Journal of Hydrology: Regional Studies 50 (2023) 101526

Contents lists available at ScienceDirect

Journal of Hydrology: Regional Studies

journal homepage: www.elsevier.com/locate/ejrh

Identifying cost-effective locations of storage dams for rainfall harvesting and flash flood mitigation in arid and semi-arid regions

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ARTICLE INFO

Keywords:
Flash flood
Morphometric parameters
GIS
Cost-effective
Wadi Tayyibah
Dams

ABSTRACT

Study region: Wadi Tayyibah is located in south Sinai, Egypt, in a region called Abou Zenima, and it is used to develop this study.
Study focus: Flash floods tremendously impact many facets of human life due to their destructive consequences and the costs associated with mitigating efforts. This study aims to evaluate the harvesting of Runoff by delineating the watersheds using the Hydrologic Engineering Center-1 (HEC-1) model and ArcGIS software in trying to benefit from it in different ways. All morphometric parameters of the basin were considered, and the risk degree of the different sub-basins was determined. The suitable locations of dams were identified using a Geographical Information System (GIS) using the basin's morphometric characteristics.
New hydrological insights for the region: The study proposed a total number of eight dams, including five dams that were recommended for sub-basin (1) and three dams in sub-basin (4), while sub-basins (2) and (3) are not suitable locations to build dams according to the contour map of Wadi Tayyibah. Results indicate that, based on the constructed flash flood hazard maps and the basin's detailed morphometric characteristics, the best locations of dams are Dam (3) in sub-basin (1) and Dam (7) in sub-basin (4), where the runoff volume reached 3.13 million cubic meters (Mm^3) and 5.56 Mm^3 for return period 100, respectively. This study is useful for decision-makers and designers for using morphometric parameters and flash flood hazard degree maps to select dam locations. Also, the cost-benefit analysis for using the morphometric parameters is required to be investigated.

Abbreviations: a.m.s.l, above mean sea level; DEM, Digital Elevation Model; DSSM, dam suitability stream model; Esri 2020, Environmental Systems Research Institute; FF, Flash Floods; GIS, Geographical Information System; GCS-WGS, Geographic Coordinate Systems - World Geodetic System; GPR, Ground Penetration Radar; HSG's, Hydrological Soil Groups; HEC-1, Hydrologic Engineering Center-1; MPDSM, Multi-Parametric Decision spatial Model; SCS-CN, Soil Conservation Service and Curve Number; SCS, Soil Conservation Service; STRM, Shuttle Radar Topography Mission; USGS, United States Geological Survey; UTM, Universal Transverse Mercator; WRRI, Water Resources Research Institute; WMS, Watershed Modeling System.

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https://doi.org/10.1016/j.ejrh.2023.101526
Received 12 March 2023; Received in revised form 28 August 2023; Accepted 7 September 2023
Available online 16 September 2023

1. Introduction

Flash floods (FF) are one of the most destructive natural hazards on the planet, responsible for the greatest number of fatalities and property damage (CEOS, 2003). Optimal site selection for a dam is one of the crucial tasks in water resource management (Shao et al., 2020). Heavy rains, land-use changes in basin areas, and the numerous engineering applications, all contribute to the severity and frequency of flood disasters. Flooding is caused by a variety of variables, including terrain, geomorphology, drainage, engineering works, and weather. Most floods are triggered by convective or frontal storms that dump a large amount of precipitation in a short time period. Rainfall duration and intensity are the most critical factors influencing flood hazards.

FF can be influenced by several other causes, particularly in desert regions. Saleh (1989) identified several of these parameters, such as precipitation characteristics, water loss and stream characteristics. Hassan (2000) presented that regular flash floods have a detrimental effect on the highway and human activity in several regions around the Gulf of Suez. Several studies concentrated on flood hazards in various parts of Egypt (El-Shamy, 1992; El-Etr and Ashmawy, 1993; Ashmawy, 1994). The drainage parameters of many basins and sub-basins around the world have been investigated using traditional geomorphologic methodologies (Horton, 1945; Strahler, 1964; Leopold and Miller, 1956; Morisawa, 1959; Krishnamurthy et al., 1996).

Numerous studies have concentrated on drainage basins and their geometric properties, incorporating stream characteristics and a quantitative assessment of the texture, pattern, shape, and topographic features of drainage basins (Abrahams, 1984). Gardiner (1990) showed that the morphometric properties of basins have been employed in certain studies to anticipate and/or define flood peaks, measure sediment outputs, and estimate erosion rates. Drainage parameters could be analyzed to derive morphometric parameters, including stream orders, basin area, basin perimeter, drainage density, stream frequency, bifurcation ratio, texture ratio, basin relief, and ruggedness number (Kumar et al., 2000).

Flood potential and/or risk applied geomorphic principles to establish correlations between basin morphology and FF impact (Patton, 1988). Field observations and topographic maps can be used to find drainage networks in basins and sub-basins, but more modern methods like remote sensing (RS) and the Digital Elevation Model (DEM) can also be used to find them (Macka, 2001; Maidment, 2002). Verstappen (1995) indicated that the main reasons to use RS are to find out how vulnerable the land and society are, to make maps of hazard zones and potential damage, to keep an eye on possible hazards, and to deal with crisis situations after a disaster. Several investigations on flood hazard and risk mapping have been conducted utilizing RS data and Geographical Information System (GIS) techniques (Hess et al., 1995; Le Toan et al., 1997). A number of investigations incorporated probabilistic techniques (Pradhan and Shafie, 2009; Bhuyian et al., 2009).

Artificial intelligence and machine learning approaches were applied to achieve the mitigation of FF by Ma et al. (2019), Arabameri et al. (2020), Costache et al. (2020, 2021) and Elmahdy et al. (2020). The machine learning approach is a very effective method in terms of accurate identification and modeling; it attempts to solve FF problems by determining the relationship between the flood risk and its factors rather than direct weight determination (Ma et al., 2019). El-Magd et al. (2021) investigated a novel method for detecting and forecasting flash flood risk in Morocco. The study investigated the performance of machine learning algorithms for mapping and forecasting flash flood susceptibility.

In other regions, hydrological simulations have been used to map flood hazards (Cunderlik and Burn, 2002; Yakoo et al., 2001). Several studies have utilized GIS and neural network approaches to map flood susceptibility (Sanyal and Lu, 2005; Zerger, 2002). In recent years, flooding-related difficulties have significantly necessitated the development of effective modeling tools for comprehending the issue and mitigating its fatal consequences. Different methods, such as the El-Shamy methodology and the ranking method, can be used to investigate the flash flood risk of watershed sub-basins. El-Shamy (1992) established two relationships to denote dangerous sub-watersheds that relate the drainage density to the bifurcation ratio and the frequency of streams and their bifurcation ratios. Sharma et al. (2010) used GIS to conduct a quantitative morphometric study in eight sub-watersheds of the Uttala River sub-basin in India. The results showed that two watersheds are more likely to be eroded and lose soil than others. Stevens and Hanschka (2014) analyzed the flood hazards in British Columbia and the link between flood maps and land usage management to promote the development and usage of flood hazard maps. The study discovered that these maps are outdated and missing several key features for enabling sustainable land use.

Flash floods are common in several regions of Egypt, like Sinai Peninsula. It is difficult and time-consuming to do flood hazard evaluation for a greater area on occasion. RS techniques, hydrological analysis, and GIS tools can provide a powerful basis for quickly and efficiently combining, manipulating, and analyzing information to determine possible flood zones. For that reason, flood hazard studies are needed to lessen the damage that could happen. Among the numerous methods for flash flood hazard zonation, the ranking method was used to calculate the probability of occurrence of the most hazardous basins. Abdel-Lattif and Sherief (2012) conducted a morphometric examination of Wadi Sudr and Wadi Wardan in Egypt and calculated hazard degrees using the El-Shamy approach to create a risk zone map, as well as analyzed if the FF threat influences both wadies. Several Wadis in Egypt and, in particular, Sinai, still without the FF hazard zonation.

The suitable sites for the hydro-projects have the least pessimistic environmental impacts (Ledec and Quintero, 2003). Also, the site suitability analysis for the construction of the dam is crucial (Ramakrishnan et al., 2009) for considering the geographical properties and the geological hazards (Niu et al., 2007; Zhou et al., 2019; Wen et al., 2020). Abdalla M. Qudah (2011) studied the economic feasibility of the Al-Karak dam project. The study showed the feasibility of the dam's contribution to the irrigation requirement. Shatnawi and Diabat (2016) showed that the selection of the dam location was reduced, and the reservoir storage capacity was reduced at an average annual rate of 0.33 million cubic meters (MCM) due to the main sediment components of Sand, silt, and clay. Hamaideh et al. (2017) studied rainwater harvesting and the selection of a groundwater storage reservoir in Wadi Ishe, Jordan, using the HEC-Hydrologic Modeling Syst. These results showed that the annual storage of the subsurface reservoir is approximately around 300

m^3 $year^{-1}$. Fedorov et al. (2019) used GIS for selecting the location of dams in flood control systems. The study showed that the geo-information method was used to justify the selection of parameters of such dams, primarily the location of a dam that minimizes the impact on the environment for the ecological factor. Shao et al. (2020) studied the optimal site selection of a dam based on the crucial parameter, stream order using a dam suitability stream model and GIS. The study showed that the proposed sites will store water for a variety of uses at the local and regional levels and reduce flood risk, which can be very useful for hydrologists and disaster risk managers. The proper selection of dam sites is beneficial to ensuring project safety, reducing construction time, and lowering construction costs. Early in the construction process, selecting and evaluating various suitable dam sites are critical (Pan and Zhang, 2021).

Previous research in arid and semi-arid regions revealed that most studies on flood risk reduction focus on a few morphometric criteria in assessing the FF hazard degree. In addition, several Wadis in Egypt and, in particular, Sinai, still without the flash flood hazard zonation. As a result, in this study, all morphometric parameters of the basin have been taken into consideration like stream number, stream Length, basin area, basin perimeter, basin length, basin width, circulatory ratio, stream frequency, drainage density, length of overland flow, Infiltration number, basin relief, relief (gradient) ratio, ruggedness number, bifurcation ratio, elongation ratio and form factor to evaluate the FF hazard degree more accurately using the ranking method, as this method was used in typical regions within the research area. The Soil Conservation Service (SCS) and curve number method (SCS-CN) used to calculate flash flood volumes in the research area, which considers land uses and infiltration rates in the area using a hydrological model called Hydrologic Engineering Center-1 (HEC-1). So, the study aims to find suitable locations of storage dams for rainfall harvesting to mitigate the hazards of FF in Wadi Tayyibah, Abou Zenima, south Sinai, Egypt. The study region is strategically significant for Egypt, so the need to find unconventional ways to utilize the flood waters in the Abu Zinema is necessary to provide a cheap source of water from rain as well as to protect the lives of the locals and their possessions. Additionally, Egypt is considered a country with a water shortage despite having the Nile River. The selection of dam locations is based on the morphometric properties of Wadi Tayyibah and the construction of a flash flood hazard degree map using GIS software.

2. Materials and method

2.1. Study area

The Sinai Peninsula is in both North Africa and Southwest Asia. It acts as a transition zone between the climates of the northern Mediterranean and the Sahara (EEAA, 2005). The current study was done on Wadi Tayyibah, South Sinai, Egypt. It is located between longitudes 33° 5′ E and 33° 24’ E and latitudes 29° 6′ N and 29° 15’ N with an area of about 360 Km^2 and a perimeter about 125 Km in a region called Abou Zenima, 33 km in length, 10.80 km in width, the maximum and minimum elevations are 1133 m and 3 m above mean sea level (a.m.s.l). The outlet of the wadi pours is in the Gulf of Suez, as shown in Fig. 1.

Abou Zenima city becomes flooded by Surface runoff water from Wadi Tayyibah. The last flash flood in Abou Zenima was on the

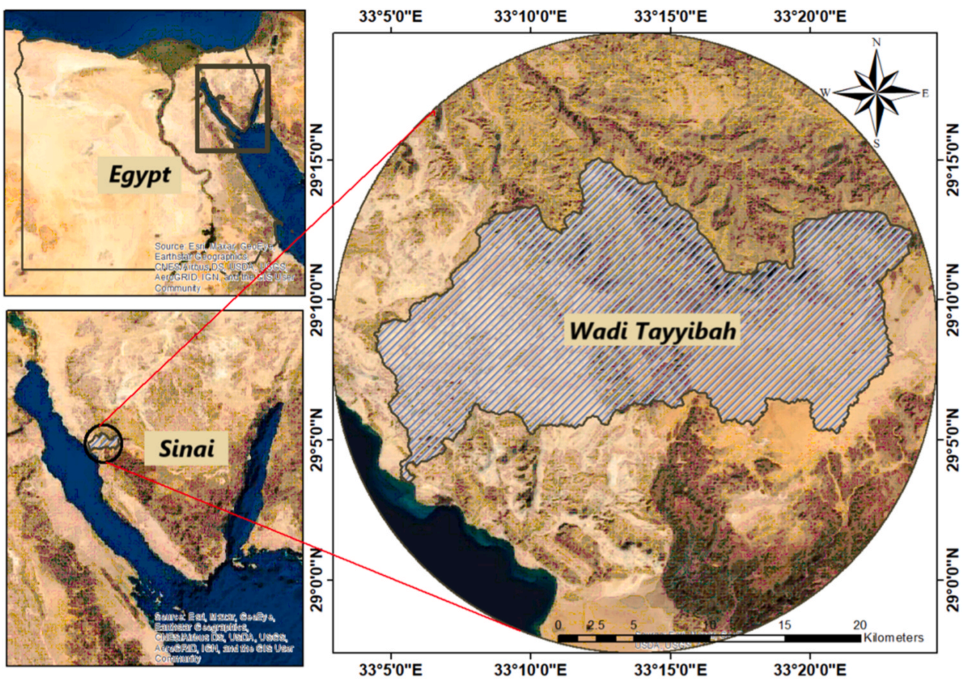

Fig. 1. Location of Wadi Tayyibah.

12th of March, 2020, which caused disasters in Abou Zenima, as shown in Fig. 2. The study area is in a semi-arid region; the climate is mostly hot and dry, with only one short rainy season. The required data to build the hydrological models and the database of the case study are rainfall data, topographical data such as Digital Elevation Model (DEM) and topographical maps, slop, geological maps, highways, and satellite images. The collected data are explained in this part as follows.

2.1.1. Rainfall data

The rainfall in most of south Sinai is typically infrequent, intermittent, and impacted by climate variance. The region is characterized by irregular and erratic precipitation and year-round high temperatures. Spring and autumn are the seasons when rainfall occurs (Ibrahim, 2004).

Precipitation data were collected from Abou-Rudes station, which is located at the intersection of longitude 33° 11' 41.69" E with latitude 28° 54' 35.19" N and 13 m AMSL, the Thiessen polygons indicate the Abou Rudes station only affects the study area, as shown in Fig. 3a; the data were of rainfall from the year 1976 to the year 1989 and from the year 2000 to the year 2018 in millimeters depth. The data came from The Water Resources Research Institute (WRRI), as shown in Fig. 3b.

2.1.2. Topographical maps

A digital topographic map of Abo Zenima was obtained at a scale of 1:50,000 which covers Wadi Tayyibah. The map was available from WRRI. The map was produced by the Military space administration in 1998. The map was exported to ArcGIS 10.3 software and was georeferenced to WGS 1984-UTM-Zone 36.

2.1.3. Digital Elevation Model

Shuttle Radar Topography Mission (STRM) DEM was downloaded with a resolution of 30 m from the United States Geological Survey (USGS) website (USGS United States Geological Survey, 2020). DEM was downloaded with the projection Geographic Coordinate Systems - World Geodetic System (GCS-WGS) 1984. it was exported to GIS software and georeferenced to WGS 1984 - Universal Transverse Mercator (UTM) - Zone 36 then the Wadi Tayyibah was extracted from it and prepared to be available for hydrological, topographic, and morphometric analysis with a maximum elevation of 1133 m and a minimum elevation of 3 m as shown in Fig. 4a.

2.1.4. Land use/land cover

The land use is an important factor in the Soil Conservation Service and curve number (SCS-CN) approach, which is used to calculate the curve number. The land uses of Wadi Tayyibah have been determined depending on the Environmental Systems Research Institute (Esri 2020) land cover map as shown in Fig. 4b as cited in (Maher et al., 2022) in which is the global market leader in geographic information system (GIS) software.

The percentage of scrub/shrub area, the building area and bare ground nearly cover all of Wadi Tayyibah's surface area are shown in Table 1.

2.1.5. Hydrological soil groups

One of requirement of the SCS-CN method is the classification of all types of soil in the study area into group A–D. (Elewa and Qaddah, 2011) created HSG's map of Sinai. This map was clipped and exported to ArcGIS10.3 software to extract Hydrological soil groups (HSG's) map of Wadi Tayyibah as shown in Fig. 5a as cited in Maher et al. (2022). The area of each group in Wadi Tayyiba indicated in Table 3.

2.1.6. Highways

There are highways that pass-through Wadi Tayyibah, including Sharm El-Sheikh Road and Ras sudr - Al Tor Road as shown in Fig. 5b. It is vital to consider which highways pass through the study area to estimate the extent to which these roads are impacted by surface runoff.

2.1.7. Slope

Slopes are defined as the angle of the earth's surface within the basin with respect to the horizontal plane (Meshram and Khadse,

Fig. 2. Heavy Rain Abou Zenima City on the 12th of March 2020.

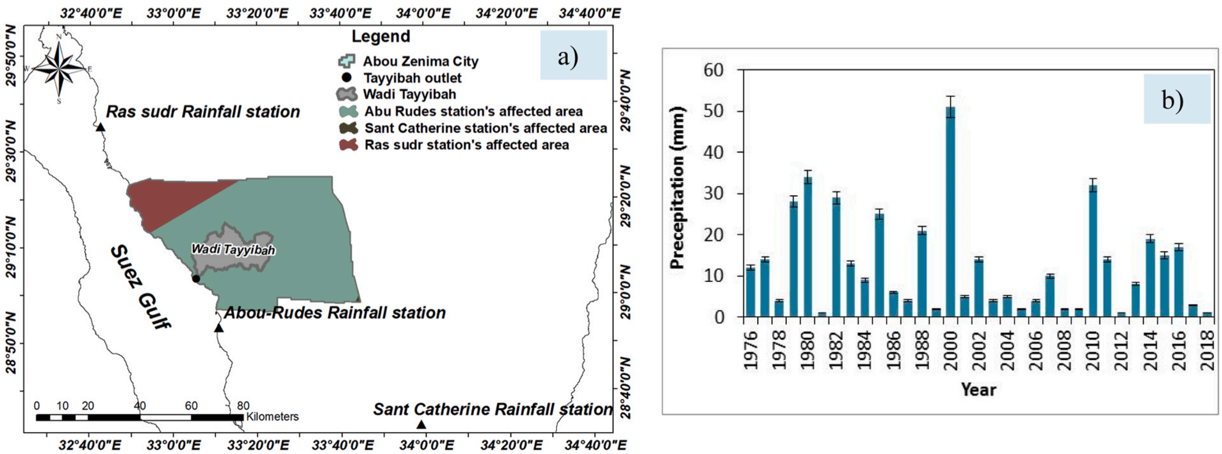

Fig. 3. Abou Rudes station for (a) Location with Thiessen polygons, and (b) annual rainfall data.

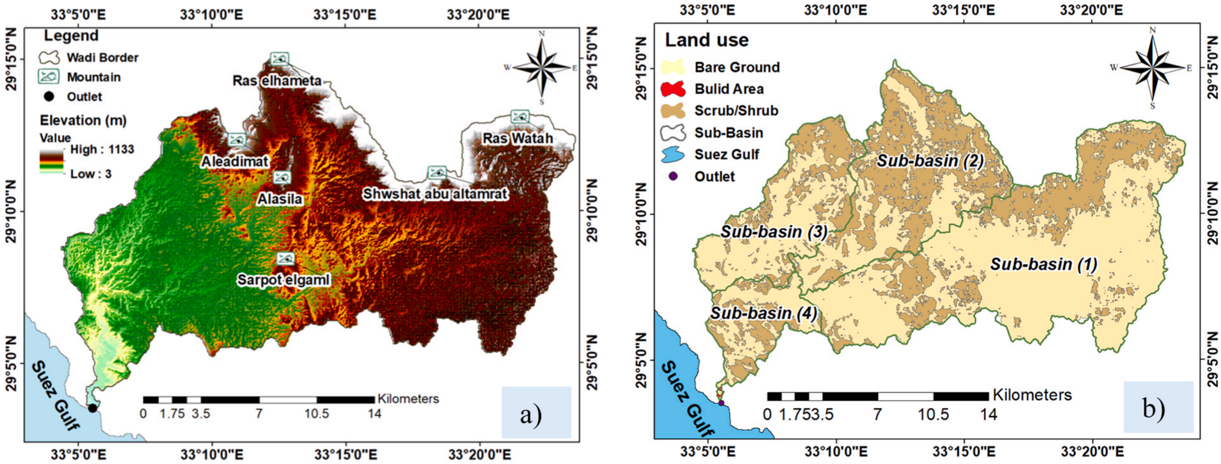

Fig. 4. Wadi Tayyibah for (a) DEM and (b) land cover.
(a) (source: extracted from DEM which downloaded USGS)

Table 1
Wadi Tayyibah's land cover.

Land use/Land cover	Sub-Basin#1 (km^2)	Sub-Basin#2 (km^2)	Sub-Basin#3 (km^2)	Sub-Basin#4 (km^2)	Total (km^2)
Scrub/Shrub	42.93	47.39	18.86	10.262	119.442
Build Area	0.0024	0	0.00713	0.102	0.11153
Bare Ground	135.34	42.078	39.59	18.44	235.448

2015). It is the result of several significant elements, including the climate and the rock type found inside the basin (Dhawaskar, 2015) It is critical for accelerating surface runoff (Lalbiakmawia, 2015) With increasing slope, the outflow gets more severe (Shultz, 2007). The slope map is created using ArcGIS software from the DEM, as shown in Fig. 6a.

The majority of wadi Tayyibah has nearly level slopes (0–5°) which cover 179.14 km^2 and represent 50.13 %, the area of lands with moderate slop (5–10°) by 79.4 km^2 and 22.30 %, moderately steep slope (10–15°) by 51.41 km^2 and 14.44 %, steep slope (15–30°) by 35.85 km^2 and 10.07 % and very steep slope (30–74°) are 10.26 km^2 and 2.88 % respectively as indicated in Fig. 6b.

2.2. Rainfall data Screening

Rainfall data screening must be made for verification of outliers and data homogeneity. Barnett and Lewis (1984) assigned the outlier that the value is not consistent with other values in the data set. While, Hawkins (1980), defined the outlier as one that disperses

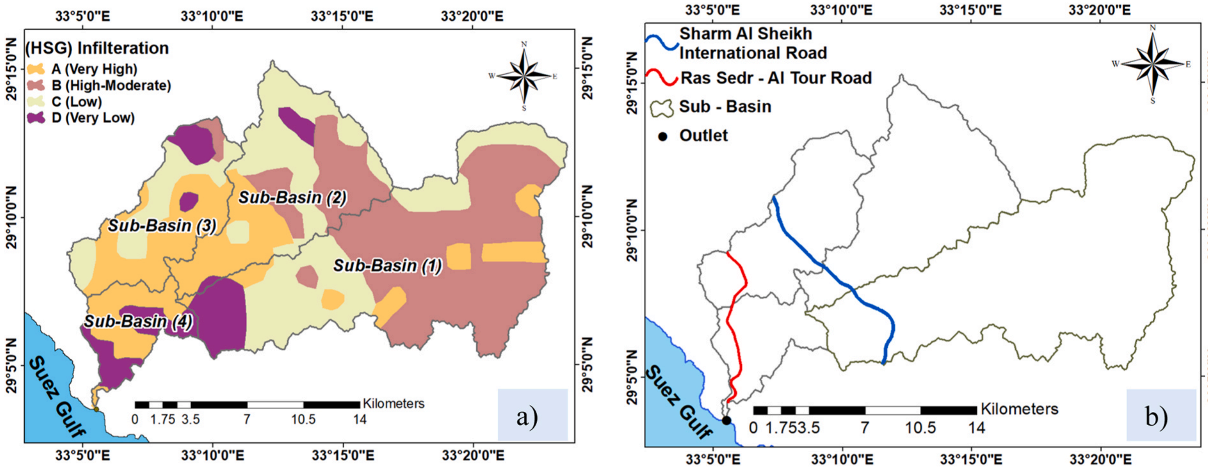

Fig. 5. Wadi Tayyibah for (a) HSGs and (b) highways.
(a) (source: extracted from DEM which downloaded USGS), (b) (source: extracted from the open street map (OSM)).

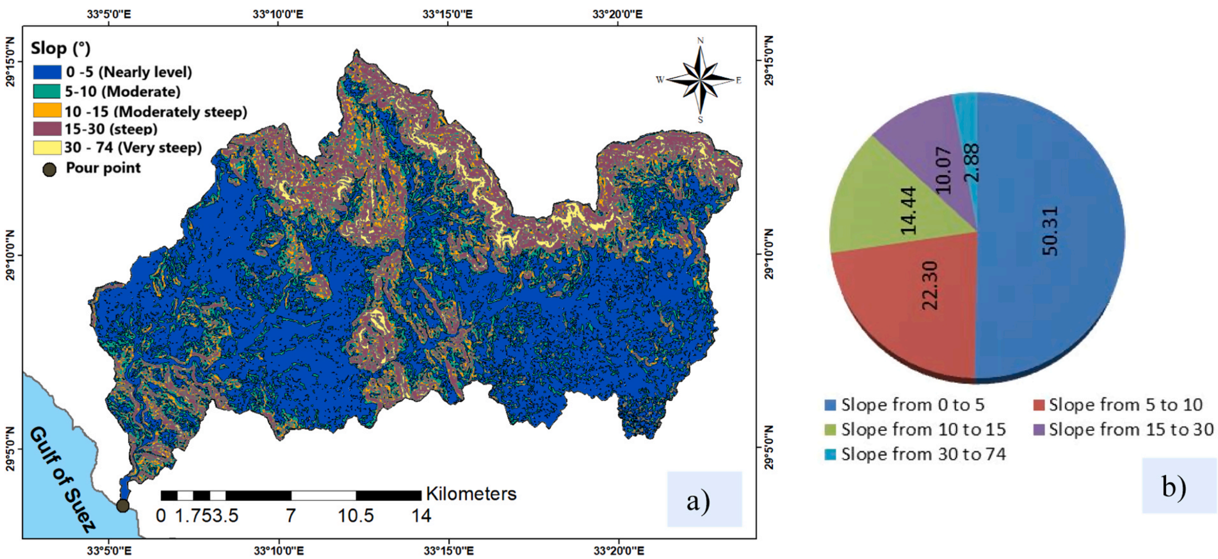

Fig. 6. Wadi Tayyibah (a) slope map, and (b) area of each slop of.
(a) (source: extracted from DEM which downloaded USGS), (b) (source: Extracted from DEM which downloaded USGS).

a lot of other records to increase doubts recorded by different mechanisms. The outlier's records were screened for Abou Rudes station using the Equations of Charles as cited in Maher et al. (2022) as follow:

$$Y_{high} = Y_{ave.} + K_n \quad \sigma_y \tag{1}$$

Table 2
Screening of outliers` records.

Station name	Abo Redus
Available records	1976–1989 & 2000–2018
Number of records	33
Kn	2.545
High outlier	2.14
Low outlier	-0.356
Max predicted Rainfall	138.177
Min predicted Rainfall	0.44
Result	No outliers

$$Y_{low} = Y_{ave.} - K_n \quad \sigma_y \tag{2}$$

$$K_n = 1.055 + 0.981\log(n) \tag{3}$$

where: (n) is number of records, (σ_y) is standard deviation of the data, (Y_{high}) represents the high outlier in log units, (Y_{low}) is the low outlier in log units, and (K_n)is coefficient of outlier depend on the number of records. The results pointed that no outliers` readings in the collected data of Abou Redus rainfall station as shown in Table 2.

Frequency analysis is a simple method used to predict the depth of storm or probability regarding its return period depending on historical records of precipitation data. Hydrological Frequency Analysis Plus (Hyfranplus) software was used to get the best fitting curve of which represent Abou Redus station's data. The best fitting curve is log Pearson type III.

The result of frequency analysis process indicates the rainfall depths for the return periods 5, 10, 25, 50, 100 and 200 years are 20.6 mm, 29.2 mm, 40.70 mm, 49.30 mm, 58 mm and 66.6 mm respectively.

2.3. Hydrological model using SCS-CN Method

SCS-CN is one of the most popular methods that is used to estimate the Runoff. This method was originated 1954 by the United States Department of Agriculture (USDA) and was developed to serve the regions of the United States, these regions there similar in its nature to Sinai. The estimate of runoff depth has been calculated from the following equations in the SCS-CN method Which is one of most common methods to extract the surface runoff from rainfall storm (Soulis and Valiantzas, 2012).

$$\mathrm{DOR} = \frac{(\mathrm{P} - \mathrm{I_a})^2}{(\mathrm{P} - \mathrm{I_a}) + \mathrm{S}} \tag{4}$$

Where DOR depth of Runoff (mm), P depth of rainfall (mm), Ia initial abstraction (mm) that involves all of losses prior the start of Runoff, evaporation, infiltration, and objection of water through vegetation ($I_a = 0.2S_r$). Sr potential maximum retention with the start of Runoff.

So, we can replace ($I_a = 0.2S_r$) in Eq. (6) (Soulis and Valiantzas, 2012).

$$\mathrm{DOR} = \frac{(\mathrm{P} - 0.2\mathrm{S_r})^2}{(\mathrm{P} + 0.8\mathrm{S_r})} \tag{5}$$

S_r can be given depend on CN Values which related with the land use and the type of soil (Soulis and Valiantzas, 2012):

$$S_r = Y\left[\frac{100}{CN} - 1\right] \tag{6}$$

Y = 10 in English units, or 254 in metric units. In Eq. (4) (S_r) can be replaced by its value from Eq. (8) to get equation of surface runoff with only two parameters as following:

$$DOR = \frac{\left[P - 0.2Y\left(\frac{100}{CN} - 1\right)\right]^2}{\left[P + 0.8Y\left(\frac{100}{CN} - 1\right)\right]} \tag{7}$$

The objective of the watershed delineation task is to identify the catchment and sub-catchment boundaries, as well as the stream network within the catchment (Maher et al., 2022). Furthermore, this objective entails estimating morphometric parameters, which

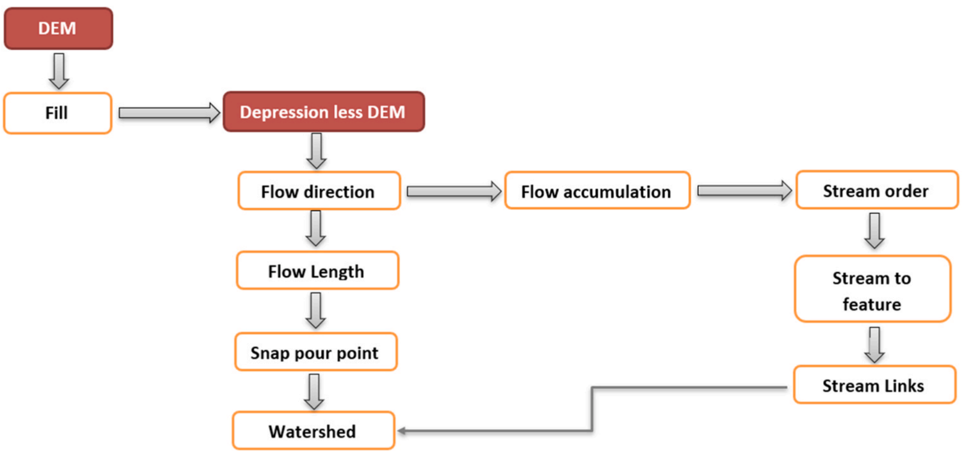

Fig. 7. Steps of Watershed delineation (modified after Maher et al., 2022).

are critical in the construction of the hydrological model. The primary requirement for completing this work is topographic survey and ground elevations data for the study area. Furthermore, topographic data is available in a variety of formats, including DEM. The Watershed delineation has been done by some of steps as shown in Fig. 7.

The risk degree of the different sub-basins is determined using morphometric parameters. Based on the morphometric characteristics and their relationships with the potential degree of risk, morphometric parameters were divided into two categories. Parameters in the first group are proportional to the degree of danger. The greater the parameter value, the greater the degree of risk, this group is listed in Table 4 from number 1 to number of 15. The parameters in the second group are inversely proportional to the degree of danger, the higher the parameter value, the lesser is the degree of risk, this group is listed in Table 4 from number 16 to number 18.

Based upon the previously determined morphological parameters, the flash flood risk can be computed in several steps. First, each parameter was analyzed using simple statistical methods based on the relationship between the parameter values and the risk of flash flooding (Pradhan, 2010). The method used is called as ranking method. For the ranking method, Bajabaa et al. (2014) created a concept to determine the hazard degree for each sub-basin as follows: A hazard scale number has been assigned to each parameter, ranging from 1 (the lowest) to 5 (highest).

For identifying the minimum and maximum values of each parameter for each sub-basin of the study area, the geometric relationship can be used to calculate the actual hazard degree for sub-basins with values between the minimum and maximum values (Davis, 1975). In the case of parameters with a direct proportional relationship (Davis, 1975):

$$\text{Hazard degree} = \frac{4(X - X_{min})}{(X_{max} - X_{min})} + 1 \tag{8}$$

In the case of parameters with an inverse proportional relationship (Davis, 1975):

$$\text{Hazard degree} = \frac{4(X - X_{max})}{(X_{min} - X_{max})} + 1 \tag{9}$$

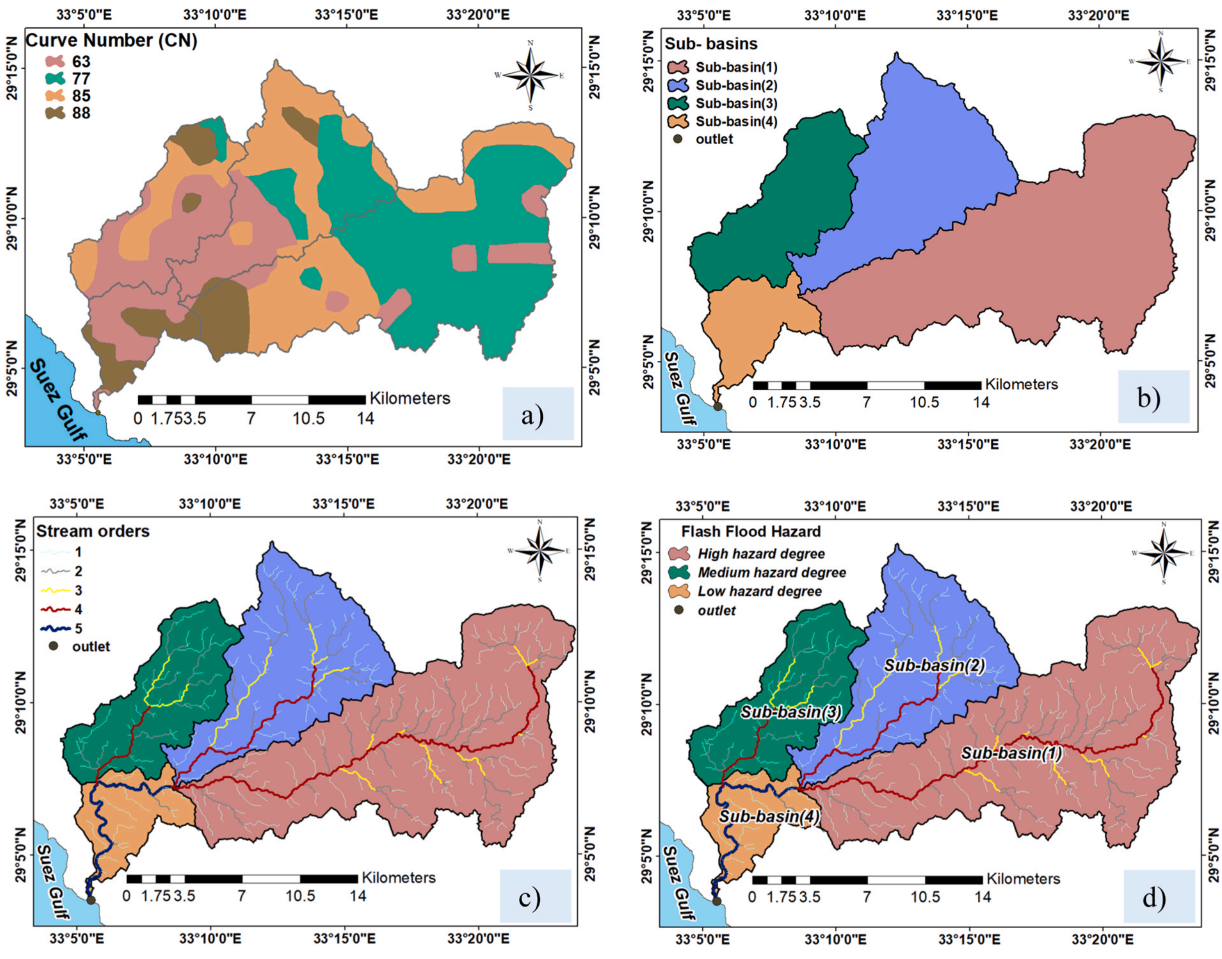

Fig. 8. Wadi Tayyibah for (a) Values of CNs. (b) Sub-basins (c) Stream orders and (d) Flood hazard map showing the high, medium, and low hazard sub-basins.

where x is the morphometric parameters used to calculate the hazard degree for each sub-basin. "X_{max}" and "X_{min}" are the maximum and minimum values of the parameters of all sub-basins, respectively.

3. Results

3.1. Curve number (CN) estimation

Curve number (CN) is one of the main important parameters required for estimating the surface runoff in SCS-CN method. CNs are numbers between (0–100), their value depends on land use and HSG referring to the map of land use (see Fig. 4b), and HSG (see Fig. 5a) of wadi Tayyibah and depending on the value of CN in arid and semi-arid regions. These maps were combined in ArcGIS software to determine the curve number of each sub basin of wadi Tayyibah as shown in Fig. 8a and Table 3. The equivalent CN of sub basins of wadi Tayyibah in case of normal soil conditions was estimated as shown in Table 3 and depending on Eq. (8) (Satheeshkumar et al., 2017).

$$CN = \frac{\sum A_c CN_c}{\sum A_c} \tag{10}$$

Where CN_c is the CN that represent on the part of basin of area A_c.

3.2. Runoff estimation of Wadi Tayyibah

The study of the morphometric analysis of Wadi Tayyibah was mainly done using DEM with 30 m resolution and topographic maps. The streams are arranged using the Strahler method (Strahler, 1957), and the various parameters are measured and calculated using Horton's (1932, 1945) as indicated in Table 4. Wadi Tayyibah is divided into four sub-basins as indicated in Fig. 8b.

DEM is a useful input for watershed analysis since it is made up of cells, each of which carries the value of its elevation. Because the downloaded pure DEM has depressions, the first step is to remove them before georeferencing to UTM WGS 84 Zone 36 N using ArcGIS 10.3 software. The direction of flow is the next step in filling sinks. The following process is termed flow accumulation; it is used to determine the number of cells that pour into each cell. Finally, the stream orders of wadi Tayyibah were defined according to Strahler (1957) as shown in Fig. 8c.

Where; Nu: Stream Number, Lu: Stream Length, A: Basin Area, P: Basin perimeter, Lb: Basin Length, Wb: Basin Width, Rc: Circulatory ratio, Rt: Texture ratio, n: number of records, P: depth of Rainfall, Fs: Stream frequency, Dd: Drainage Density, Lg: Length of overland flow, If: Infiltration number, Bh: Basin relief, Rh: Relief (gradient) ratio, Rn: Ruggedness number, Rb: Bifurcation ratio, Re: Elongation ratio, Rf: Form factor.

In the ArcGIS environment, flash flood-prone wadis were defined and analyzed, and the final flood hazard map as shown in Fig. 8d, was produced with the conservative values of the ranking score mentioned in Table 5. That map indicated that the sub-basin (1) has a high hazard degree of flash flood, sub-basins (2) and (3) a medium hazard degree of flash flood and the sub-basin (4) has low hazard degree of flash flood.

There are numerous number of computer programs to simulate the rainfall-runoff relationship (Al-Weshah, 2002). The selected computer model for simulating wadi Tayyibah is the Hydrologic Engineering Center-1 (HEC-1) model under Watershed Modeling System (WMS) 10.1 software. WMS is comprehensive hydrologic analysis software that was developed by Brigham Young University's Environmental Modelling Research Laboratory in partnership with the United States Army Corps of Engineers Waterways Experiment, but it is now produced by Aquaveo. This software can compute basin parameters such as area, slope, runoff volume, and concentration time, as well as perform automated watershed delineation. It can also be used as a graphical user interface for various hydraulic and hydrologic models. This software also provides several display options for presenting terrain surfaces and exporting generated images. The Runoff of wadi Tayyibah was estimated depending on the SCS-CN method using the HEC-1 model for different return periods. The design storms of different return periods were obtained depending on the historical data of the Abou Redus rainfall station using HyfranPlus software. The developed hygrographs of Wadi Tayyibah for the return period of 100 years are indicated in Fig. 9.

Table 3
HSGs areas of sub-basins and Curve Number of wadi Tayyibah.

	HSG	A	B	C	D	Wadi Tayyibah`s	
Sub Basin# 1	Area (km^2)	16.87	98.27	51.02	12.68	178.83	-
	Curve Number	63	77	85	88	-	78.74
Sub Basin# 2	Area (km^2)	23.06	26.63	36.38	3.57	89.65	-
	Curve Number	63	77	85	88	-	77.08
Sub Basin# 3	Area (km^2)	30.44	2.17	20.04	5.97	58.61	-
	Curve Number	63	77	85	88		73.59
Sub Basin# 4	Area (km^2)	16.70	0.00	0.00	12.19	28.9	-
	Curve Number	63	77	85	88	-	73.55
Total	Area (km^2)	-	-	-	-	360	-
	Curve Number	-	-	-	-	-	77

Table 4
Morphometric properties of Sub-basins of wadi Tayyiba.

	Morphometric properties	Symbol/Formula	Ref.	Sub-basin (1)	Sub-basin (2)	Sub-basin (3)	Sub-basin (4)
1	Stream Number	Nu	Strahler (1957,1964)	166.00	90.00	67.00	21.00
2	Stream Length (km)	Lu	Strahler (1957)	224.53	106.65	71.34	94.49
3	Basin Area (km2)	A	Schumm (1956)	179.95	89.59	58.48	28.03
4	Basin perimeter (km)	P	Schumm (1956)	107.32	70.39	55.47	40.24
5	Basin Length (km)	Lb	Schumm (1956)	26.19	16.08	13.05	8.52
6	Basin Width (km)	Wb	Schumm (1956)	6.87	5.57	4.48	3.28
7	Circulatory ratio	$Rc = 4\pi A/P2$	Miller (1953)	0.20	0.23	0.24	0.22
8	Texture ratio	$Rt = N/P$	Horton (1945)	1.55	1.28	1.21	0.52
9	Stream frequency	$Fs = \sum Nu/A$	Horton (1932)	0.92	1.00	1.15	0.75
10	Drainage Density	$Dd = \sum Lu/A$	Horton (1932, 1945)	1.25	1.19	1.22	3.37
11	Length of overland flow (km)	$Lg = 1/(2Dd)$	Horton (1945)	0.40	0.42	0.41	0.15
12	Infiltration number	$If = Dd \times Fs$	Faniran (1968)	1.15	1.20	1.40	2.53
13	Basin relief (km)	$Bh = Zxax - Zmim$	Strahler (1957,1964)	0.96	0.87	0.69	0.31
14	Relief (gradient) ratio	$Rh = Bh/Lb$	Strahler (1957)	0.04	0.05	0.05	0.04
15	Ruggedness number	$Rn = Bh \times Dd$	Schumm (1956)	1.20	1.04	0.84	1.04
16	Bifurcation ratio	Rb	Strahler (1953)	4.93	5.18	4.65	6.07
17	Elongation ratio	$Re = 2\sqrt{(A/\pi)}/Lb$	Schumm (1956)	0.58	0.66	0.66	0.70
18	Form factor	$Rf = A/(Lb)2$	Horton (1932)	0.26	0.35	0.34	0.39

Table 5
Ranking score for different morphometric parameters as well as the total score value.

Morphometric properties	Symbol	Sub-Basin 1	Sub-Basin 2	Sub-Basin 3	Sub-Basin 4
Stream Number	Nu	5.000	2.903	2.269	1.000
Stream Length (Km)	Lu	5.000	1.922	1.000	1.604
Basin Area (Km2)	A	5.000	2.621	1.802	1.000
Basin perimeter (Km)	P	5.000	2.798	1.908	1.000
Basin Length (Km)	Lb	5.000	2.711	2.025	1.000
Basin Width (Km)	Wb	5.000	3.552	2.339	1.000
Circulatory ratio	Rc	1.000	3.907	5.000	2.995
Texture ratio	Rt	5.000	3.953	3.677	1.000
Stream frequency	Fs	2.748	3.576	5.000	1.000
Drainage Density	Dd	1.105	1.000	1.054	5.000
Length of overland flow (Km)	Lg	4.716	5.000	4.850	1.000
Infiltration number	If	1.000	1.130	1.718	5.000
Basin relief (Km)	Bh	5.000	4.465	3.326	1.000
Relief (gradient) ratio	Rh	1.095	5.000	4.645	1.000
Ruggedness number	Rn	5.000	3.231	1.000	3.247
Bifurcation ratio	Rb	4.220	3.505	5.000	1.000
Elongation ratio	Re	5.000	2.200	2.297	1.000
Form factor	Rf	5.000	2.281	2.381	1.000
Total Score		70.88	55.76	51.29	30.85

3.3. *Flash flood protection*

The floods in Egypt have resulted in numerous losses in terms of life, property, and infrastructure, and most of the flood water is wasted without benefit despite the critical need for it. As a result, the current study is attempting to propose numerous solutions to lessen the hazards of torrential rains in Wadi Tayyibah, as well as to take advantage of the torrential water in many elements of basin development. There are eight suggested scenarios for dam locations in Wadi Tayyibah. The dam's location is chosen such that the dam's length is appropriate and restricted between two high points, and there is a lake with a suitable storage capacity for the quantity of rain, making the dam financially feasible. There are eight contour lines with elevations of 320 m, 340 m, 400 m, 380 m, 220 m, 200 m, and 140 m. As shown in Fig. 10a.

The suggested location of dams is indicated in Fig. 10b. According to the contour map of Wadi Tayyibah, there are no suitable locations to build dams in sub-basins (2) and (3). Five dam construction locations were recommended for sub-basin (1), as well as three dams for sub-basin (4).

The properties of the dams are indicated in Table 6, the lake volume 27.13 million cubic meters (Mm^3), 131.17 Mm^3, 26.38 Mm^3, 367.95 Mm^3, 107.51 Mm^3, 229.99 Mm^3, 104.71 Mm^3, and 75.64 Mm^3 from Dam (1) to dam (8) respectively.

The dams from (1) to (5) are in the sub-basin (1) where the runoff volume equal 3.13 Mm^3 for return period 100 years as shown in Fig. 9b. So, the best economic location in sub-basin (1) is Dam (3) according to Table 6. Also, dam (6) and dam (7) are in the sub-basin (4) where the runoff volume equal 5.56 Mm^3 for return period 100 as shown in Fig. 9b so the best economic location of wadi in sub-basin (4) is Dam (7) according to Table 6. The dam's (8) location is inconvenient because the Ras sudr-El Tour highway runs through it

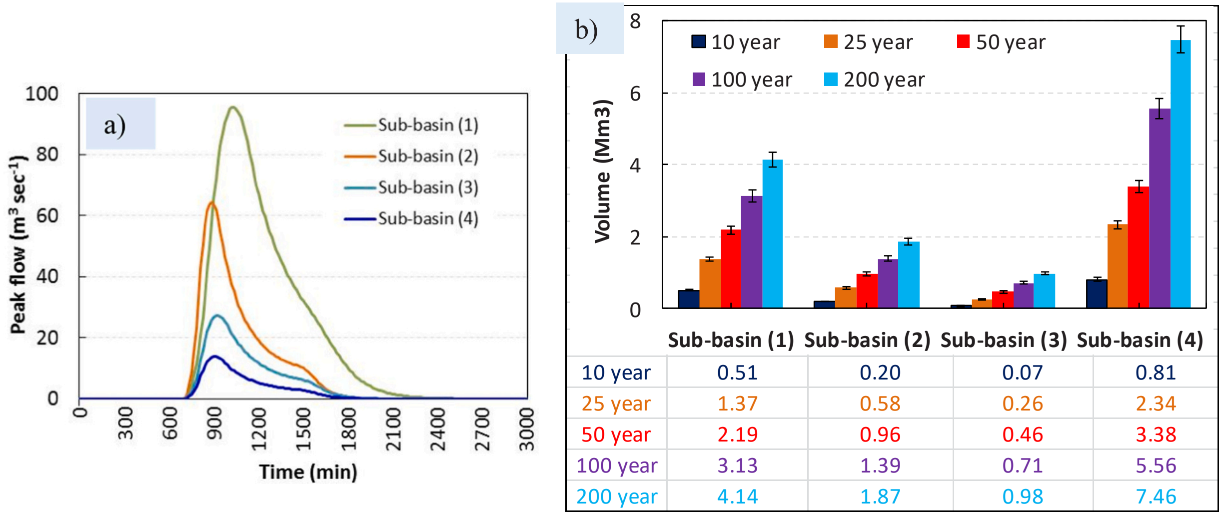

Fig. 9. Wadi Tayyibah for (a) Hydrograph of return period 100 years and (b) runoff volumes of return periods 10, 25, 50,100 and 200 years for all sub-basins.

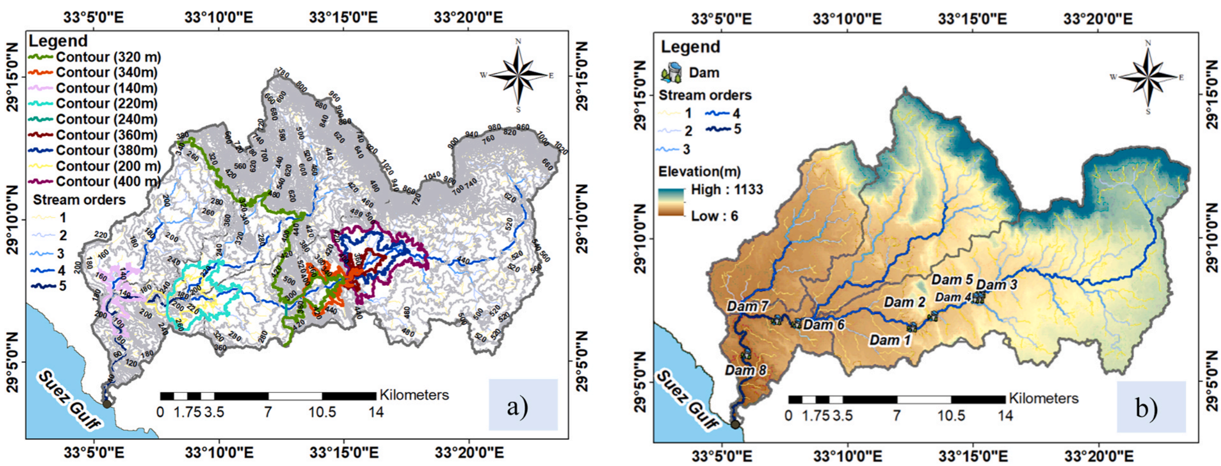

Fig. 10. Suggested dams for (a) contour lines location and (b) locations.

Table 6
Properties of the recommended dams.

Dam#	Max. level (m)	height (m)	Length (km)	Lake volume (Mm^3)
Dam (1)	320	55	0.96	27.13
Dam (2)	340	60	0.45	131.17
Dam (3)	360	40	0.65	26.38
Dam (4)	400	75	1.03	367.95
Dam (5)	380	50	0.38	107.51
Dam (6)	220	55	1.12	229.99
Dam (7)	200	60	1.05	104.71
Dam (8)	140	60	0.95	75.64

as shown in Fig. 11a.

So, the best locations of dams are Dam (3) in sub basin (1) and Dam (7) in sub-basin (4) as indicated in Fig. 11b. The Ras sudr-El tour and Sharm al sheikh international highways cross the streams of wadi Tayyibah so they need protection against the flash floods as shown in Fig. 11b.

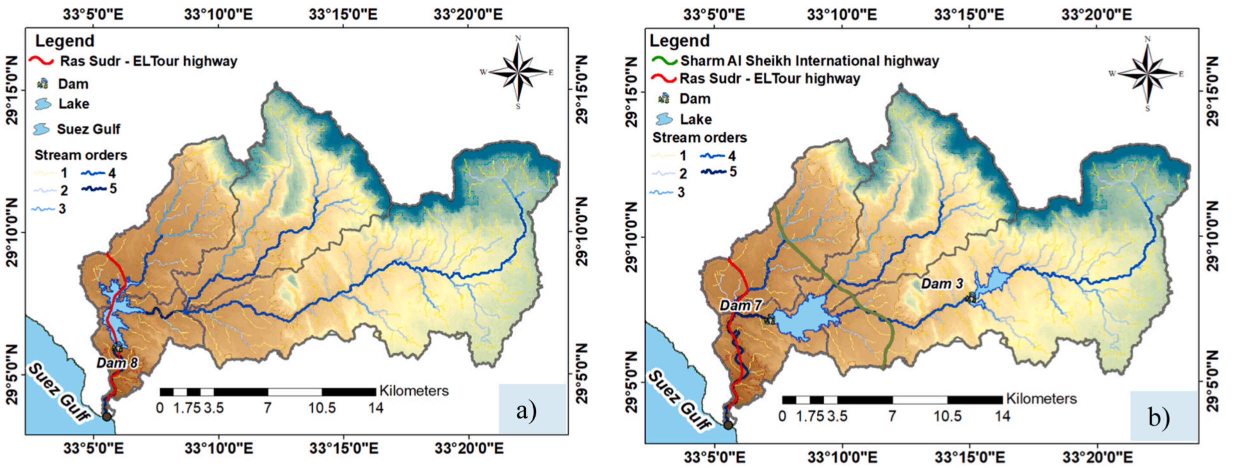

Fig. 11. Wadi Tayyibah for (a) Location of dam (8) and Ras sudr-El tour highway and (b) the best locations of dams are dam (3) in sub basin (1) and Dam (7) in sub-basin (4).

4. Discussion

The current study was done on Wadi Tayyibah, South Sinai, Egypt; the last flash flood in Abou Zenima was on the 12th of March 2020, which caused disasters in Abou Zenima. The rainfall data were from the year 1976 to the year 1989 and from the year 2000 to the year 2018 in millimeters of depth. STRM DEM was downloaded with a resolution of 30 m from (USGS, 2020) website US. The equivalent CN of sub basins of Wadi Tayyibah in normal soil conditions was estimated to be 77.

The risk degree of the different sub-basins is determined using morphometric parameters based on the morphometric characteristics and their relationships with the potential degree of risk, morphometric parameters were divided into two categories. Parameters in the first group are proportional to the degree of danger. The parameters in the second group are inversely proportional to the degree of danger. Based on the determined morphological parameters, the flash flood risk was computed risk in several steps; each parameter was analyzed using simple statistical methods based on the relationship between the parameter values and the risk of flash flooding (Pradhan, 2010). A hazard scale number has been assigned to each parameter, ranging from 1 to 5. For identifying the minimum and maximum values of each parameter for each sub-basin of the study area, the geometric relationship was used to calculate the actual hazard degree for sub-basins with values between the minimum and maximum values.

The dam's location is chosen such that the dam's length is appropriate and restricted between two high points, and there is a lake with a suitable storage capacity for the quantity of rain, making the dam financially feasible. The results of the current study showed that the selection dam's locations are based on the dam's length to be appropriate and restricted between two high points, according to the contour map of Wadi Tayyibah.

There are no suitable locations to build dams in sub-basins (2) and (3). Five dam construction locations were recommended for sub-basin (1), as well as three dams for sub-basin (4). Also, the storage lake volume reached 27.1278 Mm^3, 131.17 Mm^3, 26.38 Mm^3, 367.95 Mm^3, 107.51 Mm^3, 229.99 Mm^3, 104.71 Mm^3, and 75.64 Mm^3 from Dam #1 to dam #8 respectively. The best economic location in sub-basin (1) is Dam #3 where the runoff volume reached 3.13 Mm^3 for a return period of 100 years in the sub-basin (1); also, the runoff volume is 5.56 Mm^3 for return period 100 so the best economic location of the wadi in sub-basin (4) is Dam #7. Because of the importance of the Ras Sudr-El Tour and Sharm al Sheikh, international highways cross the streams of Wadi Tayyibah, so they need protection against flash floods. The dam's (8) location is inconvenient because the Ras Sudr-El tour highway runs through it.

The results of the current study agree with many researchers, in which they proved the usage of check dams around the world and their utility for a variety of applications by Piton et al. (2015), Abbasi et al. (2019) and Lucas-Borja et al. (2019). A survey of the literature on land suitability for the location of the check dam allows the identification of variables affecting the selection of an appropriate site. Moore et al. (1991) noted that widespread usage of DEM maps based on GIS technological advancements has advanced hydrological and environmental research projects. The storage capacity was determined for one or more dam heights and can be calculated using GIS spatial information analysis. Choong-Sung Yi et al. (2010)) employed location analysis methods to find the best placement for small hydropower plants in the upper Geum River basin in Korea. They used a geospatial information system to analyze location and discovered six possible small hydropower plant sites. Ali et al. (2014) assessed the suitability of the chosen site location for a subsurface dam building to serve as strategic water supply storage, alleviating aridity and water scarcity in this area of arid to semi-arid climate inside the Isayi watershed, Garmiyan area, Kurdistan Region using GIS and RS via satellite images, as well as DEM. They selected the site location for construction of a subsurface dam depending on the geologic, structural, geomorphologic, hydrologic and hydrogeologic characteristics with a Ground Penetration Radar (GPR) survey. Rahmati et al. (2019) proposed using geomorphometric and topo-hydrological parameters to create a suitability map that can be used to guide site selection at the watershed scale.

Raaj et al. (2022) attempted to identify the best dam placement in the Surat district for minimizing flood occurrences, improving surface water budgets, and constructing groundwater recharge sites. They employed recent advancements in RS, GIS and decision-making procedures to map the Dam Sites Suitability Model (DSSM). They concluded that rainfall and stream order were the most important elements influencing the dam site location map. Hagos et al. (2022) used RS and GIS techniques in conjunction with the dam suitability stream model and multi-criteria decision analysis to identify potential sites for multi-purpose dam construction. The results showed that the topography and land use of three proposed dam sites in the upper part of the watershed are likely preferable for irrigation, fishery, and clean drinking water supply. These dams in the watershed's lower reaches, however, are better suited to hydropower generation.

The limitations of this study are required to apply the economic feasibility study for using the morphometric parameters based on the morphometric characteristics and their relationships with the potential degree of risk in the selected dam's locations.

5. Conclusions

The main purpose of this study is to identify the cost-effective locations of storage dams for rainfall harvesting and flash flood mitigation in wadi Tayyibah at South Sinai, Egypt based on hazard maps and the basin's detailed morphometric characteristics relying on SCS-CN method and using HEC-1 Model and ArcGIS software. The study area was divided into 4 sub-basins with areas 178.83 km^2, 89.65 km^2, 5.61 km^2, and 28.,9 km^2 respectively. The study proposed a total of 8 dams, the storage lake volume for Dam (1) to dam (8) reached 27.1278 Mm^3, 131.1660 Mm^3, 26.3772 Mm^3, 367.9533 Mm^3, 107.5104 Mm^3, 229.9851 Mm^3, 104.7132 Mm^3, and 75.6405 Mm^3 respectively. The results showed that the best dam locations are Dam (3) and Dam (7) in sub-basin (1) and (4), where the runoff volume reached 3.13 (Mm^3) and 5.56 Mm^3 for return period 100, respectively. The current study for flash flood hazard maps and morphometric characteristics for rainfall harvesting is useful for the decision-makers in selecting the best investment location of storage dams. Also, the study recommends investigating the cost visibility of the investment dam's location. Through this study, we seek in the future to apply a multi-parametric decision spatial model (MPDSM) in the process of selecting dams to reduce the risks of floods. We also seek to rely on artificial intelligence techniques and integrate them within the limits of the study to see the extent of their impact on the results.

Ethical Approval

This article does not contain any studies with human participants or animals performed by any authors.

Consent to Participate

Informed consent was obtained from all individual participants included in the study.

Consent to Publish

Informed consent was obtained from all participants in the study.

CRediT authorship contribution statement

Amir S Ibrahim; Islam S Al Zayed; Fahmy S. Abdelhaleem; Mahmoud M. Afify: Conceptualization, Methodology, Investigation, Formal analysis, Data curation. **Amir S Ibrahim; Islam S Al Zayed; Fahmy S. Abdelhaleem; Mahmoud M. Afify:** Visualization, Writing – original draft. **Ismail Abd-Elaty:** Writing – review & editing, Resources, Supervision. **Ashraf Ahmed:** Editing, review, and supervision.

Availability of data and materials

Upon reasonable request.

Funding

There is no funding source.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

No data was used for the research described in the article.

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