GIS-based Flood Hazard Mapping in the West Bank, Palestine

Sameer Shadeed
An-Najah National University

GIS-based Flood Hazard Mapping in the West Bank, Palestine

استخدام نظام المعلومات الجغرافية لتطوير خارطة الخطورة المرتبطة بالفياضانات في فلسطين

Sameer Shadeed

سمير شديد

Water and Environmental Studies Institute, An-Najah National University, Nablus, Palestine

E-mail: sshadeed@najah.edu

Received: (4/12/2017), Accepted: (6/12/2018)

Abstract

Worldwide, flood is one of the highly damaging natural hazards followed by catastrophic consequences. Thus, it become essential to develop simply obtainable flood hazard map so as help decision makers in formulating of proper corrective and preventive strategies. This study utilizes the Analytic Hierarchy Process (AHP) to develop a flood hazard map to well protect people life and properties. Method applicability was demonstrated on the West Bank, Palestine (5624 km^2). GIS-based multi criteria decision analysis (MCDA) employed to combine spatial weighted factors for different criteria including runoff curve number, rainfall depth, flow accumulation, drainage density, surface elevation, surface slope, surface cover, distance from drainage network, and population density. Results indicate that about 29%, 36% and 12% of the total West Bank area are medium, high and very high vulnerable for flood hazard, respectively. Whereas land having low and very low flood hazard areas represent about 15% and 8%, respectively. Moreover, most of the Palestinian communities in different districts are located in high and very high flood hazard prone areas where about 90% of the total population are living. The attained results can be adapted to realize any administrative strategy changes for cohesive flood hazard management in Palestine.

Keywords: Flood Hazard Mapping, GIS, AHP, Coherent Flood Hazard Management, Palestine.

ملخص

عالميا، يعتبر الفيضان واحدا من المخاطر الطبيعية الضارة للغاية والتي يمكن ان تكون مصحوبة بتبعات كارثية. لذلك، اصبح من الضروري تطوير خريطة مخاطر الفيضان التي يمكن الحصول عليها ببساطة، حتى تساعد صانعي القرار في صياغة الاستراتيجيات التصحيحية والوقائية المناسبة. في هذه الدراسة تم استخدام طريقة التسلسل الهرمي التحليلي (AHP) لتطوير خريطة مخاطر الفيضان من أجل حماية حياة الناس وممتلكاتهم في الضفة الغربية، فلسطين البالغة مساحتها حوالي 5624 كم^2. تم توظيف طريقة تحليل القرار متعدد المعايير (MCDA) المستند إلى نظم المعلومات الجغرافية (GIS) في الجمع بين العوامل المكانية الموزونة (حسب اهميتها) لعدد من المعايير بما في ذلك مؤشر الجريان السطحي (CN)، كمية الأمطار، تراكم تدفق الفيضان، كثافة التصريف السطحي، الارتفاع عن سطح البحر، معامل انحدار سطح الارض، الغطاء السطحي، البعد عن شبكة التصريف (الاودية) والكثافة السكانية . تشير النتائج إلى أن حوالي 29٪ و 36٪ و 12٪ من إجمالي مساحة الضفة الغربية معرضة لخطر الفيضان المتوسط والعالي والعالي جداً، على التوالي. في حين تمثل الأراضي ذات مناطق مخاطر الفيضانات المنخفضة والمنخفضة جداً حوالي 15٪ و 8٪ على التوالي. اضافة لذلك، فإن معظم التجمعات السكانية الفلسطينية في المحافظات المختلفة تقع في المناطق المعرضة لخطر الفيضانات العالية والعالية جدا حيث يعيش حوالي 90 ٪ من مجموع السكان. يمكن الاعتماد على نتائج الدراسة وتكييفها من اجل تحقيق تغييرات إستراتيجية مستدامة لإدارة مخاطر الفيضانات في فلسطين.

الكلمات المفتاحية: رسم خرائط مخاطر الفيضانات، نظام المعلومات الجغرافية (GIS)، طريقة التسلسل الهرمي التحليلي (AHP)، إدارة مخاطر الفيضانات، فلسطين.

Introduction

Worldwide, flood is one of the most frequent and destructive natural hazards, which in most cases, lead to catastrophic consequences to natural resources, loss of human being and assets (Kowalzing, 2008; Khan *et al.*, 2011; Jonkman & Dawson, 2012, Yashon & Ryutaro, 2014). Urbanization in many regions in the world will enlarge potential flood hazards, which imply pressure on landuse planning (Yashon & Ryutaro, 2014). Urbanization has direct impacts on hydrological characteristics (e.g. infiltration decrease, runoff increase). This in turn will increase the frequency and magnitude of floods (Alaghmand *et al.*, 2010). Moreover, the predicted global climate change and the accompanying severe weather conditions (e.g. increasing rainfall intensity) will also increase frequency and severity of flood (Dihn *et al.*, 2012).

In the West Bank, Palestine and due to climate change, extreme weather conditions are becoming more frequent. High rainfall intensity and interference of the natural infiltration processes by engineered surfaces are increasing the potential occurrence of flash floods and therefore intensifying the prevailing flood hazards in West Bank districts (Shadeed, 2008, Shadeed & Lange, 2010). This situation is becoming worst given the lack of proper hydraulic infrastructures (e.g. culverts) required for safe disposal of the accumulated flood. For instance, in winter of 2012, an extreme rainy storm event occurred followed by an unexpected flash flood. Accordingly, three people passed away in Tulkarm district and many roads across much of the West Bank districts were flooded. This situation has geared up the urgent need to identify high flood vulnerable areas and to have proper mitigation and effective response in place. Flood hazard mapping (FHM) is viewed to be an efficient tool for assessing such natural hazards and foreseeing likely vulnerable regions and accordingly proposing proper mitigation actions (Coppock, 1995; Black & Burnes, 2002; Nyarko, 2002; Dewan *et al*., 2007; Fernandez & Lutz, 2010; Daniel *et al*., 2015; Nerantzis *et. al*., 2015).

Numerous multi criteria decision analysis (MCDA) approaches were used in FHM (Parakash, 2003). The analytic hierarchy process (AHP) is one the most commonly applied MCDA approaches in FHM (Ho, 2008; Feizizadeh & Blaschke, 2012; Yashon & Ryutaro, 2014; Nerantzis *et. al*., 2015). In various decision making processes, the AHP is one of the GIS-based MCDA approaches that have been effectively used (Lai, 1995). GIS-based MCDA is a simple, straightforward and powerful spatial analysis method that allows the manipulation of different spatial data to be used in MCDA challenges (Malczewski, 1999; Feizizadeh & Blaschke, 2012; Nyeko, 2012). In addition, it is a smart method to have an informative output from a multiple input of physical and non-physical data that can, together with expert opinion, be used to make comparison judgments (Chen & Wang, 2004; Sumathi *et al*., 2008; Gbanie *et al*., 2013; Kazakis *et al*., 2015).

GIS-based MCDA were used for FHM in many regions around the world to contribute in achieving the sustainable flood management and eventually helps the strategic planning purposes (e.g. Islam *&* Sado, 2002; Sanyal & Lu, 2005; Sanyal & Lu, 2006; Gautam & Kharbuja, 2006; Abou El-Magd *et al*., 2010; Ozcan & Musaoglu, 2010; Alaghmand *et al*., 2010; Dawod *et al*., 2011; Forkuo, 2011; Thilagavathi *et al*., 2011; Bhadra *et al*., 2011; Orok, 2011; Sarhadi *et al.*, 2012; Yashon & Ryutaro, 2014; Elkharachy, 2015).

This research aims at mapping flood hazard for the entire West Bank districts. Thus, an integrated approach using GIS-based MCDA was adopted. The MCDA approach entails that the choice is built on a predetermined and limited number of decision variables (criteria) described by their attributes. Accordingly, in this research multiple criteria driving flood hazard mapping in the West Bank were identified. These are: runoff curve number, rainfall depth, flow accumulation, drainage density, surface elevation, surface slope, surface cover, distance from drainage network, and population density.

Once the criteria are selected, sub-criteria are derived from attributes to describe these criteria better. The AHP approach was adopted through constructing of a pairwise comparison matrix to assign relative importance (weight) for each criterion based on a preference scoring scale which ranges from (1 to 9) (Saaty, 1980). Sub-criteria were scored also from 1 to 9 and adjusted under the GIS environment. This procedure makes the MCDA approach very attractive to be applied under the GIS environment to resolve spatially based natural hazards mapping problems (Jankowski, 1995; Chakhar & Mousseau, 2008; Nyeko, 2012).

A key output in this research is the creation of flood hazard map for the entire West Bank. The produced map aims to identify high vulnerable areas based on administrative units (districts) given different criteria that are relevant to flood risks. The creation of administrative based flood hazard maps is valuable and essential for decision makers to formulate proper flood remedial plans (Sanyal & Lu, 2005). The easily available and accessible (for technical and non-technical stakeholders) flood hazard map will improve the in place flood emergency response of different actors in the West Bank districts. Additionally, it makes the implementation of adaptive flood management strategy easy and cost effective and thus improve the natural resources allocation (Forkuo, 2011). This in turn, can help the key decision makers (e.g. the Palestinian water authorityand the Ministry of local governorates) to outline specific policies and mitigation measures to support any managerial changes towards proper implementation of sustainable flood management strategy in Palestine.

Description of the Study Area

The West Bank, Palestine is located in the Middle East, west of Jordan (see Figure 1). It has an area of about 5,624 km^2. The ground surface elevations range between 1,022 m above mean sea level in the south (in Hebron) and 410 m below mean sea level in the proximity of the Dead Sea (in Jericho), (UNEP, 2003). Administratively, the West Bank is divided into 11 districts (see **Figure 1**) with a total population of around 3 million people projected for mid of the year 2016 (PCBS, 2016).

The West Bank climate can be generally described as a Mediterranean one which experiences extreme seasonal variations. The climate varies between hot dry in summer to wet cold in winter with short transitional seasons (Shadeed, 2008). The rainy season usually extends from October to April. In winter, more than 80% of the annual rainfall commonly occurrs (Shadeed, 2012). In general, rainfall is characterized by its high temporal and spatial variability. Annual rainfall ranges between less than 100 mm in the Jordan Valley to more than 700 mm in the central mountains of the West Bank (Shadeed & Almasri, 2010). Assuming dry conditions, the curve number (CN) for the West Bank is ranging from 21 to 74 with an average value of about 50. This in turn indicates the high runoff potential in the study area (Shadeed & Almasri, 2010). The CN is a dimensionless catchment parameter ranging from 0 (no runoff) to 100 (runoff equals rainfall). Extreme rainfall events accompanied with flash floods are getting more frequent in the study area (Shadeed, 2008).

Seven land use classes were existed in the West Bank. These are: rough grazing/subsistence farming (61.7%), permanent crops (14.3%), arable land (14.3%), built-up areas (5%), irrigated farming (2.6%), Israeli settlements (1.4%), and woodland/forest (0.7%) (MoP, 1997; Shadeed, 2011).

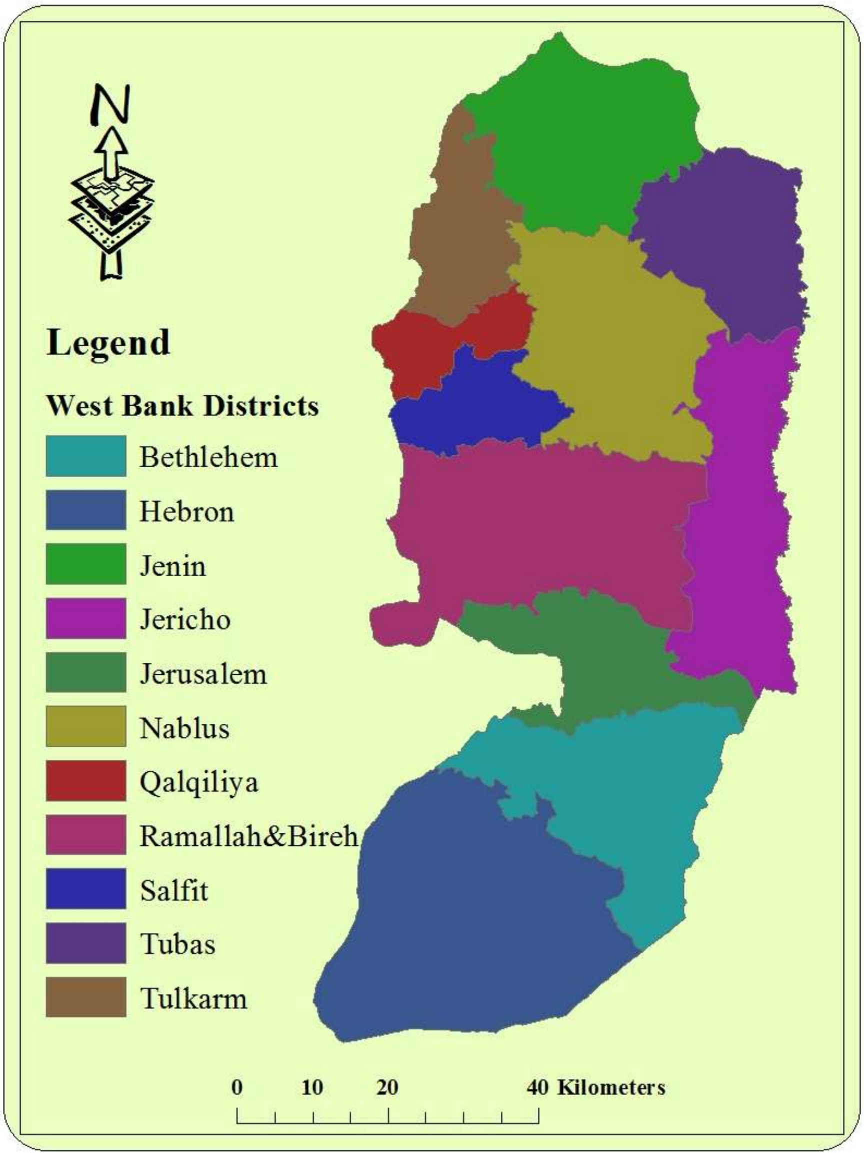

Figure (1): Location Map of the West Bank Districts.

Materials and Methods

The methodology used in this research to develop the flood hazard map for the West Bank was heavily dependent on GIS as depicted in Figure 2.

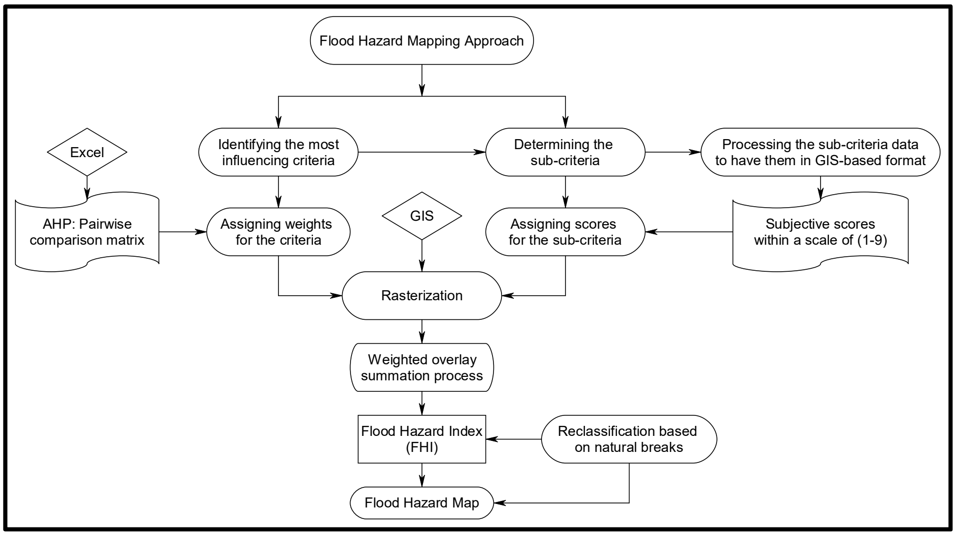

Figure (2): General conceptual flowchart methodology.

Firstly, the main influencing factors (criteria) of flood hazard in the West Bank were identified based on the best available datasets at national level (MoP, 1997; Shadeed, 2008). As a result, nine factors were identified and compiled into a GIS-based database. The factors are: runoff curve number (CN), rainfall depth (RD), flow accumulation (FA), drainage density (DD), surface elevation (SE), surface slope (SS), surface cover (SC), distance from drainage network (DS), and population density (PD). The spatial extent of runoff potential hazard was evaluated based on the CN map which was developed for the study area (Shadeed & Almasri, 2010). The CN implies the effect of soil texture and land cover on the process of flood generation and infiltration. The Inverse Distance Weighting method (IDW) was used to map the spatial distribution of rainfall based on the available long term average annual rainfall data at raingauge stations. A 25×25m digital elevation model (DEM) was available and used to derive the factors of FA, DD, SE, and SS. The SC factor was based on the study area landuse map. Given the drainage network from the DEM, DS factor was obtained. PD is estimated based on the population census data for each district (PCPS, 2016).

Secondly, different weights were estimated for each factor by adopting the AHP pairwise comparison matrix and using a scoring system based on a preference scale which ranges from 1 to 9 (Saaty, 1980) (see **Table 1**). The normalized values (weights) of different criteria are presented in **Table 2**. The weight of each criterion reflects its importance in flood hazard potential.

Table (1): Flood Hazard Criteria: AHP Pairwise Comparison Matrix.

Criteria	CN	RD	FA	DD	SE	SS	SC	DS	PD
CN	1	2	3	4	5	6	7	8	9
RD	0.50	1	2	3	4	5	6	7	8
FA	0.33	0.50	1	2	3	4	5	6	7
DD	0.25	0.33	0.50	1	2	3	4	5	6
SE	0.20	0.25	0.33	0.50	1	2	3	4	5
SS	0.17	0.20	0.25	0.33	0.50	1	2	3	4
SC	0.14	0.17	0.20	0.25	0.33	0.50	1	2	3
DS	0.13	0.14	0.17	0.20	0.25	0.33	0.50	1	2
PD	0.11	0.13	0.14	0.17	0.20	0.25	0.33	0.50	1

Table (2): Normalized Flood Hazard Criteria: AHP Pairwise Comparison Matrix.

Criteria	CN	RD	FA	DD	SE	SS	SC	DS	PD	Mean	Weight (%)
CN	0.35	0.42	0.40	0.35	0.31	0.27	0.24	0.22	0.20	0.307	31
RD	0.18	0.21	0.26	0.26	0.25	0.23	0.21	0.19	0.18	0.218	22
FA	0.12	0.11	0.13	0.17	0.18	0.18	0.17	0.16	0.16	0.154	15
DD	0.09	0.07	0.07	0.09	0.12	0.14	0.14	0.14	0.13	0.109	11
SE	0.07	0.05	0.04	0.04	0.06	0.09	0.10	0.11	0.11	0.076	8
SS	0.06	0.04	0.03	0.03	0.03	0.05	0.07	0.08	0.09	0.053	5
SC	0.05	0.04	0.03	0.02	0.02	0.02	0.03	0.05	0.07	0.037	4
DS	0.04	0.03	0.02	0.02	0.02	0.02	0.02	0.03	0.04	0.026	3
PD	0.04	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.02	0.019	2

Once performing pairwise comparisons of criteria, the AHP gives researchers efficient and flexible method to check and improv consistency. The consistency ratio (CR) is calculated as CR = [CI/RI], where; CI (consistency index) = [(λ-n)/(n-1)], RI = random consistency index, λ = the normalized principal eigenvector, and n = the number of factors (criteria) (Saaty, 1980). A sufficient degree of consistency is achieved if the calculated value of CR is smaller or equal to 0.1. Hence, judgments (scores assigned for the used criteria) are adequate. On the other hand, if the CR value is greater than 0.1, then the judgments are considered inconsistent and the pairwise comparison needs to be revised (Saaty, 1996, 2000). From Saaty, 1996 and for n = 9, λ = 9.6, and RI = 1.45, the CR was found to be 0.052. This in turn indicates that the judgements made for criteria weights are acceptable. Thirdly, all criteria are divided into five sub-criteria and a user-specified cell values (scores) were subjectively assigned from 1 to 9 for each one (see **Table 3** and **Figure 3**). Theoretically, values which are close to 9 have the highest hazard, whereas the lowest hazard areas have values close to 1.

Table (3): Flood Hazard Scoring Assigned for the Sub-criteria.

#	Criteria	Sub-criteria	Score
1	CN	< 50	1
		50 – 60	3
		60 – 70	5
		70 – 80	7
		≥ 80	9
2	RD (mm/year)	< 200	1
		200 – 350	3
		350 – 500	5
		500 – 650	7
		≥ 650	9
3	FA (pixel)	< 122515	1
		122515 –	3
		245029 –	5
		367544 –	7
		≥ 490058	9

... continue table (3)

#	Criteria	Sub-criteria	Score
4	DD (km/km^2)	< 0.3	1
		0.3 – 0.4	3
		0.4 – 0.5	5
		0.5 – 0.6	7
		≥ 0.6	9
5	SE (m)	< 0	9
		0 – 250	7
		250 – 500	5
		500 – 750	3
		≥ 750	1
6	SS (degree)	< 3.56	9
		3.56 – 7.89	7
		7.89 – 12.73	5
		12.73 – 19.35	3
		≥ 19.35	1
7	SC	Built-up Areas	9
		Irrigated Farming	7
		Arable Land	5
		Rough Grazing	3
		Woodland/Forest	1
8	DS (m)	< 100	9
		100 – 300	7
		300 – 600	5
		600 – 1000	3
		≥ 1000	1
9	PD ($Persons/km^2$)	< 200	1
		200 – 400	3
		400 – 600	5
		600 – 800	7
		≥ 800	9

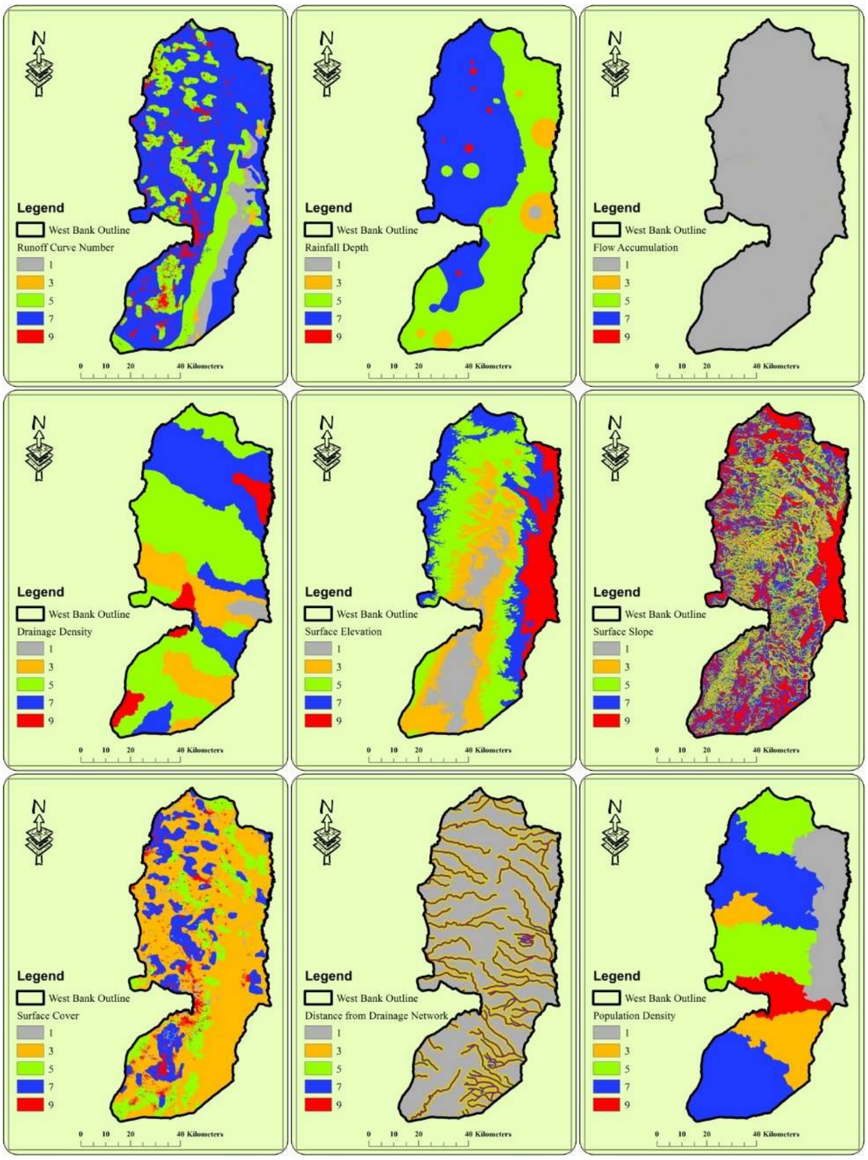

Figure (3): The scored raster grids of the nine criteria for the study area.

Finally, ArcMap 10.1 is utilized to estimate the flood hazard index based on the weighted overlay summation process (WOSP) of different thematic layers. The WOSP is a weighted linear method commonly used in GIS-based decision-making analysis (Store & Jokimäki, 2003). This method allows the manipulation of various spatial input grids by aggregating the weighted cell values together. Each input grid (factor) is multiplied by its assigned weight and the results are summed as $FHI_j = \sum_{i=1}^{n} W_i . S_{ij}$, where FHI_j is the final cell flood hazard index, Wi is a normalized weight ($\sum W_i = 1$), and S_{ij} is the hazard score of the ith cell with respect to the jth grid (Malczewski, 1999).

Results and Discussion

Based on the theoretical framework of the flood hazard mapping, and after performing the WOSP, the flood hazard index map is produced for the entire West Bank districts. The map was classified into five hazard categories (very low, low, medium, high, and very high) by natural breaks (Jenks) approach (See **Figure 4**). As such, ArcMap identified breaks by recognizing intrinsic classification scheme of the input data. Thus, datasets are classified into groups in which breaks are set where notable jump exist in the data values (Nerantzis *et. al.,* 2015).

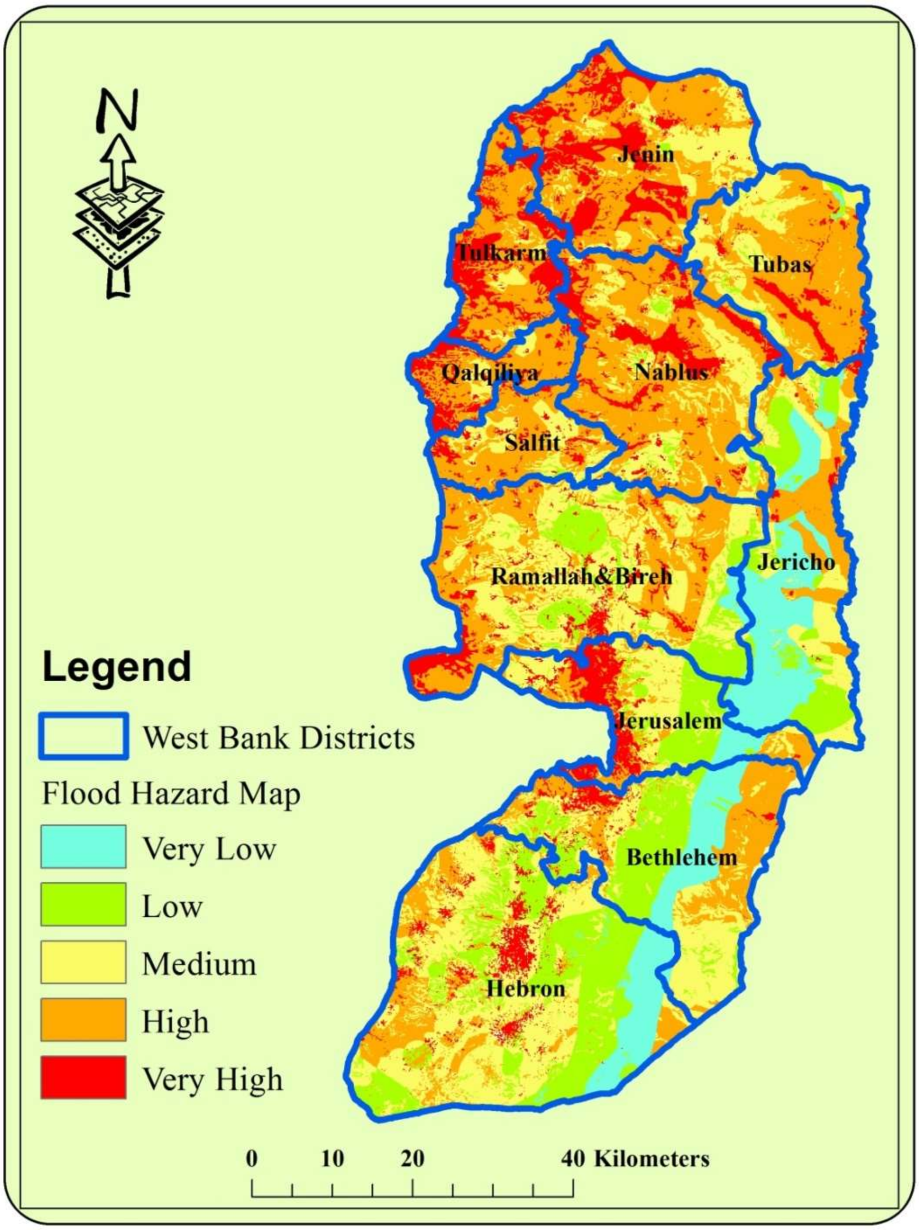

Figure (4): Flood Hazard Map of the West Bank Districts.

The developed map indicates that the medium to high flood hazard classes make up the largest areas in the West Bank (65%). Moreover, high flood hazard areas are mostly located in the north western parts whereas the very low and low ones located in the south eastern parts. This spatial trend is matched with the spatial distribution of rainfall and runoff potential. Very high flood hazard areas are in general sparsely distributed in the western parts of the West Bank with some concentrated areas in the middle parts (in Jerusalem district) and in the north (in Tulkarm, Qalqiliya, Jenin and Nablus districts). This very high flood hazard potential, in these areas, might be a result of their higher runoff potential, rainfall values and population and low surface elevations.

Table 4 provides flood hazard prone areas for the West Bank districts. Whereas Figure 5 presents, the percentages of the flood hazard areas in the West Bank and its districts.

Table (4): West Bank districts flood hazard categories.

District	Flood Hazard Intensity Class (Area, km^2)					
	Very Low	Low	Medium	High	Very High	Total
Jenin	0.0	2.6	111.5	287.2	146.2	547.5
Tubas	2.0	12.4	116.7	249.5	34.4	415
Tulkarm	0.0	0.0	25.2	140.3	104.7	270.2
Nablus	0.6	14.3	143.5	361.5	106.8	626.7
Qalqilya	0.0	0.0	17.3	95.4	45.2	157.9
Salfit	0.0	4.0	57.7	121.9	21.8	205.4
Ramallah & Bireh	14.5	135.8	324.9	288.7	76.5	840.4
Hebron	94.6	316.3	408.4	155.9	59.8	1035
Bethlehem	93.7	159.1	177.9	150.5	26.0	607.2
Jerusalem	23.3	82.1	104.1	75.4	69.1	354
Jericho	203.2	109.5	120.6	119.6	11.6	564.5
Entire West Bank	**432**	**836**	**1,608**	**2,046**	**702**	**5,624**

Figure (5): Percentages of the flood hazard areas in the West Bank and its districts.

From the table and the figure, it can be concluded that about 36% (2046 km^2) and 12% (702 km^2) of the total West Bank area are high and very high vulnerable for flood hazard, respectively. This in turn substantiates the dire need to enhance and upgrade the existing hydraulic infrastructures (e.g. culvers) in these areas to safely handle expected flood amounts and accordingly mitigate its catastrophic consequences. Whereas land having medium flood hazard form about 29% (1608 km^2) of the total West Bank area. In such areas, attention should be also taken for infrastructure development to avoid unfavourable consequences. Finally, low and very low flood hazard areas form about 15% (836 km^2) and 8%

(432 km^2) from the total West Bank area, respectively. Further, it is clear that the districts of Tulkarm, Qalqiliya and Jenin have the highest very high flood hazard prone areas which account for about 39%, 28%, and 27% from the total districts' areas, respectively. Moreover, very low and low flood hazard classes take more than 55% of the total Jericho district area.

The number of communities and total population likely to be affected by different flood hazard classes are determine as summarized in **Table 5**.

Table (5): Number of communities and total population which may be affected by different flood hazard classes in the West Bank.

Flood Hazard Class	Number of Communities Likely to be Affected	Total Population Likely to be Affected	Total Population (%)
Very Low	7	15,951	0.5
Low	30	74,819	2.5
Medium	76	214,950	7.3
High	112	383,804	13.1
Very High	299	2,245,844	76.5
Total	**524**	**2,935,368**	**100**

It is clear from the table that about 90% of the total West Bank population living in 411 communities are susceptible to high and very high flood hazard risk. About 7% of population (76 communities) belonging to the medium flood hazard zone. Whereas the remaining, 3% of population living in 37 communities, belonging to low and very low flood hazard zones. Such information is very crucial for planners in developing of flood warning and flood plain control systems.

Conclusions

This study has dealt with flood hazard mapping in the West Bank based on administrative scale (district) by adopting an integrated approach using GIS-based MCDA. The obtained results confirm that the GIS-based MCDA can be utilized to provide planners with a coherent and informative spatial flood hazard data. The use of MCDA for various flood influencing factors is recognized to be valuable in the mapping of the potential flood prone areas in the West Bank. Nine criteria (runoff curve number, rainfall depth, flow accumulation, drainage density, surface elevation, surface slope, surface cover, distance from drainage network, and population density) were investigated to delineate potential flood prone areas in the West Bank districts. The AHP pairwise comparison matrix approach was adopted to assign different criteria weights. The sensitivity of the attained results is subjective to the uncertainty of the given data criteria weights and criterion scores. Thus, it is essential to perform a sensitivity analysis by changing the criteria weights and criterion scores in order to quantify the severity of hazard and to provide insights into the generated flood hazard map.

The absence of long term flood measures and statistics make the verification of the obtained results impossible. As such, it is recommended to build stream-gauging network in the West Bank main Wadis so as to tune the flood influencing criteria weights and criterion scores and to improve the results accordingly. However, for further and detailed flood hazard research studies, collaborative efforts have to be concentrated on how to integrate the obtained results (the first in the West Bank) with other techniques such as hydrological models once the required rainfall and runoff data become available.

Finally, although the available data are limited, the work provides an overall valuable picture about the vulnerability of different West Bank districts to flood hazard. This in turn indicates that even under data scarce regions and limited resources yet much can be performed to assist the decision makers through providing essential information to mapping high potential flood hazard prone areas and thus to formulate proper corrective and preventive strategies including but not limited to early warning and emergency preparedness plans, flood control engineering structures enhancements, and floodplain management protocols.

References

- (PCBS). Palestinian Centre Bureau of Statistics. (2016). *Annual Statistics*. Estimated Population in the Palestinian Territory Mid-Year by Governorate.
- Abou El-Magd, I. Hermas, E. ElBastawesy, M. (2010). GIS-modelling of the spatial variability of flash flood hazard in Abu Dabbab catchment, Red Sea Region, Egypt. *Egypt. J. Rem. Sens. Space Sci.*, 13, pp. 81–88
- Alaghmand, S. Bin-Abdullah, R. Abustan, I. & Vosoogh, B. (2010). GIS-based River Flood Hazard Mapping in Urban Area: A Case Study in Kayu Ara River Basin, *Malaysia. Int. J. Eng. Technol*, 2, 488–500.
- Bhadra, A. Choudhury, S. & Kar, D. (2011). *Flood Hazard Mapping in Dikrong Basin of Arunachal Pradesh (India)*. World Acad. Sci. Eng. Technol, 60, 1613–1619.
- Black, A. Burns, J. (2002). *Re-assessing the flood risk in Scotland*. Sci Total Environ 294:169–184.
- Chakhar, S. Mousseau, V. (2008). GIS-based multicriteria spatial modeling generic framework. *Int. J. Geog*. Inf. Sci. 22 (11), 1159–1196.
- Chen, S.P. & Wang, R.Y. (2004). *Analyzing hazard potential of typhoon damage by applying grey analytic hierarchy process*. Nat. Hazards, 33, 77–103.
- Coppock, J.T. (1995). *GIS and natural hazards: An overview from a GIS perspective*. In Geographical Information Systems in Assessing Natural Hazards; Carrara, A., Guzzetti, F., Eds.; Springer: Berlin, Germany, Volume 6, pp. 21–34.
- Daniel, A. Gerald, F. & Valentijn, V. (2015). *Modeling Flood Hazard Zones at the Sub-District Level with the Rational Model Integrated with GIS and Remote Sensing Approaches*. Water, 7, 3531-3564; doi: 10.3390/w7073531

- Dawod, G.M. Mirza, M.N. Al-Ghamdi, K.A. (2011). *GIS-based spatial mapping of flash flood hazard in Makkah city*, Saudi Arabia J. Geogr. Inf. Syst., 11 (3) (2011), pp. 225–231 http://dx.doi.org/10.4236/jgis.2011.33019.(URL http://www.SciRP.org/journal/jgis)
- Dewan, A. Islam, M. Kumamoto, T. & Nishigaki, M. (2007). *Evaluating flood hazard for land-use planning in greater Dhaka of Bangladesh using remote sensing and GIS techniques*. Water Resour. Manag. 21 (9), 1601–1612. http://dx.doi.org/10. 1007/s11269-006-9116-1 (ISSN 09204741).
- Dihn, Q. Balica, S. Popescu, I. & Jonoski, A. (2012). Climate change impact on flood hazard, vulnerability and risk of the Long Xuyen Quadrangle in the Mekong Delta. *Int. J. River Basin Manag*, 10, 103–120.
- Elkharachy, I. (2015). Flash Flood Hazard Mapping Using Satellite Images and GIS Tools: A case study of Najran City, Kingdom of Saudi Arabia (KSA). *The Egyptian Journal of Remote Sensing and Space Science*. 18. 261-278.
- Feizizadeh, B. & Blaschke, T. (2012). Land suitability analysis for Tabriz County, Iran: a multi-criteria evaluation approach using GIS. *Journal of Environmental Planning and Management*, 56: 1-23.
- Forkuo, E.K. (2011). Flood hazard mapping using Aster Image data with GIS. *Int. J. Geomat*. Geosci., 1 (4)
- Gautam, D. K. & Kharbuja, R. G. (2006). Flood hazard mapping of Bagmati River in kathmandu valley using geo-informatics tools. *Journal of Hydrology and Meteorology*, vol. 3, no. 2677, pp. 1–9, 2006.
- Ho, W. (2008). Integrated Analytic Hierarchy Process and its applications: A literature review. *Eur. J. Oper. Res*. 18, 211–228.

- Islam, M.M, Sado, K. (2002). Development of priority map flood countermeasures by remote sensing data with geographic information system. *Journal of Hydrologic Engineering.* 7, 346–55.
- Jankowski, P. (1995). Integrating geographical information-systems and multiple criteria decision-mamking methods. *Int. J. Geog. Inf. Syst*. 9 (3), 251–273.
- Jonkman, S.N. & Dawson, R.J. (2012). *Issues and Challenges in Flood Risk Management—Editorial for the Special Issue on Flood Risk Management*. Water. 4, 785–792.
- Kazakis, N. Ioannis, K. & Thomas, P. (2015). *Assessment of flood hazard areas at a regional scale using an index-based approach and Analytical Hierarchy Process: Application in Rhodope–Evros region, Greece*. Science of the Total Environment. 538:555–563. DOI: 10.1016/j.scitotenv.2015.08.055
- Khan, S.I. Hong, Y. Wang, J. Yilmaz, K.K. Gourley, J.J. Adler, R.F. Brakenridge, G.R. Policelli, F. Habib, S. & Irwin, D. (2011). *Satellite Remote Sensing and Hydrologic Modeling for Flood Inundation Mapping in Lake Victoria Basin: Implications for Hydrologic Prediction in Ungauged Basins*. IEEE Trans. Geosci. Remote Sens. 49, 85–95.
- Malczewski, J. (1999). *GIS and Multicriteria Decision Analysis*. John Wiley & Sons, Inc. 392 pp.
- MoP (Ministry of Planning), (1997). *MoP Database*. Open files and personal communications. Ministry of Planning, Ramallah, Palestine.
- Nerantzis, K. Ioannis, K. & Thomas, P. (2015). *Assessment of flood hazard areas at a regional scale using an index-based approach and Analytical Hierarchy Process: Application in Rhodope–Evros region, Greece*. Science of the Total Environment. (538) 555–563
- Nyarko, B.k. (2002). Application of a rational model in GIS for flood risk assessment in Accra, Ghana. *Journal of Spatial Hydrology*. 2 (1): 1-14.

- Nyeko, M. (2012). GIS and multi-criteria decision analysis for land use resources planning. *Journal of Geographic Information System*, 4: 341-348.
- Orok, H. (2011). *A GIS Based Flood Risk Mapping of Kano City*, Nigeria; University of East Anglia: Norwich, UK.
- Ozcan, O. & Musaoglu, N. (2010). *Vulnerability Analysis of Floods in Urban Areas Using Remote Sensing and GIS*. In Proceedings of the 30th EARSeL Symposium: Remote Sensing for Science, Education and Culture, Paris, France.
- Parakash, T.N. (2003). *Land suitability analysis for agricultural crops: a fuzzy multicriteria decision making approach*. Thesis (Msc). The International Institute for Geo-Information Science and Earth Observation (ITC), Enschede, The Netherlands.
- Saaty, T.L. (1980). *The analytic hierarchy process: planning, priority setting*, resource allocation. McGraw-Hill International, New York, USA.
- Saaty, T.L. (1996). *Decision Making for Leaders: The Analytic Hierarchy Process for Decisions in a Complex World*. RWS Publication, Pittsburgh, PA.
- Saaty, T.L. (2000). *Fundamentals of Decision Making with the Analytic Hierarchy Process*. RWS Publications, Pittsburgh, PA.
- Sanyal, J. & Lu, X. X. (2006). GIS-based flood hazard mapping at different administrative scales: A case study in Gangetic West Bengal, India. *Singapore Journal of Tropical Geography*. 27. 207–22. doi:10.1111/j.1467-9493.2006. 00254. x
- Sanyal, J. & Lu, X.X. (2005). *Remote sensing and GIS-based flood vulnerability assessment of human set-tlements: a case study of Gangetic West Bengal*, India. Hydrological Processes 19, 3699–716.
- Sarhadi, A. Soltani, S. & Modarres, R. (2012). Probabilistic flood inundation mapping of ungauged rivers: linking GIS techniques and frequency analysis. *Journal of Hydrology*, vol. 458-459, pp. 68–86.

- Shadeed, S. & Almasri, M. (2010). *Application of GIS-based SCS-CN method in West Bank catchments, Palestine*. Water Science and Engineering. 3(1): 1-13. [doi:10.3882/j. issn.1674-2370.2010.01.001].
- Shadeed, S. & Lange, J. (2010). *Rainwater Harvesting to Alleviate Water Scarcity under Dry Conditions: a Case Study in Faria Catchment, Palestine*. Water Science and Engineering, 3(2): 132-143. [doi:10.3882/j.issn.1674-2370.2010.02.002].
- Shadeed, S. (2008). *Up to Date Hydrological Modeling in Arid and Semi-arid Catchment, the Case of Faria Catchment*, *West Bank, Palestine*. PhD. dissertation. Faculty of Forest and Environmental Sciences, Albert-Ludwigs-Universität, Freiburg imBreisgau, Germany.
- Shadeed, S. (2011). *Developing a GIS-based Suitability Map for Rainwater Harvesting in the West Bank*, Palestine. Professional Environmental Education for Sustainable Development: Plugging the Hole. International Conference. Birzeit University, Palestine.
- Shadeed, S. (2012). Spatio-temporal drought analysis in arid and semi-arid regions: A case study from Palestine. *The Arabian Journal for Science and Engineering*. 38: 2303–2313, doi:10.1007/s13369-012-0504-y
- Store, R. & Jokimäki, J. (2003). *A GIS-based multi-scale approach to habitat suitability modeling*. Ecological Modelling 169, 1–15.
- Thilagavathi, G. Tamilenthi, S. Ramu, C. Baskaran, R. (2011). *Application of GIS in Flood Hazard Zonation tudies in Papanasam Taluk*, Thanjavur District, Tamilnadu. Adv. Appl. Sci. Res. 2, 574–585.
- Yashon, O. & Ryutaro, T. (2014). *Urban Flood Vulnerability and Risk Mapping Using Integrated Multi-Parametric AHP and GIS: Methodological Overview and Case Study Assessment*. Water. 6. 1515-1545; doi:10.3390/w6061515.