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GIS-Based Multi-Criteria Decision Analysis for Flash Flood Hazard and Risk Assessment: A Case Study of the Eastern of Minya Area, Egypt †

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Abstract: Flash floods are considered one of the most devastating and frequent extreme climatological natural hazards in the world. El Minya is one of the most vulnerable area in Egypt for flash flood problems. It was affected by several hazardous historical flash floods events. These events could lead to both catastrophic losses of life and severe damage to infrastructures of study area. The study area is located in the middle of Egypt about 240-km southern of Cairo, It is situated along the Limestone Plateau facing El Minia governorate. The main objective of this study to assess the flash flood hazard and risk in along the human activites in the study area. An integration of Geographic Information Systems with Multi-Criteria Decision Analysis Approach were used for Mapping Flash flood hazard and risk in the watershed area. A significant Criteria including Geology, Hydrology, Topography, Soil, Land Cover, and Rainfall data were chosen to evaluate the hazard map. Remote sensing imagery was used for Land Use /Cover Mapping to assess the vulnerable human activites. ArcGIS–based Weighted Overlay Modeling was used to combine the criteria to calculate the final decision map.

Keywords: Flash Flood; Multi-Criteria Decision Making Analysis; Minya; GIS-AHP; Weighted Overlay Modeling

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1. Introduction

Flash floods are one of the most devastating natural disasters in the world, it causing damages of properties and killing more than 5000 people every year and register the highest mortality rate among the other riverine and coastal flooding disasters [1].

Egypt is consider one of countries that suffering from flash floods hazard and risk in mountains and nearby areas, every year peoples, human activites, urbanized areas and infrastructure threaten by rainwater inundation. In the last few years, Egypt has experienced several flash floods events that caused serious damages and loss of lives, infrastructures and buildings. The analysis of historical flash floods events over Egyptian land indicate that the eastern desert was received a highly destructive repetitive flash flood events started in 1979 along El-Quseir and Marsa Alam, which killed 19 people and destroyed the coastal highway. Flash flood of Marsa Alam city which happened in 1991 and cause big-damage, Alexandria city flash flood that killed 21 people in 1993, as well as, a well knowing flash flood happened in 1994 and caused severe damages of infrastructure and loss of lives in Assiut governorate [2].

In October 2016, a devastating flash flood event has strike Ras-Gharib city, killed dozens, and caused damage of infrastructure [3]. Minya area has been affected by several flash flood events since 1975; a heavy rainfall happened in Upper Egypt. It destroyed about 180 houses and displaced 1500 citizen [4]. In November 1997, a flash flood effected the area of study and killed 53 person, and destruction of 260 houses [4]. Recently, In

March 2020, a heavy rainfall flashflood has strike the area, it cause land subsidence and a huge damages of EL Geish highway, infrastructure, and settlements.

Figure 1. Photographs show destruction of El Geish Highway by March 2020 flash flood. Source: https://www.youm7.com (Online Newspaper published in 14 March 2020).

Geographic Information System (GIS) is an important technique that provides the capacity to design geospatial identities, analyzes, and manipulates of spatial information. This information can be managed and organized through attribute tables. The tabulated data linked to the geographic features, which may contain multiple quantitative and qualitative information.

GIS-based AHP calculations is very important to reveal spatial trends and relationships between geospatial data and retrieving valuable information for decision making [5]. Multi-Criteria Decision Analysis (MCDA) is a decision-making technique developed to make solutions of the complex-decision problems [6]. The GIS-MCDA uses Analytical Hierarchical Process (AHP) method for controlling and arranging the parameters to investigate complex decision [7]. The GIS-MCDA method has ability to process and combine different types of geospatial data (rainfall map, land cover, soil types, slope map, drainage density); results can be visualized and presented in maps [5]. It is very important spatial decision tool for spatial planning and management issues [8,9]. Integration of GIS and MCDA has been globally applied to assess flood hazard and risk assessment in Greece [6,10], Iran [7], Malaysia [11], Saudi Arabia [12], and in India [13].

2. Study Area

Minya area located about 240 km southern of Cairo city the capital of Egypt on the crossing of (Longitude 31° 30′ N, Latitude 28° E). The drainage basin were selected for study has two large valleys (Wadi al-Tarfah and Wadi al-Bustan) crossing the limestone plateau. The mouth of the basin situated in the eastern of Beni-mazar city in the North-eastern Minya city. The area of study is extending to cover most of eastern part of Minya governorate; it is cover an area 10,682.9 Sq. km. as shown in Figure 2.

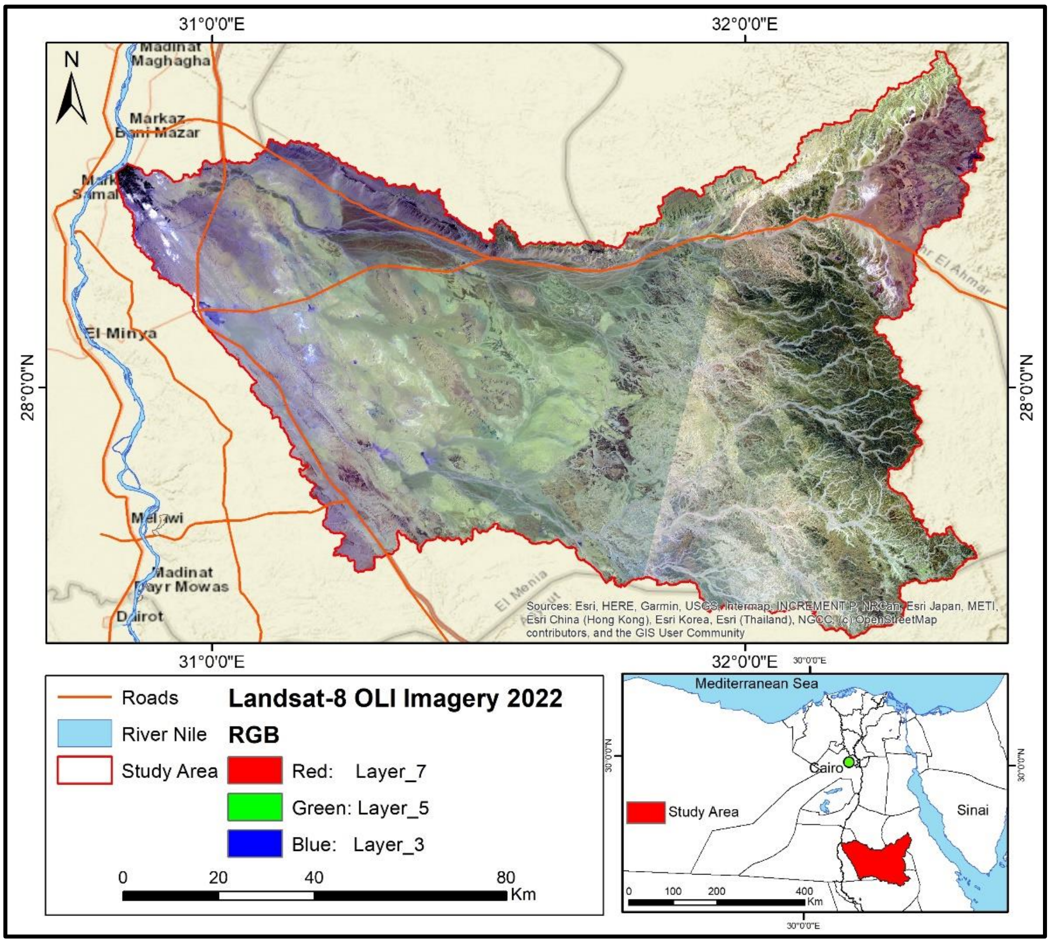

Figure 2. Location Map of Study Area.

3. Materials and Methods

Satellite remote sensing and GIS data were collected for this study to generate the flash flood hazard map based on the AHP technique as shown in the flowchart in Figure 3. Six significant flood-controlling factors were selected based on the physical and natural properties of study area including (Elevations, Slopes, Soils, Hydrology, Land Cover, Geology and Rainfall). GIS-based MCDA has the ability to examine multi criteria factors thematic maps using weighted overlaid analysis to assess the flash flood hazard map and risk along human activites [6,7].

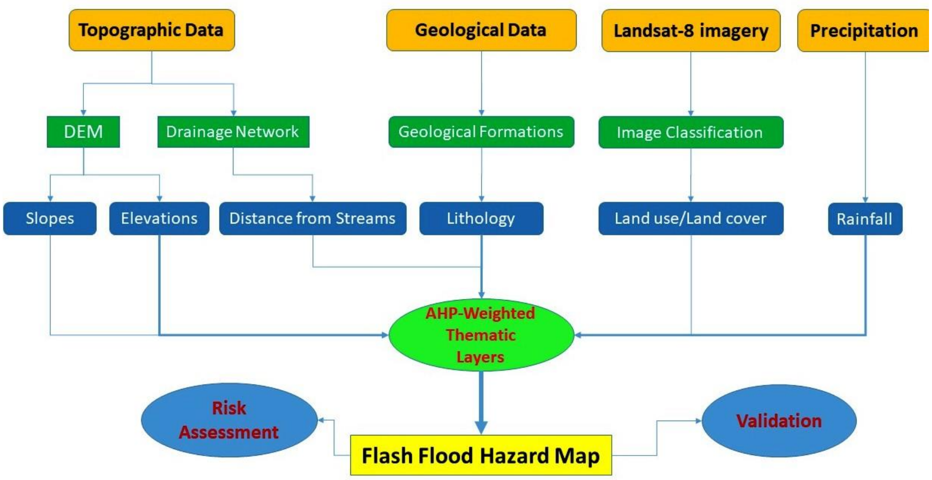

Figure 3. Flowchart show MCDA method applied in this study.

The Analytical Hierarchy Process (AHP) has been applied in this study to assess the flash flood hazard and risk in the watershed of study area; spatial criteria used in this study come from Geology, Topography, Rainfall, Hydrology, Soil, and Land Cover Maps.

3.1. Lithological Data

The Egyptian Geological map of study area scale 1:500,000 were digitized and analysed to identify the lithological units, three major geological formations were detected. (1) Quaternary deposits including Sand Sheets, Wadi Deposits, and Gravels. (2) More than 80% of study area is covered by Eocene Limestone formations include the Samalut, Minia, Maghagha, Observatory, Qarara, and Thebos formations. In addition (3) The Cretaceous formations which include Rakhiyat, Galala, Sudr, Umm Omeiyed, Hawashiya, and Wadi Qena Formations as shown in Figure 4. Geological Formation is very important for permeability map that effect in flash flood hazard.

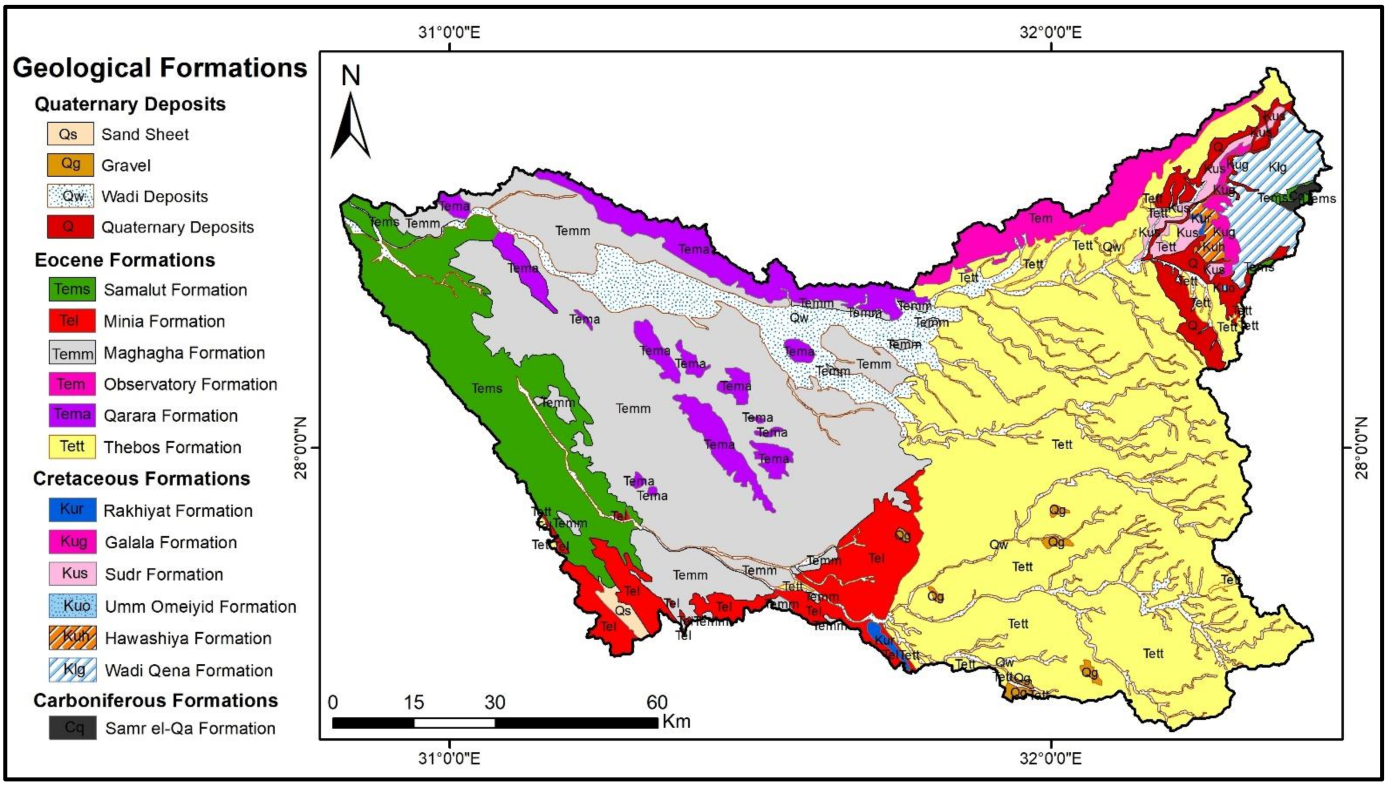

Figure 4. Geological Formations of Study Area.

3.2. Topography

Topographic analysis is a significant factor for flash flood hazard and risk assessment, satellite based Digital Elevation Models (DEM's) include SRTM-1arc second (30-m spatial resolution) were downloaded and processed to extract elevations, contours, slopes, aspects, and hydrological analyses as shown in Figure 5a–c.

3.3. Watershed Delineation

Hydrology is consider the main effective factor in Flash flood intensity and its risk. ArcGIS-based Spatial Modeler used to delineate and mapping stream orders, Flow accumulation, Flow Direction and Watershed using Strahler equation. The drainage basins has been selected for study contain two large valleys as shown in Figure 5e.

3.4. Rainfall (mm)

The climate is one of the most important factors, which directly effects on intensity of flashflood and run off processes. Satellite based Rainfall data of this study area were collected and analysed from 2015-2020. (https://power.larc.nasa.gov/data-access-viewer/). Figure 5d show a spatial surface estimation of the rainfall data using IDW interpolation method.

3.5. Land Use/Land Cover (LU/LC)

Landsat-8 OLI imagery taken in 2022 were downloaded from the USGS website. Pre-processing were done and then unsupervised classification algorithms were used to map the Landuse/cover classes for study area. This map is significant for Flood hazard and risk assessment.

3.6. Hydrological Soil Group (HYSOGs250m)

The global Hydrological Soil Group data were downloaded from the website: https://daac.ornl.gov/SOILS/guides/Global_Hydrologic_Soil_Group.html to identify the geographic distribution map of soils inside the study area, three different soil categories were detected in the study area as shown in Figure 5f.

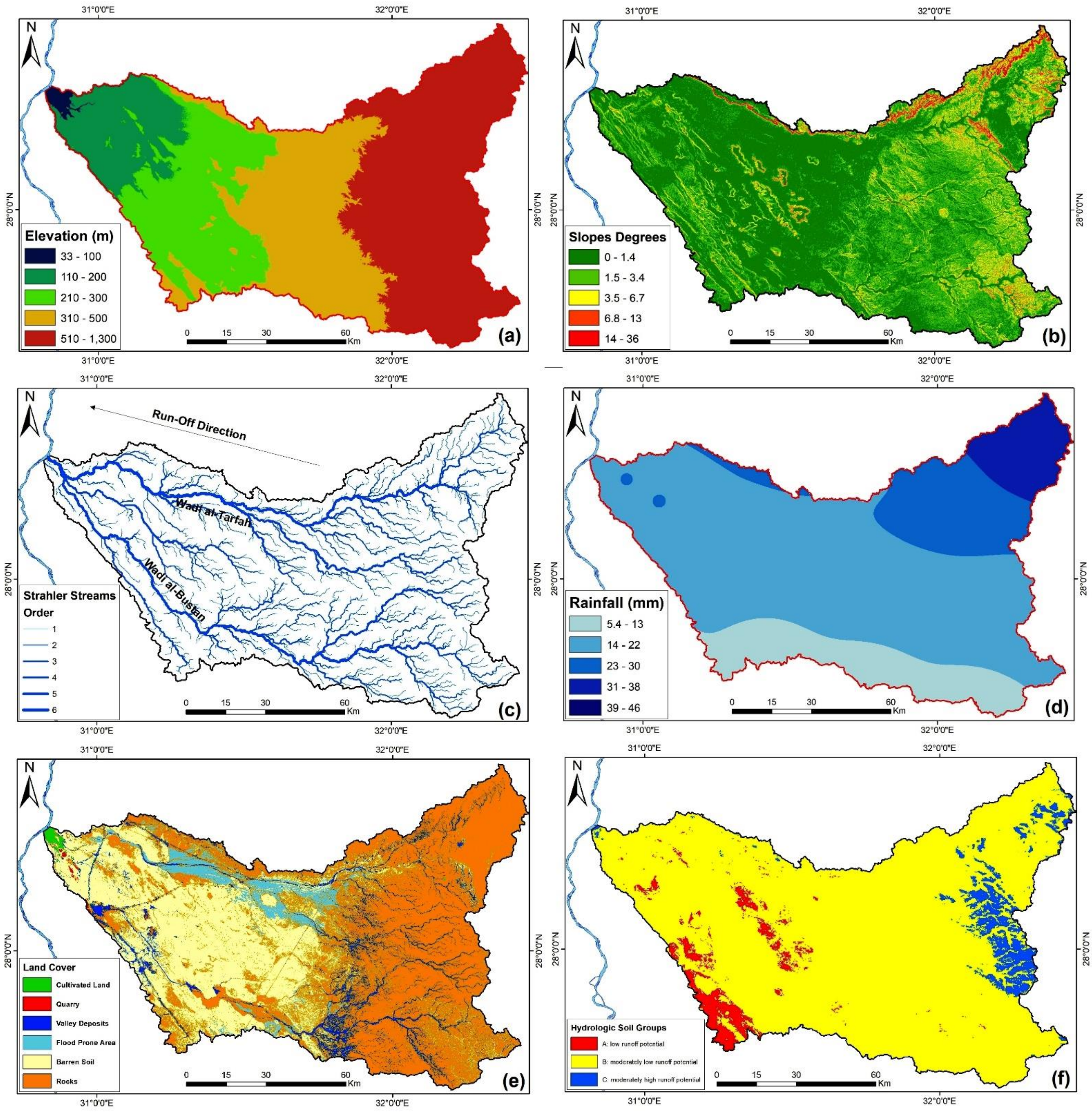

Figure 5. Multi-Criteria Applied In This Study. (**a**) Elevation (m); (**b**) Slopes Degrees; (**c**) Streams; (**d**) Rainfall from 2010-2020 in mm; (**e**) Land use/Land cover in 2020; (**f**) Hydrological Soil Group based HYSOGs250m.

4. Results and Discussion

Eight selected spatial criteria that applied in this study have been reclassified to hazard degrees for each factor separately from (1 to 5 values) (very low to very high) respectively as shown from Figure 6.

4.1. Topographic Hazard Zonation

Five-hazard degrees were assigned for Topography, the lowest elevation land consider a higher rate of flash flood than the highest elevated area.

4.2. Slopes Hazard Zonation

The slopes degrees is a topographic factor refer to the flow speed of the rainfall-Run-off water, the areas with less slope degrees are consider at risk with flood and inundation than the steep slope cliffs.

4.3. Distances from Wadis (Rivers) Zonation

The surrounded land of the channels is much prone to effect by floodwater. In this study the 3rd, 4th, 5th and 6th stream orders are consider the main channels that filled by water during floods. 200-m buffer zone is consider the Very High risk zone, while the land far with 1000 m from the main channels is safe area.

4.4. Drainage Density Hazard Zonation

It is a hydrological factor refers to number of streams in the study area. GIS is capable of calculate the line density of streams in the sq. km. Areas with a higher density consider at risk than the lower density areas.

4.5. The Permeability Hazard Map

Study area has different geological formations, the quaternary deposits considered as permeable land (low risk area). While, the Eocene limestone formations were considered semi-permeable zone (moderate risk). The carboniferous formation is much older considered impermeable zone (high risk).

4.6. The Soil Group Hazard Zonation

Three soil groups were selected. The group (A) is consider lowest hazard zone, because it refer to sand deep sandy soils with very high intrusion rates. The group (B) is moderate hazard zone because it is relatively fine grains soil with moderate intrusion rates. Moreover, the group (C) is consider the highest hazard degree zone in this study area because it show a fine grains soil with low intrusion rates.

4.7. Land Use/Land Cover Hazard Map

The classified of satellite imagery of study area produced several classes of land cover categories. The classes of dry valleys, Wadi paths and flood prone area consider the highest risk areas. While, the cultivated land is less risk.

4.8. The Precipitation Hazard Map

Rainfall data density were classified into five- hazard zones according to the amount of rainfall (mm). The higher rainfall area assigned as a higher risk area.

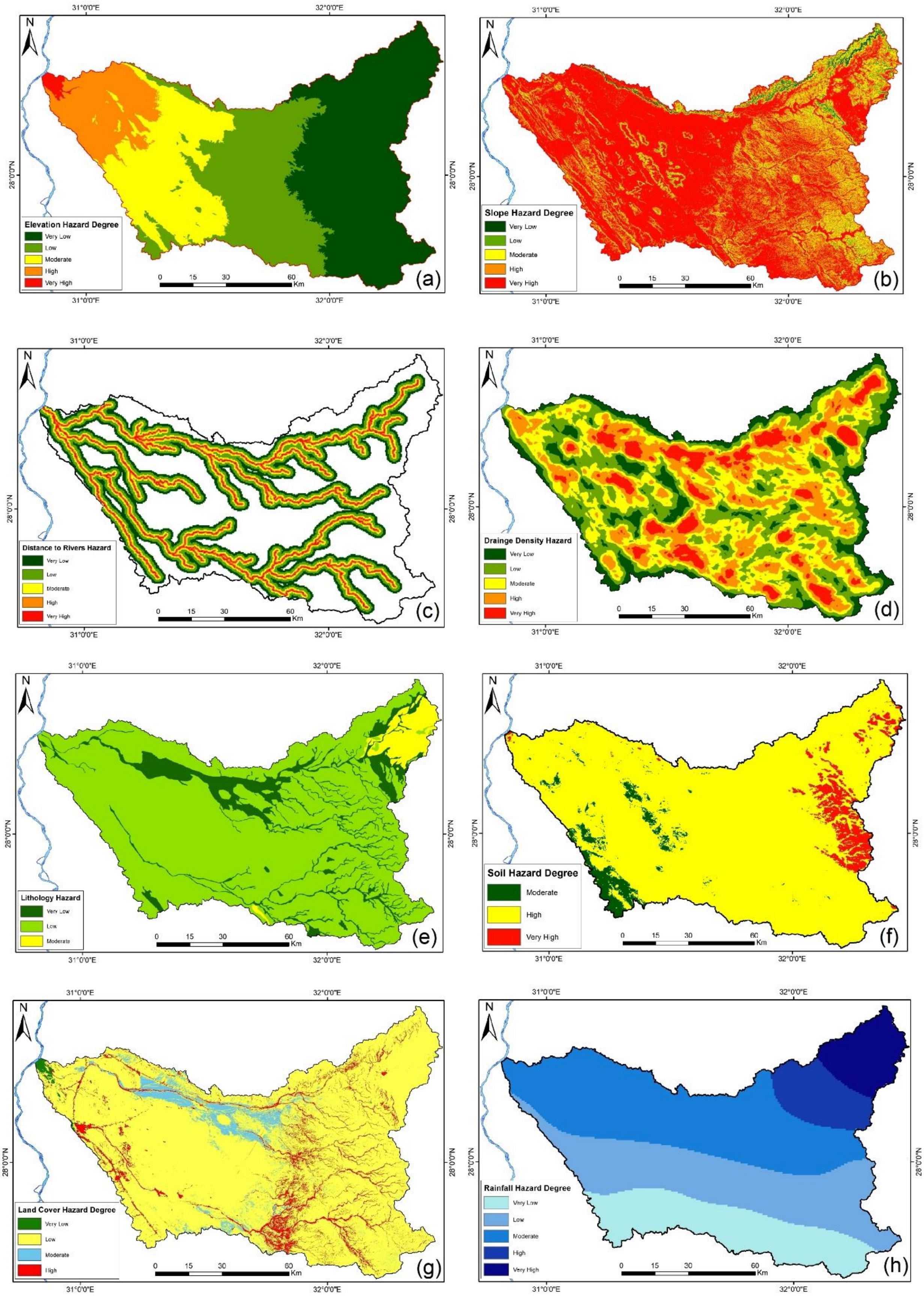

Figure 6. Spatial Multi-Criteria Hazard Zonation. (**a**) Elevation; (**b**) Slopes; (**c**) Distance from Rivers; (**d**) Drainage Density; (**e**) Lithology; (**f**) Soil Hazard; (**g**) Land Cover Hazard; and (**h**) Rainfall.

Multi-Criteria Decision Making Analysis techniques is using the analytical hierarchy process analysis which link between multi-spatial data in the same scale. To apply these techniques, the Weighted Overly Modeling were used to calculate weight of each factor and linked all factors together using mathematical equations. Table 1. Show Pairwise comparison matrix for factor criteria (selected 8-factors). In addition, the percentage of importance criteria values, which calculated in this study, is shown in Table 2.

Table 1. Pairwise comparison matrix for factor criteria.

Factors	El	SL	Li	RF	DoR	DD	LC	Sg
El	1	2	1	1	3	7	1	1
SL	1/2	1	2	8	2	6	4	2
Li	1	1	1	3	3	3	2	3
RF	1	1/8	1/3	1	1	2	2	2
DoR	1/3	1/2	1/3	1	1	1	2	4
DD	1/7	1/6	1/3	1/2	1	1	3	3
LC	1	1/4	1/2	1/2	1/2	1/3	1	3
Sg	1	1	1/3	1/2	1/4	1/3	0	1
Sum	5.98	5.04	5.83	15.50	11.75	20.67	15.33	19.00

El: Elevation, **SL**: Slopes, **Li**: Lithology, **RF**: Rainfall, **DoR**: Distance from Rivers, **DD**: Drainage Density, **LC**: Land Cover, **Sg**: Soil Groups.

Table 2. Percentage Values of Importance using the Analytic Hierarchy Process (AHP).

Factors	El	SL	Li	RF	DoR	DD	LC	Sg	Sum	Criteria Weight	Criteria Weight %
El	0.1673	0.3967	0.1714	0.0645	0.2553	0.3387	0.0652	0.0526	1.5118	0.1680	17
SL	0.0837	0.1983	0.3429	0.5161	0.1702	0.2903	0.2609	0.1053	1.9677	0.2186	22
Li	0.1673	0.0992	0.1714	0.1935	0.2553	0.1452	0.1304	0.1579	1.3203	0.1567	16
RF	0.1673	0.0248	0.0571	0.0645	0.0851	0.0968	0.1304	0.1053	0.7314	0.1013	11
DoR	0.0558	0.0992	0.0571	0.0645	0.0851	0.0484	0.1304	0.2105	0.7511	0.0935	10
DD	0.0239	0.0331	0.0571	0.0323	0.0851	0.0484	0.1957	0.1579	0.6334	0.0804	9
LC	0.1673	0.0496	0.0857	0.0323	0.0426	0.0161	0.0652	0.1579	0.6167	0.0785	8
Sg	0.1673	0.0992	0.0571	0.0323	0.0213	0.0161	0.0217	0.0526	0.4677	0.0620	7
Sum										1.00	100

The result map from this study is presented in Figure 7. Three different hazard and risk zones were identified using the previous criteria, The Higher hazard Degree Zone has displayed in the red Color in the downstream run-off water, the main highway of Elgeish Road and Minia–Ras Ghareb Highway as well as the cultivated land along the fluvial fans will seriously affected with the downstream water. The Moderate hazard zone is covering a larger area surrounded with the human activites.

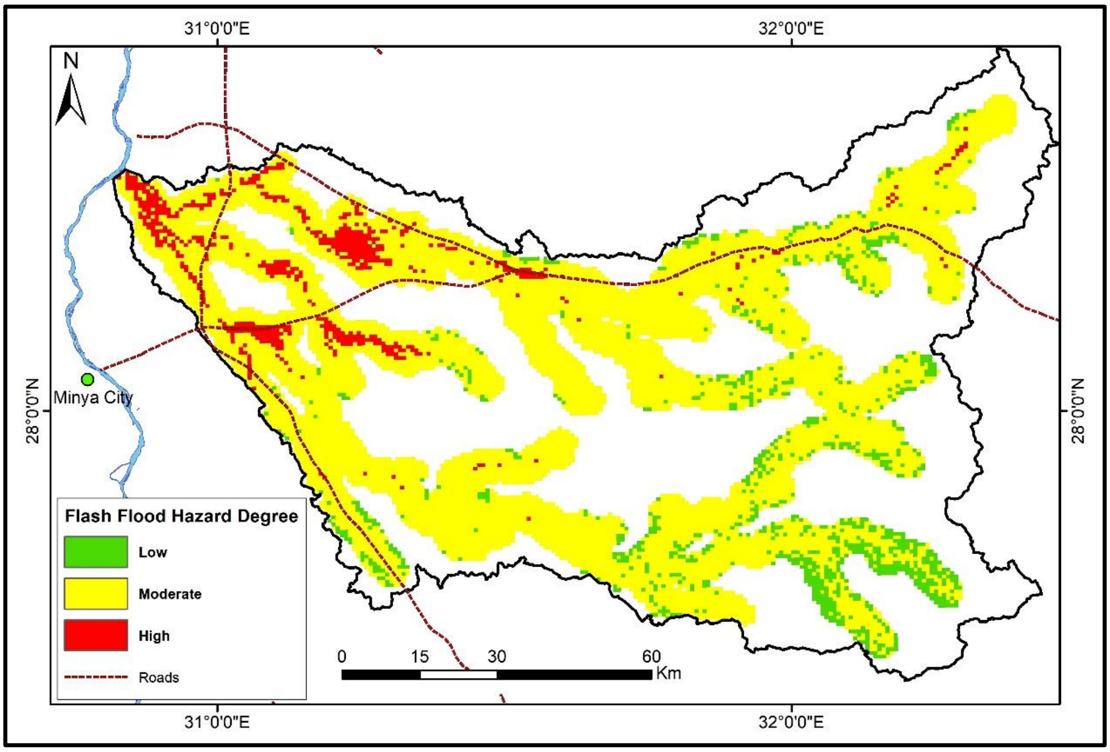

Figure 7. Flash Flood hazard Map based on MCDA.

5. Conclusions

This study applied the Multi-criteria Decision Making Analysis Approach in Geographic Information Systems. It was used in several studies around the world and recommended for the flash flood hazard and risk mapping. There is no previous studies applied this techniques for assessing flash flood in this study area. This technique is consider the most effective because it has the ability to link between multi-sources spatial data at the same scale to detect the best geospatial solution for decision makers. In this study, the available criteria were used and combined in the weighted overly modeling in GIS to map the vulnerable areas with flash flood in a watershed basin in Middle Egypt. The results of this study show a higher flood zone in the downstream area, this area is occupied with highways, cultivated lands, and human settlements. It is highly recommended to use MCDA-based AHP techniques for Flash flood hazard and risk mapping in the future studies.

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Conflicts of Interest: The authors declare no conflict of interest.

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