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Landslide Susceptibility Mapping of Samsun (Turkey) Province Using Frequency Ratio and AHP Methods

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Analytical Hierarchy Process
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ABSTRACT

Landslide susceptibility mapping is of critical importance to identify landslide-prone areas to reduce future landslides, casualties, and infrastructural damages. In this study, the Landslide Susceptibility Map of Samsun (Turkey) was produced. The Slope, elevation, land use, soil, proximity to stream networks and lakes, proximity to fault lines were selected as parameters. All parameters were divided as the sub classes according to their properties. The Frequency Ratio method was applied to determine the relationship between the parameters and the landslide events. Paired comparison matrices were created to determine the weights of the parameters using the Analytical Hierarchy method. The weighted overlay operation was applied to the classified and weighted map data using ArcGIS program. As a result, the Landslide Susceptibility Map was produced as divided to 5 classes.

1. INTRODUCTION

Disasters are inevitable events. Disasters can destroy the society resources, cause humanitarian effects, trigger financial and economic problems, or have negative consequences and impacts on the environment (Reduction, 2009). The landslides events are being seemed to be important disasters because of loss of life and property in Turkey (Ildır, 1995). The landslides can be defined as the downward movement or sliding of parts such as soil and rocks, under the influence of gravity or external factors such as earthquakes and continuous rains (AFAD, 2014).

The production of landslide susceptibility maps is extremely crucial to prevent material and moral losses. The accuracy of produced map is important part of the process. Thus, the production process of these maps requires the evaluation and analysis of all influencing factors together (Kavas, 2009).

The Landslide Susceptibility Map of Samsun (Turkey), was produced in this study. The reason for choosing this application area is the presence and frequency of landslide events in this region (Elevli et al., 2012). Samsun (Turkey) location map is given in Fig. 1.

The Slope, elevation, land use, soil, proximity to stream networks and lakes, proximity to fault lines were taken as parameters causing the landslide.

As a result of this study, the landslide susceptibility map divided into 5 sub-sections was produced. The produced map was compared with the previous landslide events in the region. According to this comparison, an accuracy of 82,03% was found.

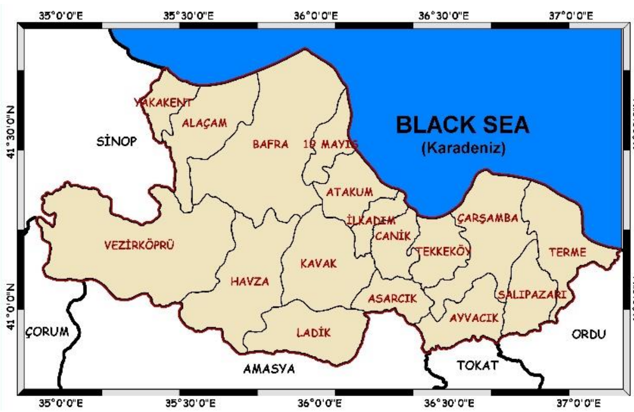

Figure 1. Location Map

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2. MATERIAL AND METHOD

Although there are many landslide susceptibility map applications in the literature (Aleotti and Chowdhury, 1999; Lee & Talib, 2005; Sisman and Tetik Biçer, 2017; Kirici, 2019), there is no consensus on the methods and parameters used in these applications. Methods and parameters may vary according to application location and characteristics (Gökçeoglu & Ercanoglu, 2001).

2.1. Material

The slope, elevation, land use status, soil condition, stream networks and lakes, fault lines were selected as parameters for the study. Data sources for the parameters are given in Table 1. The parameters to be used in the study were mapped using ArcGIS program. Slope, land-use, soil, elevation, proximity to stream networks and lakes, proximity to fault lines maps are given in Fig. 2-7.

Table 1. Data Sources

Parameters	Data Source
Slope	earthexplorer.usgs.gov
Land Use	land.copernicus.eu
Soil	OMU - Faculty of Agriculture
Elevation	earthexplorer.usgs.gov
Stream Networks	download.geofabrik.de
Fault Lines	atag.itu.edu.tr
Landslide Inventory	Samsun AFAD

2.1.1. Slope

Slope is the basic stability parameter that affects the sliding and normal stresses at the surface. Researchers have come to a consensus that the slope is an input parameter in the analysis made in the landslide susceptibility area. It is more common among researchers that the angle of inclination is directly proportional to the risk of landslides (Baeza & Corominas, 2001; Karsli et al., 2009).

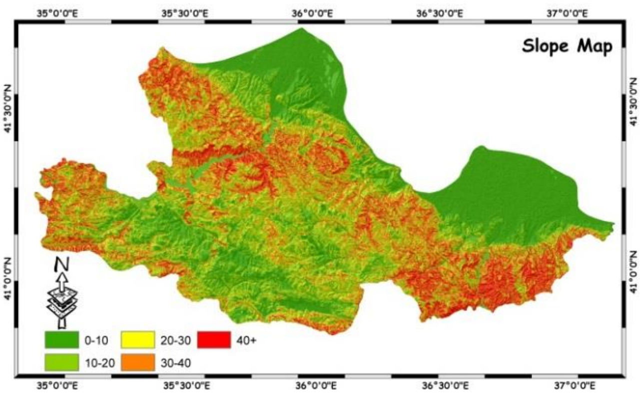

Figure 2. Slope Map

2.1.2. Land Use

The land use can be the reason of landslide events. Plants sometimes have positive and sometimes negative effects on landslides. It is widely believed that plants with large and strong roots have positive effects, where they are concentrated. As it is known, plants absorb and evaporate water from their leaves and reduce the effect of rainfall. On the other hand, the roots and stems of the plant increase the permeability of the ground surface and open the way for the water on the surface to pass directly into the ground (Gökçeoglu & Ercanoglu, 2001). Thus, the relationship between the areas like artificial, agricultural, forest, wetlands and water with sparse and dense vegetation and landslides should be evaluated.

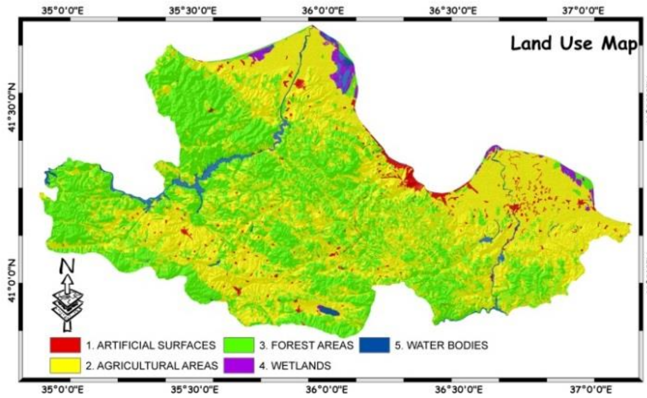

Figure 3. Land Use Map

2.1.3. Soil

Landslide events are directly related to soil properties such as strength, permeability and hardness (Baeza & Corominas, 2001). Since the lithological features will give important information about the landslide sensitivity of the study area, it should be evaluated correctly (Guzzetti et al., 1999). Therefore, soil plays an important role in order to determine Landslide susceptibility.

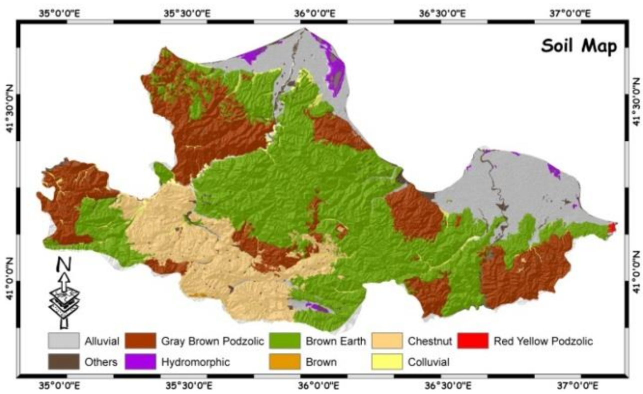

Figure 4. Soil Map

2.1.4. Elevation

Topographic features vary with altitude. The elevation causes topographic differences in the study area. The researchers stated that the lower elevation areas are less susceptible to landslides than high elevation. In another study, it was noted that the soil cover formed on medium-height hillsides due to material coming from higher areas is more sensible to landslide events compared to the soil cover at the other altitude levels. Elevation controls temperature and vegetation. Generally, the occurrences of landslides increase with the increase of elevation before reaching a threshold elevation, where the landslide probability reduces due to rock and soil characteristics and other geotechnical parameters (Guzzetti et al., 2009).

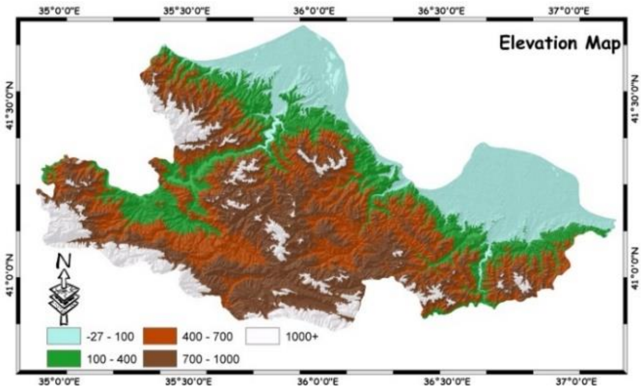

Figure 5. Elevation Map

2.1.5. Stream Networks and Lakes

In the literature, there is no consensus on the distance of stream networks or lakes regarding landslide susceptibility (Tetik Biçer, 2017). It is accepted by researchers that landslide susceptibility decreases when the distance to the river increases. The river negatively affects the stability of the ground soil by saturating some of the materials with water or by eroding the heel. As a result, the effect of rivers on hillside sensitivity should be determined and a buffer zone should be established with field observations.

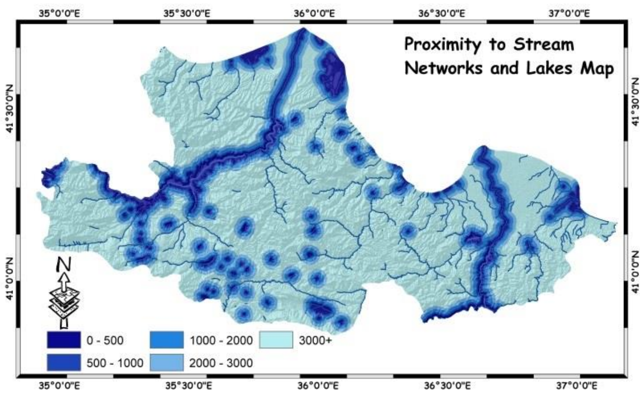

Figure 6. Proximity to Stream Networks and Lakes Map

2.1.6. Fault Lines

Some landslides can be associated with fault lines areas because of weakness of the material surrounding them. Being close to the fault lines may cause fragmentation of rocks and this may negatively affect the strength of the hillsides (Luzi and Pergalani, 1999). The more buffer zone should be created, taking into account the different proximity for proximity to fault lines. (Wachal and Hudak, 2000).

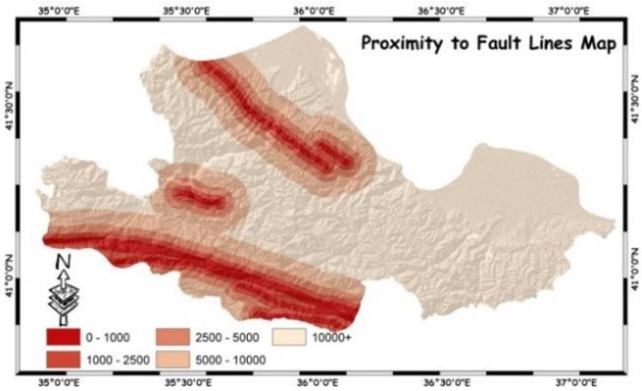

Figure 7. Proximity to Fault Lines Map

2.1.7. Landslide Inventory

Landslide inventory is defined as data containing information about the location, type, activity and physical characteristics of landslides in a region. The information about past landslides are obtained as the first step of landslide susceptibility. It is thought that the future landslides may occur under conditions similar to the past landslides. (Varnes, 1984).

For this reason, the Landslide Inventory Map of the study area was created by using the landslide events 1950 - 2020 (AFAD, 2020). The Landslide Inventory map is illustrated in Fig. 8.

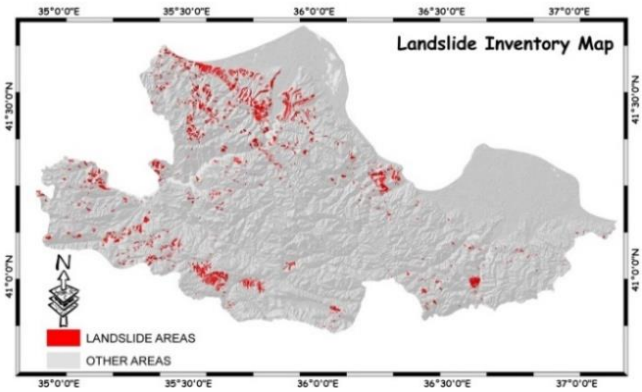

Figure 8. Landslide Inventory Map

2.2. Method

There are a lot of landslide susceptibility analysis methods like Frequency Ratio, Analytical Hierarchy Process, Weight of Evidence, Logistic Regression, Fuzzy Logic and Artificial Neural Networks. Human brain is successful in processes such as learning, remembering, and guessing. However, Computer technologies are successful in mathematical and statistical operations (Tabar & Sisman, 2020). For this reason, the use of computer technologies in studies provides speed, time and convenience.

The obtaining process of landslides susceptibility map divided into two parts in this study.

The first part was the implementation of the Frequency Ratio (FR) method. The FR method was used to determine the importance of the parameters and the intervals in which they affect the analysis map. The values of the selected parameter classes were calculated using from Fig. 2-7 according to FR method to determine the importance of the parameters and the intervals in which they affect the analysis map.

In the second part, the weight of the parameters was determined. A binary comparison matrix was created using the Analytical Hierarchy Process (AHP). The comparison values used in the method were determined by considering the landslide susceptibility studies and the region characteristics.

2.2.1. Frequency Ratio Method

The Frequency Ratio (FR) method is based on density analysis. The basic principle is based on transferring all parameters to the Geographical Information Systems (GIS) and making density analysis with the landslide inventory map (Lee & Talib, 2005).

Frequency ratio is defined as (b) / (a), where (a) corresponds to the ratio of the number of pixels with landslides in the parameter subgroup to the total number of pixels with landslides, and (b) corresponds to the ratio of the number of pixels of the parameter subgroup in the area considered, to the total number of pixels in the area under consideration (Lee & Talib, 2005).

Slope, elevation, soil, land use, proximity to the stream networks and lakes, proximity to fault lines classes are given in Table 2-7.

Table 2. Slope Classes

Attribute (degree)	Landslide area (% b)	Total area (% a)	Frequency ratio (b/a)
0 – 10	22,66	33,73	0,67
10 – 20	36,08	21,21	1,68
20 – 30	20,49	17,86	1,15
30 – 40	12,10	13,13	0,92
40+	8,66	13,71	0,63

Table 3. Elevation Classes

Attribute (meter)	Landslide area (% b)	Total area (% a)	Frequency ratio (b/a)
-27 – 100	13,26	21,18	0,63
100 – 400	33,26	17,83	1,86
400 – 700	21,65	23,65	0,92
700 – 1000	24,41	27,40	0,89
1000+	7,51	10,11	0,74

Table 4. Soil Classes

Attribute	Landslide area (% b)	Total area (% a)	Frequency ratio (b/a)
Other soils	1,64	2,31	0,71
Gray Brown P.	22,57	23,88	0,94
Chestnut	18,30	13,75	1,33
Colluvial	1,25	1,40	0,89
Red Yellow P.	0,00	0,09	0,00
Hydromorphic	0,00	0,94	0,00
Alluvial	0,83	14,18	0,06
Brown	0,03	0,06	0,44
Brown Earth	55,19	41,39	1,33

Table 5. Land Use Classes

Attribute	Landslide area (% b)	Total area (% a)	Frequency ratio (b/a)
Artificial areas	1,63	2,00	0,82
Agricultural areas	67,96	52,36	1,30
Forest areas	30,03	42,64	0,70
Wetlands	0,00	1,02	0,00
Water areas	0,46	2,17	0,21

Table 6. Proximity to Stream Networks and Lakes Classes

Attribute (meter)	Landslide area (% b)	Total area (% a)	Frequency ratio (b/a)
0 – 500	3,29	6,86	0,48
500 – 1000	3,98	4,62	0,86
1000 – 2000	10,98	10,44	1,05
2000 – 3000	13,52	10,96	1,23
3000+	68,31	67,31	1,01

Table 7. Proximity to Fault Lines Classes

Attribute (meter)	Landslide area (% b)	Total area (% a)	Frequency ratio (b/a)
0 – 1000	16,38	7,02	2,40
1000 – 2500	13,97	6,87	2,03
2500 – 5000	14,27	8,62	1,66
5000 – 10000	19,14	17,57	1,09
10000+	35,67	60,12	0,59

2.2.2. Analytical Hierarchy Process

The Analytical Hierarchy Process (AHP) was developed by L. Saaty in 1977 as a model that will enable the solution of multi-parameter decision making problems (Kavzoğlu et al., 2012).

Priority and weight vectors are calculated by normalizing the pairwise comparison matrix. Therefore, the elements in the columns of the matrix are divided by the sum of each column to form a normalized pairwise comparison matrix. The row elements in the new matrix are summed and the value obtained as a result of the sum is divided by the number of elements in the row. In this way, a weight vector or priority vector is created (Kavas, 2009; Tombus & Ozulu 2005).

Weights take a value between 0 and 1 and their sum equals to 1 (Malczewski, 1999; Ozturk & Batuk, 2010). The weights of this study are given in Table 8.

Table 8. Map Weights

	a	b	c	d	e	f	Weights
a	1						%17,20
b	1,00	1					%16,60
c	0,50	0,33	1				%9,10
d	2,00	2,00	2,00	1			%22,40
e	0,50	0,50	1,00	0,50	1		%9,50
f	1,00	2,00	2,00	2,00	2,00	1	%25,20

a. slope, b. elevation, c. land use status, d. soil, e. proximity to stream networks and lakes, f. proximity to fault lines

The weight of the parameters was calculated after the comparison matrix. The consistency ratio was found as CR = 0,039. Since the obtained ratio was below 0,10, which is the highest value determined for the correct execution of the study, there was no need to repeat the pairwise comparison method (Wind & Saaty, 1980).

3. RESULTS

The parameters to be used in the field of study were determined. The data of the parameters were mapped with the help of GIS.

The maps were weighted by using the FR method by calculating the areal rates associated with the landslide inventory map. The data pixels have been reclassified according to their weight.

The weights of the parameters relative to each other were determined using the AHP.

A susceptibility map was produced by applying the weighted registration process. The map produced was classified in 5 different categories according to risk groups: very low, low, medium, high and very high. Landslide susceptibility map is given in Fig. 9.

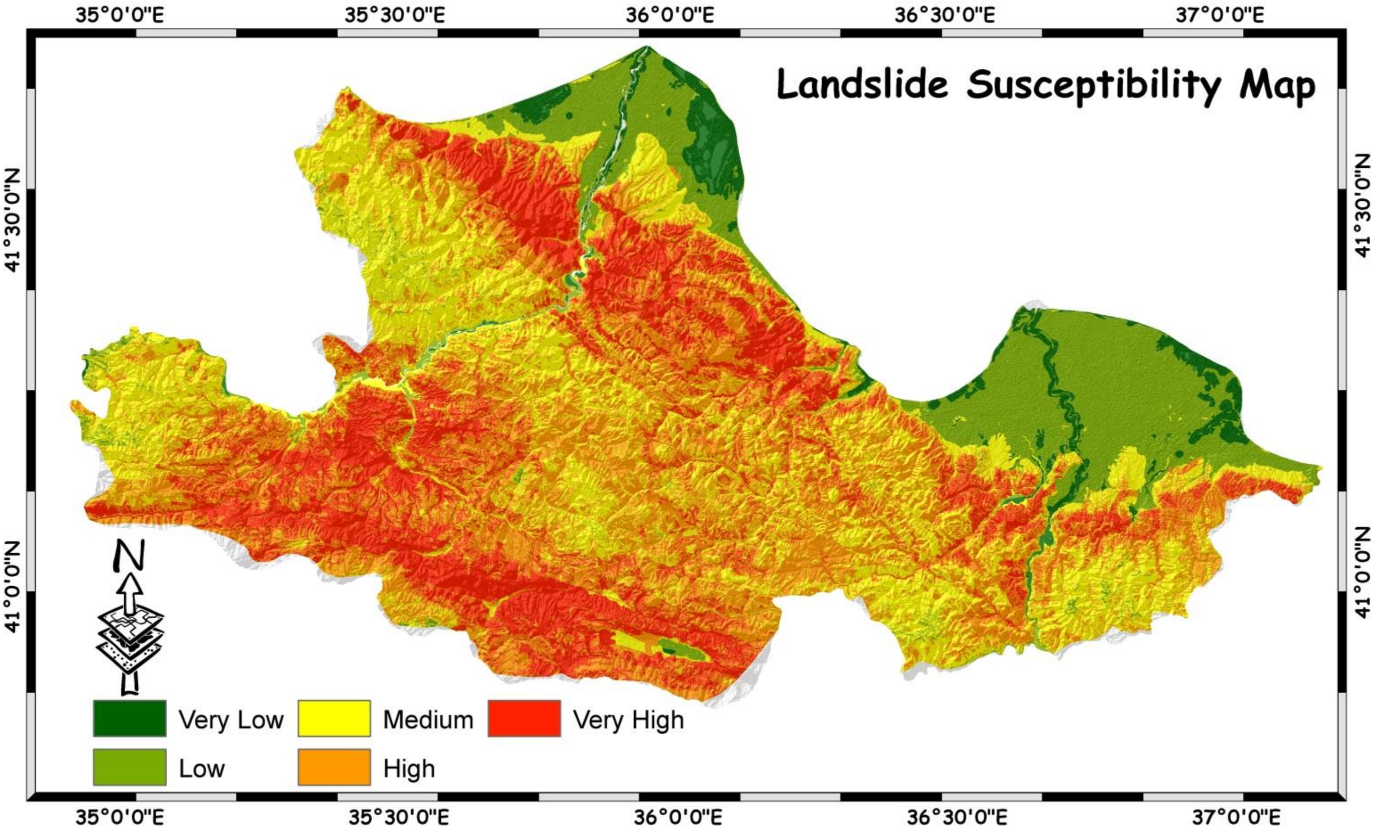

Figure 9. Landslide Susceptibility Map

Table 9. Risk Values of Parameter Classes

Parameters	Classes	Class Risk (%)	Class Area (%)
Slope	0 – 10	36,73	33,73
	10 – 20	90,52	21,21
	20 – 30	74,99	17,86
	30 – 40	59,22	13,13
	40+	37,17	13,71
Elevation	0 - 100	10,20	21,18
	100 - 400	88,52	17,83
	400 - 700	67,66	23,65
	700 - 1000	67,84	27,40
	1000+	56,62	10,11
Land Use	Artificial areas	28,74	2,00
	Agricultural areas	68,53	52,36
	Forest areas	50,40	42,64
	Wetlands	0,00	1,02
	Water areas	5,24	2,17

Table 9. (Continued)

Proximity to Stream Networks and Lakes	0 - 500	24,90	6,86
	500 - 1000	53,72	4,62
	1000 - 2000	59,58	10,44
	2000 - 3000	69,08	10,96
	3000+	59,73	67,31
Proximity to Fault Lines	0 - 1000	96,55	7,02
	1000 - 2500	93,43	6,87
	2500 - 5000	94,12	8,62
	5000 - 10000	78,31	17,57
	10000+	38,89	60,12
Soil	Other soils	18,94	2,31
	Gray Brown P.	45,90	23,88
	Chestnut	94,63	13,75
	Colluvial	41,26	1,40
	Red Yellow P.	10,69	0,09
	Hydromorphic	1,00	0,94
	Alluvial	1,76	14,18
	Brown	2,20	0,06
	Brown Earth	76,62	41,39

4. DISCUSSION

The produced landslide susceptibility map was compared with the parameter classes used in the study. Risk values of parameter classes are given in Table 9.

Although it was seen that landslides could occur in every class, the highest risk interval was determined as the range of 10-20 degrees with 90,52% in Slope Classes. When the elevation classes are examined, it was seen that landslide events are less in the range of 0-100 meters. The highest risk interval for the elevation was determined as the range of 100-400 meters with 88,52%. While it was observed that landslide events were less in artificial areas, swampy areas and water areas in the land use classes, the highest risk areas were determined as agricultural areas with a rate of 68.53%. In the soil classes, it was observed that landslide events were less in red-yellow podzolic soil, hydromorphic soil, alluvial soil and brown soil classes. The highest risk soils were determined to be chestnut soils with a rate of 94,63%. When the parameter of proximity to stream networks and lakes classes is examined, it is seen that the landslide risk is close in each class. When the proximity to stream networks and lakes classes are examined it was found that the rate of landslides in each class, although the parameter is not distinctive for the study area. For the proximity to fault lines classes, it was observed that landslide events are less in areas more than 10 kilometers away. The highest risk range has been determined as the 0-1 kilometer range with 96,55%.

5. CONCLUSION

GIS is important for collecting and processing geographic data of objects. Transforming data into geographic information with geographic analysis and viewing geographic data helps to plan activities.

Landslide susceptibility maps are of great importance in predicting future landslides and ensuring land use planning (Basara et al., 2020)

The landslide susceptibility map obtained was compared with the landslide inventory map (Fig. 8) for verification. The areas and rates of the landslide susceptibility classes are tabulated in Table 9.

Table 10. Landslide Susceptibility Classes

Attribute	Landslide area (km^2)	Total area (km^2)	Landslide incident (%)	Total area (%)
Very Low	0,04	332,59	0,01	3,50
Low	3,57	1280,23	0,95	13,47
Medium	64,25	2364,19	17,01	24,88
High	114,29	3381,41	30,27	35,58
Very High	195,46	2144,45	51,76	22,57

When susceptibility classes are examined it was seen that 82,03% of the old landslide events occurred in high and very high class, 17,01% occurred in middle class and 0,96% occurred in low and very low class.

In the spatially analysis of landslide events, it was seen that the sensitivity classes are examined spatially, high-risk areas constitute 58,15% of all areas, medium-risk areas constitute 24,88% of all areas and low-risk areas constitute 16,97% of all areas.

As a result, it is possible to say risk analysis methods should definitely be used in order to prevent future financial and moral losses caused by landslides that occur in different spatial structures.

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