GIS-Based Flood Risk Assessment in Urban Areas: Case Study Amman City

Muheeb Awawdeh[1*], Hassan Rwashdeh[1], Khaldoon Al-Qudah[1] and Monther Jamhawi[2]

[1]Department of Earth and Environmental Sciences, Yarmouk University, Irbid, Jordan

[2]Department of City Planning and Design, Jordan University of Science and Technology, Irbid, Jordan

Abstract: Flooding events cause economic, social and environmental damage and lives loss. Flood's magnitude and its consequences are aggravated by human activities in many circumstances such as urbanization. Wadi Ain Ghazal in Amman city has serious flood problems, yet no integrated flood hazard and risk assessment has previously been developed for the basin. This study addresses that gap by assessing flood hazard and risk in Wadi Ain Ghazal using GIS-Based Spatial Multi Criteria Approach given that flood hazard and risk maps are effective tools for reducing flood damage. Six flood causative factors (elevation, slope, drainage density, land use land cover, manholes, and rainfall) and three elements at risk (population, roads and cropland) were processed and assessed in GIS environment. The Fuzzy Analytic Hierarchy Process approach was used for weighing the factors and combined in a weighted overlay operation to determine the flood hazard and risk. The major findings of the study revealed that most of the lowlands in the downstream part of the sub-basin that is located in the eastern and southwestern parts are within high to very high flood hazard and flood risk level with area coverage close to 27% and 27.5% respectively. The risk assessment of flood and in particular the critical facilities (*e.g.*, hospitals) sheds light on the measures needed by the concerned authorities to formulate their development strategies accordingly. Together, the resulting hazard, vulnerability, and risk maps offer a practical decision-support framework that planners in Amman, and in comparable arid urban basins elsewhere, can apply directly to guide land-use planning and infrastructure investment.

Keywords: Floods, GIS, Hazard, Risk, Jordan.

1. INTRODUCTION

Urban sustainability can be influenced by a wide range of economic, social and environmental factors such as floods. Flood is a common natural disaster in the world and cause serious loss of life and economic. Human settlement and land use practices can have an impact on the natural processes, which increase or decrease the risk. Furthermore, it should be noted that climate change is likely to increase both the magnitude and frequency of extreme weather events and lead to greater flooding [1, 2]. To quantify the negative impact of severe flood events, an objective method of assessment is required. Traditionally, this is done by analyzing tangible (*i.e.*, direct economic) and intangible impacts. Tangible impacts refer to those easily recognizable as being direct consequences of flooding and measured in monetary terms, whereas intangible impacts are not measurable in monetary terms and range from loss of life to post-event stress related problems [3].

Flood hazard is defined as the probability of potentially damaging flood situations in a given area and within a specified period of time, while flood risk is the probability that flood of a given magnitude and a given loss will occur within a given time span [4]. A flood hazard depends on the flood magnitude *i.e.*, the flood depth, velocity, and duration. Flood risk analysis identifies possible damage scenarios, to estimate scenario probabilities, and to assess the consequences. The results of flood risk analysis should be the basis for deciding the appropriate flood mitigation options [5].

There are various reasons of flooding; the most important are rainfall characteristics, topography (height and slope) and land use land cover (LULC). LULC changes has direct implication on the hydrological cycle. It is an important characteristic in the runoff process that affects infiltration, soil erosion, and evapotranspiration. Due to rapid development, land cover is subjected to changes causing many soils to become impervious surfaces, which lead to decrease in the soil infiltration rate and consequently increase the rate of runoff. Urbanization has aggravated flooding due to some reasons such as restricting the floodwater flow, covering large parts of the ground with impervious surfaces (*e.g.*, houses ad roads), obstructing channels, and building drains [6-8].

Incidents of flash flooding have claimed the lives of a few hundreds in Jordan over the last few decades and affected the lives and livelihoods of thousands.

*Address correspondence to this author at the Department of Earth and Environmental Sciences, Yarmouk University, Irbid, Jordan;
E-mail: awawdeh@yu.edu.jo

Received on 07-06-2026 Accepted on 24-07-2026 Published on 27-07-2026

E-ISSN: 2311-8741/26

Flashfloods in 1966 claimed 295 lives in Ma'an city south Jordan and in 2018, at least 32 people killed in Dead Sea area, most of them school children. Amman city, the capital of Jordan, is exposed to hazards such as floods and Landslides. The mountainous topography of the city along with the rapid expansion of urbanization makes many parts of the city prone to flood hazards. Unusually heavy rains often lead to flooding in low-lying areas of the city, which paralyzed the city, affecting facilities, buildings, commercial markets, transportation, the power grid as well as the loss of life. The city has responded to these disruptions by establishing protocols for emergency operations, including rapid-response communications centers and elaborate community coordination processes [9].

Several recent devastating floods have been recorded in Amman [10] such as the heavy rain on 5 November 2015, in which 4 people died and it damaged the commodities and assets of over 500 shops and warehouses, with the losses estimated at around 5 million JDs. The floodwater also inundated some buildings at the University of Jordan disrupting classes [10]. Three people died because of flooding caused by heavy rain on 3 November 2014, which inflicted damage on public and private property. The water and sewage networks could not cope with heavy rainfall [11]. Downtown Amman is an important and essential part of the historical center of Amman and the remains of the Roman city of Philadelphia. The downtown area is of great importance from an archaeological point of view, where many historical sites are found such as the Nymphs' Path, the Roman Amphitheater, the Odeon Theater, the Column Square, and the ruins of Mount Citadel. Flash floods flooded the Roman amphitheater several times, which caused disruption in tourism activities.

The lack of comprehensive studies (*e.g.*, hydrology) necessitates the development of a comprehensive storm-water master plan to incorporate in the city planning and development [10]. There are few studies [12-15] addressed the problem of floods in Jordan, but none is about Amman. Recently, the UN-Habitat Jordan launched flood risk assessment, hazard mapping study for downtown Amman. Therefore, this study will help to fill an existing gap in the available information and identify the zones that are vulnerable to flood hazard and related risks. The main objective of the study is to conduct a GIS-based flood risk assessment of Ain Ghazal sub-basin by which a flood hazard and a flood risk map can be developed based on spatial flood risk index map. Multi-criteria analysis approach by using GIS was applied in to identify the flood hazard and flood risk. The usage of GIS is a common practice in hazard and risk assessment because it provides several advantages, such as it is a powerful tool to identify and to visualize all the components of risk (hazard, exposure, and vulnerability), requires less data and less time consumption especially in a well-established geodatabase condition, easier to be communicated with the stakeholder and decision maker, and relatively user-friendly comparison with other methods [16].

2. METHODS

2.1. Study Area

Jordan capital and most-populous city is Amman, home to about 4.5 million people [17]. The climate in Amman is sub-tropical Mediterranean, and the city experiences hot dry summers and cold, wet winters. Amman has a mountainous topography and diverse climate. The rainy season starts in October and ends in May with most rain falls in January and February. The western parts of the city are more wet with orographic effect and exposed more to the frontal precipitation where annual rainfall may exceed 500 mm whereas, in the eastern parts of city is more influenced by arid climate and rainfall drop to 250mm [18]. The daily average temperature ranges from approximately 8°C in winter to around 25°C in summer with annual average temperature 17.3°C.

From hydrological perspective, Amman city is located within Wadi Ain Ghazal watershed (156 km^2) which is a sub-basin of the grater basin of Amman Zarqa River, (Figure **1**). The elevation in the watershed ranges from around 699 m a.s.l. in the lowlands of the eastern side to 1,122 m above m.s.l on the northwestern highlands (Figure **1**). The highest elevations dominate the northwestern parts of the study area. The major stream of the Wadi is running E-W in the lower part of the Wadi where the elevations in the range 709-927 m. Most of the study area is considered as urban sub urban. Agricultural practices are covering the western and northwestern parts of study area, while most of the area (85%) is occupied by bare lands and urbanization. LULC in the study area are classified into forest, cropland, orchard, pasture, bare rocks, bare soil and urban.

2.2. Background

Different qualitative and/or quantitative approaches can be adopted in order to assess flood hazard and

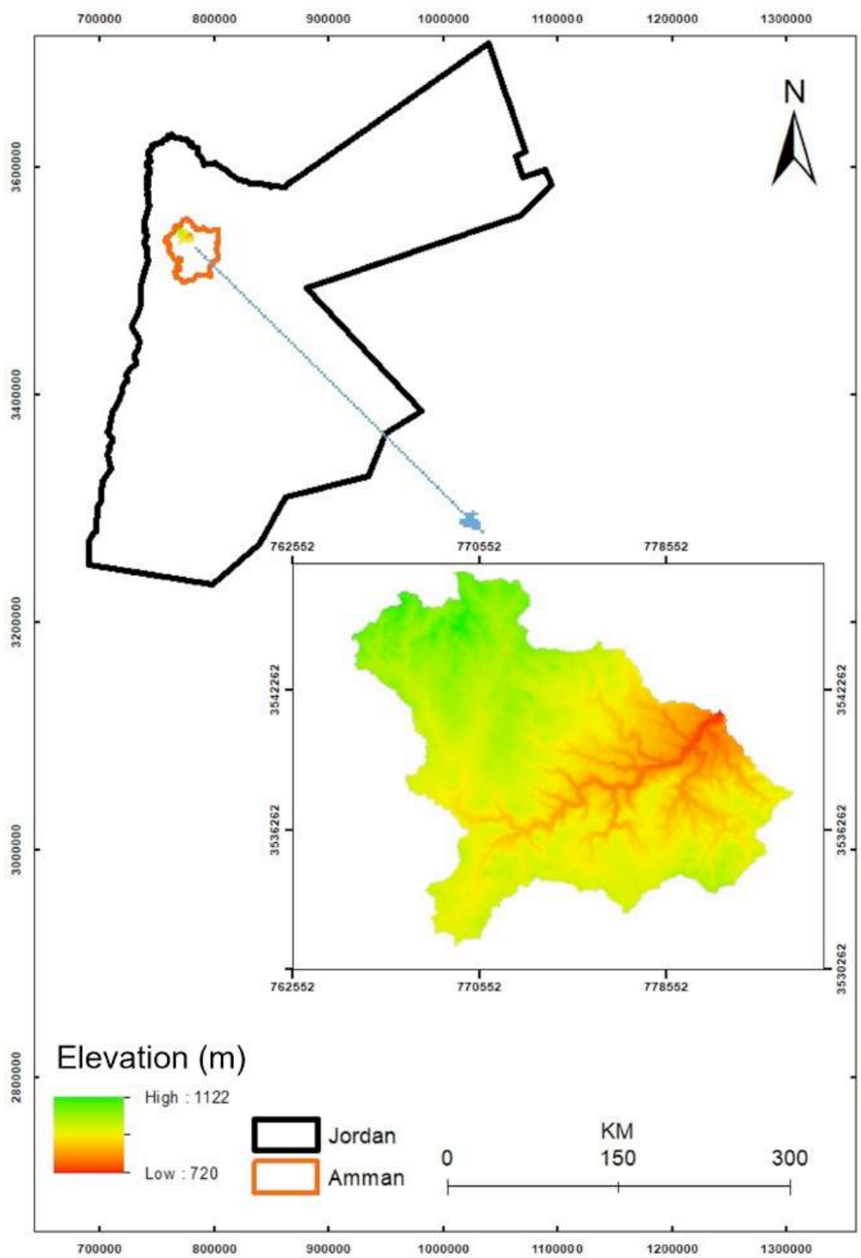

Figure 1: Location and topography map of Wadi Ain Ghazal sub-basin, Jordan.

risk. Quantitative methods are based on numerical expressions of the relationship between controlling factors and floods. The qualitative methods are based on researchers' opinions; however, several qualitative approaches integrate the concept of ranking and weighting which makes them semi-quantitative in nature [19]. Both qualitative and semi-quantitative methods are generally used as they are simple, and able to handle data scarcity [20-22]. This study adopts a semi-quantitative approach to develop a flood risk index map using Spatial Multi-Criteria Analysis (SMCA) in GIS. The assessment of flood risk in this study is based on the definition of risk expressed by equation 1, following [23].

Risk = Hazard + Vulnerability

Equation (1)

The technique flow of flood risk assessment is illustrated in Figure **2**. The flood risk index method starts with the selection of indicator maps (Table **1**). The indicators are subdivided into hazard and vulnerability indicators. After processing the indicators, they were standardized and summed by weight to obtain the hazard and risk maps.

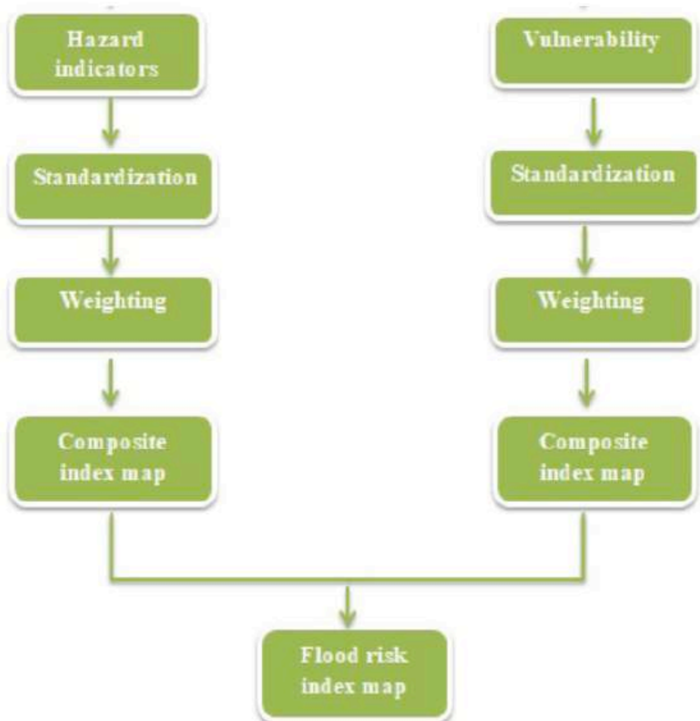

Figure 2: General framework for building the flood risk assessment model.

Table 1: Type and sources of data used in the study.

Data	Format	Source
Elevation	Radarsat_1 digital elevation model	Alaska Satellite Facility
Rainfall	Rainfall records (avarage maximum daily rainfall)	Ministry of Water and Irrigation
Land use land cover	Landsat image	Google Earth
Flood control projects	Autocad	Grater Amman Municipality
Population	Statistical Blocks	Department of Statistics
Roads	Shapefile	Grater Amman Municipality

The data required for flood hazard and risk mapping were obtained from various sources such as Grater Amman Municipality (GAM) and the Ministry of Water and Irrigation (MWI). Data of flood control project were the most problematic which as it was limited to manholes only with little attributes.

1. Elevation: a digital elevation model with 12.5 m resolution was downloaded from the Alaska Satellite Facility.

2. The average maximum daily rainfall data of the years 2005 to 2015 were collected from 9 station (Wadi Es-Sir/Natural Resource Authority, Amman Hussein College, Jubeiha, Wadi Es-Sir, Na'ur, Ministry WI, Sahab, Hummar and Sweilih) (Figure **3**). The data were provided by the Ministry of Water and Irrigation.

3. The land use land cover was prepared from Google Earth. LULC is an important parameter in the assessment of flood hazard and risk as they play an important role in the runoff.

4. Population data were collected from the Department of Statistics Census of 2004.

5. Flood Control Projects: manholes spatial distribution in the study area were obtained from GAM.

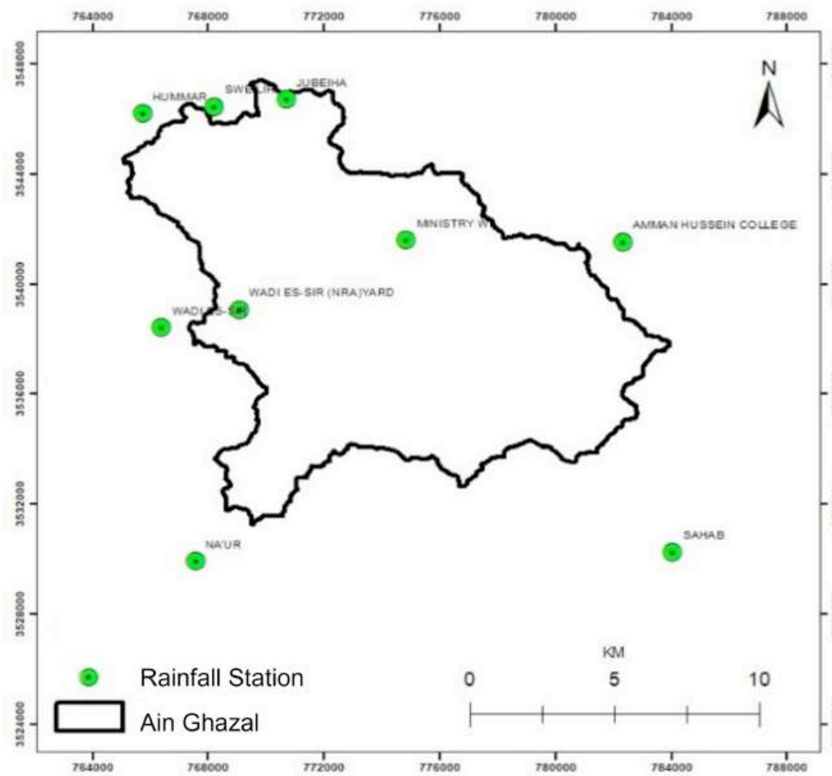

Figure 3: The rainfall stations used in the study of Wadi Ain Ghazal, Jordan.

All collected data has been transformed to the Universal Transverse Mercator coordinate system Zone 36N.

2.3. Spatial Multi-Criteria Analysis (SMCA)

The input is a set of maps that spatially represents the criteria for flood hazard and flood risk. These maps were grouped, standardized, and weighed. Whereas the composite index map is the output indicating the realization of the inputs [19]. The composite index map provides a score that possesses a range based on the assigned weight, for each grid cell and calculated using equation 2 [24]:

$$u_i = \sum_{j=1}^{m} v_{i,j} w_j$$

Equation (2)

The weights (w_j) are non-negative and add up to 1, and $V_{i,j}$ is a transformed performance score for X_i,k (the rating factors) on a scale of 0 to 1, where 1 represents the best performance.

The flood risk index is generated by the summation of the two composite index maps for hazard and vulnerability (Eq.1). The intermediate map of hazard is constructed by overlaying the six intermediate weighted maps (elevation, slope, land use land cover, drainage density, flood control projects, and rainfall) using addition (Eq.2). The intermediate map of vulnerability is generated by combining the three vulnerability types (population, transportation, and cropland) (Eq.2).

2.4. Indicator Analysis

The selection of evaluation criteria is a crucial step because the inclusion or exclusion of criteria can greatly influence the results of the evaluation process. While the evaluation criteria should be complete to ensure that the whole problem is encompassed; the set of criteria should be minimal to reduce the complexity of the evaluation process [25]. These indicators are classified into hazard and vulnerability indicators.

Flood causative factors particularly in the study area were identified from literature. Hazard indicators include elevation, slope, land use land cover, drainage density, flood control projects, and rainfall. Three vulnerability indicators were considered: population (social vulnerability indicator), cropland (economic vulnerability indicator), and transportation (physical vulnerability indicator).

2.5. Standardization Rules

To make an SMCA possible, the input layers need to be standardized from their original values to the value ranging from 0 to 1. This is because the indicators have different measurement scales and that their relations to flood risk are also different. The standardization process is different between a positive indicator having a positive correlation with flood risk, and a negative indicator having a negative correlation with flood risk (Table **2**) [26]. For the positive indicators, the maximum method (I) (equation 3) is used whereas, the maximum method (II) (equation 4) is used to the negative indicators (Mao 2001).

$$v_{is} = \frac{x_i - x_{i\,\min}}{x_{i\,\max} - x_{i\,\min}}$$ Equation (3)

$$v_{is} = \frac{x_{i\,\max} - x_i}{x_{i\,\max} - x_{i\,\min}}$$ Equation (4)

Here, for the indicator i, vis a standardized value, x_i is an initial value, *xi* max is the maximum value, and *x*i min is the minimum value.

2.6. Development of Weights

To employ SMCA as a supporting tool, the weights must reflect the preferences among a set of entities. There are different methods can be applied to calculate the weights [27]. The Analytical Hierarchy Process (AHP) [28, 29]. is one of the most widely used multi-criteria decision-making tools that has been adopted by decision makers and researchers [30]. The traditional AHP method is challenging as it uses an exact value to express the decision maker's opinion in a comparison of alternatives [31]. It does not reflect the human way of thinking [32], and it is incapable of effectively accommodating the inherent ambiguity and imprecision in the pair-wise comparison table [33]. Therefore, the Triangular Fuzzy AHP [34] was utilized in this study as it is providing interval judgments rather than fixed value judgments. The first task of the fuzzy AHP method is to decide on the relative importance of each pair of factors in the same hierarchy. The pairwise comparisons are described by values taken from a pre-defined set of ratio scale values as presented in Table **3**.

Table 2: Evaluation indicators with their corresponding standardization method.

Flood Risk	Indicators	Sub Indicators	Standardization
Hazard	Condition	Elevation	Maximum (II)
		Slope	Maximum (I)
		Land use land cover	Maximum (II)
		Drainage density	Maximum (I)
		Flood control project	Maximum (II)
	Triggering	Rainfall	Maximum (I)
Vulnerability	Social	Population	Maximum (I)
	Economic	Cropland	Maximum (I)
	Physical	Transportation	Maximum (I)

Table 3: Triangular fuzzy conversion scale (Radhakrishnan and Kalaichelvi, 2014).

Linguistic scale for relative importance	Triangular fuzzy scale	Reciprocal of triangular fuzzy scale
Exactly the same	(1,1,1)	(1,1,1)
The same importance	(1/2,1,3/2)	(2/3,1,2)
Slightly important	(1,3/2,2)	(1/2,2/3,1)
Serious importance	(3/2,2,5/2)	(2/5,1/2,2/3)
More serious importance	(2,5/2,3)	(1/3,2/5,1/2)
Absolute importance	(5/2,3,7/2)	(2/7,1/3,2/5)

Using the Triangular Fuzzy Conversion scale given above, the pairwise comparison matrix was constructed for flood hazard in Table **4**. Table **5** presents the pairwise comparison matrices for hazard conditions that include five indicators. The only indicator that represented the hazard triggering is the rainfall average maximum daily and it is given a weight of 0.315 (Table **6**).

Table 4: Flood hazard weights.

Hazard	Condition	Triggering
Condition	(1,1,1)	(1,3/2,2)
Triggering	(1/2,2/3,1)	(1,1,1)

Table 6: Hazard triggering weight.

Hazard triggering	Rainfall (average maximum Daly)
Rainfall (average maximum daily)	(1,1,1)

In a similar manner the aggregated pairwise comparison matrix for vulnerability criteria was constructed (Table **7**).

The aggregated pairwise comparison matrices for vulnerability criteria are shown in Table **8**.

Table 8: Flood risk weight.

Risk	Hazard	Vulnerability
Hazard	(1,1,1)	(1,3/2,2)
Vulnerability	(1/2,2/3,1)	(1,1,1)

Table 5: Hazard conditions weight.

Hazard (Condition)	Elevation	Land use land cover	Slope	Drainage density	Manhole
Elevation	(1,1,1)	(1/2,1,3/2)	(1 ,3/2 ,2)	(3/2,2,5/2)	(2,5/2,3)
Land use land cover	(2/3,1,2)	(1,1,1)	(1,3/2 ,2)	(3/2,2,5/2)	(3/2,2,5/2)
Slope	(1/2,2/3,1)	(1/2,2/3,1)	(1,1,1)	(1/2,1,3/2)	(1,3/2,2)
Drainage density	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(2/3,1,2)	(1,1,1)	(1/2,1,3/2)
Manhole	(3/1,2/5,1/2)	(2/5,1/2,2/3)	(1/2,2/3,1)	(2/3,1,2)	(1,1,1)

Table 7: Flood vulnerability weights.

Vulnerability	Population	Road	Cropland
Population	(1,1,1)	(3/2,2,5/2)	(1,3/2,2)
Road	(2/5,1/2,2/3)	(1,1,1)	(1,3/2,2)
Cropland	(1/2,2/3,1)	(1/2,2/3,1)	(1,1,1)

Table 9: Evaluation indicators with their corresponding weight values.

Flood Risk	Hazard		Vulnerability 0.315
	Condition 0.685	Triggering 0.315	
Elevation	0.303		
Land use land cover	0.285		
Slope	0.168		
Drainage density	0.135		
Flood control project	0.109		
Rainfall		1	
Population			0.55
Roads			0.29
Croplands			0.16

3. RESULTS AND DISCUSSION

3.1. Results

3.1.1. Weight of Indicators

The results of weight calculations for all criteria and sub-criteria were determined (Table **9**). The highest weights for hazard indicators were for the elevation and land use land cover indicators, whereas the lowest weight was assigned to the flood control projects. For vulnerability indicators, population was assigned the highest weight (0.55).

3.1.2. Hazard Indicators

Elevation

The study area is located between the elevation 709 and 1,084 meters a.s.l. Historically, low-lying areas were known to be the worst hit by floods in Amman city. Figure **4** shows the standardized elevation map of the study area, in which the highest values are concentrated along the streams and neighboring area of Wadi Ain Ghazal.

Slope

The slope plays a fundamental role in flood hazard mapping [36] as it indicates the degree of elevation variability in adjacent grids [37, 38]. Nonetheless, flood risk is directly affected by the terrain variations in certain ranges that are not limited to neighboring grids. Thus, the standard deviation of elevation was selected as a topographic indicator [39, 40]. The standard deviation of elevation has a great influence on flood hazard assessment because it governs the amount of surface runoff produced, the precipitation rate, and displacement velocity of water over the equi-potential surface. The resulting standardized map is shown in Figure **5**, where the highest values are along the streams of the Wadi in the south and northeast of the catchment.

Land Use Land Cover

The infiltration capacity increases with increasing the vegetation and percentage of organic matter and decreasing in the bulk density of the soil [41, 42, 43]. For that reason, the infiltration will be reduced, increasing the rate of runoff and decreasing the lag

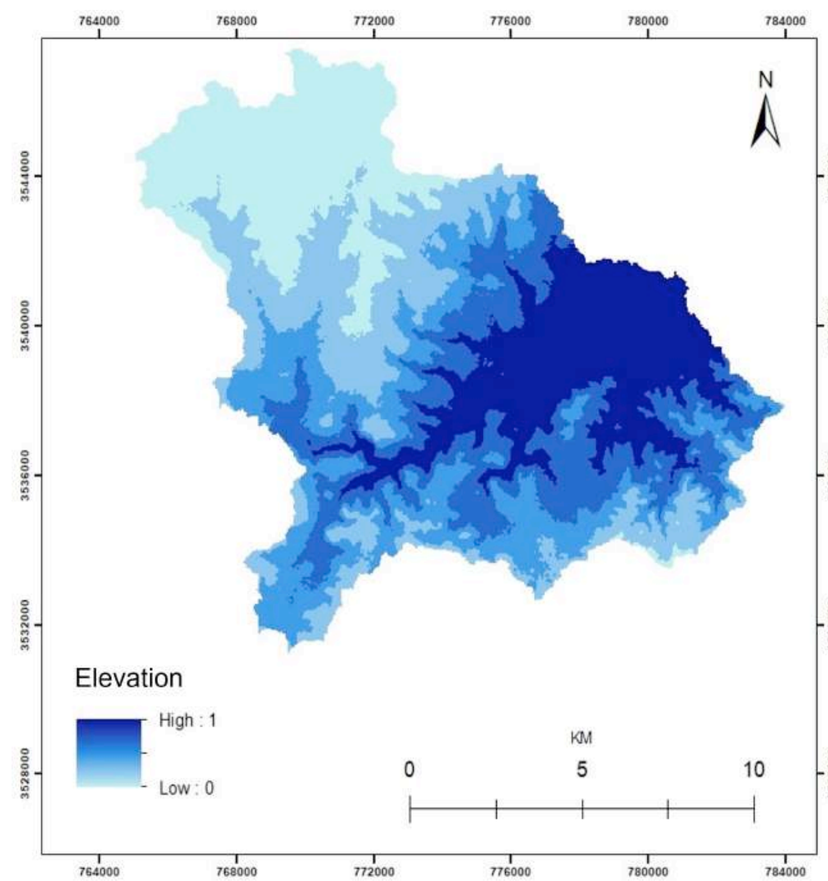

Figure 4: Standardized elevation map in Wadi Ain Ghazal, Jordan.

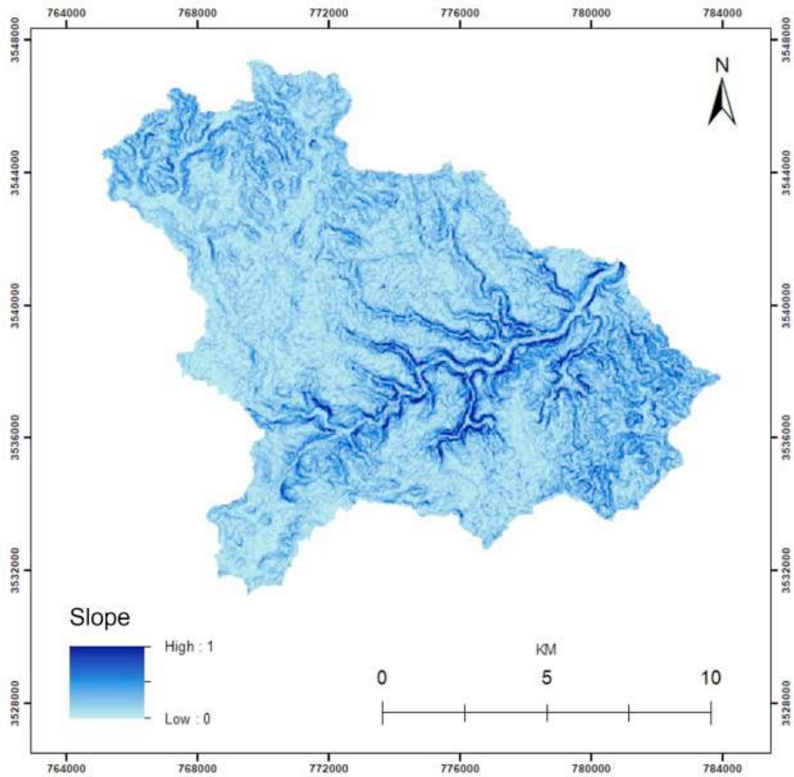

Figure 5: Standardized slope in Wadi Ain Ghazal, Jordan.

time in urban areas. There are seven different types of LULC in Ain Ghazal: forest, cropland, orchard, pasture, bare rocks, bare soil and urban (high, moderate and low). Those types were rated according to their relations to runoff generation (Table **10**) according to literature and local experts. The standardized map of Land use/cover is presented in Figure **6**.

Table 10: Land use land cover rating.

LULC type	Rating
Forest	1
Cropland	2
Orchard	3
Pasture	4
Bare soil	6
Bare rock	9
Urban low density	7
Urban moderate density	8
Urban high density	10

Drainage Density

Drainage systems developed in an area are dependent on the slope, the nature and attitude of bedrock [36]. Drainage density is a fundamental concept in hydrologic analysis which is defined as the ratio of the length of drainage per basin area. The rating for drainage density decreases with increasing drainage density. The drainage density was calculated using the Line Density function that calculate a magnitude per unit area within a radius around each cell [44]. Finally, the standardized map of the drainage density indicator was produced (Figure **7**).

Flood Control Projects

The presence of manholes is often a very effective factor in reducing the hazard of flooding. They have an inverse relationship with flood for instance increasing number and size of manholes leads to decreasing the hazard. Manhole density was used as an indicator for the fighting-calamity capability of flood control projects. The manholes were installed almost all over the study area with lower density in elevated areas.

Rainfall

A high precipitation over a short period of time is the most important factor responsible for triggering floods. Rainfall intensity is the best data for flood hazard and risk assessment. The average daily maximum rainfall was utilized in this study. Natural neighbor technique was used for interpolation. The distribution of rainfall showed that the northwest part of the study area

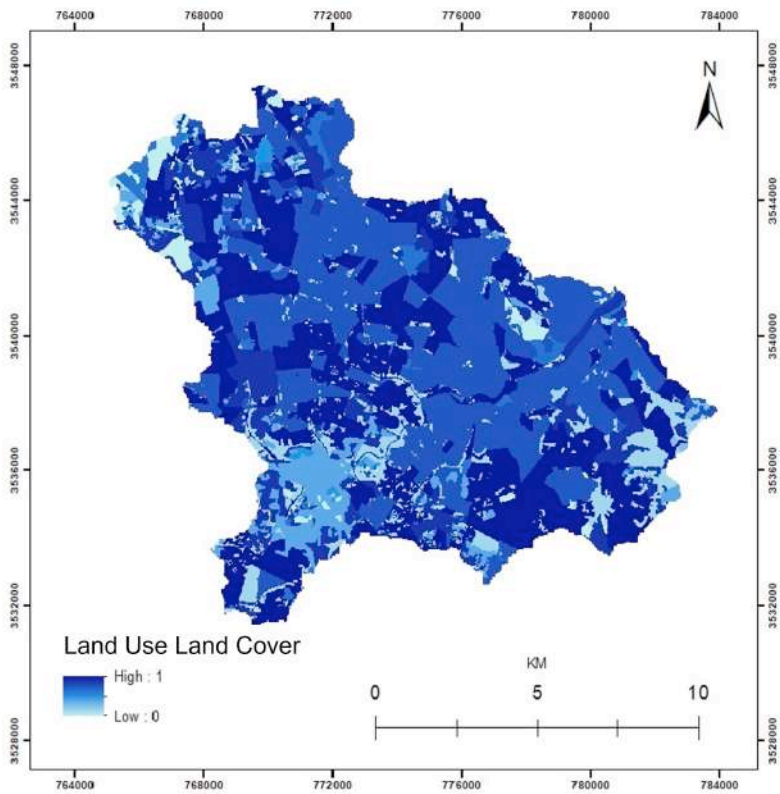

Figure 6: Standardized land use land cover types in Wadi Ain Ghazal, Jordan.

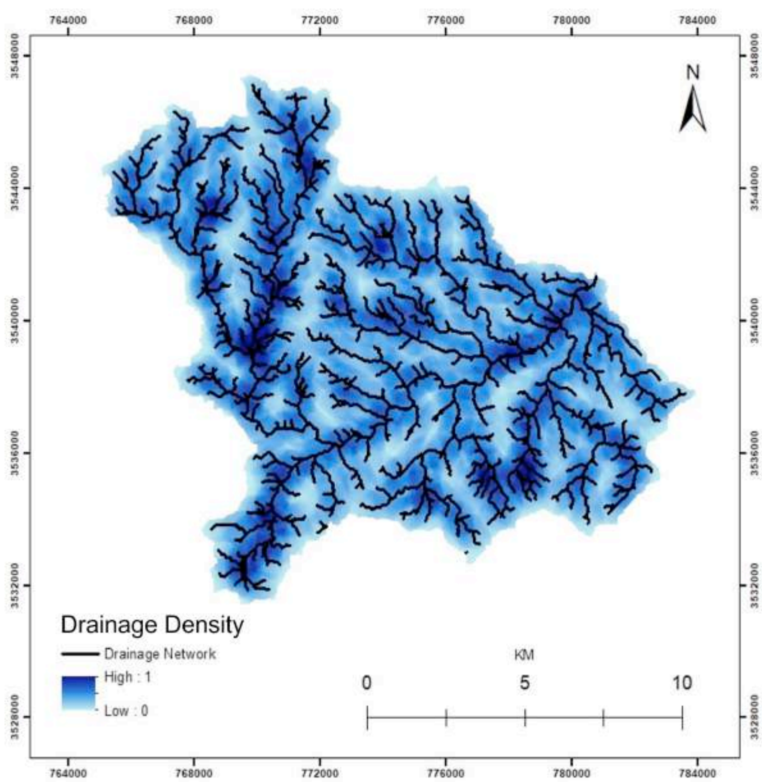

Figure 7: Standardized drainage density map in Wadi Ain Ghazal sub-basin, Jordan.

receives highest rainfall while the southeast portion receives the lowest amounts. The standardized map is shown in Figure **8**.

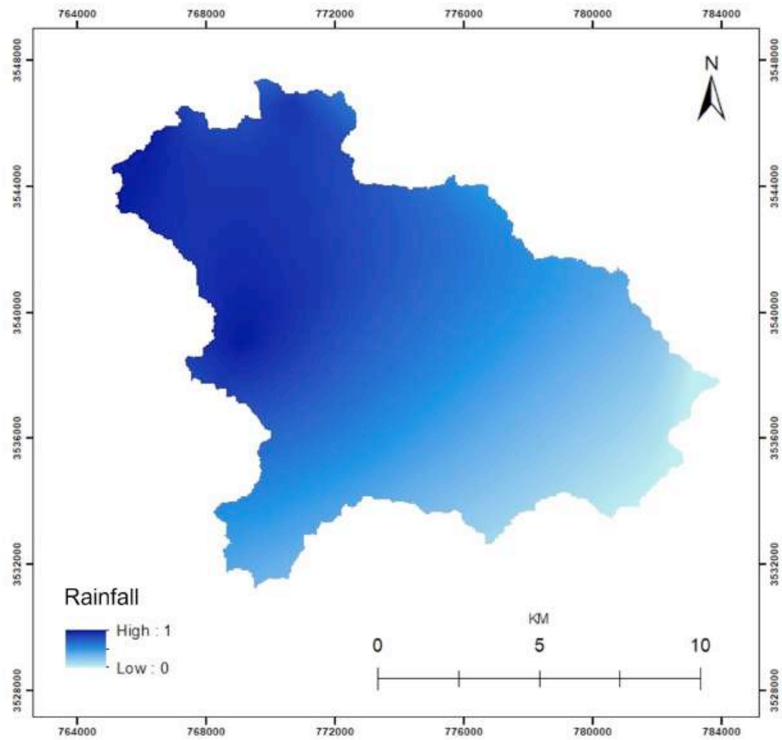

Figure 8: Standardized rainfall mean maximum daily rainfall in Wadi Ain Ghazal, Jordan.

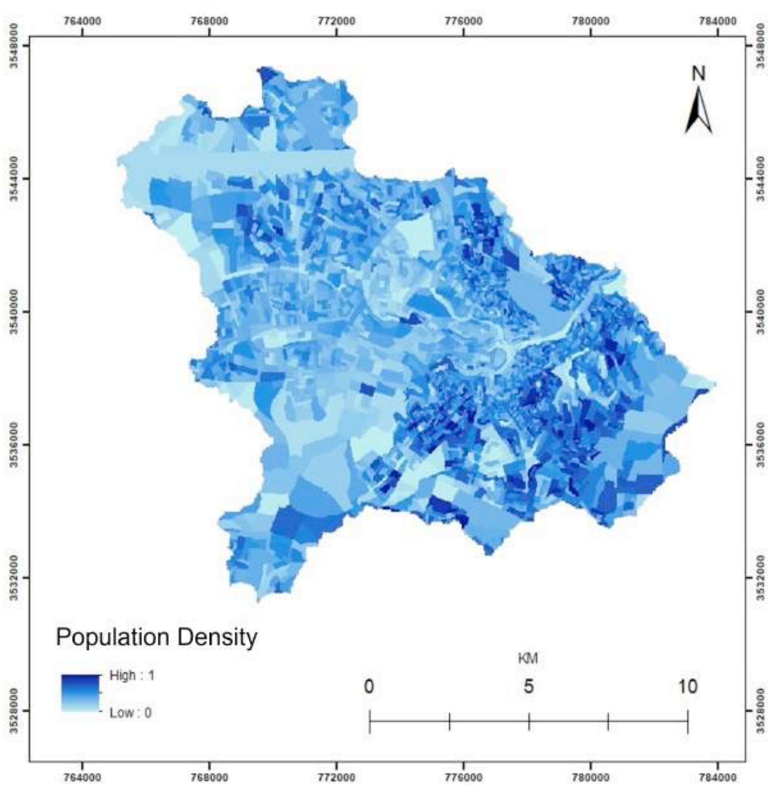

Figure 9: Standardized population density in Wadi Ain Ghazal, Jordan.

3.1.3. Vulnerability Indicators

Three factors define societies' vulnerability to floods; exposure, susceptibility and resilience [45]. The vulnerability of any system is a function of the exposure and susceptibility of that system to hazardous conditions and the resilience of the system to adapt and/or recover from the effects of those conditions [46]. [47] Describes exposure as the measure of susceptible elements (goods, infrastructure, cultural heritage and agricultural fields) within a region threatened by a hazard. Susceptibility is defined as the elements exposed within the system, which influence the probabilities of being harmed at times of hazardous floods. The selection of vulnerability indicators was made after analyzing a similar work in literature [26, 37, 48, 49, 50]. Considering the unavailability of some documents and data, three key indicators were considered: population (social vulnerability indicator), cropland (economic vulnerability indicator), and transportation (physical vulnerability indicator).

Population

The population density was calculated by number of populations per area. Most of the population is located on the southeastern side of the study area. The standardized map is shown in Figure **9**. The population density is dominating the southern and central parts of the Wadi because of the lower elevations.

Transportation

The road density was calculated for the transportation indicators. The highest density of roads are located in the central parts of the study area and most of the high density roads are close to the drainage density which means most of wadis were converted to be roads by GAM. The standardized map is shown in Figure **10**.

Cropland

Although the proportion of agricultural land is not large in the region, it has an important role in the economy of farmers. Thus, the percentage of cropland was chosen as an indicator. The cropland percentages were higher in the western and southern parts of the study area (Figure **11**).

3.2. Discussion

3.2.1. Flood Hazard Map

The rating values of each factor were given through discussion with concerned researchers and according

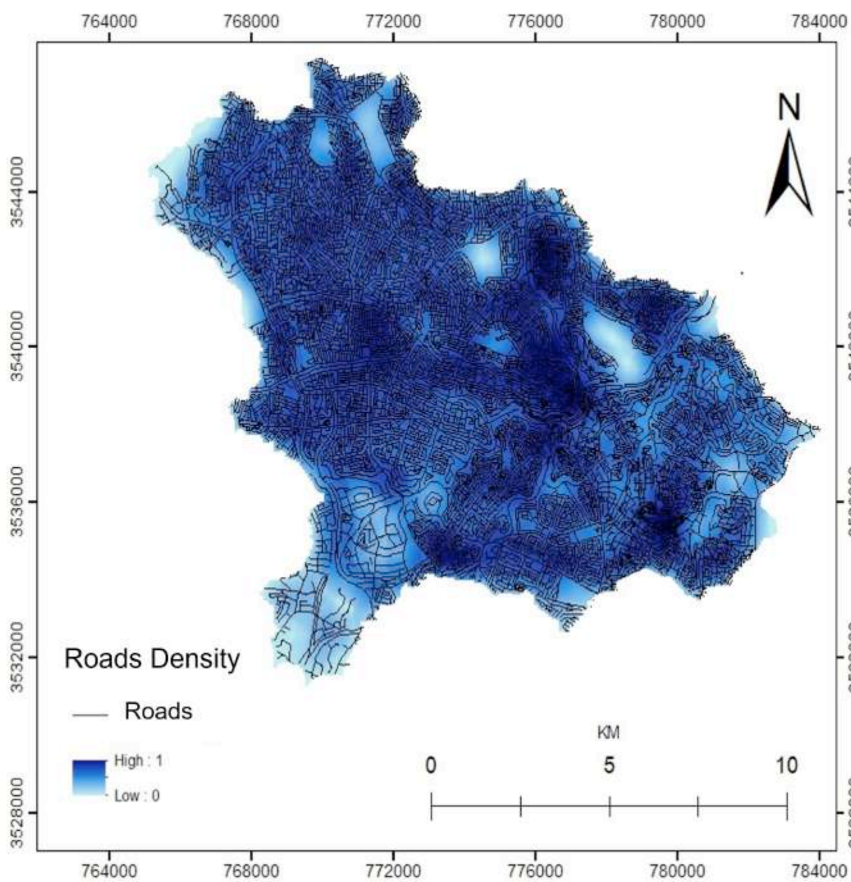

Figure 10: Standardized road density in Wadi Ain Ghazal, Jordan.

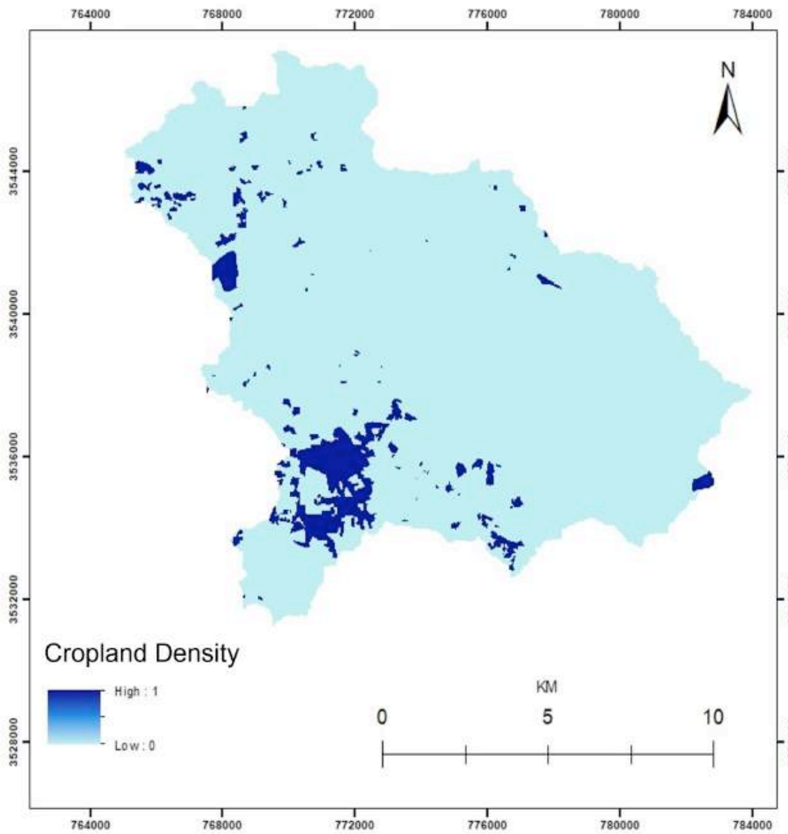

Figure 11: Standardized cropland percentage in Wadi Ain Ghazal, Jordan.

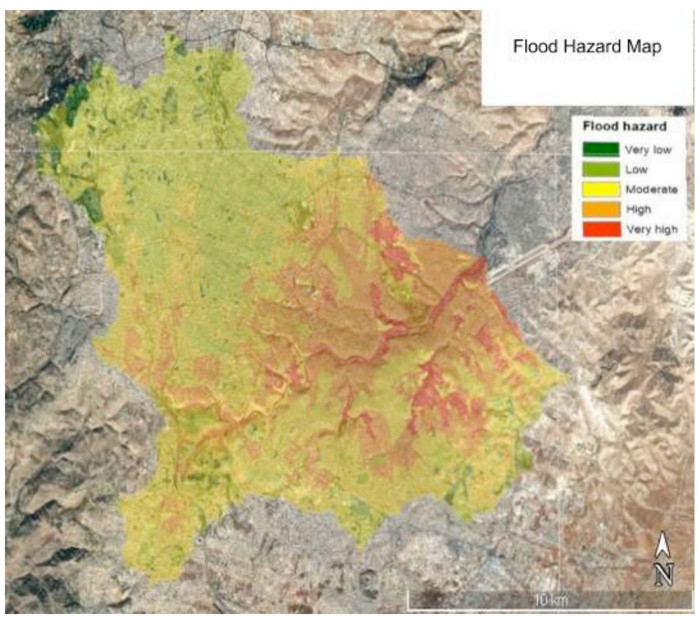

Figure 12: Flood hazard map of Wadi Ain Ghazal, Jordan.

to published literature. To assess the flood hazard (Figure **12**) the standardized (St.) hazard factor maps were combined in raster calculator in the ArcGIS environment using the following equation:

Flood Hazard = **(**0.685 × (0.303 × [St. Elevation] + 0.285 × [St. Land Use Land Cover] + 0.186 × [St. Slope (STD)] + 0.135× [St. Drainage Density] + 0.109 × [St. Flood Control Project]) + (0.315 × [St. Rainfall]))

Equation (5)

The hazard index map was classified into five zones: very low, low, moderate, high, very high. Figure **12** shows that the southeastern and eastern central regions in the study are classified as high flood hazard zones; mainly because they are lowlands, while the low hazard zones are found in the regions of high lands. As long as the rainfall factor has been given the highest weight followed by elevation and LULC factors respectively in the flood hazard analysis model, the flood hazard map model result seems to coincide with the ground truth.

3.2.2. Flood Vulnerability Map

A vulnerability analysis considers the population and structures at risk within the flood-prone area. The analysis evaluates the potential costs of flooding in terms of damages to buildings, crops, roads, and critical infrastructure, such as utilities [51]. Because vulnerability analysis identifies the population at greatest risk, it can also be used to identify the emergency responses that may be required, including the need for temporary shelters and evacuation requirements. The analysis is also valuable for planning on the level of flood protection [52].

As the study area is largely classified as an urban area, it is likely to have high vulnerability, firstly on the population and their property, economic and social. This is followed by the secondary transport operations and traffic movements, and finally the production processes that may affect some farmers in their agricultural business. Figure **13** shows the final venerability map of Wadi Ain Ghazal as a result of the following equation:

Vulnerability = (0.55 × [St. Population] + 0.29 × [St. Roads] + 0.16 × [St. Cropland)])

Equation (6)

3.2.3. Flood Risk Map

Risk analysis is considered central in risk management framework. In this phase, aspects of hazard analysis, exposure analysis, risk estimation and visualization are assessed. Flood risk mapping was determined by combining the degree of flood hazard, and the integrated vulnerability using the following equation:

Risk map = (0.685 × Hazard) +(0.315 × Vulnerability)

Equation (7)

The final integrated flood risk map (Figure **14**) shows that the lowland regions, which were identified as the areas of highly prone flood hazard of the Ain Ghazal, are designated as high and very high flood risk areas. These high and very high flood risks areas are located mainly in the eastern and the southeastern regions of the study area. Other small regions are found in the western and southwestern parts. The highly populated settlement areas in the eastern and the southeastern regions need immediate attention for alleviating potential future flood risk.

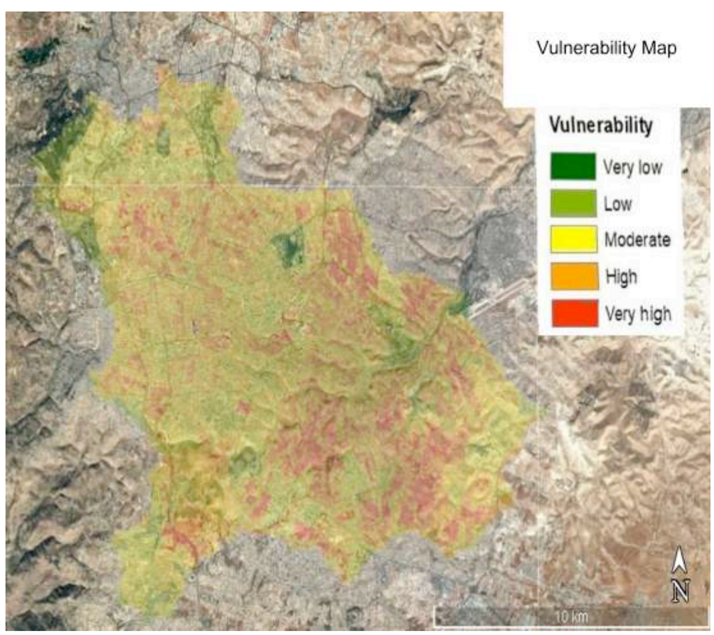

Figure 13: Vulnerability map of Wadi Ain Ghazal, Jordan.

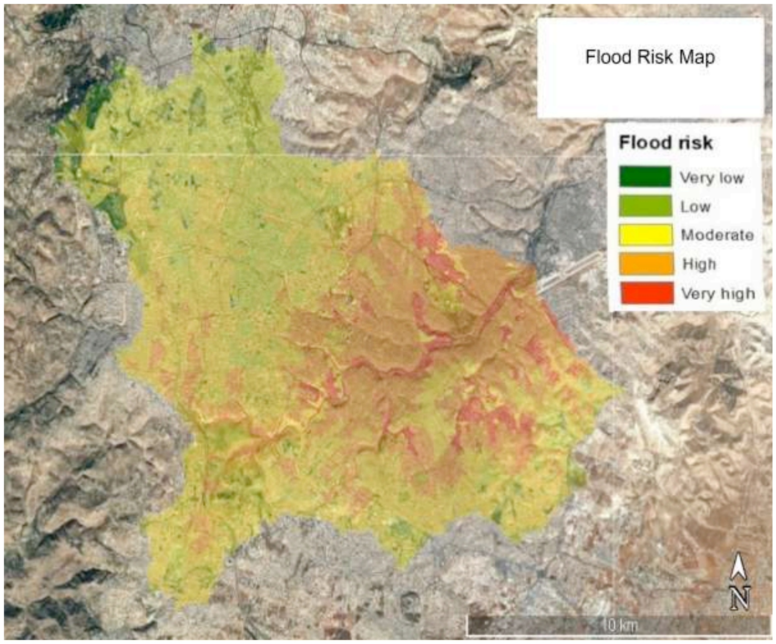

Figure 14: Flood risk map of Wadi Ain Ghazal, Jordan.

Table **11** is a statistical summary of the different classes in hazard, vulnerability, and risk maps. Twenty seven percent of Wadi Ain Ghazal area is classified as high to very high hazard, 61% categorized in terms of vulnerability as high to very high, whereas 44% of the area is under high to very high risk.

3.2.4. Risk Assessment of Critical Facilities

Flood risk assessment has gained increasing attention due to its importance in flood management. In this phase, consideration is given to the protection of lives and assets [53]. This assessment could support the mitigation or prevention of the damages. Raising awareness among people in vulnerable area supports managing emergencies in-time, or avoiding building in flood prone areas [51]. Considering land-use planning can help to reduce risks and impacts on the buildings and people. Flood risk assessment for Wadi Ain Ghazal took into consideration the spatial relationship between the critical facilities and the different classes of flood risk. Critical facilities are the most urgent and important assets within the community. The community will be able to make better decisions about how to expend resources to protect critical facilities because of this type of assessment. There are two types of critical facilities: essential facilities and high potential loss facilities.

Essential facilities

Essential facilities include all facilities considered essential for the health and welfare of the whole population such as civil defense centers, fire stations, evacuation shelters, and health care facilities. Figure **15** presents the flood hazard map overlain by the various types of essential facilities. The percentage of essential facility located in the high and very high

Table 11: Area percentage of Hazard, Vulnerability and Risk classes.

Class	Area %		
	Hazard	Vulnerability	Risk
Very low	38	25.7	39.2
Low	17.5	13.2	16.7
Moderate	17.4	12.2	16.7
High	17.4	5.0	16.7
Very high	9.7	43.9	10.7

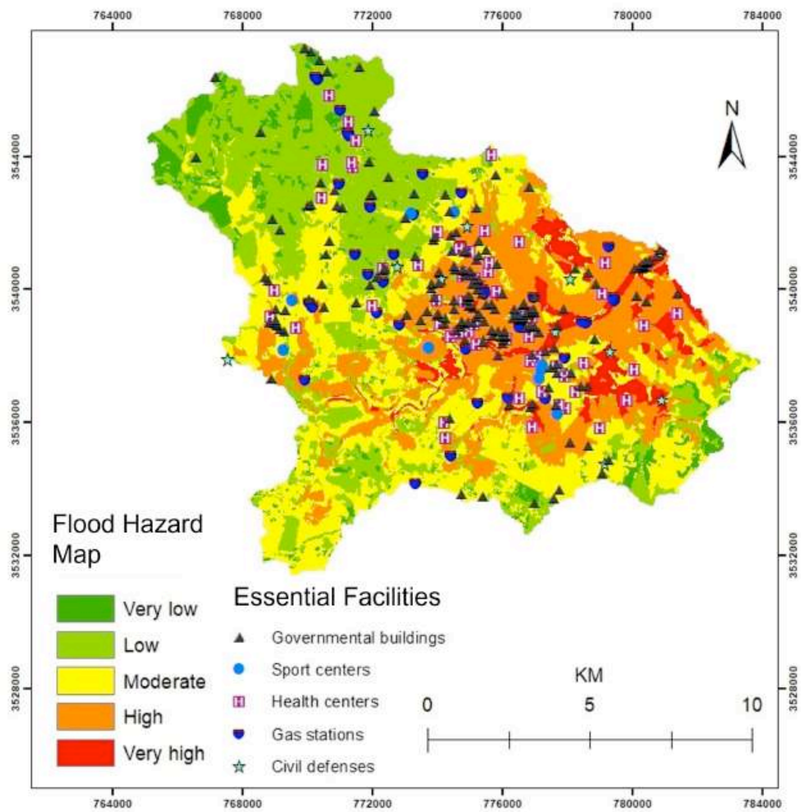

Figure 15: Essential facilities with flood hazard map in Wadi Ain Ghazal, Jordan.

Table 12: Percentages of the essential facilities located within each flood hazard zone.

Type of facilities	Number in the study area	Percentage (%)		
		Moderately hazard zone	High hazard zone	Very high hazard zone
Governmental	183	27	44	13
Sport centers	10	30	50	0
Health centers	60	32	52	3
Gas stations	40	33	25	10
Civil defenses	14	21	36	29

hazard zones were significant. The highest percentage was for civil defense centers (65%) and the lowest one was gas stations (35%) (Table **12**).

High potential loss facilities

This type of critical facilities includes all facilities to contain high population densities such as hotels and educational centers. Figure **16** presents the flood hazard map overlain by the various types of high potential loss facilities. The percentage of high potential loss facilities for the high and very high zones was 72% for the hotels and 41% for the education centers (Table **13**).

3.2.5. Environmental and Engineering Implications for Sustainable Urban Development and Flood Risk Management in Wadi Ain Ghazal

The hazard and risk maps point to a clear cause: with roughly 85% of the basin now bare land or urban and only 15% remaining under cropland, orchard, or forest, the loss of permeable surface has cut infiltration and shortened the time between rainfall and peak runoff. The overlap between high road density and high drainage density in the central catchment suggests many natural wadi channels have effectively been paved over, removing conveyance exactly where it's needed most. Preserving the remaining cropland and

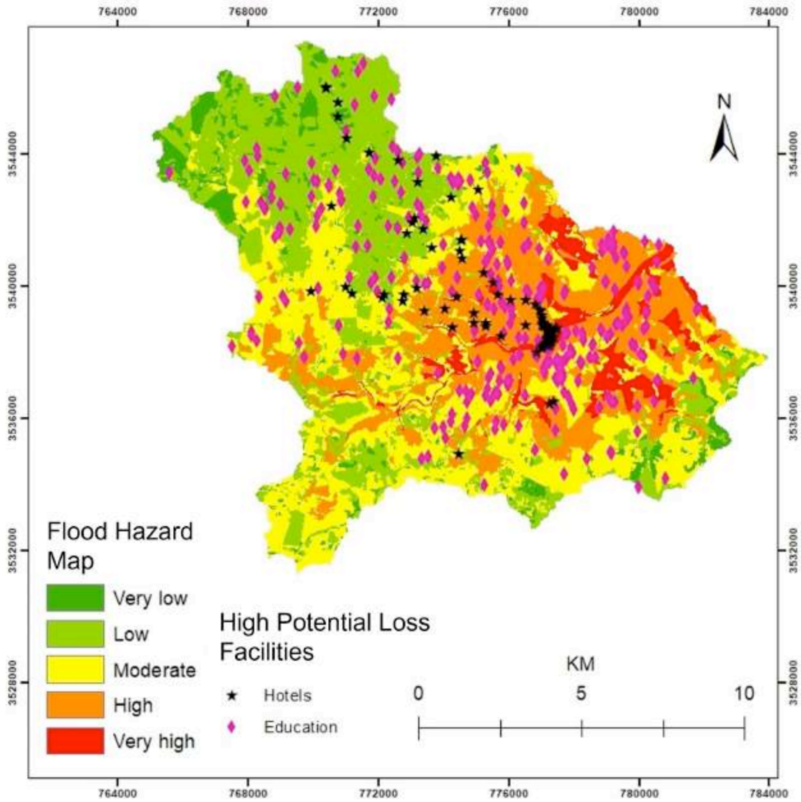

Figure 16: High potential loss facilities with flood hazard map in Wadi Ain Ghazal sub-basin, Jordan.

Table 13: Percentage of essential facilities located within each flood hazard zone.

Type	Number	Percentage (%)		
		Moderately hazard zone	High hazard zone	Very high hazard zone
Hotels	103	17	59	13
Education	311	35	40	1

open space, and restoring vegetation along former wadi alignments, would help recover some of this lost capacity at far lower cost than downstream structural fixes. On the engineering side, flood control projects (the manhole network) received the lowest weight of any hazard factor in the model, consistent with Amman's water and sewage system repeatedly failing during the 2014 and 2015 storms discussed earlier. Rehabilitating this network means resizing it to current rainfall intensities, not just repairing what exists, and pairing it with sustainable urban drainage and slope-appropriate measures in the steeper reaches of the basin.

The urgency is sharpest for critical facilities: 65% of civil defense centers, 72% of hotels, and 41% of education centers sit in high to very high hazard zones. This calls for flood-proofing and structural reinforcement where facilities remain, and relocation where the hazard is too severe to mitigate in place.

Ultimately, these findings argue for embedding the hazard and risk maps into the Greater Amman Municipality's land-use master plan and building-permit process as a standing input, so future zoning and infrastructure decisions are made with this evidence rather than discovered to conflict with it later.

4. CONCLUSIONS AND RECOMMENDATIONS

Although flooding is an unavoidable natural phenomenon, but we can minimize its adverse effects by better planning. Moreover, flood events associated with urban areas and large cities will continue to increase as these urban centers continue to grow. Human activities have increased impacts of flood events, creating risks by building in flood prone areas. To manage flood risk, it is essential to have a flood risk map created by geospatial technology.

The geo-database developed from this study provides information on the flood hazard and flood risk of Wadi Ain Ghazal and can serve as good decision support system for flood hazard managers. The geo-database developed from this study is, to our knowledge, the first integrated GIS-based flood hazard, vulnerability, and risk assessment carried out for Amman city, and it provides a ready decision support system that flood hazard managers can apply directly rather than a purely academic exercise. There are settlements in the study area that are subjected to very high to high flood risk. Hence those settlement areas need immediate attention for alleviating potential future flood risk. The results show that 44.5% of the study area is located within the moderate to very high hazard flood zones, and about 61% of the study area is moderately to very highly vulnerable to floods. This led to the occurrence of 27.5% of the sub-basin under high to very high flood risk. The risk assessment for the critical facilities showed a very high portion of them are under high to very high flood hazard, which means an immediate attention is necessary to avoid future losses.

Because the study area is mainly urban it is difficult if not impossible to demolish or reduce them for economic and social reasons. Therefore, the following measures are recommended to adverse flood risk:

1. Rehabilitation of drainage network.

2. Adopt appropriate engineering techniques to reduce the potential hazard from flash floods.

3. Review of the land use master plants, in particular building permits in the zones of high flood hazard.

4. Re-locating the most important critical facilities.

Because it links hazard, vulnerability, and risk directly to specific locations and facilities rather than treating flood risk in the abstract, the GIS-based framework developed here can be applied by decision-makers with only modest technical resources, and it can be extended with little modification to other flood-prone basins in Jordan, and to comparable arid or semi-arid urban catchments elsewhere, facing the same combination of rapid urbanization and limited drainage infrastructure.

CONFLICTS OF INTEREST STATEMENTS

The authors declare that there are no relevant financial or non-financial competing interests to report.

AUTHORS’ CONTRIBUTION

Muheeb Awawdeh: Research conceptualization and design, Supervision, writing review and editing.

Hassan Rwashdeh: Data curation, Formal analysis, vvisualisation, writing original draft

Khaldoon Al-Qudah: Supervision, writing review and editing.

Monther Jamhawi: Writing review and editing.

All authors have read and agreed to the published version of the manuscript.

ACKNOWLEDGEMENTS

The authors are grateful to the Greater Amman Municipality for providing free dataset used in the analysis. This research received no specific grant from any funding agency.

FUNDING

The authors are grateful to the funding provided by the Deanship of Research and Graduate Studies at Yarmouk University and the ICSC-World Laboratory (Geneve).

ETHICAL STATEMENTS

Ethical approval and informed consent were not required for this study as it exclusively utilized secondary, aggregated, and publicly available data.

REFERENCES

[1] Amiri, M.J.; Eslamian, S.S. Investigation of climate change in Iran. J. Environ. Sci. Technol. 2010; 3(4): 208-216. https://doi.org/10.3923/jest.2010.208.216

[2] Maghsood F, Moradi H, Bavani A, Panahi M, Berndtsson R, Hashemi H. Climate Change Impact on Flood Frequency and Source Area in Northern Iran under CMIP5 Scenarios. Water 2019; 11(2): 273. https://doi.org/10.3390/w11020273

[3] Parlon T. Flood policy review final report. In: The Office of Public Works (OPW) Report of the Flood Policy Review Group 2003, pp. 38-40.

[4] Merz B, Thieken AH, Gocht M. Flood Risk Mapping at the Local Scale: Concepts and Challenges. In: Begum, Stive, M., Hall, JW., editors, Flood risk management in Europe: Innovation in Policy and Practice. Springer Science & Business Media 2007; p. 231-251. https://doi.org/10.1007/978-1-4020-4200-3_13

[5] Thieken A (2008) Floods, flood losses and flood risk management in Germany. PhD thesis, Mathematisch-Natur wissens chaftlichen Fakultät der Universität Potsdam, Germany.

[6] Harris E, Rantz S. Effects of urban growth on streamflow regimes of Permanente Creek, Santa Clara County, California. USGS WSP 1591B; 1964.

[7] Konrad C, Booth D. Hydrologic trends associated with urban development in western Washington streams. United States Geological Survey Water-Resources Investigations Report 02-4040; 2002.

[8] Konrad C, Booth D. Hydrologic changes in urban streams and their ecological significance. American Fisheries Society Symposium 2005; 47: 157-177.

[9] Rockefeller Foundation () Amman Resilience Strategy. Unpublished report. Amman; 2017.

[10] Noghai M (2015) Four dead as heavy downpour wreaks havoc on Amman. Jordan Times Newspaper [cited 2017 April 27]. Available from: http: //www.jordantimes.com/news/local/four-dead-heavy-downpour-wreaks-havoc-amman.

[11] Namrouqa H (2014) Three die as flash floods sweep central, northern regions. Jordan Times Newspaper [cited 2017 March 3]. Available from: http: //www.jordantimes.com/news/local/three-die-flash-floods-sweep-central-northern-regions.

[12] Al-Weshah R, El-Khoury F. Flood Analysis and Mitigation for Petra Area in Jordan. Journal of Water Resources Planning and Management 1999; 125(3): 170-177. https://doi.org/10.1061/(ASCE)0733-9496(1999)125:3(170)

[13] Al-Qudah K. Floods as Water Resource and as a Hazard in Arid Regions: a Case Study in Southern Jordan. Jordan Journal of Civil Engineering 2011; 5(1): 148-159.

[14] Alhasanat H (2014) Flash Flood Assessment for Wadi Mousa City-Jordan. Procedia Economics and Finance 2014; 18: 675-683. https://doi.org/10.1016/S2212-5671(14)00990-3

[15] Farhan, Y, Anaba, O and Salim, A. Morphometric Analysis and Flash Floods Assessment for Drainage Basins of the Ras En Naqb Area, South Jordan Using GIS. Journal of Geoscience and Environment Protection 2016; 4: 9-33. https://doi.org/10.4236/gep.2016.46002

[16] Malczewski J. GIS-based land-use suitability analysis: a critical overview. Progress in Planning 2004; 62(1): 3-65. https://doi.org/10.1016/j.progress.2003.09.002

[17] Department of Statistics (2017) Estimated population of 2017 from Census Data. Amman, Jordan. [cited 2017 March 31]. Available from: http: //dosweb.dos.gov.jo/population/population-2/.

[18] Greater Amman Municipality. The Amman Climate Plan: A Vision For 2050 Amman. Unpublished report. Ministry of Environment; 2019.

[19] Wang YM, Li ZW, Tang Z, Zeng GM. A GIS-Based Spatial Multi-Criteria Approach for Flood Risk Assessment in the Dongting Lake Region, Hunan, Central China. Water Resource Manage 2011; 25: 3465-3484. https://doi.org/10.1007/s11269-011-9866-2

[20] Zhan X, Zhu G, and Wen Y. Risk evaluation for flood disasters in the plain area based on GIS. Resource Environ Yangtze Basin 2003; 12(4): 388-392.

[21] Zhang H, Zhang J, Han J. GIS-based assessment and zoning of flood/waterlogging disaster risk: a case study on middle and lower reaches of Liaohe River. J Nat Disasters 2005; 14(6): 141-146.

[22] Furdada G, Calderon L, and Marques M. Flood hazard map of La Trinidad (NW Nicaragua). Method and results. Nat Hazards 2008; 45: 183-195. https://doi.org/10.1007/s11069-007-9156-8

[23] Maskrey A. Disaster mitigation: a community based approach. Oxford: Oxfam GB; 1989.

[24] Hajkowicz S, Collins K. A review of multiple criteria analysis for water resource planning and management. Water Resour. Manag. 2007; 21: 1 553-1566. https://doi.org/10.1007/s11269-006-9112-5

[25] Keeney R, and Raiffa H. Decisions with multiple objectives preferences and value tradeoffs. Cambridge: Cambridge University Press; 1993. https://doi.org/10.1017/CBO9781139174084

[26] Mao DH. Comprehensive assessment and analysis on the risk degree of flood-waterlogging in Dongting Lake region. Chinese, J Nat Disasters 2001; 10(4): 104-107.

[27] Zimmermann HJ, Gutsche L. (1991) Entscheiden bei unscharfer Information. In: Multi-Criteria Analyse. Heidelberger Lehrtexte Wirtschaftswissenschaften. Springer, Berlin, Heidelberg [cited 2018 May 21]. https://doi.org/10.1007/978-3-642-58198-4

[28] Saaty TL. Axiomatic foundations of the analytic hierarchy process. Manag Sci 1983; 32: 841-855. https://doi.org/10.1287/mnsc.32.7.841

[29] Saaty TL, Vargas GL. Models methods concepts and applications of the analytic hierarchy process. Boston: Springer; 2001. https://doi.org/10.1007/978-1-4615-1665-1

[30] Vaidya OS, Kumar S. Analytic hierarchy process: an overview of applications. Eur J Oper Res 2006; 169: 1-29. https://doi.org/10.1016/j.ejor.2004.04.028

[31] Wang TC, Chang TH. Application of TOPSIS in evaluating initial training aircraft under fuzzy environment. Expert Syst Appl 2007; 33(4): 870-880. https://doi.org/10.1016/j.eswa.2006.07.003

[32] Kahraman C, Cebeci U, Ulukan Z. Multi criteria supplier selection using fuzzy AHP. Logist Inf Manag 2003, 16(6): 3 82-394. https://doi.org/10.1108/09576050310503367

[33] Deng H. Multicriteria analysis with fuzzy pair-wise comparison. Int J Approx Reason 1999; 21: 215-231. https://doi.org/10.1016/S0888-613X(99)00025-0

[34] Chang, Da-Yong. Application of Extent Analysis Method on Fuzzy AHP, European Journal of Operation Research 1996; 95: 649-655. https://doi.org/10.1016/0377-2217(95)00300-2

[35] Radhakrishnan R, and Kalaichelvi A. Selection of the best school for the children-a decision making model using extent analysis method on fuzzy analytic hierarchy process. International Journal of Innovative Research in Science. Engineering and Technology 2014; 3(5): 12334-12344.

[36] Alemayehu Z. Modeling of flood hazard management for forecasting and emergency response of 'Koka' area within Awash River basin using remote sensing and GIS method. MSc Thesis, Addis Ababa University, Ethiopia; 2007.

[37] He BY, Zhang HL, Zhang S, Ding GP. GIS-based risk evaluation for flood disaster in Hubei province. Chinese. J Nat Disasters 2002; 11(4): 84-89.

[38] Tang C, and Zhu J. A GIS based regional torrent risk zonation. Acta Geograph Sin 2005; 60(1): 87-94.

[39] Wan Q. Analysis and evaluation for flood disaster system. Beijing: Science; 1999.

[40] Zhou C, Wan Q, Huang S. A GIS-based approach to flood risk zonation. Acta Geograph Sin 2000; 55(1): 15-24.

[41] Dunne T. Field studies of hill slope flow processes, In: Kirkby MJ, editor, Hill slope Hydrology. Chichester: Wiley 1978; p.277-293.

[42] Faulkner H. Vegetation covers density variations and infiltration patterns on piped alkali sodic soils: implications for the modeling of overland flow in semi-arid areas. In: Thornes

J.B (ed.) Vegetation and erosion. Chichester: Wiley 1990; p.317-346.

[43] Zeigler AD. Hydrological consequences of landscape fragmentation in mountainous northern: evidence of accelerated overland flow generation of Hydrology 2004; 287: 124-146. https://doi.org/10.1016/j.jhydrol.2003.09.027

[44] Silverman BW. Density estimation for statistics and data analysis. London: Chapman and Hall; 1986.

[45] Balica SF, Wright NG. A network of knowledge on applying an indicator-based methodology for minimizing flood vulnerability. Hydrol Process)2009; 23(20): 2983-2986. https://doi.org/10.1002/hyp.7424

[46] Smit B, Wandel J. Adaptation, capacity and vulnerability. Global Environ Change 2006; 16: 282-292. https://doi.org/10.1016/j.gloenvcha.2006.03.008

[47] Fekete A. Validation of a social vulnerability index in context to river-floods in Germany. Nat Hazards Earth Syst Sci 2009; 9: 393-403. https://doi.org/10.5194/nhess-9-393-2009

[48] He B, Zhang H, Du Y, Zhongshan Y and Li B. Flood risk assessment of Hubei province. J Yangtze River Sci Res Inst 2004; 21(3): 21-25.

[49] Du J, He F, Shi PJ. Integrated flood risk assessment of Xiangjiang River Basin in China. J Nat Disasters 2006; 15(6): 38-44.

[50] Huang MS, Huang CC. Research on grade model of flood risk assessment. Chinese. J Catastrophology 2007; 22(1): 1-5.

[51] UNISDR (United Nations International Strategy for Disaster Reduction) (2004) Guidelines for Reducing Flood Losses. Geneva: UNISDR [cited 2017 August 3]. Available from: http: //www.unisdr. org/fi les/5353_PR200402WWD.pdf.

[52] Balica S, Wright N, Meulen F. A flood vulnerability index for coastal cities and its use in assessing climate change impacts. Nat Hazards 2012; 64: 73-105. https://doi.org/10.1007/s11069-012-0234-1

[53] Hussein A. Flood hazard and risk assessment through incorporating GIS with hydrodynamic modelling: case study of Muda River. MSc thesis, Universiti Sains Malaysia; 2009.

https://doi.org/10.12974/2311-8741.2026.14.03