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FLOODS HAZARDS ASSESSMENT BY INTEGRATING HYDROLOGIC MODELING AND A GEOGRAPHIC INFORMATION SYSTEMS (MULTI-CRITERIA DECISION TECHNIQUE)

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ABSTRACT:

The protection of urban areas located on the eastern side of the Nile River in Upper Egypt, which is highly exposed to flood hazards, represents one of the most important priorities of the Egyptian state to achieve the future of sustainable urban development for Egypt's Vision 2030. This research deals with two main steps: The first step is to combine a hydrological model (HEC-1) with a geographic information system (GIS) to obtain high-caliber hydrological modeling. The second step is to create a flood hazard map by GIS- Model Builder based on the multi-criteria decision analysis method in geographic information systems (GIS-MCDA) based on the application of the Analytic Hierarchy Process (AHP). The research flagged out that the obtained results would most probably assist decision-makers Creating a clear vision for sustainable development in the region. In addition to that, the research highlighted the importance of implementing flood hazards management activities to ensure the environmental rehabilitation of watersheds to avoid flood disasters.

Keywords: Geographic Information Systems (GIS); Model Builder; Hydrologic Modelling (HEC-1); multi-criteria decision analysis (MCDA); Flood Hazard Map (F.H.M).

تقييم مخاطر الفيضانات من خلال دمج النمذجة الهيدرولوجية ونظم المعلومات الجغرافية (تقنية القرار متعدد المعايير)

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الملخص

تمثل حماية المناطق الحضرية الواقعة على الجانب الشرقي من نهر النيل في صعيد مصر والمعرضة بشدة لمخاطر الفيضانات ، إحدى أهم أولويات الدولة المصرية لتحقيق مستقبل التنمية العمرانية المستدامة لرؤية مصر ٢٠٣٠. يتناول هذا

البحث خطوتين رئيسيتين: الخطوة الأولى هي دمج نموذج هيدرولوجي (HEC-1) مع نظم المعلومات الجغرافية (GIS) للحصول على نمذجة هيدرولوجية عالية الجودة. تتمثل الخطوة الثانية في إنشاء خريطة مخاطر الفيضانات بواسطة GIS-Model Builder بناءً على طريقة تحليل القرار متعدد المعايير في أنظمة المعلومات الجغرافية (GIS-MCDA)اعتمادا على تطبيق عملية التسلسل الهرمي التحليلي (AHP). تم التخطيط لمنهجية البحث لتشمل خمس تحقيقات (التحقيقات النظرية والميدانية والعددية والتحليلية والاستنتاجية) .أشار البحث إلى أن النتائج التي تم الحصول عليها ستساعد على الأرجح صانعي القرارفي التخطيط من أجل التنمية المستدامة لهذه المنطقة. بالإضافة إلى ذلك ،البحث سلط الضوء على أهمية تنفيذ أنشطة إدارة مخاطر الفيضانات لضمان إعادة التأهيل البيئي لمستجمعات المياه لتجنب كوارث الفيضانات.

1. Introduction

Floods like any other natural phenomenon that have positive impacts if they are wisely managed. However, they may have many negative impacts if they are handled without enough preparedness. The dry and mountainous nature of the Middle East emphasizes the fact that management of this phenomenon is extremely important not only to avoid their negative impacts but also to make use of such freshwater resources. Floods are considered one of the worst natural disasters. During the stage from 1995 to 2017, 2.3 billion people were affected by these floods. Nearly 157,000 people were passed away due to this natural hazard. Furthermore, financial losses were valued at more than 662 billion dollars **(Wahlstrom and Sapir, 2017)**. To reduce flood hazards, flood-subjected regions over various return periods are very essential to be precisely specified **(Billa, et al, 2006).** Moreover, drawing flood-risk maps is one of the essential precautions against flood disasters**. (Bubeck, et al, 2012)**. Over the past few decades, flood modeling using the hydrological and hydraulic modeling programs has evolved dramatically with the advent of GIS and satellite-derived remote sensing imagery and the emergence of high-resolution digital elevation models (DEMs) **(Song, Y, et al, 2018)**. Mapping hazardous zones are very useful for the assessment and management of flood hazards. These maps are helpful for flood protection and land-use planning **(EU IPA 2010 TWINNING PROJECT, 2010). The Committee on Floodplain Mapping Technologies (2007)** prefers utilizing the geographic information system (GIS) to produce flood risk maps due to its superiority in analysis, manipulating, and mapping of huge spatial data. **Gericke and Plessis (2012)** compared the watershed characteristics as collected by the ArcGIS with manual calculations. they concluded that the success of applying the ArcGIS in estimating these parameters but of course the ArcGIS is superior due to its quickness**.. Kourgialas and efrerer (2016)** have assessed and mapped the flood risk in the island of Crete in Greece using data about the rainfall, topography, and flood flow. The relative weights of these parameters were estimated based on subjective opinions. Thereafter, they used the map algebraic functions available in ArcGIS to map the flood risk using five classes of symbols (from very high to very low). **Al-Abadi et al. (2016)** used only topographic characteristics to assess flood risk in a watershed in the south of Iraq. According to **De Brito and Ever (2016)**, the Analytic Hierarchy Process (AHP), one of the pairwise comparing methods, is the most common multiple criteria assessment method. That is because it is straightforward, understandable, and allows subjective participation of the experts. AHP molders the complex multi-criteria into a hierarchy process. It originates the importance of each criterion, to the other corresponding criteria. The multi-criteria decision analysis method, based on geographic information systems (GIS-MCDA), is the method used most widely in geographic, schematic, and applied studies. In urban areas, flood hazard modeling using this method is appropriate. Calculating the weight of each criterion is performed through the Analytic Hierarchy Process (AHP). **(Kazakis, et al, 2015; Khabat, et al 2016; Somaiyeh and Mehran, 2017; Andi, et al, 2017; Olga, et al 2018.)** However, ArcGIS is a very powerful software but it is frequently needs to use long series of data analysis steps. In these situations, ModelBuilder is very useful to automate these processes. (**Ghabayen and Salha (2013); Omran et al. (2011); Magesh and Chandrasekar (2012); Elmoustafa et al. (2015**)). The technique that applied in this research will contribute to the planning of safe cities from the flood risk and help in selecting the best protection structures at the lowest possible cost.

2. Study area

The technique used in this research will be applied to the village of Hegaza-Bahari, which is one of the villages of Qus Center in the Governorate of Qena in Upper Egypt. The area of the village of Hegaza-Bahari is 17865292.1299 m^2 according to the administrative division of the Arab Republic of Egypt for the year 2017. The village of Hegaza-Bahari is surrounded on the east by the eastern desert of Egypt, on the west by the village of Olikat, on the north by the village of Al-Kalahin, and on the south by the villages of Hegaza. The location of Hegaza-Bahari village in Qus Center in the Governorate of Qena according to the administrative division of Egypt 2017 is shown in figure 1. Through the use of topographic maps, scale 1: 50,000 sourced from the Egyptian Survey Authority, it was found that the village of Hegaza-Bahari faces one main watershed coming from the Red Sea Mountain ranges. The village of Hegaza-Bahari ranks second among the villages and cities of Qena governorate in terms of the number of times it was exposed to Flood Hazards in the period between 1979 and 2016, as it was exposed to flood risks 10 times in that period, about 22% of the total number of times that the villages and cities of the Qena governorate were exposed hazards from surface runoff, and there are urban expansions in the flood plains.

3. HYDROLOGIC MODELING

In the hydrological investigation, the maximum precipitation on the watersheds was determined. In addition, the streams and basins with their geomorphological characteristics were demarcated using integrating a hydrological model (HEC-1) with a geographic information system(GIS). This is presented, as follows:

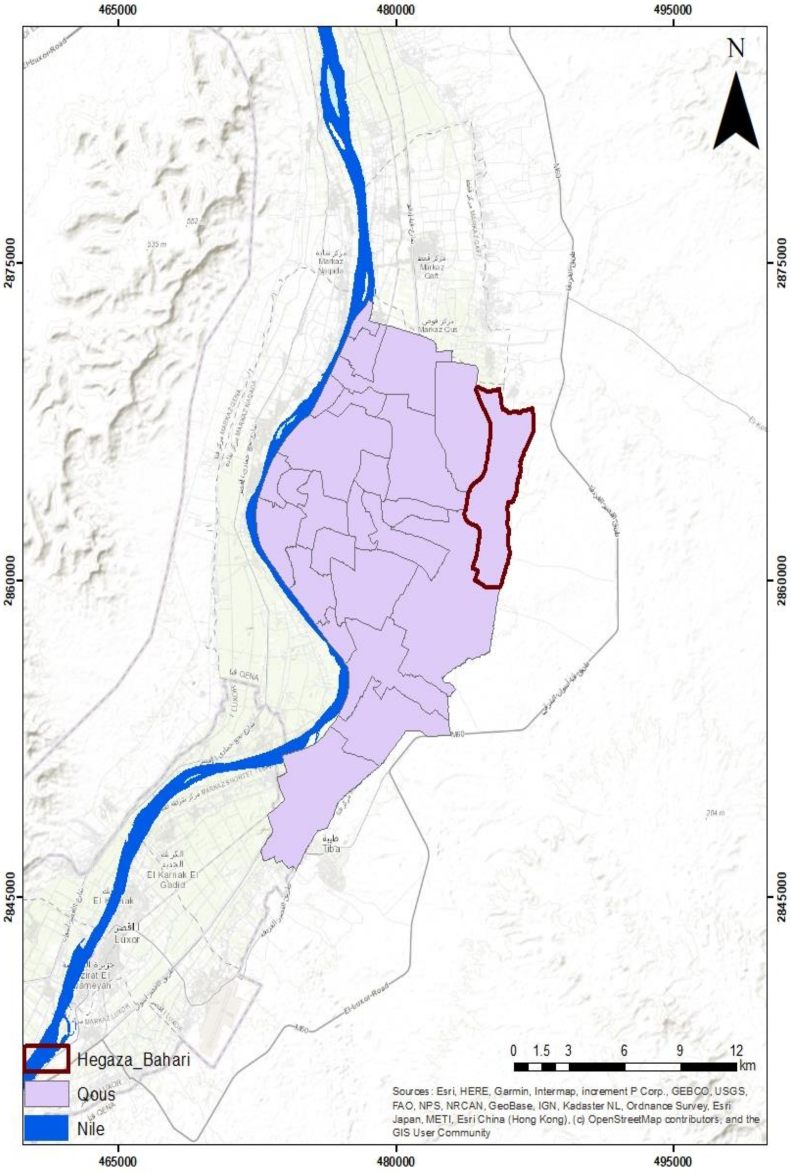


Figure 1. Location of Hegaza -Bahari village according to the administrative division of Egypt2017

3.1 Analysis of rainfall data

Determining the accurate data of the quantities of precipitation that fell on the watersheds is one of the most important factors that help in calculating the accumulated floods from those precipitations. In the metrological study, daily precipitation data available on globalweather.tamu.edu over the 36 years of 1979 through 2014, was used. A Weibull method was used in the statistical distributions according to the Egyptian Code for Water Resources and Irrigation Works to determine the depth of precipitation for different return periods as shown in Table 1.

Table 1. Precipitation depth for different return periods by Weibull method.

Weather station No.	Longitude	Latitude	Return period (Year)		
			25	50	100
			Max.24 hr. precipitation depth (mm/day)		
1	32.8125	25.4467	19.7	25.2	31
2	33.125	25.4467	22.7	30	37.8
3	32.8125	25.7589	28.8	34.5	44.1
4	33.125	25.7589	25.7	35.1	45.5

3.2 Extraction of drainage streams and drainage basins

The process of determining and demarcating watersheds and basins was carried out using integrating a hydrological model (HEC-1) with a geographic information system(GIS) to obtain high-caliber hydrological modeling by the following steps:

- It fills the sinks in a raster.
- It creates a flow raster from the cell to its neighbour.

The input raster representing a continuous surface.

Output flow direction raster

The output raster that shows the flow direction from each cell to its steepest downslope neighbor. This output is of integer type.

Force all edge cells to flow outward (optional)

Specifies if edge cells will always flow outward or follow normal flow rules.

- Unchecked—If the maximum drop on the inside of an edge cell is greater than zero, the flow direction will be determined as usual; otherwise, the flow direction will be toward the edge. Cells that should flow from the edge of theso. This is the default.
- Checked—All cells at the edge of the surface raster will flow outward from the surface raster.

Output drop raster (optional)

An optional output drop raster.

The drop raster returns the ratio of the maximum change in elevation from each cell along the direction of flow to the path length between centers of cells, expressed in percentages.

This output is of floating-point type.

- It creates an accumulated flow raster to the cell.
- It optionally evaluates the raster cells.
- It denotes segment order to represent linear network

It creates a raster to delineate drainage basins in this study, digital elevation models (DEMs) with an accuracy of 30 meters were used, obtained through earthexplorer.usgs.gov. The results of the streams derived from digital elevation models are compared to watershed paths with topographic maps, scale 1: 50,000 sourced from the Egyptian Survey Authority, it turns out that there is a match between them. Streams within the Wadi Hegaza-Bahari watershed are classified using geographic information systems (GIS) into five classes, where class 5 indicates very high hazard while class 4 indicates high hazard, class 3 indicates medium hazard, class 2 indicates a low hazard. Finally, class 1 indicates a very low hazard as shown in figure 2. Stream's statistics of Wadi Hegaza-Bahari Watershed are shown in table 2.

3.3 The morphological characteristics

During the hydrological investigation, the morphological characteristics were extracted by integrating drainage streams, drainage basins and contour map; figure (3). The main drainage basin is divided into seven sub-basins as shown in figure 4. The geomorphological characteristics of these seven basins are shown in Table 3.

Table 2. Stream's statistics of watersheds affecting the village of Hegaza-Bahari

Stream order no.	Sum_Length (Km)	percentage%
1	64.31	45.662%
2	45.54	32.335%
3	20.98	14.896%
4	5.06	3.593%
5	4.95	3.515%

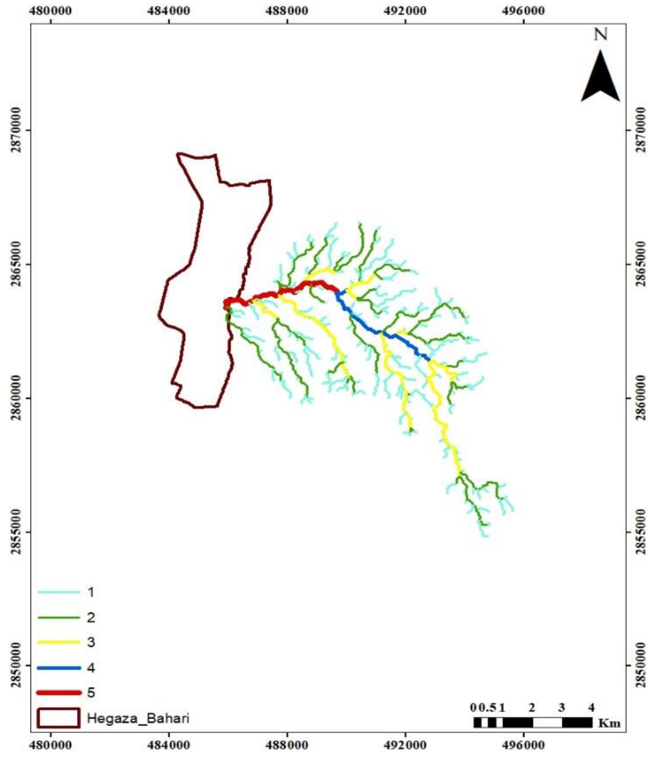
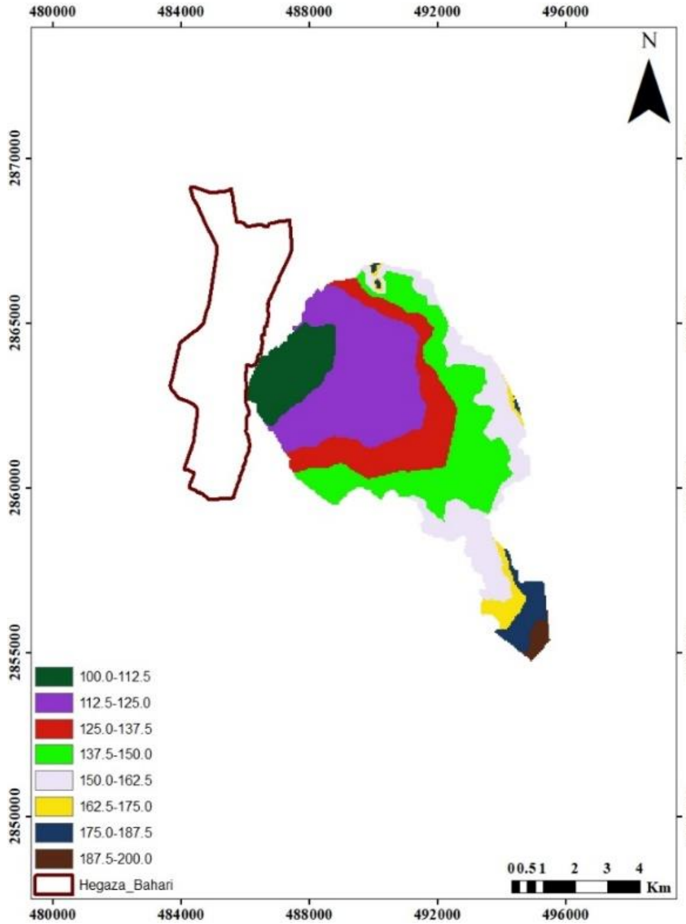


Figure 2. Classification of streams in watersheds affecting the village of Hegaza-Bahari.

Table 3. The geomorphological characteristics of sub-basins

	Sub-Basin no.						
Basins Data	**B 1**	**B 2**	**B 3**	**B 4**	**B 5**	**B 6**	**B 7**
Basin Area (km^2)	**3.12**	**6.49**	**6.47**	**9.99**	**5.25**	**10.42**	**12.08**
Basin Slope (m/m)	**0.0355**	**0.0381**	**0.0348**	**0.0480**	**0.0354**	**0.0443**	**0.0456**
Basin Length (m)	**4261.4**	**4933.04**	**5129.7**	**4233.95**	**3800.04**	**4570.88**	**7788.1**
Basin Perimeter (m)	**15601.8**	**20324.4**	**24872.6**	**19922.8**	**19734**	**28062.5**	**32075.8**
Shape Factor	**5.83**	**3.75**	**4.07**	**1.79**	**2.75**	**2**	**5.02**
Sinuosity Factor	**0.88**	**1.09**	**1**	**1.01**	**1.01**	**1.01**	**1.07**



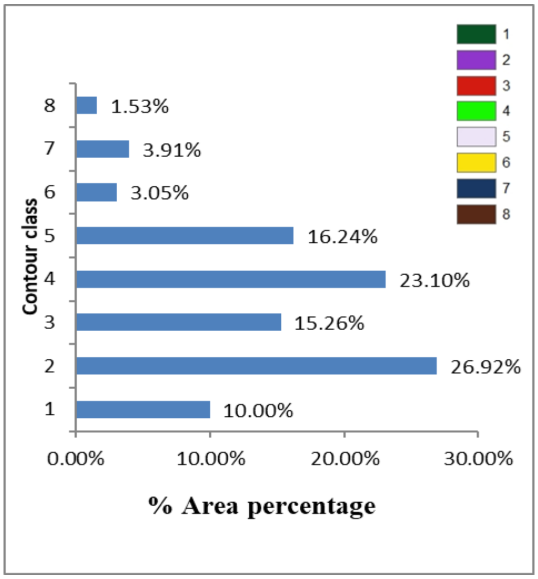


Figure 3. Contour map of Wadi Hegaza-Bahari Watershed.

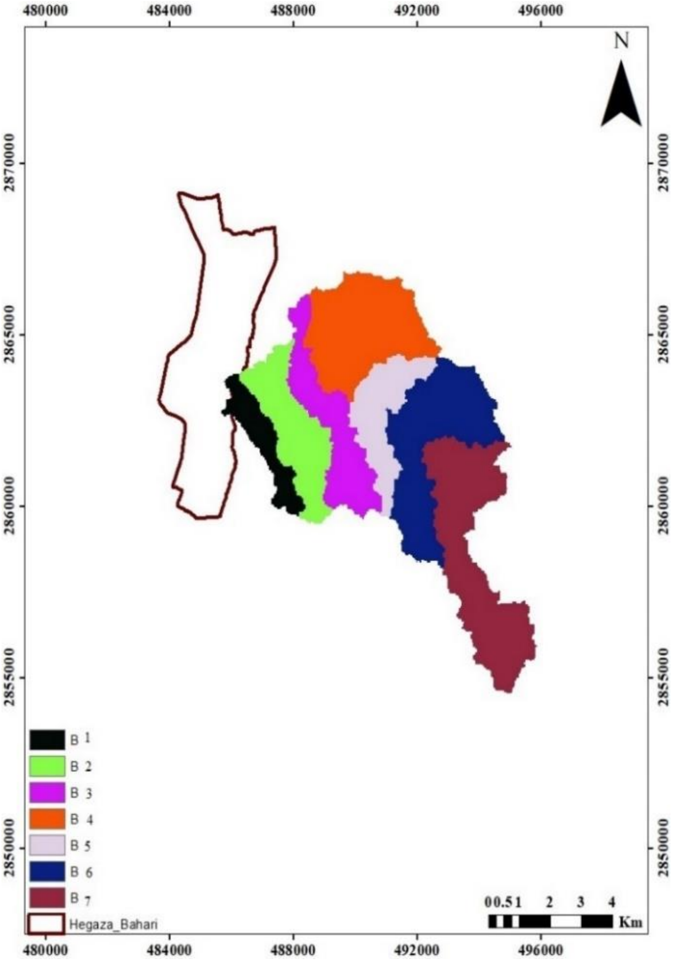


Figure 4. Sub-basins map of Wadi Hegaza -Bahari Watershed

3.4 Watersheds Curve Number

Via the hydrological investigation, the effective precipitation amounts were calculated, where a mathematical method represented the rainfall losses by relating the total rainfall to the surface runoff by implementing the curve number method. This method depends on the combination of two important elements in the study area (i.e., the definition of hydrological groups and the land use). Using the GIS data, the hydrological group was combined with the land use in the hydrologic model (HEC-1) and the Watersheds affecting the Hegaza-Bahari Village, total curve number was defined to be 85.

4. Integrating MCDA and GIS (GIS-MCDA)

MCDA based on GIS was implmented to identify the number of norms that influence flood hazard increment. Each norm weight was designated using AHP, where 7 criteria were signposted, as follows:

- Euclidean distance
- Slope
- Soil types
- Flow accumulation
- Precipitation intensity
- Drainage Density
- Land use

The criteria are presented in figures (5) to (11).

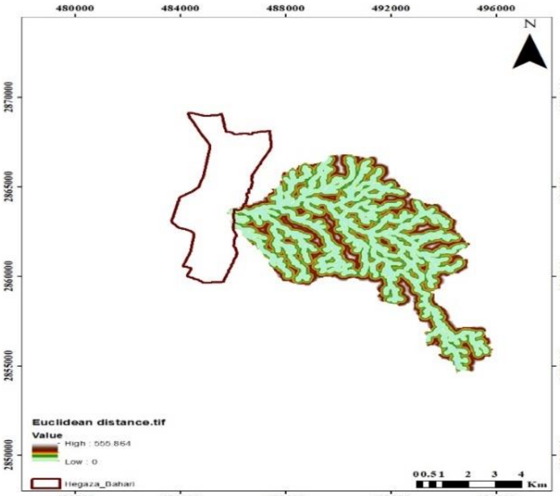


Figure 5. The Euclidean distance map.

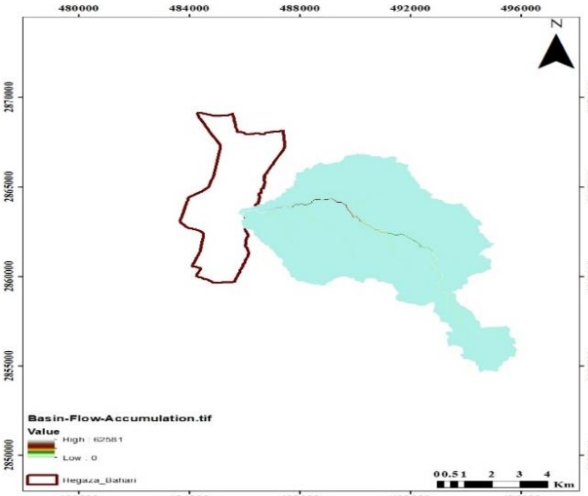


Figure 6. Flow accumulation map.

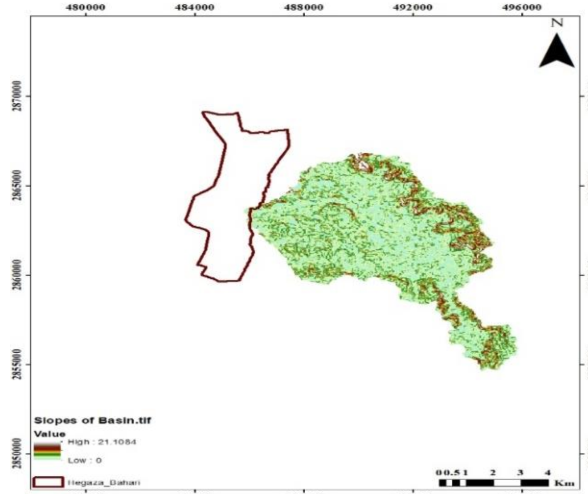


Figure 7. Slope map.

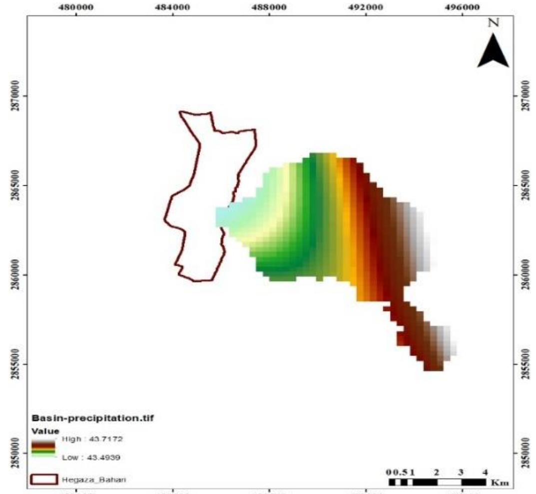


Figure 8. Precipitation intensity map.

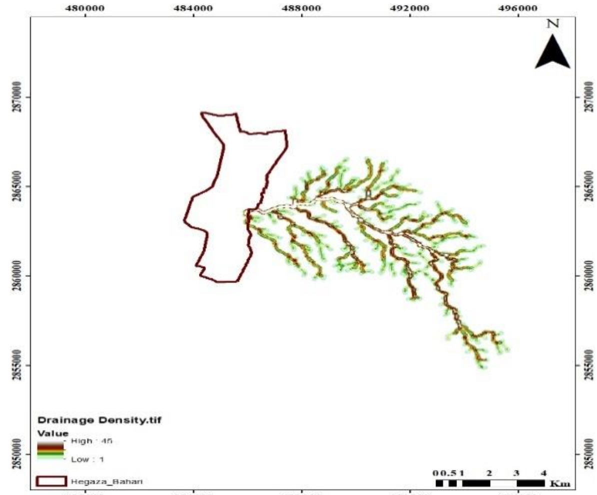


Figure 9. Drainage density map.

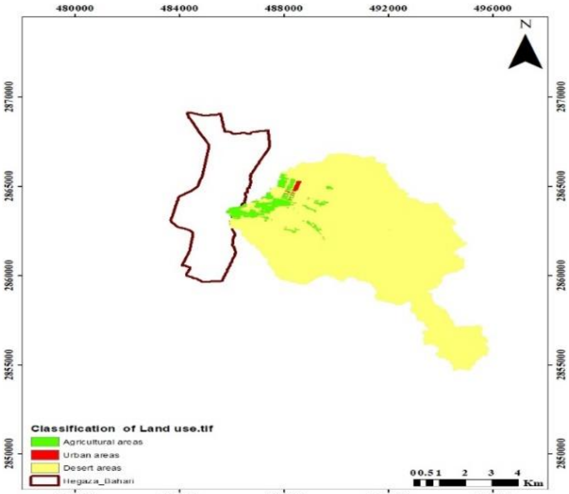


Figure 10. Land use map.

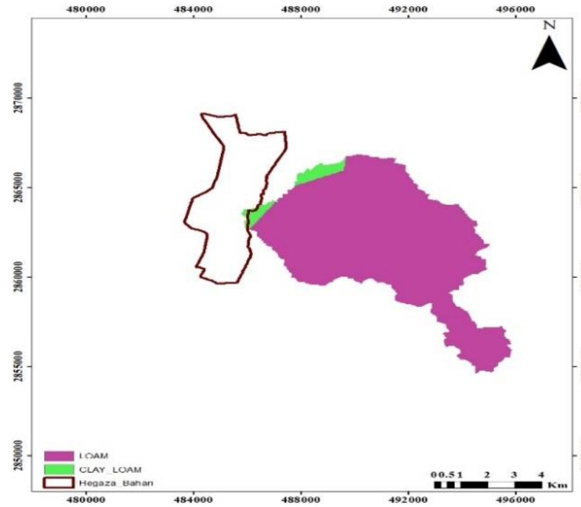
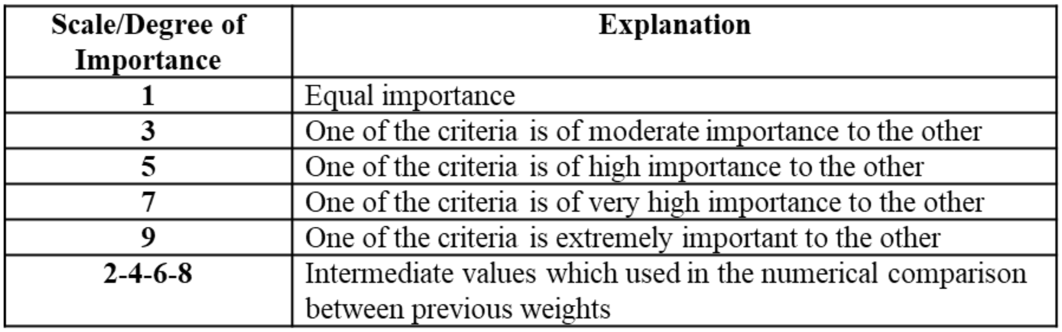


Figure11. Soil types map.

4.1 Application of AHP

AHP is a tool of MCDA. Thomas-Saaty put forward AHP, which is a mathematical theory. It was applied in different fields. AHP method is a hierarchical-framework. It creates the significance of every norm to the other norms. Table 4 highlights the significance of AHP norms, after Thomas-Saaty.

Table 4. The norms significane after Thomas-Saaty.



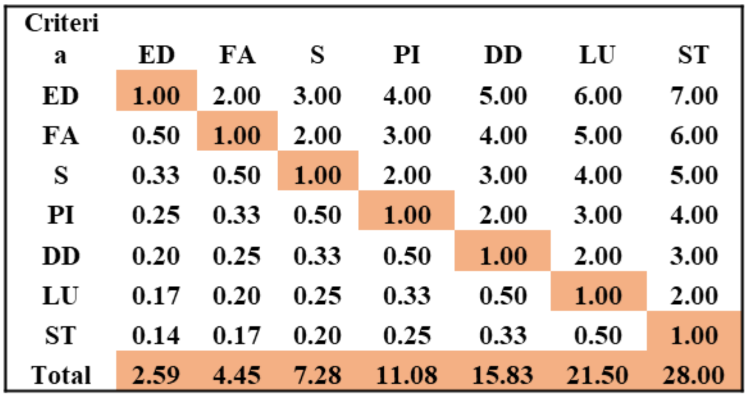
Scale/Degree of Importance	Explanation
1	Equal importance
3	One of the criteria is of moderate importance to the other
5	One of the criteria is of high importance to the other
7	One of the criteria is of very high importance to the other
9	One of the criteria is extremely important to the other
2-4-6-8	Intermediate values which used in the numerical comparison between previous weights

The flood-hazard map was created by AHP in 4 steps, as follows:

4.1.1 1st Step: Signpost the importance-values for the norms

The 1st step establishes the importance-values of each norm relative to others, after table 4, in a hierarchical level. Table 5 contrasts the implemented 8 norms together with their assigned-importance.

Table5. Matrix of paired comparison for the norms.



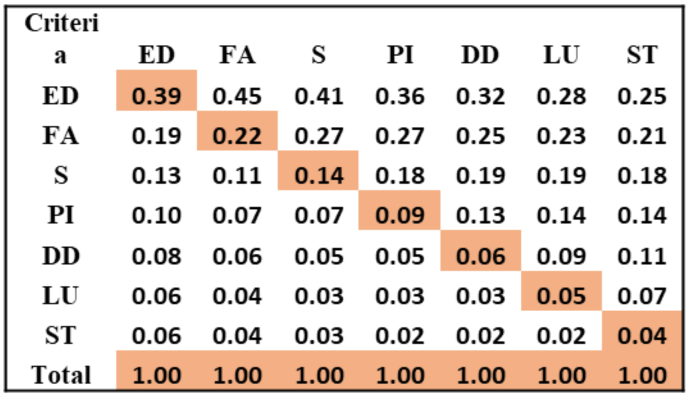
Criteria	ED	FA	S	PI	DD	LU	ST
ED	1.00	2.00	3.00	4.00	5.00	6.00	7.00
FA	0.50	1.00	2.00	3.00	4.00	5.00	6.00
S	0.33	0.50	1.00	2.00	3.00	4.00	5.00
PI	0.25	0.33	0.50	1.00	2.00	3.00	4.00
DD	0.20	0.25	0.33	0.50	1.00	2.00	3.00
LU	0.17	0.20	0.25	0.33	0.50	1.00	2.00
ST	0.14	0.17	0.20	0.25	0.33	0.50	1.00
Total	2.59	4.45	7.28	11.08	15.83	21.50	28.00

Where:
ED: Euclidean-distance, F-A: flow-accumulation, S: slope, PI: Precipitation-intensity, DD: drainage- density, LU: land- use, and ST: soil-type.

4.1.2 2nd Step: Designate the Importance-Values percentages

Table 6 lists the Importance-Values percentages by AHP.

Table6. Importance-Values percentages by AHP

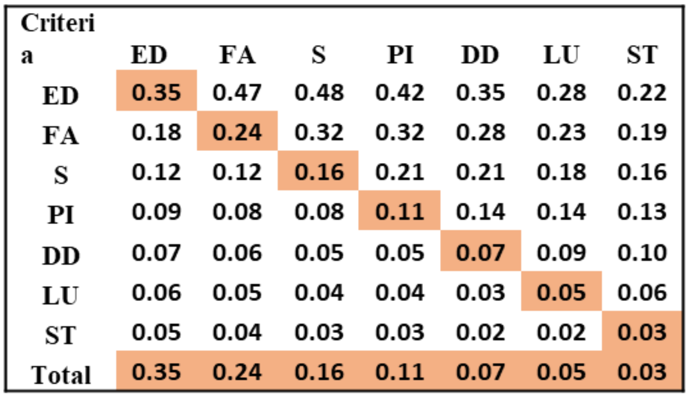


Criteria	ED	FA	S	PI	DD	LU	ST
ED	0.39	0.45	0.41	0.36	0.32	0.28	0.25
FA	0.19	0.22	0.27	0.27	0.25	0.23	0.21
S	0.13	0.11	0.14	0.18	0.19	0.19	0.18
PI	0.10	0.07	0.07	0.09	0.13	0.14	0.14
DD	0.08	0.06	0.05	0.05	0.06	0.09	0.11
LU	0.06	0.04	0.03	0.03	0.03	0.05	0.07
ST	0.06	0.04	0.03	0.02	0.02	0.02	0.04
Total	1.00	1.00	1.00	1.00	1.00	1.00	1.00

4.1.3 3rd Step: Establish the matrix of Weight-Values

Tables 7 and 8 present the weight-values matrices, according to norm priority.

Table 7. weight-values matrices, according to norm priority



Criteria	ED	FA	S	PI	DD	LU	ST
ED	0.35	0.47	0.48	0.42	0.35	0.28	0.22
FA	0.18	0.24	0.32	0.32	0.28	0.23	0.19
S	0.12	0.12	0.16	0.21	0.21	0.18	0.16
PI	0.09	0.08	0.08	0.11	0.14	0.14	0.13
DD	0.07	0.06	0.05	0.05	0.07	0.09	0.10
LU	0.06	0.05	0.04	0.04	0.03	0.05	0.06
ST	0.05	0.04	0.03	0.03	0.02	0.02	0.03
Total	0.35	0.24	0.16	0.11	0.07	0.05	0.03

Table 8. Norms weight-values by AHP.

Criteria	Value Weight	Weight Relative	Total of Rows
ED	2.57	0.35	7.34
FA	1.75	0.24	7.36
S	1.16	0.16	7.29
PI	0.76	0.11	7.17
DD	0.49	0.07	7.07
LU	0.33	0.05	7.05
ST	0.23	0.03	7.10
ʎMax			7.20

4.1.4 4th Step: Signpost Consistency-Verification

A matrix is consistent, if the multiplication of every 2 values is comparable to one and if the elements of the column are mutual to those in the equivalent row. The consistency-verification is described, as follows:

$$\text{C-I} = \frac{ʎ\text{Max} - n}{n - 1} \tag{1}$$

Where:

n : norms number.

C-I is more acceptable near 0, which indicates its higher confidence and consistency-verification. However, the further CI goes away from o, the higher the inconsistency, where consistency-ratio is described, as follows:

$$\text{Consistency-ratio} = \text{C-I}/\text{R} \tag{2}$$

R : random-index, according to Table 9.

Table 9. "N" (Matrix-order) and "R" random-index.

N	1	2	3	4	5	6	7	8	9	10
R	0	0	.52	.89	1.11	1.25	1.3	1.4	1.45	1.49

From the previous table, the random-index "R" is 1.3, where 7 criteria were utilized and the consistency-verification was 0.0250.This is considered to be acceptable.

Table 10. Weights by AHP.

Criteria	Total of Rows	Relative Weight	Weight (in %)
ED	2.45	0.35	35.04%
FA	1.66	0.24	23.75%
S	1.11	0.16	15.90%
PI	0.74	0.11	10.56%
DD	0.49	0.07	6.96%
LU	0.32	0.05	4.62%
ST	0.22	0.03	3.18%
Total	7	1.00	100.00%

5. RESULTS AND DISCUSSION

By integrating the data analyzes previously explained in hydrological modeling, it is possible to obtain calculations of the discharge and volume of the surface runoff at the outlet of the watershed affecting the village of Hegaza- Bahari. The hydrographs by HEC-1 at the outlet of the watershed for different return periods as shown in figure 12. The seven criteria used in this study were combined according to the weight of each criterion calculated by AHP in the GIS-ModelBuilder as shown in figure 13 to produce a flood hazards map shown in figure 14.

Hazards within the Wadi Hegaza-Bahari watershed are classified using geographic information systems (GIS) into five classes, where class 5 indicates very high hazard (its area is. 0.4% of the total area) while class 4 indicates high hazard (its area is. 2.5% of the total area), class 3 indicates medium hazard (its area is. 10% of the total area), class 2 indicates a low hazard (its area is. 37% of the total area). Finally, class 1 indicates a very low hazard (its area is. 50.1% of the total area).

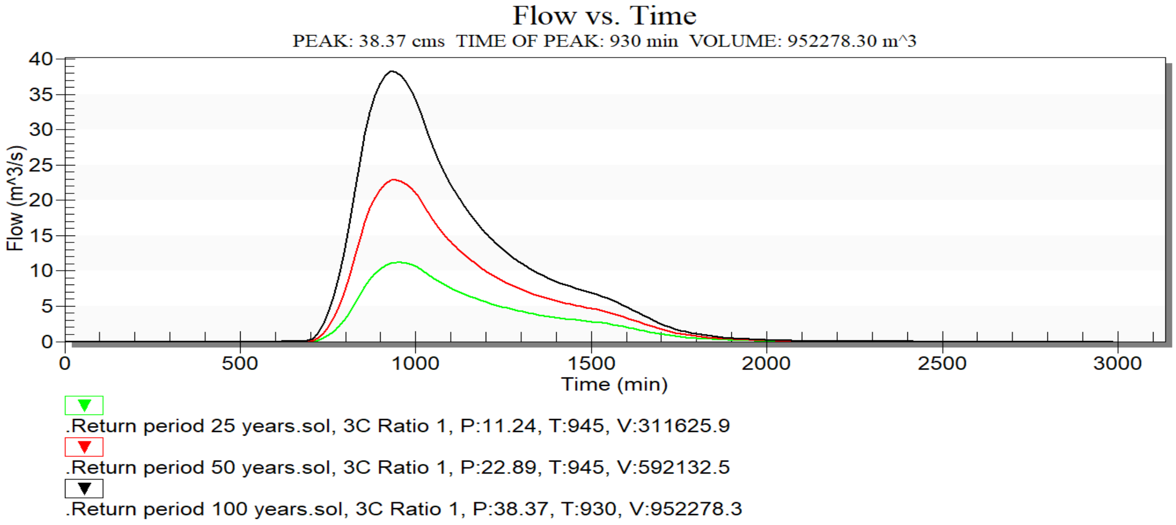


Figure 12. Hydrographs at watershed outlet for different return periods by HEC-1

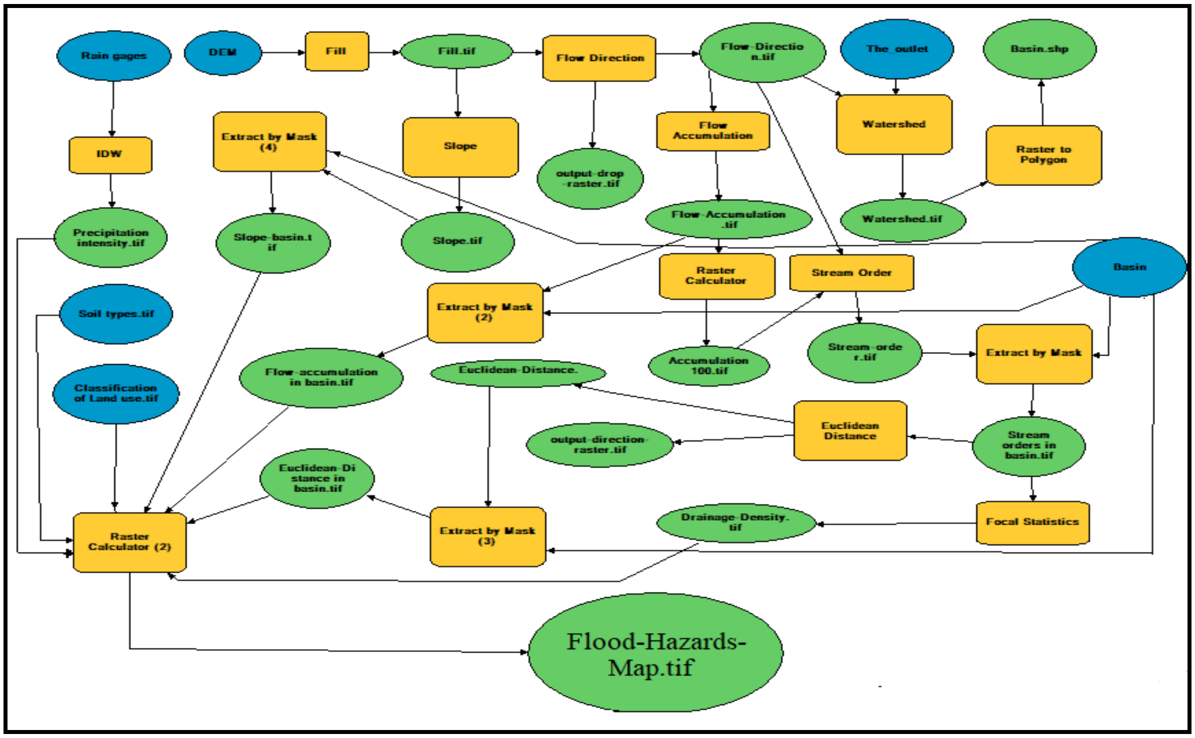


Figure 13. GIS-MCDA and flood hazards map.

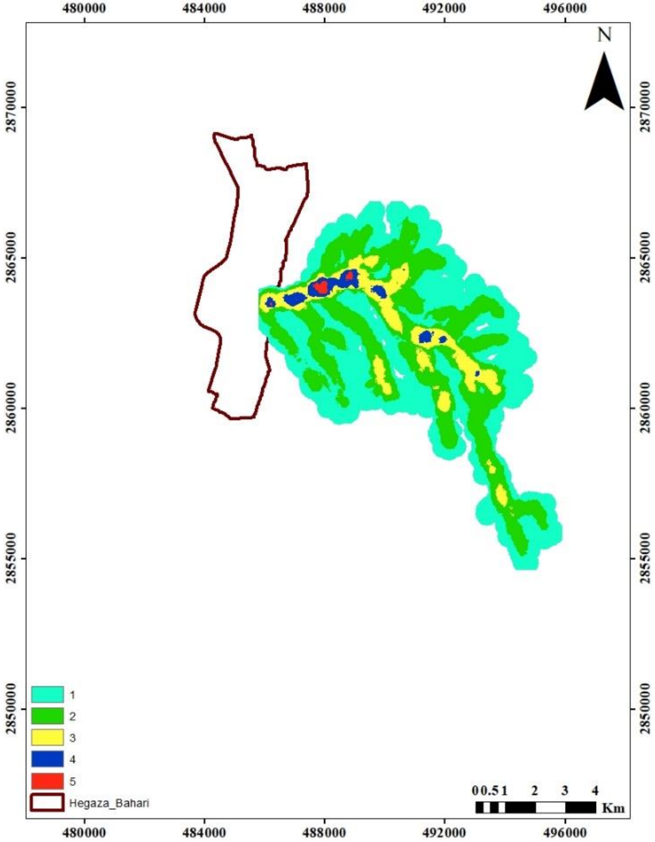


Figure 14. Flood hazard in Hegaza-Bahari Village.

6. CONCLUSION

Based on the obtained results, the following conclusions were deduced:

- MCDA integrated with GIS-MCDA visualized local flood hazard assessment mapping that will assist decision-makers in the execution of flood hazard management activities.
- Mapping the flood hazard index will contribute in planning safe areas, which will achieve the sustainable urban development, in terms of Egypt Vision 2030.
- WMS (HEC-1) has a high capacity for extracting drainage streams, drainage basins, and morphological characteristics.
- The maximum discharge value was calculated throughout 25- 50-100 year.
- Modelbuilder visualized Hegaza-Bahari Village as a watershed coming from Red Sea Mountain with an area of 53.82 km^2.
- Total length of streams that affect Hegaza-Bahari Village is 140.84 km.
- The obtained results will assist flood hazards management activities and will contribute in rehabilitating watersheds to withstand flood disasters.

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