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Estimation of flash flood using surface water model and GIS technique in Wadi El Azariq, East Sinai, Egypt

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Abstract

The study of flash flood hazard phenomenon and runoff potentialities are the major task of a hydrologists especially in arid and semi-arid regions. This paper presents a new approach to modeling flash floods in dryland catchments by the integration between physiographic features of the study basin, Geographic Information System (GIS) and Watershed Modelling System (WMS). Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) data was used to prepare a digital elevation model (DEM) with 30 m resolution and Geographical Information System (GIS) was used to evaluate the linear, areal and relief characteristics of Wadi El Azariq basin, East Sinai, Egypt. The qualitative and quantitative analysis of thirty eight morphometric parameters were estimated and interlinked to produce nine effective parameters for evaluation of the flash flood hazard in the study area. As a result of the sparse hydrologic information, the relation between rainfall and runoff was calculated depending on the morphometric information, GIS techniques, Watershed Modeling System (WMS) and Hydrologic Engineering Center-Hydrologic Modeling System software (HEC HMS). Based on the nine effective morphometric parameters that have a direct effect on flood prone area and control the hydrologic behavior of the basin, flash flood hazard of Wadi El Azariq sub-basins were identified and classified into two groups (High and low hazard degrees). Hydrographs for Wadi El Azariq basin were constructed with different return periods of maximum daily rainfall. The calculated volume of the total surface runoff ranges from 4.1×10^6 m^3 to 13.8×10^6 m^3 at return periods of 5 years and 100 years

respectively based on the maximum daily rainfall events. This study draws specifics about the flash flood prone areas, planning rainwater harvesting and flood management approaches of Wadi El Azariq basin.

Key words: Morphometric parameters, Flash flood, Runoff, Hydrograph, GIS, WMS Modeling.

1. Introduction

Water security and flood hazards are of great environmental, economical and political importance for all dryland countries (Tooth, 2000). Flooding and associated sediment transport in drylands receives little recognition as environmental problems, due to the relative infrequent occurrence of runoff events and lack of observations (White, 1995; Gheith and Sultan, 2002). The paucity of good quality rainfall and discharge data presents a particular problem for hydrological analysis in dryland catchments (McMahon, 1979). Direct measurements of runoff hydrographs and associated sediment transport in dryland catchments are very rare. The major task of a hydrology study is to compute flash flood. There are conceptual methods and empirical methods for computation of flash flood. Data and information required for hydrologic analysis varies from method to method. The arid and semi-arid environments suffer massive flash floods that cause infrastructure damages and fatality. Sinai Peninsula and its vicinities is an example for arid and semi-arid regions where hydrologic measurements of surface runoff and flash floods are mostly rare as a result of the difficulty of access, shortage of available funding, and safety issues associated with sampling these extreme events. Most of the drainage basins (Wadis) in arid and semi-arid regions have no gauges that measure runoff or rainfall continuously. Due to these limitations, GIS technique are of great importance in dryland hydrological modeling, and are increasingly being used to estimate a range of hydrological variables for the parameterization of hydrological models.

Managing water resources is a serious challenge in many countries especially in the arid and semi-arid regions. Flash flood risk assessment is an essential and important task in water resources management yet abuts practice yet it is difficult one. The main challenge to assess flash flood risk in arid regions is the scarcity of hydrologic information and data. Basin system modeling with limited hydrologic information and data results in unobtainable rainfall-runoff models parameters, which makes the calibration on direct measured runoff data impossible, and hence requires to be obtained by other techniques (Bloeschl, 2005). Rainfall-runoff modeling is very important for sustainable development of water resources and for the protection from flood hazard and drought. Rainfall and runoff data are critical hydrological elements for the flood mapping in basin systems. Therefore, when scarcity of measured hydrological data exists in the study area, flood inundation maps are dependent on the topographic and geomorphic features of the basin (Sen et al., 2012).

The integration between GIS, and physiographic features of basin to assess flash flood hazard has been continually upgraded and widespread since beginning of 21st century, as a result of the increased availability of spatial databases and GIS software (Zerger and Smith 2003). Several studies are cited in the literature, relating to flood hazard evaluation and zonation using GIS depending on physiographic features of the drainage basins (Sui and Maggio 1999, Merzi and Aktas 2000, Guzzetti, and Tonelli 2004, Sanyal and Lu 2006, He et al., 2003, Fernadez and Lutz 2010, El Osta and Masoud, 2015). Physiographic features of the drainage basin in numerous localities on the earth were investigated by traditional geomorphological methods (Horton 1932 1945, Strahler 1964, Rudriaih et al., 2008; Nageswararao, et al., 2010 and Al Saud 2009). According to Gardiner (1990) physiographic characteristics of hydrographic basins have been used for prediction and description of maximum flood discharge and estimation of erosion rate, underlying the importance of such studies. Physiographic features of basin is used in huge studies of climate, geology, geomorphology and hydrology like rainfall-runoff relationships, hydrograph properties, soil erosion, sedimentation and hydrological behaviors of drainage basins (Jolly 1982; Ogunkoya et al., 1984; Aryadike and Phil-Eze 1989). Qualitative and quantitative analysis of the drainage basins to evaluate the flash flood hazard has instigated many of hydrologists to determine the interrelationships between morphometric parameters and influence of flood (Patton 1988). Extraction of water divides and basin tributaries can be accomplished by regular procedures depending on field visits, monitoring and topographic and geologic maps, or with GIS techniques (Macka 2001, Maidment 2002). The desired goal of this paper is to estimate the total runoff of the main hydrographic sub basins to provide appropriate controlling system for management of the surface water and protect the strategic areas in Wadi El Azariq basin, East Sinai, Egypt, as well as for direct infiltration of rainfall and to the infiltration of runoff water along Wadi beds for aquifer's recharge. These stage indicators were based on the integrated methodology that connects of a geographical information system GIS, a digital elevation model (DEM), the physiographic features of the basin and the rainfall-runoff modeling (WMS and HEC-HMS) to estimate the flash flood risks and hydrograph generation in arid environment under data scarcity by simulating the average maximum rainfall event to set up the rainfall-runoff model of Wadi El Azariq basin.

2. Research area

The intense majority of the Egyptian population lives in the Nile Valley and Delta region, leaving most of the land area of Egypt uninhabited. The Egyptian government wishes to exploit and fully develop natural resources throughout the country and has proposed a target of 25% land habitation by 2050. The Tushka Project, west of Lake Nasser, is a well-known example of a

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government development plan intended to expand habitation into the Sahara Desert. 5 ð 109 m3 of water will be annually diverted from Nasser Lake into the Tushka basin through artificial channels constructed in order to create a new community away from the Nile floodplain and Delta (Kim and Sultan, 2002). The province of Sinai Peninsula is another key site in these sustainable development plans, and is the focus of the research presented here. It represents a strategic depth for Egypt's security concerns on its eastern border, spanning 6% of the country's territory and containing a long border with Israel of over 200 kilometers. Infrastructure, settlements and land reclamation for agriculture activity through El Salam Canal project, which will channel Nile River water to the Sinai Peninsula are proposed to accommodate more than two million people on this region. The area under consideration (Wadi El Azariq basin) belongs to the administrative division of the province of the northeastern part of Sinai Peninsula. It was selected for this study due to its hydrological and location importance, where it is located between Egypt and Palestine in the northeastern part. The upper stream of this basin is located in Palestine while the downstream is located in Egypt and occupies an area about 2278 km^2, where it lies between 33º 55` and 34º 45` longitudes (East) and 30º 30` and 31º 15` latitudes (North) with length of about 101 km (Fig.1). The landforms of Wadi El Azariq basin are considered the result of the tectonic movements which built up the main landforms. The latter geologic and climatic events modified them and finally led to the present landforms. Its surface exhibits three main hydrogeomorphologic units: the watershed areas (highlands), the water collectors (lowlands) which are flat in general with a little slope from south to north and the Delta, which is considered the main geomorphologic features where the Wadi width attains 40 km in the outlet. On the other hand, a sand dune accumulates from east and west directions with elevation ranges from 40-50 m and it increases gradually toward the west till El-Arish city. Moreover, the main

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stream of the Wadi is covered by vegetation. The rock units that crop out in the Wadi El Azariq basin range in age from the Holocene to Cretaceous and described in detailed as follows (Fig. 2):

- Holocene deposits which include:

1. Sand dunes accumulations, which cover the most area of study in the form of beach sand dunes with ripple marks shape, sand sheets and scattered lenses intercalated within the wadi deposits.
2. Beach deposits: it extend along the coastal shore line from El-Arish to Rafah beyond Gaza in the form of friable sands to consolidated sandstone as a result of calcareous material as calcium carbonate
3. Recent Wadi deposits: which known as Wadi fill that cover the main stream of Wadi El Azariq and its tributaries, and composed of sand, clay and silt with thickness varying from 4 m to 28 m.

- Pleistocene deposits:

These deposits cover the most area of eastern coast of Sinai Peninsula and it can be classified as follows:

1. Wadi deposits of delta wadi El Azariq have a thickness ranging from 47 to 144 m and composed mainly of sand, silt, clay and gravel.
2. Calcareous sandstone unit (Kurkar) forms the lower part of the quaternary successions along the EL-Arish – Rafaa coastal zone, and extends for 20-25 km from the coast. It is bottomed by the Miocene to the north of El Arish airport and by the Cretaceous carbonates/shale complex in the faulted block at Lahfan.

- Miocene deposits

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These deposits are not outcropping on the surface of the area but it occurs underneath the Quaternary sediments in the form of clay to the south of El-Arish airport.

- Eocene deposits:

These deposits were found in the form of sandy clay, marl and marly limestone to the north of Lehfen, and in the form of clay and gypsum near the coastal belt of Rafah.

- Cretaceous deposits:

These deposits were found in the form limestone to the east and south of the studied basin.

Hydrologically, Wadi El Azariq basin is one of the most important basins within the northeastern part of Sinai Peninsula which is receiving a considerable amount of annual rainfall and shows characteristics typical of Semi-arid region in its lower parts while arid conditions appear in its mountainous parts. Due to the limited development of this hyper-arid area, rainfall and runoff gauging stations have not yet been installed within the study area. The nearest meteorological station is located in El Gudeirat area 120 km to the west. The average rainfall depths vary from 60 mm to 100 mm per year which mostly falls during Spring and Autumn near the Mediterranean Sea. The direct infiltration of rainfall and to the infiltration of runoff water along Wadi beds forms the main source of the aquifer's recharge. The study area is characterized by frequent flash floods events that occur almost annually (Fig. 3). Therefore, in this study, a general framework is going to be developed to investigate such events and to come up with a risk assessment for flash flood hazards in arid environment. Flash flood is a reflection of a prompt response when water levels in the drainage tributaries reach maximum discharge rates within few minutes to hours the beginning of the storm, which means an extremely very short alarming time (Georgakakos, 1992; Creutin and Borga, 2003; Collier, 2007; Younes et al., 2008). Flash floods

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usually occur in arid regions as a result of extensive rain events causing major losses of properties and lives (Subyani 2009). The hydrological data for planning purposes, and also suggests that the rate of recharge of groundwater aquifers in the concerned area is currently being underestimated in this research.

3. Morphometric characteristics of the study basin

Studying of morphometric parameters for Wadi El Azariq basin and its sub-basins is very important and helpful to assess the flash flood risk. Qualitative and quantitative analysis of Thirty eight parameters were determined based on many references (Horton, 1945, Melton, 1957 and Strahler, 1957) as mentioned in Table 1. All the basin characteristics were studied and grouped into four groups using DEM of SRTM of 30 meter resolution as mentioned in Table 1 and 2 (El Bastawesy et al., 2013 and Masoud 2014) and described as follows:

3.1. Drainage network characteristics

Drainage network characteristics are dealing with the physical features of the streams (tributaries) of the study basin as show in Table 1 and 2.

The stream orders (u) of Wadi El Azariq basin and its sub-basins are ranging from 6^{th} order to 7^{th} order. The highest orders have minimum numbers of the streams but the lowest orders have maximum number of streams.

Stream numbers and lengths (Nu) of Wadi El Azariq are measured for each subbasin using a digital chartmeter. Basins of more stream numbers have more stream length which gives good chance for groundwater potentiality than the others of low numbers of streams.

Wadi El Azariq basin and its sub-basins characterized by bifurcations ratio (Rb) and weighted mean bifurcation ratio (WMRb) closed to 4, which indicates to the effect of lithology and geologic structure control upon the drainage basin.

Main valley lengths of Wadi El Azariq basin and its sub-basins are ranging from 25.8 km to 75.6 km as shown in Table 2. These differences between the lengths of main channels are due to the effect of lithology and structural control.

Main channel index and sinuosity of Wadi El Azariq basin indicate that basins of low sinuosity have shorter time of concentration the others of high sinuosity and this means that the basins of high sinuosity have good potentiality for ground water recharge than the others.

According to Horton (1945) and Pareta and Pareta (2011a), Rho coefficient (ρ), it is an important factor concerning the drainage density to hydrologic development of the basin and influences upon the estimation of water concentration capacity. Rho values of Wadi El Azariq and its sub-basins are shown in Table 2; basins of low Rho values have low capacity for water storage than the others of higher values, this variation of Rho value are due to the effect of climate and Geology.

3.2. Basin Geometry characteristics

Parameters of basin geometry include about 13 elements such as (area, length, perimeter, width, elongation ratio, circularity artio, etc.) as shown in table 1 and 2. Results show that Wadi El Azariq basin and its sub-basin characterized by large basin area with basin length ranges between 34 km and 101 km as shown in Table 2 and Fig.4. Basins of long lengths, perimeters and wider have more groundwater recharges potentiality than the others of short length and narrow.

Results of circularity and elongation ratios indicate that Wadi El Azariq basin and its sub-basins characterized by elongated shape with good potentiality of groundwater recharge.

Schumm (1965) reported that the texture ratio (Rt) is playing a significant role in hydrologic behavior which depends on the lithological, infiltration and topographic characteristics of the basins. Based on Horton (1945) and Smith (1958), the (Rt) of Wadi El Azariq basin and its sub-basins belongs to the intermediate to fine texture categories. Basins of low Rt values have a good potentiality for groundwater recharge than the others of high Rt values (Pareta and Pareta, 2011a).

Horton (1932) and Gregory and Walling (1985) defined the form factor ratio (FFR) as a numerical index which is responsible about the basin shape and is consider as a controlling factor of the water flow through the tributaries, and it ranges between 0.1 and 0.8. Table 2 shows that Wadi El Azariq basin and its sub-basins have a limited range from 0.22 to 0.32. According Gupta (1999) basins of low FFR values are characterized by elongation shape, with low peak of hydrograph and long and long travel time (Gupta 1999).

Resulted inverse shape form values (Sv) and shape index (Ish) of Wadi El Azariq basin and its sub-basins are tabulated in Table 2. The higher values of Sv and Ish indicate that the basin characterized by elongated shape which results in a higher potentiality of groundwater recharge than the other basins of values result in more potentiality for surface runoff accumulation.

Resulted values of compactness ratio (S_H) and Fitness ratio (Fr) for Wadi El Azariq basin and its sub-basins are tabulated in Table 2. Based on Melton, (1957) and Pareta & Pareta, (2011a), basins of Low S_H values and high Fr values are characterized by elongated shape with less erosion. While basins of high S_H values and low Fr values are characterized by circular shape which have high potentiality of flash flood.

According to Chorley et al., (1957) and Lykoudi and Zanis (2004), Lemniscate (Ls) is consider as one of the important morphometric parameters which is responsible about the shape and slope of the drainage basin and it ranges between 0.50 to 1.80. Resulted Ls values in Table 2 show that Wadi El Azariq basin and it sub-basins are characterized by high elongated which leads to high potentiality of groundwater recharge.

3.3. Drainage texture characteristics

Drainage texture parameters are included about six morphometric elements as shown in Table 1 and 2 such as (stream frequency, drainage density, drainage intensity, over land flow, infiltration number and drainage pattern). High values of density indicate that the drainage basin characterized by high potentiality of surface runoff accumulation with short time of concentration than the others of low drainage density.

Low value of Di denotes that both D and F have a slight influence upon the intensity of erosion which reflects the rainfall intensity and also the type of lithology. Low value of over land flow (Lo) shows that the precipitated water could be accumulated quicker than that of the other basins of high Lo values.

Infiltration number (FN) is significant parameters expresses the infiltration behavior of the drainage basin. Basins of high FN values are characterized by low infiltration rate and high potential of flash flood concentration. Based on Pareta and Pareta, (2011b), drainage pattern (Dp) is helpful element to understand the stage of erosion cycle which reflects the slope, lithological, structural effect. Figure 3 and Table 2 show that Wadi El Azariq basin and its sub-basins have dendritic patterns which are characterized by good potentiality for groundwater recharge.

3.4. Basin relief characteristic

Basin relief characteristics involve about 10 morphometric parameters which are concerning with the elevations of hydrographic basin. All the relief characteristics such as (maximum, minimum and mean elevation, relief ratio, main channel slope, etc.) are tabulated in

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Table 2, which show that Wadi El Azariq basin and its sub-basins belong to the category of medium to low elevation as shown in Figure 5.

Higher values of relief ratio (Rr) and main channel slope (SI%) indicate that the basin characterized by steep slope and high relief than that basins of lower values.

Resulted basin flow direction (BFD) of Wadi El Azariq is corresponding with the course of its valley which is directed into to Red Sea with mean direction of 59° NW (Fig. 6).

Mean basin slope (Sm) is significant and effective element of the hydrographic basin which is reflecting the influence of relief characteristics upon the hydrologic behavior of the basin. Thematic slope map of Wadi El Azariq (Fig. 7) has been generated by using surface analyst tools of ArcGIS-10. Basins of low slope have small potentiality of surface runoff and the generating hydrograph characterized by low peak of discharge and longer time of concentration. While basins of high (steep) slope yields hydrograph characterized by high peak of discharge high volume of surface runoff with short time of concentration.

According to Melton (1965) ruggedness number (Rn), is consider as a significant index that expresses of relief characteristics of the hydrographic basin. Basins of higher value of (Rn) are characterized by steep and long slope.

Hypsometric curve is defined as non-dimensional of the proportion of the basin areas above a certain elevations. Schumm (1956), Strahler (1964), Leopold et al., (1964), and Hurtrez et al., (1999), reported that the hypsometric curve is concerning with relief characteristics, structural geology and age of the basin. Strahler (1952, 1957, and 1964) and Hurtrez et al., (1999) recognized three form categories of hypsometry curve as follow:

- Young, (Convex curve)
- Mature (S shape curve), and

- Old or distorted (Concave curve).

Figures (8a and b) show that Wadi El Azarik basin characterized by concave curve of old stage. Bishop et al., (2002) reported that the Hypsometric integral (HI) is an important parameters and is relating to the relief characteristics of the drainage basin, and is expressing the rate of erosion with the geologic history. HI is calculated according to Hurtrez et al., (1999), Chorley & Morley (1959); Haan & Johnson (1966), Singh et al., (2008) and Masoud 2014 and 2015 and it ranges between 0 and 1. Calculated HI value of Wadi El Azariq is equal to 0.28 which could be consider as a low value and it designates mature to old basin influenced by erosion and tectonic effects with moderate potentiality of surface runoff accumulation and partially groundwater recharge.

4. Flash flood hazard evaluation

As result of scarcity historical hydrological data of the Wadi El Azariq sub-basins, so this section consider as attempt to evaluate the flash flood hazard for based on the effective morphometric parameters which have a direct influence upon the runoff concentration. The effective nine parameters were selected and analyzed for flash flood hazard degree assessment according to (Davis 1975), and (Masoud 2014 and 2015), by the following Eqs. 1 and 2 as shown in Table 3.

$$\text{Hazard degree} = \frac{4(\text{X - Xmax})}{(\text{Xmin - Xmax})} + 1 \qquad (1) \qquad \text{For the hazard of WMRb}$$

$$\text{Hazard degree} = \frac{4(\text{X - Xmin})}{(\text{Xmax - Xmin})} + 1 \qquad (2) \quad \text{For the other 8 morphometric parameters}$$

Where X represents the geo-morphometric parameter of the sub-basin, X_{max} represents the maximum value of the geo-morphometric parameter overall study sub-basins and X_{min} is the minimum value. Sum total of the hazard degree for separately sub-basin represents the total flood hazard of that sub-basin and range from 24.39 to 30.16 as shown in tables 2 and 3. Based on calculated values of hazard degree, Wadi El Azariq sub-basins can be ordered into two classes; sub-basins of low hazard degree value is equal to 1 (as sub-basin 1) and sub-basins of high hazard of hazard degree is equal to 5 (as sub-basins 2 and 3) as shown in Figure 9 and Table 2 and 3. This means that sub-basin1 is characterized by high potential for groundwater recharge than the other sub-basins which have high potential for surface runoff concentration. So, some suspending dams should be constructed at the joining between streams of 4th and 5th orders.

5. Hydrologic data and methods

5.1. Rainfall distribution

Due to the lack of detailed scientific analysis of rainfall data in the literature for flood risk assessment in arid and semi-arid regions, this study examined a systematic approach to analyze rainfall data in arid basins for flood risk evaluation. The results will be linked with hydrologic modeling such as WMS for runoff potentials estimation of Wadi El Azariq basin. Methodology of the rainfall distribution in the study area is arranged as follows:

1. Collection of maximum daily rainfall data from the nearest rain gauge station of El Gudeirat.
2. Statistical analyses (frequencies) are applied to maximum daily rainfall events.
3. Communal probability distribution functions for maximum values are fitted to the data.
4. The best probability distribution roles are nominated using the Root Mean Square Error (RMSE).

Return period analysis and time series of maximum daily rainfall of time period about 23 years (1991-2014) are presented in Figure 10 and Tables 4 and 5. Statistical analytical tests (frequency and spatial analyses) concerning rainfall stations have been carried out using SMADA software. Time duration of obtained recorded rainfall data ranges from 27 to 54 years.

Numerous different frequency distributions have been fitted to the maximum daily rainfall for each station for obtaining the best distribution. Used distributions functions are: Normal; Two-parameter Log-Normal; Three-Parameter Log-Normal; Pearson Type III; Log-Pearson Type III and Gumbel. According to Chow et al., (1988), the best fitting of the distribution function is selected depending upon the RMSE, given by the following formula:

$$\text{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left[\hat{R}_i - R_i\right]^2} \quad \text{(3)}$$

Where, R_i is the observed rainfall depth at the station, $\hat{R}_i$ is the expected rainfall depth from the probability distribution, and n is the number of data points at the station.

RMSE values for the various cases describe the average discrepancy between the expected and the observed values. For the spatial analysis of the rainfall, the method of the inverse square distance weighting is used to map estimated rainfall for different return periods over the Wadi area. A brief description of the methodology is given by Viessman, et al., (1977).

From the aforementioned analysis, it has been shown that El Gudeirat rain gauge stations which are located on the south part of the study basin are following Gumbel distribution.

5.2. Creating a Storage Capacity Curve

Storage capacity curves are defined as the inter-relationship between elevation, area and volume which is created based upon the option in WMS using DEM (Fig. 5) as reported by Masoud (2015). WMS creates the storage capacity curves by starting at the outlet elevation and incrementing the elevation by the number of definite divisions till the specific water surface elevation (Dam) is achieved.

Figures 11 and 12 show the elevation-volume and the elevation- area curves (a & b) for whole basin and sub-basin 2 respectively. The calculated maximum volume at the proposed dam

(Fig. 13) with an elevation 12 m (amsl) for the whole basin is about 165×10^6 m^3 with an area is about 35 km^2. While, the maximum volume at the constructed dam for sub-basin2 with an elevation 204 m (amsl) is about 35×10^6 with an area is about 3.5 km^2. In the area- elevation curve, shows uneven curve with some hurdles. These hurdles indicate that the basin area has no variation with elevations. This means, the mountains' sides are almost have a steep slope at those elevations.

5.3. Model construction

The study basin is consider as one of the arid basins with very scarce measured hydrological data, so, the relationship between rainfall and runoff is necessary for the sustainable development of the water resources and for the protection from the flood hazard and drought. This study based upon the inter-connection between morphometric parameters, GIS techniques, WMS, HEC-HMS and the available scarce data of return period of maximum daily rainfall. Infiltration characteristics in this program depends on the type of curve number (CN) used in the Soil Conservation Service (SCS, 1972 and 1985) formula which now is changed to (NRCS).

CN is a function of hydrologic soil group and land use, it can be calculated by overlaying a land use and soil coverage with the drainage basin. According to Gheith and Sultan, 2002, CN of this study is calculated based on geological outcrops and SCS method (now is NRCS). Runoff is the excess rain, which is the total precipitation volume after subtracting infiltration and the potential maximum retention. The infiltration rate and potential maximum retention depend upon soil characteristics and basin geomorphology. Therefore, runoff amount depends on precipitation, soil type, lithology, soil moisture conditions and topography. The Soil Conservation Services (SCS) of the USA (1985 and 1986) developed an equation to calculate runoff from a drainage basin called SCS Runoff Curve Number (CN) Method which is as follows:

$$R= (P-I_a)^2/ (P-I_a+S) \ldots\ldots (4)$$

Where R is the runoff depth, P is the precipitation depth, I_a is initial abstraction factor and S is the potential maximum retention depth. I_a is empirically derived from the maximum soil water retention as in Eq. (6), which is related to the soil drainage characteristics (e.g. CN values).

$$I_a= 0.2\ S \ldots\ldots (5)$$

I_a accounts normally for losses due to evaporation, plant uptake, and water retained in surface depressions during the rainfall event. S accounts for the total amount of water retained in the drainage basin during the rainfall event, essentially I_a and Infiltration. Using Eqs. (5 and 6) the initial abstraction is calculated to be about 8 mm (Anonymous 1960), which matches with the mean value of the evaporation of the study area during the rainfall season. The potential maximum retention is calculated using a hydrological parameter called curve number (CN) as in the following equation:

$$S= (25400/CN)-254 \ldots\ldots (6)$$

According to Gheith and Sultan, 2002, due to the rainfall events in the study area are very rare; the moisture content can be ignored. The land use type and hydrologic conditions were classified as natural desert landscape and desert shrub (poor coverage, <30% ground cover). Three lithological types crop out in the study area: Quaternary deposits, fractured limestone of Tertiary and sandy limestone of. According to the NRCS (1986) classification of hydrologic soils, the Quaternary deposits in the study area were classified as type (A) soils with a curve number of 63, the Tertiary and Cretaceous deposits of limestone were classified as type (B) with a curve number 77 (Table 6). The weighted CN for mixed outcrops can be computed using Table 5 as follows:

$$CN=\sum_{i=1}^{k} A_i CN_i \Big/ \sum_{i=1}^{k} A_i \quad \ldots\ldots (7)$$

Where (CN_i) corresponds to the suitable (CN) for the part of the Wadi that has an area (A_i). Once the suitable CN is obtained, Eqs. (4 – 6) can be used to estimate the accumulated runoff as a function of total accumulated rainfall. The respective assignments of the curve numbers for Wadi El Azariq basin and its sub-basins based on Eq. (7) are summarised in Table 6.

WMS has implemented many of lag time equations and allows choosing the suitable method to automatically compute lag time and time of concentration. Because most of the equations were developed for specific watersheds (e.g. size, land cover etc.) a user should consider the assumptions made about a given equation, and try to identify one that used watershed conditions similar to the one being studied. Most commonly used equation for lag time is the SCS equation (1972), this equation may be used when computing the unit hydrograph using Snyder's method (1938) or SCS method. In this study SCS equation was used to calculate the time of concentration and lag for Wadi El Azariq basin, sub-basin1, sub-basin2 and sub-basin3 as shown in Table 7 and 8.

5.4. Hydrograph generation

Excess rainfall, or effective rainfall, is that rainfall which neither retained to the land surface nor infiltrated into the soil. After flowing across the watershed surface, excess rainfall becomes direct runoff at the watershed outlet. Hydrograph generation is the final step carried out in the modeling process to calculate the total surface runoff for the study basin. Required parameters for generating a unit hydrograph based upon the SCS dimensionless method including SCS lag time in minutes using WMS and HEC-HMS are tabulated in Table 7 and 8.

Twenty different hydrographs for Wadi El Azariq basin and its three main sub-basins have been constructed with different return periods of maximum daily rainfall as shown in Figures (14 – 17). Calculated runoff volume of Wadi El Azariq basin ranges from 4.1×10^6 to 13.8×10^6 m^3 at elevation is 4.5 m (amsl) to 6.5 m (amsl) with an inundation area is 3.6 km^2 and 8 km^2 at return periods of 5 years and 100 years respectively as shown in Figures (14 – 17). Hydrograph elements and all the input and output data of Wadi El Azariq basin and its sub-basins are tabulated in Table 6 and 7.

Figure 18 (a and b) shows Inundated Areas which are considered as a promising areas for groundwater recharge potentiality of Wadi El Azariq basin and its sub-basin2 at the proposed dam and constructed dam respectively. Areas of inundation were calculated during return period of 10 years and it is about 51 km^2 (12000 feddan) as shown in Figure 18a and it is about 80 km^2 (20000 feddan) as shown in Figure 18b.

6. Results and discussion

In the context of hydraulic design, hydrologic analysis provides estimates of flash flood magnitudes as a result of precipitation. These estimates consider processes in a watershed that transform precipitation to runoff and that transport water through the system to a project's location or constructing dams for direct infiltration of rainfall and to the infiltration of runoff water along Wadi beds forms the main source of the aquifer's recharge. Wadi El Azariq basin considers as one of the arid basins which receives annually rainfall less than 100 mm, but the problem is sometimes this basin receives some rainfall events of high intensity which cause a flash flood leads to deconstruction of the infrastructures and life. Wadi El Azariq basin and its sub-basins have order of stream ranging from 6th order to 7th order. The highest orders have minimum numbers of the streams but the lowest orders have maximum number of streams. This behavior of stream order with its number is due to the lithology and rainfall intensity, where the majority of the tributaries up to the 3rd order are originated at the highest elevation parts, creating steep slopes, but the tributaries of higher than 4th order are originated in low elevated parts. Wadi El Azariq basin and its sub-basins characterized by bifurcations ratio (Rb) and weighted mean bifurcation ratio (WMRb) closed to 4, which indicates to the effect of lithology and geologic structure control upon the drainage basin.

According to the calculated geometric characteristics, Wadi El Azariq basin and its sub-basins are characterized by large basin area with basin length ranges between 34 km and 101 km which indicate causes the elongated shape with good potentiality of groundwater recharge. Wadi El Azariq basin and its sub-basins belongs to the intermediate to fine texture categories with dendritic pattern which allow by high potentiality for groundwater recharge. Wadi El Azariq and its sub-basins have weighted mean bifurcation ratio higher than 3 which reflect elongated, high elevated basin and influenced by geologic structures. Wadi El Azariq basin and its sub-basins belong to the category of medium to low elevation.

The shape characteristics of the Wadi El Azariq and its sub-basins (circularity, elongation and compactness ratios), reflect the dominance of moderate to high elongation characters. The elongation ratio is an important parameter for the basin hydrology and for the estimation of flood hazard. For a given rainfall event, the less elongated basins will generate a greater peak run-off and faster travel velocities to the outlet. Hypsometric integral values of Wadi El Azariq and its sub-basins are less than 0.6 which indicated that the Wadi El Azariq basin and its sub-basins are late mature close to old, of eroded and dissected basin.

Due to calculated value of hazard degree, main sub-basins of Wadi El Azariq could be classified into two groups; sub-basins of high hazard degree which have hazard value of 5 (su-

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basin2 and sub-basin3) and sub-basins of low hazard which has hazard degree of 1 (sub-basin1). This means that the sub-basin1 has the maximum potentiality for groundwater recharge than the other sub-basins which have the potentiality for surface runoff accumulation. So, some hindering dams should be constructed at the connection between streams of 4th and 5th order for sub-basin3 to recharge the shallow groundwater aquifer in Egypt.

As a result of the scarcity of actual rainfall and runoff data, rainfall events which applied for Wadi El Azariq basin were selected according the return period of maximum daily rainfall (5, 10, 25, 50 and 100 years) of El Gudeirat station. As a result of the model applied to Wadi El Azariq, a rainfall events of a total of 14, 18, 23, 26 and 29 mm of return periods 5, 10, 25, 50 and 100 years produce a discharge volume of 4.1×10^6, 5.6×10^6, 8.7×10^6, 10.7×10^6 and 13.8×10^6 m^3 respectively at the delta of the Wadi El Azariq basin. The discharge volume of the main sub-basins of Wadi El Azariq and its maximum peak are tabulated in Table 7.

Because of Wadi El Azariq basin is characterized by arid conditions with high average evaporation, scarce vegetation a high porosity of the Quaternary deposits in the delta and main tributaries of the basin. Calculated infiltrations in the Wadi El Azariq basin and its sub-basins have a wide variation from one return period to the other. Infiltration losses of Wadi El Azariq basin ranges from 29.6 % for return period 5 years and 51 % for return period 100 years, while for the sub-basins 1 and 2 it ranges from 28.5% to 51% for return periods of 5 years and 100 years respectively. Sub-basin 3 has the highest infiltration where it ranges from 35% to 57% at return periods of 5 years and 100 years respectively. The transmission losses were controlled by the basin and channel physical characteristics (geometry, shape, slope, etc.), type of soil, depth to bed rock, temperature and duration of flow. This means that the potentiality of groundwater recharge is higher at sub-basin3 than the others. Accordingly, a proposed management system aims at capturing more runoff water in the area to prevent flood hazard and increase infiltration water result in recharge to the groundwater as shown in Figure 13. The proposed system starts by the management of successive incomplete low rocky dams and boulders. The barriers can be achieved by accumulating the available boulders of weathering product without cementation (El Shamy, 1992). The system end by the construction of big masonry dams at the outlet of the watershed area. By this Wadi El Azariq basin develops through recharging the groundwater aquifers, and also ensures the protection of the strategic areas from flash flood.

Conclusion and recommendations

The integration between physiographic features of the study basin, Geographic Information System (GIS) and Watershed Modelling System (WMS) is very important to evaluate the hazard degree of basin and flash flood especially in arid regions which is suffering from the scarcity of data. Flash floods can be affected by many factors such as topography and catchment area, where topography is the result of geology and climate that determine landforms, slopes and local of micro-topography. In this study the topography is considered as the important controlling factor on the hydrological response to flash flood because the study area is suffering from the scarcity of data. The flood inundation maps are based on the topographic and geomorphic features of Wadi El Azariq basin.

Estimating of groundwater recharge in arid regions is an extremely important but difficult task and the main reason is the scarcity of data in arid regions. As a result of the scarcity of hydrologic information, the relation between rainfall and runoff was calculated depending on the morphometric information, GIS techniques, WMS and HEC HMS software. It is recommended that some dams and dikes are very important to construct for hindering of the runoff water to infiltrate and recharge the shallow aquifer at the crossing point between the fourth stream order and fifth stream order. There are two promising recharging areas which cover an area about 131 km^2 in this study, need to be addressed through detailed study using geophysical tools and drilling test wells. This study provides in-depth analysis of the flash flood prone areas of Wadi El Azariq basin and its sub-basins and the mitigation measures. This study will help to plan rainwater harvesting and watershed management in the flash flood alert zones for the future.

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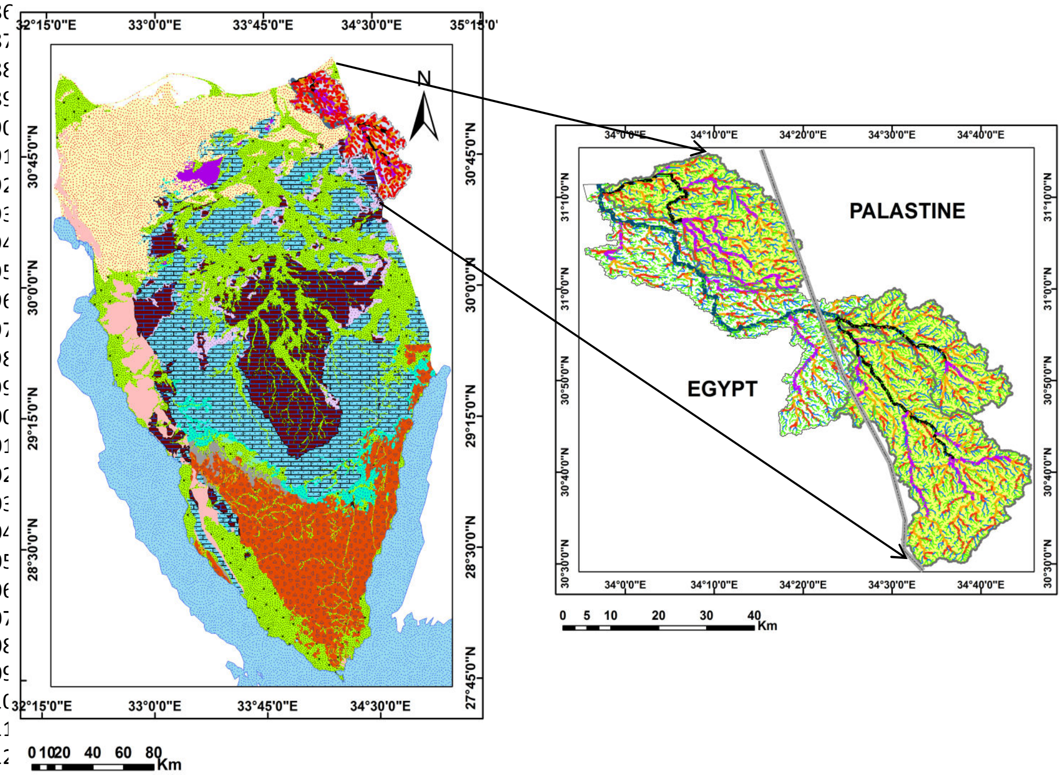

Fig. 1. Location map of Wadi El Azariq, East Sinai, Egypt.

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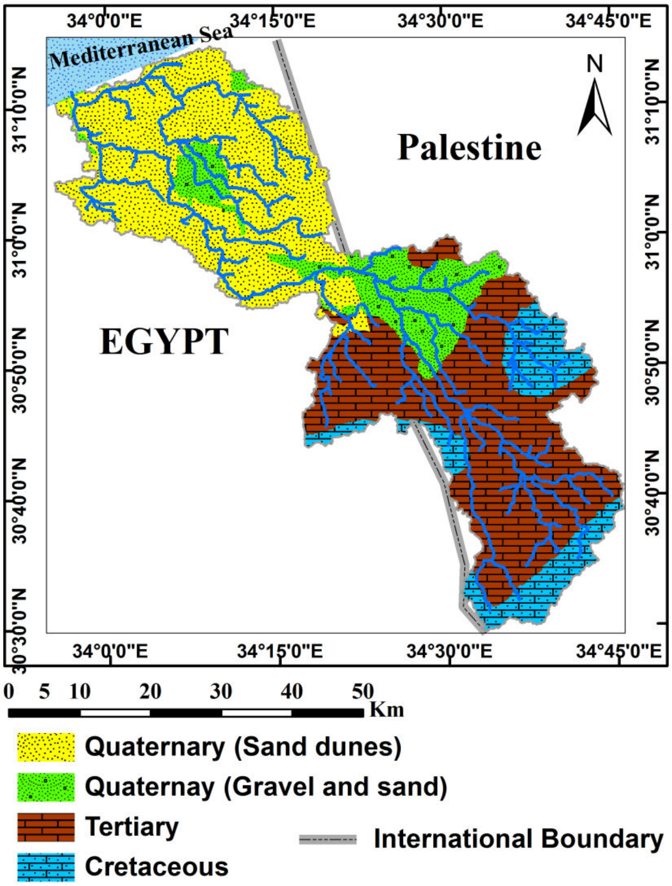

Fig. 2. Simplified geological map of Wadi El Azariq basin.

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Fig. 3. Field photos show the development of flash floods that occurs in Wadi El Azariq (March, 2014).

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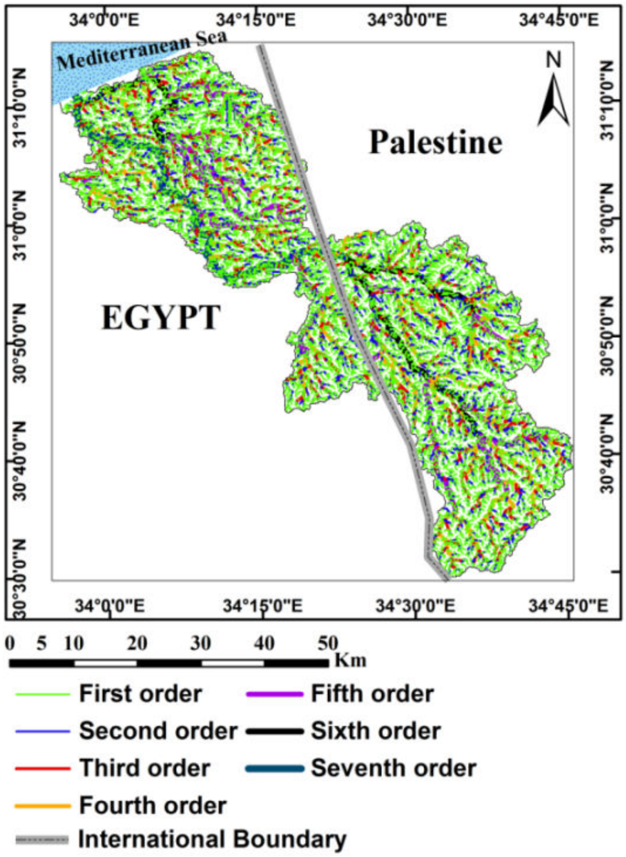

Fig. 4. Stream order of Wadi El Azariq basin.

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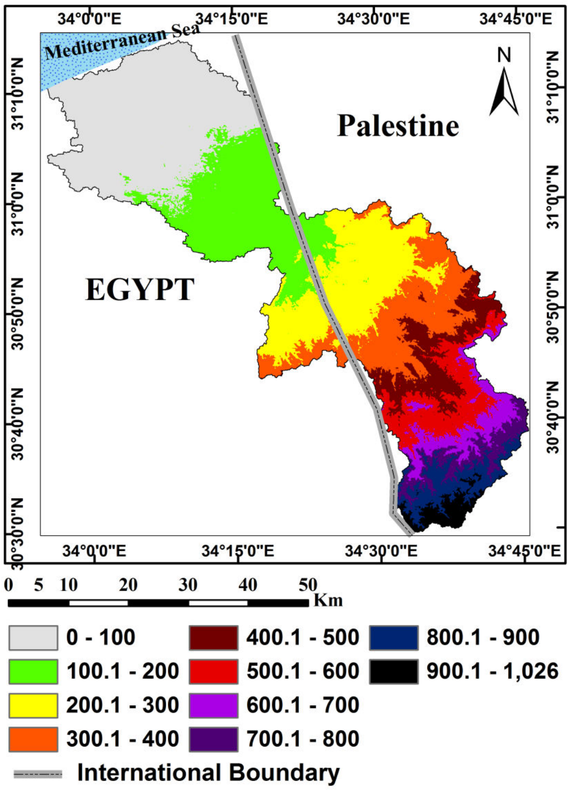

Fig. 5. Map of digital elevation model (DEM) of the of Wadi El Azariq basin.

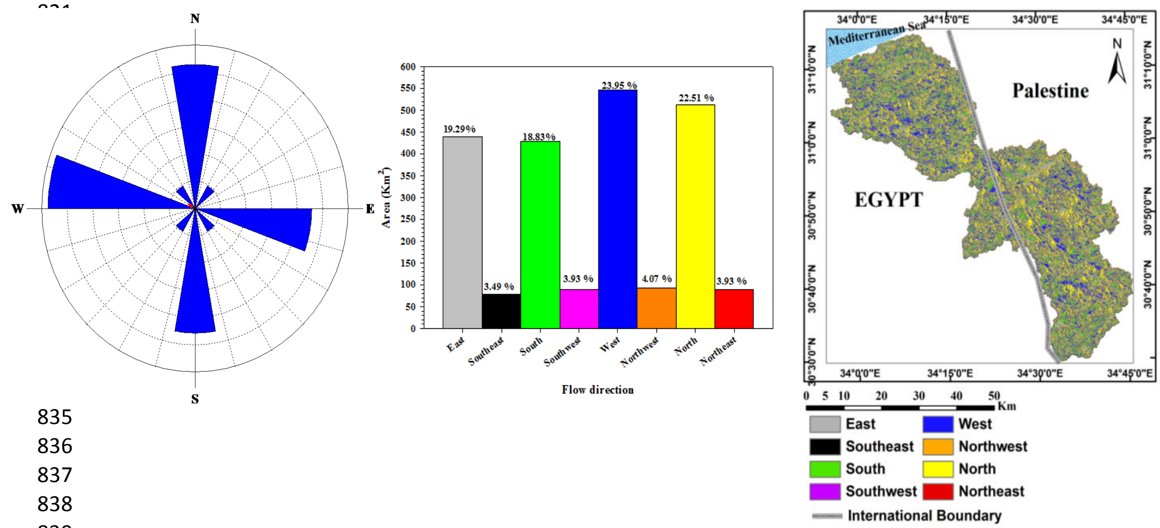

Fig. 6. Flow direction map, histogram and rose diagram of Wadi El Azariq basin.

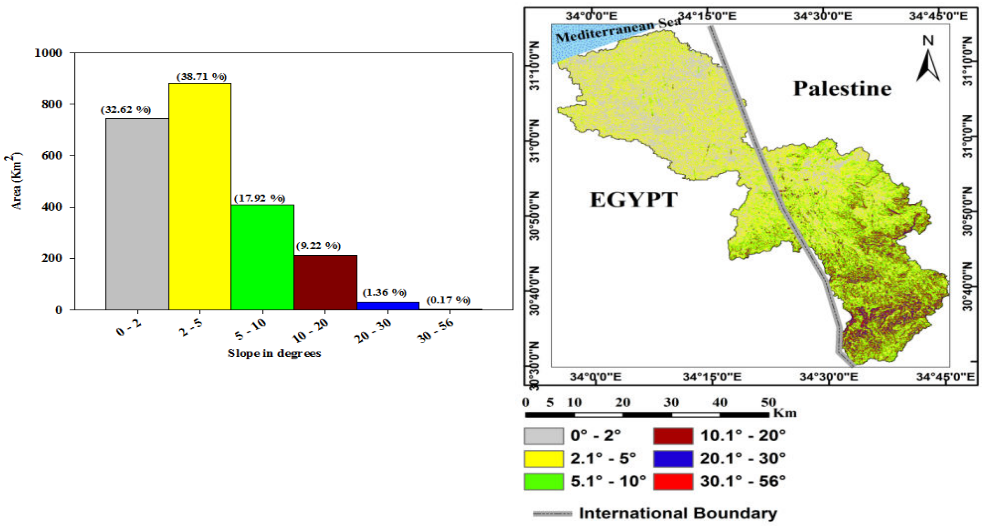

Fig. 7. Slope map and its histogram of Wadi El Azariq basin.

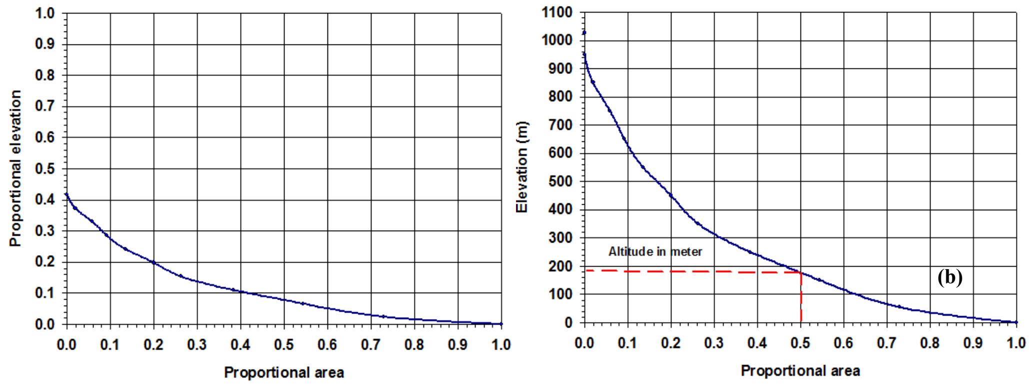

Fig. 8. Hypsometric curve (a) and altitude (b) of Wadi El Azariq basin.

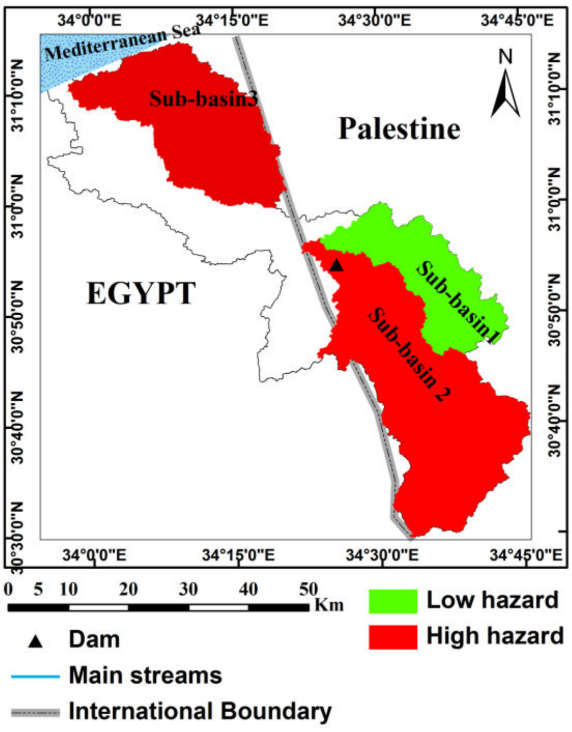

Fig. 9. Map of flash flood hazard degree of Wadi El Azariq sub-basins.

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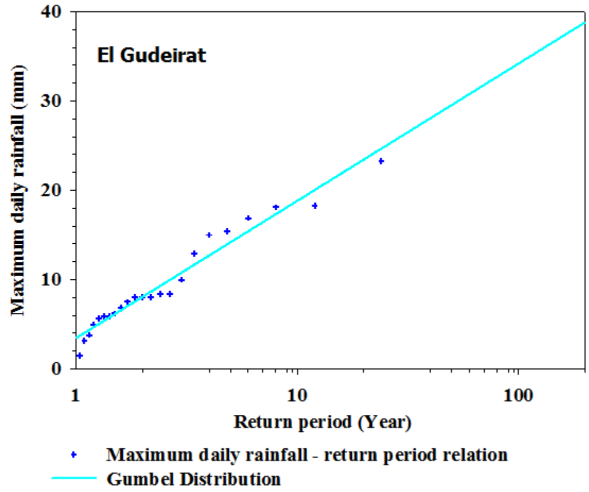

Fig. 10. Graphical representation of maximum daily rainfall at different return periods for the temporal analysis of rainfall data at El Gudeirat station.

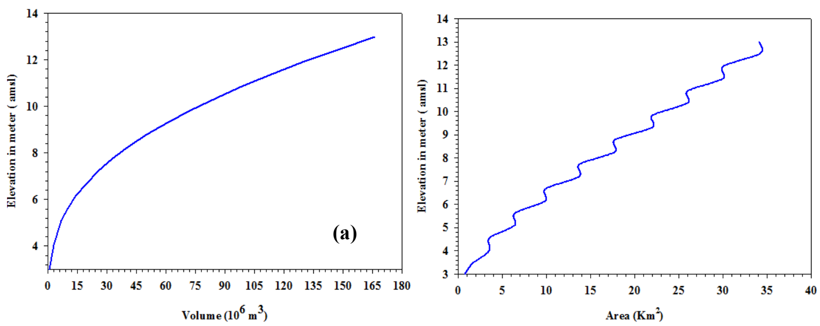

Fig. 11. Storage capacity curves for whole Wadi El Azariq basin.

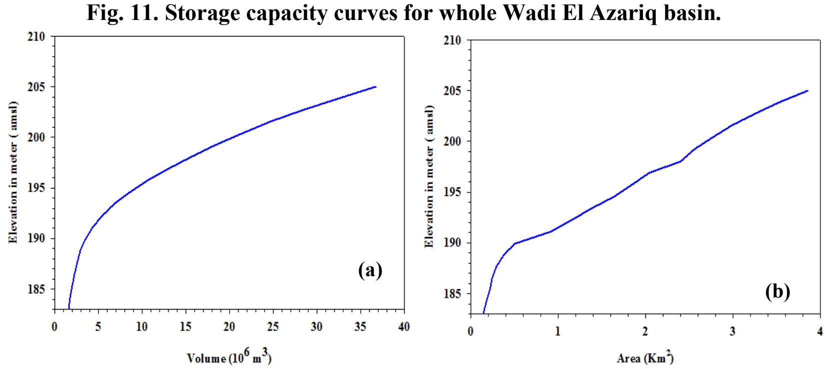

Fig. 12. Storage capacity curves for sub-basin2.

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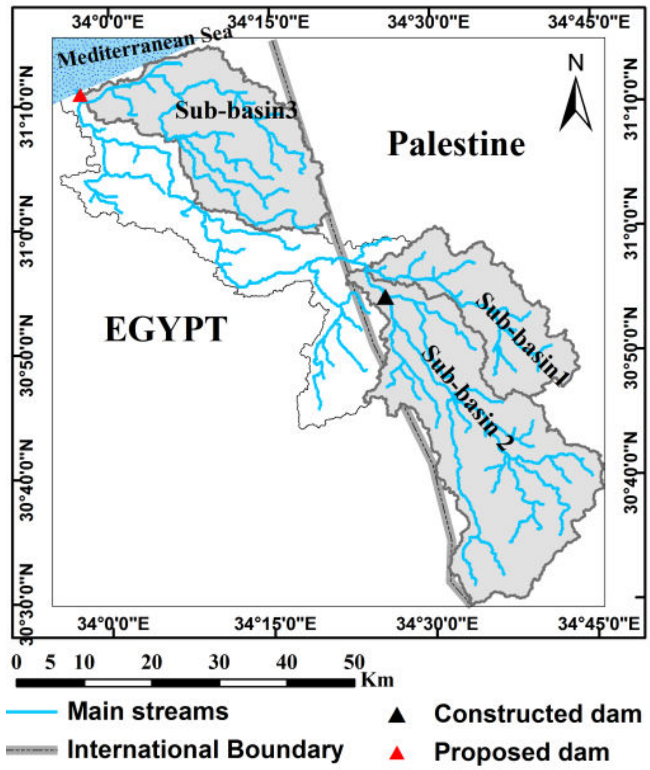

Fig. 13. Location map of the main sub-basins and dams of Wadi El Azariq basin.

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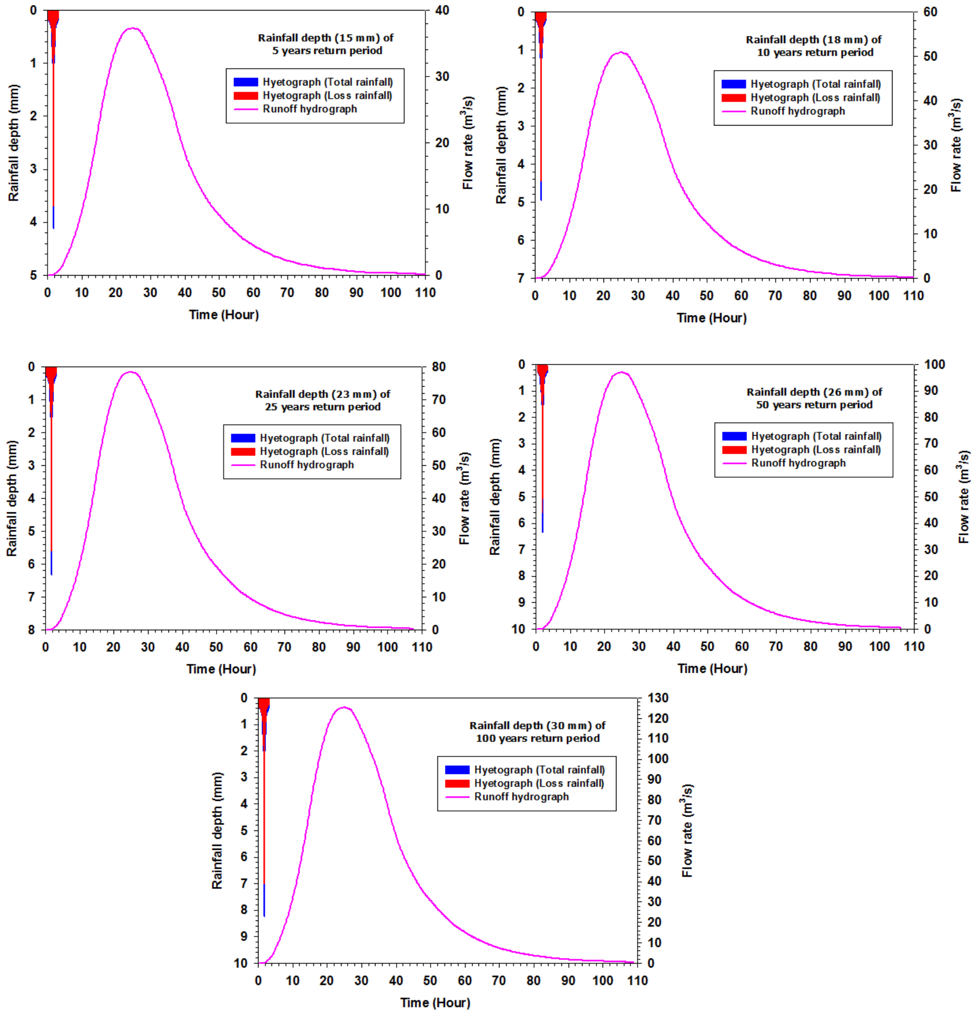

Fig. 14. Hydrographs of Wadi El Azariq basin at different return periods.

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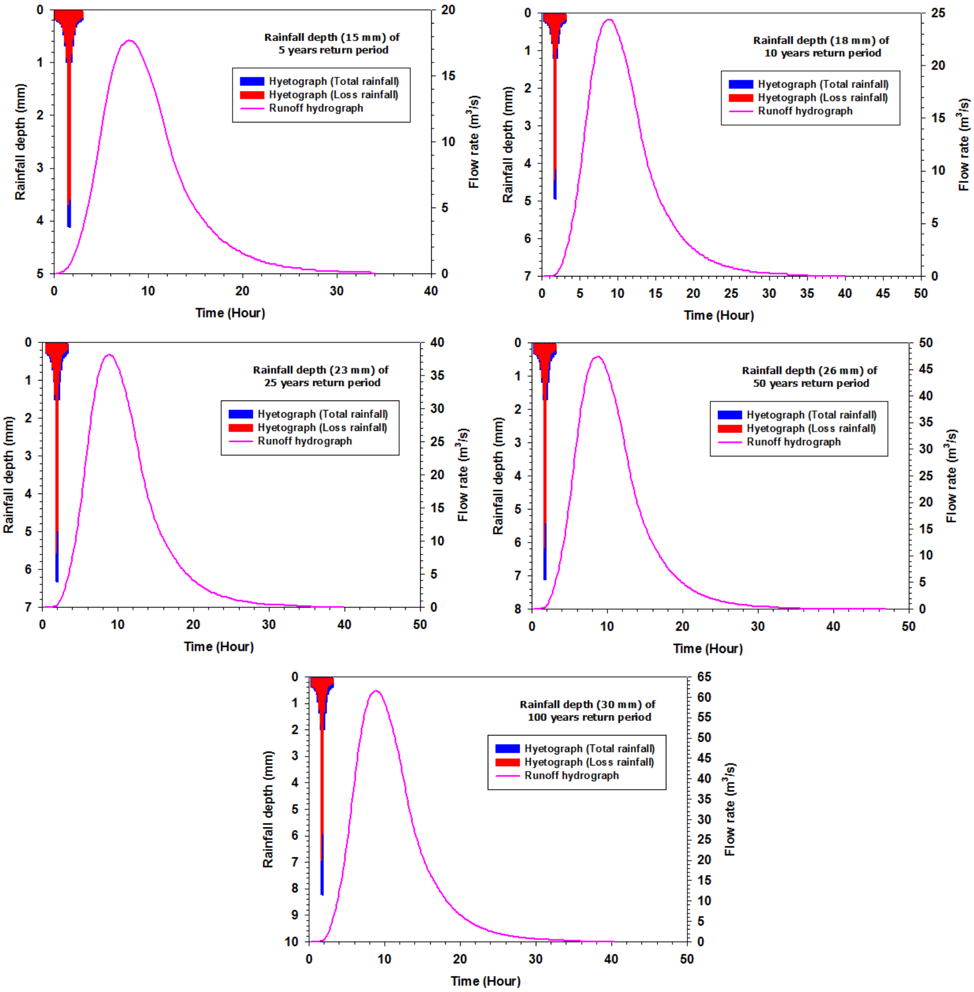

Fig. 15. Hydrographs of sub-basin1 at different return periods.

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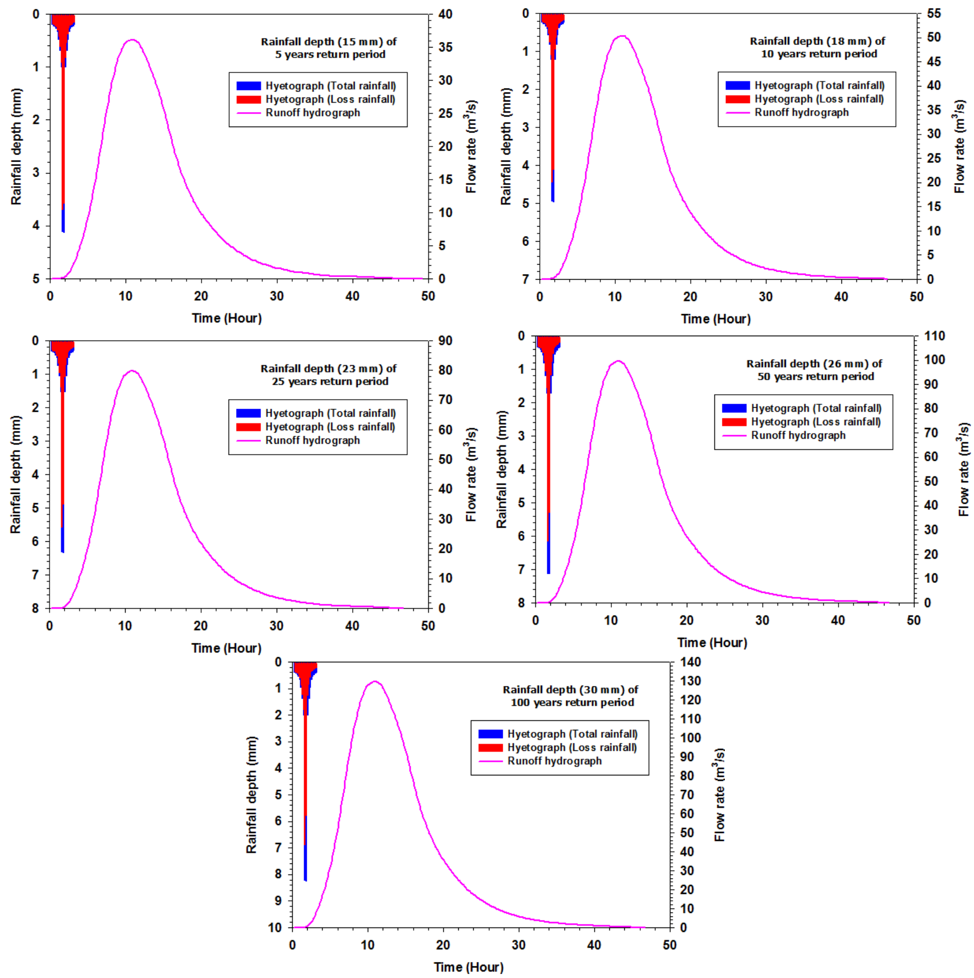

Fig. 16. Hydrographs of sub-basin2 at different return periods.

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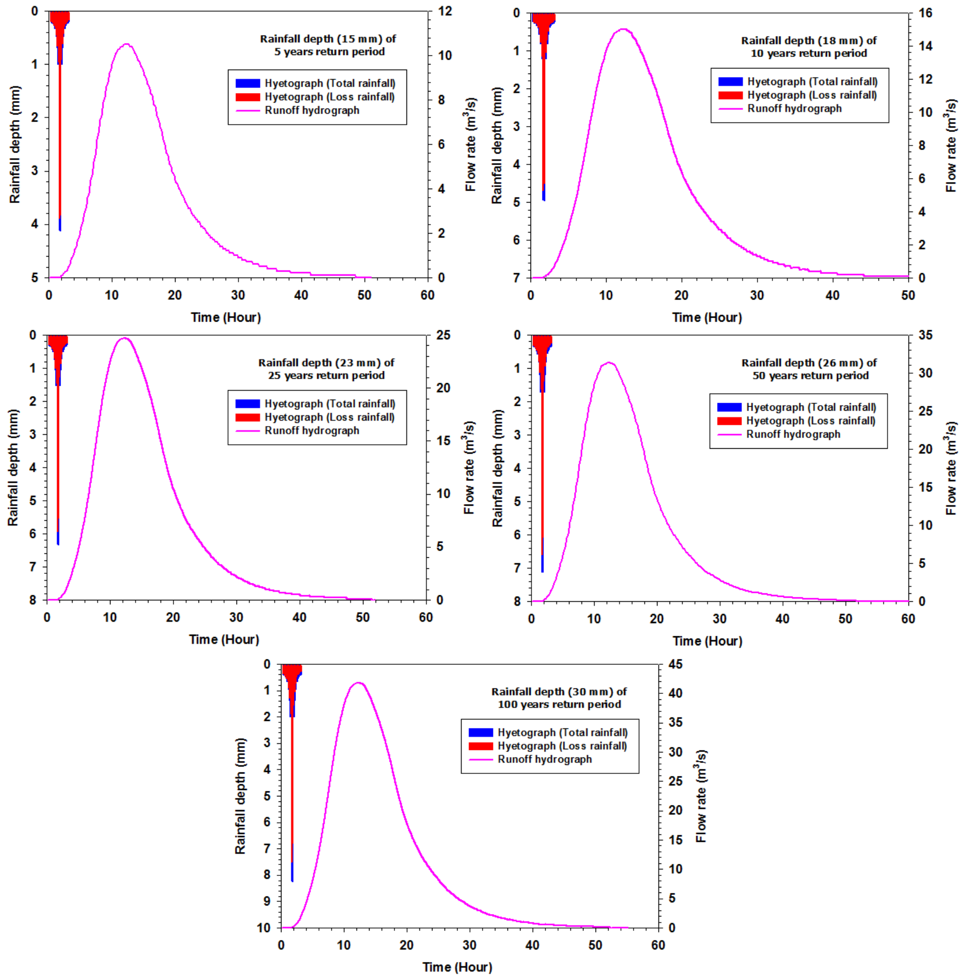

Fig. 17. Hydrographs of sub-basin3 at different return periods.

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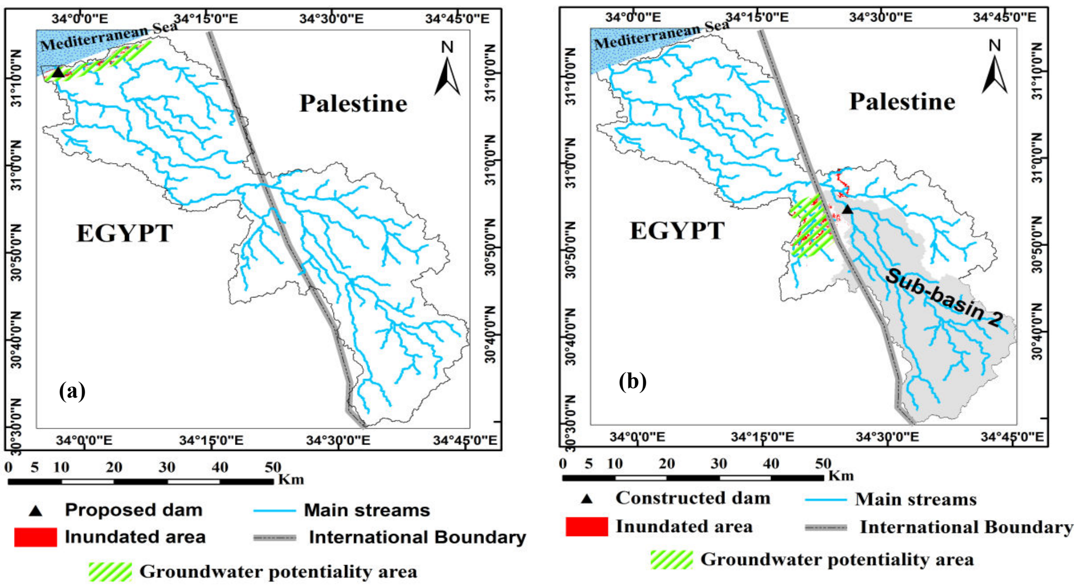

Fig. 18. Inundated area and groundwater potentiality map of Wadi El Azariq basin (a) and its sub-basin2 (b) at return period of 10 years.

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Table 1. Morphometric parameters formulas.

Morphometric Parameters			Formula	Reference
Drainage Network	1	Stream order ($_u$)	Hierarchical Rank	Horton (1945), Strahler (1952 & 1964)
	2	Stream number (N_u)	Nu = N1+ N2 + N3+…..Nn	Strahler (1952)
	3	Stream length (L_u)	Lu= L1+L2+...... Ln	Horton (1932)
	4	Bifurcation ratio (Rb)	$Rb = Nu / \mathrm{Nu} + 1$	Horton (1945) and Strahler (1964)
	5	weighted mean bifurcation ratio (WMRb)	$WMRb = \frac{\Sigma\,(Rbu / Rbu + 1)(Nu + Nu + 1)}{\Sigma\,N}$	Strahler (1952)
	6	Main channel Length (MC)	GIS software Analysis	
	7	Main channel index (MCi)	Ci = (Main channel length) / (Maximum straight of the main channel)	Mueller (1968)
	8	Sinuosity (Si)	$Si = VL / LB$	Gregory and Walling (1973)
	9	Rho coefficient (ρ)	$\rho = L_u r/Rb$	Horton (1945)
Basin Geometry	10	Watershed Area (A)	GIS software Analysis	Schumm (1956)
	11	The basin length (LB)	GIS software Analysis	Schumm (1956)
	12	The basin perimeter (Pr)	GIS software Analysis	Schumm (1956)
	13	Basin Width (W)	$W = A / LB$ (km)	Horton (1932)
	14	Circularity ratio (Rc)	$Rc = 4\pi A / \mathrm{P}r^2$	Miller (1953)
	15	Elongation ratio (Re)	$\mathrm{Re} = (2\sqrt{A/\pi} / LB$	Schumm 1956
	16	Texture ratio (Rt)	$Rt = \Sigma\, Nu / \mathrm{Pr}$	Horton (1945)
	17	Form factor ratio (FFR)	$\mathrm{FFR} = A / LB^2$	Horton (1932)
	18	Inverse shape form (Sv) or Shape factor ratio (Sf)	$Sv = LB^2 / A$	Horton (1932)
	19	Basin shape index (Ish)	$Ish = 1.27\, A / LB^2$	Haggett, 1965
	20	Compactness ratio (S_H)	$S_H = \mathrm{Pr} / 2(\sqrt{\pi A})$	Horton (1945)
	21	Fitness ratio (Fr)	Fr = Channel length / Perimeter	Melton (1957)
	22	Lemniscate shape (Ls)	$Le = (3.14)\,(BL)^2 / (4A)$	Chorley et al., (1957)

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Table 1. Continued:

Morphometric Parameters			Formula	Reference
Drainage texture	23	Stream Frequency (F)	$F = \sum_{i=1}^{K} Nu \Big/ A$	Horton (1932 & 1945)
	24	Drainage density (D)	$D = \sum Lu \Big/ A$	Horton (1932 & 1945)
	25	Drainage Intensity (Di)	Di = F/D	Faniran (1968)
	26	Length of overland flow (Lo)	$Lo = 1/2D$	Horton 1945
	27	Infiltration Number (FN)	FN = (F)(D)	Faniran (1968)
	28	Drainage pattern (Dp)	Stream network using GIS software Analuysis	Horton (1932)
Relief characteristics	29	Maximum elevation (H_{max})	GIS software Analysis using DEM	
	30	Minimum elevation (H_{min})	GIS software Analysis using DEM	
	31	Relief (Rf)	Rf = Highest elevation-Lowest elevation	Strahler (1952)
	32	Internal relief (E)	E= (E85-E10)	Strahler (1952)
	33	Mean Elevation (Hm)	GIS software Analysis using DEM	
	34	Relief ratio (Rr)	$Rr = (Rf \Big/ LB)100$	Schumm (1956)
	35	Slope index (SI %)	$SI = (E \Big/ 0.75VL)100$	Majure and Soenksen (1991)
	36	Mean basin slope (Sm)	GIS software Analysis using DEM	
	37	Ruggedness number (Rn)	$Rn = Rf.D$	Melton (1957)
	38	Hypsometric Integral (HI)	$HI = (Elev - Elev_{min}) / Elev_{max} - Elev_{min})$ Elev is the mean elevation, $Elev_{max}$. is the maximum elevation and $Elev_{min}$ is the minimum elevation,	Strahler(1952)

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Table 2. Morphometric parameters and hazard degree of Wadi El Azariq basin.

Morphometric Parameters			Wadi El Azariq Basin			
			Whole Basin	Name of Sub-basins		
				Sub-basin 1	Sub-basin 2	Sub-basin3
Drainage Network	1	($_u$)	7.00	6.00	6.00	6.00
	2	(N_u)	8825.00	1182.00	2881.00	2068.00
	3	(L_u)	5710.30	758.60	1874.80	1373.40
	4	(Rb)	3.99	4.24	5.00	4.51
	5	(WMRb)	5.45	5.34	6.20	5.50
	6	(MC)	75.60	25.8	41.70	30.40
	7	(MCi)	1.45	1.23	1.25	2.02
	8	(Si)	0.75	0.76	0.80	0.76
	9	(ρ)	0.47	0.53	0.37	0.45
Basin Geometry	10	(A)	2278.00	309.00	788.00	518.00
	11	(LB)	101.00	34.00	52.00	40.00
	12	(Pr)	543.50	163.00	262.00	179.00
	13	(W)	22.60	9.10	15.20	13.00
	14	(Rc)	0.10	0.15	0.14	0.20
	15	(Re)	0.53	0.58	0.61	0.64
	16	(Rt)	16.23	7.25	11.0	11.60
	17	(FFR)	0.22	0.27	0.29	0.32
	18	(Sv) or (Sf)	4.48	3.74	3.43	3.10
	19	(Ish)	0.28	0.34	0.37	0.41
	20	(S_H)	3.21	2.62	2.63	2.22
	21	(Fr)	0.14	0.16	0.16	0.17
	22	(Ls)	3.52	2.94	2.70	2.43
Drainage texture	23	(F)	3.87	3.83	3.66	3.99
	24	(D)	2.51	2.46	2.38	2.65
	25	(Di)	1.55	1.56	1.54	1.51
	26	(Lo)	0.20	0.20	0.21	0.19
	27	(FN)	9.71	9.40	8.70	10.6
	28	(Dp)	Dendritic	Dendritic	Dendritic	Dendritic
Relief Characterizes	29	H_{max}	1026.00	674.00	1019.00	170.00
	30	H_{min}	0.00	147.00	131.00	1.00
	31	(Rf)	1026.00	527.00	888.00	169.00
	32	(E)	555.00	175.00	450.00	100.00
	33	(Hm)	291.00	344.00	538.00	75.00
	34	(Rr)	0.010	0.016	0.017	0.004
	35	(SI %)	0.010	0.010	0.014	0.004
	36	(Sm)	4.40	4.80	7.30	1.90
	37	(Rn)	2.60	1.30	2.11	0.45
	38	(HI)	0.280	0.37	0.46	0.44
Summation of Hazard degree				24.39	30.16	30.00
Hazard degree				1	5	5

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Table 3: Hazard degree evaluation for Wadi El Azariq sub-basins.

Morphometric parameters	Sub-basins		
	1	2	3
(WMRb)	5.34	6.20	5.50
Hazard WMRB	5.00	1.00	4.26
(A)	309.00	788.00	518.00
Hazard (A)	1.00	5.00	2.75
(Rt)	7.25	11.00	11.60
Hazard(Rt)	1.00	4.45	5.00
(Ish)	0.34	0.37	0.41
Hazard (Ish)	1.00	2.71	5.00
(F)	3.83	3.66	3.99
Hazard (F)	3.06	1.00	5.00
(D)	2.46	2.38	2.65
Hazard (D)	2.19	1.00	5.00
(Rr)	0.02	0.02	0.00
Hazard (Rr)	4.69	5.00	1.00
(SI %)	0.01	0.01	0.00
Hazard (SI%)	3.40	5.00	1.00
(Rn)	1.30	2.11	0.45
Hazard (Rn)	3.05	5.00	1.00
Summation Hazrd	24.39	30.16	30.00
Degree	1	5	5

Table 4. Root mean square error of the rainfall stations at El Gudeirat station, south part of the study basin.

Distribution type	Stations
	El Gudeirat
Normal	1.21
2 Parameter Log Normal	0.98
3 Parameter Log Normal	0.94
Pearson Type III	0.86
Log Pearson Type III	0.79
Gumbel Type I	0.77

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Table 5. Prediction (millimetre) for distributions of selected return periods (in years) based on duration data.

Gudeirat rainfall station	Distribution type	Probability	0.80	0.90	0.96	0.98	0.99
		Return period (Years)	5	10	25	50	100
	Gumbel Type I	Rainfall depth (mm)	14.0	18.0	23.0	26.0	29.0

Table 6. Assignments of curve numbers for different outcrops types in Wadi El Azariq basin and its sub-basins.

Basin	Total Area (km^2)	Substrate		Type of soil group	Value of CN	Weighted CN
		Rock Type	Area (km^2)			
Whole Wadi El Azariq	2278.0	Quaternary	1176	A	63.0	70.0
		Tertiary	840.0	B	77.0	
		Cretaceous	262.0	B	77.0	
Sub-basin 1	309.0	Quaternary)	84.0	A	63.0	73.2
		Tertiary	117.0	B	77.0	
		Cretaceous	108.0	B	77.0	
Sub-basin 2	788.0	Quaternary (Gravel and sand)	94.5	A	63.0	75.4
		Tertiary	553.5	B	77.0	
		Cretaceous	140.0	B	77.0	
Sub-basin 3	518.0	Quaternary	518.0	A	63.0	63.0

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Table 7. Input and output parameters of Wadi El Azariq basin and its sub-basin1 for hydrograph generation and storage capacity using GIS, WMS and HEC-HMS.

Parameters	Description of the parameters	Type of parameters	Wadi El Azariq basin					Sub-basin1				
Total area (km^2)	The area of the studied basin in km^2	Input parameters	2278					309				
Modelled area (km^2)			2186					306				
Overland flow (m)	The flow length for sheet flow over surface		200					200				
Slope (m/m)	The average land slope		0.01					0.01				
Pervious area (km^2)	The area that allows relatively free passage of water		2050					278				
Impervious area (km^2)	The land which allows for abstraction but upon which no infiltration takes place. Rain which fall onto this type of the land will either be abstracted, flow directly to the outlet of the watershed or flow onto the pervious watershed regions.		228					31				
Weighted curve number	See the text		70					73				
Initial abstraction (mm)	See the text		8					8				
Return period (Years)	Estimation of rainfall of given value		5	10	25	50	100	5	10	25	50	100
Total rainfall (mm)	Total rainfall (mm) for a series of time increments		14.0	18.0	23.0	26.0	29.0	14.0	18.0	23.0	26.0	29.0
Total rainfall duration (hour)	Event duration in hour		3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Rainfall intensity (mm/h)	Rainfall intensity (mm/h)		4.7	6.0	7.7	8.7	9.7	4.7	6.0	7.7	8.7	9.7
Type of rainfall distribution (hyetograph)	Type of rainfall distribution (hyetograph		Gumbel Type I					Gumbel Type I				
Calculated time of concentration (hour)			22.3					7.6				
Calculated lag time (hour)	See the text		13.4					4.6				
Calculated maximum flow rate (peak discharge) m3/s		Output parameters	37.3	50.8	78.4	97.0	125.2	18.0	24.4	38.0	47.4	62.0
Runoff volume (10^{6}m^3)			4.1	5.6	8.7	10.7	13.8	0.6	0.8	1.3	1.6	2.1
Infiltration (mm)			4.14	7.50	11.1	13.1	14.7	4.0	7.4	11.0	12.0	14.2
Rainfall excess (mm)			1.86	2.50	3.90	4.90	6.30	2.00	2.60	4.00	6.00	6.80
Maximum elevation (m) above mean sea level			4.5	5.0	5.1	5.3	6.0	180.0	181.0	182.5	183.0	185.0
Maximum of flooded inundation area (km^2)			3.6	3.8	6.4	6.8	9.0	0.2	0.3	0.5	0.6	0.8

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Table 8. Input and output parameters of sub-basin2 and sub-basin 3 of Wadi El Azariq basin for hydrograph generation and storage capacity using GIS, WMS and HEC-HMS.

Parameters	Description of the parameters	Type of parameters	Sub-basin2					Sub-basin3				
Total area (km^2)	The area of the studied basin in km^2	Input parameters	788.0					518.0				
Modelled area (km^2)		Input parameters	782.0					497.0				
Overland flow (m)	The flow length for sheet flow over surface	Input parameters	210					190				
Slope (m/m)	The average land slope	Input parameters	0.014					0.004				
Pervious area (km^2)	The area that allows relatively free passage of water	Input parameters	709					492				
Impervious area (km^2)	The land which allows for abstraction but upon which no infiltration takes place. Rain which fall onto this type of the land will either be abstracted, flow directly to the outlet of the watershed or flow onto the pervious watershed regions.	Input parameters	79					26				
Weighted curve number	See the text	Input parameters	75.4					63.0				
Initial abstraction (mm)	See the text	Input parameters	8					8				
Return period (Years)	Estimation of rainfall of given Value	Input parameters	5	10	25	50	100	5	10	25	50	100
Total rainfall (mm)	Total rainfall (mm) for a series of time increments	Input parameters	14.0	18.0	23.0	26.0	29.0	14.0	18.0	23.0	26.0	29.0
Total rainfall duration (hors)	Event duration in hour	Input parameters	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Rainfall intensity (mm/h)	Rainfall intensity (mm/h)	Input parameters	4.7	6.0	7.7	8.7	9.7	4.7	6.0	7.7	8.7	9.7
Type of rainfall distribution (hyetograph)	Type of rainfall distribution (hyetograph	Input parameters	Gumbel Type I					Gumbel Type I				
Calculated time of concentration (hour)	See the text	Input parameters	11.0					17.0				
Calculated lag time (hour)	See the text	Input parameters	6.6					10.2				
Calculated maximum flow rate (peak discharge) m^3/s		Output parameters	36.1	50.4	80	100	130	10.5	15.0	25.0	31.4	42.0
Runoff volume (10^{6}m^3)		Output parameters	1.6	2.2	3.4	4.3	5.6	0.5	0.75	1.2	1.6	2.1
Infiltration (mm)		Output parameters	4.00	7.30	10.70	12.50	14.80	4.90	8.50	12.50	14.80	16.80
Rainfall excess (mm)		Output parameters	2.00	2.70	4.30	5.50	6.20	1.10	1.50	2.50	3.20	4.20
Maximum elevation (m) above mean sea level		Output parameters	183.0	186.0	189.0	191.0	192.3	2.5	2.8	3.0	3.2	3.2
Maximum of flooded inundation area (km^2)		Output parameters	0.14	0.25	0.50	0.90	1.20	0.2	0.3	0.5	0.7	1.1