

Hydrochemical evaluation of groundwater in Khartoum state, Sudan

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Abstract

Hydrochemical investigations of groundwater have been carried out on objectives of evaluating groundwater quality. This paper presents assessment of hydrochemical characteristic of groundwater in Khartoum state, Sudan. The approaches followed here include the chemical analyses for major ions chemistry and MapInfo draw exchange to construct the hydrochemical maps of total dissolved solids (TDS), sodium (Na^+), bicarbonate (HCO_3^-), and chloride (Cl^-) ions. The hydrochemical characteristics of the groundwater in each aquifer and management consideration were discussed. Sources of major ions in groundwater were analyzed. The hydrochemical maps of the aforementioned species were constructed. Relationship of groundwater to use was elaborated. High concentrations of hydro chemical constituents and the occurrence of calcrete (CaCO_3) and evaporite in upper aquifer suggests along history of evaporation and increasing leachates.

Key words: Total dissolved solids, hydrochemical constituents , groundwater, aquifer.

1. Introduction

Variations in natural and human activities reflect spatial variations in the hydrochemical parameters of the groundwater. The difference of dissolved ions concentration in groundwater are generally, governed by lithology, velocity and quantity of groundwater flow, nature of geochemical reactions, solubility of salts and human activities [1, 2]. Khartoum state is located in the arid region of Central Sudan and intensively inhabited during the last decenniums, leading to expansion of the residential areas from the surface watercourses. Suitable quantity and quality of groundwater become a more crucial alternative resource to meet the drastic increase in social, agricultural, and industrial development and to avoid the expected deterioration of groundwater quality due to heavy abstraction for miscellaneous uses. Hence, hydrochemical investigations are the main objectives for the groundwater system in Khartoum state. In this paper, results of preliminary investigation are conducted in form of table, hydrochemical maps and graphs to evaluate the vertical and horizontal variation in groundwater chemistry, which was more related to salinity hazards.

2. Study area

The study area sited between latitudes $15^\circ 00' - 16^\circ 00'$ N and longitudes $32^\circ 15' - 33^\circ 30'$ E covers an area of 7200 Km^2 (Figure 1). It is semi-arid area characterized by hot dry summer (April-June) and cold dry winter (November-February). The annual rainfall is 157mm, mainly during July to September. Most of the area is flat plain, where the surface elevation ranges between 380 to 400 m a.s.l. Elevated ridges and isolated inselbergs are encountered in the northeast, northwest and southwest of the area. The main watercourses are, Blue Nile, White Nile, River Nile and seasonal streams.

3. Geology and Hydrogeology

The geologic setting is composed of Basement Complex, Omurman formation, and Gezira formation [3]. The basement complex consists of acid grey gneisses and granite. Omdurman

formation is composed of a sequence of sandstone, conglomerate and mudstone, of more than 400 m thick, rests unconformably on the Basement complex [4]. Gezira formation covers the area between the Blue and White Nile, and small strip east of the Blue Nile. It consists of a sequence of unconsolidated interbedded clay, silt, sand and gravel layers. Calcrete, evaporite and salt rocks are characteristic features of the upper part of Gezira and Omdurman formation. The thickness of Gezira formation ranges from few meters to more than 80 m [5]. Omdurman and Gezira formation encompass the main aquifer systems.

Hydrogeologic system is composed of an upper aquifer developed in the upper part of Gezira and Omdurman formations and a lower aquifer at the deeper parts of these formations. The upper aquifer is semi-confined and up to 120 m thick, whereas, the lower aquifer is dominantly confined with thickness variation of 150-500m [4]. Depth to water level varies from few meters to more than 85 m. The aquifer system is exclusively recharges from Blue Nile, White Nile, River Nile, direct precipitation and seasonal streams. The hydraulic conductivity of the lower aquifer (21.6 m/d) is ten orders higher than the upper one [5]. Aquifer systems are partially hydraulically connected. The groundwater flow direction is generally outwards of river courses with hydraulic gradient varies from 0.01 close the rivers to 0.0006 at far distance.

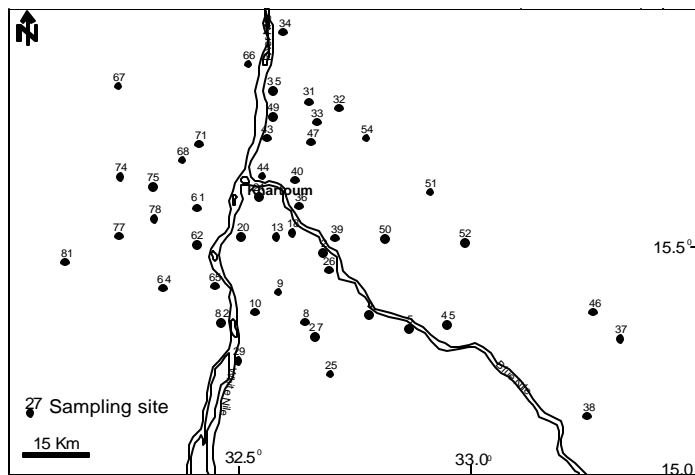


Figure 1: Sampling sites location map of the study area

4. Sampling and Analytical Procedure

Eighty-three samples from boreholes at depths ranges from 30 to 85 m were collected for hydrochemistry (Figure 1). They were analyzed for the major ion chemistry, 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-meter. Further analyses for major ions were performed in the Non-Nile Sudan water research central Laboratories: total dissolved solids (TDS) were measured by sample evaporation techniques. Bicarbonate (HCO_3^-) and total alkalinity (T Alk.) were estimated by titration with HCl. Total hardness (TH) and calcium (Ca^{2+}) were analyzed titrimetrically. Sodium (Na^+) was analyzed by flame photometry. Chloride (Cl^-) was estimated by titration with AgNO_3 . 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 $\pm 5\%$. All values were in milligram per liter (mg/l) unless otherwise indicated. The hydrochemical characteristics of groundwater in the study area were summarized as statistical overview in table 1.

Table 1: Statistic overview of hydrochemical characteristics of groundwater

Parameters	Eastern area			Central area			Omdurman area		
	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
pH	6.5	8.4	7.6	7.2	8.4	7.8	6.8	9.6	7.7
EC ($\mu\text{s}/\text{cm}$)	281	4070	918	263	3180	718	116.1	4690	867
TDS	150	2890	626	184	2204	492	180	3283	751
Hardness	52	618	208	42	920	174	70	950	194
Alkalinity	124	372	232	75	573	239	2	402	30.3
HCO_3^-	122	372	237	98	573	233	110	402	239
Cl^-	12	817	105	10	585	78	12	1007	137
Na^+	25	980	116	8	304	96	16	504	127

5. Results and discussion:

The pH of groundwater in upper and lower aquifers, varies within small ranges (Table 1), elaborates a fresh and a slight trend of alkaline chemical reaction within the groundwater environment [6]. The electric conductivity (EC) varies from 281 to 4070 $\mu\text{S}/\text{cm}$ in the eastern area (East of River and Blue Nile), from 263 to 3180 $\mu\text{S}/\text{cm}$ in the Central area (Between Blue and White Nile) and from 116 to 4690 $\mu\text{S}/\text{cm}$ in Omdurman area (West of River and White Nile) see Table 1, & Figure 1. These measurements indicate that there are probably fresh water ($<500 \mu\text{S}/\text{cm}$), marginal water (500-1500 $\mu\text{S}/\text{cm}$) and brackish water types (1500-5000 $\mu\text{S}/\text{cm}$) in the area. Alkalinity varies within considerable ranges in the eastern, central and Omdurman area elaborates alkaline water type (Table 1). This indicates the existence of calcretes (CaCO_3) and silicate weathering processes in the upper Gezira and Omdurman formation. Hardness concentrations, with respect to [7] classifications, indicate that Omdurman area Characterized by moderately soft (50-100 mg/l) to hard (200-300 mg/l), whereas, the eastern and central areas range from moderately soft to very hard ($>300 \text{ mg/l}$) see table 1.

Mean total dissolved solids (TDS) at eastern, central and Omdurman area are 625, 491 and 751 mg/l respectively (Table 1). The hydrochemical map shows high salinity zones in the eastern area (Hattab-Idd Kalamon zone), central area (Waghara-Isealy zone) and Omdurman area (AlGulei-Tureis zone) see Figure 2. A tendency of decreasing concentration with respect to aquifer depth (Figure 3) marks a brackish water type (TDS $>1000 \text{ mg/l}$) in the upper aquifer and moderately fresh water type (TDS $<1000 \text{ mg/l}$) in the lower aquifer (Table 1). These salinity ambiguities are sanctioned to the dissolution of silicate minerals, evaporite deposits, low hydraulic gradient (< 0.001), increasing distance from the recharge sources and high evaporation and evapotranspiration rates in this semi-arid area.

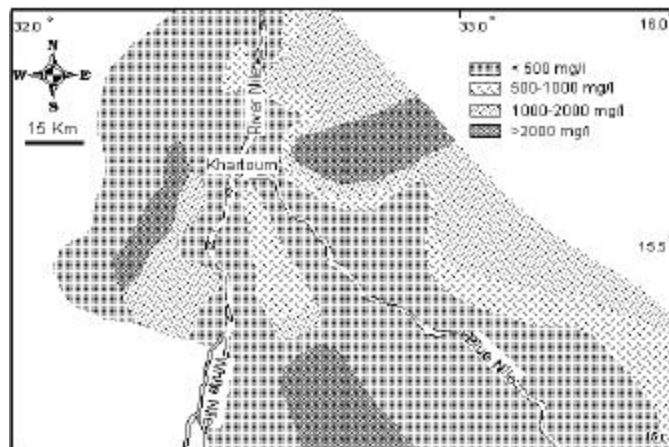


Figure 2. Areal distribution of TDS

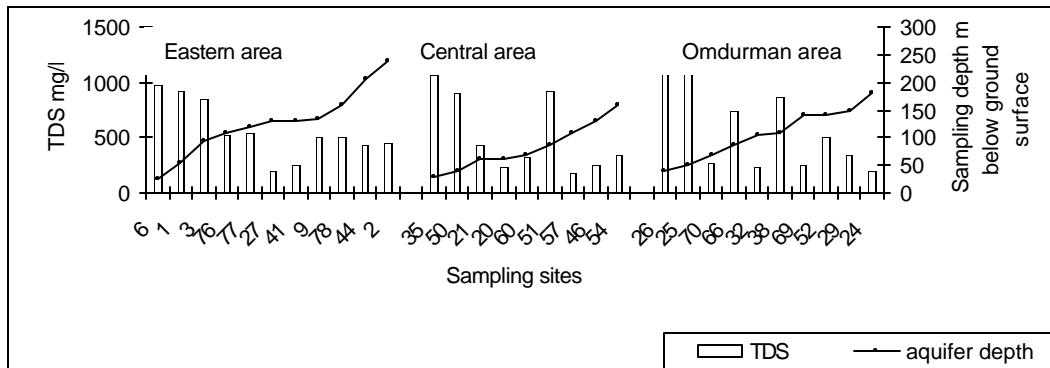


Figure 3. TDS and sampling depth distribution

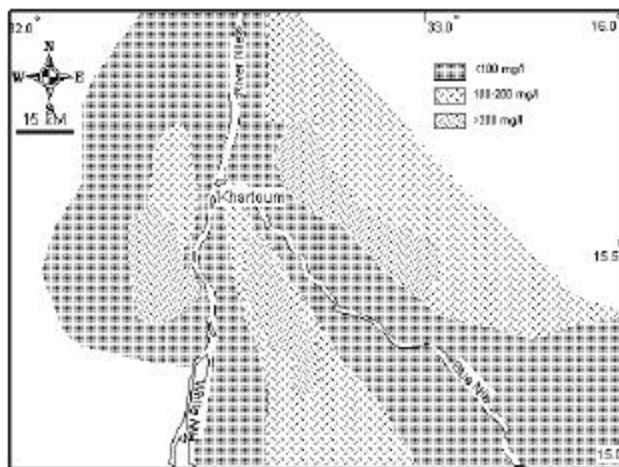
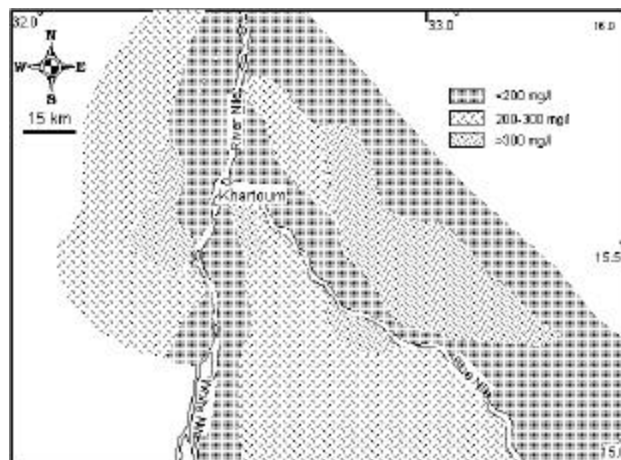


Figure 4. Areal distribution of sodium

Sodium is comparatively low and varies within small ranges (Table 1). This is ascribed to adsorption on mineral surfaces of high cation exchange capacities such as clays. Hence, relatively high concentration appears as irregular troughs generally trending northwest-southeast concordant with the regional flow



direction (Figure 4). Significant increasing of sodium along the regional flow direction, suggests the silicate weathering and/or dissolution of soil salts (Na_2SO_4) that characterize the upper part of Gezira and Omdurman formations.

Bicarbonate concentration varies in the range of 122-372, 98-573 and 110-402 mg/l in the eastern, central and Omdurman area respectively (Table 1). High concentration trough zones were appeared outwards of river courses (Figure 5). This is caused by the carbon dioxide (CO_2) present in the soil zone formed from the decay of organic matter and the root respiration and may also be derived from the dissolution of silicate and feldspars minerals and the weathering of parent materials (calcretes) due to consecutive dry and wet conditions, characterized the semi-arid area.

The chloride concentration in the study area, with few exceptions, is relatively low with mean values of 105, 78, and 136 mg/l in the eastern, central and Omdurman area respectively (Table 1). Moreover, the concentration decreases with increasing distance from surface watercourses forming a longitudinal troughs generally trending north-south or northwest-southeast (Figure 6). The analogous distribution of chloride, sodium and total dissolved solids indicates a common source of these ions such as leaching of saline residues in the soil due to climatic conditions and anthropogenic activities.

6. Relationship of groundwater to use

The main objectives following the hydrochemical investigations of groundwater is to determine its suitability to different uses. Hence, hydrochemical investigations indicate that water from the upper aquifer ranges from generally acceptable to poor for domestic uses. Whereas, that from lower aquifer is comparatively good for both drinking and household purposes, although very saline and hazards zones were encountered at the eastern central and Omdurman area.

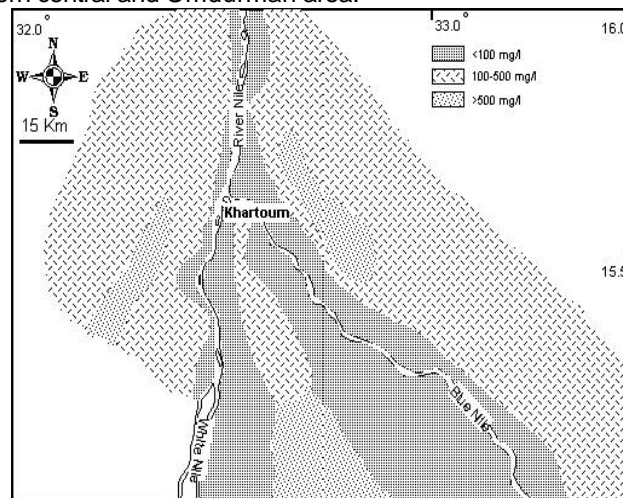


Figure 6. Areal distribution of chlorides

7. Conclusions and recommendations

Ion concentrations in the study area are appreciably tends to increase with increasing distance from the surface water systems. High salinity marks the upper aquifer and down-gradient zones of the study area may ascribe to differential cation exchange, precipitation and dissolution processes within mudstone strata of Omdurman formation, evaporites (Gypsum and rock salt) and clayey silt of Quaternary Gezira formation, high evaporation and evapotranspiration and a high field capacity of the soil and low hydraulic gradient. On water management consideration, the most frequent methods to decrease water quality

fluctuation is the recharge techniques through spreading water on the land surface to percolate to the water table and/or direct injection of water through wells with some consideration to be given to water chemistry .For agricultural development it is recommended to build small dams for surface water storage on seasonal streams and basin to be use during droughts as additional resource to avoid or to attenuate demographic unbalances and desertification risk in the study area. Moreover, special management of salinity control and certain kind of plants with good salt-tolerance should be considered. It is also strongly recommended to extract potable groundwater from the lower aquifer using wells that should be grouted through the upper salinity zones, using appropriate techniques, to prevent mixing of poor water quality.

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References

- [1] Karanth K.B. (1997). Groundwater assessment, development and management. Tata McGraw-Hill Publishers, New Delhi.

- [2] Bhatt K.B., Salakani, S. (1996). Hydrogeochemistry of the upper Ganges River, India. J. Geol Soc. India 48; 171-182.
- [3] Wycisk, P. and Others (1990): International sequence development and structural control of Phanerozoic strata in Sudan, Berliner, Geowiss. Abh. (A), ,Berlin, Vol. 120.1, P. 45 – 86

- [4] Kohnke, M., Skala, W. and Erpenstien, K. 1993. Nile groundwater interaction modeling in the northern Gezira plain for drought risk assessment. In: *Geoscientific research in Northern Africa* (Edited by Thorweihe, U and Schandelmeir, H.) pp.705-711. Balkema Rotterdam, Netherlands.
- [5] Magboul, A.B. (1992): Hydrogeology of the Gezira area (Central Sudan). M.Sc. thesis, University of Khartoum.

- [6]Fetter, C. W., (1999). Contaminant hydrogeology, Second Edition. Prentice-Hall, Inc.

- [7] Twort, A.C., F.M. Law, and F.W., Crowely (1987): Water supply, 3rd edition, Edward Arnold (publisher) Ltd, 41 Bedford Square.