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Comparison of classic and fuzzy analytic hierarchy processes for mapping the flood hazard of Birjand plain

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Abstract

Flood is one of the most destructive natural hazards which impose vast costs in order to compensate its effects, especially in areas where there are manifestations of human development (such as cities). Urban development, particularly in the margins of rivers, has increased flood damages in recent decades. The aim of this study was to develop flood hazard maps of Birjand plain based on analyses of multi-criteria decision-making and geographic information system (GIS). This model was developed using six criteria including precipitation depth, basin slope, permeability, land use, proximity to river, and sub-basin shape. In this method, paired comparison of options was conducted by surveying the experts' opinions in this field using a questionnaire, and geometrical averaging was employed to calculate the weights of the criteria. According to the map prepared by means of Fuzzy Analytic Hierarchy Process (FAHP), 1.17 percent of the catchment area of Birjand is imposed to very probable hazard of flood and about 10.77 percent of the basin area is of high flood hazard. Moreover, in accordance with the Analytical Hierarchy Process (AHP) model, 3.29 percent of the basin is in the high hazard zone and 12.23 percent is located within the zone of high hazard. Comparison of results indicated that FAHP mapping approach is more compatible with the recorded data of recent floods.

Keywords: *Fuzzy Analytic Hierarchy, Spatial Prioritizing, potential flooding area, Urban Basin.*

1. Introduction

Flood phenomena is one of the natural disasters which has always caused damages in our country throughout history. Unfortunately, fundamental and dramatic measures for controlling floods have not yet been adopted in different regions of the country. Generally, despite the frequency of floods' occurrence, their damages are soon forgotten in our country. Moreover, due to anthropogenic alterations in catchment characteristics over the time, the flooding is exacerbated. Infringing to the riverine and neglecting river maintenance in the river plains, non-engineering measures in terms of flood control in rivers, which is due to insufficient understanding of the morphological and hydrological conditions of the river, have led to major floods and consequent extreme damages. Thus, looking for temporary solutions in order to identify the areas prone to flood is necessary and inevitable (Dehghani et al., 2014). Researches and studies conducted for defining a flooding indicator and determining flood prone areas in various parts of the world indicate that a single method has not been applicable for this purpose. Fernández and Lutz (2010) used GIS and multi-criteria decision-making for mapping the flood hazard for Yerba Bwana city in the state of Tukaman, Argentina. They found that the most critical areas are of the points close to the drainage channel. Fanghua and Guanchun (2010) carried out flood hazard assessment using a fuzzy group multi-criteria decision-making method for a basin in Sri Lanka. They considered average flood depth and the extension of the flooded area as risk indices. Moreover, indicators such as population density were determined as indicators of vulnerability. See and Openshaw (2000) employed fuzzy clustering technique to improve flood forecasting confidence in the UK. The same approach was used by Roger (2000) to provide soil hydrological characteristic maps in France,. Both studies confirmed that the methods based on the fuzzy logic are more suitable due to good implementation, lower cost, and a better performance. Abrishamchi et al. (2005) studied the application of compromise programming, which is one of the multi-criteria decision-making methods for managing urban floods in Zahedan, Iran. Dehghani et al. (2014) employed the integration of GIS and Fuzzy analysis to determine sub-basins with high sediment production and high flood occurrence in Forg Watershed, which suffers from the lack of meteorological and hydrometer stations. In this work, considering the factors simultaneously impacting flood and erosion, the priority of proceedings to reduce flooding was identified. Salehi et al. (2014) used the Buckley Fuzzy Analytic Hierarchy Process and programming in Matlab software, to obtain the weights of five criteria, including proximity to drainage network, flow accumulation, slope, elevation, and developed and undeveloped lands. Then, by means of applying the criteria weights in GIS, the Tehran flood hazard was mapped. Radmehr and Araghinejad (2015) employed Fuzzy programming supportive system based on spatial analysis; whereat the first stage, Analytic Hierarchy Process was used to determine the structure of the decision-making process and to estimate the weights of standard maps, and then via the Fuzzy Topsis approach, the final ranking of sub-basins located in Tehran was defined. Afterwards by shifting the weights of decision-making criteria and generating weighting scenarios, model sensitivity was analyzed and ultimately the sub-basin which won the first priority in most scenarios was introduced as a hazardous one.

Since the Birjand plain is located in arid and semi-arid climates with low amounts and irregular spatial and temporal distribution of precipitation and existence of potential flood prone areas, it is necessary to identify these prone areas to prevent the financial damages. This study aims to identify flood prone areas in this plain using a Fuzzy-AHP (FAHP) approach.

2. Data set and methodology

Study area

South Khorasan province is located in a dry climate and the concentration and centralization of the rural areas are mostly in the mountainous regions and in the centre of the province. Birjand basin, which is a sub-basin of Lut Desert, is located in this province. It is located in the eastern part of country and in a distance of 480 kilometres away from southeast Mashhad. The Birjand plain is in the coordinates of 32° 34’E to 33° 8’E and 58° 41’N to 59° 44’N. In a geographical respect, the plain boarder is limited to the Asadabad and Chahak Mosavieh plains from north, Mokhtaran plain from south, and Sarbishe plain from east (Keshavarz, 2014).

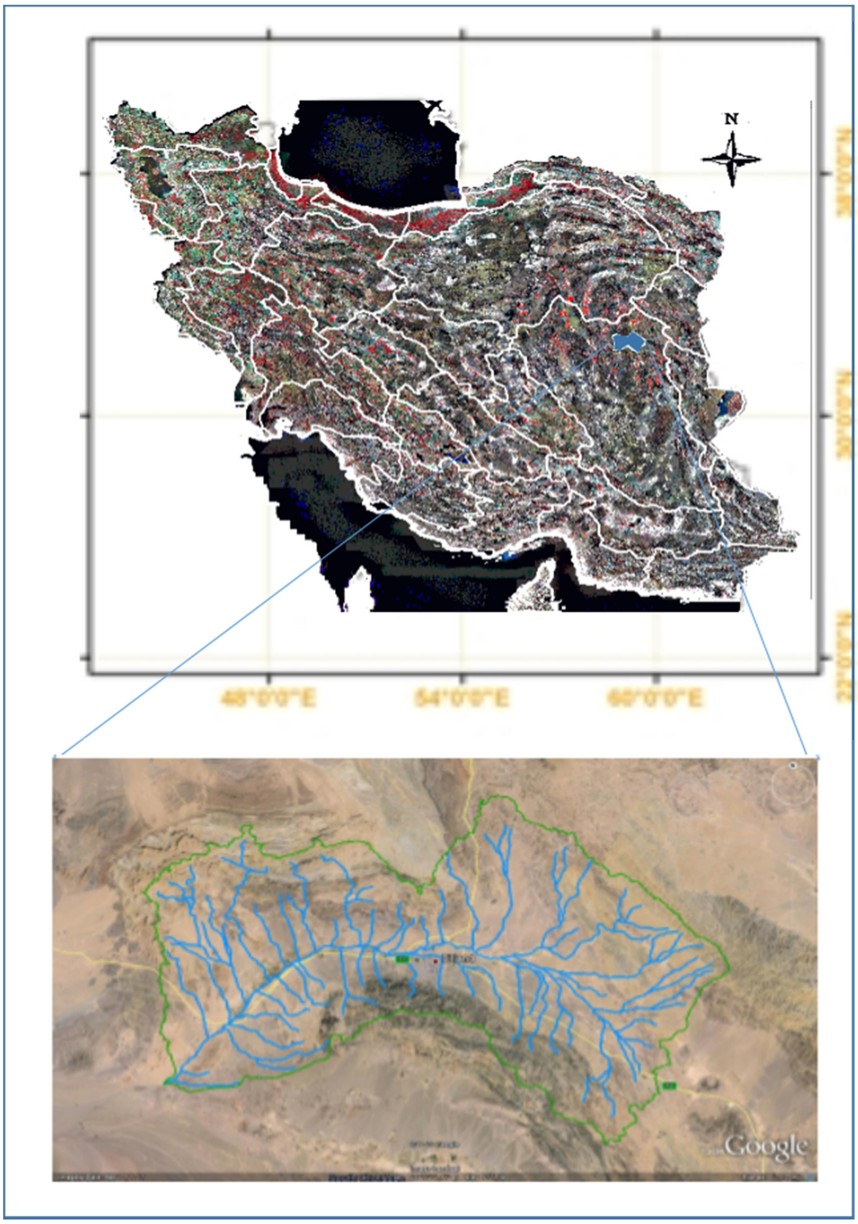


Fig. 1. GeographicLocation of Birjand plain

To select the flood prone areas in Birjand plain, the appropriate criteria in the evaluation were first determined and combined using library studies and surveying the literature and prior researches of the subject. The criteria with less significance were then excluded. Ultimately, six criteria including precipitation, slope, permeability, land use, proximity to river, and sub-basin shape were chosen due to their compatibility with the research technique. Afterwards, in collaboration with organizations such as Regional Water Authority of South Khorasan, Department of Natural Resources and Watershed of South Khorasan, Aab Pouy Water Consulting Engineers, data from research conducted by Keshavarz et al. (2014) alongside utilization of information involved in data obtained from meteorological stations in South Khorasan, the primary data and maps for this study were provided in ArcGIS 9.3 environment. Raster data layers related to the aforementioned criteria were also extracted. AHP paired comparison questionnaire was used to acquire experts' opinions. In order to a better design of the questionnaire, Google Docs-Google Forms tool was used.

Multi-criteria decision-making

Multi-criteria decision-making method consists of a series of techniques (including sum of weights or convergence analysis) which allows scoring and weighting a range of criteria related to a topic to be later ranked by experts and beneficiaries. Multi-criteria decision-making implies on valuing the options that are evaluated by several criteria (Sovary, 2008).

Analytic Hierarchy Process (AHP)

Analytical Hierarchy Process (AHP) developed by Saaty (1980), is amongst powerful and simple methods for solving multi-criteria decision-making issues and is used when conflicting decision criteria make it difficult to choose among the options. This method is based on paired comparisons and is in accordance with three concepts of analyzing, adaptive judgment and synthesis of priorities.

In the concept of analysis, hierarchical decomposition of the decision-making process is necessary. The principal of synthesis provides each of the spatial priorities involving determined relative scales at different levels of hierarchy and creates a combined set of priorities for the elements in the lowest level of hierarchy (the options). The Index offered as an indicator of compatibility by Saaty (1980), was employed as the compatibility criteria in the judgments.

In order to consider the compatibility in judgments, this index should be smaller than 0.1. If the index is greater than 0.1, the decision-makers should reconsider their judgments (Darayi, 2012). In order to model the uncertainties of human preferences, the theory of fuzzy sets was combined with the paired comparisons in the Analytic Hierarchy Process. Thus, a more nuanced understanding of the provided decision-making process was achieved (Ayag and Ozdemir, 2006).

Consistency index and consistency ratio can be determined by the equations 1 and 2, as follows:

$$CI = (\lambda_{max} - n)/(n-1) \qquad (1)$$

where CI is the index of consistency in judgments, n is the number of decision criteria, λ_{max} presents the maximum eigen value,

$$CR = CI/RI \qquad (2)$$

where CR is the consistency ratio in the judgments of decision-makers, RI represents the random index which is in accordance with n (table 1) (Asgharpour, 2010). For the present study, the value of RI was set to 1.24, considering the number of factors, i.e. 6.

Table 1. Values of RI

N	2	3	4	5	6	7	8	9	10
RI	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Providing the final map using AHP

After ensuring the consistency of the paired comparison matrices (decision matrices) filled by experts, criteria weighting was carried out using "Eq. (3)":

$$w_i = \frac{b_{ij}}{\sum_{i=1}^{k} a_{ij}} \qquad (3)$$

In this equation, w_i is the weight of the i^{th} criteria, k is the number of decision-making criteria, b_{ij} presents the geometric mean of each row of the matrix of paired comparison, which is calculated by "Eq. (4)".

$$b_{ij} = \left(\prod_{i=1}^{k} a_{ij}\right)^{1/k} \qquad (4)$$

where a_{ij} is the importance of the i^{th} criteria in relation to the j^{th} criteria (Keshavarz, 2014)

After calculating the importance coefficient of each criterion for each of the experts' comparisons matrices and the geometric mean of all matrices for each criterion, the final weight was obtained for the desired criteria.

Afterwards, according to the calculated weights in the previous steps by allowing mathematical operations on raster maps in Arc GIS 9.3 Raster Calculator, different layers were combined and the final map was prepared.

Providing the final map using FAHP

In this method, after considering the consistency of the paired comparison matrices using table (2), scores of paired comparison matrices of experts were converted into triangular fuzzy numbers, where each number represents a linguistic variable. Then, the fuzzy paired comparison matrices, three matrices for every expert, were obtained. In this study, 13 experts responded to the questionnaire amongst which two questionnaires were excluded considering their high incompatibility index.

Table 2. Fuzzy numbers in accordance with linguistic variables (Li et al., 2009)

Linguistic variable	Positive triangular fuzzy numbers	Revert positive triangular fuzzy numbers
Equally important	(1,1,1)	(1,1,1)
Intermediately important	(3,2,1)	(1.1,3.1,2)
Moderately important	(4,3,2)	(1.1,4.1,3.2)
Intermediately important	(5,4,3)	(1.1,5.1,4.3)
High important	(6,5,4)	(1.1,6.1,5.4)
Intermediately important	(7,6,5)	(1.1,7.1,6.5)
very important	(8,7,6)	(1.1,8.1,7.6)
Intermediately important	(9,8,7)	(1.1,9.1,8.7)
Absolutely important	(9,9,9)	(1.1,9.1,9.9)

According to the method proposed by SeeSora and Buckley, the fuzzy weights of the decision-making criteria were calculated based on the following procedure:

1- Using Alpha pruning to convert each matrix into three paired comparison matrices. By considering α = 1, the center matrix of ($R_{\mathrm{b}}^{\mathrm{k}}$) and α = 0, along with minimum and maximum matrices (R_a^k and R_c^k) were obtained in accordance with equations (5) and (6) (Keshavarz, 2014):

$$\alpha = 1 \rightarrow R_b^k = \left(r_{ij}\right)_b^k \qquad (5)$$

$$\alpha = 0 \rightarrow \left\{R_a^k = \left(r_{ij}\right)_a^k, R_c^k = \left(r_{ij}\right)_c^k \right. \qquad (6)$$

where K is the number of experts, a, b and c are the minimum, the center, and the maximum points of a triangular fuzzy number, respectively.

2- Estimating the criteria weights for each of $R_{\mathrm{b}}^{\mathrm{k}}$,$R_{\mathrm{a}}^{\mathrm{k}}$, and $R_{\mathrm{c}}^{\mathrm{k}}$ matrices:

$$\mathrm{w}_{\mathrm{b}}^{\mathrm{k}} = (w_i)_b^k \;,\quad w_a^k = (w_i)_a^k \;,\quad w_c^k = (w_i)_c^k \qquad (7)$$
$$i = 1,2,\dots,n$$

3- Calculating $M_{\mathrm{a}}^{\mathrm{k}}$ and $M_{\mathrm{c}}^{\mathrm{k}}$ constants using relations (8) and (9):

$$\mathrm{M}_{\mathrm{a}}^{\mathrm{k}} = min\left\{\frac{w_{ib}^k}{w_{ia}^k}\middle| 1 \le i \le n\right\} \qquad (8)$$

$$M_c^k = max\left\{\frac{w_{ib}^k}{w_{ic}^k}\middle| 1 \leq i \leq n\right\} \qquad (9)$$

4- Calculating upper and lower bounds of fuzzy weights by "Eq. (10)":

$$\mathrm{W}_{\mathrm{ia}}^{*\mathrm{k}} = M_a^k w_{ia}^k \text{ , } W_{ic}^{*k} = M_c^k w_{ic}^k \qquad (10)$$

The upper and the lower thresholds of the weights are as:

$$\mathrm{W}_{\mathrm{a}}^{*\mathrm{k}} = (\mathrm{w}_{\mathrm{i}}^{*})_{\mathrm{a}}^{\mathrm{k}}, \qquad W_c^{*k} = (w_i^*)_c^k \qquad (11)$$

By combiningW_a^{*k},W_b^{*k}, and W_c^{*k} , the fuzzy weights matrix was obtained for the k^th^ expert as:

$$W_i^k = \left(w_{ia}^{*k}, w_{ib}^{*k}, w_{ic}^{*k}\right) \qquad (12)$$

5- In order to combine the opinion of different experts, the geometric mean of Fuzzy weights is employed:

$$W = \left(\prod_{k=1}^{k} w_i^k\right)^{\frac{1}{k}} \qquad (13)$$

where, $w_{\mathrm{i}}^{\mathrm{k}}$ is the Fuzzy weight of the kth expert for the ithcriterion

6. Obtained fuzzy weights are converted to crisp and classic forms using the equation proposed by Chen (2000):

$$CC_i = d(w_i, 0)/d(w_i, 1) + d(w_i, 0) \; (14)$$

$$i = 1,2, \dots, n \, , 0 \leq CC_i \leq 1$$

In this equation, $d(w_i, 0)$ and $d(w_i, 1)$ are the measured distances between two Fuzzy numbers and CC_i represents the weight of the criterion of interest:

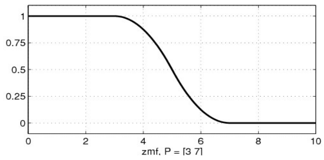
$$d(w_i, 0) = \sqrt{1/3\,((w_{ia} - 0)^2 + (w_{ib} - 0)^2 + (w_{ic} - 0)^2)} \qquad (15)$$

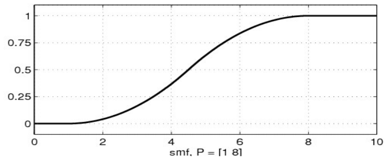
$$d(w_i, 0) = \sqrt{1/3\,((w_{ia} - 1)^2 + (w_{ib} - 1)^2 + (w_{ic} - 1)^2)} \qquad (16)$$

After calculating the weights, in order to convert the criteria into a non-dimensional space, the entire criteria maps were converted to raster layers between zero and one. Based on Fuzzy theory, membership of the members in the set is between 0 and 1, hence the given numbers are neither zero nor one, but a number between zero and one (Ramsey et al., 2015). A fuzzy set is determined using the fuzzy membership degree (also called possibility).

There are several fuzzy membership functions including S-shaped (increasing), Z-shaped (decreasing), linear, trapezoidal, and triangular (Richards and Boyce, 2001). The equations of the Z-shaped and S-shaped functions, which are applicable for the parameters of this research, are presented in table 3 (Kooze Pazan Dezfooli, 2009).

Table 3- Charts of the Fuzzy membership functions

Membership function	Curve
$\begin{cases} 1, & x \leq a \\ 1-2\left(\frac{x-a}{b-a}\right)^2, & a \leq x \leq \frac{a+b}{2} \\ 2\left(b-\frac{x}{b-a}\right)^2, & \frac{a+b}{2} \leq x \leq b \\ 0, & x \geq b \end{cases}$ Membership function_ Z Shape	 Curve of Membership function (Z Shape)

$\begin{cases} 1, & x \le a \\ 2\left(\frac{x-a}{b-a}\right)^2, & a \le x \le \frac{b+a}{2} \\ 1-2\left(\frac{b-x}{b-a}\right)^2, & \frac{b+a}{2} \le x \le b \end{cases}$ Membership function _S Shape	 Curve of Membership function (S Shape)

Based on the above equations, numerical value of each pixel within a map is a number between zero and one. After creating the raster layers, decision parameters were converted to fuzzy forms in ARC Map 9.3 (Figures 2 to 7). In the fuzzy layers, each of the pixels was awarded values between zero and one, which were the membership degrees of the raw amounts of the relevant criteria in that pixel. For each pixel, the calculated weight of each criterion was multiplied by the membership degree of the relevant criterion of the same pixel to obtain the actual value of each criterion for that pixel. Then, using fuzzy algebraic adding operator in ARCGIS 9.3, the fuzzy layers were combined through affecting their weights and the final informative layer of the plain was obtained.

The Fuzzy algebraic adding operator=1-$\prod_{i=1}^{x}\left(1-\mu(i)\right)$ (17)

μ_i indicates the outcome of multiplying the fuzzy map by the weights of each criterion, which were obtained previously.

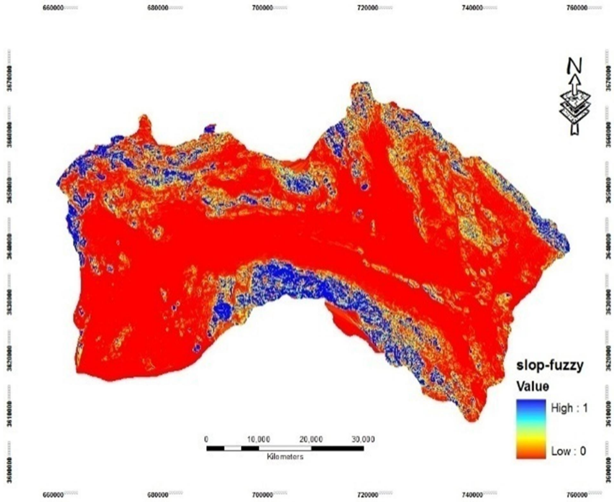


Fig. 2. Fuzzy map of slop

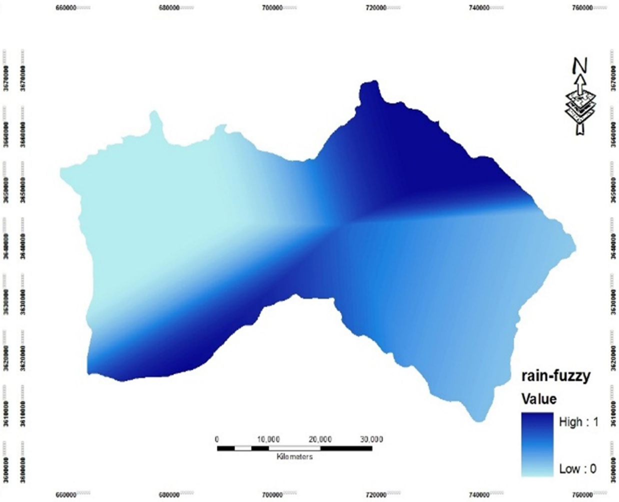


Fig. 3. Fuzzy map of rainfall

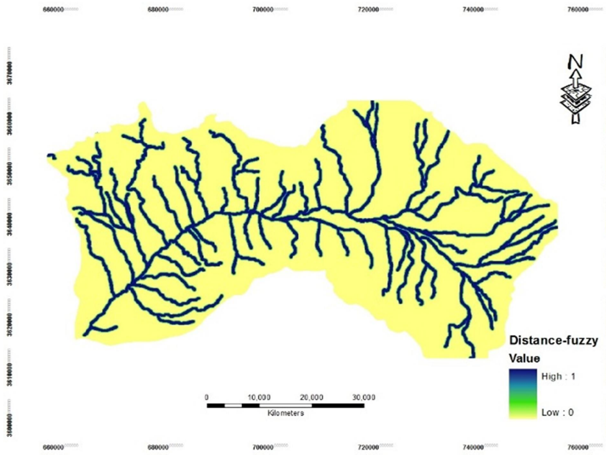


Fig. 4. Fuzzy map of proximity to river

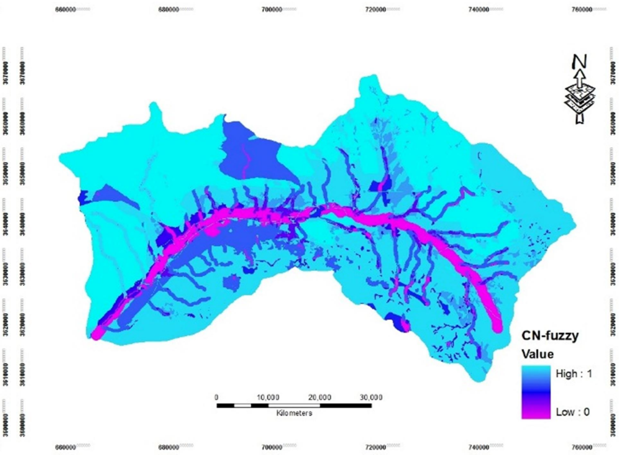


Fig. 5. Fuzzy map of permeability criterion (CN)

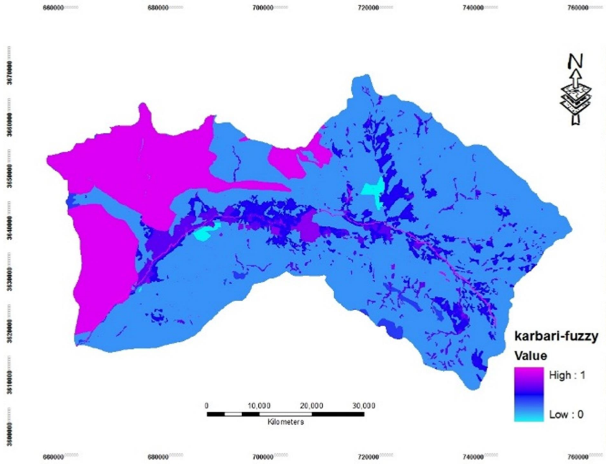


Fig.6. Fuzzy map of land use

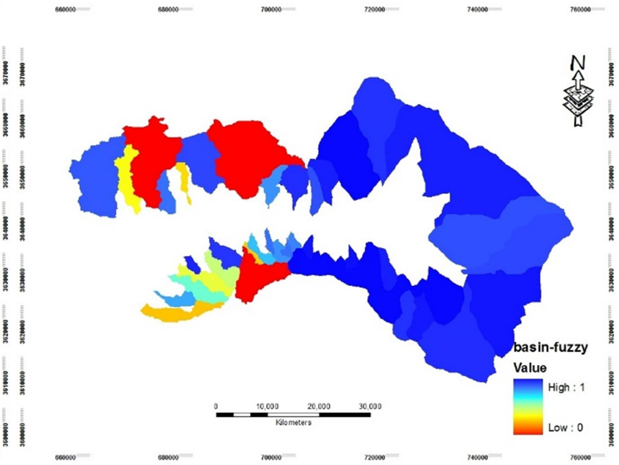


Fig. 7. Fuzzy map of sub-basin shape

Classifying the final maps

After preparing the final layer of the potential flood hazard of the plain, the final map was classified into seven classes by dividing the values of pixels into equal intervals. The ranges of different classification categories are presented in Table 4.

Table 4. Border of the classification categories for AHP and FAHP methods

Classes	**AHP**	**FAHP**
Inconsiderable	2.5 – 3.16	0.017 – 0.102
Very low	3.16 – 3.82	0.102 – 0.189
Low	3.82 – 4.48	0.189 – 0.275
Medium	4.48 – 5.14	0.275 – 0.361
Relatively High	5.14 – 5.79	0.361 – 0.447
High	5.79 – 6.46	0.447 – 0.533
Very high	6.46 – 7.12	0.533 – 0.619

Calculating the adoptability percentage of AHP and FAHP models

After conducting a classification with similar values for the final maps of AHP and FAHP models, Cross Tabulate Area operator can be employed in GIS environment to match the two models and to determine the frequency of the similar pixels (the percentage of compatibility) in different classes using "Eq. (18)" (Hajizade., 2010).

$$\text{Compatibility percentage} = \frac{\textit{Sum of the common pixels of classes}}{\text{sum of the whole pixels}} 100 \qquad (18)$$

The presence or absence of significant difference between the output maps obtained from both methods was investigated using Chi-Square test in accordance with "Eq. (19)" (Dowdy et al., 2004).

$$x^2 = \sum_i \frac{(O_i - E_i)^2}{E_i} \qquad (19)$$

Where, O is the number of pixels of FAHP map as the observed data, E is the number of pixels of different classes of AHP map as the expected values, and i represents the number of categories of classification.

3. Results and Discussion

Computed weights by AHP and FAHP

According to the aforementioned descriptions and table (5), the weights of criteria were obtained through employing two methods of classic and Fuzzy Analytical Hieratic Processes. By combining the maps of the criteria using the weights, the final map was prepared as shown in figure (8). The areal proportion of each class of flooding map is shown in Table (6).

Table 5. Classic weight of the criteria

Name of the criterion	**Weight of the criterion**	
	AHP	**FAHP**
Precipitation	0.314	(0.22,0.3,0.4)
Slope	0.212	(0.16,0.2,0.25)
Curve number	0.056	(0.06,0.05,0.04)
River distance	0.215	(0.2,0.2,0.22)
Land use	0.085	(0.08,0.08,0.09)
Sub-basin shape	0.034	(0.03,0.03,0.03)

Table 6. Area percentage of each flooding class of the plain

Classes	**The area percentage of the class**	
	AHP	**FAHP**
Inconsiderable	0.72	0.2
Very low	8.75	5.9
Low	49.78	28
Intermediate	12.59	26.26
Relatively high	12.64	27.69
High	12.23	10.77
Very high	3.29	1.17

Figure 8 shows that by moving from west of plain to the eastern part, the hazard of flood increases and the low hazard class mostly compromises the central parts of the plain. Relatively high to very high hazard areas are mostly within north eastern and southern strips. This may be due to the high levels of precipitation in these regions (high precipitation statistics in the rain gauge stations) with respect to the weight dedicated to the precipitation criteria. Furthermore, the slope and permeability criteria in these areas have higher weights and hence are not ineffective in the results.

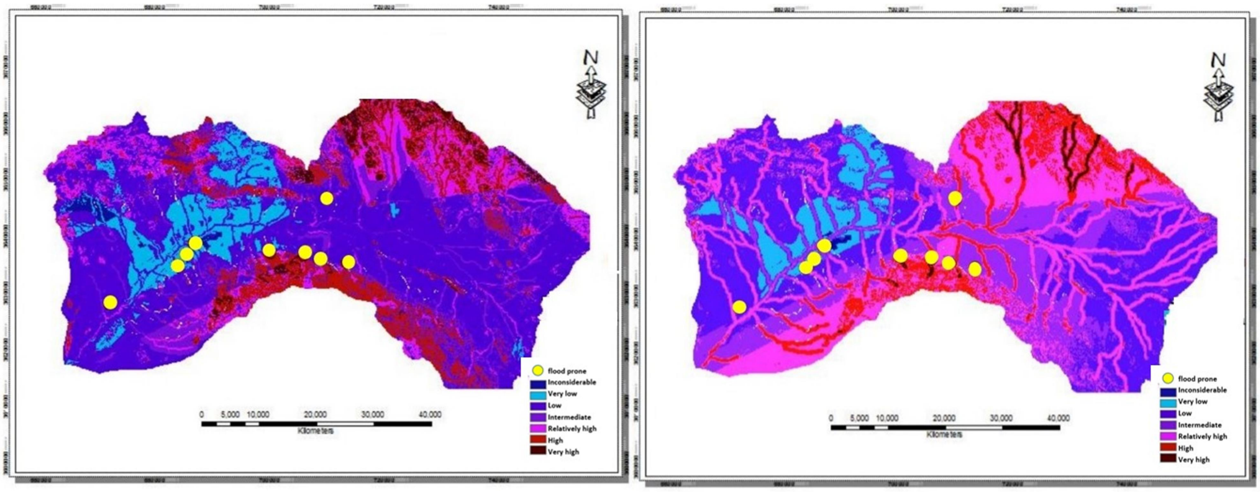


Fig. 8. Final mapping of Birjand basin in terms of flooding hazard using AHP and FAHP methods

The results of FAHP method, mostly classify the plain in the low, intermediate, and high hazard classes. This is obvious since northeast and southwest parts of plain and also most of the areas close to the river own a high hazard of flooding. Precipitation and curve number criteria in the northeast and southwest are of relatively proper condition and hence own a high fuzzy value, which is the reason why these areas are placed as high and very high classes. In the western parts of the plain and the eastern strip, the precipitation criterion is low and inconsiderable and has a fuzzy value of zero or close to zero. Moreover, the slope criterion is of a low fuzzy value and consequently results in low hazard, although the permeability and the fuzzy value of land use is high.

Moreover, the criterion of sub-basin shape insignificantly affects hazard rate, since it has an inconsiderable fuzzy value. In the central areas and in the urban area, the sub-basin shape and slope criteria hold low fuzzy values, the permeability criterion is of high value, and precipitation and land use criteria own average values. Therefore, it is expectable that these areas fall within the intermediate hazard class. The river distance criterion, which holds the second highest fuzzy value after precipitation, has led to high and very high hazards for the areas near the stream.

According to table (6) and the results of FAHP model, 1.17 percent of the basin area is prone to very high hazard of flooding and 10.77 percent of the basin area is prone to high hazard of flooding, while the majority of this percentage is in the northern and southern parts of the basin. According to the flood hazard map of the basin illustrated in figure (8) and contrast to what is expected, by getting close to the main branch of the river and merging more branches into the main river of the studied basin, the hazard of flooding does not increase, which is due to the involvement of a few of the most important factors affecting the flood event. In most parts, precipitation is of high amounts. Therefore, when combined with other factors such as the slope of basin and permeability, these factors led to a high hazard of flood in this part of the basin.

Difference in pixels of different classes

Table (7) depicts the difference in the number of pixels in different classes of each of the two methods. Difference in the expansion territory of different classes in the two comparing maps can also be expressed as the difference between the two maps, where one of these cases has been referred to in Figure (9).

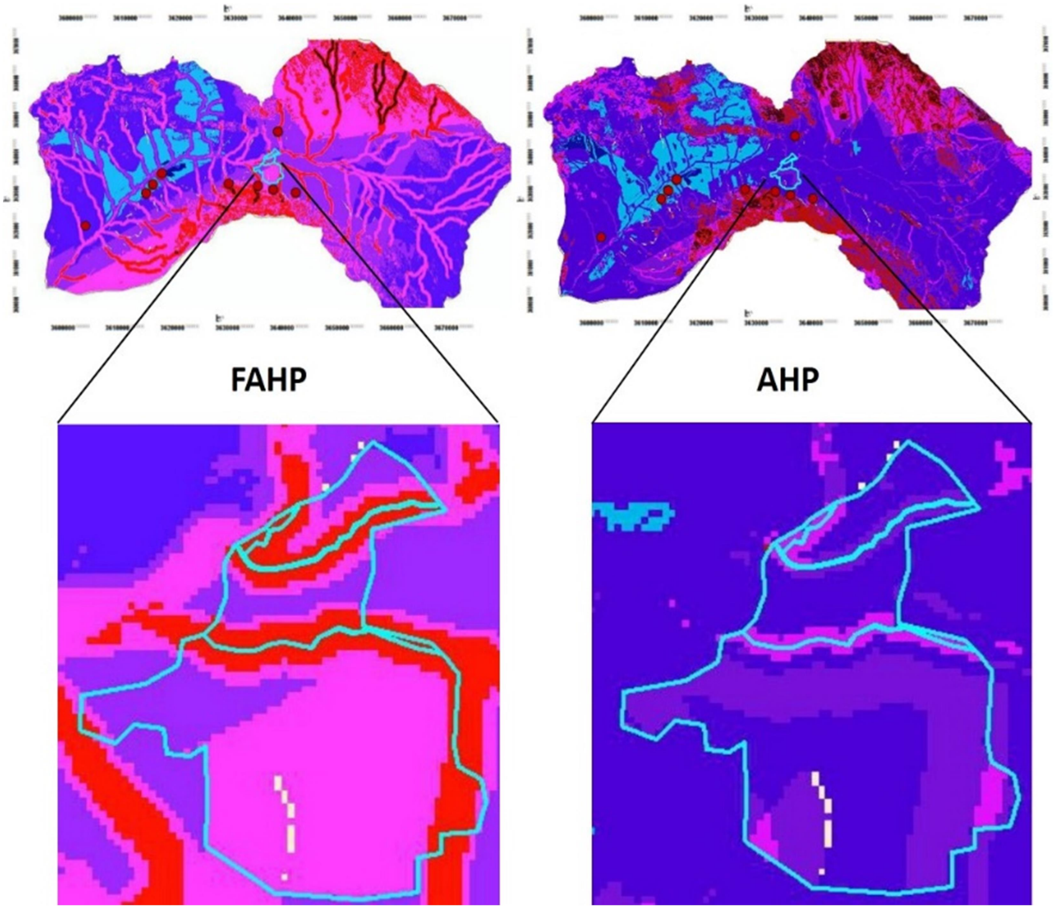


Fig. 9. Differences in expansion territory in different classes of FAHP and AHP maps in the urban area

Calculating percentage of agreement of AHP and FAHP models

The frequency of the corresponding common pixel classes in the two methods are shown in table (7).

Table 7. Frequency of common pixels in different classes of Birjand plain

Classes	Inconsiderable	Very low	low	Intermediate	Relatively high	High	Very high
Inconsiderable	441	178	0	0	0	0	0
Very low	1405	14745	3023	105	100	0	0
Low	266	8256	69310	7388	4666	1701	0
Intermediate	254	5213	54141	10687	6905	8539	264
Relatively high	0	240	32874	18609	20967	15689	2254
High	0	3	3561	4402	8055	12056	7206
Very high	0	0	6	7	676	2069	1047

According to "Eq. (19)"and table (7), two models match at a percentage of 39.49. To assess the significant level of the difference between the two maps, using "Eq. (20)", the calculated Chi-Square value equalled 147996. To determine whether the χ^2 is small or large, two parameters of degrees of freedom (DF) and the significant level were used (Kordi, 2008). In this study, the degree of freedom was achieved according to "Eq. (21)":

DF = (Number of classes of the classifying the final map - 1) * (Number of comparing maps) (21)

Thus, considering a degree of freedom of 6 and at a significant level of 5 percent, the critical Chi-Square value (χ^2) equals 12.59, using the table of Chi-Square values. If for each classified class, O=E and $\chi^2=0$, then the results of both methods are the same and there are no differences. However, if $E\neq O$ and $\chi^2\neq 0$ and the calculated value of χ^2 is smaller than the critical Chi-Square, then the results of both methods would be insignificantly different and the null hypothesis would be approved. Finally, if $O\neq E$ and $\chi^2\neq 0$, but the computational value of χ^2 is greater than the amount of the critical Chi-Square, the results are significantly different. According to the calculations, the computational Chi-Square value is much greater than the critical Chi-Square and therefore, the final results obtained from AHP and FAHP are significantly different. To select the most suitable method of mapping, the final maps were compared with the recorded flood data.

Comparing the final map with the recorded flood data by Birjand Regional Water Authority

Judging the model acceptability can be carried out using other information including ground truth data. Hence, the coordinates of the plain where the destructive floods occurred during 2014-2016 were acquired from Birjand Regional Water Authority. Position of these points in the mapping levels are illustrated in figure (8). According to the classification, six points of FAHP method are of relatively high hazard zone. Furthermore, three of the points are near the main stream and the outlet of basin. So it can be concluded that the obtained plan has good agreement with data gathered from local authorities regarding flood affected areas. In spite of the proximity of some of points to the streams, six points of AHP method were within the low and very low hazard zones. Also, since FAHP method considers the uncertainty of the experts' opinions in making decisions, employing FAHP method is recommended for mapping potential flood hazard.

4. Conclusion

This study sought to identify flood prone areas in the plains of Birjand. Using maps and considering the included priorities within them, decisions on flood prone locations were made.

he final mapping of the potential hazard of flooding in the studied basin was based on the weights of information layers using two methods of Fuzzy (FAHP) and classic (AHP) Analytic Hierarchy Processes. Results indicated a high adoptability between areas with high hazard of flooding and the conducted mapping using Fuzzy Analytic Hierarchy Process. Regarding flood hazard obtained through applying FAHP method, the precipitation criterion with a weight of 0.414 and the river distance criterion with a weight of 0.215 were more important than other criteria, considering their extreme control over runoff discharge from the basin surface. In contrast, sub-basin shape and curve number criteria with respective coefficients of 0.034 and 0.056 were of less importance. Consequently, although controlling climatic factors, such as intensity, duration, and type of precipitation is impossible, by taking actions within the catchment area (especially in high-hazard flood zones) such as reducing slope in a series of steps at different parts of the basin, organizing the main stream bed, watershed measures and so on, it is possible to minimize the dangers of flooding.

According to the final map obtained from FAHP, areas with high flood potential hazard were mainly located in high altitudes of northern and southern mountainous areas and in the riverine.

In areas with higher precipitation, steeper slopes, and mainly rocky coverage along with residential areas, there were poor pastures or undeveloped lands. Accordingly, about 30 percent of the basin surface was of high or very high flood potential. Therefore, in order to reduce soil erosion and life and property damages caused by this high potential and to control and use flood volume beneficially in order to compensate a significant part of the regional needs, this should be considered in environmental programming so as to lead negative aspects towards positive results.

Using hierarchical model in the environment of geographic information system can help identify and reveal flood prone areas with relatively acceptable speed and accuracy. Despite this, the central judgment of the method can be one of its weaknesses, since in cases of lack of enough knowledge, experience, and understanding toward the subject and the area, it may lead to incorrect results. Nonetheless, its ability to link to geographic information systems and high speed of calculations are amongst its advantages.

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