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Assessment of Flood Hazard West of Sohag Governorate, Egypt

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Abstract: Although Egypt has limited rainfall events, flashfloods are responsible for huge losses of lives and infrastructure. In this study, the geomorphometric parameters of the hydrographic basins in the area west of Sohag city, Upper Egypt was carried out. Stream orders, lengths and numbers, bifurcation ratio, drainage frequency and density, circularity and elongation ratios for 16 drainage basins in the study area are quantified to develop a system for flood hazard assessment and mitigation using ESRI's ArcGIS 10.1. The similarities in the calculated bifurcation ratios of the studied basins indicate that the genetic conditions of the stream orders are the same for each basin. Drainage densities show that these basins were developed under almost the same climatological and hydrogeological conditions. Most of the basins (62%) showed moderate hazard possibility, 25% exhibit low hazard possibilities and wadis El-Kawamil Bahri and El-Shaykh El-Aqra exposed high hazard possibilities. Due to the establishment of new urban areas, industrial zones, land reclamation and different types of projects in the study area, it is recommended to build small dams on appropriate locations for areas with high-moderate hazard probability to protect it and restore the excess water derived from any runoff and could be used for cultivation.

Keywords: Geomorphometric parameters – Flashfloods – Hazard Potential – Bifurcation ratios – Sohag, Egypt.

1 Introduction

Characterizing and recognition the locations where hazardous processes are going to occur and their natural or human-induced return period (i.e., time between events) is of particular importance. [1] As a result, outlining the natural and human-induced hazards is environmental planning to avoid those locations where the hazards are most likely to occur and to zone the land appropriately. Also, carefully considering the important links between geologic processes, the environment, and society is required. The low desert zone in the study area (latitudes 26° 22' 00" and 26° 29' 30" N and longitudes 31° 31' 00" and 31° 41' 30" E) ((Figure 1) that surround Sohag governorate, acquire major development projects. These projects include; Sohag new city, the air port, the new exension of Sohag University, the West Gerga industrial zone, land reclamation of serveral hunderd of feddan and the deser roads connecting Sohag to Assiut and Aswan. Therefore, analyzing and assessment of the natural hazards and recommending the means of protection in the area are of great importance. Unfortunately, these changes in the landuse and the establishment of forementioned projects have been carried out without proper consideration of the geo-natural hazards in the area. [2] Thereto, the potential geo-environmental hazards that can occur in the area include flash floods; sand dune movement and drifting; swelling and shrinkage of clay deposits; karastification due to carbonate rocks dissolution; land subsidence and discharge of wastewater in open pits near urbanization. In this study, flash flood hazard assessment in the area and their impacts will be investigated.

Several factors has been found to affect flooding and vulnerability to public, these including changes in landuse, urbanization and squatter settlements and sub-standard constructions, and increased household density. [3] Flood hazards are controlled by different factors that include topography, geomorphology, drainage, engineering structures, and climate. Saleh stated the following factors that influence flood potentiality: rainfall and its characteristics, water loss (evaporation and infiltration), drainage basins, drainage networks, drainage orders, drainage characteristics, and environmental and human processes. [4] The average topographic elevation of the low desert zone in the study area ranging from 78-105 m above sea level. The old cultivated land about 68 m above sea level, surrounded from east and west by the limestone plateau with average elevation of 250 m. As a result a general slope from west to east. The plateau is intersected

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by many wadis that have a general east-west slope that suffered from flash floods, especially in the recent years due to the development activities. Wadi El-Kawamel is the main wadi that located in front of the University (Figures 2, 4). The low level areas will be the most vulnerable zones for the flash floods.

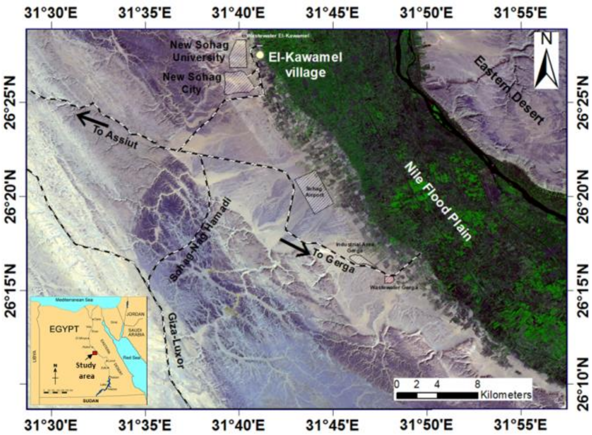

Fig.1: Location map of the study area.

The present study aims to create quantitative analysis of the drainage basins to develop a system for flood hazard assessment and mitigation and future development, utilizing the most up-to-date available data sets.

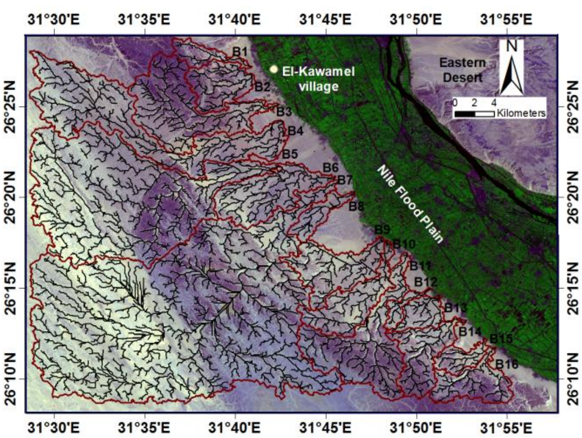

Fig.2: Shows the drainage basin and main drainage lines in the area west of Sohag.

2 Geology

Quaternary sediments are known to be the main water bearing formation of the Nile Valley aquifer. The general geology of Sohag area is reviewed form the pervious publication (Figure 3). [5], [6], [7] The sedimentary succession in the area is represented by sediments of the Lower Eocene to the recent deposits. Lower Eocene limestone represented by Thebes Formation. [5] It composed of massive to laminated limestone with flint nodules and marl rich with Nummulites sp. and planktonic foraminifera. In the Early Pliocene, the sea invaded the valley and formed a long estuary from Cairo to Aswan resulted in the deposition of a thick succession of estuarine and fluviatile dominated sediments that composed mainly of clay and muddy sands called the Muneiha Formation. [6], [8] During the Early Pleistocene, the river system was mostly running in east - west directions, deriving its water from within Egypt and also from the Red Sea hills in Suddan. [7] The sedimentary rocks which still covered the basement complex of the central and southern Eastern Desert were the main sources of the sediments deposited during this stage. These sediments were mostly from the Nubia sandstone widely distributed in the Eastern Desert of Egypt. The sediment was first named by Said as the Qena Formation and is composed mainly of quartzitic sand and gravel deposited under sedimentological conditions characterized by braided and low to moderate sinuosity streams. [9] The deposits of the Qena Formation are lacking in basement fragments and are rich in heavy minerals of the metamorphic terrain of the Sudanese Red Sea hills. [6] The Qena Formation plays an important role in the hydrogeological conditions and represents the main water bearing formation in this region of the Nile Valley aquifer. At the top of Qena Formation, there is a section of sands and gravels derived from igneous and metamorphic rocks. These sediments show both alluvial and fluviatilefacies and are known as the Kom Ombo Formation. [10] In the Sohag area, the Kom Ombo Formation is represented by very coarse cross-bedded sands together with gravel intercalation. [7] During the Middle Pleistocene, the Eastern Desert continued to supply sediments through its active wadis. At the same time, Ethiopian water reached Egypt for the first time and a mixture of Egyptian and Ethiopian sediments was deposited giving rise to a sedimentary succession called the Ghawanim Formation. [6] It consists of cross-bedded fluviatile sand and gravels together with interbedded bands and lenses of conglomerate and quartzitic sandstone. The great supply of Ethiopian water coupled with the dry phase over Egypt during the Late Middle Pleistocene resulted in an exotic suspended load river, carrying sediments from Ethiopia and later from equatorial Africa. The product of this phase in the Nile Valley is called the Dandara Formation and its lithological characteristics are made of poorly sorted coarse, medium, fine to very fine sands. Recent wadi deposits are found on the surface of the older sediments throughout the desert areas outside the cultivated land. [6]

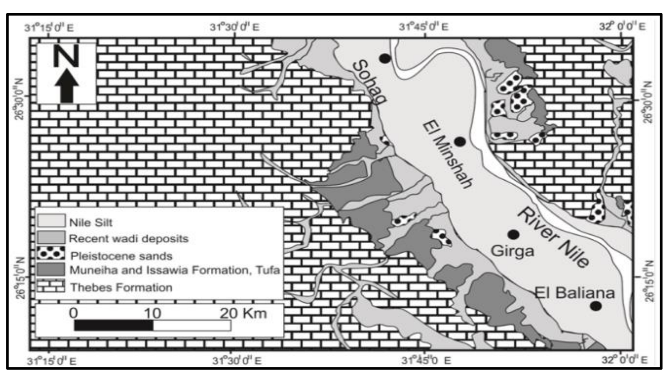

Fig. 3: Geological map of the study area.

3 Methodologies

In the present study, the watersheds are delineated for each basin for quantitative geomorphometric analysis. The area consists of 16 basins (Figure 2). The drainage basins, drainage networks, and their geomorphometric parameters in the study area were analyzed from the topographic maps (scale 1:50000), where all the elements have been digitized, coded, measured, and extracted using ArcGIS 10.1. These elements were verified using Landsat TM image 30 m resolutions. Basin area and length, stream order and stream number, bifurcation ratio, drainage frequency, density, stream length and relief ratio.

3.1 Basin area

Basin area is determined by the areas outlined by the watershed. The basin area affects stream numbers, lengths, and the water collected and runoff in the wadis. [11] In the present work, ArcGIS 10.1 is used to estimate the total surface area of each basin (Table 1).

3.2 Basin length

Basin length could be measured using different methods. Ref. Smart et al. defined the basin length as the length of line from the downstream to the highest point on the basin perimeters, where Gardiner stated that the basin length is longest on the basin or the length of the longest line laying between the basin perimeters ending at the downstream. [12] [13] He also defined the basin length as the length of line bisecting the basin perimeter and starting from the downstream. Maxwell defined the basin length as the length of line passing through the main stream and ending at the downstream. [14] In the present work, the definition of the basin length of Maxwell is applied in measurement. The measured basin lengths for the selected basins are shown in (Table 1).

3.3 Basin width

The basin width (W_b) is calculated as the basin area divided bybasin length using ArcGIS 10.1.

$$W_b = \frac{A_b}{L_b}$$

Where,

A_b is the basin area

L_b is the basin length

Table (1) shows the basin widths of the selected wadis in the study area.

3.4 Basin perimeter

The perimeter represents the water divide between basins. The variations in basin perimeters are controlled by the basin area, length and width. [15] Table (1) shows basin perimeter of some the basins.

Table 1: Area (km^2), perimeter (km), length (km), and width (km) of the studied drainage basins.

Basin	Basin name	Area (km^2)	Perimeter (km)	Length (km)	Width (km)
B1	W. N. Kawamel Bahari	10.04	22.71	7.57	1.33
B2	W. El-Kawamil Bahari	23.14	25.85	6.54	3.54
B3	W. El-Kawamil Qibbli	60.41	58.66	19.11	3.16
B4	W. Tag El-Waber	92.56	93.44	29.62	3.13
B5	W. El-Yataiyim	185.39	96.95	34.50	5.37
B6	W. Al-Aqaba El Sughra	38.38	40.93	13.40	2.86
B7	W. El-Rashayda	391.68	155.53	42.48	9.22
B8	W. El-Raqaqna	11.07	22.57	7.70	1.44
B9	W. Bayt Khalaf	34.41	42.86	12.00	2.87
B10	W. Bayt Dawod	29.80	43.90	15.10	1.97
B11	W. El-Dukhan	57.82	64.95	17.50	3.30
B12	W. El-Mahasnah	5.39	17.76	5.44	0.99
B13	W. El-Shaykh El-Aqra	11.64	19.92	7.10	1.64
B14	W. Hanafi	27.35	34.99	10.47	2.61
B15	anonymous	9.82	20.16	6.00	1.64
B16	W. El-Gir El Gharbi	23.57	33.72	8.33	2.83

3.5 Stream order

Stream order is a numbering system for the surface drainage segments which can assist in the identification of hydrograph. In the present study, ranking of streams has been carried out based on the method proposed by ref.[15], [16]. Strahler presented a system of stream orders in which unbranched fingertip tributaries (smallest conduit) are order 1 (first order). [15] When two first order conduits join, a conduit of order 2 is formed. Two conduit of the same order must join to increase the order of the new conduit. The main stream has the highest order number. The drainage area of a watershed or stream order will be that area contributing surface flow to the drainage conduit. The stream orders determined vary from one basin to another with max. six orders (Figure 4).

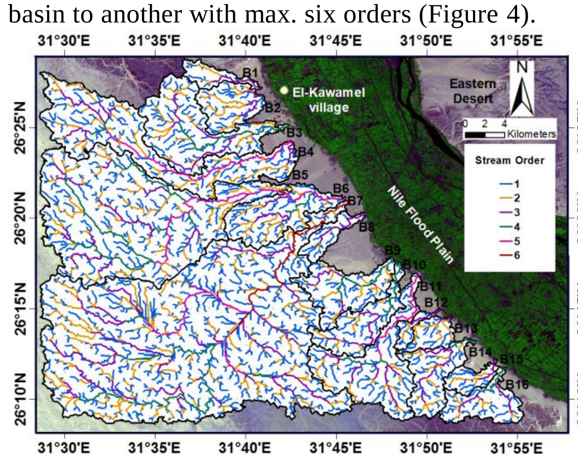

Fig.4: Shows the drainage basins and stream ordering in each basin in the area west of Sohag.

3.6 Stream number

Ahmed mentions that the stream numbers for individual orders are counted for the considered basin. [11] The total stream numbers of all orders are found to be ranged few for small basins to thousands for large basins. Table (2) shows the stream order lengths and the stream order numbers of the selected wadis in the study area. Horton indicated that, in natural conditions, a strong relation exists between stream order and numbers unless basins are affected by geologic factors. [17] The relationship between stream order and numbers is shown in Fig. (5) for the different basins in the study area. The figure reveals that there is a strong relationship between the two factors for most of the studied basins. Wadi El-Kawamil Bahari shows a slight departure from such relation, indicating that this wadi is most likely affected by geological structures.

3.7 Stream lengths

Stream length is measured from mouth of a river to drainage divide with the help of ArcGIS 10.1. These measurements showed that the stream length of a given order is greater than that of the next lower order and less than that of the next higher order. Table (2) shows the stream order lengths of the selected wadis in the study area.

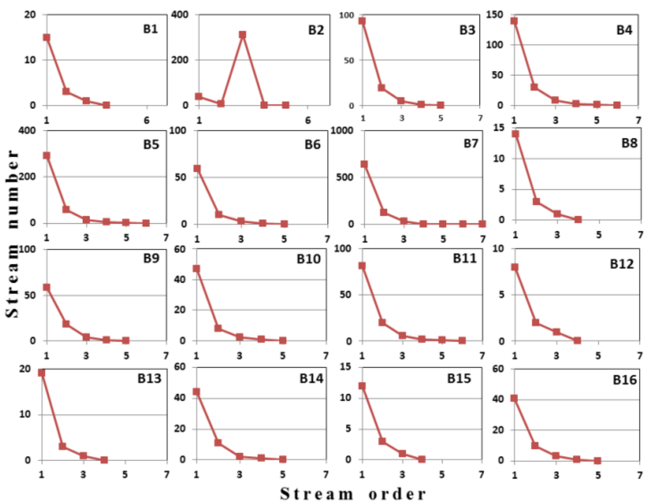

Fig.4: Plotting of stream numbers against stream order for each basin in the area west of Sohag.

3.8 Bifurcation ratio (Rb)

According to Schumm, the term bifurcation ratio is defined as the ratio of the number of the stream segments of given order (N_u) to the number of segments of the next higher orders (N_{u+1}). [17] Bifurcation ratio is expressed by the following formula: [15]

$$R_b = \sum_{u=1}^{n} \frac{N_u}{N_{u+1}}$$

Where,

N_u is the number of streams of a given order

N_{u+1} is the number of streams of a higher next order

The bifurcation ratios for the studied basins are shown in (Table 3). The small values of the bifurcation ratios indicate that the difference between stream numbers from one order to another is not large. The similar values of the calculated bifurcation ratios indicate that the genetic and evolution conditions of the stream orders are the same for each basin.

Bifurcation ratio characteristically ranges between 3.0 and 5.0 for basins in which the geologic structures do not distort the drainage pattern and with more than 10 where structural controls play dominant role with elongate narrow basins. [16], [19] As shown in the table the bifurcation ratio is ranging between 3.00 and 4.67. W. El-Shaykh El-Aqra shows the highest bifurcation ratios while Wadi W. El-Mahasnah shows the lowest bifurcation ratios values.

3.9 Drainage frequency (Df)

This defined as the number of stream segments per basin area and calculated from the following relation: [17]

$$D_f = \frac{N_u}{A_b}$$

Where,

N_u is the total number of streams of all orders in a certain basin

A_b is the basin area

The small values of drainage frequencies are attributed to the small area of these basins, whereas the relatively higher values are attributed to large basin areas. High value of drainage frequency increases the possibilities of runoff. As shown in the (Table 3) the drainage frequencies are ranging between 1.63 and 2.33. W. El-Gir El Gharbi is considered as the highest drainage frequency while W. El-Raqaqna shows the lowest drainage frequency values.

Table 2: Stream number (N) and stream length in km (L) for the studied drainage basins.

Stream Order		B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	B15	B16
1	N	15	38	93	140	291	59	640	14	58	47	81	8	19	44	12	41
	L	4.7	19.8	47.6	72.7	140.7	35.50	324.6	10.0	27.7	23.4	45.9	4.2	12.0	20.8	10.4	17.3
2	N	3	7	19	30	57	10	123	3	18	8	20	2	3	11	3	10
	L	4.47	15. 6	22.8	41. 9	67.9	16.52	157.6	1.7	14.7	8.4	16.0	2.3	8.8	12.8	5.1	6.9
3	N	1	312	5	8	15	3	31	1	4	2	6	1	1	2	1	3
	L	5.6	5.9	14.8	16.6	30.8	10.60	89.8	5.9	6.6	9.9	11.7	3.62	1.4	10.5	3.1	6.8
4	N		1	1	2	5	1	4		1	1	2			1		1
	L		0.82	12.7	2.71	32.6	7.71	36.6		8.9	7.3	5.2			2. 9		4.6
5	N				1	1		3				1					
	L				20.52	18.4		18.2				10.9					
6	N							1									
	L							20.4									
Total N		19	358	118	181	369	73	802	18	81	58	110	11	23	58	16	55
Total L		14.8	42.1	98.0	154.3	290.4	70.3	647.1	17.6	57.8	49.0	89.6	10.1	22.2	46.9	18.5	35.6

3.10 Drainage density (Dd)

Drainage density is defined as the total length ofstreams of all orders per drainage area. Density factors related to climate, rock types, relief, infiltration capacity, vegetation cover, surface roughness and run-off intensity index. Of these, surface roughness has no significant correlation with drainage density. The drainage density indicates the closeness of spacing of channels. [20] Amount and type of precipitation influencesdirectly to the quantity and characters of surface runoff. Areas with high precipitation lose greater percentage of rainfall in runoff and resulting in more surface drainage lines. Amount of vegetation and rainfall absorption capacity of soils that influences surface runoff rate affects the drainage texture of an area. Semi-arid regions have finer drainage density texture than humid regions. Low drainage density results in areas of highly resistant or permeable sub-soil material, dense vegetation and low relief. High drainage density is the result of weak or impermeable sub-surface material, sparse vegetation and mountainous relief. Low density leads to course drainage texture while high drainage density leads to fine drainage texture. Drainage density is expressed by the length of streams per basin area, and calculated from the following relation: [20]

$$D_d = \frac{L_u}{A_b}$$

Where;

$L_u$is the total length of all stream orders

$A_{b,}$ is the basin area

Areas of high drainage density are associated with large flood flows and low proportion of groundwater contribution with increasing drainage density, the path length of overland flow decreases, consequently the velocity of runoff increase. [21] As shown in the (Table 3) the drainage density is ranging between 1.47 and 1.91. W. El-Shaykh El-Aqrais consider as the highest drainage density while W. N. Kawamel Bahari shows the lowest drainage density values. The low drainage density values for most of the wadis is attributed to the fact that a large parts if these wadis are located in the downstream of the basins (at Nile fringes) where the relief is low and the density of plant cover is very low in their catchment area. It is important to mention that the downstream part of the basins is covered by sands and gravels and plays an important role in recharging the quaternary shallow groundwater aquifer (in case of rainstorms) which found in the area.

3.11 Circularity ratio (Rc)

Basin shape is largely controlled by the length and frequency of streams, geological structures, land use/land cover, climate, relief and slope of the basin. Ref. [22] defined the basin circularity ratio as the ratio of the basin area to the area of a circle with the same perimeter as the basin. He described the basin of the circularity ratios range 0.4 to 0.5 which indicates strongly elongated and highly permeable homogenous geologic materials. Values greater than 0.5 are suggesting that they are more or less circular in shape and are characterized by the high to moderate relief and the drainage system were structurally controlled. Circularity ratio (R_c) can be expressed as follows: [23]

$$R_c = \frac{4\pi A}{P^2}$$

Where,

A = Area of the basin (km^2)

P = perimeter of basin

The values of circularity ratio of the studied basins are ranging from 0.13 to 0.44 (Table 3).

3.12 Elongation ratio (Re)

Ref. [18] defined elongation ratio (R_e) as the ratio of diameter of a circle of the same area of the basin to the maximum basin length. This ratio gives an idea about the hydrological character of a drainage basin. Values of elongation ratio ranging between 0 and 0.6 indicate rotundity and low degree of integration within a basin and values between 0.6 and 1.0 assumes pear shaped characteristics of a well-integrated drainage basin. [16] Elongation ratios greater than 1.0 indicating lower relief, whereas values lower than 0.80 indicating high relief and steep slope. [23] Elongation ratio (R_e) can be expressed as follows: [18]

$$R_e = 2(A/\pi)^{0.5}/L_b$$

Where,

A = Area of the basin (km^2)

L_b= Basin length

The values of circularity ratio values of the studied basins vary from 0.37 to 0.83 (Table 3). W. El-Kawamil Bahari consider as the highest elongation ratio while W. Tag El-Waber shows the lowest elongation ratio.

Table 3: Bifurcation ration (R_b), drainage frequency (F_d), drainage density (D_d), Circularity ratio (R_c) and the Elongation ratio (R_e) of the studied drainage basins.

Basin	Bifuraction ratio (R_b)	Drainage frequency (F_d)	Drainage density (D_d)	Circularity ratio (R_c)	Elongation ratio (R_e)
B1	4.00	1.89	1.47	0.24	0.47
B2	3.59	2.12	1.82	0.44	0.83
B3	4.56	1.95	1.62	0.22	0.46
B4	3.60	1.96	1.67	0.13	0.37
B5	4.23	1.99	1.57	0.25	0.45
B6	4.08	1.90	1.83	0.29	0.52
B7	4.25	2.05	1.65	0.20	0.53
B8	3.83	1.63	1.59	0.27	0.49
B9	3.86	2.32	1.68	0.24	0.55
B10	3.96	1.95	1.64	0.19	0.41
B11	3.10	1.90	1.55	0.17	0.49
B12	3.00	2.04	1.87	0.21	0.48
B13	4.67	1.98	1.91	0.37	0.54
B14	3.83	2.12	1.72	0.28	0.56

B15	3.50	1.63	1.88	0.30	0.59
B16	3.48	2.33	1.51	0.26	0.66

4 Flood predictions

Flood prediction is an attempt to determine whether a flood of a particular magnitude will occur during a specified future time span. In this study some of the morphometric parameters were used in flood prediction and to evaluate the hazard probability of the different basins. These parameters include bifurcation ratio, drainage density, drainage frequency, and circulation and elongation ratios. Each parameter is classified into three classes based on the morphometric characteristics and in relations to their potential degree of risk. The equation used is (Max–Min)/3. The values for each parameter are classified into three intervals. For example, basins of high frequency and high density values tend to collect more runoff water, which increases the rate of flow discharge out of basin, resulting in a high risk value and then the higher the parameter value the higher is the rank. In such basins, the rate of downward infiltration is expected to be low in basins of high frequency and high density values, and subsequent high flow discharge out of basin, resulting in a high risk value. Low basin bifurcation ratio (the higher the parameter value the lower is the risk) will reflect a high flooding risk. Basins with higher circularity and elongation ratios (R_c and R_e) tend to have higher flash flood potentiality. Based upon these numbers, we can categorize basins according to their risk of occurrence of flash floods. The raw score for each feature was normalized using (equation 1). The normalized scores are ranged from (0 to 1) used in equation 2 to calculate the value of total flood hazard. Based upon the relationship between the parameter values and the risk of flash flood, the analysis of each parameter was calculated using a simple statistical method. [24] The raw score for each feature was normalized using (equation 1). The normalized scores are ranged from (0 to 1) used in equation 2 to calculate the value of total flood hazard.

$$X_j = (R_j - R_{min}) / (R_{max} - R_{min}) \quad (1)$$

Where,
X_j: is the normalized score R_j: is raw score
R_{min}: is the minimum score R_{max}: is the maximum score

$$\textit{Flooding hazard} = \textit{Normalized bifurcation Ratio } (R_b) + \textit{Normalized Frequency } (D_F) + \textit{Normalized Density } (D_d) + \textit{Normalized Circularity } (R_c) + \textit{Normalized Elongation } (R_e) \quad (2)$$

5 Flood hazard Mapping

Flood hazard mapping is used to determine the areas susceptible to flooding when discharge of a stream exceeds the bank-full stage. A reliable model of the flood hazard assessment in the area is critical to understand what the consequences of any future floods in the area and to isolate areas with high hazard probability. As a result, the distribution of the valleys, and most hazard basins in the area were distinguished. Flash flood prone wadis can be assessed and delineated through the use of ArcGIS 10.1. As a part of the research project, this methodology was used to determine the hazard of flash floods in each basin in Sohag area. For the analysis and development of hazard map, the author used the drainage basin maps with the data extracted from Tables (1, 2, 3 and 4). The attribute table for the drainage basins was added to the ArcGIS 10.1 database in building the drainage basin hazard map and is classified into high, moderate, and low hazard basins (Figure 6).

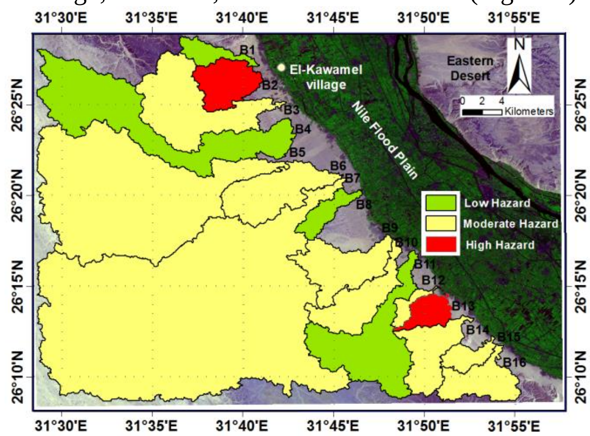

Fig.6: Flood hazard risk map based on morphometric parameter for the drainage basins in the study area.

6 Conclusion and recommendations

One of the most interesting aims of morphometric analysis is to derive information in quantitative forms about the geometry of the fluvial system that can be correlated with hydrologic information. The results of the evaluation of the morphometric characteristics of the 16 hydrographic basins in the areas west of Sohag city could lead to the following conclusions:

1-The strong relation between stream orders and numbers of the studied basins indicates the non-structure control of all the basins except Wadi El-Kawamel Bahari, where the relation indicates that this basin is affected by geologic structures.

2-The similarities in the calculated bifurcation ratios of the studied basins indicate that the genetic conditions of the stream orders are the same for each basin.

3-The relatively same range of drainage densities indicates that these basins were developed under almost the same climatological and hydrogeological conditions.

4-Flood hazard assessment of the area showed that most of the basins exhibit moderate hazard except wadis W. N. Kawamel Bahari, W. Tag El-Waber, W. El-Raqaqna, and W. El-Dukhan, exhibit low hazard possibility and W. El-Kawamil Bahri and W. El-Shaykh El-Aqra showed high hazard possibility.

To avoid the area from the overland flow hazards, it is recommended:

1-Small dams or barrage could be constructed on appropriate locations to restore the excess water derived from any runoff and could be used for cultivation (W. El-Kawamel Bahari, W. El-Shaykh El-Aqra, W. El-Kawamil Qibbli, W. El-Yataiyim, W. Al-Aqaba El Sughra, W. El-Rashayda, W. Bayt Khalaf, W. Bayt Dawod, W. El-Mahasnah, W. Hanafi and W. El-Gir El Gharbi.

2-A lined large channel could be excavated as a source of water at specific locations upstream.

3-Construction of new settlement on the slopes of these wadis should be prohibited.

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