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Landslide Susceptibility Analysis with AHP and FUCOM; a case Study of Taşova

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Abstract

Various studies are carried out in order to minimize the loss of life and property that may occur after a disaster. One of these studies is disaster risk maps. In order to prepare disaster risk maps, first of all, the criteria affecting them according to the type of disaster should be determined well. Multi-Criteria Decision Making Methods (MCDM) and spatial analyzes are needed as it will be difficult to evaluate more than one criterion alone. MCDM methods help both to weight criteria and to rank among alternatives. The criteria determined for disaster risk maps are weighted with the help of criterion weighting methods, so that the analysis is performed according to these weights and the most optimum result is obtained. In this study, two different Landslide Susceptibility Maps were obtained for Taşova district of Amasya province by using Analytical Hierarchy Process (AHP) and Full Consistency Method (FUCOM). Twelve criteria were determined for map production and raster data was created by performing various spatial analyzes for these criteria. Two different landslide susceptibility maps were obtained by giving criterion weights to the generated raster data.

1. Introduction

Today, studies are carried out to produce disaster risk maps due to the loss of life and property during disasters. There are many known disaster types and multiple criteria affecting these disasters. In order for these criteria to be evaluated simultaneously, the spatial analysis of the data is done first, and then weights are assigned to the criteria with MCDM methods. 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 reliable results will be obtained. One of the risk maps is the landslide susceptibility analysis.

Landslide is defined as a noticeable downslide or movement of landslide rock, soil or pieces of land due to gravity or external factors such as earthquakes and 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.

In the studies, maps were generally made with the Analytical Hierarchy Process (AHP). In this study, it was desired to compare the Full Consistency Method (FUCOM) developed by Pamucar et al. in 2018 and the AHP method. For this, two different maps were created by using both methods of landslide susceptibility analysis for the Taşova district of Amasya province.

2. Method

In this section, the methods are briefly explained and criteria for landslide susceptibility analysis are determined.

2.1. Analytical hierarchy process (AHP) method

The Analytical Hierarchy Process is a method developed by Thomas Saaty in 1980 that provides a basis for comparing decision-making criteria in a mathematical structure by creating a hierarchical structure.

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

Organizing goals, attributes, issues, and stakeholders in a hierarchy serves two purposes. Provides an

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overview of the complex relationship vessels inherent in the situation; and 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 second stage, each criterion is compared with other criteria and values are assigned according to the importance scale in Table.1 prepared by Saaty. With these values, nxn dimensional pairwise comparison matrix is created for n criteria.

Table 1. Saaty Significance Scale

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

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).

$$Wi = \frac{\sum_{j=1}^{n=1} bi,j}{n} \text{ (i=1,2,3,…n ; j=1,2,3,….n)} \quad (1)$$

In the last step, the consistency ratio (CR) of the measures is calculated. If the consistency ratio (CR) according to Saaty is less than 0.1, the comparisons are consistent, if it is greater than 0.1, the comparisons are inconsistent.

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 (Yilmaz 2010).

$[C_{ij}]_{nx1} = [a_{ij}]_{nxn} \times [w_{ij}]_{nx1}$

$[d_{ij}]_{nx1} = [Cij]_{nx1} / [w_{ij}]_{nx1}$

$$\boldsymbol{\lambda} = \frac{\sum_{i=1}^{n} di}{n} \quad \text{(i=1,2,3,…n)}$$

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

Finally, the randomness indicator (R1) prepared by Saaty, determined according to the number of criteria, is selected from the table and the consistency ratio (CR) is calculated (Equation 2).

Table 2. Hourly 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

$$\mathbf{CR} = \frac{\lambda - n}{(n-1)Rl} \quad (2)$$

2.2. Full consistency method (FUCOM)

The Full Consistency Method (FUCOM) is one of the criteria weighting methods based on expert opinion, developed by Pamucar, Stevic and Sremac in 2018.

FUCOM selections have pairwise comparisons of criteria for which only n − 1 comparisons are required in the model. The model implies the implementation of a simple algorithm capable of validating the model by determining the deviation from the full consistency of comparison (DFC). (Pamucar 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 3).

$$Cj(1) > Cj(2) = Cj(3) > \ldots > Cj(n) \quad (3)$$

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 (Equation 4) with n-1 elements is obtained.

$$\varphi = \{\varphi\ 1/2\ ,\ \varphi\ 2/3\ \ldots\ \varphi\ n/(n+1)\} \quad (4)$$

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. (Aycin 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 5)

$$\frac{w_n}{w_{n+1}} = \varphi_{n/(n+1)} \quad (5)$$

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 6.

$$\varphi_{n/(n+1)} \times \varphi_{(n+1)/(n+2)} = \frac{w_n}{w_{n+2}} \quad (6)$$

If the conditions in Equation 2.5 and Equation 2.6 are met, the expressions in Equation 2.7 are used to find the criterion weights, and solutions are made with simple codes with programs such as Excel Solver or MATLAB with a linear programming model. As a result of the solution, the consistency deviation (min (DFC(X))) being zero (0) indicates that full consistency is achieved.

$$\begin{gathered}\text{Min } X \\ \left|\frac{w_{j(n)}}{w_{j(n+1)}} - \varphi_{n/(n+1)}\right| \leq X, \forall j \\ \left|\frac{w_{j(n)}}{w_{j(n+2)}} - \varphi_{n/(n+1)} \times \varphi_{(n+1)/(n+2)}\right| \leq X, \forall j \\ \text{Wj} > 0, \forall j \\ \sum_j wj = 1\end{gathered} \tag{7}$$

2.3. Study area

The study was carried out for the town of Taşova in Amasya. Taşova District.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. is A certain part of it is sloped and a certain part of it is plain with high altitude difference. In the landslide density map of Turkey published by MTA, it has been seen that Taşova district carries a landslide risk. Regional landslides have been observed during times of heavy rainfall. Therefore, this study area was chosen.

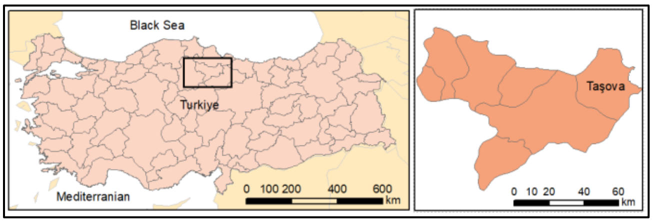

Figure 1. Study area

2.4. Determination of criteria and criterion maps

The criteria are the decision components used in the evaluation of alternatives to reach the goals, so it is necessary to be meticulous in the determination of the criteria. 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)

Regardless of the method used in the preparation of landslide susceptibility maps, or whatever the geographical location, there is a general tendency to use parameters such as slope, lithology, land use potential or vegetation, slope direction, distance to main faults, drainage and relative height.(Gokceoglu and Ercanoglu 2001)

The criteria used for this study are as follows: slope shape, slope, elevation, aspect, lithology, precipitation, proximity to the river, proximity to the road, ndvi (vegetation), land use, soil type, fault line, a total of twelve criteria were used. The raster data of each criterion were prepared by performing various spatial analyzes with the ArcGIS program.

a) Elevation

It has been reported that the height conditions of the topography are also an effective factor in the formation of landslides. (Ozsahin 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 (Gokceoglu and Ercanoglu 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. Gokceoglu and Ercanoglu 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 (Dag 2007).

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

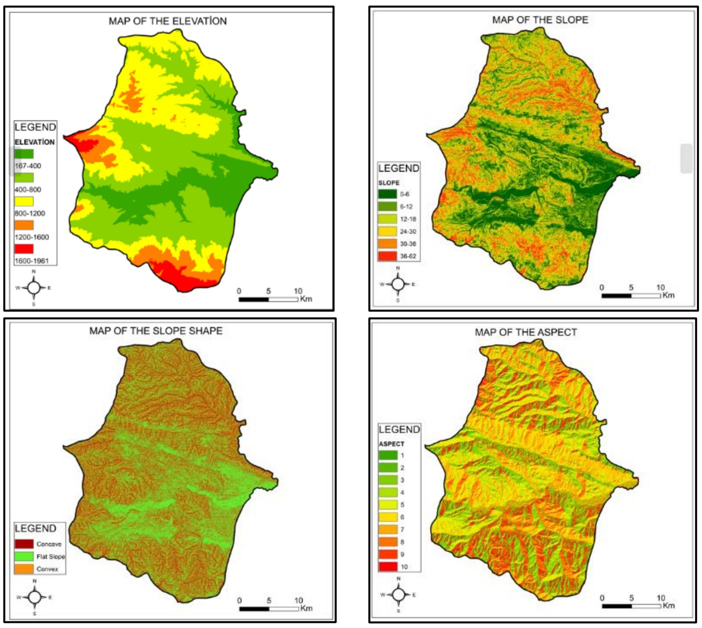

Figure 2. Elevation-Slope-Slope Shape-Aspect Maps

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 (Yalcin, 2007).

The maps of these three criteria were obtained by using the multiple ring buffer analysis of the proximity tool. (Figure-3 Distance to fault line, distance to streams, distance to roads)

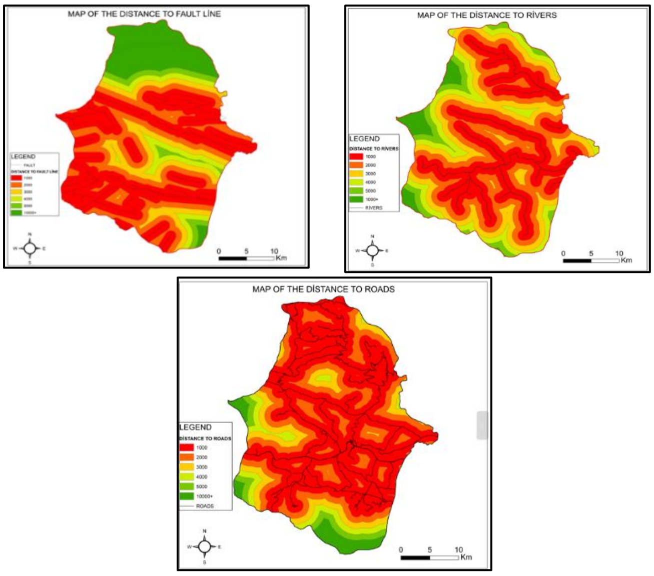

Figure 3. Distance to fault line-Distance to rivers-Distance to roads Maps

h) Lithology

Lithology is one of the important parameters affecting landslide formation and plays an important role in landslide susceptibility studies. Because different lithological units have different sensitivities for active geomorphological processes such as landslides. 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 (vegetation) 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 is also 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 (Ozsahin, 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. The land use map was obtained from the Copernicus page by classifying the CORINE 2018 vector data and they are shown in Figure-4.

k) NDVI (Vegetation)

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 (Ozsahin,2015). The annual precipitation of Taşova district is 967mm.

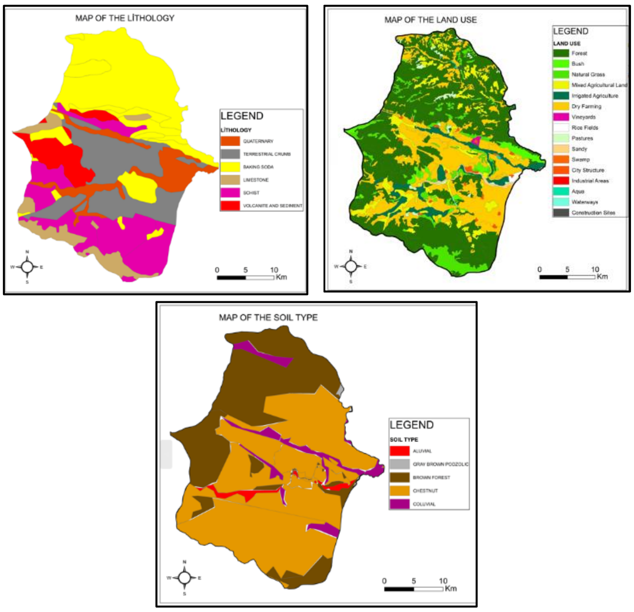

Figure 4. Lithology-Soil Type-Land Use Maps

The last two criteria maps were made as follows: NDVI (vegetation) data was calculated with the help of band4 and band5 in the lansat satellite image ((band5-band4)/(band5+band4)). The precipitation map is produced at the end of the calculations made with the help of climate data. (Figure 5. NDVI (vegetation), Precipitation)

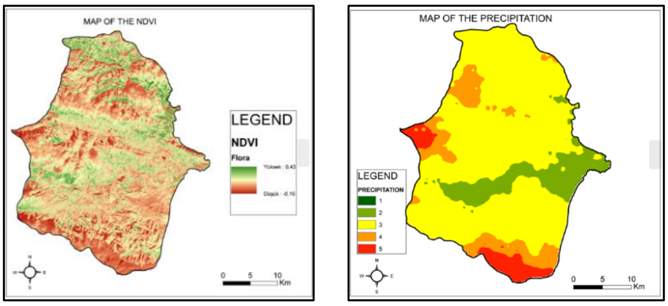

Figure 5. NDVI (vegetation), Precipitation Maps

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 obtained by the AHP method and the FUCOM method are shown in Table 4.

When we look at the table, the most important weights found by AHP were lithology, while the least important criterion was vegetation. The consistency calculated in the AHP was found to be 0.02 and since it was less than 0.1, the measurements were considered consistent.

When we look at the weights found with FUCOM, the most important criterion was lithology, while the least important criterion was vegetation. 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.

When we compared the two methods, a total of 144 comparisons were made with AHP, while 11 comparisons were made with FUCOM. Consistency was found to be 0.02 with AHP, while full consistency was obtained by finding 0 with FUCOM.

Table 3. AHP and FUCOM criterion weights

CRITERIA	Weights with AHP	Weights with 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 (Vegetation)	0.013	0.0275

By using the weights obtained from the raster data produced separately for each criterion, 'Weighed Sum' analysis was performed in both methods and landslide susceptibility maps were obtained. Figure 6 shows the map made with the FUCOM method, while Figure 7 shows the map made with the AHP method.

The area of each class was calculated with the help of the pixels of the classes from the maps obtained. Percentages were made by dividing the total area by the area of each class. As can be seen in Table 5, while risk-free, low-risk and high-risk areas gave similar results, medium-risk areas and risky areas gave different results in the two methods.

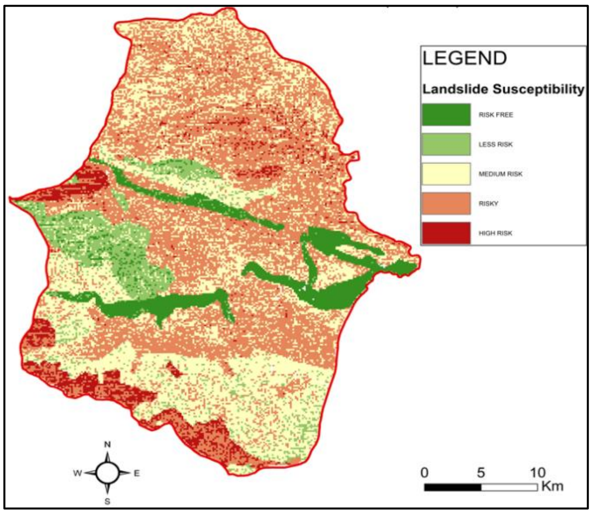

Figure 6. Landslide Susceptibility Map with FUCOM

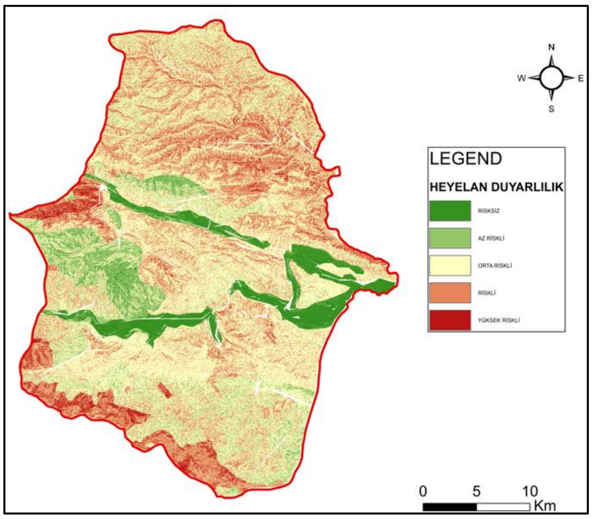

Figure 7. Landslide Susceptibility Map with AHP

Table 5. Percentages of Map Classes Made with AHP and FUCOM

	Ratios found with AHP (%)	Ratios found with 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

4. Conclusion

In the study, two different landslide susceptibility maps of Taşaova district were created by using AHP and FUCOM criterion weighting. The maps are divided into five classes and the risk-free areas are green and the high-risk areas are red. By making area calculations from pixels according to colors, ratio calculations were made over the total area.

As a result of the calculations, the risky area was found to be 27%, and the high-risk area was 3%, according to AHP. According to the FUCOM method, the risky area was 42% and the high-risk area was 5%. The percentage of risky areas in the map made with the FUCOM method was higher than the AHP method.

We said that the FUCOM method differs from the AHP method with less pairwise comparison and full consistency. With fewer comparisons, the effect of expert opinion is reduced. 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.

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

Finally, landslide susceptibility maps can be prepared with various methods and criteria data. The aim of this study is to examine the similarity and dissimilarity between the two methods.

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