Assessment of the renewable groundwater resources of Wadi El-Arish, Sinai, Egypt: modelling, remote sensing and GIS applications

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Abstract Recharge of the alluvial aquifers flooring Wadi El-Arish in central and northern Sinai, Egypt was investigated. A hydrological model that combined the spatial and temporal distribution of rainfall, suitable infiltration parameters, and appropriate sub-basin unit hydrographs to estimate rainfall excess, transmission losses along stream networks, and downstream runoff was developed. The Wadi El-Arish watershed receives an annual average rainfall of \(981.3 \times 10^6\) m\(^3\) in the rainy season (November–March) of which our model indicates that \(938.7 \times 10^6\) m\(^3\) is the initial upstream loss, \(32.5 \times 10^6\) m\(^3\) is the transmission loss recharging the alluvial aquifers flooring the stream network, and \(10.1 \times 10^6\) m\(^3\) is downstream runoff.

Key words alluvial aquifer; arid region; groundwater recharge; Landsat TM, remote sensing; Sinai, transmission losses

INTRODUCTION

Sporadic storms over the Sinai hills (Egypt) are channelled as surface runoff and subsurface waters through a network of minor valleys, which join into a few valleys that ultimately drain towards the Mediterranean Sea, the Gulf of Suez, or the Gulf of Aqaba. The largest of these drainage basins is the Wadi El-Arish watershed (22,000 km\(^2\)), which collects over 60% of Sinai’s precipitation. We constructed a hydrological model to calculate initial upstream loss, transmission loss, and downstream runoff for the Wadi El-Arish watershed. The model integrated Landsat Thematic Mapper (TM), Digital Terrain Elevation (DTED), meteorological, and geological data in a geographic information system (GIS) environment.

METHOD

Digital mosaics were generated and co-registered. Three data sources were used: three-arc-second DTED, TM data (Fig. 1(a)), and geological maps. Watersheds and channel networks (Fig. 1(b)) were then delineated from the DTED and verified by comparison to co-registered TM scenes and geology maps. Monthly mean precipitation values averaged between 1920 and 1980 mm (Legates & Wilmott, 1997) and an archival
Fig. 1 (a) Mosaic of four Landsat TM band-5 images covering the Precambrian volcanic-sedimentary rocks cropping out in southern Sinai (dark) and the Cretaceous and Tertiary outcrops (bright) to the north, which are largely composed of sandstone and limestone, respectively. The outlet of Wadi El-Arish, covered by box A, is enlarged in Fig. 2. (b) Distribution of watersheds and streams network in Sinai Peninsula. Also shown are the areas (in km²) covered by the identified watersheds.

Hyetograph were adopted as input to the hydrological model. We assumed a single rain event for each month. The US Soil Conservation Service (SCS) curve number method (SCS, 1985) was adopted to calculate upstream initial losses in the sub-basins. Soils were classified into three types: Quaternary valley deposits as type A; Nubian Sandstone (NSS) as type B; and massive Tertiary limestone and basement rocks as impervious areas. Runoff calculations were enabled by adopting the SCS unit hydrograph (SCS, 1985) and by using the Riverside County lag-time equations for mountainous, foothill, and valley areas (Riverside County Flood Control, 1978). Channel routing was conducted by using the Muskingum routing method (McCarthy, 1938), whereby the average Manning's coefficient for gravel bed rivers was calculated according to procedures developed by Jarrett (1984). We adopted expressions developed for a similar arid environment (Saudi Arabia) to calculate transmission losses (groundwater recharge) in the stream networks from the known volume of runoff upstream (Walters, 1990). The aerial extents of soil types and various geomorphic features (valleys, mountains, and foothills) were identified from co-registered TM, DTED, and geological digital mosaics.
DISCUSSION AND RESULTS

We identified 18 watersheds across Sinai, the largest (22,000 km$^2$) of which is the Wadi El-Arish watershed (Fig. 1(b)). Each of the El-Watir, Awag, Girafi, Dahab and Kid watersheds covers an area of 1500–3500 km$^2$, and each of the remaining 12 watersheds covers an area less than 1500 km$^2$. The hydrological model was applied to calculate the upstream initial loss, transmission loss, and runoff in the Wadi El Arish watershed for each of the rainy months of November, December, January, February and March (Table 1).

Average annual recharge rates for the El-Arish aquifer were obtained by adding the transmission losses deduced for the five rainy months (Table 1). Our estimate for the annual recharge rate ($32.5 \times 10^6$ m$^3$) is conservative because it is based on average monthly precipitation values, whereas in reality rain storms in Sinai are more likely to occur as infrequent events or as rare large or extreme events. Large (26 mm) and extreme (76 mm) rainstorms were reported to occur once every ten years and sixty years, respectively in the St Catherine area (JICA, 1999). Assuming that these rare events cover an area 150 km long and 50 km wide, centred on St Catherine, we found that the recharge and initial losses from the 60-year events (76 mm) are sub-equal, each amounting to approximately 50% of the total precipitation. Considerably lower
Table 1 Results of hydrology model for Wadi El-Arish watershed (all values $\times 10^6$ m$^3$).

<table>
<thead>
<tr>
<th></th>
<th>Total precipitation</th>
<th>Upstream losses</th>
<th>Transmission losses</th>
<th>Downstream runoff</th>
</tr>
</thead>
<tbody>
<tr>
<td>November</td>
<td>144</td>
<td>139.6</td>
<td>4</td>
<td>0.4</td>
</tr>
<tr>
<td>December</td>
<td>202.5</td>
<td>192.7</td>
<td>5.7</td>
<td>4.1</td>
</tr>
<tr>
<td>January</td>
<td>201.1</td>
<td>192.4</td>
<td>4.6</td>
<td>3.1</td>
</tr>
<tr>
<td>February</td>
<td>270.6</td>
<td>254.4</td>
<td>14</td>
<td>2.2</td>
</tr>
<tr>
<td>March</td>
<td>163.1</td>
<td>158.6</td>
<td>4.2</td>
<td>0.3</td>
</tr>
<tr>
<td>Average annual</td>
<td>981.3</td>
<td>938.7</td>
<td>32.5</td>
<td>10.1</td>
</tr>
<tr>
<td>10-year event (26 mm)</td>
<td>92.8</td>
<td>63</td>
<td>29.5</td>
<td>0.3</td>
</tr>
<tr>
<td>60-year event (76.2 mm)</td>
<td>271.9</td>
<td>131.8</td>
<td>135.4</td>
<td>4.8</td>
</tr>
</tbody>
</table>

recharge (32% of precipitation) and higher initial losses (68% of precipitation) were computed for the relatively smaller (26 mm), 10-year events (Table 1). Unfortunately, records for the temporal and spatial distribution of these infrequent-to-rare events are incomplete and thus could not be used to evaluate the recharge of the Wadi El-Arish alluvial aquifer. Future studies will benefit from Egypt’s current efforts to further develop Sinai’s meteorological network. A fairly large (100 km$^2$) depression outlined by the 200-m contour on Fig. 2 at the outlet of Wadi El-Arish could potentially be used to enhance both the recharge of the alluvial aquifer under investigation and local agricultural activity (e.g. area B on Fig. 2) if the outlet (point C on Fig. 2) of the depression was dammed.

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REFERENCES


