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Original research

Mapping flood vulnerability using hydrologic modeling and GIS-based morphometric analysis

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Abstract:

The most frequent kind of natural disasters is flash flooding, which happens when too much water floods normally dry areas. Flash Floods can inflict extensive destruction, including loss of life, damage to private property, and destruction of vital infrastructure. Therefore, this scientific research aims to study all the factors that affect these floods and conduct the necessary hydrological studies of Wadi El Assiuti depending on hydrological indicators and morphometric analysis to assess flash flood risk. Thirty-six parameters are calculated and are put into four categories (drainage texture, drainage network, relief characteristics, and basin geometry). The following ten indices are chosen: Precipitation (P), Elevation (ELEV), Slope (SL), Drainage density (Dd), Terrain Ruggedness Index (TRI), Stream Power Index (SPI), Sediment Transport Index (STI), Topographic Wetness Index (TWI), Topographic Position Index (TPI), and Normalized Difference Vegetation Index (NDVI). According to each index's proportional importance, it is weighted by applying the Analytical Hierarchy Process (AHP) technique. The Wadi El Assiuti occupies an area of (6045.57 Km^2). The wadi, which consists of 926 streams having 3326.82 kilometers in length, is associated with the 6th order. After the map is created, it explains that nearly 45.5% of the wadi is ranked as regions of high and very high danger, and 30.3% as regions of moderate danger. While almost 24.1% of the Wadi is classified as low and very low. This study can be beneficial for decision-makers and local authorities who want to implement mitigation measures to alleviate the danger of flash floods, like the floods of Darinka village on November 2, 1994.

Keywords: Hydrological indicators, Morphometric analysis, (AHP), Flash flood hazard.

1. Introduction

Devastating natural disasters like flash floods have the potential to destroy infrastructure on both public and private property, destroy lives, and result in enormous financial damages.(Tola & Shetty, 2022). Industrial and technological progress, which resulted in change of climate stands out as a crucial element that led to the emergence of floods around the world (Berz et al., 2001).

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Extreme rain events impact the regularity, severity, geographic extent, length, and timing of significant floods, and climate change also affects these factors. These factors are also affected by climate change (Hidayah et al., 2022). The catastrophes caused by weather have become more frequent and more intense. Due to the quick conversion of natural land covers to impermeable surfaces and the detrimental consequences of climate change (Chowdhury, 2024). In the era of climate change, it is crucial to map and evaluate the risk of flood to manage floods effectively (Faizan et al., 2023). Numerous factors, including the morphometric features of the drainage basins, the regional geology, and the settings of the floodplains, influence the likelihood of flooding (Oktariyanti et al., 2023; Subyani & Al-Dakheel, 2009). Climate change has recently increased the risk of flash floods in many parts of the world, causing disastrous consequences (Elsadek & Almaliki, 2024). Climate change affects how often and how big flash floods are, especially in hot deserts, where heavy rains are characterized by their high speed, brief duration, and quick discharge peak. Clarification of the various relationships between the watershed drainage pattern's elements will be provided, along with a comparative assessment of wadies with various geological and climatic regimes (Karmokar & De, 2020). When assessing and selecting basins for water conservation, the quantitative examination of morphometric features is crucial. Floods arise from river overflow caused by morphological changes in the river channel's shape brought about by soil erosion and sedimentation (Puno et al., 2015). Several studies conducted a morphometric analysis of river basins using Remote Sensing (RS) and GIS methodologies (Sakmongkoljit et al., 2021). GIS has been utilized to apply the Stream Power Index (SPI) and Sediment Transport Index (STI) of Guelmim City, Morocco, as well as to extract characteristics and topographic profiles (Elsadek et al., 2019). Weighing criteria conceptually is related to multi-criteria decision analysis (MCDA). One of the methods for determining the relative relevance of the indices is the AHP, which has various uses. To find possible groundwater regions in the Pohru Watershed of the Jhelum Basin—Western Himalaya, India, AHP is applied by integrating with RS and GIS (Costa et al., 1999). Because GIS-based AHP can easily obtain the weights of many different criteria and combine large amounts of diverse data, it has been used to handle a variety of decision-making difficulties (El-Rawy et al., 2022; Kamel & El Ella, 2024). To improve flood prevention and mitigation measures, flood susceptibility mapping is a useful tool for spatial water management, especially important for flood-prone areas to guide policy planners and decision-makers about the hazards of flooding in the Wadi El Assiuti. The purpose of this research is to how we can study, analyze, and get information about flash floods and how we obtain the ideal solution to mitigate the flash flood in The Wadi El Assiutti. Where there is notenough data about the flash flood in this region.

2. Materials and methods

2.1. Study area

Part of the Nile Basin in the northeast of the Sahara Desert, the Wadi El-Assiuti is situated in the central-western portion of the Eastern Desert as shown in Fig. 1 and 2. The study area is bounded by latitudes 27° 05 and 27° 45 N and longitudes 31° 15 and 32° 30 E. It drains the Nile River by running from the northeast to the southwest. The Wadi El-Assiuti region is entirely covered in sedimentary rocks. Abdel Kareem and El-Baz 2015b reported that the average annual precipitation of the study area in the period between 1998 and 2013 was about 10 mm/day. In general, the average rainfall rate is about 0.7 mm/month, with a relative humidity of 38%, and the average lowest and maximum temperatures were 18 °C and 40 °C, respectively (Kamel & El Ella, 2024).

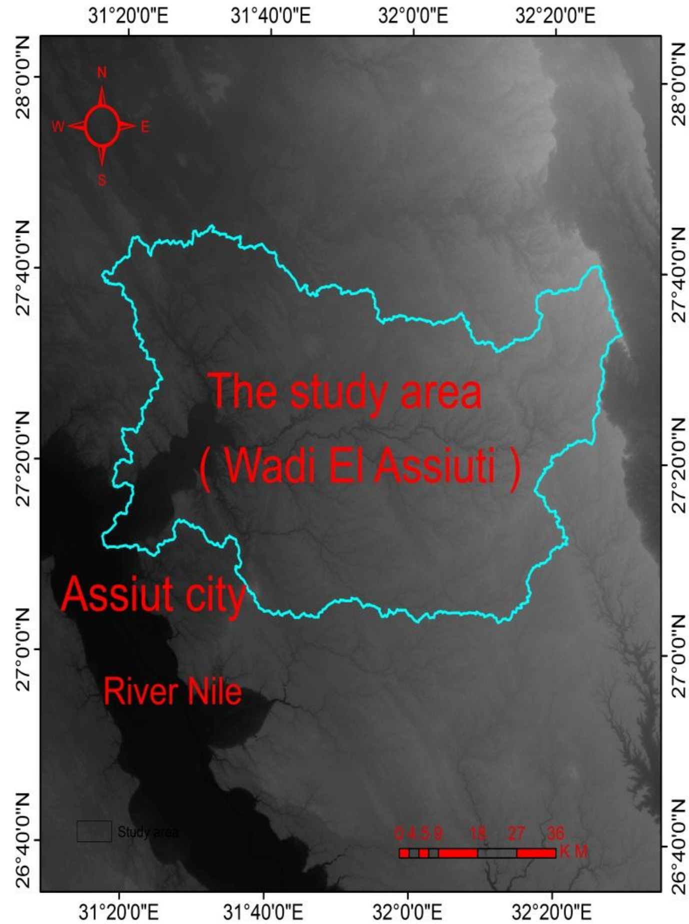

Fig.1. The study area

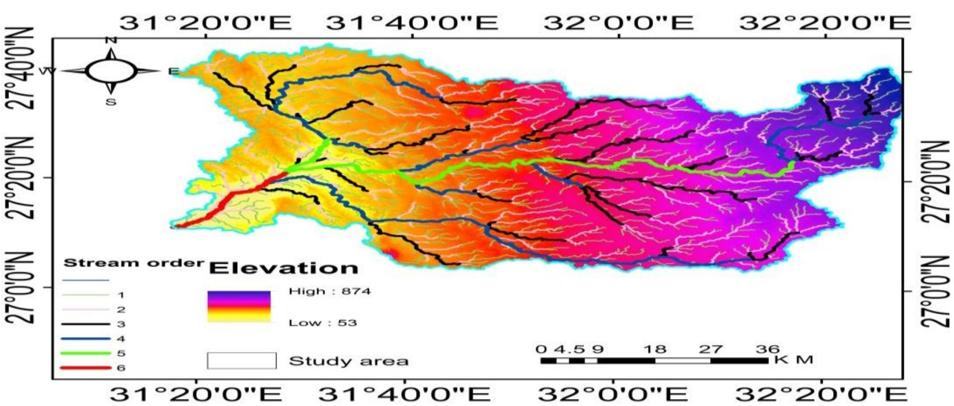

Fig. 2a. Elevation and stream order

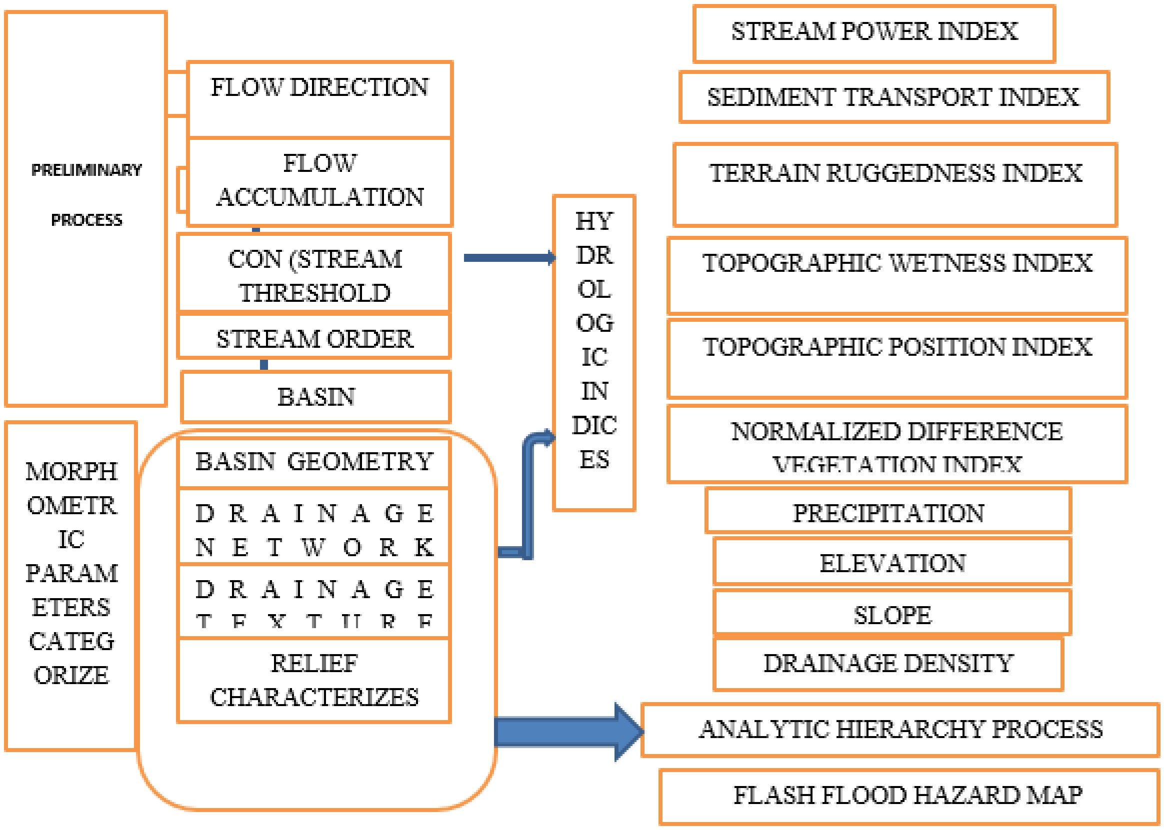

Fig. 2b. Flow chart of the methodology

2. 2. Data

The 30-m-resolution Radar Topography Mission data (SRTM) from the Shuttle is utilized to create a Digital Elevation Model (DEM). The area of Wadi El Assiuti is (6045.57 km^2) and its elevation is from 53m to 874m. The research steps to study this area are broken down into four phases. The first phase is determining the study area by using ArcGIS software. In the second phase, the morphometric parameters are calculated and categorized into 4 groups (Drainage texture, Drainage network, Relief characteristics, and Basin geometry). In the third phase, 10 hydrological indices, Precipitation (P), Elevation (ELEV), Slope (SL), Drainage density (Dd), Terrain Ruggedness Index (TRI), Stream Power Index (SPI), Sediment Transport Index (STI), Topographic Wetness Index (TWI), Topographic Position Index (TPI), and Normalized Difference Vegetation Index (NDVI), were utilized in the last phase. The AHP technique was applied by creating a pairwise matrix that includes these 10 indices, calculating each index's relative weight, and then using their weights to create a flood hazard map.

2. 3. Morphometric parameters

Morphometric analysis is necessary for sustainable water conservation (Suma & Srinivasa, 2017). Morphometric analysis measures several stream features to assess a watershed's characteristics (Panhalkar et al., 2012). This is the second phase, where 36 morphometric parameters are calculated and categorized into four groups (drainage texture, drainage network, relief characteristics, and basin geometry) as situated in Table 1.

2.4. Hydrological indices

Ten hydrological indices are used. These indices are (SPI, STI, TRI, TWI, TPI, NDVI, P, Sl, Elev, and Dd), which are calculated as follows:

SPI clarifies Channel erosion potential and landscape dynamics (Moore et al., 1991).

$$SPI = (As)(\tan\beta) \qquad (1)$$

As refers to the flow accumulation and β refers to the slope.

STI gives important details regarding the transportability of sediments in each basin's stream network.

$$STI = \left(\frac{As}{22.13}\right)0.6 * (\sin\beta/0.0896)1.3 \qquad (2)$$

TRI represents one of the major elements influencing surface storage capacity and runoff velocity.

$$TWI = \ln(As/\tan\beta) \qquad (3)$$

TPI, proposed by Reily et al (1999), measures each cell's height on a digital elevation map by comparing it to the average neighborhood elevation given around that cell.

$$TPI = Z0 - (\textstyle\sum 1 - \mathrm{nZn/n}) \qquad (4)$$

Z0 refers to the target point altitude, Zn refers to the height of the points inside the local window, and n refers to the total number of points used in the evaluation around the target one.

NDVI: Bands 5 and 4 of Landsat 8 are used to determine the NDVI using the following equations. The NDVI values for Wadi El Assiuti range from -0.05 to 0.57. Positive values from 0.36 to 0.57 indicate vegetation formations and negative ones represent water.

$$NDVI = (NIR - R)/(NIR + R) \qquad (5)$$

$$NDVI = \frac{(B4-B3)}{(\mathrm{B4+B3})(Inlandsat4-7)} \qquad (6)$$

$$NDVI = (B5 - B3)/(\mathrm{B5 + B3})(Inlandsat8) \qquad (7)$$

RED is the value of reflectance of the red channel and NIR is the value of reflectance of the infrared channel

2. 5. Analytical Hierarchy Process (AHP)

The purpose of this process is to measure the relative weight of each index, as well as its impact on the final flood map. In this technique, a 10 * 10 matrix was generated, and the indices were evaluated according to the comparative scale suggested by Saaty (1987), which consists of integer numbers between 1 and 9, where 1 refers to the factors have the equally important, and 9 refers to one factor has extreme importance, in the next step we assumed the criteria weights, then weighted sum value is assumed by taking the sum of each value in the row, Consistency index is calculated by using the principal eigenvalue (λ_{max}).

$$Ci = (\lambda_{max} - n)/(\mathrm{n} - 1) \qquad (8)$$

Ci refers to an index of consistency, n refers to the number of compared elements
finally, the Consistency ratio is computed as the following equation:

$$C_R = \frac{CI}{\mathrm{R}} \qquad (9)$$

Where R refers to an index of Random and (C_R) must be less than or equal to 0.1, if the value of $C_R > 0.1$ the matrix should be modified (Sani et al., 2010).

3. Results and discussion

3.1. Morphometric analysis

As we mentioned previously, Morphometric analysis is divided into four groups, as follows:

3.1.1. Basin geometry

Eleven parameters are calculated by using ArcGIS software 10.8.1 as shown in Table 1:
The watershed area(A) of Wadi El Assiuti is 6045.57 km^2.so this wadi is classified by size into a large basin according to (Horton, 1932), where its area is > (100 km^2). The basin length is assumed (LB), it is (126 km). The basin perimeter (Pr) is (512.44 km). The basin width (W) of the study area is (47.98 km). The Circul ratio (Rc) is 0.29 according to (Miller, 1953), and the elongation ratio (Re) is assumed (0.69) < (0.7). This refers to (Re) being elongated according to (Asode et al., 2016). Because of the longer basin, runoff will be less effective and have more time to reach the outflow. The form factor ratio (FFR) is 0.38. A small (FFR) value means more extended and less severe precipitation. The basin shape index (Ish) is 0.48 calculated according to (Gould, 1967), which means the form of the basin is less round, and vice versa. The compactness ratio (Cc) is 1.86, the less circular the basin, the slower the fluid flow. The lemniscate shape (Ls) shows the basin form (Chorley, 1957). (Ls) is equal to 2.06. This value refers to the basin shape being elongated because (Ls) > 2 according to (Lykoudi & Zarris, 2004), and Its concentration time is longer from the outlet to the furthest point in the basin.

3. 1. 2. Drainage network

ArcGIS software 10.8.1 is used to calculate eleven parameters including main channel length (vl), mean stream length (Lsm), weighted mean stream length ratio (Luwm), stream length ratio (lur), main channel index (ci), sinuosity (si), stream number (Nu), stream order (u), stream length (lu), bifurcation ratio (Rb), the Weighted Mean Bifurcation Ratio (WMRB), as shown in Table 1.
The stream order (u) is a method used to analysis of a drainage basin and a numeric order of links in a stream network (Greenbaum, 1989). As shown in Fig.3. It has a single exit by which water is transported via the basin's drainage network. The stream order of Wadi El Assiuti is 6th order. The stream number (Nu) is the stream number in each order (Smith, 1950). Wadi El Assiuti contains 926 stream. Stream length (Lu) is known as the whole length of streams in each order (Strahler, 1964). The total stream length of the study area is 3326.82 km. The stream order increases with a decrease in the stream number (Horton, 1932). The Bifurcation ratio (Rb) is determined by dividing the sum of stream branches of a specific order (Nu) by the sum of branches of the subsequent higher order (Nu +1). The (Rb) of Wadi El Assiuti is 3.89. That means this area is described as moderate to high runoff, it has less porous rocky hills and is characterized by steep slopes (Farhan, 2017). The weighted mean bifurcation ratio (WMRB) is 4.44. This value is evidence that it is a high mountain area that is very sensitive to soil erosion and water runoff. As illustrated in Table 2.

The main channel length (VL) is 200.65 km. It has been defined as the distance between the farthest point in the Wadi El Assiuti and its outlet. The mean stream length (Lsm) is estimated by dividing the length of the stream (Lu) by the number of streams (Nu). For specific order according to (Sahu et al., 2017), his value is (24.06). The stream length ratio (Lur) is computed by (Lsm) of the order (U) by Lsm of the order U-1, and it was (1.95). The weighted mean stream length ratio (Luwm) is (2.33), as indicated in Table 3. The main channel index (Ci) is computed by dividing the length of the main channel by its maximum straight, which is (100.33 km). The sinuosity (Si) is defined as the proportion of the length of the main channel to the length of the basin, (Si) of Wadi El Assiuti is (1.59). This reveals that the water takes an extended period to reach the wadi's exit and abundant groundwater opportunities.

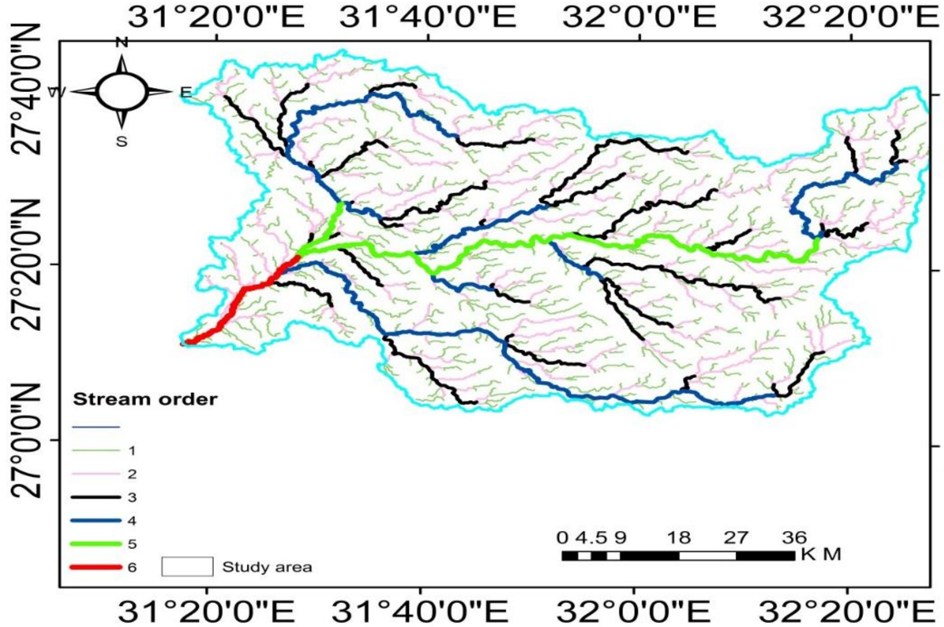

Fig. 3. Stream order

3. 1. 3. Drainage texture

ArcGIS software 10.8.1 is used to calculate seven parameters (F, Dd, Di, Rt, Lo, Fn, Dp), as illustrated in Table 1 :

The Stream frequency (F) is (0.15) which shows the lithological characteristics of the wadi. The drainage density (Dd) is the ratio of the basin's total area to its total stream length. The Dd of Wadi El Assiuti is 0.55< 2, so it is categorized in the very coarse class according to (Srinivasa Vittala et al., 2004) and (Pareta & Pareta, 2011). Drainage intensity (Di) is (0.28). A. Faniran (Faniran, 1968) defined (Dd) as the proportion of drainage density to stream frequency. (Dd)The texture ratio (Rt) is defined as the total stream number of all orders per perimeter. (Rt) of Wadi El Assiuti is (1.81) < (6.4) which means it is coarse according to the (Smith, 1958) classification. The length of the overland flow (Lo) is (0.91). A. N. Asode, et al (Asode et al., 2016) have proved that there are three values of (Lo): high (>0.3), moderate (0.2–0.3), and low (< 0.2), so the study area is categorized as a high class (Asode et al., 2016). The infiltration number (FN) is calculated from this equation $(FN) = (Dd) \times (F)$. It is equal to 0.08. (F) Give an overview of the infiltration properties of the study area.

Drainage pattern (Dp): The main pattern of Wadi El Assiuti is dendritic. It is a randomly formed dendritic pattern that develops in an area of homogeneous or uniform rocks. It is controlled by the topography of the land.

3.1.4 Relief characteristics

ArcGIS 10.8.1 software is used to calculate seven parameters as shown in Table 1.

Studying the basin's topographical features helps in knowing the flow's direction and velocity, as well as understanding the erosion process. Therefore, ArcGIS software is used to determine the maximum and minimum elevation. The Max. elevation of the study area is 874m. Min elevation is 53m. In general, infiltration is reduced, and runoff is increased on higher slopes, and vice versa. Low to moderate infiltration and heavy runoff are indicated by the Wadi with moderate to high slopes (Sreedevi et al., 2009). The relief (Rf) is calculated according to the following equation, (maximum elevation - minimum elevation). The relief of Wadi El Assiuti is 821m. O. Singh, A. Sarangi, et al (Singh et al., 2008) mentioned the value of The Hypsometric integral (HI) is between (0-1), (Hi) is equal to 0.5, which means Wadi El Assiuti is in the mature stage.

The relief ratio (Rr) is the ratio between (Rf) to (LB) (Strahler, 1957; Schumm, 1956). The (Rr) value of the study area is 0.01. Regardless of topographic variations, Rr makes comparisons of any basin's relative relief. Ruggedness number (Rn) is an index of slope that gives a specialized illustration of the roughness of the terrain inside a basin. The value of Rn of Wadi El Assiuti equals 0.45. Basins that have a high value of (Rn) are vulnerable to soil erosion and increased surface runoff, and vice versa.

Table 1: Calculation of Morphometric Parameters

Groups	Number	Morphometric Parameter	Equation	Value
Basin geometry	1	Watershed Area(A)	ArcGIS 10.8.1 software	6045.57m^2
	2	Basin length (LB)	ArcGIS 10.8.1 software	126km
	3	Basin perimeter (Pr)	ArcGIS 10.8.1 software	512.44km
	4	Basin width (w)	$W = A/LB$	47.98km
	5	Circularity ratio (Rc)	Rc=4*3.14*A/Pr^2	0.29
	6	Elongation ratio (Re)	Re=1.128(A)^.5/L	0.69
	7	Form factor ratio (FFR)	FFR=A/LB^2	0.38
	8	Inverse shape form (Sv)	Sv=LB^2/A	2.63
	9	Basin shape index (Ish)	Ish= 1.27A/LB^2	0.48
	10	Compactness coefficient (Cc)	Cc=P/2*(A3.14)^.5	1.86
	11	Lemniscate shape (Ls)	Ls= 3.14*BL^2/4A	2.06
Drainage network	12	Stream order (U)	Hierarchical rank	6^{th}
	13	Stream number (Nu)	Nu=N1+N2+……..+Nn	926
	14	Stream length (Lu)	Lu=L1+L2……+Ln	3326.82m
	15	Bifurcation ratio (Rb)	Rb=Nu/Nu+1	3.89
	16	Weighted mean bifurcation ratio (WMRB)	As illustrated in Table (2)	4.44
	17	Main channel length (VL)	ArcGIS 10.8.1 software	200.65
	18	Mean stream length (Lsm)	Lsm=Lu/Nu	24.06
	19	Weighted mean stream length ratio (Luwm)	As illustrated in Table (3)	2.33
	20	stream length ratio (Lur)	Lur=Lsmu/Lsmu-1	1.95
	21	Main channel index (Ci)	Ci=Main channel length/ Maximum straight of the main channel	100.33
	22	Sinuosity (Si)	Si=VL/LB	1.59
Drainage texture	23	Stream frequency (F)	F=Nu/A	0.15
	24	Drainage density (D)	D=Lu/A	0.55

	25	Drainage intensity(Di)	Di=F/D	0.28
	26	Texture ratio (Rt)	Rt=Nu/pr	1.81
	27	Length of overland flow (Lo)	Lo=1/2D	0.91
	28	Infiltration number (FN)	FN=F*D	0.08
	29	Drainage pattern (Dp)	ArcGIS 10.8.1 software	
Relief characteristics	30	Maximum elevation (Hmax)	ArcGIS 10.8.1 software	874m
	31	Minimum elevation(Hmin)	ArcGIS 10.8.1 software	53m
	32	Mean elevation (Hm)	ArcGIS 10.8.1 software	462m
	33	Relief (Rf)	Rf=Hmax-Hmin	821
	34	Hypsometric integral (Hi)	Hi=(Elev-Hmin)/(Hmax-Hmin)	0.5
	35	Relief ratio (Rr)	Rr=Rf/LB	0.01
	36	Ruggedness number (Rn)	Rn= D*Rf	0.45

Table 2: Calculation of Stream order (u), stream number(Nu), bifurcation ratio(Rb) and weighted mean bifurcation ratio(Rbwm).

U	Nu	Rb	Nu-r	Rb*Nu-1	Rbwm
1	717				4.44
2	163	4.40	880.00	3870.92	
3	34	4.79	197.00	944.44	
4	9	3.78	43.00	162.44	
5	2	4.50	11.00	49.50	
6	1	2.00	3.00	6.00	
Total	926	3.89	1134.00	5033.31	

Table 3: Calculation of stream length (Lu), mean stream length(Lsm), stream length ratio(Lur), and weighted mean stream length ratio(Luwm) of Wadi El Assiuti

U	Nu	Lu	Lsm	Lur	Lur-r	Lur*Lur-1	Luwm
1	717	1582.19	2.21				2.33
2	163	885.97	5.44	2.46	2468.16	6079.46	
3	34	428.12	12.59	2.32	1314.09	3044.25	
4	9	273.57	30.40	2.41	701.69	1693.89	
5	2	126.52	63.26	2.08	400.09	832.65	
6	1	30.45	30.45	0.48	156.97	75.56	
Total	926	3326.82	24.06	1.95	5041	11725.81	

3. 2. Hydrological indices

SPI symbolizes the force of a flowing stream regarding erosion and shows possible erosion of streams. The SPI values are between 0 and 66.3. In the stream with the lowest order, SPI is minimum, and vice versa as illustrated in Fig. 4a. The STI has been used to explain the processes related to deposition and erosion. The STI values are from 0 and 12365.5. High values of STI are associated with increased susceptibility to sedimentation, erosion, and flooding. The STI is lowest in the first-order streams and increased as the stream order rose until it reached the highest level in the fifth order as indicated in Fig. 4b. The TRI has a big impact on water speed. The values of TRI are between 0.069 and 0.92. Wadi El Assiuti has positive values of TRI. This means the study area is a mountainous area with steep slopes as illustrated in Fig. 4c. The TWI values are between -6.46 and 13.38. The region with a high value of TWI is more likely to risks of flooding. The low values of TWI are dispersed over the whole region of the wadi, while the higher values of TWI are found at the wadi's outlet as shown in Fig. 4d. The TPI values of Wadi El Assiuti are from - 87.8 to 120, where the negative values refer to areas most vulnerable to flood risk Fig. 4e.

The NDVI values of Wadi El Assiuti are from -0.05 to 0.57. It has been noted that most of the wadi's region is water as shown in Fig. 4f. The precipitation: 12 precipitation stations are used, and the distribution values of rain on them are 0.0055- .0118. The amount of rain and the duration of its fall are the most significant causes of floods. By reviewing the precipitation map, we noticed that the rain that falls in the northeast of the wadi is the largest, and despite this, the water flow is directed towards the southwest, as it is the lowest elevation area as indicated in Fig. 4g.

The elevation of Wadi El Assiuti is from 53m to 874m. The highest elevation is noticed in the northeast of the wadi while the lowest elevation is noticed in the southwest. This elevation change explains the reason for the water flowing to the wadi's exit in the southwest as shown in Fig. 4h.

The slope is considered the primary element that controls the speed and direction of water flow, which in turn leads to the appearance of floods. The steeper the slope, the faster the water flows, and, vice versa. The slope in Wadi Al Assiuti ranges from 0° to 28.7° as shown in Fig. 4i. The drainage density (Dd) is an important factor for studying the topographic properties of the basin, where it affects the current and possible outflow from a basin. The Dd in Wadi El Assiuti ranges from 0 to 446. it is noticed that the higher Dd values appear in the Wadi outlet, and this helps to increase heavy rain and Water runoff as shown in Fig. 4j.

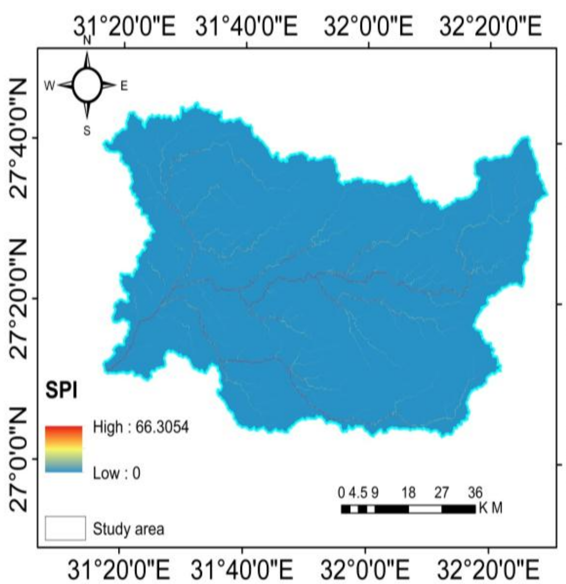

Fig. 4a

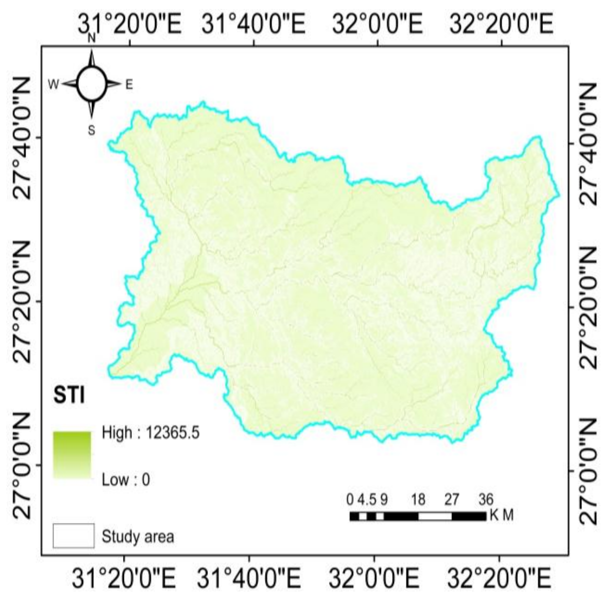

Fig. 4b

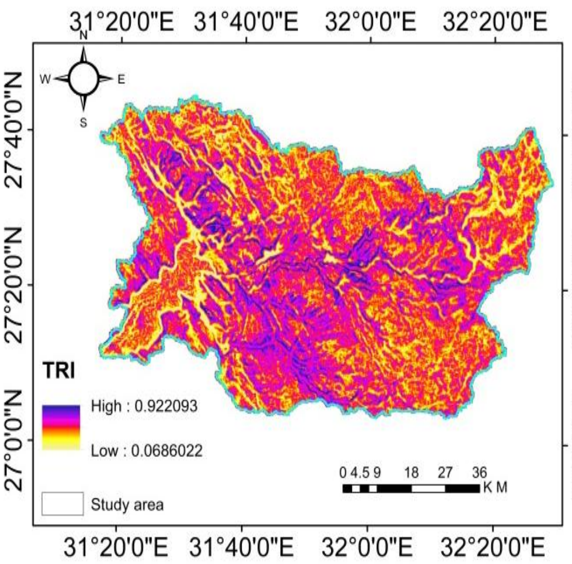

Fig. 4c

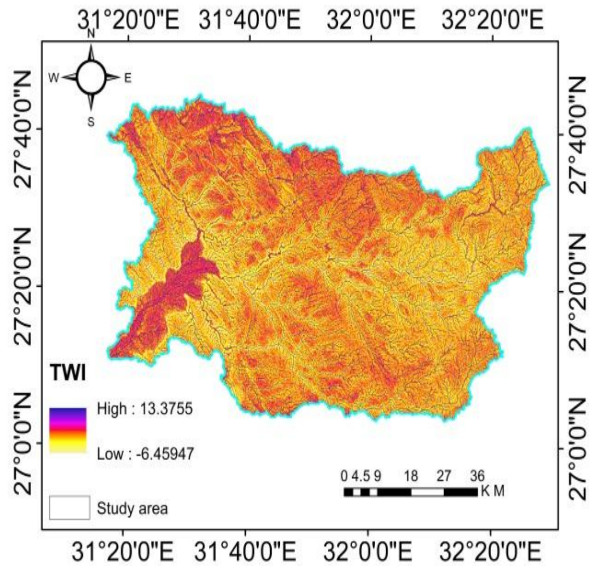

Fig. 4d

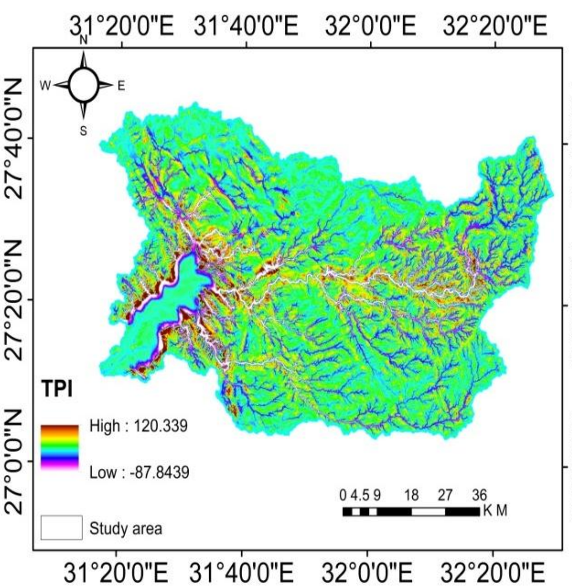

Fig. 4e

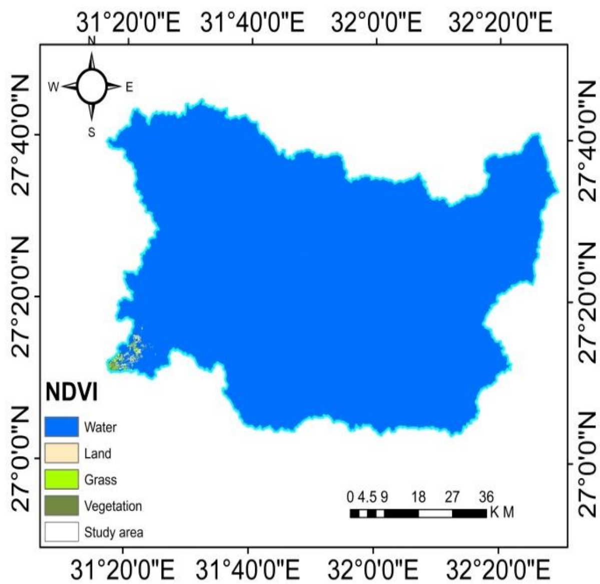

Fig. 4f

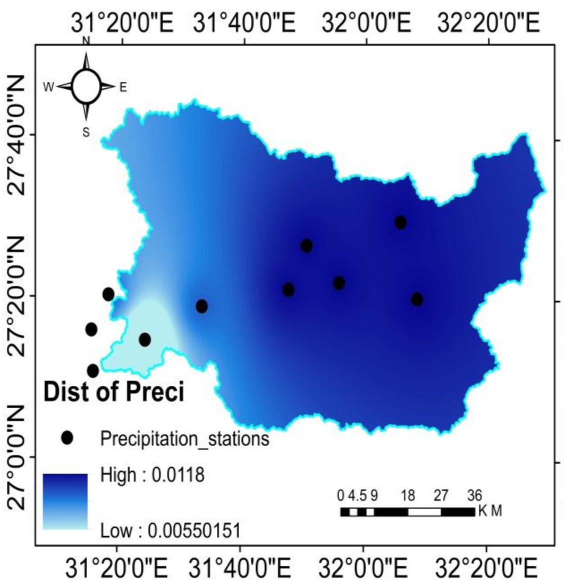

Fig. 4g

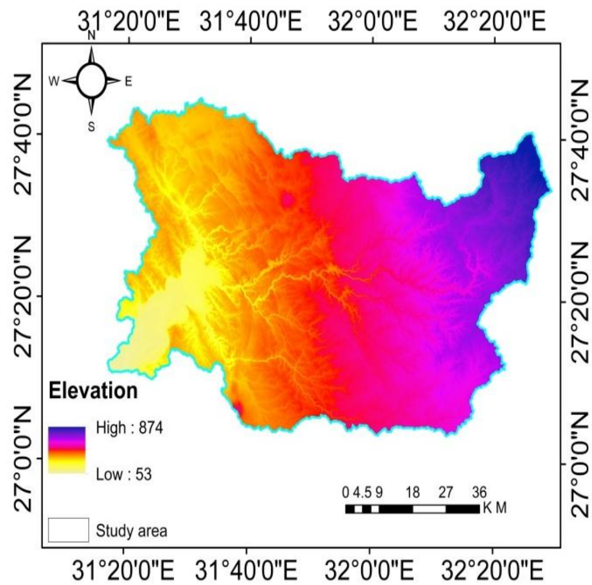

Fig. 4h

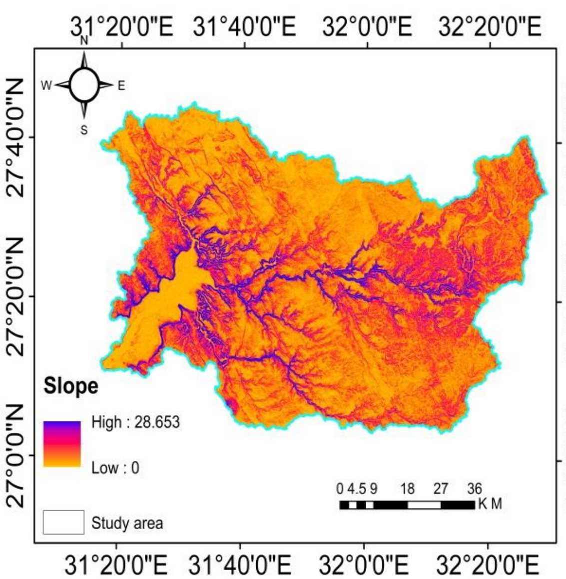

Fig. 4i

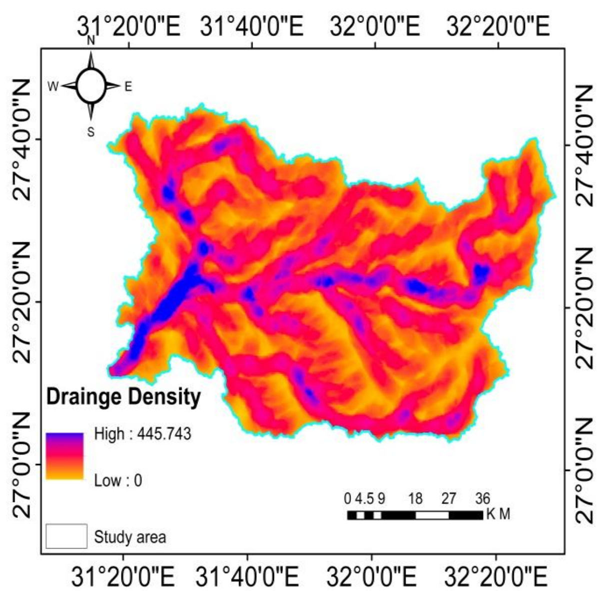

Fig. 4j

Fig 4. Maps of the spatial distribution of the hydrological indices

3.3 Analytical Hierarchy Process (AHP) and Map of Flood Risk

In this study area, we used (AHP) technique, where pairwise comparison matrix (10*10) matrix) is generated, the indicators are evaluated according to the comparative scale suggested by Saaty (1987). The λmax = 11.11, CI= 0.124, and finally CR = 0.083, the CR value is acceptable, because it is < 0.1 according to (T. L. Saaty, 1990). Five risk categories are assigned to each index: very low, low, moderate, high, and very high as shown in the Tables (4,5,6). In ArcGIS, the weighted overlay tool is utilized to create the final map of flash flooding risk. By reviewing the map, we noticed that the regions with high and very high degrees are situated in the middle and southwest portion of the research area, which is equivalent to approximately 45.55 % of the entire region of the wadi. While the regions with moderate degrees are 30.3 % of the entire area. Moreover areas with low and very low represent almost 24.15 % of the wadi (as shown in Fig. 5).

Table (4) matrix of pairwise comparison

Pairwise comparison matrix										
Hydrological index	SPI	STI	TRI	TWI	TPI	NDVI	P	ELEV	SL	Dd
SPI	1	9	2	3	2	4	1/4	1/5	1/4	1/2
STI	1/9	1	1/9	1/9	1/9	1/9	1/9	1/9	1/9	1/9
TRI	½	9	1	3	2	3	1/3	1/2	1/3	1/2
TWI	1/3	9	1/3	1	1	2	1/4	1/3	1/4	1/3
TPI	½	9	1/2	1	1	3	1/4	1/4	1/2	1/3
NDVI	¼	9	1/3	1/2	1/3	1	1/5	1/4	1/2	1/3
P	4	9	3	4	4	5	1	4	4	3
ELEV	5	9	2	3	4	4	¼	1	1	1
SL	4	9	3	4	2	2	¼	1	1	1
Dd	2	9	2	3	3	3	1/3	1	1	1
Sum	17.69	82	14.28	22.61	19.44	27.11	3.23	8.64	8.94	8.11

Table 5: Values of criteria weight

Hydrological index	SPI	STI	TRI	TWI	TPI	NDVI	P	ELEV	SL	Dd
SPI	0.0565	0.1098	0.1401	0.1327	0.1029	0.1475	0.0775	0.0231	0.0280	0.0616
STI	0.0063	0.0122	0.0078	0.0049	0.0057	0.0041	0.0344	0.0129	0.0124	0.0137
TRI	0.0283	0.1098	0.0700	0.1327	0.1029	0.1107	0.1033	0.0578	0.0373	0.0616
TWI	0.0188	0.1098	0.0233	0.0442	0.0514	0.0738	0.0775	0.0386	0.0280	0.0411
TPI	0.0283	0.1098	0.0350	0.0442	0.0514	0.1107	0.0775	0.0289	0.0559	0.0411
NDVI	0.0141	0.1098	0.0233	0.0221	0.0171	0.0369	0.0620	0.0289	0.0559	0.0411
P	0.2261	0.1098	0.2101	0.1769	0.2057	0.1844	0.3098	0.4627	0.4472	0.3699
ELEV	0.2826	0.1098	0.1401	0.1327	0.2057	0.1475	0.0775	0.1157	0.1118	0.1233
SL	0.2261	0.1098	0.2101	0.1769	0.1029	0.0738	0.0775	0.1157	0.1118	0.1233
Dd	0.1130	0.1098	0.1401	0.1327	0.1543	0.1107	0.1033	0.1157	0.1118	0.1233
Criteria weight	0.09	0.01	0.08	0.05	0.06	0.04	0.27	0.14	0.13	0.12

Table 6: Calculating the Weights of Hydrological indices

Flood causative criterion	Class	Susceptibility Class Ranges and Ratings	Susceptibility Class Ranges	Weights
SPI	0-1.82 1.83-7.28 7.29-17.7 17.8-35.1 35.2-66.3	Very Low Low Moderate High Very High	1 2 3 4 5	9
STI	0-291 292-1160 1170-2620 2630-5090 5100-12400	Very Low Low Moderate High Very High	1 2 3 4 5	1
TRI	0.0686-0.37 0.371-0.467 0.468-0.551 0.552-0.648 0.649-0.922	Very Low Low Moderate High Very High	1 2 3 4 5	8
TWI	(-6.46)-(-3.58) (-3.57)-(-1.95) (-1.94)-(0.386) 0.387-3.81 3.82-13.4	Very Low Low Moderate High Very High	1 2 3 4 5	5
TPI	(-87.8)-(-25.8) (-25.7)-(-7.02) (-7.01)-4.41 4.42-19.1 19.2-120	Very High High Moderate Low Very Low	5 4 3 2 1	6
NDVI	(-0.0505)-0.104 0.105-0.152 0.153-0.245 0.246-0.351 0.352-0.573	Very High High Moderate Low Very Low	5 4 3 2 1	4
P	0.0055-0.00676 0.00677-0.00802 0.00803-0.00928 0.00929-0.0105 0.0106-0.0118	Very Low Low Moderate High Very High	1 2 3 4 5	27
ELEV	53-231 232-369 370-491 492-626 627-874	Very High High Moderate Low Very Low	5 4 3 2 1	14
SL	0-1.91 1.92-4.16	Very High High	5 4	13

	4.17-7.64	Moderate	3	
	7.65-13	Low	2	
	13.1-28.7	Very Low	1	
Dd	0-89.1	Very Low	1	12
	89.2-178	Low	2	
	179-267	Moderate	3	
	268-357	High	4	
	358-446	Very High	5	

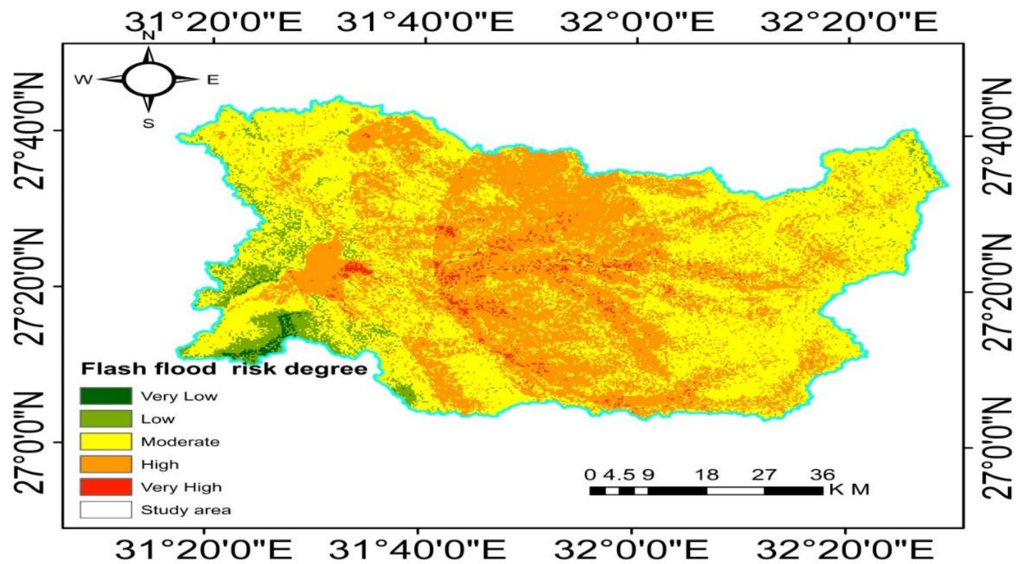

Fig. 5. Flash Flood Risk Map

4. Conclusion

The most frequent kind of natural disaster in the globe is flash flooding, causing huge damage to lives and possessions. A lot of procedures have been experienced all over the world to lessen flooding, particularly flash flooding. Mapping areas vulnerable to flood disasters is one of the most constructive methods that allows for controlling damage caused by flood risks. In our current study, thirty-six parameters are calculated and classified into four groups (drainage texture, drainage network, Relief characteristics, and basin geometry). ArcGIS software is used to compute ten indexes (SPI, STI, TRI, TWI, TPI, NDVI, P, ELEV, SL, and Dd). AHP technique is applied to determine the relative weight for each index, and a matrix of pairwise comparison is generated by using a 10 × 10 matrix. CR is calculated and it is acceptable. ArcGIS is used to generate a flash flood risk map. The created flash flood map indicates that the regions with high and very high degrees are situated in the middle and the southwest portion of the research area, which is equivalent to approximately 45.55 % of the entire region of the wadi, so to lessen future flash floods, several flood channels could be established in areas where floods are predicted to occur, flood dates could be predicted using contemporary weather monitoring equipment, or obstacles (dams) could be gathered at the outlets and key locations of the dangerous sub-basins. While the regions with moderate degrees are 30.3 % of the entire area. Moreover areas with low and very low represent almost 24.15 % of the wadi. The reliability of the AHP technique is good and would be proposed as a dependable method for assessing the risk of flood, especially for locations with inadequate information. Areas located near the wadi's outlet in the southwestern part are moderate, whereas areas located in the middle of the wadi are high and more vulnerable to flooding. This study is considered a guide that can be used by planners, and decision-makers on appropriate supervision of flood-prone areas, ensuring appropriate and sustainable social and economic development. Floods are useful in replenishing groundwater supplies. Although this process occurs naturally in some areas, we advise government authorities to plan for storing excess flood water to help refill natural reservoirs underground or to create artificial flood catchments and connect them to the nearest natural water body such as the Nile River or main canals so that they can be used during dry periods.

Recommendations

•The various mitigation systems have the advantages of reducing flash flood water velocity, increasing the time before the flood peak reaches lower parts of the drainage system, allowing for increased influent seepage along the wadi floor, reducing sediment erosion, and assisting in the conservation of runoff water.

•Establishing several flood channels in some places where floods are expected to pass

• identifying the locations of floods and avoiding the establishment of any infrastructure in their path

•Using modern weather monitoring devices that play a role in predicting flood dates

•Preparation by the competent authorities and taking all possible measures

•A collection of impediments (dams) at the outlets and strategic places of the hazardous sub-basins may be erected to reduce future flooding.

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