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# Flash Flood Risk Estimation of Wadi Qena Watershed, Egypt Using GIS Based Morphometric Analysis

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## Abstract

Flash flooding is one of the periodic geohazards in the eastern desert of Egypt where many parts of Upper Egypt, Sinai, and Red Sea areas were hit by severe flash floods, for example in 1976, 1982, 1996 and January 2010. The hazard degree for each sub-basin was determined using the approach developed by El-Shamy for assessing susceptibility of sub-basins to flash flooding risk. To identify at-risk sub-basins, two different methods were applied. The first method is based on the relationship between the drainage density and bifurcation ratio, and the second one uses the relationship between drainage frequency and bifurcation ratio. The three morphometric parameters (the bifurcation ratio, drainage density, and stream frequency) were extracted and calculated for each sub-basin of the watershed. Based on the final hazard degree resulting from the two methods, a detailed hazard degree map was extracted for all sub-basins. The results illustrate that there are no sub-basins with low risk of flooding. The sub-basins with the highest hazard degree are concentrated in the middle of the watershed although they have smaller areas compared with the surrounding sub-basins. The sub-basins located at the boundary of the watershed have an intermediate risk of flooding and moderate potential for groundwater recharge. This constructed map can be used as a basic data for assessment of flood mitigation and planning.

**Keywords:** Morphometry; Risk; Flood hazard; Groundwater recharge; Eastern desert of Egypt; Geographic information systems

## Introduction

Flash flooding is one of the most dangerous natural disasters because it is highly unpredictable. Natural catastrophes occur frequently and their effect and frequency appear to have greatly increased in recent decades, mostly because of environmental degradation [1-4]. Many factors contribute to the flooding problem, including topography, climate, engineering structures, geomorphology, drainage and climate change. There are some other related factors in the desert regions which affect the severity flash floods. Some of these factors involve environmental and human processes, drainage networks, drainage characteristics, water loss (evaporation and infiltration), and rainfall characteristics [5]. Morphometric analysis and studies include evaluations of streams by measurement of different network properties. Evaluation of morphometric parameters could be estimated from the analysis of different drainage parameters such as stream order, basin area, perimeter, stream frequency, drainage density, length of drainage channels, concentration, time and bifurcation ratio [6].

Human activities and highways in many areas in the Gulf of Suez are affected seriously by frequent flash floods [7]. Numerous studies have concentrated on the flood hazards in various areas of Egypt as the Red Sea drainage basins along the Qena-Safaga highway and the Red Sea basins between latitudes 24° 41′ and 25° 26′ [8-10]. To reduce the impact of flash floods, analysis of the morphometrical parameters of the drainage basins is required. Determination of drainage networks within watersheds or sub-watersheds can be carried out using traditional methods such as topographic maps and field observations, or alternatively with advanced approaches using remote sensing and digital elevation model (DEMs) [11-12]. In this respect, drainage networks and basins extents can be extracted by using DEMs [13]. Also, in recent years, Geographic Information Systems (GIS) and remote sensing have been increasingly important as tools to evaluate geo-environmental hazards. Remote sensing and GIS tools are today employed as primary information sources in hazard/disaster assessment. Radar remote sensing data have been widely used for flood observation across the globe [14-15], while GIS and neural network methods have been used for flood susceptibility mapping in many case studies [16-18]. The aim of this study is to use GIS-based morphometric analysis to determine the riskiest flash flood sub-basins in Wadi Qena Watershed. The results can be used by planners and developers to avoid risky areas and minimize damage resulting from flash floods.

## Materials and methods

### 1) Study area

Due to the topography of the Red Sea Mountains, rainfall generates rapid stream-flows, or alternatively, a large volume of rain falls in a short amount of time, causing flash flooding. Flash flood are characterized by their rapid occurrence and very limited opportunity for issuing warnings. Many parts of Upper Egypt, Sinai and Red Sea areas have been affected severe flash floods (Ex. In March 1976, April1983, April 1985, January 2010, and January 2013). Because the area is classified as an arid zone, monitoring systems are lacking. The study area is located at the eastern side of Qena meander in the Upper of Egypt. Wadi Qena is located between Red Sea in the east and River Nile in the west within latitudes 26° 10′ to 28° 05′ N and longitudes 32° 20′ to 33° 36′ E as shown in Figure 1(a). The watershed contains some main roads as shown in Figure 1(b).

The area of Wadi Qena Watershed is approximately 15,455 $km^2$ [20]. Based on Köppen climate classification [21], the climate of the study area is classified as hot summers and cold winters as it is located in the dry desert. According to the Egyptian Meteorological Authority (EMA), rainfall in the study area is scarce with an average value of only 3.2 mm a year (Figure 2). In summers, the highest recorded temperature reach 41 °C in July while for winter season, the lowest temperature reach 7.5 °C at night during January (Figure 3). The climatic data for Wadi Qena drainage basin are traditionally acquired from the closest weather station which is located at 26° 30′ N and 33° 06′ E in the south of the watershed. The mountainous area, located along the eastern boundary, varies in elevation, ranging from 77 m to 1,866 m above mean sea level (AMSL) as illustrated in Figure 4.

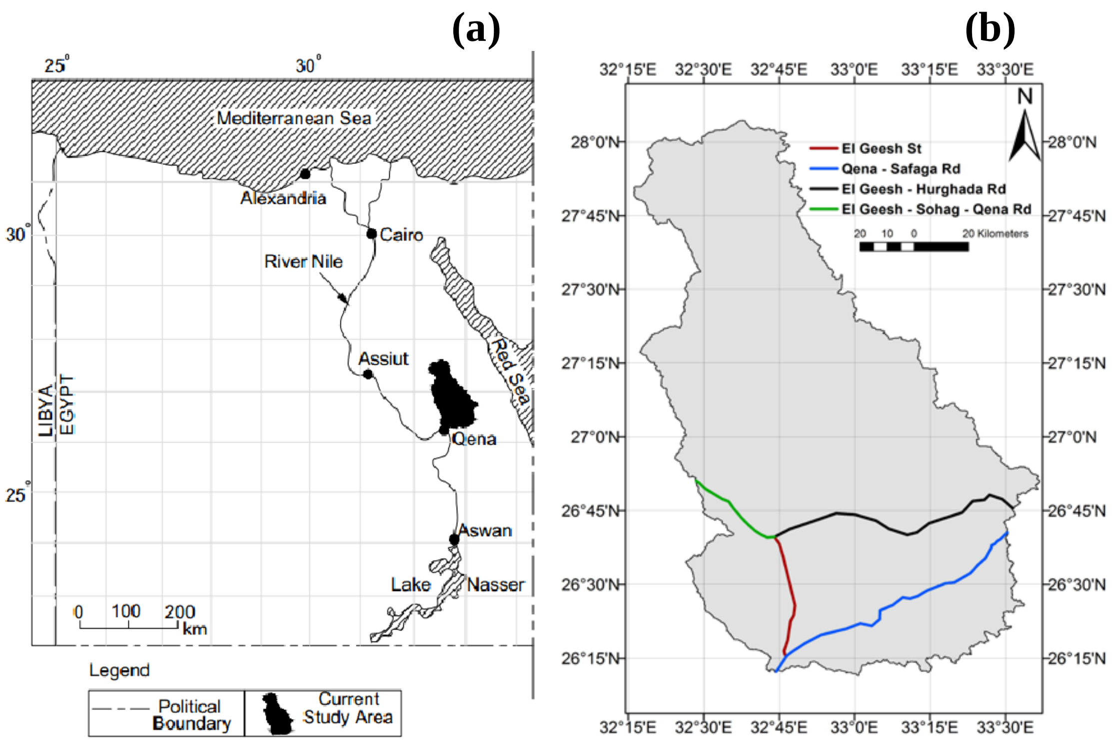


**Figure 1** a) Egypt map and the location of study area [19] and b) roads within the watershed.

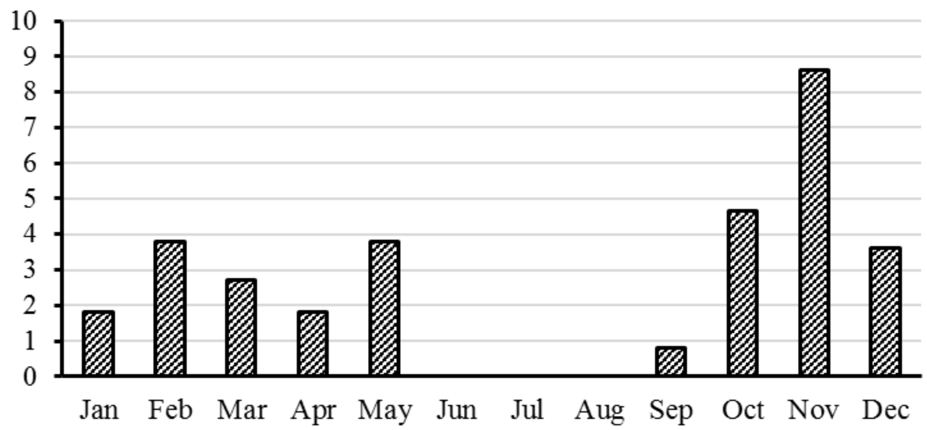


**Figure 2** Data of rainfall rates (mm/month) during 1986-2005 obtained from the Egyptian Meteorological Authority (EMA).

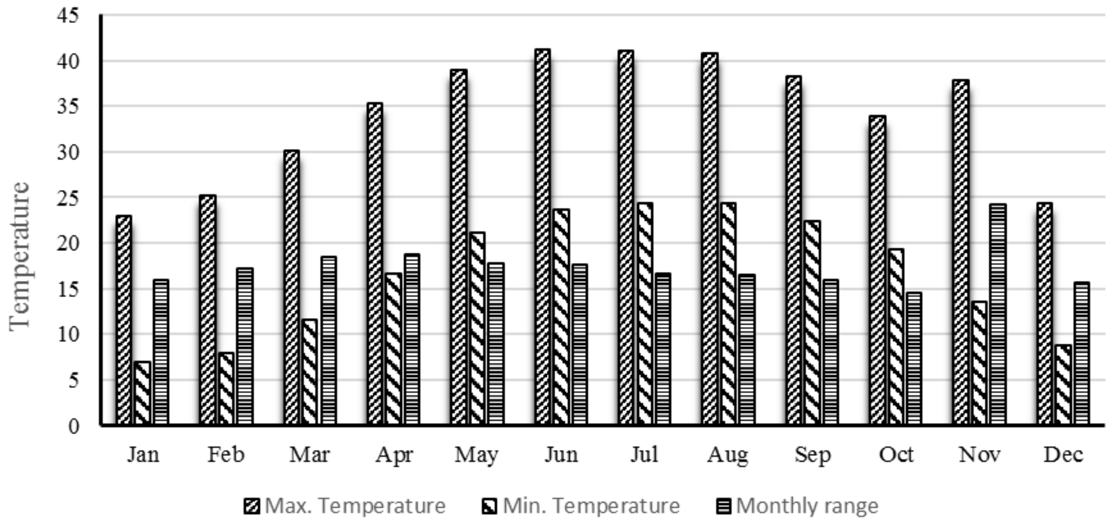


**Figure 3** Data of temperature in degree Celcius (°C) 1986-2005 obtained from the Egyptian Meteorological Authority (EMA).

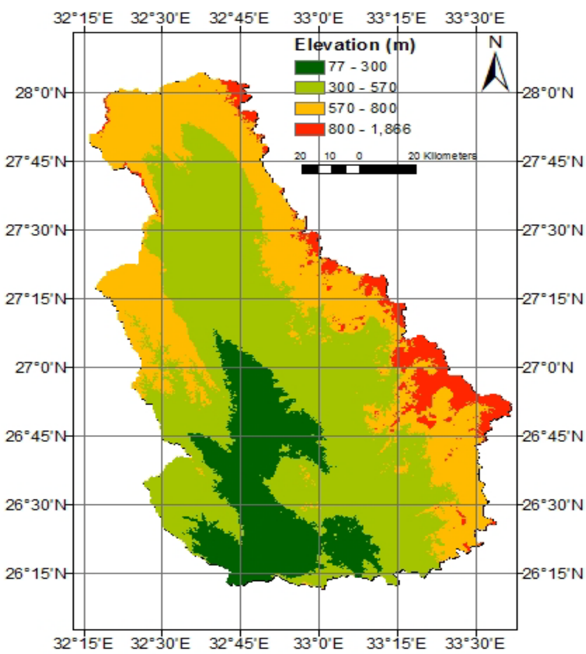


**Figure 4** Topography of the study area.

Flood hazard assessment studies are necessary to mitigate damage. In the current study, morphometric characteristics have been analyzed to estimate the flood risk of the sub-watersheds within Qena Watershed using the approach of El-Shamy [22]. A detailed hazard degree map is presented based on the final degree of hazard. This map can be used as a baseline for assessment of flood mitigation and planning.

**2) Modeling method**

Terrain pre-processing has been utilized to create a model of the watershed basin of the study area. This pre-processing used a DEM of Wadi Qena watershed obtained from Shuttle Radar Topography Mission (SRTM) data, with 90 m spatial resolution (Figure 5). These processes clip the boundary of the watershed to derive a drainage network of the study area in addition to creating a flow direction raster by using flow direction algorithms after removal of small imperfections [23]. After that, the flow accumulation could be derived. The post-processing involved using the DEM in a GIS environment for estimation the morphometric parameters (Area (A), Stream Order (u), Stream Number (Nu), Stream Length (Lu), Drainage Density (D), Stream Frequency (F) and the Bifurcation Ratio (Rb)). The morphometric parameters were extracted and calculated for each sub-basin of the watershed.

Runoff is affected by the size and the area of watershed; the larger the watershed, the larger the runoff and storage of water in the basin. Stream order is a method of assigning a numeric order to links in a stream network and the situation of a stream in the hierarchy tributaries. It is the essential parameter for analysis of any drainage basin. The stream order of the sub-watersheds has been determined using the method proposed by Strahler [24] where the first order of the streams are the streams which have no tributaries. The second order refers to a stream with tributaries only from the first order. When two second order streams join, a third order is formed. When two of third order streams join, a fourth order stream is formed. Also, Stream Number (Nu) and Stream Length (Lu) had been derived to calculate Stream Frequency (F) and Drainage Density (D).

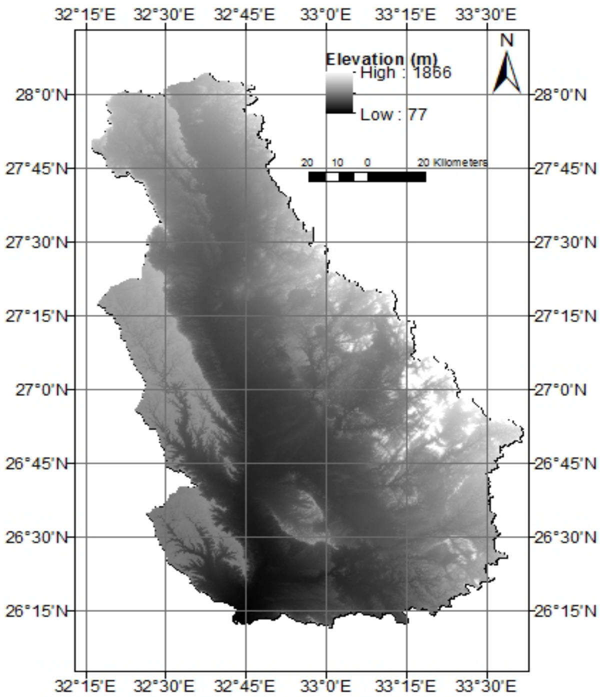


**Figure 5** Digital Elevation Map (DEM) of Wadi Qena Watershed.

Drainage Density (D) is the ratio between the total distances where the streams run in the sub-basin to total sub-basin area; thus it has units of reciprocal of length. Drainage density refers to the spacing of streams. It is influenced by many factors such as resistance to weathering, relief, climatic changes, type and permeability of rocks and vegetation that control the characteristic length of the stream [25]. Also, it is worth mentioning that the higher value of drainage density with large amount of rainfall resulted in runoff where high density of streams and rapid stream response. The Stream Frequency (F) of a drainage basin is the total number of streams of all orders per square kilometer where it reflects the texture of the drainage network. The Bifurcation Ratio (Rb) is a dimensionless property, considered as the index of relief and distortion. The Rb of one order is observed that it differs from its next order; these irregularities are determined by the geological and lithological development of the drainage basin [24]. Bifurcation ratios show a small range of variation for different areas or for different environment except where the powerful geological control dominates [26]. According to Strahler [24], the lower value of Rb is a representative of the watersheds, which have less structural turbulences and drainage pattern has been deformed [27]. Higher value of Rb indicates high effect of structural control on the drainage pattern.

The hazard degree for each sub-basin was determined using the approach developed by El-Shamy [22] for evaluating susceptibility of sub-watersheds to flash flooding risk. To identify the hazardous sub-watersheds, two different methods were applied. The relationship between the drainage density and bifurcation ratio is used in the first method, and the second one is based on the relationship between the drainage frequency and bifurcation ratio. Each approach uses a figure which is divided into three zones; including zone A refers to high potential for groundwater recharge and low possibility for floods, zone B refers to high possibility for floods and low potential for groundwater recharge and zone C represents sub-basins with intermediate possibility for floods and moderate potential for groundwater recharge. A detailed hazard degree map was extracted for all sub-basins and presented based on the final hazard degree resulting from the two methods. The final hazard degree for each sub-basin was estimated by comparing the results of each method. If a basin has two different situations, then the most hazardous one has been selected.

## Results and discussion

The watershed comprises 70 sub-basins as shown in Figure 6. Based on Horton's methodology [28], the sub-basins were classified by size into three categories; small (< 50 $km^2$), medium basins (50-100 $km^2$) and large basins (> 100 $km^2$). The area of sub-basins ranged from 28 $km^2$ to 1,465 $km^2$ and total area of the watershed was 15,488 $km^2$.

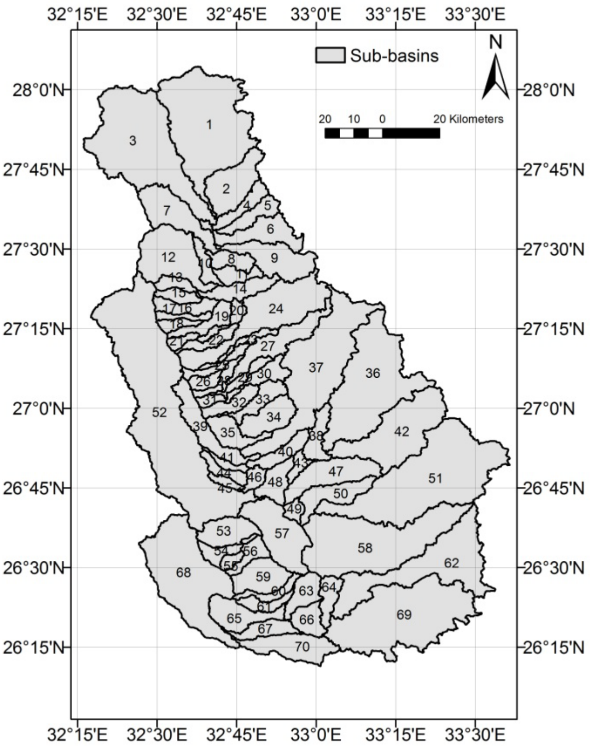


**Figure 6** Sub-basins of the study area.

As shown in Figure 7, about (84 %) of sub-basins were classified by size as large, while the medium and small areas represent 12.51 % and 3.19 %, respectively.

The stream order of the watershed related to $5^{th}$ order is illustrated in Figure 8. The watershed has altogether 273 streams in 5 orders. A total of 210 streams were classed as first order streams, with the numbers of streams decreasing with increasing stream order. The total length of streams in the watershed is 3,073.81 km. The minimum length was in fifth-order streams, at 81.4 km, with first order streams showing a maximum length of 1,631.88 km. Drainage Density (D) which indicates the landscape dissection, infiltration capacity of the land, runoff potential, climatic conditions, and vegetation cover of the basin, ranged from 0.176 $km^{-1}$ to 4.85 $km^{-1}$. On the other hand, bifurcation ratios reached 2.667. Moreover, the values of stream frequency of the sub-basins ranged from 0.11 $km^{-2}$ to 0.71 $km^{-2}$.

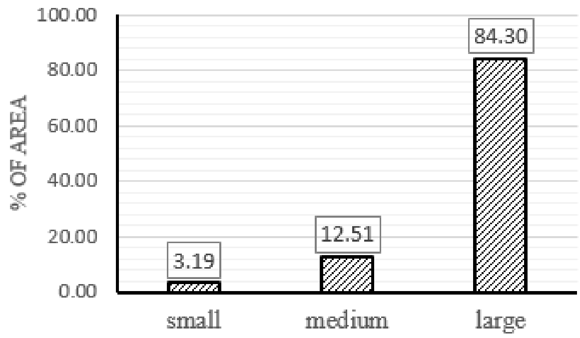


**Figure 7** Classification of sub-watersheds.

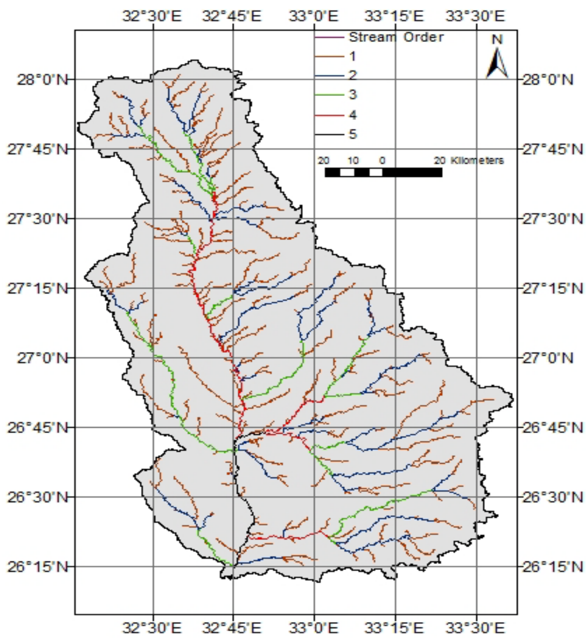


**Figure 8** Stream order of the watershed.

The low values of stream frequency of the sub-basins point to the fact that the watershed includes scarce plant cover. Stream frequencies of the sub-basins have a small variation which comes from the similarity in lithology of the sub-basins. The lower values of drainage density and stream frequency for the sub-basins indicated that runoff is slower and flooding less likely. To identify the hazardous sub-basins, two different methods were used as shown in Table 1. For the first method, there are not any sub-basins in the zone A and the sub-basins are spread in the high and moderate zone (Figure 9); however, for the second method, there are no sub-basins in the high or low zone and all sub-basins are concentrated in the intermediate zone (Figure 10).

**Table 1** Classification of sub-basins based on El-Sahmy's approach and the assessment based on the final results

| **Rb vs F** | | | **Rb vs D** | | | **Final assessment** | | |
|---|---|---|---|---|---|---|---|---|
| Sub-basin ID | Degree | % of total area | Sub-basin ID | Degree | % of total area | Sub-basin ID | Degree | % of total area |
| There are not any sub-basins in the zone (A) | L | 0 % | There are not any sub-basins in the zone (A) | L | 0 % | There are not any sub-basins in the low zone | L | 0 % |
| All sub-basins are in zone (C) | M | 100 % | 1-2-3-6-7-9-12-24-27-34-35-36-37-38-39-42-47-48-50-51-52-53-54-56-57-58-59-61-62-63-64-65-66-67-68-69-70 | M | 87 % | 1-2-3-6-7-9-12-24-27-34-35-36-37-38-39-42-47-48-50-51-52-53-54-56-57-58-59-61-62-63-64-65-66-67-68-69-70 | M | 87% |
| There are not any sub-basins in zone (B) | H | 0 % | 4-5-8-10-11-13-14-15-16-17-18-19-20-21-22-23-25-26-28-29-30-31-32-33-40-41-43-44-45-46-49-54-55-60 | H | 13 % | 4-5-8-10-11-13-14-15-16-17-18-19-20-21-22-23-25-26-28-29-30-31-32-33-40-41-43-44-45-46-49-54-55-60 | H | 13% |

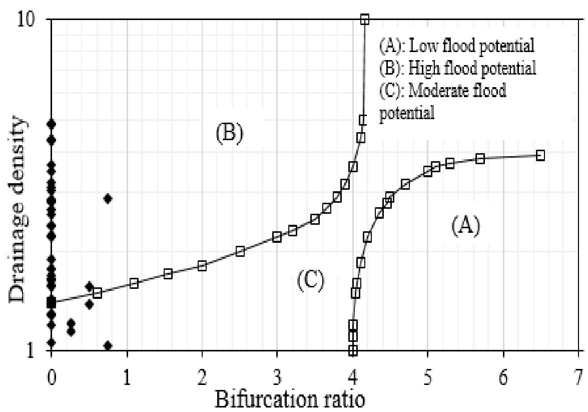


**Figure 9** Flooding susceptibility: El-Shamy's approach (The Bifurcation ratio vs. Drainage density).

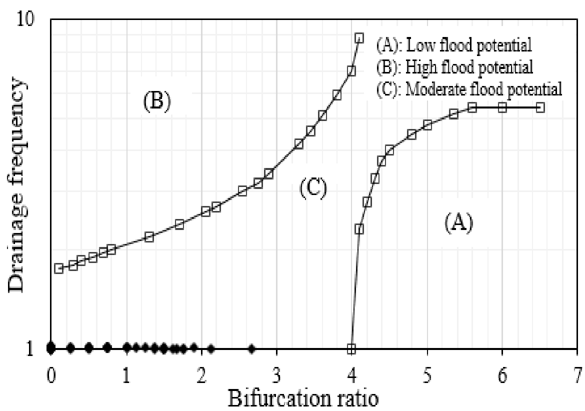


**Figure 10** Flooding susceptibility: El-Shamy's approach (The Bifurcation ratio vs. Drainage frequency).

A detailed hazard degree map was extracted for all sub-basins using the two methods as shown in Figure 11. The sub-basins with the highest hazard degree are concentrated in the centre of the watershed although their smaller areas comparing with the sub-basins with an intermediate possibility for floods and moderate potential for groundwater recharge which are at the boundary of the watershed. These sub-basins with high hazard degree have altogether 1982 $km^2$ (about 13 % of the watershed area).

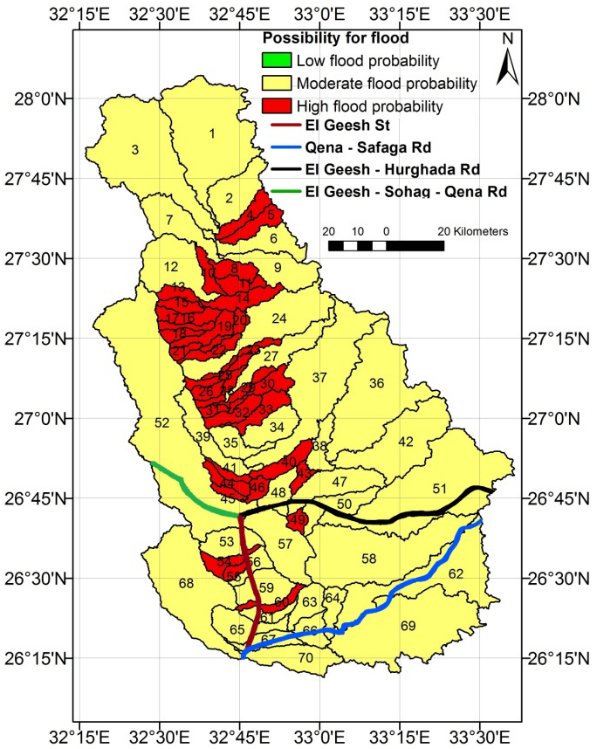


**Figure 11** The hazard degree map for all sub-basins and the roads within the watershed

## Conclusion

In the present study, GIS-based morphometry and remote sensing data were used to map flash flood risk for the Wadi Qena Watershed, Eastern Desert, Egypt. A morphometric approach based on El-Shamy's approach was used to identify flash flood prone areas. A flood hazard map was prepared to delineate flood prone areas and it was found that the sub-basins with the highest hazard degree are concentrated in the middle of the watershed. Such a map can assist decision makers to evaluate potential impacts of natural risks quickly and assist further to initiate appropriate measures for impact reduction. It also helps during post-disaster situations in assessment of damage and losses due to flooding. Moreover, GIS can aid in identifying flood prone areas or fore-casting areas likely to be flooded based on the analysis of the drainage basins. The results shown in this research can help developers, planners and engineers in effective planning and development, in order to minimize the impacts of flash floods.

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