Evaluation of groundwater resources in Tokar Delta, Sudan

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ABSTRACT An estimate is given of the groundwater resources in Tokar Delta, an area lying on the Sudanese coast of the Red Sea; and the quality of these resources is assessed.

INTRODUCTION

Tokar Delta is a semiarid region on the Sudanese coast of the Red Sea, located between latitudes 18°00' and 18°45'N and longitudes 37°15' and 38°30'W (Fig.1). The surface area of the delta is about 1450 km², and it is fed by an intermittent stream called Khor Baraka. The Khor Baraka basin covers an area of about 4645 km², has a circumference of about 1050 km and lies on the Precambrian-Cambrian crystalline Basement Complex. This catchment drains the Red Sea Hills which are situated partly in Sudanese territory and partly in Erythrean territory. The Khor Baraka basin has a compacity index (defined as the ratio of basin perimeter to the circumference of a circle with area equal to that of the basin) of 1.38, an average altitude of 1300 m, an average slope of 6.2 m km⁻¹, a drainage density of 0.0125, an average depth of rainfall of 252 mm year⁻¹, most of which falls between April and September, and an average evapotranspiration of 237 mm year⁻¹ compared with a potential of 1548 mm year⁻¹. The annual surface runoff has varied from 205 to 960 x 10⁶ m³, with an average runoff equivalent to 13.45 mm over the basin.

HYDRODYNAMICS OF THE AQUIFER

Groundwater occurs in Tokar Delta in clastic sediments deposited in an arcuate prograding delta in which there are lagoons and barrier islands (Tahir Hussein, 1980). It occurs at a depth of 7-9 m in the upstream part of the delta, at 10-12 m in the centre and at 3-6 m in the downstream portion of the delta. The general flow is parallel to the direction of the surface flow, i.e. from SSW to NNE and from SW to NE (Fig.2). The main recharge is from the waters of the Khor Baraka and other small ephemeral streams.
The hydraulic gradient obtained from Fig. 2 averages 0.002; in the upstream portion it is 0.0046, in the centre it ranges between 0.005 and 0.001, and downstream it is about 0.0005.

Transmissivity and storage coefficients were obtained from four pumping tests in observation wells near Doulaybyai, Krimbit (upstream), Tebelanai (centre) and Eqlim (downstream of the delta). Three methods were used to obtain the transmissivity and storage coefficient from the pumping test data. First the Theis and Jacob methods were applied; most of the resulting curves showed a drainage effect and thus conditions were favourable for application of Boulton's method, the results of which are summarized in Table 1. The wide range of transmissivity values reveals the heterogeneous nature of the sediments: low values ($1 \times 10^{-3} \text{m}^3\text{s}^{-1}$) in the lagoons and downstream area due to the accumulation of fine sediments, and higher values ($1 \times 10^{-2} \text{m}^3\text{s}^{-1}$) are attributed to the barrier islands and the upstream portion of the delta due to the presence of coarser materials. The storage coefficient varies from about 0.003.
in the lagoonal zones to 0.26 in the barrier islands and upstream sediments.

The hydrodynamic data are characteristic of an unconfined aquifer in the upstream portion of the delta that fingers downstream in semi-confined conditions.

Table 1  Average values of transmissivity and storage coefficient in Tokar Delta

<table>
<thead>
<tr>
<th>Borehole</th>
<th>Theis's method</th>
<th>Jacob's method</th>
<th>Boulton's method</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$T$ (m$^2$/s)</td>
<td>$S$</td>
<td>$T$ (m$^2$/s)</td>
</tr>
<tr>
<td>Doulayai (a)</td>
<td>5.26 x 10^{-3}</td>
<td>0.058</td>
<td>9.23 x 10^{-3}</td>
</tr>
<tr>
<td>Doulayai (b)</td>
<td>1.06 x 10^{-2}</td>
<td>0.074</td>
<td>1.12 x 10^{-1}</td>
</tr>
<tr>
<td>Krimbit</td>
<td>8.7 x 10^{-2}</td>
<td>0.135</td>
<td>1.22 x 10^{-1}</td>
</tr>
<tr>
<td>Tebelanai</td>
<td>1.08 x 10^{-2}</td>
<td>0.263</td>
<td>4.75 x 10^{-2}</td>
</tr>
<tr>
<td>Eglim (a)</td>
<td>1.0 x 10^{-2}</td>
<td>0.125</td>
<td>3.27 x 10^{-2}</td>
</tr>
<tr>
<td>Eglim (b)</td>
<td>1.62 x 10^{-2}</td>
<td>0.135</td>
<td>1.57 x 10^{-2}</td>
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</tbody>
</table>
QUALITY OF GROUNDWATER IN TOKAR DELTA

Because studying the water chemistry helps in the understanding of the hydrogeology of the aquifer as well as the distribution of good quality water, the amount of total dissolved solids (TDS) was

Fig. 3 Distribution of total dissolved solids in Tokar Delta groundwaters.
measured in all wells available in the delta; in addition, data were used from a complete analysis of the water carried out by the Rural Water Department of Khartoum.

As the water in the delta suffers from contamination by sea water, it is useful to distinguish areas of such contamination from areas of potable water suitable for human and animal consumption. At the same time it is useful to study the fresh water/sea water interface in the deltaic sediments of Tokar. Using the TDS distribution (Fig.3) and the chloride distribution (Fig.4) we identified the following zones in Tokar Delta (Fig.5):

**Zone I: The area contaminated by sea water** This zone occupies an area extending inland to within 30 km of Eglim, at an altitude of 23 m a.m.s.l. The TDS exceeds 2000 mg l\(^{-1}\) and the chloride content is 20 meq l\(^{-1}\).

**Zone II: The transition zone between sea water and continental waters** This zone occupies an area of about 10 km wide between 30

![Fig. 4 Chloride concentrations in Tokar Delta groundwaters.](image)
Fig. 5 Water quality zones in the Tokar Delta.

and 40 km from the coast at altitudes of between 20 and 30 m a.m.s.l. The TDS is between 1000 and 2000 mg l\(^{-1}\). Any further drilling should be avoided in this zone to prevent sea water intrusion from moving further inland and thus causing serious contamination of the aquifer.

**Zone III: The fresh water zone** This area includes the upstream portion of the delta extending from the apex to the Krimbit region. The TDS ranges between 520 and 1000 mg l\(^{-1}\); the chloride content ranges from 0.08 to 10 meq l\(^{-1}\). This zone covers an area of about 230 km\(^2\).

**Zone IV:** This represents what the sedimentological studies (Tahir Hussein, 1980) defined as the lagoonal area in Tokar Delta. The TDS exceeds 3000 mg l\(^{-1}\) but there is no corresponding increase in chloride concentration. The salinity is thus attributed to the depositional regime and not to sea water intrusion.
STATIC WATER RESOURCES IN TOKAR DELTA

The volume of water that accumulates annually above the lowest level attained in the aquifer can be estimated as follows:

\[ dv = dh \ p \ A \]

where \( dh \) is the variation in water level (m), \( p \) is the effective porosity of the aquifer, and \( A \) the surface area (m\(^2\)).

For the fresh water zone the short term fluctuations in water level were measured and found to be 1.5 m, the effective porosity is 16\% and the surface area \( 230 \times 10^6 \text{m}^2 \). Thus \( dv = 55.2 \times 10^6 \text{m}^3 \text{ year}^{-1} \). This volume represents the amount of fresh water that can be exploited safely from the aquifer of the Tokar Delta.

Comparison of this amount with the surface runoff shows that the recharge comes mainly from infiltration of seasonal floods, and that underground flow is small.

CONCLUSION

Groundwater occurs in the sediments of Tokar Delta in an arcuate prograding delta in which lagoonal zones and barrier islands can be distinguished. The groundwater occurs at an average depth of 7 m in an unconfined aquifer with a trend to semiconfined conditions towards the downstream part of the delta. The transmissivity ranges between \( 1 \times 10^{-3} \text{m} \text{s}^{-1} \) and \( 1 \times 10^{-1} \text{m} \text{s}^{-1} \) and the storage coefficient varies from 0.003 to 0.26.

Tokar Delta is divided into four zones: a fresh water zone, a transitional zone, a zone of sea water intrusion and a low yielding lagoonal zone with bad quality water. The quantity of water that can be safely exploited is \( 55.2 \times 10^6 \text{m}^3 \text{ year}^{-1} \).

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REFERENCES


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