

# Mapping Flash Flood Potential and Risk Level Using GIS Techniques and the Flash Flood Potential Index (FFPI) in Amman Zarqa Basin of Jordan

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Jordan is located in an arid and semi-arid climatic zone, where about 80% of the country, known as the "Badia". Generally, this is classified as a dry or arid region. Climate change is expected to exacerbate the current aridity and scarcity of water resources in Jordan. Sudden and extreme weather events are becoming more common; this likely means longer and drier summers, more severe droughts, harsher winters, and an increase in flash floods. Jordanian Civil Defense reported that during 1963-2019, 451 people were killed and about one million people affected by flash floods. This research aims to determine the critical locations of flash floods in the Amman Zarqa Basin. This research methodology depends on using four variables (slope, vegetation cover/density, soil type/texture, and land use/cover) under the GIS environment to calculate the Flash Flood Potential Index (FFPI). This index has not been used in Jordan (up to our knowledge). Five scenarios were used in this study, based on previous reviews and the last one (scenario 5) based on Jordanian experts of flash floods in Jordan. The results show that increasing the weight of slope and land use in different FFPI equations will increase the values of FFPI. Reducing the vegetation density by 50% resulted in limited effects on the importance of FFPI. The risk level is divided into four categories (extreme, high, medium, and low) related to the FFPI values. Scenario two, which uses equal weights for all parameters, had the lowest risk level all over the area. Scenario four, which double the consequences of the slope and the land use with respect to the other two parameters. This has the highest risk level over the study area. Based on equation no. 5, which is modified based on Jordanian experts' opinion, the low-risk level covered 9.01% of the basin. Besides, the medium, high, and extreme risk levels covered 72.96%, 15.89%, and 2.14% of the study area, respectively.

Keywords: flash floods, FFPI, climate change, risk level, Jordan

## Introduction

Climate change is among the worldwide natural phenomena that have received the most consideration in different life domains. In 2014 IPCC reported an increase in the extreme precipitation events in various locations globally, which implies high flood risks. The flash flood due to climate change impact that creates a negative effect on human and natural systems. These phenomena are becoming more frequent and have detrimental environmental, economic, political, and security implications. Thus, researchers assessed flash flood exposure and vulnerability in areas around the world (White (1975), Tobin (1986), Hughey (2006), Ruin *et al.*, (2008), Fuchs (2009), Creutin *et al.* (2013), Almomani and Shawaqfah (2013), Spitalar *et al.* (2014), Fuchs *et al.*, (2015), Terti *et al.*, (2015), Karagiorgos *et al.*, (2016a, 2016b)). The American Meteorological Society (AMS (2000) defined the flash flood as "A flood that rises and falls quite rapidly with little or no warning, usually as the result of intense rainfall over a relatively small area" (AMS, 2000). Hydrologists and experienced forecasters are aware of areas that are most prone to flash flooding. Still, precisely these areas are and which sites are the most vulnerable have often not been studied in detail or adequately documented. Creating a "Flash Flood Potential Index (FFPI)" will, therefore, help to represent how "flashy" the land is in certain areas. An index such as this will significantly improve the flash flood warning accuracy. Smith (2003) was the first researcher who developed an FFPI for the Colorado River basin by considering four factors: slope, vegetation cover/density, soil texture, and land use. Additional FFPI studies were carried out by (Kruzdlo (2010), Ceru (2012), Zogg and Deitsch (2013), Arachchige and Perera (2015), Teodor and Matreata (2011), Zaharia *et al.* (2012), Minea (2013), and Pravalie and Costache (2014)). This investigation utilizes the FFPI model to recognize zones with high flash flood likely dependent on an assessment of physiographic factors controlling the development of flash floods in the Amman Zarqa Basin (AZB). The original FFPI equation was developed by Smith (2003) using equation (1). This investigation utilizes the FFPI model to recognize zones with high flash flood likely dependent on an assessment of physiographic factors controlling the development of flash floods in the Amman Zarqa Basin (AZB).

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The original FFPI equation was developed by Smith (2003) using equation (1). Each input parameter has a scale from 1–10, divided by the sum of weightings ( $N$ ) to determine the overall FFPI between 1–10.

$$FFPI = \frac{(n(M) + L + S + V)}{N} \quad (1)$$

Where  $n$  is the slope layer weight ( $>1$ ),  $M$  is the land Slope,  $L$  is Land Cover/Use,  $S$  is Soil Type/Texture,  $N$  is the sum of weightings (With  $L=S=V=1.0$  and  $M>1.0$ ). In 2009 Brewster modified the original FFPI (Smith (2003)) for application in Binghamton, NY. The modified FFPI provided more considerable weight to the slope and less weight to the vegetation cover than the land use and soil type, indicating a high potential for flash flood in the areas with the highest slope (equation 2).

$$FFPI = \frac{(1.5(M) + L + S + 0.5(V))}{4} \quad (2)$$

In 2010, Krzudlo, used an equal weighting pattern for equation (1) and applied FFPI for State College, Pennsylvania.

$$FFPI = \frac{(M + L + S + V)}{4} \quad (3)$$

Ceru (2012) modified equation (3) by giving extra weight to the slope and land use/cover based on hydrologists consultant advice from the Mid Atlantic River Forecast Center (equation (4)).

$$FFPI = \frac{(M + L + S + V)}{N} \quad (4)$$

Where  $N$ =Number of input variables, ( $S$  and  $V$  are given weights of 1,  $N$  is greater than 4, as the slope and land use/cover were given a value greater than 1. These four equations describe the flash flood potential index quantitatively based on the study area (slope, land cover/use, and soil type/texture and vegetation). They, therefore, can be used to identify flash flood-prone locations. In 2013, Zogg and Deitsch used various weights for the physiographic parameter to acquire the best outcomes. Their study shows that the most significant slope zones will be represented better when using the slope in percent than using gradient degrees.

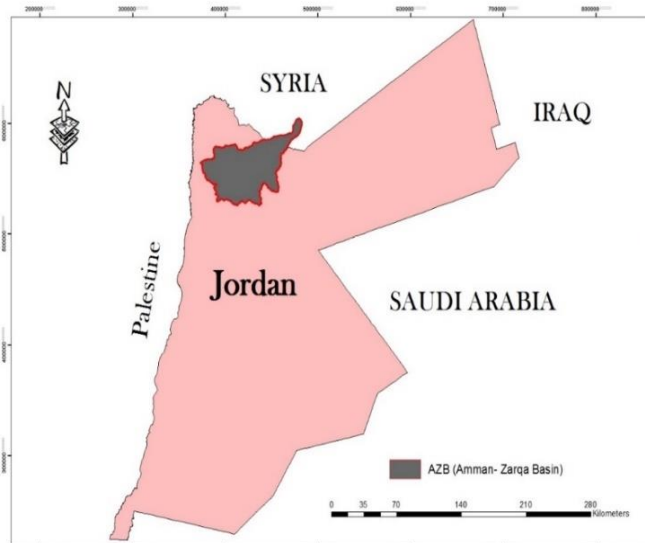
## 1 Material and Methods

### 1.1 Study Area

The study area is shown in **Figure 1** (Amman Zarqa Basin or AZB) of 3918 km<sup>2</sup> lies between the lines of Jordan, JTM (Jordan Transverse Mercator). Coordinates E370 and E470, N525 and N585 (89% is located in Jordan and 11% inside Syria). The largest axis of the basin (116km) extends from north northeast to south-southwest, and its perpendicular axis is about 67km.

#### 1.1.1 Topography

The topography in the basin changes from west to east, where the hilly areas comprise a large part of the western and the surrounding regions along the basin's boundary. Altitude gradually decreases towards the center of the basin and the Jordan Valley's catchment outlet near Deir Allah in the west (AlMahamid, 2005). From the center of the catchment, the altitudes increase towards the northeast into Syria. The highest point of the catchment (1570 m above mean sea level (a.m.s.l.)) in Jabel El-Arab/Jabel El-Druz is located north of Salkhad town Syria. The lowest point in the catchment is about 140 m below mean sea level (b.m.s.l) near Deir Allah town in Jordan (**Figure2**). The whole catchment's general slope is relatively high, although the central and eastern part is almost flat plateaus surrounded by hills from the west and south, which have the highest gradients. The slopes of the mountains are modest in most of the catchment area. The slopes do not exceed 15% and are mostly well below 5%. Gradients of 15% to 30% are standard in the western part (lower part) of the catchment. Steep slopes that exceed 30% occur only in hilly places in parts of the west of northwestern highlands, and in some cliffs, along wadis, the slopes reach 70%. In the eastern part of the catchment near Qasr Al-Hallabat, there is a



**Fig.1** Location map of the study area Highlighted is the Amman-Zarqa Basin (AZB).

mudflat of about 500 km<sup>2</sup>.

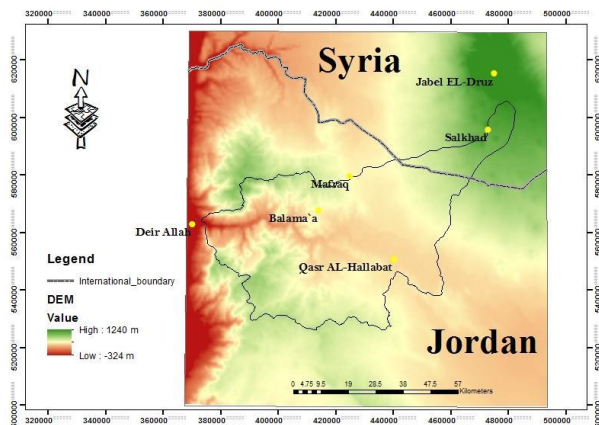


Fig. 2 DEM of Amman-Zarqa Basin (AZB)

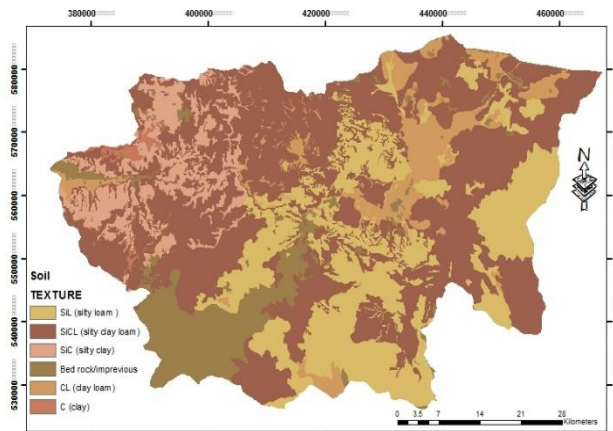


Fig. 3 Soil Texture of Amman- Zarqa Basin (Hammori *et al.*, 2015).

Soil Texture at a particular location can be determined based on different parameters (temperature, water flow, vegetation cover, land use, solar radiation, rock type, and wind). AZB soil texture can be subdivided into five soil groups depending on the soil texture (Figure 3).

### 1.1.3 Climate

Climatologically, Jordan belongs to the Mediterranean region, described as a dry season (May to September) with relatively high temperatures and a rainy season of lower temperatures in the remaining part of the year. Sometimes have moderate frosty nights and some snowfalls for few days over the highlands (Al Mahamed, 2005). Typically, cold and warm weather fronts and low-pressure depressions move from west-southwest to east-northeast in the southern Mediterranean area during the winter. The cold and warm fronts are steered by depressions that occur over Cyprus and reach Jordan in a southwesterly to northeasterly direction. Also, the orographic effect causes rainfalls in Jordan Valley (western and eastern parts). Thunderstorms of intensive precipitation could occur in the warm months of April, May, and October. In the summertime, no determined air-mass movements affect the region's weather, and no precipitation occurs. From west to east of Jordan, the topography plays the primary role in changing the rainfall and temperature. Rain because of the orographic effect and temperature with the altitude and wind speeds. Evaporation and evapotranspiration are affected by altitude, wind speed, humidity, soil moisture, and canopy cover.

### 1.1.4 Land use

The land use of AZB comprises 65 % bare rock, including urbanized areas, and 35% natural crops, field crops, and trees (Figure 4). More than 90% of the agricultural activities (25.27% from the total area) are located in the western and north-eastern parts of AZB. According to the land-use, which is created based on Landsat imagery. Using High-resolution images (Landsat 8) was downloaded from the website (<http://earthexplorer.usgs.gov/>). After that, the multi-band raster imagery converted to a single-band raster with several categorical land use classes using the supervised classification method, based on the personal user experience. The land use of AZB varies from urban, bare soil, bare rocks, field crops, and Trees; based on the satellite imagery, the total amount of irrigated land is about 17 km<sup>2</sup>. The vegetation density map (IUCN, (2015)) was used to assess the FFPI (Figure 5).

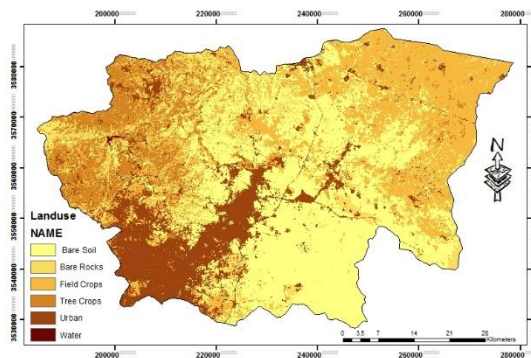
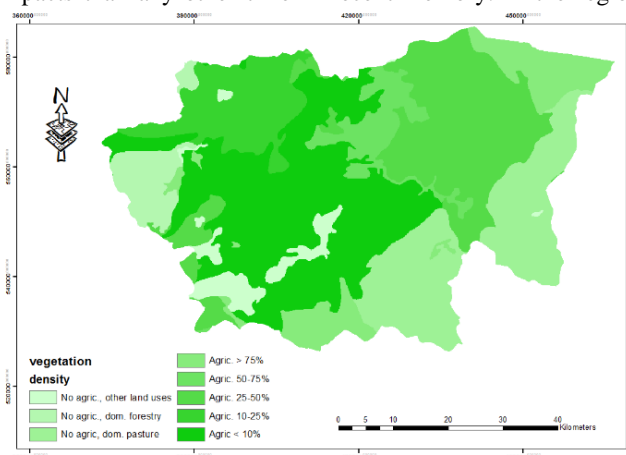


Fig. 4 Land use of the study area.

### 1.2 Flash Flooding in the Study Area

Flash flood events are growing worldwide, with more disastrous impacts than any other time in recent memory. In the regional countries, the synergy of natural disasters, fast urbanization, scarcity of water, and climate change has developed as a severe challenge to decision-makers. Historically, Jordan was affected several times by flood disasters. Recently disasters related to flash floods, landslides, and droughts are becoming more frequent. Although there is no scientific relation is given to prove this phenomenon, but research is still undergoing. These kinds of disasters have caused losses in life and cost millions of economic damages in different parts of the country. **Table 1** presents a summary of the major floods and storms in Jordan since 1963. Jordanian Civil Defense Records shows that during the most recent three decades, flash floods brought about the 451 death. There are fifteen surface water basins in Jordan. Most wadis in AZB are characterized by seasonal flow in the form of flash floods. In addition, there are two rivers (perennial flow), namely Yarmouk and Jordan River.

In the regional



**Fig. 5** Vegetation Density in the study area (IUCN, 2015)

There are eight flood gages in the study area; the first was installed in 1963 on the Zarqa River on the Jerash Bridge (AL0060). Eight gauging floods (**Figure 6**) were installed in the next decade (AL0040, AL0061, AL0062, AL0063, AL0064, AL0065), and the last one was installed in 2002 (AL0070). The analysis of flood events recorded by the above flood gages showed that between 1.6 and 8.1 (average 3.98) runoff events per year occur across the basins (MWI, 2012). The average number of incidents at each flood station in the study area is given in **Table 2**.

**Table 1** Major floods and storms in Jordan since 1963 (compiled from EM-DAT Database and Jordan Civil Defense Statistics).

Disaster	Date	Killed	Affected	Disaster	Date	Killed	Affected
Flood	1963	25	No Data	Flood	2009	6	265
Flood	1964	6	No Data	Flood	2010	7	522
Flood	1966	259	No Data	Flood	2011	7	132
Flood	1987	9	29	Flood	2012	6	491
Flood	1991	11	18,000	Flood	2013	0	2214
Flood	1997	2	No Data	Flood	2014	0	540
Storm	2000	9	200	Flood	2015	4	300,000
Storm	2002	5	125	Flood	2016	3	200,000
Flood	2007	9	169	Flood	2018	35	150,000
Flood	2008	6	185	Flood	2019	42	200,000

**Table 2.** Analysis of the average number of incidents at each station (MWI, 2012)

Stations	Station name	Catchment (km <sup>2</sup> )	Number of incidents	Number of years	Avg. events/Year
AL0040	Wadi Um al Dananeer	37.1	180	43	4.2
AL0060	Zarqa at New Jerash Bridge	3554.3	373	46	8.1
AL0061	Wadi Sleihi	38.0	228	46	5.0
AL0062	Ain Ghazal	155.7	67	16	4.2
AL0063	Wadi Zarqa at Sukhne	642.8	110	30	3.7
AL0064	Wadi Dhuleil at Sukhne	2375.0	40	17	2.4
AL0065	Wadi Abdoun	75.9	68	26	2.6
AL0070	Wadi Zatari	421.6	14	9	1.6

### 1.3 Data and Methods

This study's required data sets collected from different sources (Table 3) shows an example where data were collected. Reclassification of raster maps, each of the four physiographic parameters obtained in the form of thematic raster layer was then reclassified into 10 classes based on their hydrological response of the watershed to flash flood generation with the help of using ArcGIS 10.2 (ESRI (2011)). Class 1 being the least favorable for flash flooding, and class 10 being the most promising for flash flooding. The FFPI values for the attributes of each parameter are shown in Table 4. All thematic maps of the four parameters were indexed to FFPI, as shown in Figures 7. After reclassifying all the data sets, the Raster Calculator in ArcGIS was used to perform the map algebra operations to calculate FFPI in the study area. This primary step's purpose was to average the layers together to construct the flash flood potential index.

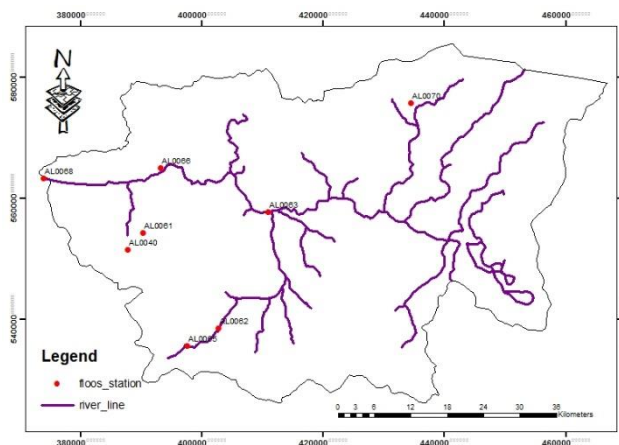


Fig. 6 Gauging Floods in AZB.

Table 3 Data Resources for Amman Zarqa Basin.

	Data set	Resolution	Source
1	Digital Elevation Model	30 m	The CGIAR Consortium for Spatial Information (CGAIR-CSI) ( <a href="http://srtm.csi.cgiar.org/">http://srtm.csi.cgiar.org/</a> ).
2	Soil Data	1:50,000	Ministry of Agriculture
3	Land use/cover	1:50,000	Generated from Landsat 8, 2019
4	Vegetation Cover/Density	1:50,000	IUCN, 2015

Table 4 Assigned FFPI values on each dataset depending on the susceptibility for flash flooding (Smith (2003), Brewster (2004), Kruzdl (2010), Smith (2010), Zogg and Deitsch (2013), and Minea (2013)).

FFPI value	Slope/DEM (Slope%)	Land Use	Vegetation Cover (%)	Soil Type
1	3 and below	Water	90-100	Water/Alluvial
2	6	Woody Wetlands, Herbaceous Wetland	80-89	Sand
3	9	Evergreen Forest	70-79	Sandy Loam
4	12	Mixed Forest	60-69	Silty Loam, Loamy sand
5	15	Deciduous Forest	50-59	Silt/ Organic Matter
6	18	Pasture Hay, Cultivated	40-49	Loam
7	21	Developed/open space, Barren Land	30-39	Sandy Clay Loam, Silty Clay Loam
8	24	Developed/low	20-29	Clay Loam, Sandy, Clay
9	27	Developed/medium	10-19	Clay
10	30 and above	Developed/heavy	0-9	Bed, Rock/Impervious

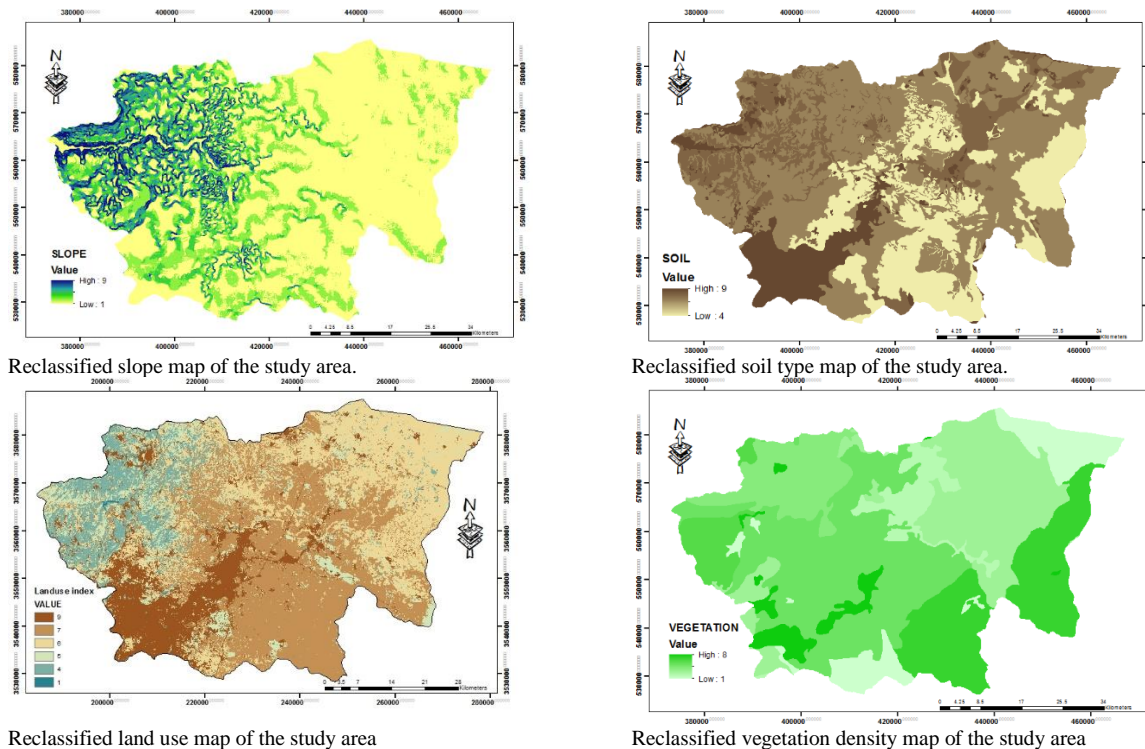


Fig.7. Reclassified maps (slope, soil, land use, and vegetation density).

1.4 Analysis.

The FFPI analysis was prepared based on five different scenarios. Each scenario used different equations (Table 5). Scenario 5 used a weighted formula. The Analytical Hierarchy Process (AHP), which was introduced by Saaty in 1980, is a popular and extensively used method for multi-criteria decision making. The AHP approach allows the use of qualitative, in addition to the quantitative criteria in evaluation. Both qualitative and quantitative information was compared using Jordanian experts' informed judgments of flash floods to derive each criterion's weights. The Jordanian experts were from 7 Jordanian University, two from the Ministry of Water and Irrigation, two from Jordanian Civil Defense, and two from the Jordanian Metrological Department. By using the AHP process, equation (5) was produced.

$$[(M*1.5) + (L*1.32) + (S*1.16) + (V*1.02)]/5 \tag{5}$$

Table 5 Equations used for FFPI scenarios.

Scenario	Equation used	Parameters used	Notes
1	$(1.5M + L + S + V)/4.5$	Slope, land use, soil, vegetation cover	Smith (2003)
2	$(M + L + S + V)/4$	Slope, land use, soil, vegetation cover	Kruzdlo (2010)
3	$(1.5(M) + L + S + 0.5(V)) / 4$	Slope, land use, soil, vegetation cover	Brewster (2009)
4	$(2(M) + 2(L) + S + V) / 6$	Slope, land use, soil, vegetation cover	Crue (2012)
5	$[(M*1.5) + (L*1.32) + (S*1.16) + (V*1.02)]/5$	Slope, land use, soil, vegetation cover	Jordanian Experts (AHP approach)

## 2 Results and Discussion

Applying the methodology described in section 1.3, the spatial representation of each scenario's FFPI values were obtained (Figures 9 through 13). Table 6 shows the percentage of area for each FFPI in each method.

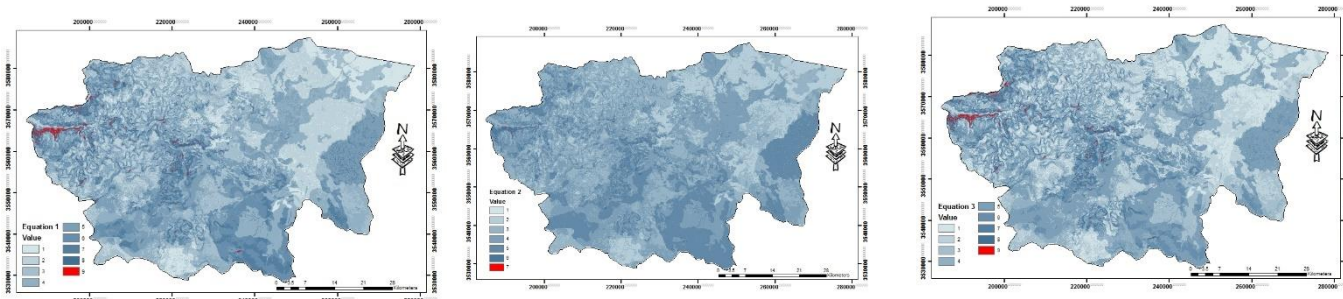


Fig. 9 FFPI of Amman Zarqa Basin-scenario 1. Fig.10 FFPI of Amman Zarqa Basin - scenario 2. Fig. 11 FFPI of Amman Zarqa Basin - scenario 3

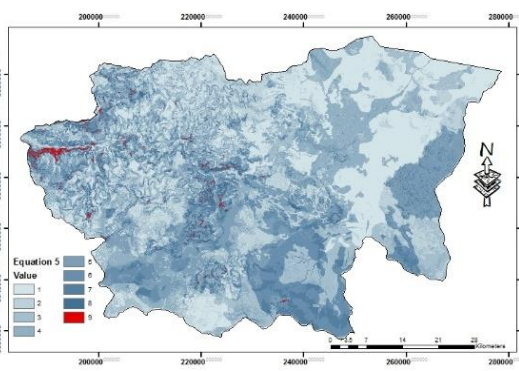
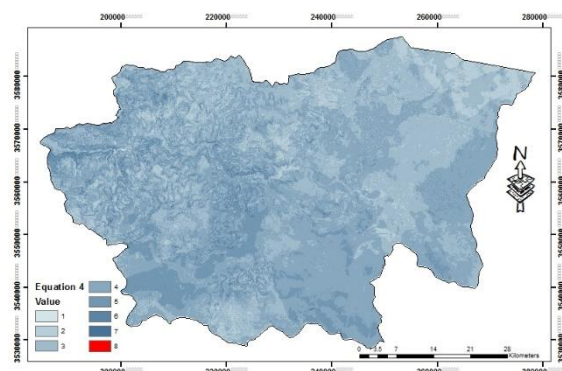


Fig. 12 FFPI of Amman Zarqa Basin - scenario 4.

Fig. 13 FFPI of Amman Zarqa Basin - scenario 5.

Concerning Scenario 1, which is based on Smith's (2003) original equation, the study area's FFPI values range between 1 and 9 (Fig. 9). The highest values of FFPI are concentrated in the northwestern part of the study area and in Amman city (the capital of Jordan). This is because these areas are more steeply sloped, and the slope is weighted 50% higher than the other parameters in this scenario by 50%. On the other hand, in about 73.27% of the study area, the FFPI values ranged between 2 and 5, reflecting the area's relative flatness. In Scenario 2, the FFPI values range between 1 and 7 (Fig. 10). The highest FFPI values are found in Amman city because this area is heavily developed. Most of the area (59.52%) has FFPI values ranging between 3 and 6.

Table 6 FFPI scenarios.

FFPI	Percentage of Area belong to different FFPI values(%)				
	Equation 1	Equation 2	Equation 3	Equation 4	Equation 5
1	6.93	0.08	13.70	0.00	20.89
2	17.07	19.61	16.01	23.26	14.25
3	16.52	15.88	14.63	24.08	16.36
4	20.96	19.29	17.80	22.71	15.73
5	18.73	24.36	23.09	24.60	13.87
6	12.36	20.62	9.77	2.55	11.56
7	5.51	0.17	3.47	2.58	5.24
8	1.58	0.00	1.20	0.20	1.65
9	0.35	0.00	0.33	0.00	0.45
10	0.00	0.00	0.00	0.00	0.00

The FFPI values in Scenario 3 range between 1 and 9 (Fig. 11). In this scenario, vegetation density was weighted lower (0.5) instead of one. Again, the highest FFPI values are in Amman city. About 55.51 % of the study area has FFPI values ranging between 3 and 5. These results are like scenario 1, which indicates that vegetation's effect was weak in calculating the FFPI in AZB.

In Scenario 4, the weight of slope and land use was doubled. The results show that 94.66% of the study area has FFPI values between 2 and 5 FFPI values. The maximum and minimum values of FFPI are 9 and 1, respectively (Fig. 12). The last scenario (Eqn.(5)), which depended on the Jordanian expert's opinion, showed the more effective flash flood mapping in the study area (Fig. 13). About 50.55% of the study area had an FFPI value between 3 and 5. The most highly ranked FFPI areas are located at the northwest of AZB. The results of each scenario were categorized into one of four classes based on FFPI values using the following equal interval classification to determine the risk level (Zogg and Deitsch 2013):

- Low= $\leq 2.5$
- Medium=Between 2.5–5
- High=Between 5–7.5
- Extreme= $\geq 7.5$

Scenario 5 had the most significant percentage of area related to an extreme and high level of risk as shown in **Table 7**, the main reason behind that the increased weight of slope and land use used in equation 5. On the other hand, equation (2) had 88.72% of the total area with a medium risk level. **Figure 14** shows the risk level map for each scenario compared with the historical risk level map for flash floods produced by IUCN in 2019. Scenario 5 is the most comparable with the historical flash flood in AZB, as shown in Fig. 14.

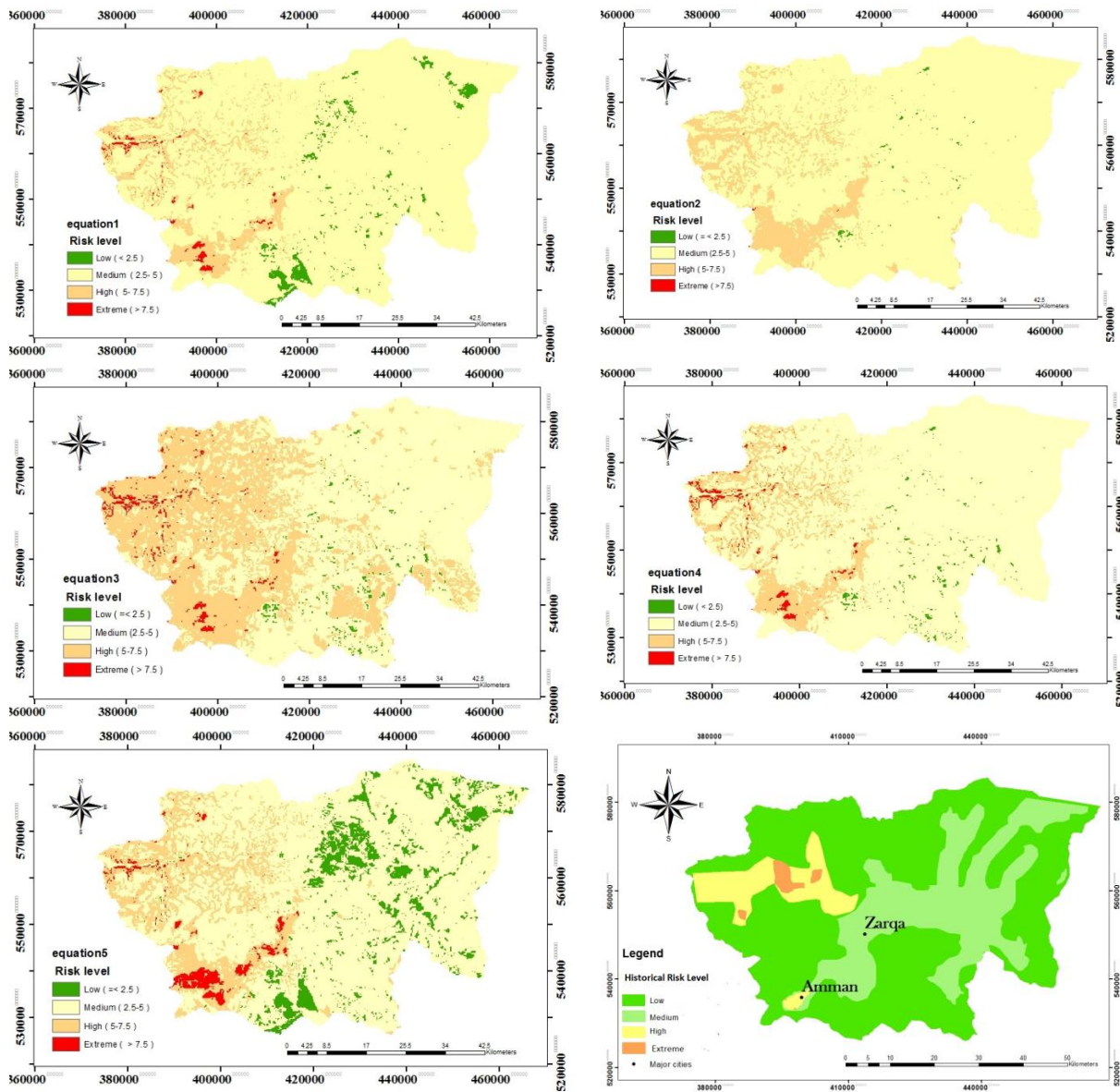


Fig. 14 Risk level map for each scenario compared with historical risk level map for a flash flood.



**Table 7** The percentage of area related to risk level (%).

Risk Level	Equation 1	Equation 2	Equation 3	Equation 4	Equation 5
Low	2.60	0.34	0.97	0.97	9.01
Medium	87.31	86.54	59.48	85.04	72.96
High	9.16	13.10	38.18	12.62	15.89
Extreme	0.93	0.02	1.37	1.37	2.14

## Conclusions

The FFPI is an index allowing researchers and decision-makers to detect susceptible places that can produce flash floods. The FFPI has not been applied to any area in Jordan. Four different scenarios are used in this study based on earlier reviews worldwide. In this research, the last scenario is modified based on the Jordanian expert's opinion on the study area's weights (slope, land use/cover, soil texture/type, and vegetation cover/density). Results showed that the slope and land use weights in the used equations were the most influential parameters in this study. The risk level for all scenarios was investigated, and the results showed that most of the study area would be subjected to a medium risk level.

## Acknowledgments

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## Nomenclature

AHP	=Analytical Hierarchy Process	[-]
amsl	=Above Mean Sea Level	[-]
AZB	=Amman Zarqa Basin	[-]
bmsl	=Below Mean Sea Level	[-]
DEM	=Digital Elevation Model	[-]
FFPI	=Flash Flood Potential Index	[-]
GIS	=Geographic Information System	[-]
IUCN	=International Union for Conservation of Nature	[-]
L	=Land Cover/Use	[-]
M	=Slope	[-]
n	=The weight of the layer	[-]
N	=Sum of weightings	[-]
S	=Soil Type/Texture	[-]

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