Groundwater Quality and Hydrogeologic Conditions in the Khartoum Area, Sudan

Elfatih Abdalla Farah

Department of Geosciences, Faculty of Science, Osaka City University
Osaka 558-8585, Japan

Abstract

The purpose of this paper is to evaluate the groundwater quality in the Khartoum area based on geological, hydro­logical, and hydrochemical investigations. The study area is occupied mainly by the Upper Gezira Formation, where mudstone layers, and calcareous nodules, matrix, and thin layers tend to increase in percentage towards the center of the area.

The groundwater flow-net of the study area represents a groundwater trough. Groundwater in each of the two aquifers of the area seems to have inherited its physico-chemical properties from the hosting sedimentary formations. The total dissolved solids, electrical conductivity, carbonate hardness, total hardness, and sodium-adsorption ratio values tend to increase towards the central zone (i.e., Soba saline zone). It is fresh, soft, and free from objectionable properties related to the drinking and irrigation uses, except in the Saba saline zone, where it is not fit for use. Extraction from only the lower aquifer is recommended within the saline zone.

Key words: Groundwater, Quality, Suitability, Salinity, Sudan

1. Introduction

In this paper, the author attempts to evaluate the quality of the groundwater and the related hydrogeologic conditions beneath the capital of Sudan. Khartoum city lies between the confluent Blue and White Niles in the arid central Sudan (Fig. 1), where the mean annual precipitation is 140 mm (1899-1989), and the mean monthly evaporation and relative humidity ranges are 14-23 mm and 16-49 %, respectively (1961-1990). This most populous region in the country is facing a demand for an additional water resource due to its rapid expansion far away from the Niles, and the consequent high cost of the infrastructures required to purify and transfer the Nile water. As a consequence, groundwater is utilized in the region for domesticity, irrigation, and industry. Development in this region depends largely on the availability of sufficient amounts of fresh water.

One of the main obstacles facing research on the groundwater resources of the Khartoum area is the incompleteness and inadequacy of geological and hydrogeological data. Hence, a preliminary evaluation of the groundwater quality is urgently needed for proper planning.

To achieve the proposed objective, the data of 61 boreholes were studied (Table 1). The investigated boreholes range in depth from 38 to 283 m, with an average depth of 94 m. The borehole data include: locations; lithological logs; well designs; depths to the piezometric water level; and physical and physico-chemical properties of water samples. For measuring the physical and physico-chemical properties, the water samples were taken after the development of the borehole, and sent immediately to the laboratory for analysis. The measurements include: electrical conductivity (EC); total dissolved solids (TDS); acidity (pH); carbonate hardness (CH); total hardness (TH); and sodium-adsorption ratio (SAR), which is calculated using the relation: SAR = Na (0.5 (Ca + Mg))0.5 defined by the US Salinity Laboratory Staff (1954).

2. General geology and hydrogeology

The study area is part of the Khartoum sub-basin (Fig. 2) that is situated at the northern periphery of the Blue Nile rift basin. This sedimentary sub-basin is elongated in a NW-SE trend, where the Pan-African Basement Complex bounds it on the northeast and southwest, and forms its bottom limit at a depth which reaches more than 500 m (Kohnke et al. 1993).

The sedimentary formations encountered during drilling activity in the area are in the following chronological order: Omdurman Formation, Lower Gezira Formation, Upper Gezira Formation, and Holocene alluvial deposits (Figs 2 and 3). The Upper Gezira Formation crops out in most of the study area. Its thickness varies from 0 at Jebel Aulia, and a few meters in the northern part of the study area to more than 100 m at the center of the southern part where it reaches its maxi-
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Jebel Aulia Reservoir

Fig. 1. Location, geologic and physiographic map of the Khartoum area showing the investigated boreholes screened in the upper (open circle) and lower (filled in circle) aquifers.

The upper one, which is partially confined, includes mainly the Upper Gezira Formation, the uppermost part of the Omdurman Formation and the alluvial deposits; 2) the lower one, which is mostly confined, is developed mainly in the Lower Gezira Formation and the lower part of Omdurman Formation (see Farah et al. 1997). The thickness of the upper aquifer increases southwards up to 120 m, whereas that of the lower one varies between 150 and 300 m (Kohnke et al. 1993). The depth to the top of the lower aquifer exceeds 300 m, except in the northern part where it is less than 50 m. Although the lower aquifer possesses relatively higher productivity and water quality (GMRDS and FIGNPRG 1979; Farah et al. 1997), the upper one is the mostly utilized due to its relative economic potentiality. Therefore, more consideration has been given to the upper aquifer in this study and, consequently, to the Upper Gezira Formation.
Fig. 2. Geology of the Khartoum subbasin (from GMRDS, 1981).
Fig. 3. Sedimentary sequence of the study area. Locations of the cross-sections are shown in Fig. 1.

Fig. 4. Map of the piezometric water level contours (in m a.s.l.) comprising the Soba trough. Arrows indicate the direction of groundwater flow.


3. Lithological characteristics

Although the Upper Gezira Formation is dominated by sands, which represent 57 percent (Farah et al. 1997), the percentage of the successively intercalated thin mudstone layers ranges from 0 at the southern part of the study area to the maximum of 82 percent of the sedimentary succession in the center (Fig. 5a). Calcrete is characteristic for this formation. It spreads all over the formation in considerable amounts in the form of nodules, matrix and beds. The lateral distribution of the calcareous layers, as well as other layers that include considerable amounts of calcrete as matrix or nodules, tends to increase towards the center of the area. It reaches the maximum of 60 percent of the whole thickness of the formation at the heart of the area (Fig. 5b). The general trend of the zone with high percentage of mudstone and calcrete is NW-SE (Fig. 5), which is in good agreement with that of the Khartoum sub-basin (Fig. 2). According to Salama (1997), the widespread presence of calcrete and other carbonate deposits, over and in most of the Tertiary deposits of central Sudan, showed that conditions were favorable for the deposition of carbonates; they were products of successive processes of evaporation and leaching by floods.

4. Physical and physico-chemical characteristics

4.1 Lateral distribution

The amount of the total dissolved solids (TDS) in the water of the upper aquifer increases towards the center of the area. It is less than 200 mg/L near the Niles and up to more than 1200 mg/L in the center (Table 1 and Fig. 6). According to the classification by Robinove et al. (1958), which is based on the total dissolved solids, a restricted zone of slightly saline water (>1000 mg/L) within the upper aquifer is observed in the center of the area around boreholes 32 and 33 in a zone known as the Soba saline zone. With exception of this zone, the groundwater stored in the upper aquifer is fresh (<1000 mg/L).

The electrical conductivity (EC) values of the upper aquifer water show a lateral distribution almost similar to that of the total dissolved solids. It ranges from less than 250 μS/cm near the Niles to more than 1500 μS/cm in the Soba saline zone (Table 1 and Fig. 6).

The total hardness (TH) of the groundwater stored in the upper aquifer ranges from moderately hard (61–120 mg/L) around the two Niles to very hard (>180 mg/L) along the central axis of the area (Table 1 and Fig. 6), based on the Durfor and Becker (1964) classification of water hardness. The carbonate hardness (CH) shows its highest content (more than 500 mg/L) in the central zone.

The sodium-adsorption ratio (SAR) also tends to increase towards the central zone. While it is less than 3 cm near the Niles, it reaches the maximum of 26 cm in the Soba saline zone (Fig. 6 and Table 1).

4.2 Dependence of the hydrochemical properties on the hydraulic and lithologic characteristics

Although fresh and soft water from the Blue and White Niles, the source of the groundwater recharge, infiltrates into the aquifer system of the area, a clear reduction of the water quality increases with distance from the Niles within the up-
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Table 1. Data used in this study

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**Notes:**
- DPS: depth to piezometric surface; Calc.: layers include calcareous material; EC: electrical conductivity; TDS: total dissolved solids; CH: carbonate hardness; TH: total hardness; SAR: sodium-adsorption ratio.
- DrS: depth to piezometric surface; Calc.: layers include calcareous material; EC: electrical conductivity; TDS: total dissolved solids; CH: carbonate hardness; TH: total hardness; SAR: sodium-adsorption ratio.
Fig. 6. Areal distribution of the physico-chemical properties of groundwater in the upper aquifer. TDS: total dissolved solids; EC: electrical conductivity; CH: carbonate hardness; TH: total hardness; SAR: sodium-adsorption ratio.
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per aquifer. The increase of the different dissolved constituents in the upper aquifer is in a good correlation with the increase of mudstone and calcite percentages within the hosting sedimentary sequence. Groundwater in contact with clay and shale often becomes saline and poor in quality because clay and shale often contain veins and nodules of gypsum and rock salt, which are highly soluble (Mazor, 1991). "... the alkalinity of natural waters can be assigned entirely to dissolved bicarbonate and carbonate without serious error" (Hem, 1992). Another factor to be considered is the groundwater movement, which is evident to be relatively slower in the central zone as it is far from the recharge source, allowing the dissolution of the soluble salts from the bearing sedimentary formation.

It can be concluded therefore that groundwater in the study area inherited its mineralization mainly from the mudstone, clay, and calcite intercalated within the hosting sedimentary formations. This interpretation is in a good agreement with that of Salama (1985; 1987; 1994; 1997) who interpreted the presence of highly saline groundwater bodies at the flowing end of each of the rift systems in Sudan as buried saline lakes, sabkhas, or playas.

4.3 Suitability of groundwater for drinking and irrigation

As an exception from the other parts of the study area, groundwater in the saline zone of the upper aquifer exceeds the TDS standard for drinking water (1000 mg/L) adopted by WHO (1984) and that of level A of the Sudanese National Standards recommended by the Sudanese Ministry of Health (1982) (Fig. 6).

The TDS and SAR in the upper aquifer exceed the threshold concentrations of 500 mg/L and 6 epm, respectively, for irrigation water, recommended by Todd (1970). They even exceed the limiting concentrations of 1500 mg/L and 15 epm, respectively, at the saline zone. Based on the classification of irrigation water proposed by the US Salinity Laboratory Staff (1954), the salinity hazard increases gradually from low near the two Niles to high at the central zone, whereas the sodium hazard is dominantly low all over the area except within the central zone, where it varies from medium to very high (Fig. 7).

The lower aquifer, where it is utilized in the northern and southeast parts of the study area, shows no restrictions for drinking or irrigation purposes (Table 1 and Fig. 7).

5. Conclusions and recommendations

The aquifer system of the study area consists of two aquifers. The upper aquifer includes mainly the Upper Gezira Formation. The lower aquifer is developed mainly in the Lower Gezira Formation and the lower part of the Omdurman Formation. The groundwater flow-net of the study area represents a groundwater trough whose bottom is around the central zone.

The lateral distribution of the groundwater mineralization is in a good correlation with the percentage of mudstone,
clay, and calcrite intercalated within the hosting sedimentary rocks. Both of them tend to increase towards the central zone. As a consequence, a slightly saline groundwater occupies the central zone within the upper aquifer, namely, the Soba saline zone, where the total dissolved solids, electrical conductivity, carbonate hardness, total hardness, and sodium-adsorption ratio show their highest values. Hence, groundwater in the study area inherits its mineral-content mainly from the hosting sedimentary formations.

Groundwater in the study area is fit for drinking and irrigation purposes except in the Soba saline zone. Therefore, extraction from only the lower aquifer with sealing of the upper one is recommended within the saline zone.

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References


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