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Comparison of results of flood hazard zoning using AHP and ANP methods in GIS environment: A case study in Ardabil province, Iran

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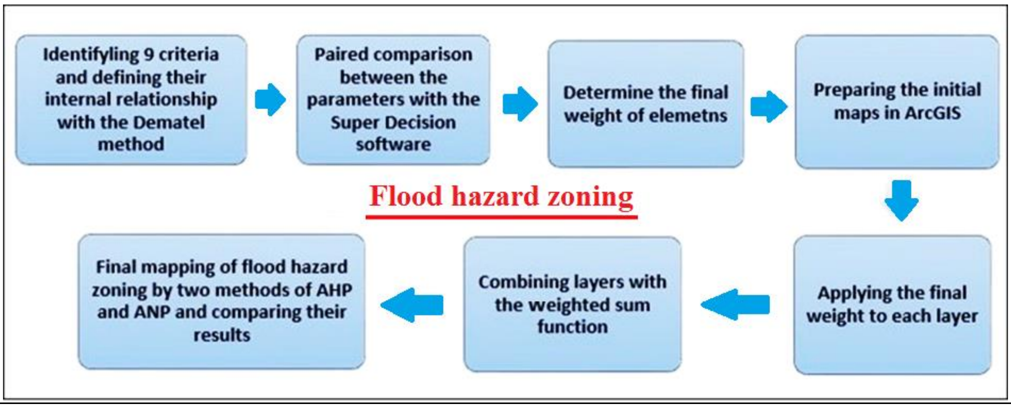
GRAPHICAL ABSTRACT



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ABSTRACT

Zoning of flood hazards in a dam catchment plays an essential role in water resources planning and management. In the present study, nine lithogenic and anthropogenic parameters including slope, elevation, curve number, distance to river, rainfall, geology, soil texture, Normalized Difference Vegetation Index (NDVI) and land use are used to achieve a flood hazard map in downstream of Sabalan dam basin in Ardabil province, Iran. After categorizing the criteria, the layers were weighted by two multi-criteria decision making (MCDM) methods including analytic hierarchy process (AHP), and analytic network process (ANP). The results showed that among the factors affecting flood formation in the study basin by AHP method were the elevation and slope factors with the weights of 0.31 and 0.18 respectively, have the highest effect; however, curve number and distance to river factors with the weights of 0.04 and 0.02 have the lowest effect. Similarly, in the ANP method, the elevation and slope factors with the weights of 0.30 and 0.21 respectively, have the highest effect and the curve number and distance to river factors with the weights of 0.02 and 0.006 have the lowest impact on flood hazard potential in the study area. The results obtained in this study can be useful in achieving sustainable management of water resources.

1. Introduction

Environmental disasters and hazards have been considered as the most destructive damaging factors to humankind and society for a long time. Flood is one of the largest and most significant hazards that take thousands of lives, damages the agriculture, fisheries, housing and infrastructure sectors and affects economic and social activities. Over a single decade (2000-2010), flood damage reached 21 billion US Dollar versus 18 billion US Dollar damage caused by the earthquake (Amirahmadi et al. 2012).

Also, in the past few years, about 70 % of annual credits of the natural disaster reduction planning and management in Iran are spent on compensating for flood damage. Besides, due to improvements in construction methods and compliance with the safety regulations of structures and facilities, their sustainability against such hazards as earthquakes has increased and because of the natural trend of development in countries like Iran, environmental and natural resource degradation has increased, which leads rises flood damage steadily (Hassanzadeh Nafooti and Khajebafghi. 2017). Due to the numerous aspects of flood damage, including the destruction of residential buildings, agricultural fields, and crops, urban facilities, filling of dam reservoirs, and reducing their useful life, it is necessary to conduct extensive studies on the flood. Brivio et al. (2002) used the integration of remote sensing data and Geographic Information System (GIS) to create a flood-prone regions' map. The result showed the proposed method is suitable for mapping the flood-prone regions. Siddayao et al. (2015) modeled urban flood hazards by GIS software and AHP model; the results of the mentioned study showed that this developed approach is a valuable tool for the national planning related to flood hazard management. Moreover, Arianpour and Jamali (2015) using the AHP

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model and GIS software, determined the effective factors and flood hazard zones in Khuzestan province, Iran, and concluded that the high slope and lower permeability have the highest impact in regions with high flood hazards.

Rahmati et al. (2015) used the AHP and HEC-RAS3 hydraulic simulation tool to identify regions with high flood hazards; then, they compare the results of two methods, which indicates that the AHP was accurate to determine flood extent and its integration with the GIS was proposed for the assessment of the flood hazard potential especially in regions with data shortage. Moreover, Mokhtari Hashi and Rahimi (2016) performed flood hazard zoning in South Khorasan province, Iran using the fuzzy logic method and prepared flood hazard zoning maps using GIS and the findings showed that about 37% of the population and the major economic and infrastructure of this province are exposed to flood hazard. Ntajal et al. (2017) developed flood hazard zonation maps in the GIS software environment by integrating GIS, remote sensing, and indicator-based flood-hazard risk assessment techniques; They concluded that low elevation, low slope, and clay texture in the region, increase flood hazard. Gigovic et al. (2017) used multi-criteria decision-making (MCDM) and AHP with GIS software for flood hazard zoning in urban regions of Palilula in Serbia; The results indicated that the left areas of the Danube river are exposed to high flood hazards. Korgialas and Karatzas (2017) presented a national-level flood hazard zoning approach (Greek case study) using multi-criteria analysis and an artificial neural network approach in the GIS environment. Their final flood hazard maps showed that agricultural and urban areas are the most sensitive regions to flood hazards. Pirnazar et al. (2017) assessed the flood hazard in the west Azerbaijan basin using Analytic Network Process (ANP) model and GIS software and concluded that the curve number (CN) (an empirical parameter for predicting direct runoff) and distance to the river had the most significant impact on the flood hazard assessment. Using AHP and ANP methods, De Brito et al. (2018) assessed the flood hazard and concluded that both methods have the proper performance in flood hazard assessment, but the ANP method is more preferred due to considering the dependence between all the criteria. Dano et al. (2019) provided a flood map in Malaysia using the GIS, ANP, and remote sensing (RS) and concluded that the ANP method was able to model the interdependence between factors affecting the flood phenomena accurately. Mind’je et al. (2019) identified areas susceptible to flood hazard using remote sensing data and GIS and concluded that Normalized Difference Vegetation Index (NDVI) and rainfall are the most influencing variables for estimating flood risk as they showed a high positive relationship with flood occurrence in the study area. Youssef and Hegab (2019) provided a flood susceptibility map using AHP and GIS techniques by the combination of different flood-related factors and the results of the accuracy assessment showed a prediction rate of 83.3% for the AHP model.

In the present study, nine lithogenic and anthropogenic parameters including slope, elevation, curve number, distance to river, rainfall, geology, soil texture, NDVI, and land use are used to achieve a flood hazard map in downstream of Sabalan dam basin in Ardabil province, Iran. After collecting and reviewing the data related to the study area, an attempt was made to provide a general framework for preparing a flood hazard map. Moreover, in this study, a flood hazard map was prepared using both AHP and ANP methods and then both methods were compared.

2. Materials and methods

2.1. Study area

The area under study is located downstream of Sabalan dam basin located in Meshkinshahr city, Ardabil province at 47°29'–48°40'E and 37°50'–38°53'N (Fig. 1). Qareh-Su river originates from the eastern slopes of Sangar and Khan Bolaghi Mountains and pours into Sabalan dam basin after 135 km bypassing north of Ardabil city and receiving branches such as Quri Chai and Balikhli Chai. This river, after passing the study area, receiving other branches such as Khiav Chai in north Meshkinshahr, eventually joins Ahar Chai. The height of this region is 739-1689 meters above sea level. The major part of the study area has a mild slope of 0-5 %.

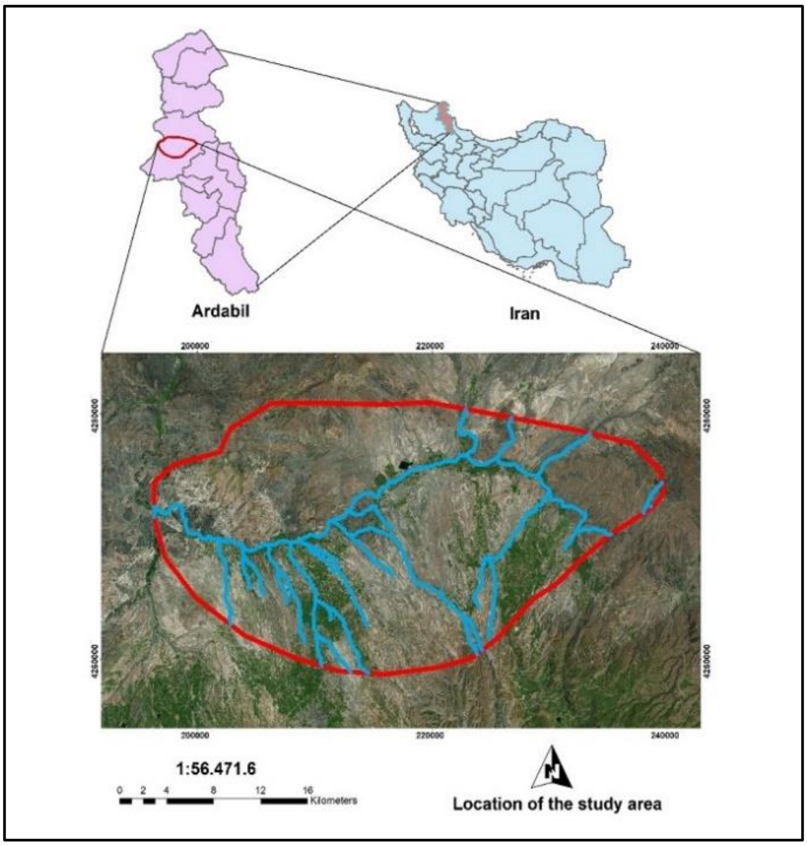

Fig. 1. The location of the study area.

2.2. Method description

In this paper, the general process presented in Fig. 2 is used to prepare hazard maps of the study area. In the first step, different criteria were determined to address the studied subject including elevation, CN, distance to river, slope, rainfall, geology, soil texture, NDVI, and land use. After identifying these criteria, they were categorized as major criteria and sub-criteria.

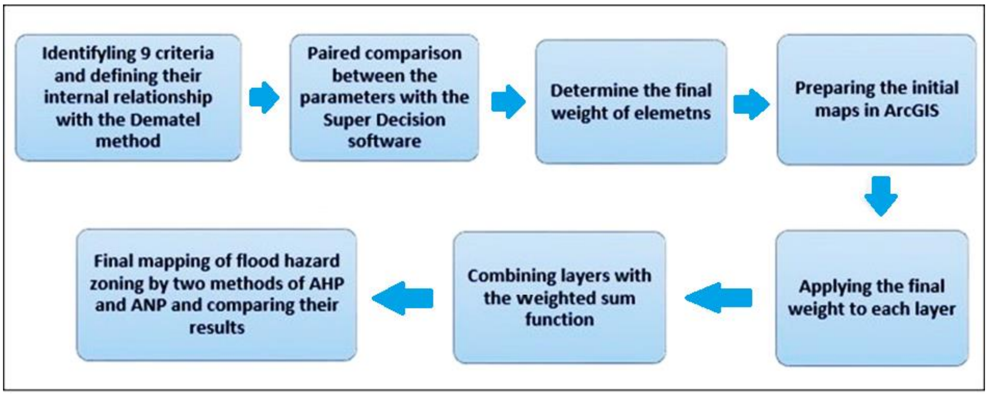

Fig. 2. Flood hazard potential mapping processes of the present study.

In the next step, the relationships between the criteria and sub-criteria are determined. In this study, the DEMATEL technique (DEcision MAking Trial and Evaluation Laboratory) was used to determine the relationship between considered factors in the ANP method. Fig. 3 shows the relationship between the parameters used in the research process. It should be noted that in the AHP method, the factors are not interconnected.

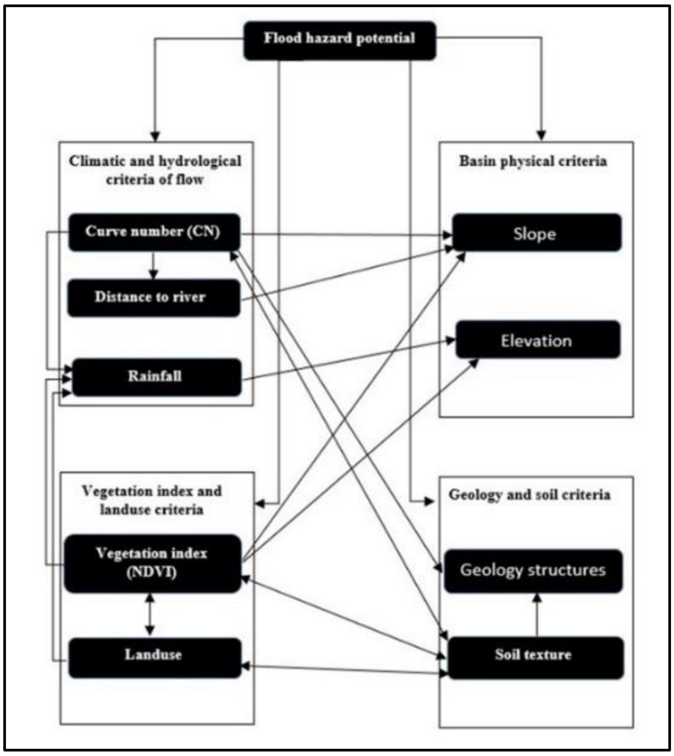

Fig. 3. Relationship between considered criteria in ANP method, using DEMATEL technique.

After determining the relationship between the criteria, the existing articles are used to determine the weight and prioritize each of them (Kazakis et al. 2015; Seejata et al. 2018; Dandapat and Panda. 2017), and then the comparison and determining the priorities of each is conducted in the Super Decision software by allocating numbers between 1 to 9 (Saaty. 1979). Finally, both AHP and ANP methods were implemented in Super Decision software, and weighing to each factor was done in the Pairwise Comparisons section of the software.

In this study, different layers such as topography, geology, and land use maps are prepared and then the required layers were studied in the ArcGIS environment. The rainfall map is also extracted using data from hydrometric stations. The Landsat 8 satellite images are used to prepare the vegetation map; In preparing this map, the NDVI is usually used, which can be calculated by Rouse et al. (1974):

$$\text{NDVI} = \frac{NIR - Red}{NIR + Red} \tag{1}$$

where, NIR is the reflection in the near-infrared spectrum, and *Red* is the reflection in the red range of the spectrum. The NDVI values are between -1.0 to 1.0, and the higher the vegetation and the degree of greenery, the closer this value is to 1.0 (Roy et al. 2016).

The CN map is created by combining land use and soil map and using the HEC-GeoHMS extension available in ArcGIS software. Finally, the sub-factors for each map are graded between 1 and 10 in ArcGIS, and the weights obtained from the Super Decision software are applied to the preparation of the final map of the potential flood hazard. Table 1 shows the ranking of the sub-criteria investigated in this study. Furthermore, Figs. 4 and 5 show the spatial distribution map of two selected sub-criteria including CN and land use.

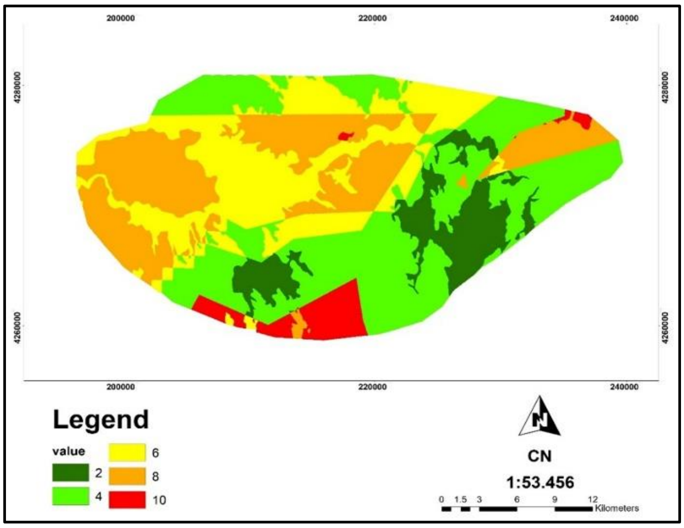

Fig. 4. Spatial distribution map of CN factor over the study area.

Table 1. Decision factors, Decision Sub-factors, and the sub-criteria ranking.

Geology										
Sub-factors	**High-level piedmont fan and valley terrace deposits**	**Gypsiferous marl**	**Rhyolitic to rhyodacitic tuff**	**Dacitic to Andesitic tuff**	**Polymictic conglomerate and sandstone**	**Coarse-grained fanglomerate**	**Andesitic tuff**	**Andesitic volcanic tuff**	**Andesitic volcanics**	**Basaltic volcanic rocks**
Rank	1	2	3	4	5	6	7	8	9	10
Land use										
Sub-factors	**Medium to dense garden cover**		**Poor garden cover**	**Medium rangelands**	**Poor rangeland cover and personal farms**		**Rainfed cultivation**	**Poor pastures**	**Urban areas**	**River**
Rank	1		2	3	5		7	8	9	10
Rainfall, mm										
Sub-factors	**319-330**		**330-340**		**340-350**		**350-360**		**360-372**	
Rank	2		4		6		8		10	
Slope, %										
Sub-factors	**0-5**		**5-10**		**10-15**		**15-30**		**30-56**	
Rank	2		4		6		8		10	
Elevation, m										
Sub-factors	**1400-1689**		**1200-1400**		**1000-1200**		**900-1000**		**739-900**	
Rank	2		4		6		8		10	
Distance to river, m										
Sub-factors	**>400**		**300-400**		**200-300**		**100-200**		**0-100**	
Rank	2		4		6		8		10	
NDVI										
Sub-factors	**-1**		**0.0-0.1**		**0.1-0.4**		**0.4-0.6**		**0.6-1.0**	
Rank	**2**		**4**		**6**		**8**		**10**	
Curve number										
Sub-factors	**36-50**		**50-60**		**60-70**		**70-85**		**85-100**	
Rank	2		4		6		8		10	
Soil texture										
Sub-factors	**Sandy Loam**		**Loam, Silty Loam**			**Sandy clay loam**			**Clay Loam, Silty clay loam**	
Rank	4		6			8			10	

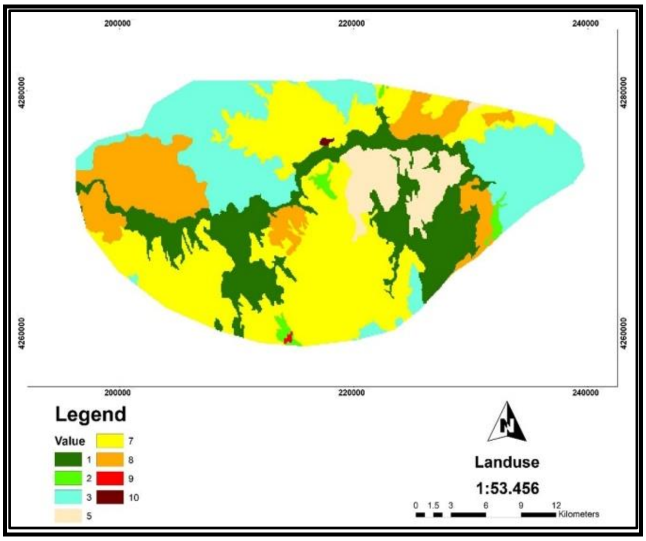

Fig. 5. Spatial distribution map of land use factor over the study area.

3. Results and discussion

3.1. Flood hazard map with AHP method

To prepare the final flood hazard map using the AHP method, the criteria network is first created by the Super Decision software (a decision making software based on AHP and ANP). Then, the final weights of the criteria are calculated according to Fig. 6; By applying these weights to each sub-criterion (or sub-factor) in GIS and matching all maps related to sub-factors as the final step, a flood hazard map is obtained using the AHP method, as shown in Fig. 7. According to Fig. 6, it can be seen that in the AHP method, the elevation and slope factors have the highest weight (i.e., highest importance) and CN and distance to river factors have the lowest relative weight compared to other criteria.

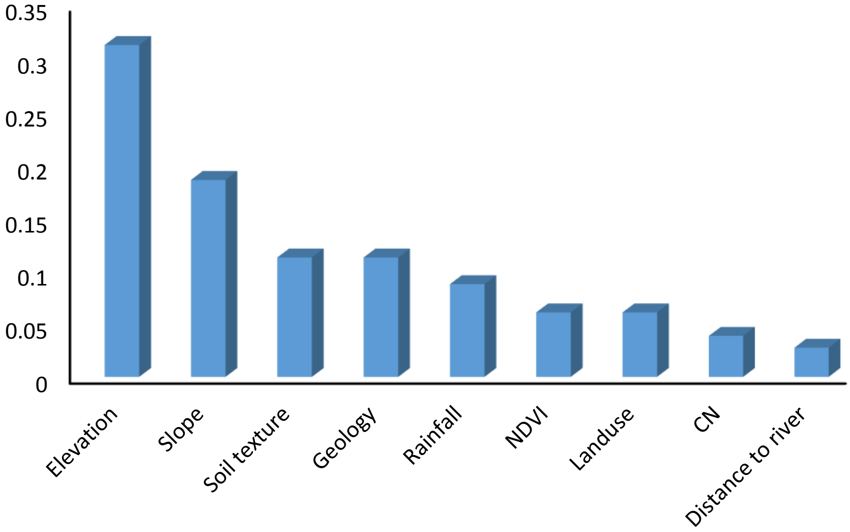

Fig. 6. The relative weight of the studied sub-criteria in the AHP method.

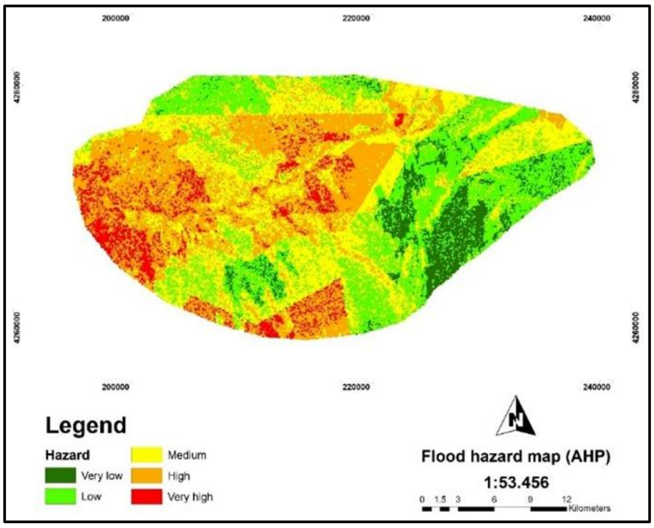

Fig. 7. Flood hazard map with AHP method in the study area.

3.2. Flood hazard map with ANP method

Similar to the previous section, to prepare the final flood hazard map, the final weights of the ANP method must first be calculated using the Super Decision software. Then, the limit matrix is formed and the weight of each cluster is determined. In the next step, the weight obtained for each criterion is multiplied by the weight of the corresponding cluster and the final weight of the elements (or factors) is calculated for applying to the corresponding maps. Fig. 8 shows the relative weights of the sub-criteria using the ANP method in the Super Decision software environment. Finally, the map of all sub-criteria is imported in the ArcMap software and the layers are combined and the final flood hazard map in the study area is produced (Fig. 9). As shown in Fig. 9, the sub-criteria of elevation and slope factors have the highest, and the distance to river factor has the lowest relative weight. Razavi Termeh et al. (2018) reported that the slope factor has the highest importance than other features in surveying flood hazards. Table 2 shows the potential flood risk by area of the study region; In this table, flood hazard potential has been investigated into five hazard classes including very high, high, medium, low, and very low hazards.

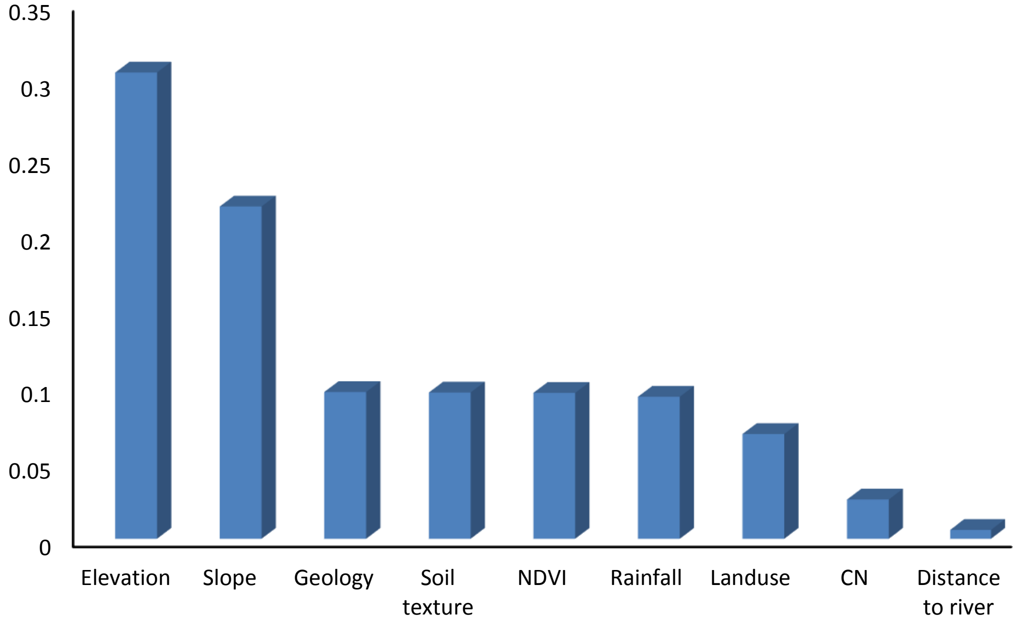

Fig. 8. The relative weight of the studied sub-criteria in the ANP method.

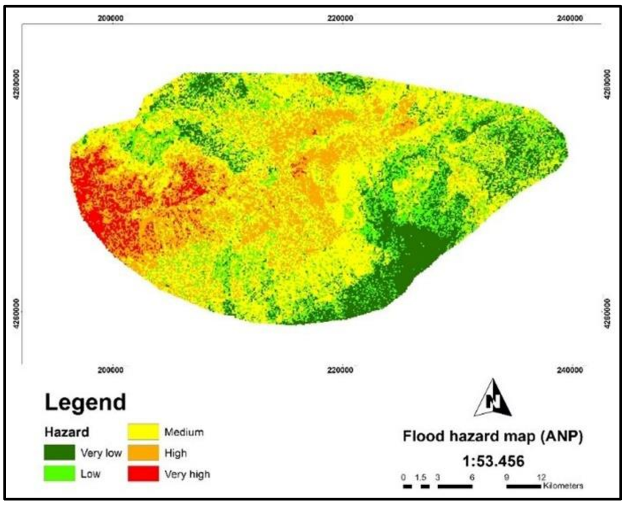

Fig. 9. Flood hazard map with ANP method in the study basin.

Table 2. Classification of flood risk potential in the study area based on both AHP and ANP methods.

Flood hazard	Area in AHP method, hectare	Area in ANP method, hectare	The total area in AHP, %	The total area in ANP, %
Very low	4953	13135	7.21	19.13
Low	17767	14079	25.75	20.51
Medium	21847	21408	31.82	31.18
High	19640	16118	28.61	23.48
Very high	4541	3917	6.61	5.71
Total	68657	68657	100	100

4. Conclusions

The results of this study indicate that various flood hazard potential measurement methods (AHP and ANP) have differences in weight and criteria priority. Despite these differences, there is not much difference in the identification of areas with high potential flood hazards. In the AHP method, the elevation and slope factors with the weights of 0.31 and 0.18 respectively, have the highest effect, and CN and distance to river factors with the weights 0.04 and 0.02 respectively, have the lowest impact on flood hazard potential. Similarly, In the ANP method, the elevation and slope factors with the weights of 0.30 and 0.21 respectively, have the highest impact, however, the CN and the distance to river factors with the weights 0.02 and 0.006 have the lowest effect on flood hazard potential. In general, the ANP method emphasizes the natural features of the region, including topography, land use, soil texture, and geology, which control the hydrological features of the water flow. According to flood hazard maps of the Sabalan dam basin prepared with both the AHP and ANP methods, in AHP, 7.21 % of the study region is related to low-hazard areas, while in the ANP method, 19.13 % of the basin identified as the low-hazard regions. In terms of average hazard, both methods had similar results and high potential hazard percentages of 5 % to 6 % were observed in both methods. As a result, in both methods, the western parts of the study area had higher flood hazard potential than the eastern parts.

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