Impact of flash flood on development potentials of Wadi Abu Ghusun, Eastern Desert, Egypt

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ABSTRACT

Groundwater is a significant water supply source in arid and semi-arid areas. It plays an important role in the construction of new communities. As communities grow and land use becomes more intensified, there are greater demands on groundwater resources. Effective groundwater management requires a clear understanding of the quality, quantity and vulnerability of this valuable resource. The Wadi Abu Ghusun is considered one of the main basins in the Eastern Desert of Egypt. It attracts official attention from several sources, including the Ilmenite mining industry and the World Food Program (WFP) in the context of the development of Bedouin communities.

Continuous development has led to extensive and increasing demand for potable water to match these activities. Therefore, the application of recent techniques in harvesting surface runoff plays a vital role in groundwater replenishment and avoids great damage to human activities, buildings and roads. To achieve these targets, a model of rainfall-runoff processes in an ungauged basin was applied. The rainfall-runoff model was used to calculate the direct runoff volume, peak discharge, and to construct a synthetic hydrograph for the Wadi Abu Ghusun. The flow rate \( Q_p \) of the synthetic hydrograph at Wadi Abu Ghusun was 52.66 m³/sec. and the time to peak \( (t_p) \) was 5.58 hours, whereas the time base \( (t_b) \) is 17.5 hours. The total discharge along the study basin was 1.88x10⁶ m³. Based on topographic maps (1:100,000), twenty two morphometric parameters of Wadi Abu Ghusun were determined. The calculated morphometric parameters as well as the hydraulic parameters indicate reasonable groundwater potentialities. The Qantas systems methods of groundwater management were recommended.

Keywords: Flash flood, Surface hydrology, Groundwater hydrology, Hydraulic parameters.

INTRODUCTION

Egypt has turned to the use of groundwater to satisfy the growing demand for water, though the agricultural groundwater use is not sustainable in drylands...
(Wang & D’Odorico, 2008). The overall trend in population size in this part of the Eastern Desert is toward increase (Andersen & Krzywinski, 2007). The available limited water resources are being outstripped by its increasing population, coupled with attendant increases in need for water. Therefore the application of recent techniques in harvesting surface runoff plays an important role in groundwater replenishment and avoidance of great damage to human activities and infrastructure.


The Wadi Abu Ghusun site is located between latitudes 24°20´ and 24°30´N and longitudes 34°45´ and 35°10´E (Fig.1). The site area is undeveloped and generally inhabited; some houses are located in the site surroundings. Its length is about 38 km, width is about 25 km, and the catchment area is about 323.9 km². The study area, as a part of the Eastern Desert, is classified as one of the driest zone in the world. It suffers from severe aridity. The lack of vegetation cover over the wadi beds results in no protection from raindrop impact, so the overland flow is concentrated by the topography and drains eastward to the Red Sea (Fig.1). Alluvium terraces and flood plains are important landforms along and near the wadi outlet into the Red Sea coastal plain.

This study focused on the Wadi Abu Ghusun, to explore the surface water potential for groundwater artificial recharge using Geographic Information System tools (GIS) and the Flood Routing Processing Model (FRP). Within the GIS environment, we prepared stream networks (Fig.2) and a Digital Elevation Model (DEM) (Fig.3), and computed various hydrologic parameters (e.g., CN, channel length, slope). The FRP model was chosen for the simulation of rainfall-runoff using rainfall data, field measurement of watershed parameters and the Soil Conservation Service (SCS) Curve Number method, which was developed in the United States for small basins (USDA, 1986; USACE, 2000).
Fig. 1: Location of Wadi Abu Ghusun within the Eastern Desert basins.

Fig. 2: Stream network of Wadi Abu Ghusun.
Site description

The geology, geomorphology and hydrogeologic setting of the area of study have been studied by many researchers. Among them are Said (1962), Samuel & Saleeb-Roufaiel (1977), El Bassiouny (1982), Khedr (1984), Montenat et al. (1986), MPGAP (1990), Phillobos et al. (1993) and Khaled (1995).

Wadi Abu Ghusun is made up of igneous, metamorphic and sedimentary rocks ranging in age from Precambrian to recent. (A brief description of these Eras is tabulated in Table 1 and Fig. 4.) Structurally, NE and NW as well as EW faulting systems are the major geologic structures crossing the basin. Fractures, joints and dykes are secondary structures accompanied by major faulting. The investigated area is dissected by a series of rhyolites dykes and quartz crossing the main stream, which have direct control on the water-bearing formations and the water flow. Both faults and joining systems affect to great extent the development of the drainage system within the area.

Table 1: Main rock units in Wadi Abu Ghusun province (after MPGAP, 1990)

<table>
<thead>
<tr>
<th>Lithostratigraphy</th>
<th>Description</th>
<th>Chronostratigraphy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Symb</td>
<td>Description</td>
<td>Stage</td>
</tr>
<tr>
<td>Qd</td>
<td>Sand sheets</td>
<td>Middle</td>
</tr>
<tr>
<td>Qw</td>
<td>Wadi deposits</td>
<td></td>
</tr>
<tr>
<td>Qp</td>
<td>Playas or mud fans</td>
<td></td>
</tr>
<tr>
<td>Qs</td>
<td>Sabkha</td>
<td></td>
</tr>
<tr>
<td>Qr</td>
<td>Coral reefs</td>
<td></td>
</tr>
<tr>
<td>Tmm</td>
<td>Includes fluviatile and</td>
<td></td>
</tr>
<tr>
<td></td>
<td>continental clastics</td>
<td></td>
</tr>
</tbody>
</table>

(Continued on next page...)
Cont. Table 1: Main rock units in Wadi Abu Ghusun province (after MPGAP, 1990)

<table>
<thead>
<tr>
<th>Symb</th>
<th>Description</th>
<th>Chronostratigraphy</th>
</tr>
</thead>
<tbody>
<tr>
<td>gy</td>
<td>Younger granitoids</td>
<td></td>
</tr>
<tr>
<td>go</td>
<td>Older granitoids</td>
<td></td>
</tr>
<tr>
<td>md</td>
<td>Metagabbro-diorite complex</td>
<td></td>
</tr>
<tr>
<td>mv</td>
<td>Geosynclinal Shadli metavolcanics</td>
<td>Pre-Cambrian</td>
</tr>
</tbody>
</table>

Fig. 4: Geologic map of Wadi Abu Ghusun (modified after MPGAP, 1990).

Materials and Methods

The morphometric parameters of the Abu Ghusun drainage basin were used in evaluating the surface water runoff and outline areas of shallow groundwater possibilities (Fig.2). Application of this study is subjected to the origin and scale of the topographic maps (1:100,000). The statistical analysis results of these morphometric parameters using Horton (1945) and Strahler & Strahler (2007) methods are listed in Table 2.
Table 2: The morphometric parameters of Abu Ghusun basin, Egypt

<table>
<thead>
<tr>
<th>No</th>
<th>Basin</th>
<th>K</th>
<th>SNu</th>
<th>SLu</th>
<th>A</th>
<th>P</th>
<th>LB</th>
<th>VL</th>
<th>R</th>
<th>E</th>
<th>Rb</th>
<th>WMRb</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Abu Ghusun</td>
<td>5</td>
<td>382</td>
<td>496</td>
<td>323.9</td>
<td>114</td>
<td>30</td>
<td>38</td>
<td>1185</td>
<td>840</td>
<td>3.97</td>
<td>4.08</td>
<td>1.18</td>
</tr>
</tbody>
</table>

Table (2)Cont.

<table>
<thead>
<tr>
<th>D</th>
<th>Lo</th>
<th>Ish</th>
<th>Re</th>
<th>c</th>
<th>S</th>
<th>Si</th>
<th>Sl</th>
<th>Rr</th>
<th>Rn</th>
<th>Rt</th>
<th>Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.53</td>
<td>0.33</td>
<td>0.46</td>
<td>0.32</td>
<td>0.68</td>
<td>2.78</td>
<td>1.27</td>
<td>0.030</td>
<td>0.04</td>
<td>1.81</td>
<td>3.36</td>
<td>100000</td>
</tr>
</tbody>
</table>

**Abbreviations**

- K = order of trunk channel
- SNu = sum. of stream numbers.
- SLu = sum. of stream lengths
- A = watershed area (Km²)
- F = stream frequency (Km²)
- D = drainage density (Km⁻¹)
- LB = basin length (Km)
- P = perimeter of the basin (Km)

- VL = valley length (Km)
- Rb = bifurcation ratio
- S = inverse shape form
- Si = sinuosity
- R = relief (m).
- SI = slope index
- Re = circularity ratio
- Rr = relief ratio
- Rn = ruggedness number
- WMRb = weighted mean
- Re = elongation ratio
- Lo = length of overland flow (Km)

**Areal characteristics**

Generally, the areal characteristics of a basin belong to the flow and sediment yield.

**Watershed Area (A):**

The watershed area of Abu Ghusun drainage basin (i.e., 323.86 km²) is measured using the GIS environment (ArcView GIS 3.2).

**Basin length and Perimeter:**

The basin length (LB) is the shortest line dividing the basin into two halves running from the mouth to the source. It attains the value 30 km in the study basin. The basin perimeter (P) describes the circularity of the basin. It is defined as the length of the curve (km) that defines the surface divide of the drainage basin. The basin perimeter in Wadi Abu Ghusun is 114 km.

**Length of Overland Flow (Lo)**

It is defined as the distance that water flows over the ground surface before it becomes concentrated in a drainage network (Horton 1945). It is expressed by the reciprocal of twice the drainage density i.e., \( Lo = \frac{1}{2D} \). The value is 0.33 km in the study basin which indicates that the water is faster to concentrate in the drainage channel.
Drainage Density (D)

Drainage density is defined as the total length of streams of different orders $\Sigma L_u$ per unit of area (A) (Horton, 1945) i.e., $D = \Sigma L_u$ (total length / A) (basin area). The drainage density, for a basin, depends on bedrock type, relief, time and climate and is responsible for runoff controlling factors (Orbson, 1970). In general, the degree to which drainage is established in a basin is expressed as well drained or poorly drained (Horton, 1932). Drainage density is related to average precipitation. Lower values reflect arid areas and more permeable materials and the largest values reflect humid regions and less permeable soils. The calculated drainage density value of the studied area using Horton’s 1945 method is 1.53 km$^{-1}$. The high density value in the Abu Ghusun basin draining the basement rock reflects the structural control and high gradient.

Texture Ratio (Rt)

The texture ratio is defined as the ratio of the total number of the basin segments to its perimeter (P) ($Rt = \Sigma N_u / P$ km$^{-1}$). The texture ratio ($Rt$) of basins was classified by Smith (1958) into three classes: coarse (< 6.4 km$^{-1}$), moderate (6.4-16 km$^{-1}$) and fine (> 16 km$^{-1}$). According to this classification, the studied basin (3.36 km$^{-1}$) can be classified as coarse texture. This indicates that the Abu Ghusun basin is in an early stage of evolution.

Basin shape

The basin shape parameter is expressed in three ways: circulatory ratio $Rc$ where $Rc = 4\pi A / P^2$ (Miller, 1953), elongation ratio $Re$ where $Re = 2 \times (A / \pi)^{0.5} / LB$ (Schumm, 1956) and shape index Ish where $Ish = 1.27 A / LB^2$ (Hagget, 1956). The values of $Rc$, $Re$ and Ish in the studied basin are 0.32, 0.68 and 0.46 respectively. Toy and Hadley (1987) pointed out that the time for concentration of flow to the main channel is less in circular basins than in elongated ones. An elongated basin has an ($Re$) value approaching zero, while a circular basin possess an ($Re$) value close to unity (Horton, 1945). Accordingly, the Abu Ghusun basin is elongated and reflects strong relief and steep ground slopes.

Relief characteristics of the drainage basin

The relief characteristics of a drainage basin are expressed by three parameters: Relief ratio ($Rr$) = $R / LB$ (Schumm, 1956), where R is the difference in elevation between the head and mouth of the basin, the Slope Index ($SI$) = $E_{85} - E_{10} / 0.75 \times VL$, where $E_{85}$ and $E_{10}$ are the elevation in meter of points at 85% and 10% of length of the main channel from its outlet, and
the Ruggedness Number \((Rn) = D \times R\) (Melton, 1957). Both \((Rr)\) and \((SI)\) are directly proportional to flooding and inverse to time of concentration. The low value of \(Rr\) (0.04) reflects coverage by large areas of sedimentary rocks which easily erode.

**Linear characteristics**

**Stream order \((u)\)**

The quantitative analysis of channel networks began with Horton’s (1945) method of classifying streams by order and a later modification by Strahler (1952). The trunk channel constitutes the highest order \((K)\) and all stream segments are assigned as orders and given the symbol \((u)\). The number of segments of each order is counted and given the symbol \((Nu)\). In the studied area the stream order is the 5th order which reveals a direct relation with the watershed area.

**Stream Length \((Lu)\)**

The stream lengths of each order were measured for the Abu Ghusun basin using the GIS environment (ArcView GIS 3.2). The total stream lengths of the investigated basin are 496 km. The stream lengths reveal a direct relationship with the watershed area \((A)\), number of the streams \((Nu)\), perimeter \((P)\) and length of the basin \((LB)\).

**Valley Length \((VL)\) and Sinuosity \((Si)\)**

The valley length is the path length of the main stream from the mouth to the source. It attains the value 38 km. Gregory and Willing (1973) defined sinuosity \((Si)\) as the length of the wadi path \((VL)\) divided by the shortest distance between mouth and the source of stream \((LB)\) i.e., \(Si = VL / LB\). The studied basin has an \(Si\) value ranging between 1 and 1.5 (transitional), reflecting structural and lithological controls.

**Bifurcation Ratio \((Rb)\)**

The bifurcation ratio is defined according to Horton (1945) as the ratio between the number of streams of a given order \(N_u\) and the number of streams of the next order \(N_{u+1}\) \((Rb = N_u / N_{u+1})\). Basins of low bifurcation ratio \((Rb)\) reveal low concentration time, forming a sharp peak discharge. On the other hand, basins of high bifurcation ratios \((Rb)\) are elongated in shape and permit the passage of runoff over a longer period of time (long concentration time), thus
giving more chance for recharging the shallow aquifers. The Bifurcation ratio value of the investigated basin is greater than 3, thus reflecting high mountainous dissected areas (Horton, 1945).

**Stream Frequency (F)**

Stream frequency is defined as the ratio of the total number of stream segments of all orders within a given basin to the total area (A) of the basin (Horton, 1945) \( F = \frac{\sum N_a}{Akm^{-2}} \). High values of stream frequency indicates that more possibilities for collection of runoff water.

Briefly, from the aforementioned areal and linear morphometric parameters, the Wadi Abu Ghusun is characterized by the following:

1. elongated mountainous dissected basin with strong relief,
2. water is faster to concentrate in the drainage basin,
3. coarse texture (i.e. early stage of evolution), and
4. covered by large area of sedimentary rocks which erode easily.

Many factors must be considered in the groundwater management and modeling of a basin. This management must be performed in accordance with an adequate geomorphologic investigation of the existing conditions. Therefore, the morphometric parameters consider a particular condition of the locality and local guidelines, if not available, should be developed. Morphometric parameters have a great effect on overland flow, time of concentration, and the rainfall-runoff relation and level of protection for a basin. In addition, some of these parameters were used in the watershed modeling program (i.e. A, R...etc.).

**Soil infiltration tests**

Infiltration is the process which describes the passage of water through the soil surface into the soil. Infiltration plays an important role in the relationship between rainfall and consequent runoff acting in determining f-curve and curve number. Consequently, its rate determines the quantity of water that will enter the soil and the quantity that will runoff.

Due to the infiltration from surface runoff water, it represents the main source for recharging the quaternary groundwater aquifer. Five infiltration tests were carried out at the investigated basin differing in soil origin and profile characteristics. The field data are shown in Table 3. The infiltration tests were carried out using the double ring infiltrometer as described by Black (1973), which considers a device for direct field measurement of infiltration rates.
The calculation is carried out by using a computer program "INFILTEST". The program calculates the "best fit" permeability and sorptivity coefficients by automatically fitting experimental infiltration test data to the Philip equation (1957a) in a least square sense based on a \textit{BASIC} language. The outputs of this program are tabulated in Table 3.

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Location</th>
<th>Cumulative inf. Equation</th>
<th>inf. Rate Equation</th>
<th>Inf. Rate m/day</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Wadi</td>
<td>$i = 1.943t^{1/2} + 0.568t$</td>
<td>$I = 0.971t^{1/2} + 0.568$</td>
<td>8.18</td>
<td>1.94</td>
</tr>
<tr>
<td>2</td>
<td>Abu Ghusun</td>
<td>$i = 2.124t^{1/2} + 0.246t$</td>
<td>$I = 1.062t^{1/2} + 0.246$</td>
<td>3.54</td>
<td>2.12</td>
</tr>
<tr>
<td>3</td>
<td>Abu Ghusun</td>
<td>$i = 1.576t^{1/2} + 0.1598t$</td>
<td>$I = 0.788t^{1/2} + 0.1598$</td>
<td>2.3</td>
<td>1.58</td>
</tr>
<tr>
<td>4</td>
<td>Abu Ghusun</td>
<td>$i = 0.133t^{1/2} + 0.268t$</td>
<td>$I = 6.636t^{1/2} + 0.268$</td>
<td>3.85</td>
<td>0.13</td>
</tr>
<tr>
<td>5</td>
<td>Abu Ghusun</td>
<td>$i = 1.522t^{1/2} + 0.0093t$</td>
<td>$I = 0.761t^{1/2} + 0.093$</td>
<td>1.33</td>
<td>1.52</td>
</tr>
</tbody>
</table>

\(i = \text{Cumulative infiltration (cm)}\). \(S = \text{Sorptivity Coefficient (cm/m}^{0.5}\)\)
\(I = \text{Infiltration Rate (m/day)}\). \(K = \text{Permeability Coefficient (cm/min)}\)

**Model Description**

The model approach used to determine the runoff volume was the SCS-CN method (SCS, 1972). We adopted the US Department of Agriculture-Natural Resources Conservation Service (NRCS) method (SCS, 1985) to calculate the initial losses in the studied basin. The (NRCS) method is commonly used in the US in areas lacking good coverage by rain gauges and in areas having poor runoff records. The method is suited for humid, semiarid, and arid conditions (SCS, 1985; Tables 2(a)-(d)) and has been successfully applied to ephemeral watersheds in the southwestern US, which resemble that of the area under discussion in climate, topography, and land use (Osterkamp \textit{et al.}, 1994; Gheith & Sultan, 2002). With this method, runoff in the basin occurs after rainfall exceeds an initial abstraction (Ia) value. Rainfall excess, \(Q\), in the NRCS method is related to the effective precipitation, \((P - Ia)\), through a maximum potential retention value, \(S\), as given by equation (1):

\[
Q = \frac{(P - Ia)^2}{(P - Ia + S)} \quad \text{Where} \quad Q, \ P, \ \text{and} \ Ia \ \text{are all in millimeter(mm).} \quad (1)
\]

The maximum retention, \(S\), is a function of an empirical curve number coefficient, \(CN\), where

\[
S = \frac{25400}{CN} - 254 \quad (2)
\]
The initial abstraction is suggested by the NRCS to be approximately 20% of the maximum potential retention value, or

$$Ia = 0.2S$$

(3)

Considering the initial loss and the potential maximum retention, the precipitation excess can be calculated; the maximum retention and the basin characteristics are related through the curve number. The standard SCS curve number method is based on the following relationship between rainfall depth, $P$, and runoff depth, $Q$ (USDA, 1986; Schulze et al., 1992):

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)}$$ for $P > 0.2S$; otherwise $Q = 0$

(4)

where $Q$ is the surface runoff (mm), $P$ is the precipitation (mm), $S$ is the soil retention (mm), $Ia$ is the initial loss (mm), and CN is the curve number. To obtain volumes, $P$ and $Q$ (in millimeters) must be multiplied by the basin area. The potential maximum retention ($S$) represents an upper limit for the amount of water that can enter the basin through surface storage, infiltration, and other hydrologic losses. For convenience, $S$ is expressed in terms of a CN, which is a dimensionless basin parameter ranging from 0 to 100. The SCS has developed tables of initial Curve Number (CNi) values as a function of the basin soil type and the land cover/use/condition. These are listed in Schulze et al. (1992). The hydrologic soil group refers to the infiltration potential of the soil after prolonged wetting. The hydrologic soil groups are defined in accordance to the standard SCS soil classification procedures, which establish a range from classification A for sand and aggregated silts with high infiltration rates, to classification D for soils that swell significantly when wet and have low infiltration rates.

On the basis of the infiltration potential and soil information for Wadi Abu Ghusun basin and the visible ground coverage, the soil group B is considered to be adequate. Weighted CN for mixed land uses can be computed using equation (5):

$$CN = \sum_{i=1}^{k} AiCNi/ \sum_{i=1}^{k} Ai$$

(5)

where $CNi$ corresponds to the specific $CN$ for the part of the watershed that has area $Ai$. using equation (5) and after substituting the $CN$ values according to B group, the weighted curve number for the study area was reported in Table 4.
\[
CN = (0.10 \times 71) + (0.70 \times 79) + (0.0 \times 61) + (0.20 \times 98) = 82
\]

**Table 4: Assignment of CN for different land uses in the study area**

<table>
<thead>
<tr>
<th>Character of surface</th>
<th>CN related to hydrologic soil groups</th>
<th>Percentage of land use area</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>Cultivated land + Dense range</td>
<td>62</td>
<td>71</td>
</tr>
<tr>
<td>Pasture/Rangeland poor condition</td>
<td>68</td>
<td>79</td>
</tr>
<tr>
<td>Pasture/Rangeland good condition</td>
<td>39</td>
<td>61</td>
</tr>
<tr>
<td>Rocks, streets, roads.....etc.</td>
<td>98</td>
<td>98</td>
</tr>
</tbody>
</table>

Accordingly, a CN of 82 was chosen. A potential retention (S) of 55.76 mm was computed by applying Equation 2. The initial loss (Ia) was estimated to be 11.15 mm from Equation 3. These values were used in the model for the Wadi Abu Ghusun basin.

**Model parameterization**

Estimation of the flood routing is the essential target of any surface water study, to predict the outflow hydrograph from a watershed area for any basin or any point on the main channel or tributary subjected to a known amount of precipitation. Given the absence of flood records for the Eastern Desert, we adopted the Synthetic Unit Hydrograph (SCS, 1985) to calculate the hydrograph at the basin outlet. According to this approach, the flood hydrograph at the basin outlet is a function of lag time (the time from the centroid of rain event to the peak discharge), which is directly related to the physical characteristics of the basin.

**A BASIC** language Flood Routing Processing computer program (FRP) was applied to calculate with graphical display, and flood routing processing includes runoff amount and watershed hydrograph using rainfall data and field measurements of watershed parameters. Figure 5 shows a schematic representation of the proposed model along with different input, output, and processing elements.

The input items of the (FRP) program include the following: (a) Size of the catchment’s area (km²), (b) Elevation of the highest and routing points and the distance between them (i.e., slope), (c) Percentage of areal distribution of natural vegetation type and basement rocks, (d) Permeability and sorptivity coefficients from infiltration tests, and (e) Frequent rainfall storm recorded with the duration (mm/hr).
The output items of the (FRP) program include the following: (A) Distribution of surface runoff with time (hydrograph), (B) Peak discharge of the flood in m³/sec, which is useful in designing different types of dams, and (D) Amount of flood discharge in m³.

![Flow chart of the hydrological model for Wadi Abu Ghusun.](image)

The program is applied according to the following assumptions and equations:

Generally, storm events in the Eastern Desert and Northern Egypt are typically short, lasting from less than one hour to a few hours (Naim, 1995). No rain gauges are located within the examined watershed on the Red Sea hills or the surrounding mountains. Thus the calibration of our surface runoff model for the Abu Ghusun basin was hindered by the absence of rain gauges over the Red Sea hills and a general lack of field observations for flooding events. Due to the lack of recording rainfall storms in or near the studied area, a synthetic rainfall storm is applied with a 5-hour duration including 3.5, 5, 4.2, 3.8, and 3.5 mm/hr respectively. To determine how the runoff is distributed over time we must introduce a time-dependent factor. The time-of concentration (tc) is used in the SCS methods. The tc is most often defined as the time required for a particle of water to travel from the most hydrological remote point in the basin to the point of collection. There are several methods available for calculating tc, one of them is the SCS method (1972).
\[ t_c = 0.01942LB^{0.77}s^{-0.385} \quad \text{Kirpich (1940)} \]

\[ i' = 0.6t_c \quad \text{SCS (1972)} \]

\[ i'p = t_l + 0.5D \quad \text{SCS (1972)} \]

\[ i'b = 2.67(1.2t_c + 0.5D) \quad \text{SCS (1972)} \]

\[ Q_p = \frac{7.4074a + A + R}{t_p} \quad \text{SCS (1972)} \]

Where:

- \( t_c \) = time of concentration in minutes
- \( LB \) = basin length in meter
- \( s \) = slope expressed as a fraction
- \( t_p \) = time to peak in minutes
- \( D \) = is the duration in min.
- \( A \) = watershed area (Km\(^2\))
- \( Q_p \) = peak discharge of the flood in (m\(^3\)/sec)
- \( R \) = rainfall excess (mm)

**Note:** All time factors are in minutes

### Results

The main items of the flood routing hydrograph for the investigated basin is compiled in Tables 5 and 6 and Fig.6. From Table 5 and 6, the flow rate \( (Q_p) \) of the synthetic hydrograph at Wadi Abu Ghusun is 52.66 m\(^3\)/sec. The time to peak \( (t_p) \) is 5.58 hours whereas the time base \( (t_b) \) is 17.5 hours. The total discharge along the studied basin, which occupies 323.86 km\(^2\) is about 1.88 x10\(^6\) m\(^3\).

![Fig. 6: Hydrograph at the outlet of Wadi Abu Ghusun.](image)

Our estimates for precipitation, initial abstraction and downstream runoff are largely controlled by the physiographic characteristics of the Abu Ghusun watershed. The topography and size of the watershed control the total precipitation over a watershed. Areas covered by Quaternary deposits are considerable, covering 70% of the Abu Ghusun watershed. We assumed that the
computed initial abstraction (Ia) contribute to the recharge of the Quaternary aquifer since precipitation onto the Holocene sand sheets and the underlying Pleistocene wadi deposits is likely to recharge the Quaternary aquifer in the study area. The groundwater potentialities in the investigated drainage basin are expected to be moderate based on the peak runoff investigated drainage basin are expected to be moderate, the peak runoff calculations, the infiltration capacities, and the geologic setting.

**Table 5:** The computed values of surface water runoff according to FRP computer program

<table>
<thead>
<tr>
<th>Basin</th>
<th>Area (Km²)</th>
<th>So (Cm/min0.5)</th>
<th>K (m/d)</th>
<th>S (mm)</th>
<th>Percentage (%) of Wadi filling</th>
<th>Hydrologic group</th>
<th>I (mm)</th>
<th>tp hour</th>
<th>tb hour</th>
<th>Qp m³/sec</th>
<th>Qx10⁶ m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abu Ghusun</td>
<td>323.7</td>
<td>0.066</td>
<td>1.46</td>
<td>3.84</td>
<td>55.76</td>
<td>10</td>
<td>70</td>
<td>20</td>
<td>B</td>
<td>11.15</td>
<td>17.5</td>
</tr>
</tbody>
</table>

**Abbreviations:**
- A = watershed area km²
- S = Potential maximum retention mm
- I = Initial abstraction mm
- So = Sorpitivity Coefficient cm/min⁰.⁵
- tp = Time to peak hour
- Qp = Peak discharge of the flood m³/sec
- tb = Duration of runoff storm hour
- Q = Total discharge m³

**Table 6:** Synthetic hydrograph records of Wadi Abu Ghusun

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>Discharge (m³/sec)</th>
<th>Time (min)</th>
<th>Discharge (m³/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>540</td>
<td>18.525</td>
</tr>
<tr>
<td>30</td>
<td>2.623</td>
<td>570</td>
<td>14.562</td>
</tr>
<tr>
<td>60</td>
<td>5.245</td>
<td>600</td>
<td>12.539</td>
</tr>
<tr>
<td>90</td>
<td>18.154</td>
<td>630</td>
<td>10.903</td>
</tr>
<tr>
<td>120</td>
<td>28.228</td>
<td>660</td>
<td>9.267</td>
</tr>
<tr>
<td>150</td>
<td>42.762</td>
<td>690</td>
<td>7.631</td>
</tr>
<tr>
<td>180</td>
<td>46.786</td>
<td>720</td>
<td>5.996</td>
</tr>
<tr>
<td>210</td>
<td>51.736</td>
<td>750</td>
<td>4.819</td>
</tr>
<tr>
<td>240</td>
<td>51.732</td>
<td>780</td>
<td>4.102</td>
</tr>
<tr>
<td>270</td>
<td>52.658</td>
<td>810</td>
<td>3.384</td>
</tr>
<tr>
<td>300</td>
<td>50.672</td>
<td>840</td>
<td>2.667</td>
</tr>
<tr>
<td>330</td>
<td>48.105</td>
<td>870</td>
<td>1.949</td>
</tr>
<tr>
<td>360</td>
<td>43.726</td>
<td>900</td>
<td>1.309</td>
</tr>
<tr>
<td>390</td>
<td>38.986</td>
<td>930</td>
<td>1.056</td>
</tr>
<tr>
<td>420</td>
<td>34.374</td>
<td>960</td>
<td>0.802</td>
</tr>
<tr>
<td>450</td>
<td>30.412</td>
<td>990</td>
<td>0.549</td>
</tr>
<tr>
<td>480</td>
<td>26.450</td>
<td>1020</td>
<td>0.296</td>
</tr>
<tr>
<td>510</td>
<td>22.487</td>
<td>1050</td>
<td>0.042</td>
</tr>
</tbody>
</table>
Groundwater management

The regional morphologic setting, the lithological properties and structural features have a direct impact on the groundwater resources in the area of study. The rain falling on the Abu Ghusun watershed flow towards the Red Sea (Fig. 7). The estimated geomorphological parameters of Wadi Abu Ghusun (Table 2) indicate reasonable groundwater possibilities. Accordingly, different types of water-bearing formations contain water of variable salinities. In the study area, groundwater of variable salinities ranging from 2900 to 14450 ppm is detected at depths varying between 10 to 16 m from the surface (Table 7). Generally, the groundwater is tapped from two main aquifers:

- The Quaternary aquifer
- The fissured crystalline aquifer (i.e., Precambrian igneous rock, gabbro)

In addition, Abu Ghusun mine gets its water from Precambrian fractured plutonic igneous rock (gabbro, 12880 ppm).

**Table 7: Hydrologic Characteristics of the Quaternary aquifer of the study area**

<table>
<thead>
<tr>
<th>Well</th>
<th>T.D. (m)</th>
<th>Q (m³/h)</th>
<th>Drawdown (m)</th>
<th>T (m²/d)</th>
<th>S</th>
<th>Salinity (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abu Ghusun -1</td>
<td>11.12</td>
<td>6</td>
<td>0.12</td>
<td>443</td>
<td>0.13</td>
<td>3580</td>
</tr>
<tr>
<td>Abu Ghusun -2</td>
<td>10.70</td>
<td>3.3</td>
<td>0.35</td>
<td>104</td>
<td>0.264</td>
<td>5500</td>
</tr>
<tr>
<td>Abu Ghusun -3</td>
<td>15.15</td>
<td>6</td>
<td>3.02</td>
<td>16</td>
<td>0.08</td>
<td>3770</td>
</tr>
<tr>
<td>Abu Ghusun -4</td>
<td>13.90</td>
<td>5</td>
<td>0.06</td>
<td>829</td>
<td>0.45</td>
<td>6500</td>
</tr>
<tr>
<td>Abu Ghusun -5</td>
<td>14.85</td>
<td>3.6</td>
<td>0.11</td>
<td>220</td>
<td>0.658</td>
<td>2900</td>
</tr>
<tr>
<td>Abu Ghusun old</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>14450</td>
<td></td>
</tr>
</tbody>
</table>

Note: T.D. = Total depth T = Transmissivity m²/day Q = Discharge m³/hour S = storage coefficient

![Fig. 7: Well location map of the Wadi Abu Ghusun.](image)
Groundwater management, particularly in arid regions, should be viewed holistically and linked to the sustainable management of the ecosystem. Ancient methods of groundwater management, such as the qanats system, provide an excellent demonstration of human ingenuity to cope with water scarcity (Adle, 2005, Ansari et al., 2005, Kahlown & Aslam, 2005). Qanats are also known as *Karez* (Afghanistan), *Galeria* (Spain), *Khotara* (Morocco), *Aflaj* (Arabian Peninsula), *Foggara* (North Africa), *Kanerjing* (China), and *Auon* (Saudi Arabia/Egypt), reflecting the widespread dissemination of the technology across ancient trading routes and political maps. A qanat is a system of water supply consisting of an underground tunnel connected to the surface by a series of shafts which use gravity to bring water from the water table to the surface (Fig.8). The main, or mother, well, is generally excavated in the mountains, penetrating deep into the water table. Water runs down a slightly sloping tunnel, gradually increasing in volume until it emerges near farms or communities. Water from qanats is brought to the surface where the soil has been enriched by sediment from alluvial fans. Cultivated land and settlement sites are situated downwards from the point where the water surfaces. The immediate outlet, *mazhar*, is the point where people take water, and it is generally found in the main square of a village. The water outlet point is very important; it is well kept and cemented and water use is monitored. A tunnel, or *payab*, channels water under the residential area to the cultivated land. A sloping corridor with steps leads from the surface to the *payab*. The first *payab* is located in the main square and is used for taking drinking water. A network of smaller *payabs* runs from the main *payab*.

![Fig. 8: A Typical Qanats System.](image-url)
Different qanats sometimes have different systems of water use for domestic consumption and for irrigation.

The following key issues are essential when using qanats as a groundwater management tool (Abdin, 2006):

1 - It is important to make sure that the water table is adequate to ensure permanency and sustainability of water supply as the first step in the planning phase;

2 - Practical knowledge of local groundwater should be secured among local *moghannis* (qanat diggers). Although this is empirical and based on land formation, color and smell of the soil and mountain rocks, natural slope of the land and specific vegetation, experience also plays an important role.

3 - Modern geological techniques, Geographical Information Systems (GIS) and Remote Sensing (RS) instruments can contribute to the restoration and reconstruction of qanats. To enable people to incorporate modern scientific approaches in their traditional knowledge networks requires preparatory research, training and appropriate support.

4 - The recharge process of the supplying aquifer should be known, conserved and continuously enhanced through artificial recharge if necessary. There are places where special dams were built in order to enrich the water table. For example, people dug wells 3-5 meters deep and 5-7m wide and filled them up with large stones found in flood beds. They directed the floodwaters to these artificial pools to enrich the water table. This ancient recharging innovation can still be used to replenish groundwater in many places.

Accordingly, nine V.E.S. stations were carried out by MPGAP (1990) and Khaled, (1995) along the main course of the Abu Ghusun wadi. The subsurface geoelectrical cross section along the wadi showed that (Fig.8):

- The surface wadi fill is composed of sand, gravel, and rock fragments, and its thickness ranges from 2 to 4 m.

- The second layer is composed of gravel and rock fragments, and its thickness ranges from 8 to 50 m.

- The bottom layer is the basement complex rocks which are massive and with infinite resistivity (dry).

As a result, the discharge is moderate and the recommended site for drilling a new water well should be at V.E.S. No.5 (Fig.9).
Generally speaking, sediment content in the inlet sector of the Abu Ghusun basin is less than the outlet. One of the reasons for this seemed to be the movement of groundwater through different formations and the development of a steep hydraulic gradient. The inlet sector of the study area is surrounded by high mountains that receive precipitation (rainfall), which infiltrates into the wadi deposits (3.844 m/d) and recharges the Quaternary aquifer. This situation was ideal for the construction of shallow wells and qanat systems at V.E.S. No.5 (Fig. 10). There are five wells of different depths in the central part of the district. The discharge rates from these wells are in the range 3.3 to 6 m$^3$/h. In addition, the total discharge along the studied basin, which occupies 323.86 km$^2$, is about 1.88 x$10^6$ m$^3$. Therefore, this region can be exploited by using the qanats system. These two means of exploiting groundwater provide millions of m$^3$ for irrigation, the Ilmenite mining industry, and the development of Bedouin communities and the World Food Program (WFP). Qanat is an appropriate way to exploit alluvial aquifers in the study area. Thus the qanat system is environmentally sustainable water harvesting and conveyance techniques through which groundwater can be obtained without causing damage to the Ilmenite mining industry or to the tapped alluvial aquifers in the arid region of Abu Ghusun basin.
CONCLUSION

Wadi Abu Ghusun is considered one of the main basins in the Eastern Desert of Egypt. It attracts attention from several official administrations, such as the Ilmenite mining industry and for development of Bedouin communities within the framework of international cooperation with World Food Program (WFP). Obviously, the continuous development has led to extensive and increasing potable water demand to match these activities. To achieve these targets, a model of rainfall-runoff process in an ungauged basin was applied. The rainfall-runoff model was used to calculate the direct runoff volume, peak discharge, and to construct a synthetic hydrograph for the Wadi Abu Ghusun. The flow rate ($Q_p$) of the synthetic hydrograph at Wadi Abu Ghusun was 52.66 m$^3$/sec. and the time to peak ($t_p$) was 5.58 hours, whereas the time base ($t_b$) is 17.5 hours. The total discharge along the study basin was 1.88x10$^6$ m$^3$). Qanat is an appropriate way to exploit alluvial aquifers in the study area. Thus qanat is environmentally sustainable water harvesting and conveyance techniques obtain groundwater without causing damage to the Ilmenite mining industry or to the tapped alluvial aquifers in the arid region of Abu Ghusun basin.

Fig. 10: Sketch illustrating the proposed Qanats system in Wadi Abu Ghusun.
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تأثير السيل الفجائية على إمكانية التنمية بوادي أبو غصون
- الصحراء الشرقية - مصر

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خلاصة

تكمّن أهمية وادي أبو غصون في أهميته الاقتصادية كمصدر لخام الإسلوب بالإضافة إلى الأنشطة الحكومية من خلال توطين البدو بهذا الوادي اعتماداً على مصادره المائية، ولذا فإن الهدف الرئيسي للبحث يقوم على تقييم وحساب الموارد السطحية الممثلة في سقوط الأمطار والجريان السطحي وكيفية الاستفادة منها في تغذية الخزان الجوفي بالمجري الرئيسي للوادي والأودية الفرعية. بالإضافة إلى إقلاع الضوء على خصائص الخزان الجوفي بالوادي من خلال إجراء تجارب الضخ والاستعاضة للنقط المائية بالإضافة إلى وضع الاقتراحات والتوصيات اللازمة للتنمية المستدامة بالوادي.