

## MAPPING FLOOD HAZARDS BY MULTI-CRITERIA DECISION ANALYSIS TECHNIQUE IN GEOGRAPHIC INFORMATION SYSTEM (GIS-MCDA)

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### ABSTRACT

In terms of the importance of constructing new mega-urban zones to achieve future sustainable urban development for Egypt's Vision 2030, this research was initiated with the objective of protecting such zones by mapping flood hazards by “Multi-Criteria Decision Analysis” based on “Geographic Information System” (GIS-MCDA), where the Hegaza Village - Qena Governorate in Upper Egypt was taken as a study area. Accordingly, a research methodology was planned to encompass five investigations (Theoretical, field, numerical, analytical and inferential investigations). The hydrology of the study area was modeled by blending GIS Model-Builder and the hydrological model (HEC-1). A flood hazard map (F.H.M) was produced based on (GIS-MCDA), in terms of the Analytic Hierarchy Process (AHP). The research flagged out that the obtained results would most probably assist decision-makers. In addition, the research highlighted the importance of implementing flood hazards management activities to ensure the environmental rehabilitation of watersheds to avoid flood disasters.

**KEYWORDS:** GIS, Model Builder, MCDA, AHP, F.H.M

### رسم خرائط مخاطر الفيضانات من خلال تقنية تحليل القرار متعدد المعايير في نظم المعلومات الجغرافية

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### المخلص

من حيث أهمية إنشاء مناطق حضرية عملاقة جديدة لتحقيق التنمية الحضرية المستدامة المستقبلية لرؤية مصر 2030، بدأ هذا البحث بهدف حماية هذه المناطق من خلال رسم خرائط لمخاطر الفيضانات باستخدام تقنية تحليل القرار متعدد المعايير القائمة على نظم المعلومات الجغرافية GIS-MCDA، حيث اتخذت قرية حجازة في صعيد مصر كمنطقة دراسة. وفقاً لذلك، تم التخطيط لمنهجية البحث لتشمل خمسة تحقيقات (التحقيقات النظرية والميدانية والعديدية والتحليلية والاستنتاجية). تم نمذجة الهيدرولوجيا في منطقة الدراسة من خلال مزج بناء نموذج بنظم المعلومات الجغرافية مع النموذج الهيدرولوجي HEC-1. تم إنتاج خريطة (مخاطر الفيضانات F.H.M) بناءً على (GIS-MCDA) التي تعتمد على عملية التحليل الهرمي (AHP). أشار البحث إلى أن النتائج التي تم الحصول عليها ستساعد على الأرجح صانعي القرار في الدولة لاتخاذ التدابير اللازمة لضمان إعادة التأهيل البيئي لمستجمعات المياه لتجنب كوارث الفيضانات.

الكلمات المفتاحية: نظم المعلومات الجغرافية، باني النموذج، تحليل القرار متعدد المعايير، عملية التحليل الهرمي، خريطة مخاطر الفيضانات.

## 1. INTRODUCTION

Flood hazard impacts are worldwide documented. However, their management is significantly important to avoid such impacts. In addition, many flood disasters were historically documented, where 2.3 billion were affected during 1995-2017. Moreover, financial losses reached 662 billion dollars (Wahlstrom and Guha-Sapir, 2015) [1]. Accordingly, flood hazards should be reduced (Billa, et al, 2006) [2] and flood-risk maps should be produced (Bubeck, et al, 2012) [3]. Accordingly, this research was initiated with the objective of protecting urban zones by mapping their exposure to flood hazard. During the theoretical investigation, literature in the field of GIS so as MCDA was assembled and scrutinized, from which it was clear that many researchers are involved in the field of flood hazards. Among these researchers was (Yang, et al, 2018) [4], who documented that hydrological so as hydraulic modeling programs emerged simultaneously with the emergence of GIS so as satellite-remote-sensing-imagery together with Digital Elevations Model (DEM). In addition, (EU IPA 2010 TWINNING PROJECT, 2010) [5] stated that mapping hazardous zones are essential for flood hazards management, flood-protection and land-use-planning. Moreover, The Committee on Floodplain Mapping Technologies (2007) [6] favored GIS in mapping flood risk due to its preeminence in analysis and manipulating enormous spatial data. However, Gericke and Plessis (2012) [7] compared watershed characteristics by ArcGIS to the manual calculations, where they assured that the obtained results of ArcGIS are superior as they consume, almost, no time. Furthermore, Kourgialas and Karatzas (2016) [8] assessed mapped flood risk in Crete using rainfall and topography data. Likewise, Al-Abadi et al. (2016) [9] implemented topographic data to evaluate flood risk in the south of Iraq watershed. Nevertheless, De Brito and Evers (2016) [10] implemented AHP in assessing flood risk, as it is a multiple criteria assessment method that captures all factors together with their inter-relationships. Similarly, (Kazakis, et al, (2015) [11]; Khosravi, et al (2016) [12]; Khaleghi and Mahmoodi, (2017) [13]; Rimba, et al, (2017) [14]; Patrikaki, et al (2018) [15]; Ahmed H. (2021) [16]) implemented MCDA, as it calculates the weight of each criterion by AHP. However, (Ghabayen and Salha (2013) [17]; Omran et al. (2011) [18]; Magesh and Ch, N. (2012) [19]; Elmoustafa et al. (2015) [20]) implemented ArcGIS as it is applicable to long data analysis steps, where Model-Builder could automate such processes. Based on scrutinizing the assembled literature, this technique was selected to be applied in this research to innovate a suitable economic protection measure.

## 2. FIELD INVESTIGATION

All through the field investigation, site visits were carried out to the study area (Hegaza Village in Qus Center in Qena Governorate in Upper Egypt), where field data were assembled and field observations were carried out. Based on the site visits and assembled data, it was clear that its area is 30 million m<sup>2</sup> according to the administrative division of Egypt 2017. The village is surrounded by the eastern desert at the East, Kalalsa Village at the West, Al-Kalahin Village at the North and Khuzam Village at the South, figure (1). Based on 1: 50,000 topographic maps, it was obvious that Hegaza has 3 watersheds evolving from the Red Sea Mountains (Wadi Hegaza - Wadi Al Uqab - Wadi Al- Tameed). According to data obtained from the Information and Decision Support Center - Qena Governorate General Office, Hegaza is the 2nd Qena governorate village exposed to flood hazards during 1934-2017, where it was exposed 10 times to floods and its exposure to hazards (from surface runoff) is 22% of the number of exposures of Qena villages; table (1).

**Table 1:** The frequency of floods in the cities and villages of Qena Governorate from 1934 to 2017

Location	Nagaa Hammadi Center	Deshna center	Qena city	Karam Amran village	Kalahin Village, Qift	Hegaza village	The village of Khazam in Qous	Total
Number of floods	3	3	12	9	2	10	6	45
Relative importance %	6.7	6.7	26.7	20	4.4	22.2	13.3	100

### 3. NUMERICAL INVESTIGATION

In the numerical investigation, the maximum precipitation on the watersheds was determined. In addition, the streams and basins were demarcated using Model-Builder. Furthermore, a flood hazard map (F.H.M) was produced based on the multi-criteria decision analysis of the GIS (GIS-MCDA), in terms of the Analytic Hierarchy Process (AHP). This is presented, as follows:

#### 3.1 Maximum Precipitation

During the numerical investigation, the maximum precipitation on the watersheds was determined in order to calculate the accumulated floods, where 36 years (1979-2014) of global data was obtained from [globalweather.tamu.edu](http://globalweather.tamu.edu)[21]. A Weibull method in (Hyfran) program was used in the statistical distribution as shown in figure (2) and the precipitation depth was determined for different return periods; table (2).

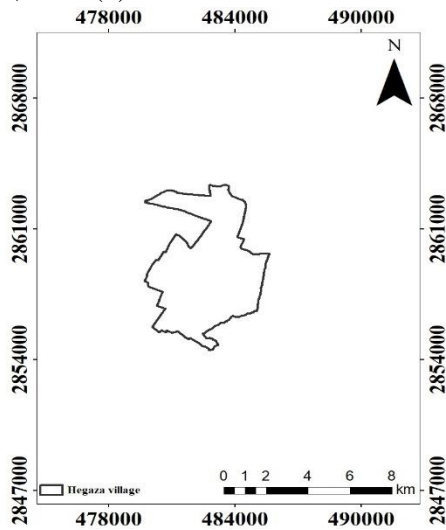


Fig. 1: Location of the study area (Hegaza Village)

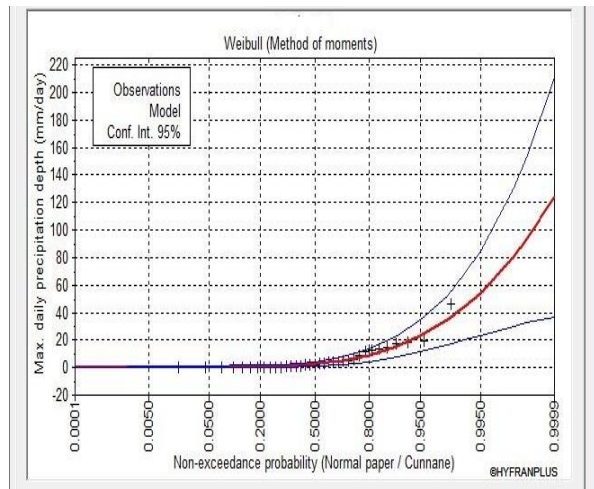


Fig. 2: Probability distribution curve for precipitation data using the Weibull method

Table 2: Precipitation depth by Weibull method for different return periods

Longitude	Latitude	Max.24 hr. precipitation depth (mm/day) for different return periods					
		5 years	10 years	20 years	25 years	50 years	100 years
32.5	25.134399	9.19	15.7	23.2	25.8	34.5	44.1

#### 3.2 Drainage Streams

Through the numerical investigation, the streams and basins were defined or demarcated using Model-Builder of the GIS, where Model-Builder is an application that creates and manages models; figure (3). It strings the geo-processing tools and feeds the output as an input of one tool to another. Model-Builder constructs and executes simple workflows. It provides methods to extend the functionality of ArcGIS. Model-Builder integrates ArcGIS with other applications, where DEMs (Digital Elevation Models), with an accuracy of 30 m, were implemented via [earthexplorer.usgs.gov](http://earthexplorer.usgs.gov)[22].

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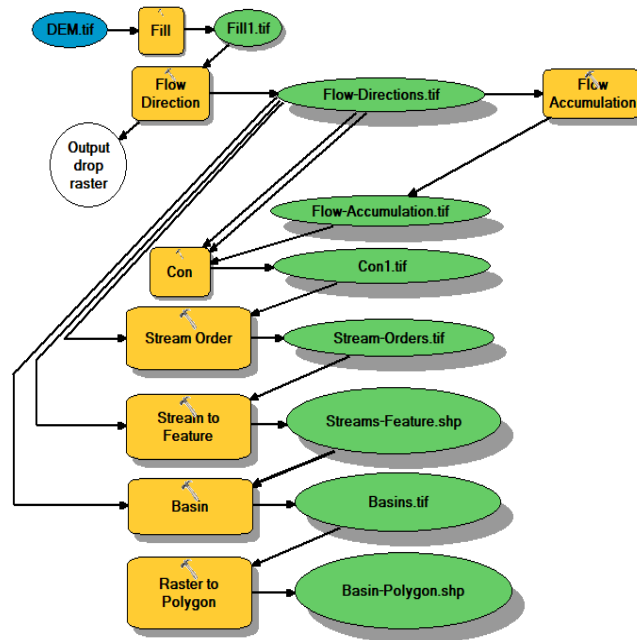


Fig. 3: Model-Builder in GIS

Internally, the implemented model goes through the following computational steps:

- It fills the sinks in a raster.
- It creates a flow raster from the cell to its neighbor.
- It creates an accumulated flow raster to the cell .
- It optionally performs an evaluation to the raster cells .
- It denotes segment order to represent linear network
- It creates a raster to delineate drainage basins.

The calibration of this model was done by entering the same study area and the same data used into the Watershed Modeling System program (WMS), showing that there is a clear match between them. From the simulation, it was apparent that the streams that affect Hegaza Village are classified into 5 classes, where 5, 4, 3, 2 and 1 indicate very high, high, medium, low and very low hazards, respectively. Table (3) lists the stream statistics of Hegaza Village. Figure (4) presents the watersheds that affect Hegaza Village.

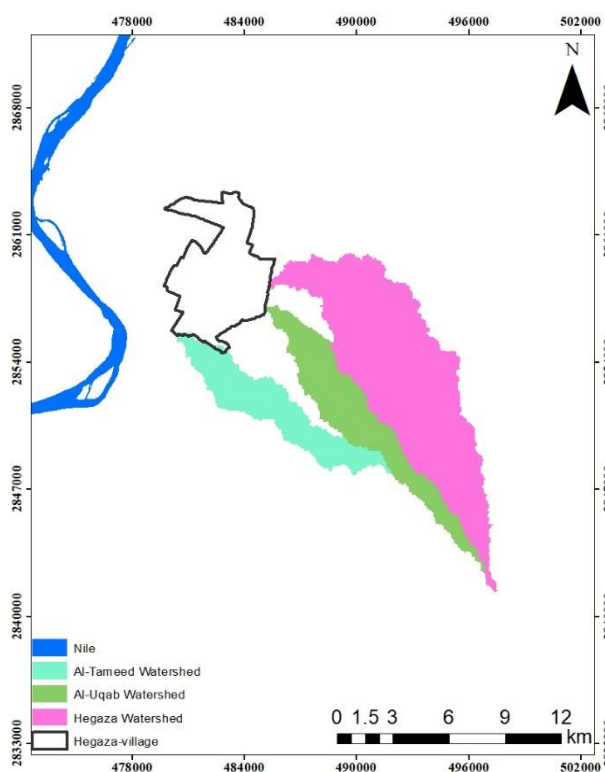
Table 3: Stream statistics affecting Hegaza Village

Stream order	Sum_Length (Km)	percentage%
Very low	159.854152	48.607%
Low	92.948106	28.263%
medium	52.547389	15.978%
High	17.795443	5.411%
Very high	5.727424	1.742%

### 3.3 Morphological Identities

During the numerical investigation, the morphological characteristics were extracted by integrating drainage streams and drainage basins. The morphological characteristics of the main basins are shown in table (4).

**Table4:** The morphological characteristics of main basins



	Wadi Hegaza	Wadi Al-Uqab	Wadi Al-Tameed
Area (km <sup>2</sup> )	70.44	26.05	21.77
Basin Slope(m/m)	0.0458	0.0503	0.0500
Basin Length(m)	21015.9	18715.82	13742.17
Perimeter (m)	74822.04	57645.52	44836.29
Shape Factor (mi <sup>2</sup> /mi <sup>2</sup> )	6.27	13.45	8.67
Mean Basin Elevation (m)	190.47	194.6	147.24
Max. Flow Distance (m)	29414.27	22814.54	18738.27
Max. Flow Slope (m/m)	0.0082	0.0098	0.0092
Max. Stream Length (m)	28831.21	22097.10	18030.89
Max. Stream Slope (m/m)	0.0081	.0096	0.0085

**Fig. 4:** Watersheds affecting Hegaza Village

### 3.4 Watersheds Curve Number

Via the numerical investigation, the effective precipitation amounts were calculated, where the rainfall losses represented by relating the total rainfall to the surface runoff by implementing the curve number method. This method depends on the combination of 2 important elements in the study area (definition of hydrological groups and the land use).

#### 3.4.1 Soil Hydrological Group

During the numerical investigation, the Soil Conservation Services (SCS) 1985[23] technique was implemented, where the soil was classified into 4 groups (A, B, C and D). They ranged between 0 and 100, where the Digital Soil Map of the World was obtained via [fao.org/geonetwork/srv/en/metadata](http://fao.org/geonetwork/srv/en/metadata)[24]. The hydrological groups (B and C) are presented in figure 5.

#### 3.4.2 Soil Land Use

The soil land use was defined by incorporating satellite visuals via [Landsat 8 / OLI](http://Landsat 8 / OLI)[25], where the analysis classified it into 3 categories (desert, agricultural and urban areas); figure (6).

#### 3.4.3 Watershed Curve Number

Implementing the GIS, the hydrological group was combined with the land use and the Watersheds affecting the Hegaza Village, curve numbers were defined to be 83.57 for Hegaza watershed, 84.132 for Al-Uqab watershed and 82.4 for Al-Tameed watershed

### 3.5 .Watersheds Precipitation Depth

Via the numerical investigation, the precipitation depth of the watersheds in Hegaza Village was determined, for a return period of 100 years. This was achieved by interpolating a raster surface from points using IDW “Inverse Distance Weighted” technique; figure (7).

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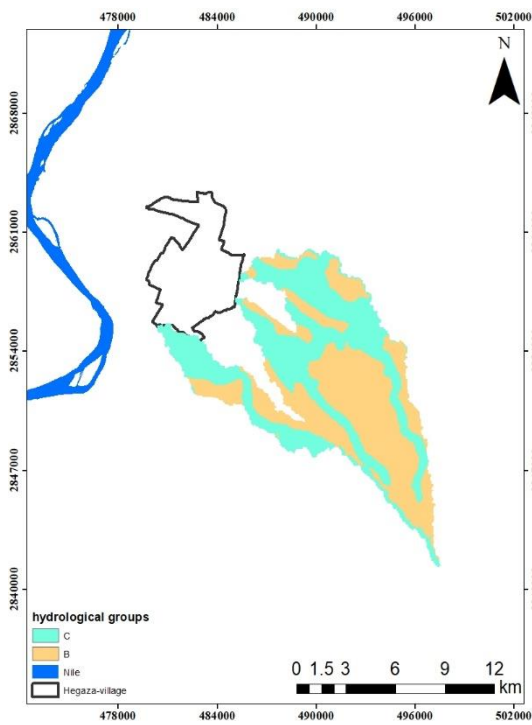


Fig. 5: Hydrological groups of Watersheds in Hegaza Village

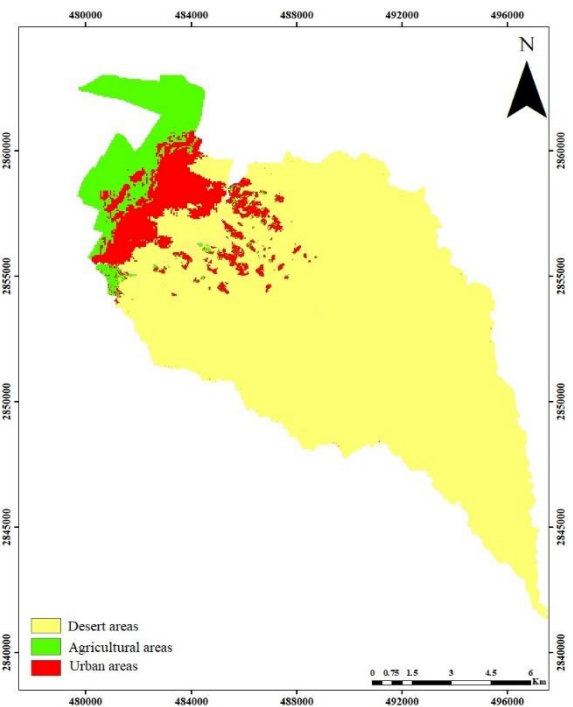


Fig. 6: Land use map in Hegaza village

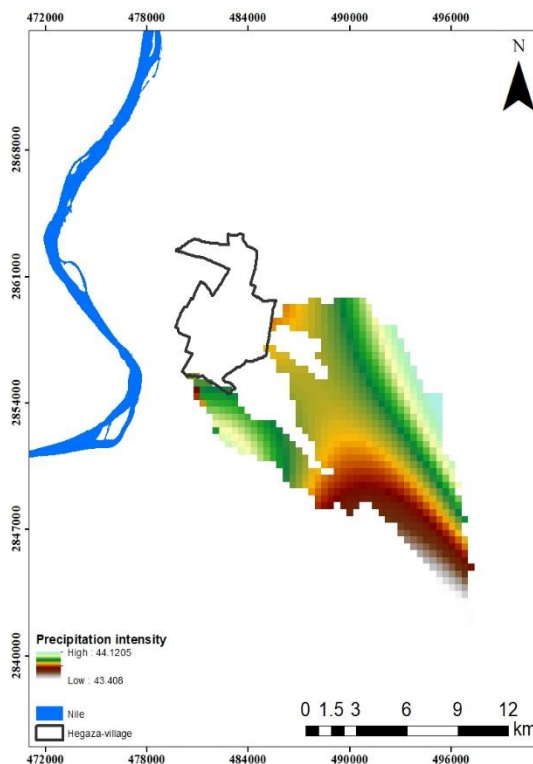


Fig. 7: Precipitation depth for a return period 100 years in Hegaza Village

### 3.6 GIS-MCDA

During the numerical investigation, the multi-criteria decision analysis based on GIS was implemented for the 7 significant criteria affecting flood hazards frequency. The weight of each criterion was determined by AHP. These criteria encompassed:

- Flow accumulation
- Euclidean distance
- Slope
- Precipitation intensity
- Drainage Density
- Land use
- Hydrological groups

The seven extracted criteria layers were reclassified in ArcGIS, to determine the degree of severity and to create the hazard maps. The reclassify tool (in the spatial analysis toolbox in ArcGIS) was applied to determine and define the hazard classes and ranks for each criterion. Hazard classes and ranks were assigned for each criterion using the experience of the authors and extensive previous studies. Classification categories of the seven main criteria affecting flooding in the study area as shown in table (5).

**Table 5:** Classification categories of the seven main criteria

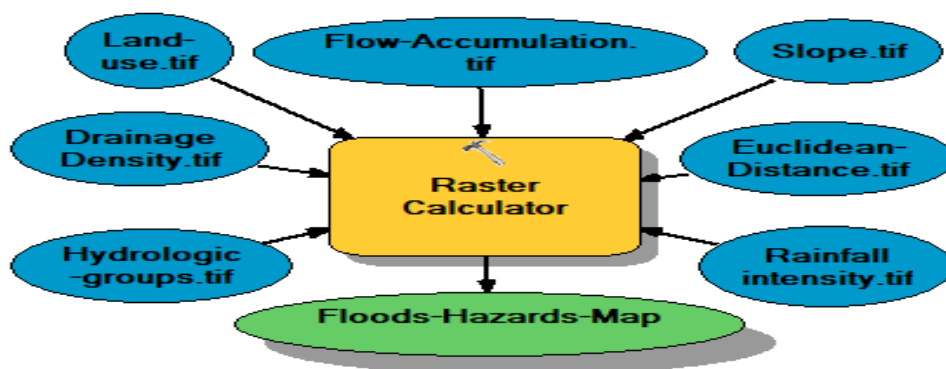
<b>critrion</b>	<b>Categories</b>	<b>Category value</b>
Flow accumulation	0 - 16565.6	2
	16565.6 - 33131.2	4
	33131.2 - 49696.8	6
	49696.8 - 66262.4	8
	66262.4 - 82828	10
Euclidean distance	0 - 99.7806	10
	99.7806 - 199.5612	8
	199.5612 - 299.3418	6
	299.3418 - 399.1224	4
	399.1224 - 498.903	2
Slope	0 - 4.7	2
	4.7 - 9.4	4
	9.4 - 14.1	6
	14.1 - 18.8	8
	18.8 - 23.5	10
Precipitation intensity	43.408 – 43.5505	2
	43.5505 – 43.693	4
	43.693 – 43.8355	6
	43.8355 – 43.978	8
	43.978 – 44.1205	10
Drainage Density	1 – 1.8	2
	1.8 – 2.6	4
	2.6 – 3.4	6
	3.4 – 4.2	8
	4.2 - 5	10
Land use	Agricultural areas	4
	Urban areas	6
	Desert areas	8
Hydrological groups	Group B	6
	Group C	8

Similarly, the weight of each criterion is ranked based on the AHP method; table (6), where their total is 100%. The 7 criteria were combined, in terms of the weight in GIS-Model-Builder figure (8).



**Table 6:** Weights of the eight criteria of the study using the AHP.

Criteria	Total of Rows	Relative Weight	Weight %
Flow accumulation	2.45	0.35	35.04%
Euclidean distance	1.66	0.24	23.75%
Slope	1.11	0.16	15.90%
Precipitation intensity	0.74	0.11	10.56%
Drainage Density	0.49	0.07	6.96%
Land use	0.32	0.05	4.62%
Hydrological groups	0.22	0.03	3.18%
<b>Total</b>	7	1.00	100.00%



**Fig. 7:** GIS-Model-Building (GIS-MCDA)

The calibration of this model was done by comparing the flood hazard map produced through this model with the flood hazard map produced by hydrodynamic modeling by (Abo-Taha M., et al, (2021) [26]), showing that there is a clear match between them.

#### 4. RESULTS AND DISCUSSION

In the analytical investigation, the obtained results were analyzed, presented and discussed, from which the following were designated

- From the GIS-model Builder, three main watersheds affect the village of Hegaza, which are in order from North to South: Wadi Hegaza, Wadi Al-Uqab, Wadi Tameed. Total lengths of streams within the watersheds affecting the village of Hegaza 328.87 km.
- The discharge and volume of the runoff at the outlet of watersheds affecting the village of Hegaza were determined by the hydrological model (HEC-1). The hydrographs at the outlet of the watersheds, for different return periods as shown in figures from 8 to 10.
- The MCDA results based on GIS identified the hazardous degree of floods within the watersheds of Hegaza Village, where it was classified into 5 classes (very high, high, medium, low and very low hazards). it was found that the areas exposed to very high and high flood hazards amounted to 21.12 km<sup>2</sup> and 28.35 km<sup>2</sup>, respectively, out of the total area of the three basins affecting the village of Hegaza estimated at 118.26 km<sup>2</sup>. The area of areas exposed to moderate flood hazards is 36.98 km<sup>2</sup>. Finally, the areas prone to low and very low flood hazards are 22.54 km<sup>2</sup> and 9.27 km<sup>2</sup>, respectively; figure (11).



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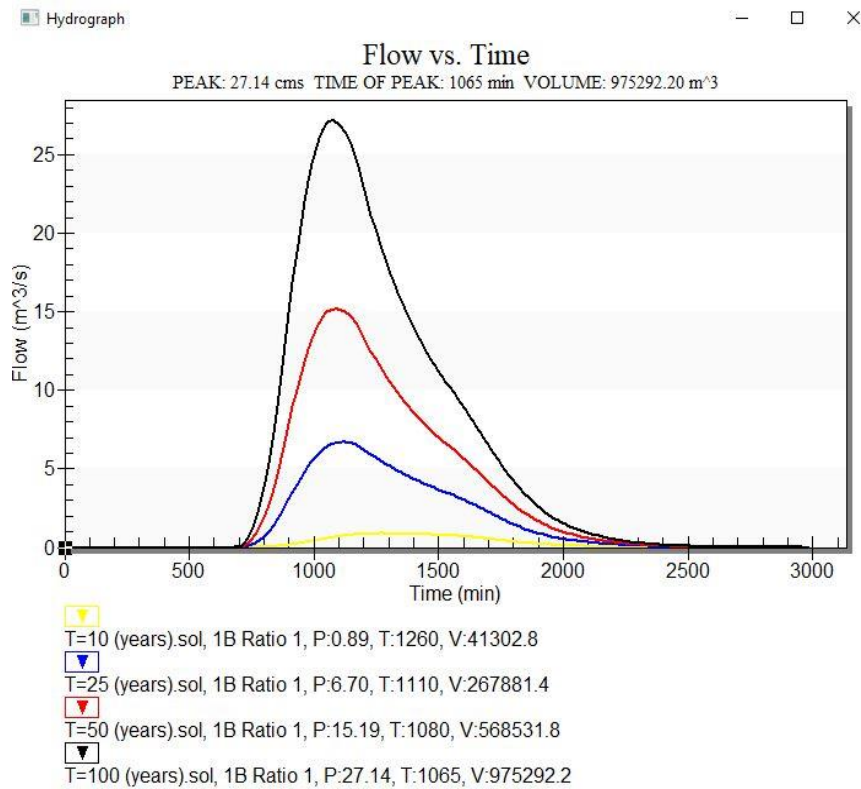


Fig. 8.: Wadi Hegaza Watershed flood flow hydrographs

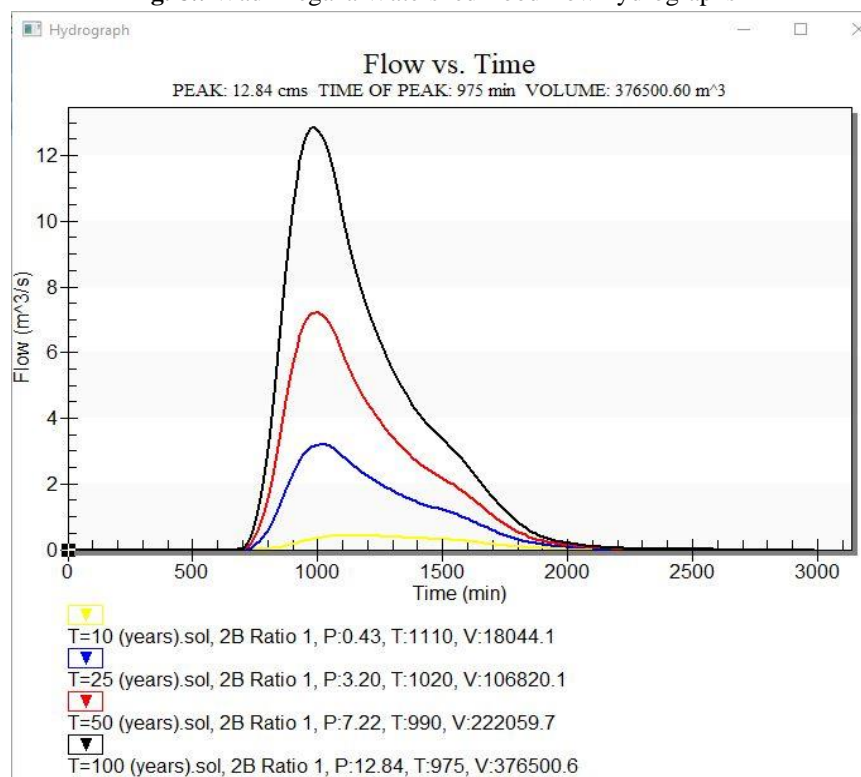


Fig. 9: Wadi Al-Uqap Watershed flood flow hydrographs

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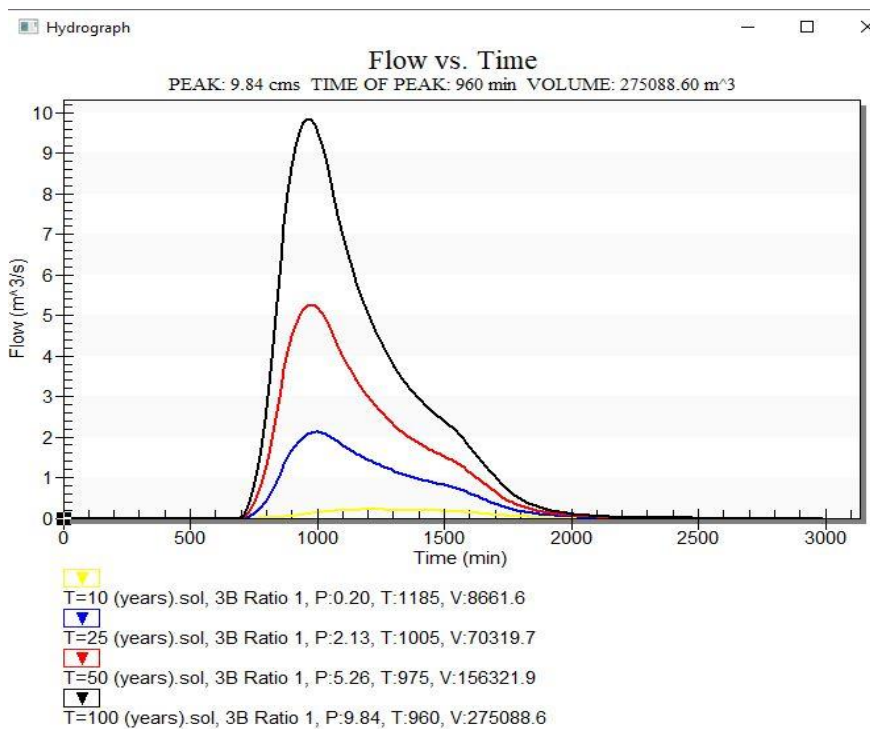


Fig10.: Wadi Al-Tameed Watershed flood flow hydrographs

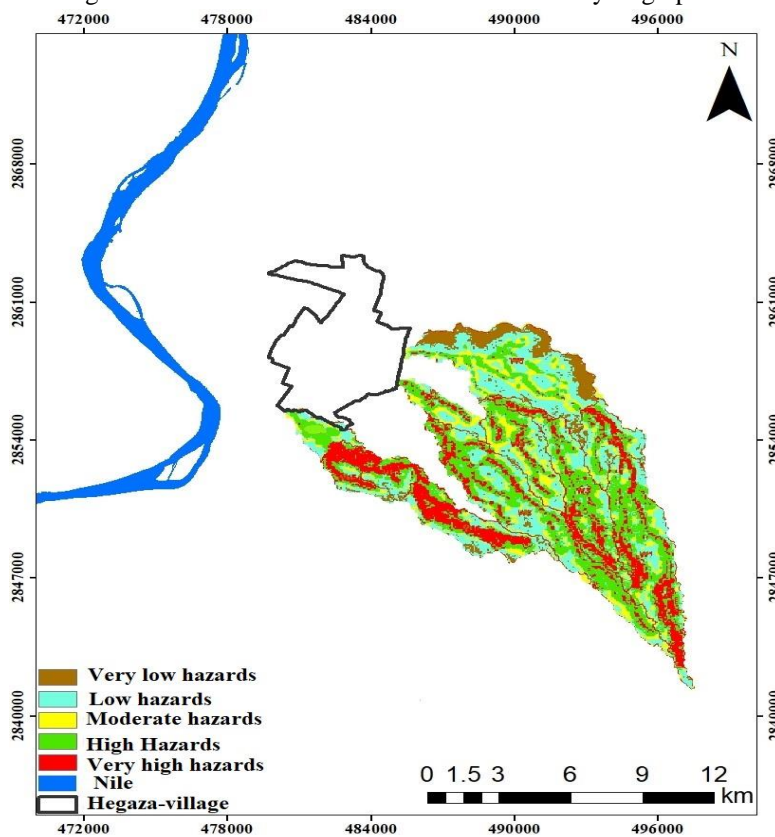


Fig. 11: Floods hazards map

## 5. CONCLUSION

During the inferential investigation, conclusions were deduced, as follows :

- The research flagged out that the obtained results would most probably assist decision-makers .
- The research highlighted the importance of implementing flood hazards management activities to ensure the environmental rehabilitation of watersheds to avoid flood disasters.
- The research emphasized that the GIS-MCDA is a new approach to local flood hazard assessment mapping and it empowers decision-makers in undertaking flood hazard management activities .
- The research results highlighted that GIS- MCDA could assist decision-makers to innovate a suitable economic protection measure.
- The hydrological modeling results indicated that it GIS is capable of extracting drainage streams, drainage basins and morphological characteristics .
- Model-Builder results identified 3 main watersheds. These are Wadi Hegaza, Wadi Al Aqab and Wadi Al Tamid with areas of 70.44, 26.05 Km<sup>2</sup> and 21.77 Km<sup>2</sup>, respectively. Their stream length is 328.87 km.
- The modeling results identified the maximum discharge at 3 outlets for return periods of 10, 25, 50, and 100 years. The peak of the discharge of the three main basins affecting the village of Hegaza was based on the use of the value of the maximum precipitation depth for a return period of 100 years, resulting from the statistical analysis of rainfall using the (Hyfran) program 27.14 m<sup>3</sup>/sec, 12.84 m<sup>3</sup>/sec and 9.84 m<sup>3</sup>/sec respectively .
- The research results demarcated the very high and high hazard areas amounted to 21.12 km<sup>2</sup> and 28.35 km<sup>2</sup>, respectively.

During the inferential investigation, recommendations were suggested, as follows:

- It is recommended to implement the utilized approach, as it assists in flood hazards management activities .
- It is suggested to utilize the implemented approach, as it ensures environmental rehabilitation of watersheds.
- It endorsed the application of the employed approach, as it ensures the reduction of flood disasters.

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