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Landslide susceptibility analysis with multi criteria decision methods; a case study of Taşova

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ABSTRACT

Natural or artificial based disasters threaten to humans. In order to minimize the loss of life and property that may occur after a disaster, various studies are carried out. One of these studies is disaster risk maps. To produce disaster risk maps, the criteria which affecting the disasters should be determined. In order to evaluate more than one criterion Multi-Criteria Decision Making Methods (MCDM) and Geographical Information Systems (GIS) are used. MCDM methods are used both to weight criteria and to rank among alternatives. In the current study Taşova district of Amasya province is used as study area and two different Landslide Susceptibility Maps were produced based on Analytical Hierarchy Process (AHP) and Full Consistency Method (FUCOM) for this region. A total of twelve criteria were determined for production of risk map and raster data was produced by performing various spatial analyzes for the current criteria. Two different landslide susceptibility maps were obtained by giving criterion weights to the generated raster data. It was observed that, Risk-free area, low risk area and high risk area rates are almost equal, but medium risk area and risk area rates are different in two different weighting methods.

1. Introduction

Nowadays, studies are carried out to produce disaster risk maps in order to reduce the loss of life and property in disasters. The studies are aimed at pre-disaster vulnerability analysis and post-disaster evacuation resistance analysis. When these objectives are combined, disaster risk maps will emerge. There are many known disaster types and multiple criteria affecting these disasters. It is very difficult to evaluate these criteria at the same time. Therefore, Multi-Criteria Decision Making Methods are needed. Multi-criteria decision-making (MCDM) is a method that enables the selection of the best choice among the criteria applied simultaneously and more than once (Zahedi, 1986; Ishizaka & Labib, 2009; Kabak et al., 2018; Arslankaya & Göraltay, 2019; Boyacı, 2020). Before evaluating the criteria, spatial analysis of the data should be done. After the spatial analysis of the data is done with Geographic Information System (GIS) or Remote Sensing (RS) methods, weights are assigned to the criteria with a determined criterion weighting method. The criterion with the highest weight will affect the risk map more, while the criterion with the least weight will affect the risk map less. Thus, more results that are reliable will be obtained.

The most common risk analyzes in the literature review are landslide susceptibility analysis, flood risk, earthquake, forest fires, and tsunami risk maps. One of these risk maps is landslide susceptibility analysis. (Gökkaya, 2014; Cankaya, 2016; Acar, 2019)

Considering the damage and losses caused, landslides, which are in the second place after earthquakes in Turkey, have caused many losses of life and property until today (Acar, 2019). According to the Ergünay (2007), since the beginning of the 20th century a total of 89500 house affected by landslides and rock falls in Turkey which is 14% of all natural disasters. A landslide is a situation where rock, soil or pieces of land shift or move noticeably down the slope due to gravity or external factors such as earthquakes, heavy rains. (Disaster Management Dictionary). Although a landslide is a natural disaster, the human factor also triggers it. Examples of human factors such as unknowingly felling trees, unauthorized mining, inadequate retaining walls on the roadside. Therefore, it allows to determine the places with landslide risk and to act carefully in those areas. Thus, the loss of life and property is minimized.

Different kind of MCDM techniques were used in landslide studies, Analytical Hierarchy Process (AHP) is one of the most used method. Landslides are affected many factors, and all factors have different weight on landslide. In the current study, it was focused to determine weight of the factors which affect landslides using two different methods which are Full Consistency Method (FUCOM) and the AHP method. To achieve this, two different maps were produced based on both

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methods of landslide susceptibility analysis for the Taşova district of Amasya province.

2. Material and Method

In this section, the study area described, AHP and FUCOM methods are shortly explained, and criteria for landslide susceptibility analysis are determined.

2.1. The study area

The study was carried out in in Taşova district of Amasya province. Taşova is located on 40° 46' 36" north latitude and 36° 13' 12" east longitude (Figure 1). The District has an area of 1051 km². The lowest altitude is 170 m where Karlık Stream meets Yeşilırmak. The highest altitude is Cami Hill, located in the South of Esençay Village, 1956 m. Regional landslides have been observed during times of heavy rainfall.

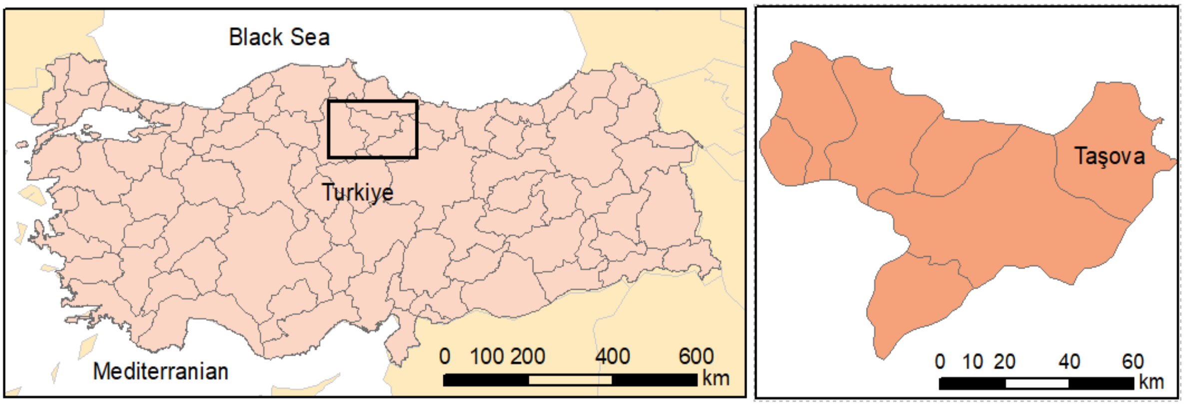

Figure1. Study area

2.2. Analytical hierarchy process (AHP)

The AHP method was developed by Thomas Saaty in 1980 that provides a basis for comparing decision-making criteria in a mathematical structure by creating a hierarchical structure.

Organizing goals, attributes, issues, and stakeholders in a hierarchy serves two purposes; first provides an overview of the complex relationship vessels inherent in the situation, second helps the decision maker to assess whether the problems at all levels are of the same magnitude, so that they can accurately compare these homogeneous elements (Saaty, 1994).

In the first stage of the method, a hierarchical model is created which shows the relations between the aim, criteria and alternatives to be obtained by taking expert opinion for the solution of the problem.

In the second stage, each criterion is compared with other criteria and values are assigned according to the importance scale in Table.1 prepared by Saaty. In line with these values, the degree of importance of the criteria to each other is filled according to the pairwise comparison matrix in Table 2. With these values, *nxn* dimensional pairwise comparison matrix is created for n criteria.

Each criterion is evaluated mutually, ignoring the other criteria. Evaluation of the criteria in this way is advantageous in cases where the number of criteria is high (Yılmaz, 2010).

Table 1. Significance Scale by Saaty

Importance Values	Value Definitions
1	Equal Importance
3	A little more important
5	Quite Important
7	Very Important
9	Highly Important
2,4,6,8	Intermediate values

Table 2. Pairwise Comparison Matrix (aij) (Ci: Criterion, i: 1, 2…n)

	C1	C2	C3	….	Cn
C1	a11	a12	a13	…	a1n
C2	a21	a22	a23	…	a2n
C3	a31	a32	a33	…	a3n
….	….	….	….	…	….
C4	an1	an2	an3	…	ann

The third step is to determine the weights of the criteria. In the pairwise comparison matrix, the sum of each column is taken and divided by each element in the column and matrix B is obtained. If we divide the row sum of matrix B by the number of criteria, that is, if the arithmetic average of the row is taken, the weights of each criterion will be found (Equation 1).

$$W_i = \sum_{j=1}^{n=1} b_{i,j} \qquad (1)$$
$$i = 1,2,3 \dots n; j = 1,2,3 \dots n$$

The consistency ratio (CR) of the measures is calculated in the last step. If the consistency ratio (CR) is less than 0.1, the comparisons are consistent; else, the comparisons are inconsistent (Equation 2-4). That is, the closer the CR is to zero, the higher the consistency of the decision matrix (Jian-Zhong et al., 2008). No matter how mathematically consistent the AHP has in itself, the realism of the results will depend on the consistency of the judgment of the decision maker in the one-to-one comparison between the criteria (Yılmaz, 2010).

$$[C_{ij}]_{nx1} = [a_{ij}]_{nxn} x [w_{ij}]_{nx1} \qquad (2)$$
$$[d_{ij}]_{nx1} = [C_{ij}]_{nx1} / [w_{ij}]_{nx1} \qquad (3)$$

$$\lambda = \frac{\sum_{j=1}^{n} d_i}{n} \quad (4)$$

a_{ij}: Pairwise comparison matrix
w_{ij}: Weight vector of criteria
C_{ij}: Column Vector
d_{ij}: Consistency Vector
λ: Base value

The basic value (λ) is calculated with the help of matrices in Equation 2 and Equation 3. Finally, the randomness indicator (Rl) is selected from table 3 prepared by Saaty according to the number of criteria.

Table 3. Saaty's Randomness Indicator

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

With the randomness indicator (Rl) and λ (basic value), the consistency ratio (CR) is calculated (Equation 5).

$$CR = \frac{\lambda - n}{(n-1)xRI} \quad (5)$$

2.3. Full consistency method (FUCOM)

The Full Consistency Method (FUCOM) method is one of the criteria weighting methods developed by Pamučar, Stevic and Sremac in 2018. The FUCOM algorithm is based on the pairwise comparisons of criteria, where only the *n − 1* comparison in the model is necessary. The model implies the implementation of a simple algorithm with the ability to validate the model by determining the deviation from full consistency (DFC) of the comparison. The consistency of the model is defined on the basis of the satisfaction of mathematical transitivity conditions. One of the characteristics of the developed new method is the lowering of decision-makers' subjectivity, which leads to consistency or symmetry in the weight values of the criteria (Pamučar et al., 2018).

The FUCOM method takes place in three stages. At the first stage, decision makers are asked to rank n criteria from the most important to the less important criteria (Equation 6).

$$C_{j(1)} > C_{j(2)} = C_{j(3)} > \cdots > C_{j(n)} \quad (6)$$

In the second stage, the comparative priorities of the criteria ranked by the decision makers in order of importance *(φ n/ (n+1)* the comparative priority vector with n-1 elements is obtained (Equation 7).

$$\varphi = \{\varphi_{1/2}, \varphi_{2/3} \dots \varphi_{n/n+1)}\} \quad (7)$$

In the FUCOM method, the decision maker(s) can use integers, decimals or values of certain scales for comparisons of criteria. This provides flexibility to decision makers in the evaluation of criteria. (Ayçin & Aşan, 2021)

In the last stage, the following two conditions must be met in order to calculate the criteria weights.

Condition 1: The ratio of the weights of the two criteria to each other should be equal to the priority value in the pairwise comparison (Equation 8).

$$\frac{w_n}{w_{n+1}} = \varphi_{n/n+1)} \quad (8)$$

Condition 2: The final values of the weight coefficients must satisfy the mathematical transitivity condition. Since *φ n/ (n+1) × φ (n+1)/ (n+2) = φ n/ (n+2)* and $\varphi_{n/(n+1)} = \frac{w_n}{w_{n+1}}$ are $\frac{w_n}{w_{n+1}} \times \frac{w_{n+1}}{w_{n+2}} = \frac{w_n}{w_{n+2}}$ must satisfy the mathematical equation. If we combine the two equations, we get equation 9.

$$\varphi_{n/n+1)} x \, \varphi_{n+1/n+2)} = \frac{w_n}{w_{n+2}} \quad (9)$$

Full consistency is achieved if the conditions in equation 8 and Equation 9 are met for criterion weighting. Full consistency, consistency deviation (min (DFC(X))) is expected to be minimal. Maximum consistency is achieved if the deviation from full consistency is zero (0).

Finally, using the expressions in equation 10 to find the criterion weights, linear programming model and solutions can be made with programs such as Excel Solver or MATLAB with simple codes.

$$\begin{aligned} & Min\ X \\ & \left| \frac{w_{j(n)}}{w_{j(n+1)}} - \varphi_{n/n+1)} \right| \le X, A_j \\ & \left| \frac{w_{j(n)}}{w_{j(n+2)}} - \varphi_{n/n+1)} x \varphi_{(n+1)/n+2)} \right| \le X, A_j \\ & w_j > 0, A_j \\ & \sum_j w_j = 1 \end{aligned} \quad (10)$$

2.4. Determination of criteria and criterion maps

Determining of the criteria is one of the most important phase of producing risk map. The criteria are the decision components used in the evaluation of alternatives to reach the goals. It should be known that each criterion included in the decision problem is effective in the decision process, as well as the criteria not addressed in the problem have an indirect effect on the decision output (Yildirim, 2019).

Slope, lithology, land use potential or vegetation, slope direction, distance to main faults, drainage and relative height are the parameters often used in the risk studies (Gökçeoğlu & Ercanoğlu, 2001).

In the current study; slope shape, slope, elevation, aspect, lithology, precipitation, proximity to the river, proximity to the road, NDVI (Normalized Difference Vegetation Index), land use, soil type, fault line were used as the criteria which affect to the landslide. The raster data of each criterion were prepared by performing various spatial analyzes with the ArcGIS software.

a) Elevation: It has been reported that the height conditions of the topography are also an effective factor in the formation of landslides. Because the determination of the heights of the landslides occurring in any region can be accepted as a data that can only give a preliminary idea. On the other hand, it has been suggested that landslides tend to occur more in high altitude areas. (Özşahin, 2015) The highest value of the region is 1956, and the lowest value is 170. A total of five classes were created in these value ranges.

b) Slope: The general tendency among researchers is that as the slope increases, the sensitivity to landslides will also increase (Gökçeoğlu & Ercanoğlu, 2001). The slope in the region varies between 0-62°.

c) Slope shape: In the studies, the effect of the shape of the slope on the landslide susceptibility was examined, but some researchers said that more landslides occurred on concave slopes, while some researchers suggested that more landslides occurred on convex slopes.

In addition, statistical evaluation of this parameter is quite difficult. Because during a landslide, the initial appearance of the slope is often distorted and this may lead to erroneous assessments during data collection. (Gökçeoğlu & Ercanoğlu, 2001). This study was carried out by accepting the statement more landslides occur on concave slopes.

d) Aspect: The slope direction (aspect) indicates the direction of the land surface and is expressed by the direction of the tangent plane at any point on the surface. Slope direction is an important parameter that is frequently used in studies related to the preparation of landslide susceptibility maps (Dağ, 2007).

The map of these four criteria was obtained using Digital Elevation Model (DEM) data in the '3D ANALYST TOOLS' analysis. (Figure 2 -5).

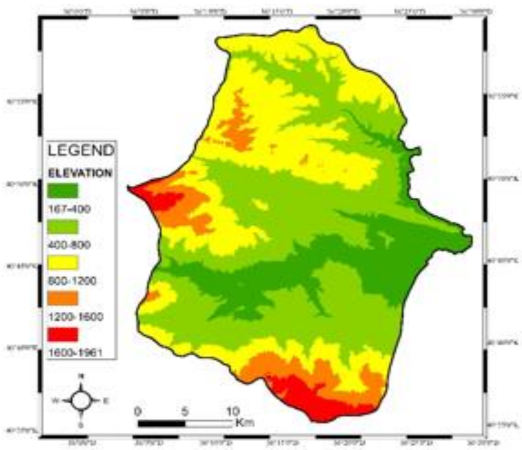

Figure 2. Elevation map

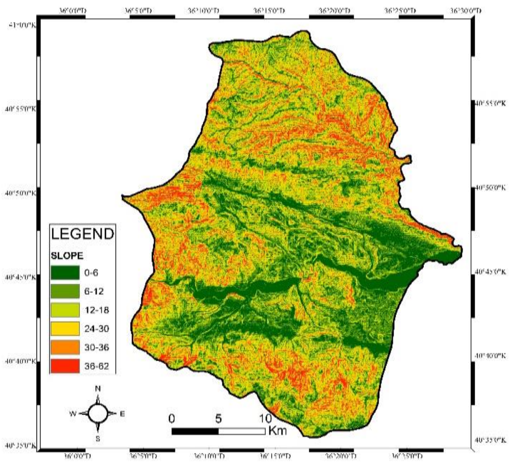

Figure 3. Slope map

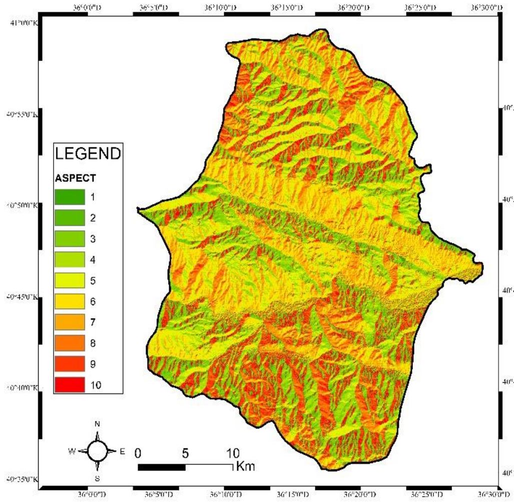

Figure 4. Aspect map

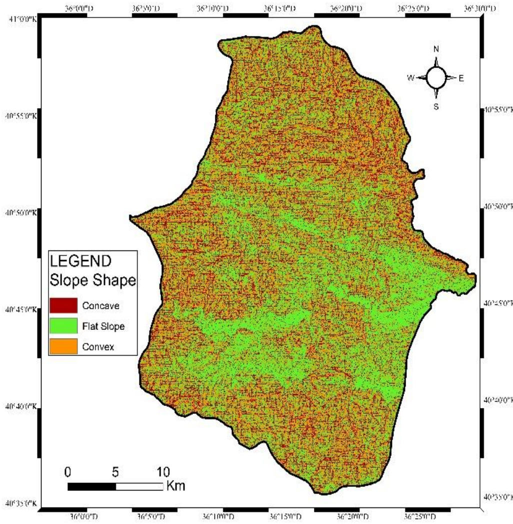

Figure 5. Slope shape map

e) Proximity to the fault line: Proximity to the fault line increases the risk of landslides. The landslide analysis was carried out by considering the faults remaining in the study area in the fault line map published by MTA.

f) Proximity to the stream: Since being close to the stream will increase the water saturation of the soil, the risk of landslide increases as you get closer to the stream.

g) Proximity to the road: The roads opened on the slopes cause a load reduction in both the topography and the slope toe. The change in topography and the decrease in load cause stress increases behind the slope and this causes the development of stress cracks (Yalçın, 2007).

The maps of these three criteria were obtained by using the multiple ring buffer analysis of the proximity tool (Figure 6-8).

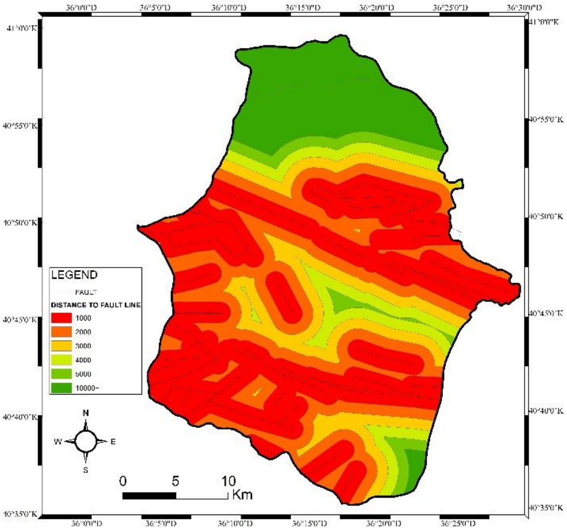

Figure 6. Distance to fault line

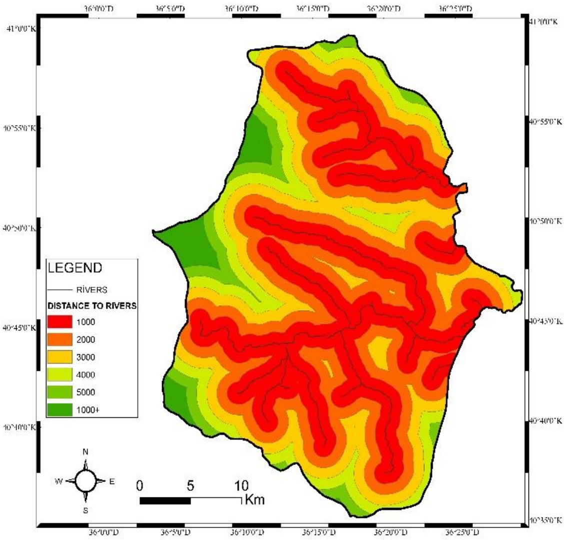

Figure 7. Distance to rivers

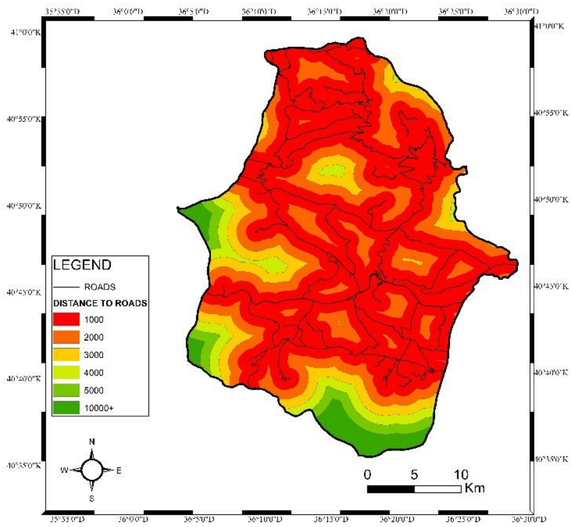

Figure 8. Distance to roads

h) Lithology: Lithology is one of the important parameters affecting landslide formation and plays an important role in landslide susceptibility studies. Using the earth sciences website published by MTA, it was determined that there are five different lithologies in the region.

i) Land use: Although the land use situation includes a part of the NDVI analysis such as forest, meadow, swamp, residential area, agricultural area, pasture, etc. It was used as a separate criterion as it would affect the landslide in certain situations.

j) Soil type: The type of soil the ground has is also very important for landslides. The soil mass covering the ground of the topography also causes the formation of landslides. In fact, soils affect landslide formation according to grain size, arrangement and types (Özşahin, 2015).

The lithology map was taken from the earth sciences site of MTA and the soil types map was taken from the agriculture portal site, coordinated and digitized. The land use map was obtained from the Copernicus page by classifying the CORINE 2018 vector data. (Figure 9-11)

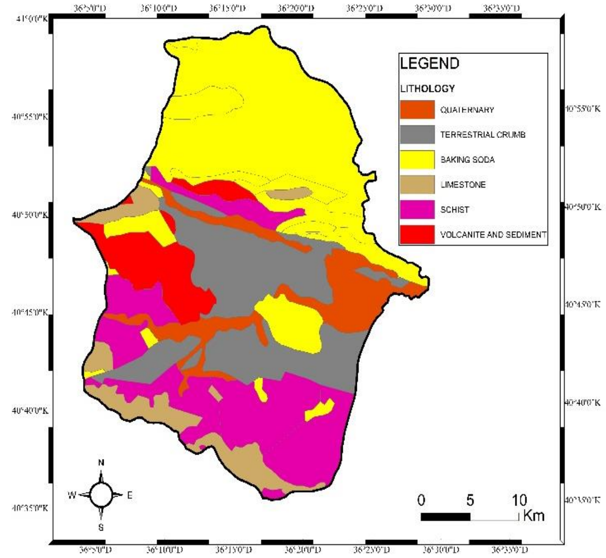

Figure 9. Lithology map

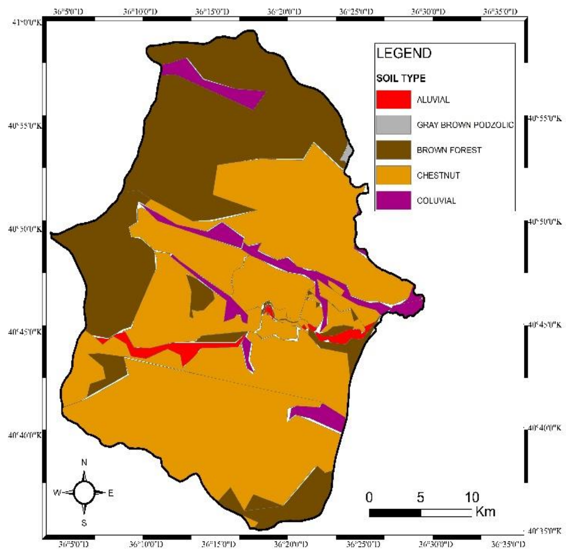

Figure 10. Soil type map

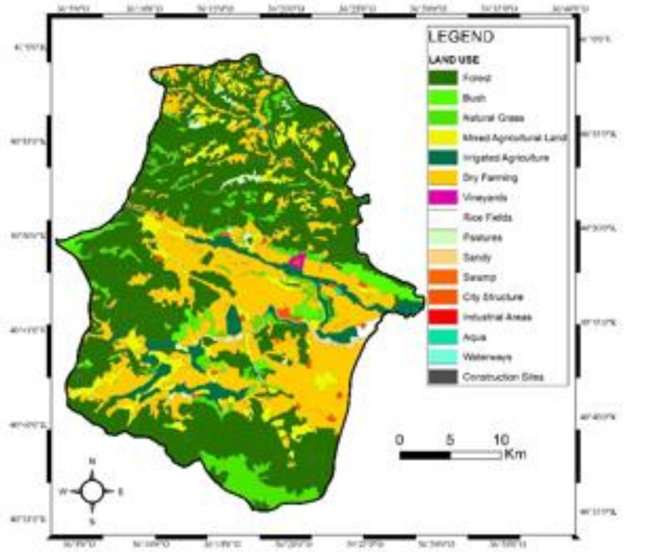

Figure 11. Land use map

k) NDVI: Landslide risk increases in areas with low vegetation density. Therefore, the NDVI map was produced and the places with low vegetation were determined.

l) Precipitation: Annual average precipitation is considered as an important factor for landslide susceptibility analysis. Because, as a result of precipitation, the ground becomes saturated with water, the groundwater level rises and the leakage forces reach their maximum value (Özşahin, 2015). The annual precipitation of Taşova district is 967mm.

The last two criteria maps were made as follows: NDVI data was calculated with the help of band4 and band5 in the Landsat satellite image (Equation 11).

$$Band5 - Band4 \ / \ Band5 + Band4 \qquad (11)$$

The precipitation map is produced at the end of the calculations made with the help of climate data. (Figure 12, 13).

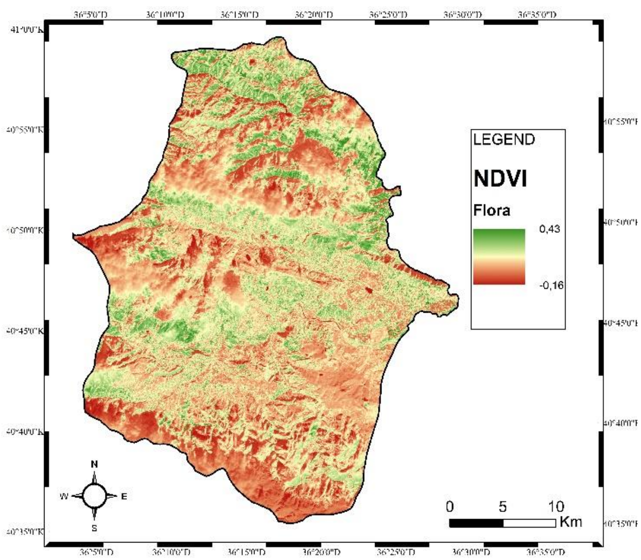

Figure 12. NDVI map

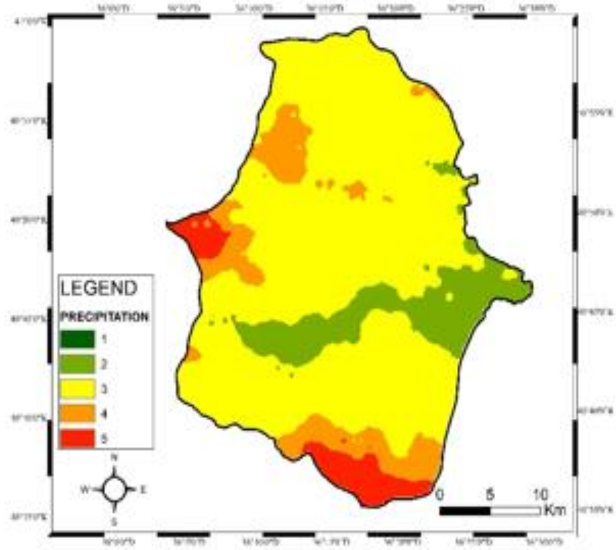

Figure 13. Precipitation map

3. Results and Discussion

The criteria weighting steps above were carried out sequentially and the criteria weights were calculated for both methods. The criteria weights calculated using AHP method and FUCOM method are shown in table 4.

According to the results, the most important weight calculated using AHP was lithology, and the least important criterion was NDVI. The consistency calculated in the AHP was found 0.02 and since it was less than 0.1, the measurements were considered consistent.

The most important criterion calculated using FUCOM was lithology, and the least important criterion was NDVI. Since the FUCOM method is based on full consistency, the consistency deviation (DFC(X)) was found to be 0 as a result of the calculations and full consistency was obtained in the measurements.

The closer the consistency rate is to zero in the AHP method, the more consistent the measures are, while in FUCOM, full consistency is essential. This shows that the measures of FUCOM are more consistent.

In the current study, a total of 144 comparisons were made with AHP, and 11 comparisons were made with FUCOM. It was observed that the FUCOM method differs from the AHP method with less pairwise comparison. With fewer comparisons, the effect of expert opinion is reduced.

Table 4. Criterion weights with AHP and FUCOM

Criteria	AHP	FUCOM
Lithology	0.204	0.2473
Slope	0.162	0.1236
Slope Shape	0.150	0.1236
Precipitation	0.125	0.0824
Aspect	0.093	0.0618
Prox. to Fault Line	0.072	0.0618
Prox. to the Stream	0.061	0.0618
Distance to Road	0.043	0.0618
Land Use	0.032	0.0495
Soil Type	0.025	0.0495
Elevation	0.019	0.0495
NDVI	0.013	0.0275

The raster data produced for each criterion separately were overlapped using 'Weighed Sum' analysis based on the weights calculated from two different methods and two landslide susceptibility maps were obtained

Figure 14 shows the map produced using the AHP method and Figure 15 shows the map produced using the FUCOM method. The Landslide Susceptibility maps are divided into five classes; Risk-free areas are dark green, low-risk areas are light green, medium-risk areas are white, risky areas are pink, high-risk areas are red.

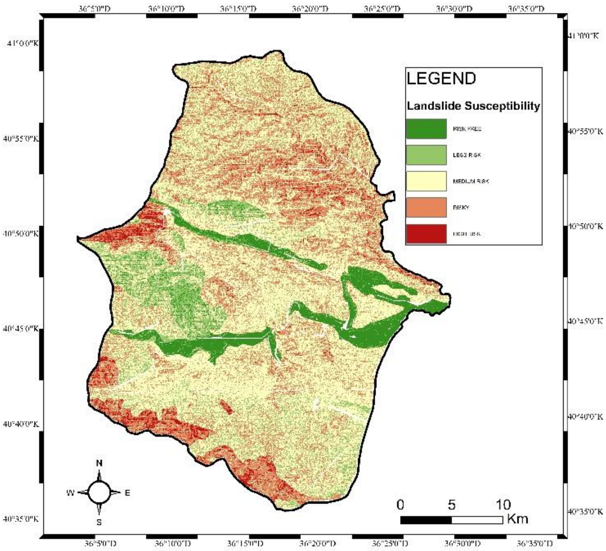

Figure 14. Landslide susceptibility map with AHP

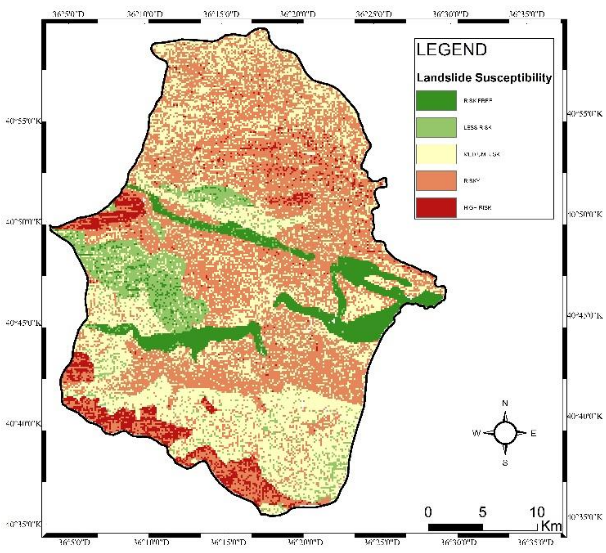

Figure 15. Landslide susceptibility map with FUCOM

When we interpret by looking at the two maps in Figure 14 and Figure 15, it is seen that the red colored areas are more in FUCOM.

The area of Landslide Susceptibility classes were calculated with the help of the pixels of the classes from the maps obtained. By making area calculations from pixels according to colors, ratio calculations were made over the total area.

Table 5 shows that; risk-free, low-risk and high-risk areas results were almost similar, but medium-risk areas and risky areas were different results in the two methods.

Table 5. Map Classes Rates calculated with AHP and FUCOM

Classes	AHP (%)	FUCOM (%)
Risk-Free Area	7.25	7.89
Low Risk Area	10.75	8.08
Medium Risk Area	50.60	35.97
Risk Area	27.95	42.98
High Risk Area	3.45	5.08

As a result of the calculations, according to AHP the risky area was determined as 27.95%, and the high-risk area was 3.45%. According to the FUCOM method, the risky area was determined as 42.98% and the high-risk area was 5.08%. The percentage of risky areas in the map produced based on FUCOM method was higher than the AHP method.

In general, it is seen that high-risk areas are in the same places in both maps. These high-risk areas are seen as areas where the slope is high and the vegetation is low.

4. Conclusion

In the current study, two different landslide susceptibility maps were produced using AHP and FUCOM criterion weighting for Taşova district.

Twelve criteria were used for both landslide susceptibility maps. These criteria are slope shape, slope, elevation, aspect, lithology, precipitation, proximity to stream, proximity to road, NDVI, land use, soil type, fault line. While the most important criterion among the AHP criteria weights was lithology with 0.204, the least important criterion was NDVI with 0.013. The most important criterion among the FUCOM criterion weights was lithology with 0.247, while the least important criterion was NDVI with 0.027. The consistency of the criteria weights was calculated for both methods. The consistency ratio with AHP was found to be 0.02, and it was seen that the measurements were consistent.

Maps of each criterion were obtained according to the studied area. Criterion maps were converted to raster data according to weights calculated by AHP and FUCOM methods. Landslide susceptibility maps were obtained by combining the weighted criterion maps in both methods.

The landslide susceptibility maps were divided into five classes and risk classes were determined. The risk of landslide increases from green to red. The ratios of the classes were calculated by pixel measurements from the maps. It was observed that risky areas in FUCOM were 15.03% higher than in AHP. It was observed that the medium-risk areas in FUCOM were 14.63% less than in the AHP. Other classes gave similar results in both methods.

Both methods are made by taking expert opinion, but FUCOM minimizes expert opinion with less pairwise comparison and provides full consistency. As a result, the FUCOM method, which is the version developed in 2018 of the AHP method, which is frequently used in the literature, can also be preferred and used in map production studies.

Finally, landslide susceptibility maps can be prepared with various methods and criteria data. The aim of this study is to compare the results which obtained AHP and FUCOM methods.

Author Contributions

The contributions of the authors of this article is equal.

Statement of Conflicts of Interest

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

This study was improved from the paper presented in the 5th Intercontinental Geoinformation Days (IGD). Research and publication ethics were complied with in the study.

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