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Production of Flood Risk Maps of Inebolu Basin Using Different Fuzzy Analytic Hierarchy Process Methods

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Abstract

Flood events, which are considered as natural disasters, cause significant loss of life and property throughout the world. In order to be fully prepared for the flood, which is a disaster of meteorological origin, it is necessary to create flood risk susceptibility maps. Flood risk susceptibilities are values determined by considering different criteria that may cause flooding. Determining the weights of these criteria is also a problem that needs to be addressed. Due to the hierarchical structure of the aforementioned criteria, the problem of determining flood risk sensitivity was deemed suitable to be modeled as a fuzzy multi-criteria decision making (MCDM) problem, and a fuzzy analytic hierarchy process (FAHP) based model was used in this study. The use of Geographic Information Systems (GIS) in basin studies is increasing day by day. Geographic Information Systems are used to collect, process and analyze existing data in order to identify potential risk areas. In this study, flood risk susceptibility maps of the İnebolu Basin, located within the borders of Kastamonu province in the west of the Black Sea Region of Turkey, were created by using different fuzzy analytic hierarchy process methods and the obtained results were compared with each other.

Keywords: AHP, Fuzzy AHP, Flood, Flood Risk Maps, GIS

1. INTRODUCTION

The phenomenon of rapid increase in the amount of water in a river bed due to more than normal rainfall in the basin or the melting of the existing snow cover in the basin and damaging the living creatures, lands, and property around the bed is called flood (URL1). Flood events, which are considered as disasters, cause significant loss of life and property throughout the world (Sunkar and Tonbul, 2010). After long-term excessive and heavy rainfall, flooding occurs especially in heavily sloped and impermeable soils. In addition, the melting of the snow cover as a result of the sudden increase in temperature in the basins where snowfall is also intense can lead to floods and affect the flood flows. The co-occurrence of both factors and the simultaneous rise of the water in the side branches constitute the most dangerous floods (URL1). The destruction of vegetation and soil loss due to reasons such as urbanization, the replacement of natural structures with impermeable surfaces such as concrete and asphalt, the clogging of rainwater discharge systems by wastes and the interventions to the natural flow of rivers are human factors that increase the severity of floods and overflows (Kadıoğlu, 2008; Özdemir, 2008; Demirel, 2018). In addition,

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misapplications in river basins have an increasing effect on the magnitude and frequency of floods (Özdemir, 2008). For these reasons, the importance of producing flood risk maps is obvious.

The classical methods of struggle developed against floods and overflows include determination of risky areas in advance and construction of flood prevention and control structures in these areas, construction of upper and lower flood passages in necessary areas, prevention of uncontrolled excessive material intake from stream beds, protection of the natural balance of stream beds, regular cleaning of storm water discharge systems in settlements, improvement of stream beds, etc (Uşkay and Aksu, 2002). The first and most important step for the correct application of classical struggle methods is the preparation of flood risk maps (Tokgözlü and Özkan, 2018). GIS-based models and spatial analyses are the most preferred methods in the preparation of flood risk maps today.

Multi-criteria decision making (MCDM) methods are used in applications such as selection, rating, and classification among the criteria that affect the decision-making process about a subject (Uludağ and Doğan, 2016).

One of the novelties of this article is that, thanks to this study, in the flood risk susceptibility maps were produced for the first-time in study area. Another novelty provided by this study is to emphasize that different fuzzy AHP methods can be used to pre-study in potential locations and that it is a very powerful application in the production of flood risk susceptibility maps. This study aims to apply the fuzzy analytical hierarchy process (FAHP) method, which is one of the fuzzy MCDM methods, in the production of flood risk susceptibility maps. For this reason, first of all, FAHP is mentioned. Among the methods in the literature the geometric mean method (Buckley, 1985) and the extent analysis method (Chang, 1996) are discussed. It is aimed to investigate the applicability of these methods in determining flood risk susceptibility.

2. STUDY AREA

İnebolu Basin is within the borders of Kastamonu province, which is located in the western part of the Black Sea Region of Turkey (Figure 1). In addition, the center of the İnebolu district is located within the borders of the basin. The average altitude of the research area is 621 m above sea level, the highest point is 1360 m and the lowest point is 0 m.

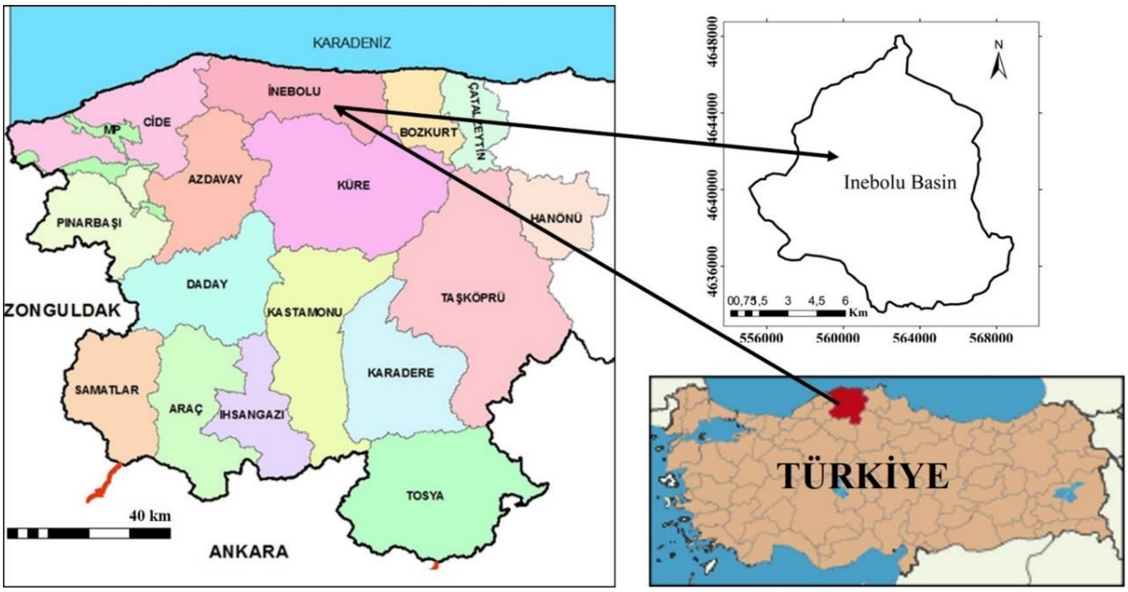

Figure 1. Site position map of the study area

The area of the İnebolu Basin has been calculated as approximately 113 km^2. According to the basin size classification system, it is in the Very Large Basins (>100 km^2) class (Özhan, 2004). The average slope of the İnebolu Basin is 19.76% and a large part of the basin has a high sloping land structure. İnebolu Basin has a high rainfall amount (1033 mm) due to the Black Sea climate effect (ÇEM, 2013).

3. MATERIALS AND METHODS

3.1. Determination of Criteria

Determining the natural and artificial factors that cause flood formation is very important in terms of evaluating the flood hazard. It is extremely important that the factors used are numerous, their quality, and that they fully characterize the problem. Rainfall, land use, lithology, elevation, distance to stream, slope, and aspect are the factors (criteria) used in this study to determine flood areas using the Fuzzy AHP method.

3.1.1 Rainfall

Since floods and overflows are disasters of meteorological origin, meteorological parameters are among the natural factors that cause floods (Hoque et al., 2019). Rainfall is one of the most important elements of climatic parameters and atmospheric circulation, and the main source of flow by providing water in the land (Tokgözlü and Özkan, 2018). In the flood assessment based on MCDM, long-term average data of annual total rainfall are generally used (Öztürk, 2009). However, due to the effects of global climate change, monthly maximum rainfall data has been used due to the high amount of rainfall between seasons and days.

While creating the areal rainfall map of the Inebolu Basin, the average annual temperature and rainfall data of 13 rainfall observation stations near the Inebolu Basin and the monthly average temperature data for January and July were obtained in order to obtain more accurate results (URL2). For rainfall distribution analysis a deterministic approach from spatial interpolation methods, namely the Radial Basis Function (RBF) method, was used. The rainfall map of the study area is given in Figure 2a.

3.1.2 Land use

Land use indirectly affects flood and overflow formation in terms of runoff of water (Tanrıverdi, 2019). The presence of vegetation in land use assumes a protective role and regulates the flow (Stefanidis and Stathis, 2013). Since the built areas (settlement areas, asphalt, concrete pavements, etc.) prevent water from penetrating into the soil to a great extent, the amount of rainfall flowing in this way is significantly higher than in areas with high surface permeability (Önsoy, 2008).

In forest areas, trees structurally open channels in the soil and rainfall accumulates in the aquifers by penetrating these gaps, and as a result, a certain amount of rainfall is mixed with groundwater, thus reducing the amount of water flowing, which reduces the risk in terms of floods and overflows (Önsoy, 2008). Agricultural plants, on the other hand, are more risky in terms of floods and overflows because their roots are in the upper layer of the soil and are weak (Ertan et al., 2021). The land use map of the study area was obtained by modifying Dengiz et al. (2016). In the study, land use was examined in 7 classes as forest, nursery, rocky, dry farming, irrigated farming, pasture, and settlement (see Figure 2b).

3.1.3 Lithology

Lithology is an important factor in the occurrence of floods because it affects the runoff. For example, a karstic structure prevents sudden flooding, while flysch or Neogene sediments with low permeability or infiltration increase flood susceptibility (Bonacci et al. 2006; Kourgialas and Karatzas, 2015; Selçuk et al., 2016).

Lithology has an indirect effect on the formation of floods and overflows because it affects the surface flow (Selçuk et al., 2016). In the study, the geological units of the region were examined in 4 classes as fully permeable, semi permeable, slightly permeable, and impermeable, using lithology reports (see Figure 2c).

3.1.4 Elevation

Altitude is a factor that is effective on temperature and temperature averages, as well as on rainfall amount, rainfall type, and evaporation amount. The altitude factor is important in terms of increasing or decreasing the amount of rainfall since the regions with low altitude also collect the rainfall from higher regions (Görcelioğlu, 2003). The elevation map of the study area is classified under 5 classes as 0-100, 100-200, 200-300, 300-400, and >400 meters (see Figure 2d).

3.1.5 Distance to stream

The distance to stream factor plays a critical role in determining the areas that will be affected by floods (Rahmati et al., 2016). The areas close to the streams are the regions that will be affected the most during the flood (Sinha et al., 2008), the effect of the flood on the environment varies depending on the amount of reinfall and the topography of the stream environment. The flooding effect of a stream flowing in a narrow valley and a stream flowing in a wide valley will be completely different (Tanrıverdi, 2019). The distance to stream map used in the study includes intervals 0-250, 250-500, 500-1000, 1000-1500, and >1500 meters (see Figure 2e).

3.1.6 Slope

Since the slope affects the runoff, soil moisture, groundwater and stream flow, it is considered as an important factor in the occurrence of floods. The slope values determine the flow rate of water depending on gravity, the transport of materials and the size of the transported material, the areas where they will be stored and where water can accumulate (Dölek, 2015). Since water accumulation is higher in flat and almost flat areas, these areas are classified as the highest risk group within the slope factor (Ogato et al., 2020). The slope map created for the study area is divided into 5 classes as 0-5, 5-10, 10-15, 15-20, and >20 degrees (see Figure 2f).

3.1.7 Aspect

Aspect is the angle between the vertical and the face of slope, in other words, aspect indicates which direction the topographic face of slope faces (Steiner and Butler, 2007). Since Turkey is located in the middle zone of the northern hemisphere, the sunshine duration is shorter on the slopes facing north. This situation not only affects the average temperature, but also indirectly affects the amount of evaporation and the time the snow stays on the ground. However, the importance of aspect especially in terms of floods is due to the fact that flat or almost flat areas are areas where rain and melting snow waters can accumulate and the risk of flooding is high (Dölek, 2015). The aspect map of the study area was evaluated in a way to include a total of 10 classes, ranging from -1 to 360 degrees (see Figure 2g).

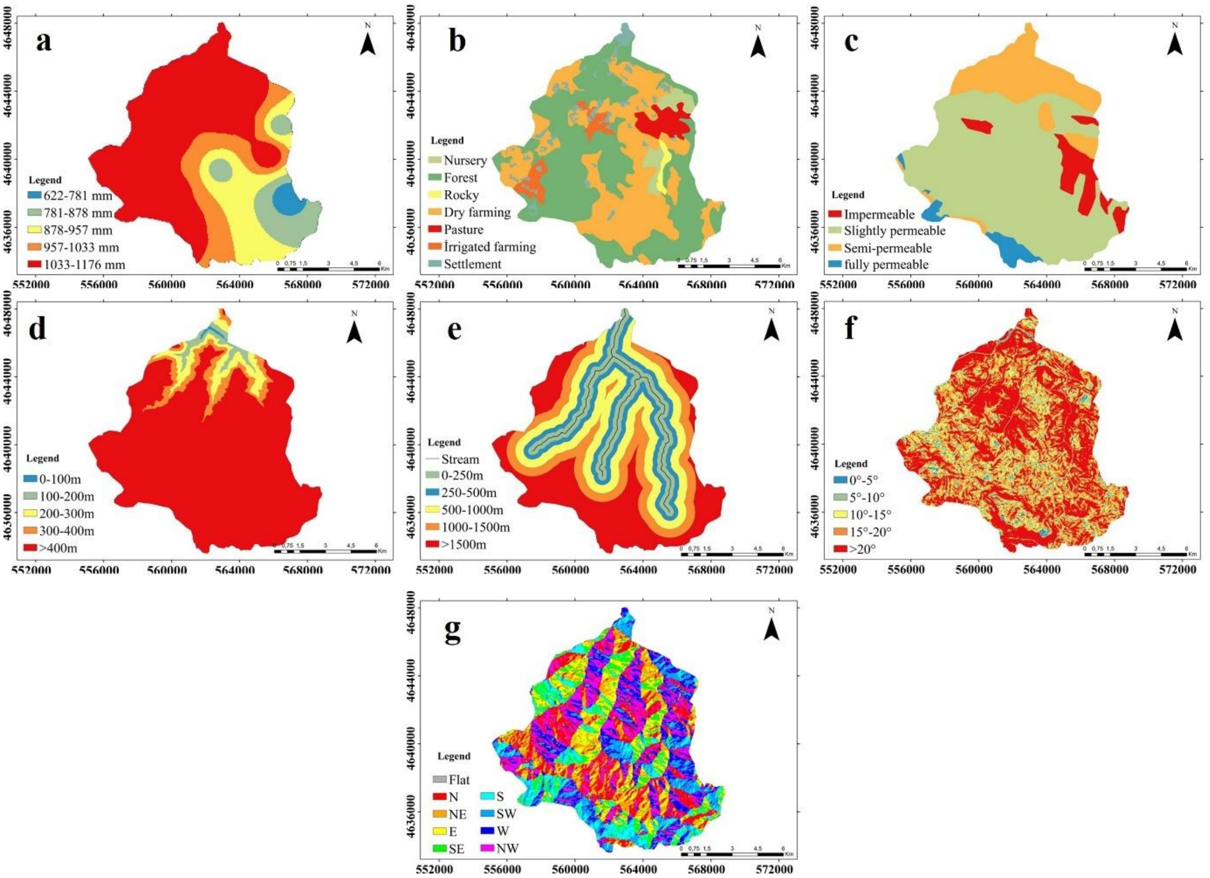

Figure 2. Criteria used (a. Rainfall, b. Land use, c. Lithology, d. Elevation, e. Distance to stream, f. Slope, g. Aspect)

3.2 Method

The analytical hierarchy process (AHP), developed by Thomas L. Saaty (1980), is one of the widely used MCDM methods. Although the AHP method uses the knowledge of experts, it cannot reflect the human way of thinking (Kahraman et al., 2003). In addition, the AHP method has been criticized for its inability to deal with uncertainty and indecision in the pairwise comparison process (Deng, 1999). Therefore, the fuzzy analytical hierarchy process (FAHP) was developed to solve hierarchical problems. The FAHP method can be applied in almost every field where uncertainty and ambiguity exist. FAHP is widely used in areas such as selection of renewable energy alternatives (Tasri and Susilawati, 2014), target market selection (Abari et al., 2012), energy efficiency assessment (Si et al., 2020), website quality evaluation (Lin, 2010), maintenance management (Duran, 2011), supplier selection (Kilincci and Onal, 2011), and measuring R&D performance effectiveness (Lee et al., 2010).

With AHP, the decision maker cannot make deterministic evaluations instead of perception-based judgment intervals. This kind of uncertainty in preferences can be modeled using fuzzy set theory. In fuzzy set theory, the ratio obtained from the decision maker is a fuzzy number described by a membership function. Here, a membership function is the degree with which elements in the judgment interval belong to the preference set (Leung and Cao, 2000). It would be more appropriate for experts to give their opinions on a subject with verbal evaluations, which is a more realistic option, rather than a definite number. These verbal evaluations are triple fuzzy numbers that show the judgment interval (Gu and Zhu, 2006). Since the fuzzy numbers do not form a natural order like the real numbers, a wide variety of methods are used to rank the fuzzy numbers. These methods have their own advantages and disadvantages, and it is difficult to decide which method is the best (Kaptanoglu and Özok, 2006). The FAHP methods used in this study are the geometric mean method (Buckley, 1985) and the extent analysis method (Chang, 1996).

In the geometric mean method proposed by Buckley (1985), fuzzy sets are used instead of classical rational numbers used in AHP. Since this method uses fuzzy numbers and includes uncertainty, it provides an uncomplicated absolute result (Kafalı et al., 2014; Özdemir and Güneroğlu, 2017).

Chang's extent analysis method (Chang, 1996) is based on the synthetic extent value S_i of the pairwise comparison and the principle of the comparison of fuzzy numbers proposed by Chang (1992). The extent analysis method is one of the most used methods in FAHP. The biggest advantage of this method is that there is no need for cutting levels and the need for calculation is low (Güner, 2005).

In this study, besides Chang (1992), two different principles for comparison of fuzzy numbers are used belonging to Liou and Wang (1992) and Abdel-Kader and Dugdale (2001). The principle developed by Liou and Wang (1992) is based on the total integral value method. In this principle, the index of optimism (α) of the decision maker is used. As the index of optimism gets bigger, there is an optimistic decision maker, and as it gets smaller, there is a pessimistic decision maker (Kaptanoğlu and Özok, 2006). Abdel-Kader and Dugdale (2001) divide a triangular fuzzy number into three parts: full memberships, partial memberships on the right, and partial memberships on the left. The index of optimism (α) is also used in this principle.

The first step in FAHP is to state the problem in a hierarchical structure, showing the objective, criteria, sub-criteria, and alternatives (Awasthi et al., 2018). In the second step, a numerical link is established between the objective and the criteria. The fuzzy scale used in the study are shown in Table 1.

Table 1. The scale of fuzzy AHP pair-wise comparison (Felix et al., 2008)

Linguistic scale for importance	Fuzzy scale	Reciprocal fuzzy scale
Equally important	(1,1,1)	(1, 1, 1)
Weakly important	(2/3, 1, 3/2)	(2/3, 1, 3/2)
Strongly important	(3/2, 2, 5/2)	(2/5, 1/2, 2/3)
Very strongly important	(5/2, 3, 7/2)	(2/7, 1/3, 2/5)
Extremely important	(7/2, 4, 9/2)	(2/9, 1/4, 2/7)

4. APPLICATION

With the literature review, it has been seen that the selection of the appropriate method is as important as the selection of the criteria to be used in the production of flood risk susceptibility maps (Wang et al., 2008).

In order to determine the flood areas with MCDM, the data set components are selected as rainfall, land use, lithology, elevation, distance to the stream, slope, and aspect. The general feature of decision making problems is fuzziness (Güler and Yomralıoğlu, 2018) and since FAHP is a more suitable method for the uncertain and complex thoughts of decision makers (Chaghooshi et al., 2012), the FAHP method is used in this study.

The importance of the selected data sets were determined by different FAHP methods and each factor was digitized in the GIS environment. Flood risk maps were created by overlaying the digitized values in the GIS environment.

The fuzzy number equivalents of the linguistically expressed criteria were determined by the experts, and the pairwise comparisons of the criteria obtained with the expert opinions are shown in the pairwise comparison matrix given in Table 2.

Table 2. Pairwise comparison matrix for FAHP

Criteria	Rainfall	Land Use	Lithology	Elevation	D. to str.	Slope	Aspect
Rainfall	(1,1,1)	(3/2,2,5/2)	(7/2,4,9/2)	(3/2,2,5/2)	(5/2,3,7/2)	(2/3, 1,3/2)	(3/2,2,5/2)
Land Use	(2/5,1/2,2/3)	(1,1,1)	(2/3,1,3/2)	(2/3,1,3/2)	(3/2,2,5/2)	(2/5,1/2,2/3)	(3/2,2,5/2)
Lithology	(2/9,1/4,2/7)	(2/3,1,3/2)	(1,1,1)	(2/5,1/2,2/3)	(2/3,1,3/2)	(2/7,1/3,2/5)	(2/3,1,3/2)
Elevation	(2/5,1/2,2/3)	(2/3,1,3/2)	(3/2,2,5/2)	(1,1,1)	(2/3,1,3/2)	(2/5,1/2,2/3)	(2/3,1,3/2)
D. to str.	(2/7,1/3,2/5)	(2/5,1/2,2/3)	(2/3,1,3/2)	(2/3,1,3/2)	(1,1,1)	(2/7,1/3,2/5)	(2/3,1,3/2)
Slope	(2/3,1,3/2)	(3/2,2,5/2)	(5/2,3,7/2)	(3/2,2,5/2)	(5/2,3,7/2)	(1,1,1)	(3/2,2,5/2)
Aspect	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(2/3,1,3/2)	(2/3,1,3/2)	(2/3,1,3/2)	(2/5,1/2,2/3)	(1,1,1)

For the sake of simplicity, let us name the geometric mean method, the extent analysis method, the method in which Liou and Wang's principle is used with $\alpha = 0.5$, and the method in which Abdel-Kader and Dugdale's principle is used used with $\alpha = 0.5$ as Method I, Method II, Method III, and Method IV, respectively. Using Method I, the fuzzy weights and weights for the criteria are given in Table 3.

Table 3. The fuzzy weights and weights of the criteria for the geometric mean method

$\boldsymbol{i}$	**Criteria**	**Fuzzy weights ($\tilde{w}_i$)**	**Weights (w_i)**
1	Rainfall	(0.157,0.249,0.386)	0.264
2	Land Use	(0.079,0.130,0.216)	0.141
3	Lithology	(0.051,0.082,0.137)	0.090
4	Elevation	(0.070,0.118,0.200)	0.129
5	Distance to stream	(0.053,0.086,0.143)	0.094
6	Slope	(0.149,0.239,0.373)	0.254
7	Aspect	(0.058,0.096,0.166)	0.107

For the other methods that will be used we need to calculate the value of fuzzy synthetic extent with respect to the $\boldsymbol{i}$th parameter

$$S_i = \sum_{j=1}^{3} M_{g_i}^{j} \odot \left[\sum_{i=1}^{7} \sum_{j=1}^{3} M_{g_i}^{j} \right]^{-1},$$

where all the $M_{g_i}^{j}$, $j = 1,2,3$ are triangular fuzzy numbers lying in Table 2 (see Chang, 1992).
We obtain

$$S_1 = (12.167,15.000,18.000) \odot \left(\frac{1}{75.986}, \frac{1}{59.750}, \frac{1}{46.846} \right) = (0.160,0.251,0.384),$$

$$S_2 = (6.133,8.000,10.333) \odot \left(\frac{1}{75.986}, \frac{1}{59.750}, \frac{1}{46.846} \right) = (0081,0.134,0.221),$$

$$S_3 = (3.908,5.083,6.852) \odot \left(\frac{1}{75.986}, \frac{1}{59.750}, \frac{1}{46.846} \right) = (0.051,0.085,0.146),$$

$$S_4 = (5.300,7.000,9.333) \odot \left(\frac{1}{75.986}, \frac{1}{59.750}, \frac{1}{46.846} \right) = (0.070,0.117,0.199),$$

$$S_5 = (3.971,5.167,6.967) \odot \left(\frac{1}{75.986}, \frac{1}{59.750}, \frac{1}{46.846} \right) = (0.052,0.086,0.149),$$

$$S_6 = (11.167,14.000,17.000) \odot \left(\frac{1}{75.986}, \frac{1}{59.750}, \frac{1}{46.846}\right) = (0.147,0.234,0.363),$$

$$S_7 = (4.200,5.500,7.500) \odot \left(\frac{1}{75.986}, \frac{1}{59.750}, \frac{1}{46.846}\right) = (0.055,0.092,0.160).$$

The fuzzy synthetic extent values S_i, $i = 1,2, \dots ,7$, will be used in the following three methods. Applying Method II, we get

$$d(S_1) = \min(1,1,1,1,1,1) = 1,$$

$$d(S_2) = \min(0.340,1,1,1,0.423,1) = 0.340,$$

$$d(S_3) = \min(0,0.573,0.705,0.007,0,0.929) = 0,$$

$$d(S_4) = \min(0.226,0.876,1,1,0.309,1) = 0.226,$$

$$d(S_5) = \min(0,0.589,1,0.720,0.012,0.944) = 0,$$

$$d(S_6) = \min(0.924,1,1,1,1,1) = 0.92,$$

$$d(S_7) = \min(0,0.655,1,0.783,1,0.085) = 0.$$

For Method III, we need to calculate $I_T^\alpha(S_i)$ for $i = 1,2, \dots ,7$ using

$$I_T^\alpha(S_i) = \frac{1}{2}[\alpha c_i + b_i + (1-\alpha)a_i], \tag{1}$$

where $S_i = (a_i, b_i, c_i)$, $i = 1,2, \dots ,7$. Hence we get the following values.

$I_T^\alpha(S_1) = 0.262$, $I_T^\alpha(S_2) = 0.142$, $I_T^\alpha(S_3) = 0.092$, $I_T^\alpha(S_4) = 0.126$, $I_T^\alpha(S_5) = 0.093$, $I_T^\alpha(S_6) = 0.245$, $I_T^\alpha(S_7) = 0.100$.

And for Method IV, letting $S = (a_1, b_1, c_1, \dots, a_7, b_7, c_7)$, we obtain

$$V(S_i) = b_i \left\{(\alpha)\left[\frac{c_i - x_{min}}{x_{max} - x_{min} + c_i - b_i}\right] + (1-\alpha)\left[1 - \frac{x_{max} - a_i}{x_{max} - x_{min} + b_i - a_i}\right]\right\}, \tag{2}$$

for $i = 1,2, \dots ,7$, where $x_{min} = \inf S$, $x_{max} = \sup S$, and $S_i = (a_i, b_i, c_i)$. The values are calculated as
$V(S_1) = 0.149$, $V(S_2) = 0.041$, $V(S_3) = 0.014$, $V(S_4) = 0.031$, $V(S_5) = 0.015$, $V(S_6) = 0.130$, $V(S_7) = 0.018$.

Note that, in (1) and (2) $\alpha \epsilon [0,1]$ is the index of optimisim. Although the analyses are made for $\alpha = 0.2$, $\alpha = 0.5$, and $\alpha = 0.8$, since there is no significant difference, we decided to give the results only for $\alpha = 0.5$.

5. RESULTS AND DISCUSSION

For the methods I-IV the normalized weights obtained for the criteria rainfall, land use, lithology, elevation, distance to stream, slope, and aspect are given in Table 4.

Table 4. Normalized weights

Criteria	Method I	Method II	Method III	Method IV
Rainfall	0.24	0.40	0.25	0.37
Land Use	0.13	0.14	0.13	0.10
Lithology	0.08	0.00	0.09	0.04
Elevation	0.12	0.09	0.12	0.08
Dist. to stream	0.09	0.00	0.09	0.04
Slope	0.24	0.37	0.23	0.33
Aspect	0.10	0.00	0.09	0.04

As a result of the FAHP studies, it was determined that rainfall has the highest weight, followed by slope, land use, elevation, aspect, distance to stream, and lithology, respectively. Considering the calculated weights of the criteria and combining them with the maps in Figure 2, flood risk susceptibility maps were created for the study area and presented in Figure 3.

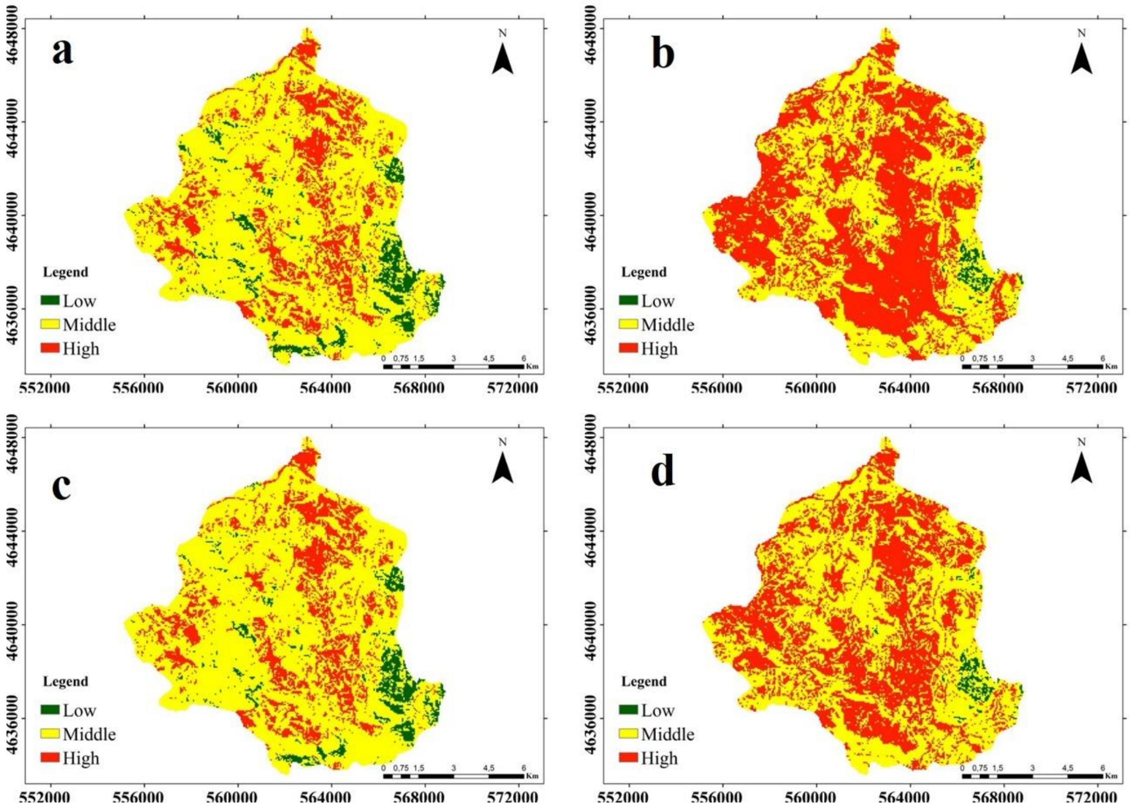

Figure 3. Produced flood risk susceptibility maps (a. Method I, b. Method II, c. Method III, d. Method IV)

The flood susceptibility maps produced by different FAHP methods are divided into three different classes as high, medium, and low susceptibility. The susceptibilities obtained as a result of the analyzes performed are found as in Table 5.

According to the results obtained from methods I-IV, the following interpretations can be made. When the flood risk susceptibility maps produced using different FAHP methods, it has been observed that the results of Method I (the geometric mean method by Buckley (1985)) and Method III (the method in which Liou and Wang's (1992) principle is used with $\alpha = 0.5$) are very consistent. On the other hand, the results obtained in Method II (the extent analysis method by Chang (1996)) and Method IV (the method in which Abdel-Kader and Dugdale's (2001) principle is used used with $\alpha = 0.5$) can be deemed to be similar to each other. It should be emphasized that the reason that Method II by Chang (1996) resulted differently than the other methods is that in this method the criteria with low weights in the other methods are not considered in the analyses. All the aforementioned methods can be used in susceptibility studies since the sum of the high and middle flood risk susceptibility in each method is above 90%.

Table 5. Susceptibility values in terms of percentage and area

Susceptibility	Method I		Method II		Method III		Method IV	
	%	km²	%	km²	%	km²	%	km²
Low	6.58	7.44	1.30	1.47	5.48	6.19	1.35	1.53
Middle	74.09	83.72	46.59	52.65	74.31	83.97	56.12	63.41
High	19.33	21.84	52.11	58.88	20.21	22.84	42.53	48.06

The findings of our study have been discussed with several recent studies in the literature in terms of criteria used and their weights (Bouamrane et al., 2022; Ekmekcioğlu et al., 2021a; Ekmekcioğlu et al., 2021b; Tella and Balogun, 2020; Wang et al. 2011).

Bouamrane et al (2022) have compared of the analytical hierarchy process and the fuzzy logic approachfor flood susceptibility mapping in Biskra basin and they calculated the weights of six evaluation criteria. They determined the most important distance from river, rainfall and land use (20%), followed by the slope(17%), soil type (13%) and elevation (%10). Ekmekcioğlu et al. (2021a) used fuzzy AHP methods that consists of thirteen flood vulnerability and hazard criteria is proposed for the generation of Istanbul's district-based flood risk map. Land use (16%) and the return period of a storm event (21%) were found as the most significant criteria for vulnerability and hazard clusters, respectively. Ekmekcioglu et al (2021b) have determined flood risk assessment in Istanbul province in Türkiye calculated the weights of 13 evaluation criteria using A hybrid fuzzy AHP-TOPSIS. They defined the highst weight value (10%) for hazard criterias such as storm water pipe network, slope, imperviousness, return period of storm event and number of rainy days in a year.The distribution of criterion weights in these three studies is similar to our study.

Tella and Balogun (2020) calculated the weights of 10 evaluation criteria using the AHP and the FAHP method for flood susceptibility in Ibadan, Nigeria. They determined rainfall (22%), runoff (18%), and distance to stream (16%) as the most important criteria. Wang et al (2011) decided that 10.95% of the area is very high risk as a result of the study using GIS and FAHP to determine flood risk assessment in the Dongting Lake region, Hunan Province, Central China. In this study, separate weighting was made in the form of hazard and vulnerability indicators. Elevation, rainfall, vegetation cover, drainage neetwork, passing flood and flood control project criterias are hazard indicators, population, production and transportation criterias are vulnerability indicators. The parameter with the highest weight in the hazard indicators class is rainfall with 68%. In the vulnerability indicators, the parameter with the highest weight is the population with 30%. The criteria used in these two studies and the distribution of the weights of the criteria differ from our study.

6. CONCLUSION

Recently, GIS tools, which are frequently used in hydrology and water resources management, are also used as important decision support systems in the preparation of flood disaster management plans. GIS tools are effective in increasing management success by using them in many areas from obtaining data to performing necessary analyzes during flood disaster management stages (Tas, 2018). In this study, flood risk maps of Inebolu Basin within the borders of Kastamonu province located in the western part of the Black Sea Region of Turkey were created in GIS environment with different FAHP methods. It has been seen that flood risk susceptibility analysis, which depends on many criteria, can be handled and solved as a fuzzy MCDM problem.

As a result of the study, as expected, forest areas have low susceptibility in terms of flood risk, while agricultural areas and artificial areas were found to be risky. Rainfall is the most decisive parameter in flood formation in all of the different FAHP methods used. For this reason, it is recommended to take precautions in areas that are considered to be high risk in the study.

Floods, one of the disasters of meteorological origin, increase due to global climate change, unplanned urbanization, and inadequate infrastructure. In this context, it is thought that the flood and overflow risk maps created in this study will be beneficial in areas such as disaster and risk management and natural resource management.

Declarations

Conflict of interest

The authors declare that they have no conflict of interest.

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