to Early Quaternary), Karab formation (Pleistocene), and the superficial layer at the top (Figure 2). The Basement Complex is composed of granitic gneiss, schist, slates, quartzite, and pegmatitic rocks. The Cretaceous sedimentary rocks consist of sandstone, siltstone, conglomerate, and mudstone, which constitute the major aquifers in the upstream zone. The Cenozoic basalt occurs as thin layers intruded within the loose formations and sometimes overlie the basement rocks. The deposits from the Setit and River Atbara primarily consist of sands, silt, clay, and gravelly clay layers that dominate this sequence. These sediments characterize the main aquifer in the middle and downstream areas. The superficial deposits, occurring as the top layer, are represented by alluvial deposits of Pleistocene to Recent age.

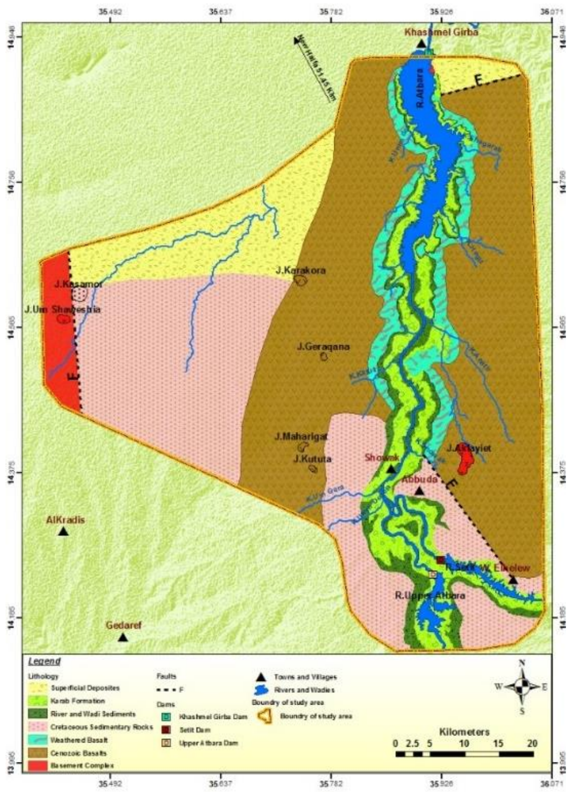

Figure 2. The Geological map of the study area showing six geological sequences.

4. Methodology

Several methods were employed during this research. These methods encompassed both fieldwork and office work to achieve the research objectives. Water samples were collected from forty-five boreholes located throughout the study area (see

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Malaysian Journal of Science 43(1): 34-43 (Mar 2024)

Figure 3). Parameters such as Total Dissolved Solids (TDS), Electrical Conductivity (EC), and pH were measured in the field using a TDS-meter and EC-pH meter. Bottles were used to collect water samples for subsequent chemical analysis in the laboratory. The concentration of anions and cations was determined at the Laboratories of the Groundwater and Wadies Directorate in Gedaref and Kassala towns, as well as the Laboratory of Kassala State Water Corporation, following standard analytical procedures that involved Titrimetric, Spectrophotometric, ultraviolet, flame photometric, and titration methods.

Geographical Information System (Arc-GIS) version 10.2 (2013) was employed to display the locations of water sampling sites and the distribution of chemical constituents as spatial maps. Microsoft Excel and Word software version 14.0.6023.1000 (2010) were used for data entry and diagram preparation. Surfer program version 9.8.669 (2009) and Digital Elevation Model Acquisition (DEM) version (2011) were utilized to create the TDS map. Piper's diagram was adopted to classify the groundwater types.

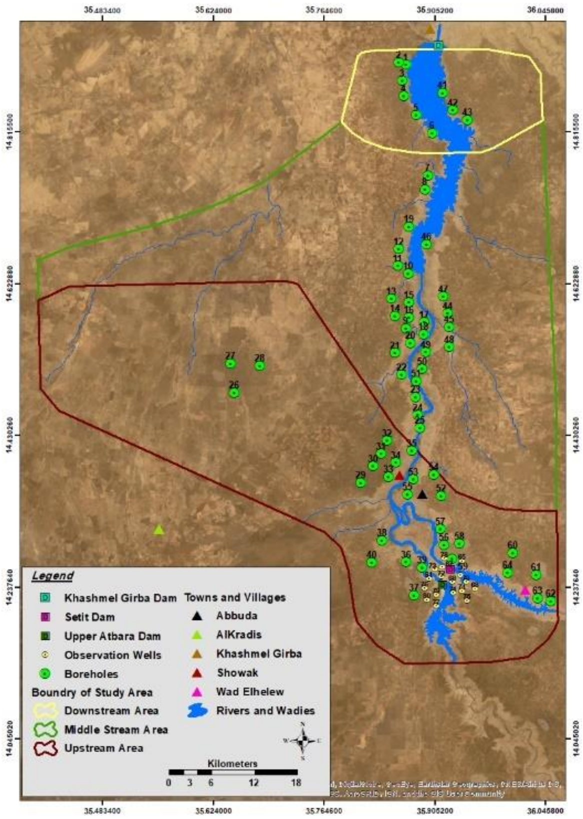

Figure 3. Location of the boreholes in the study area, water samples were taken from forty-five boreholes.

5. Results and Discussion

The groundwater characteristics in the study area are explained in the following sections (Table 1). The electrical conductivity (EC) in the study area varies between 287 and 3580 µS/cm. The high EC values in the study area are primarily concentrated in the fractured basaltic aquifers in the downstream area (Eldeweh well) (Figure 4), the middle area (Umm Oud, Mabroukah, and Shaoat Sharg wells) (Figure 5), and the upstream area (Karkora 1 well) (Figure 6). With regard to the concentration of EC in the study area, it complies with WHO and SSMO standards, except for nine sites that exceed the established standards (Table 1).

The hydrogen ion concentration (pH) of the solution indicates the effective hydrogen concentration H+ (Mazor, 2004) and is mathematically expressed as follows:

$$pH = -\log H^{+} \qquad (1)$$

The pH values in the study area range from 6.2 to 8.5, which falls within the normal range for water quality (Hem, 2005). However, there are four exceptions where samples from Magat Abd Elnabe2, Magate Shoot Shamal, Umm Oud, and Mellagah1 villages exhibit high sodium content, leading to elevated pH values. In general, the pH values in the study area conform to the established standards of both WHO and SSMO, except for these four sites (Table 1).

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Malaysian Journal of Science 43(1): 34-43 (Mar 2024)

Table 1. Statistic overview of chemical and physicochemical analysis of wells in the study area (Data in mg\l unless otherwise indicated)

\Downstream

Parameter	MAX	MIN	AVERAGE	STANDARD DEVIATION
Hardness	204	28	138	58.77414
pH	8.4	7.2	7.9	0.517687
EC(µS/cm)	2050	287	1048.667	744.133
TDS	1333	201	695.1667	463.8467
Ca	56	6.4	24.4	19.6204
Mg	39.4	1.92	18.48667	15.59632
Na	420	250	319.4167	61.43648
K	4.3	1.5	2.583333	0.978604
HCO^3	427	97.6	270.3333	123.905
Cl	404	6.39	134.6483	159.7418
SO^4	250	0.5	100.5833	110.7495
No^3	7.8	0.44	5.253333	3.062644

Midstream

Parameter	MAX	MIN	AVERAGE	STANDARD DEVIATION
Hardness	960	150	316.1471	191.1748
pH	8.8	6.2	7.976471	0.620009
EC(µS/cm)	3139	582	1234.941	792.3401
TDS	2040	378	803.1176	516.5334
Ca	71.3	6.88	33.49882	19.16756
Mg	190	4.5	56.34706	39.69301
Na	400	93.52	281.4171	80.9951
K	31	1.3	4.475	0.830662
HCO^3	1411	174.3	387.2353	285.6081
Cl	1098	10.7	156.2706	263.8523
SO^4	508	12	93.73529	122.162
No^3	18.48	0	2.826235	4.493662

Upstream

Parameter	MAX	MIN	AVERAGE	STANDARD DEVIATION
Hardness	514	28	215.9545	116.3363
pH	8.6	6.6	7.654545	0.509647
EC(µS/cm)	3340	287	992	576.5388
TDS	1670	200	600.0909	308.7955
Ca	90	6.4	36.19091	22.58415
Mg	110	1.92	31.28	25.85884
Na	360	7.04	171.5859	98.02315
K	46	1.2	5.217727	9.263125
HCO^3	793	78	383.15	161.4407
Cl	670	21.1	93.77091	136.2717
SO^4	175	0	73.02273	51.60714
No^3	44	0	10.99545	9.910983

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Malaysian Journal of Science 43(1): 34-43 (Mar 2024)

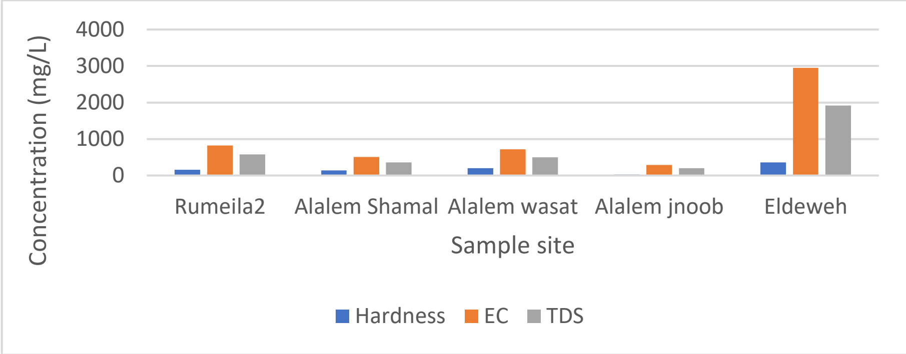

Figure 4. Comparison between TDS and Total Hardness (mg/L) and EC (µS/cm) in groundwater in downstream sector.

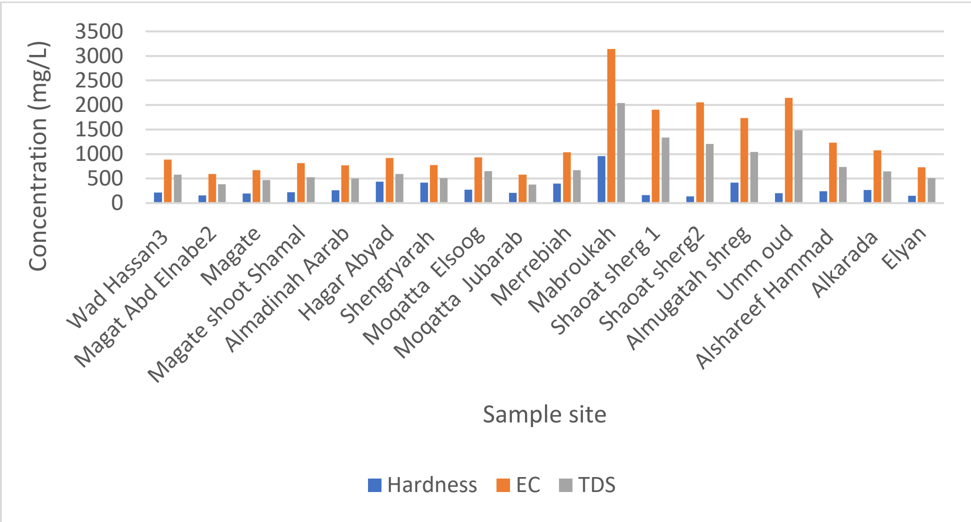

Figure 5. Comparison between TDS ,Total Hardness (mg/L) and EC (µS/cm) in groundwater in middle sector.

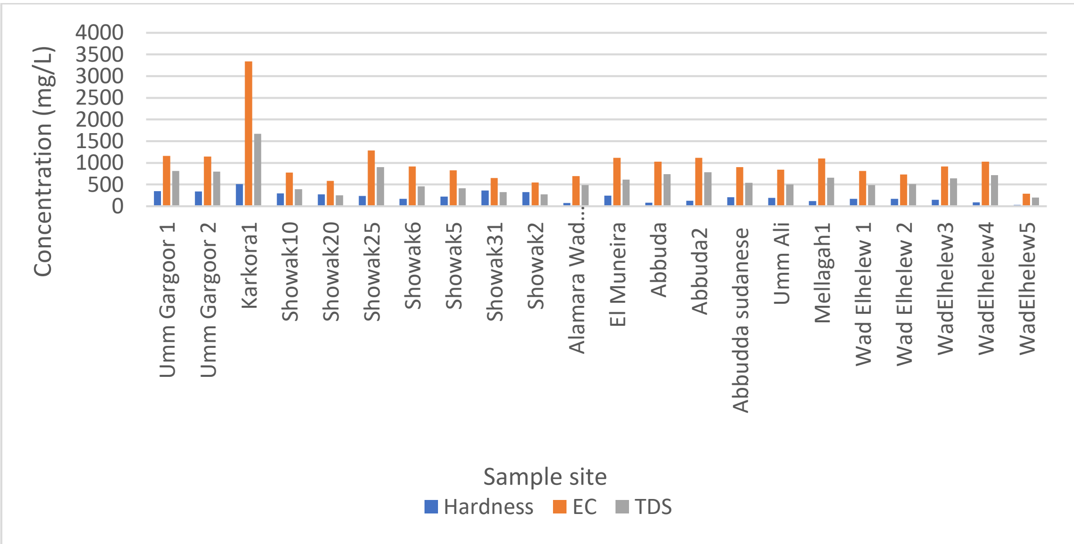

Figure 6. Comparison between TDS and Total Hardness (mg/L) and EC (µS/cm) in groundwater in upstream sector.

DOI:https//doi.org/10.22452/mjs.vol43no1.4
Malaysian Journal of Science 43(1): 34-43 (Mar 2024)

There are conflicting definitions and difficulties in characterizing hardness, as noted by Hem et al. (1982). TH is primarily attributed to the concentration of magnesium and calcium salts. In the specific study area, total hardness ranges from 28 to 960 (see Figure 7). According to the classifications by Sawyer & McCarly (1967), the groundwater in this area can be categorized from soft water to hard water.

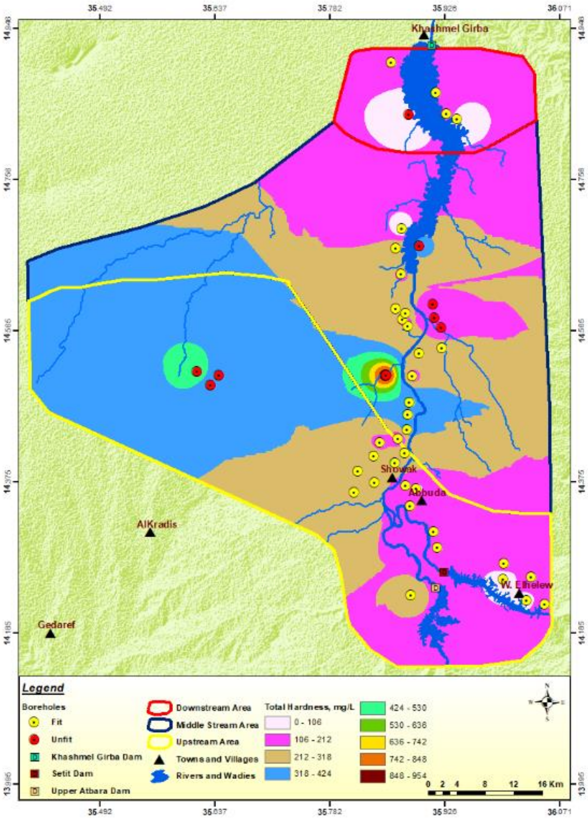

Figure 7. Spatial identification of Total Hardness showing the study area is classified from soft water to very hard water.

TDS in water consists of inorganic salts, including calcium, sulfates, chlorides, magnesium, potassium, sodium, and bicarbonates, as mentioned by Hago (2014). In the study area, TDS values range from 200 to 2040 mg/L (see Table 1). The salinity levels vary from slightly saline to moderately saline, with the exception of seven samples that are highly saline and exceed the established standards (see Figures 3, 4, and 5). In general, the TDS levels in the study area meet the standards, except for nine specific sites (see Figure 8).

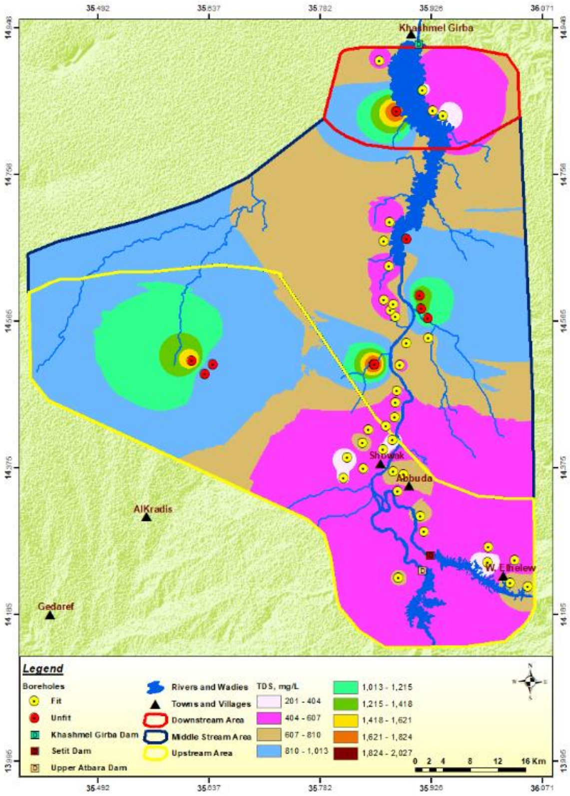

Figure 8. Spatial identification of TDS; the concentration of TDS at the study area within the WHO and SSMO standards except nine sites are above the standards.

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Malaysian Journal of Science 43(1): 34-43 (Mar 2024)

The major dissolved solids of water in downstream, middle and upstream areas are presented in the following Figures.

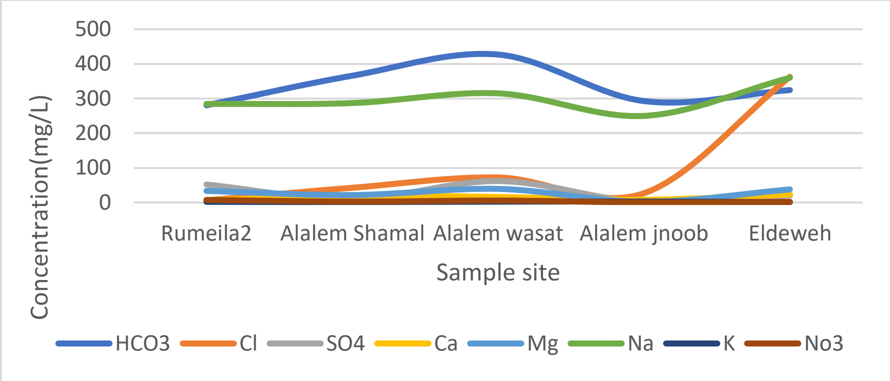

Figure 9. Major dissolved solids in groundwater in downstream sector (mg/L).

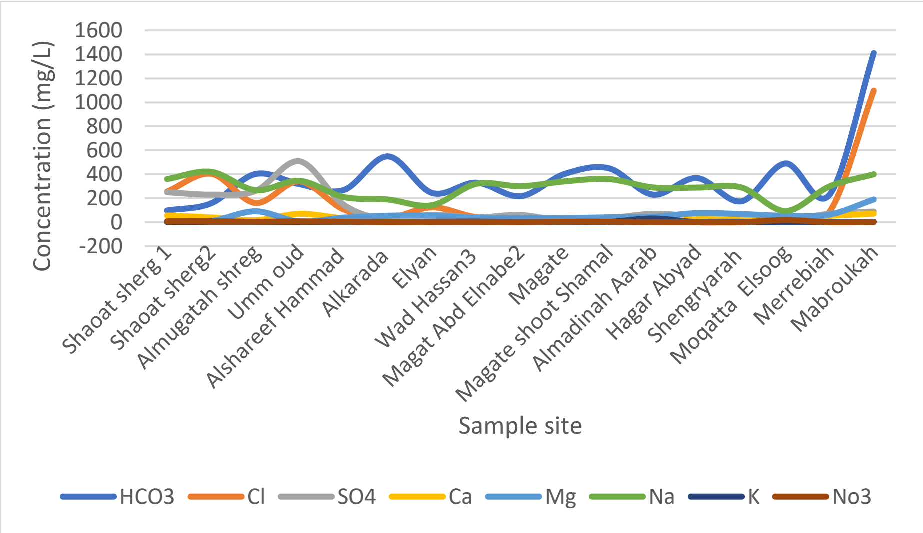

Figure 10. Major dissolved solids in groundwater in midstream sector (mg/L).

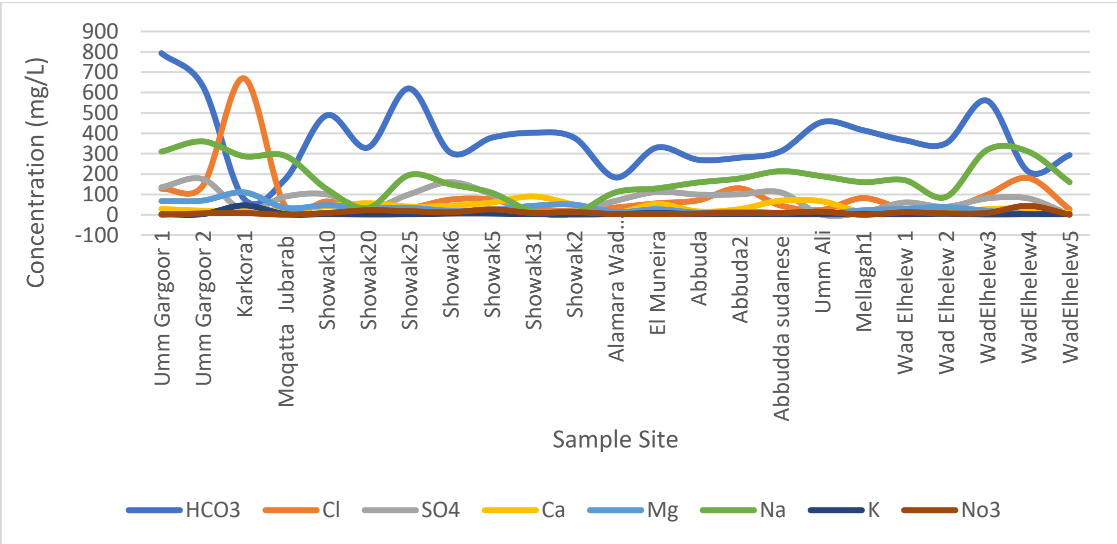

Figure 11. Major dissolved solids in groundwater in upstream sector (mg/L).

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Malaysian Journal of Science 43(1): 34-43 (Mar 2024)

Calcium (Ca^{2+}) ions are abundant in the Earth and mobile in the hydrosphere. Calcium is one of the most common ions in subsurface water (Davis & Dewiest, 1966). However, the minimum value of calcium in the study area is 6.4 mg/L, while the maximum value is about 90 mg/L (see Table 1). Generally, high concentrations of calcium are found in the middle area (Mabroukah wells) (see Figure 10) and in the upstream area (Showak and Abbuda wells) (see Figure 11), which may be attributed to the dissolution of carbonate minerals in the country rock.

The primary source of Magnesium (Mg^{2+}) in groundwater in the study area involves basic volcanic rocks rich in ferro-magnesian minerals (Olivine, pyroxene, and amphiboles). In water chemistry, the geochemical behavior of Mg^{2+} is similar to that of Ca^{2+} (Davis & Dewiest, 1966). The concentration of magnesium in the study area ranges between 1.92 and 190 mg/L (see Table 1). It increases towards the boundary of the recharge area, where volcanic rock is concentrated, such as Mabroukah well in the middle area (see Figure 10) and Karkora1 and Umm Gargoor wells in the upstream area (see Figure 11). Generally, magnesium levels in the study area meet the WHO and SSMO standards, except for four specific sites.

The Sodium ion concentration (Na^+) in the study area generally ranges between 10 and 415 mg/L (see Table 1). High sodium values are observed in the downstream area (Eldeweh well) (see Figure 9) and in the middle area (Shaoat Sherg 1&2, Almugatah Shareg, and Mabroukah wells) (see Figure 10). This may be a result of Aegirine Pyroxene in the granitic rocks. More than 50% of the sites have high sodium concentrations, exceeding the WHO and SSMO standards.

The Potassium concentration (K^+) in the study area is lower than sodium. In the middle area (Almadinah Aarab well) and in the upstream area (Karkora1 well), the K^+ concentration reaches relatively high values (31 and 46 mg/L, respectively) (see Figures 10 and 11). The variation in potassium levels in groundwater is related to leaching processes along the groundwater regime, especially from southwest to northeast (higher values upstream and lower values downstream). The Potassium concentration in the study area generally meets the WHO and SSMO standards, except for the Karkora site (upstream area), which exceeds the standards.

The sulfate concentration (SO_4^{2-}) displays significant spatial variation. The increase in sulfate concentration does not entirely coincide with the direction of groundwater flow. Sulfate concentrations in the study area range between 0.7 and 500 mg/L (see Table 1). High sulfate values are observed in wells located in volcanic zones in the middle of the study area, such as Shaoat sherg (1) and (2), Almugatah sherg, and Um Oud (see Figure 10). This may be attributed to volcanic intrusions, which can impact groundwater quality in the mentioned boreholes. Sulfate concentrations in the study area generally meet the WHO and SSMO standards, except for four specific sites.

The dissociation of Bicarbonate (HCO_3^-) to carbonate is influenced by the pH value. The dissolution of carbonate rocks and the presence of carbon dioxide in the soil and atmosphere are considered the main sources of bicarbonate and carbonate in water. Bicarbonate concentrations in the study area range between 78 and 1411 mg/L (see Table 1). High bicarbonate values are found in Mabroukah (middle area) and Umm Gargoor 1 (upstream area) boreholes (see Figures 10 and 11), possibly due to evaporite deposits in the calcareous sandstone, thick mudstones, and upper soil layer. Generally, bicarbonate concentrations meet the standards, except for fourteen specific sites.

Chloride (Cl^-) is the main element in water exposed to the atmosphere (Hem, 1992). Chloride concentrations in the study area range between 6 and 1098 mg/L (see Table 1). High chloride concentrations are observed in the middle zone (Mabroukah well) and the upstream zone (Karkora1 well) (see Figures 10 and 11), possibly due to the dissolution of chloride minerals in the basaltic or granitic rocks (Kuarod & Sandell, 1963). Generally, chloride levels in the study area meet the WHO and SSMO standards, except for six specific sites located in basaltic zones.

Nitrate concentration (NO_3^-) in the study area is very low. Nitrate may have originated from organic matter contamination within the aquifer. During this study, other sources of contamination, such as fertilizers, were not reported, especially those located away from horticultural zones (see Table 1).

The primary ions' composition in groundwater is used to identify groundwater facies, classified based on the cations and anions. Such classification can be graphically represented using various methods (Hem, 1992). Collins (1923), Piper (1944), Raji & Alagbe (1997), and Domenico & Schwartz (1998) have proposed and modified chemical analysis methods.

Based on Piper's diagram, the majority of well samples collected from the study area (60%) belong to the mixed groundwater type, while (40%) fall into Na-HCO_3, Na-Cl, and Ca-Mg-HCO_3 groundwater types (see Figure 12).

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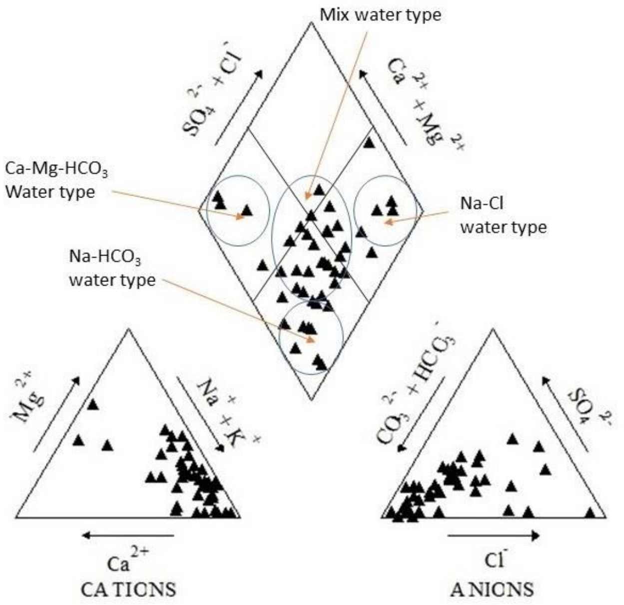

Figure 12. The diagram shows groundwater facies in the study area.

In terms of water quality analysis for the 45 groundwater samples collected from the study area, the TDS values range from 201 to 801 mg/L, which falls within the acceptable range for human consumption. However, nine samples exhibit TDS values ranging from 1201 to 2040 mg/L, exceeding the standards set by WHO and SSMO, making them unsuitable for human consumption. This higher TDS content is attributed to elevated levels of sodium (Na^+), magnesium (Mg^{2+}), and chloride (Cl^-) in the basaltic rocks. The majority of the samples (60%) belong to mixed groundwater types, while the remaining samples are classified as Na-HCO_3, Na-Cl, and Ca-Mg-HCO_3 groundwater types.

The primary land use and human activity in the study area are rain-fed plantation. Irrigation in the region relies on either rainfall or direct extraction from surface water sources. Fortunately, most of the groundwater samples in the study area are suitable for irrigation purposes.

6. Conclusion

The TDS values in the study area range from 200 to 800 mg/L, making the water suitable for human use. However, nine samples have TDS values ranging from 1200 to 2040 mg/L, rendering them unsuitable for human consumption. These elevated TDS levels may be attributed to the concentrations of magnesium (Mg^{2+}), chloride (Cl^-), and sodium (Na^+) in the basaltic rocks.

Based on the findings from the investigations mentioned above, it is strongly recommended to employ isotopic techniques using O18 to identify the source of salinity in the nine sites that exceed the established standards. Additionally, due to population growth and horticultural expansion within the study area, it is advisable to conduct chemical and bacteriological analyses annually to monitor changes in the water quality of the study area.

7. Acknowledgments

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6. References

Brassington, R. (2007). Field Hydrogeology. 3th ed. London: John Wiley and Sons, 265 pp.

Collins, W. D. (1923). Graphic Representation of Water Analyses. Indus and Eng. Chem. 15 (4), 394-394.

Davis, S. N. and Dewiest, R. J. M. (1966). Hydrogeology. New York: John Wiley and Sons, 463 pp.Deer, W. A., Howie, R. A., and Zussman, J. (1978). Rock Forming Minerals. Second ed. New York: John Wiley and Sons, vol. 2A.

Domenico, P. and Schwartz, F. (1998). Physical and Chemical Hydrology. Second ed. New York: John Wiley & Sons.

Edmunds, W.M., Darling, W.G., Kinniburgh, D.G. & Mallgoub, S. (1992). Sources of recharge at Abu Delaig, Sudan. J. hydrol.131, p.1-24.

Fadull, H.M., Salih, A. A., Ali, I. A and Lnanagaz, S. (1999). Use of Remote Sensing to Map Gully Erosion along the Atbara River, Sudan. JAG, Volume 1-issue 3/4 -1999, pp.175-180.

Hago, Ali. Hago. (2014). Hydrochemical characteristics of groundwater, midstream area–Gash River basin, Eastern Sudan .pub .Ph.D. Thesis. TU Berlin, Germany.144pp.

Hem J. D., Roberson C. E., and Fournier R. B. (1982). Stability of -MnOOH and manganese oxide deposition from spring water. Water. Resour. Res., 18:563–570.

Hem, J.D. (1992): Study and interpretation of the chemical characteristics of natural water. US. Geological Survey Water Supply Paper 2254, 263p.

Hem, J. D. (2005). Study and interpretation of the chemical characteristics of natural water. University Press of the Pacific, Hawaii.

Hussein, M.T & Adam, E.G. (1995). Water quality of the Gedaref basin, Sudan. Hydrological Science Journal, Vol.40. No2, pp.205-216.

Hussein, T. Mula, A.G & Schneider. (1989). Geological and Seismic investigations with regard to shallow groundwater explorations in eastern Sudan Republic. Journal of African earth Sciences ,Vol,8.No.1, pp.75-78.

Ibrahim, K. E., Hussein, M. T. & Gidoo, I.M. (1992). Application of combined geophysical and hydrogeological technique to groundwater exploration. A case study of Showak – Wad Elhelew area, eastern Sudan. Journal of Africa Earth Science, Vol.15, No.1, pp.1-10.

Kuarod, P.K. & Sandell, E.B. (1963). Chlorine in Igneous rocks, some Aspect of the Geochemistry of Chlorine. Bullet in Geological society of America.Vol64.pp.879-898.

Mazor, Emanuel. (2004). Isotopic Groundwater Hydrology. 3rd ed. New York: Marcel Dekker, 453pp.

Mirgani, M. (2002). Concepts and models for the characterization of the West Gedaref Hydrogeologic System, Sudan. Ph.D. Thesis, Berlin.117pp.

Pebesma, Jan. Edzer (1996). Mapping Groundwater Quality in the Netherlands, pub .Ph.D. Thesis. Universiteit Utrecht, Netherlands.105 pp.

Piper, A. M. (1944). A graphical procedure in the geochemical interpretation of water analysis. Am. Geophys. Union Trans 25, 914-928.

Raji, B. and Alagbe, S. (1997). Hydrochemical facies in parts of the Nigerian basement complex. Environ. Geol. 29, pp 46– 49.

Reinhard, Kirsch. (2006). Groundwater geophysics, A tool for hydrology. Springer-Verlag Berlin Heidelberg,493pp.

Saeed, E.M. (1969). Groundwater appraisal of the Gash River basin at Kassala, Kassala province, Democratic Republic of Sudan. Ministry of Industry and Mining, Geological and Mineral Resources Dept.Bull.17.88.pp.

Sawyer. C. N. and McCarty, P. L. (1967). Chemistry for sanitary engineers, 2nd ed. McGraw – Hill, New York, 518 pp.

SSMO.(2002). Sudanese Standards and Metrology Organization, Drinking Water Standard, ICS 13.060.00.

Technical committee – Kassala, Reports, (1996): Hydrochemical investigations on the eastern bank of River Atbara (Adr Habib area), G.W.A., Kassala. Unpublished report.

W.H.O. (2009). Guidelines for Drinking-water Quality, Geneva, Switzerland.

Zeinelabdein, K. A. E., Bireir, F. A., Abdelraheem, M. A. (2017). Hydrogeological, IWRM, EIA and Geophysical Investigations in Algadaref, Hamadaeit and Algoz, Areas of Kassala State and Elmafaza and Elgalabat, Areas of Gedaref State, Eastern Sudan. (Unpublished report).

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