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GROUNDWATER QUALITY IN KHARTOUM STATE, SUDAN

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Chemical analyses have been carried out for several groundwater samples collected from 28 producing wells in the area east of the Nile and the Blue Nile rivers, Khartoum State, Sudan. Three hydrogeochemical facies are delineated: sodium-chloride-sulfate (Na-Cl-SO_4), calcium-magnesium-bicarbonate (Ca-Mg-HCO_3), and sodium-calcium-magnesium-bicarbonate (Na-Ca-Mg-HCO_3). This study indicated that the groundwater quality in the study area, which lies within the Nubian Aquifer, is fit for human and agricultural purposes except at a few localities which contain high chlorides, sodium and sulfates, as well as high values of electrical conductivity above the permissible limits of the World Health Organization standards. The groundwater is also fit for irrigation purposes except at the same localities due to high salinity and a high concentration of sodium ions.

INTRODUCTION

The population of Khartoum State, Sudan, depends mainly on the fresh surface water of the Nile River and its main tributaries, the Blue Nile and the White Nile, which meet at the Mugran area, Khartoum State, for their drinking water. The surface water is treated and distributed to the people in three main cities through pipelines, although there are many producing groundwater wells inside the cities. With the tremendous increase in population, there is a growing demand for groundwater exploration and exploitation as there are many villages, rural population centers and new residents around the three main cities.

Both governmental and private sector efforts in the field of groundwater in the Khartoum area focus mainly on exploration and exploitation of groundwater. Information about groundwater quality is generally lacking. This paper is an assessment of the hydrochemical aspects of the groundwaters in eastern Khartoum State and an evaluation of the different groundwater types and their suitability for domestic and agricultural purposes. There are vast areas around Khartoum, as in all of the Sudan, that are suitable for irrigated agriculture.

LOCATION AND GEOLOGICAL SETTING

The study area lies entirely in the eastern part of Khartoum State, mainly occupying vast areas of the Eastern Nile Province. The area is located between latitudes 15.42^0 and 15.78^0 N and longitudes 32.45^0 and 32.93^0 E, and it is bounded by the Nile and Blue Nile rivers on the west. It is about 400 square kilometers in area (Figure 1).

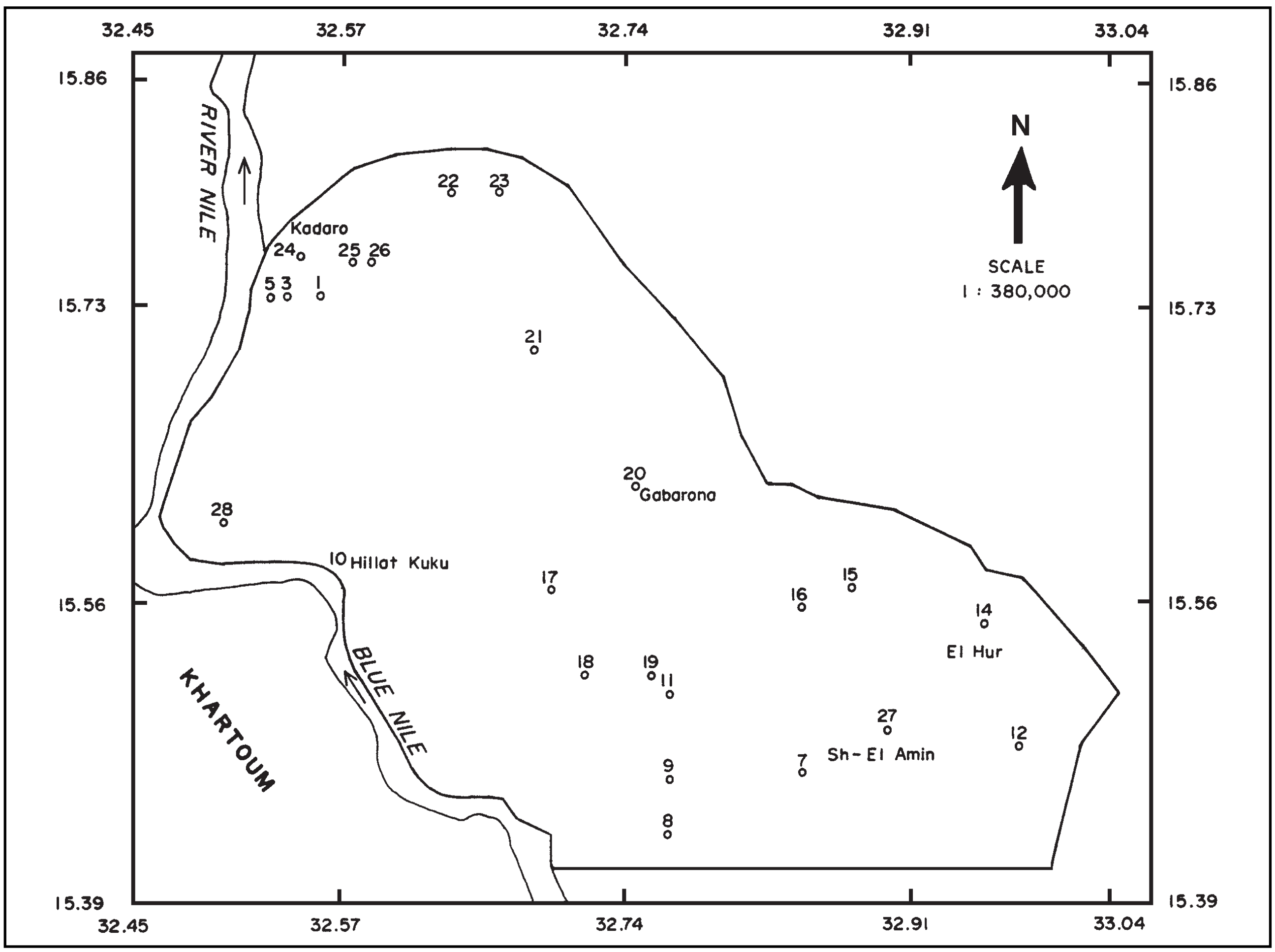

Figure 1. Locations of the boreholes in the study area.

The climate is arid with an average annual rainfall of about 167 mm during the summer season (July-September), and evaporation is about 10 mm/day (Haggaz and Khairalla, 1988). It has a hot summer (April-October) with little rainfall and a cold dry winter. The mean annual daily maximum air temperature is 37.1 ^{o}C with extremes of 47.2 ^{o}C. The lowest temperature is 6 ^{o}C recorded December 24, 1951. The area is densely populated and people earn their living by working in towns.

The topography of the area is flat with some scattered sand dunes drained by small wadis, and it is crossed from the eastern side by the Khor Soba draining towards the Blue Nile. The area is entirely confined to the Nubian Sandstone Formation, which is of upper Cretaceous age (Whiteman, 1971). The Nubian Sandstone Formation here belongs to the Great Nubian Aquifer of North Africa, which mainly lies in north Sudan and extends to the north into Egypt and Libya. The oldest rocks in the study area belong to the Basement Complex System (Whiteman, 1971). They consist of granites, gneisses and schists which crop out at the surface outside the area, mainly to the north and the east. The Basement Complex rocks are overlain unconformably by the Nubian Sandstone, which consists mainly of flat-lying or gently dipping rocks made up of continental sediments, which include sandstones, grits, mudstones, and extra-formational and intra-formational conglomerates (Khairalla, 1966; Whiteman, 1971). The Nubian formations are overlain by alluvial deposits of the Blue Nile and the main Nile. The alluvial deposits consist of poorly sorted clays and silts with sandy and gravelly lenses believed to be Quaternary in age (Whiteman, 1971). In some places the alluvial deposits and the Nubian Formation are covered by windblown sands and recent Nile silts.

Groundwater occurs mainly in the Nubian Sandstone Formation and the alluvial deposits of the Niles. The aquifers of the Nubian Sandstone and the alluvial deposits are believed to be hydraulically interconnected (Khairalla, 1966). Two aquifers have been recognized in the Nubian Formation, an upper aquifer of variable thickness (10–300 m) and lower one more than 400 m thick with higher values of transmissibility and permeability (Bureau of Geological Research, 1979). The depth to the saturated zone is variable, ranging from 5 m near the rivers up to 10 m at a distance of about 2.3 km east of the Blue Nile.

MATERIALS AND METHODS

Groundwater samples were collected from 28 locations (Figure 1). The water samples were collected in clean 1 liter polyethylene plastic bottles and stored in a cooler for 24 hours. From each location two water samples were collected, one was acidified with nitric acid for anions determination. Electrical conductivity and pH were determined in the field.

Analysis for the cations Na^{+}, K^{+}, Ca^{2+}, Mg^{2+} was carried out using a Perkin Elmer Atomic Absorption Spectrophotometer (Model 1100). The anions SO_4^{2-}, Cl^{-}, HCO_3 and CO_3^{2-} were analyzed using a Dionex ion chromatograph 2000i.

RESULTS AND DISCUSSION

The results of the chemical analyses are presented in Table (1). Table (2) shows the range in values of each ion and parameter and the World Health Organization (WHO) standards.

The pH ranges from 8.2 to 9.9. Table (1) show that more than 92 percent of the samples had pH values outside the permissible range of 6.5 – 8.5 (WHO, 1984) (more than 8.5). The range of electrical conductivity in the investigated area is between 310 to 5620 umohs/cm. According to Langengger (1990), the importance of electrical conductivity is its measure of salinity, which greatly affects the

Table 1. Chemical Composition of Groundwater in the Study Area *

No.	Locality	pH	E.C.	TDS	T.H.	Ca	Mg	Na	K	HCO_3	CO_3	Cl	SO_4
1	Um Dureiwa	8.8	460.0	362.0	164.2	28.0	22.8	31.0	1.5	244.0	0.0	35.0	58.4
2	Daroshab South	9.1	506.0	340.0	128.1	14.4	22.4	43.0	0.8	256.2	0.0	20.0	58.4
3	Daroshab North	8.6	533.0	356.0	160.2	17.8	28.2	43.0	1.7	231.8	0.0	20.0	69.1
4	Samrab East	9.6	520.0	372.0	138.1	18.4	22.4	110.0	1.0	219.6	0.0	92.2	42.8
5	Halfaya	8.2	470.0	320.6	124.0	61.0	20.0	16.0	3.4	237.0	0.0	5.3	12.0
6	Um Dawanban	9.7	818.0	508.0	148.0	16.0	26.2	110.0	4.0	256.2	12.0	30.0	72.4
7	Abu Groon	9.6	1203.0	734.0	146.0	12.0	28.2	187.2	3.0	122.0	0.0	250.0	210.0
8	Eid Sharoam	9.8	964.0	626.0	168.0	16.8	75.0	1.2		268.4	0.8	92.8	134.1
9	Sh.Mustafa Amin	9.9	1033.0	628.0	242.0	20.8	46.2	190.0	1.5	256.2	0.0	114.0	94.6
10	Hillat Kuku Inst.	9.8	310.0	256.0	120.0	16.8	18.9	17.0	0.5	122.0	0.0	35.0	77.4
11	El Direisab	9.9	825.0	500.0	132.0	14.4	23.3	150.0	4.0	219.6	6.0	124.0	108.0
12	Idd Um Dom	9.6	734.0	434.0	100.0	11.2	17.5	51.0	6.3	122.0	0.0	132.0	91.4
13	Es Sutra	9.9	461.0	286.0	92.0	10.4	16.4	35.0	6.3	97.0	0.0	106.4	64.2
14	El Hur	9.4	844.0	512.0	108.0	13.6	17.9	51.0	7.3	97.6	0.0	99.3	119.3
15	Um Usheira	9.9	1402.0	872.0	118.0	15.2	19.4	107.5	7.8	207.4	0.0	350.0	194.2
16	Yafa	9.4	4300.0	3038.0	300.0	56.0	38.0	215.0	13.0	122.0	0.0	756.0	664.0
17	Idd Babikir North	8.5	446.0	312.0	128.0	17.6	20.4	58.0	1.0	183.0	0.0	70.9	78.0
18	Galaat Duggo	8.7	1536.0	914.0	172.0	27.2	25.2	107.5	1.5	158.6	3.0	230.4	232.0
19	Sh. A/Rahman	8.8	797.0	430.0	134.0	20.0	20.4	53.0	3.0	170.8	0.0	116.9	27.0
20	Gabarona	9.0	1190.0	997.0	176.0	16.8	52.6	147.5	2.5	414.8	9.0	340.6	567.8
21	Hattab	8.6	1413.0	864.0	176.0	24.0	28.2	87.5	1.0	170.8	0.0	226.8	223.0
22	El Shafeiab	8.8	534.0	288.0	138.0	21.6	20.4	36.0	1.0	170.8	0.0	88.6	52.7
23	Allogab	8.8	343.0	281.6	266.3	36.0	42.7	215.0	0.8	195.2	15.0	288.4	580.0
24	Kadaro	8.6	387.0	308.0	170.0	21.6	28.2	25.0	0.9	231.8	0.0	25.0	69.0
25	Um El Qura	8.7	512.0	346.0	150.2	14.4	27.7	35.0	0.7	244.0	3.0	49.6	57.6
26	Kadaro Mil.Camp	8.8	887.0	616.0	154.2	14.4	28.7	52.0	0.9	292.8	12.0	88.6	129.2
27	Sh.Amin Balla	9.2	5620.0	3800.0	365.0	63.0	53.0	232.0	5.0	120.8	-	798.0	680.0
28	Saeed Factory	-	705.0	470.0	220.0	54.0	20.0	36.2	0.0	224.7	-	68.0	139.0

* All concentrations in ppm except E.C. in umohs/cm and pH.

Table 2. Range of Values of Chemical Parameters from the Study Area and WHO Guidelines for Drinking Water*

Parameter	Range	Mean	Accept. Level[a]	Max. perm. Level[a]
Ca^{2+}	10.4-63	24.05		200.0
Mg^{2+}	16.4-53	27.35		
Na^{+}	16.0-232	89.87		200.0
K^{+}	0.0-7.8	3.2		
HCO_3^-	97.0-414.8	202.3		
SO_4	12.0-680	175.2		400.0
NO_3^-	0.00-0.55	--		
Cl^-	5.3-798.0	176.9		250.0
Total Hardness	365.0-92.0	165.7		
TDS.	281.6-3800	706.1		
Elect. Conduct.	310-5620			1000.0
pH	8.2-9.9		6.5	8.5

*All values in ppm except E. C. (umohs/cm), and pH. ([a]) WHO (1984).

taste and thus has a significant impact on the user's acceptance of the water as potable. According to Mallevialle and Suffer (1987), the single most important class of consumer complaints with regard to water supplies are related to taste and odor problems. A look at Table (1) indicates that all the electrical conductivity values are far below the WHO guidelines (1984) of 1400 uS/cm, except at certain localities namely boreholes 15, 16, 18, 21, and 27.

Sodium ions occur in small concentrations exceeding the WHO guidelines for drinking water at borehole 27 (Elsheikh Elamin Balla), where it reaches a concentration of 232 ppm. The average concentration of Ca and Mg are 24.05 and 27.35 respectively, while those of Na and K are 89.87 and 3.2 respectively.

These cations are possibly derived from chemical weathering of the feldspars and micas which are some of the minerals characterizing the rocks of the area (Nubian Sandstone Formation). These ions are among species that are constantly involved in cation exchange processes and interaction with aquifer materials (Mercado, 1985).

Sulfate concentration in the area is low and does not pose a water quality problem except at certain localities, namely boreholes 16, 20, 23 and 27 where it exceeds the WHO guidelines (1984). These localities lie in a northwest to southeast trending zone in the area.

Chloride ions have a wide range between 5.3 to 798 ppm, with an average value of 176.9. The high concentration of chloride ions is an indication of groundwater salinity, and high salinity in the area occurs at boreholes 7, 15, 16, 20, 23, and 27. These wells lie approximately in a northwest to southeast trending zone, and they are the same ones which have the high sulfate concentration.

QUALITY AND USABILITY OF GROUNDWATER

The quality of groundwater is a function of physical, chemical and biological parameters, so there are different water quality standards for various purposes (WHO, 1984). Geology also imposes its chemistry on the groundwater system i.e., the aquifer material has its effect on the groundwater chemistry.

Drinking water standards are generally based on two main criteria (Davis and De Wiest, 1966): (1) presence of objectionable taste, odors and color; and (2) presence of substances with adverse physiological (health) effects. Results of hydrochemical analysis in the study area showed that the groundwater is chemically potable and suitable for domestic and agricultural uses, except at certain localities, which have high concentrations of certain ionic species, higher than the maximum acceptable limits of the WHO standards (Table 2). As an example see high Na and Cl ions at boreholes 16, 23 and 27.

The suitability of groundwater in the for irrigation has been determined using a modified Wilcox classification model (Table 3).

Table 3. Modified Wilcox Quality Classification of Irrigation Waters*

Water class	**Na^+ (%)**	**Elect. Cond. μmhos/cm**	**Salinity hazard**
Excellent	20	250	Low
Good	20-40	250-750	Medium
Permissible	40-60	750-2000	High
Doubtful	60-80	2000-3000	Very high

*Data source Todd (1980).

Irrigation water quality is dependent upon its specific electrical conductance, relative proportion of sodium ions to other cations, types of plants, soil and climate. On the basis of the Wilcox modified classification, the groundwater in the study area can be classified as follows:

1. Good irrigation water with medium salinity, i.e. electrical conductivity between 250-750 umohs/cm and low TDS, represented by boreholes 1, 2, 3, 4, 5, 10, 13, 17, 22, 23, 24, 25, and 28. They represent 46 percent of the boreholes in the area and generally are located at the north.

2. Permissible irrigation water with high salinity, i.e. with electrical conductivity ranging between 750-2000 and with acceptable TDS, represented by boreholes 6, 7, 8, 9, 11, 12, 14, 15, 18, 19, 20, 21 and 26. They represent 46 percent of the boreholes in the study area. These boreholes are mainly found in the area east of the Blue Nile, and east of boreholes 16 and 26.

3. Doubtful irrigation water with electrical conductivity more than 2000 (with very high salinity) and with very high TDS, greater than 3000 ppm, together with high Na and Cl ions outside the permissible levels of the WHO (1984). This water type is found at boreholes 16 and 27. Because of the high Na ion concentrations in this water it is unfit for irrigation purposes because Na reacts with the soil and reduces its permeability.

HYDROGEOCHEMICAL FACIES

The concept of hydrogeochemical facies has been used to denote the diagnostic chemical character of water solutions in hydrogeologic systems (Back, 1966). These facies reflect the effect of chemical changes which occur as water moves through the different lithologic strata, the hydrogeochemical facies of the study area showed that there are three types of groundwater in the study area:

1. Saline water type, which is sodium–chloride–sulfate ($Na–Cl–SO_4$). It is found at boreholes 16, 20, 23, and 27 in a northwest to southwest trending zone in the study area.

2. Calcium–magnesium–bicarbonate ($Ca–Mg–HCO_3$) water type, which is found at boreholes 5, 10, and 24 near the recharge areas adjacent to the Nile and the Blue Nile.

3. Sodium–calcium–magnesium-bicarbonate ($Na–Ca–Mg–HCO_3$) water type which is found at a wide range of boreholes representing the transitional zone between the recharge area (the Nile and the Blue Nile area) and ElSheikh El Amin Balla area. As examples see boreholes 19 and 11.

CONCLUSIONS

On the basis of analytical results obtained from the groundwater geochemistry the following can be concluded:

- The groundwater in the area is potable and good for domestic and other uses except at certain localities.

- In all boreholes the pH is greater than 8.5 except at borehole no. 5 (Halfaya). The water is basic or alkaline with pH exceeding the maximum permissible level of the WHO (1984) standards for drinking water.

- The high salinity in the area can be explained as being due to localized hydrogeological processes.

There are three hydrogeochemical facies in the area, (1) sodium-chloride-sulfate, (2) calcium-magnesium-bicarbonate, and (3) sodium-calcium-magnesium-bicarbonate.

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REFERENCES

Bureau of Geological Research (1979). Ground water resources in Khartoum Province, Part II, Fed. Inst. Geosci., Nat. Resources, Hannover.

Davis, S.N. and R.J.M. De Wiest (1966). Hydrogeology, New York: John Wiley and Sons.

Haggaz, Y.A.S. and M.K. Khairallah (1988). Paleohydrology of the Nubian Aquifer North East of the Blue Nile, near Khartoum, Sudan, J. Hydrology, 99: 117-125.

Khairallah, M.K. (1966). A study of the Nubian Sandstone Formation of the Nile Valley between latitude 14º N and 17º 42´N with reference to ground water geology, Msc. Thesis, University of Khartoum.

Langenegger, O. (1990). Ground water quality in rural areas of western Africa. UNDP-Project INT/81/ 026, 10 pp.

Mallevialle, I. and O.H. Suffer (1987). Identification and treatment of taste and odors in drinking water, Denver: American Water Works Association Research Foundation, Lyonnaise des Eaux.

Mercado, A. (1985). The use of hydrogeochemical patterns in carbonate, sand and sandstone aquifers to identify intrusion and flushing of saline water. Groundwater 23:635-645.

Todd, D.K. (1980). Groundwater Hydrology, 2nd edition, John Wiley, New York.

Whiteman, A.J. (1971). The Geology of the Sudan Republic, Clarendon, Oxford.

WHO (1971). International Standards for Drinking Water (2nd edition), World Health Organization, Geneva.

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