Slide Type Landslide Susceptibility Assessment of the Büyük Menderes Watershed Using Artificial Neural Network Method

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Abstract

The Büyük Menderes watershed is the largest drainage watershed in Western Anatolia with an area of approximately 26000 km². In the study area, almost 863 landslides occurred, extending over 222 km² with a mean landslide area of 0.21 km². In this study, landslide susceptibility assessment was carried out using Artificial Neural Network method which is one of the data driven methods. Geology, digital elevation model, slope, topographic wetness index, roughness index, plan, profile curvatures, and proximity to the active faults and rivers were used as landslide conditioning factors. In susceptibility assessments, landslides were separated by 70 % analysis, 15 % test and validation data sets by random selection method. The performance of the landslide susceptibility map was assessed by the area under the receiver operating characteristic curves, error histogram, and confusion matrix, respectively. The area under the receiver operating characteristic curves, analysis, testing, validation, landslides and study area was found 0.82, 0.84, 0.86, 0.82. The susceptibility map had a high prediction rate in which high and very high susceptible zones corresponded to 26 % of the study area including 82 % of the recorded landslides.

1. Introduction

Land-use planning is at the center of the sustainable development process and potential natural hazards such as landslides, floods and earthquakes should be taken into account in planning studies. Susceptibility maps showing, where landslides can occur spatially constitute one of the important stages of regional scale planning and landslide mitigation studies (Akgun et al. 2012; Abanco et al. 2016, Nsengyumva et al. 2018; Chawla et al. 2018; Ietto et al. 2018; Silva et al. 2018; Achour et al. 2018; Chen et al. 2018; Chu and Chen 2018; Hu et al. 2018; Pham et al. 2019; Sharma and Mahajan 2019; Panchal and Shrivastava 2020; Cordoba et al. 2020; Bui et al. 2020). The preparation of landslide susceptibility maps depends on many factors, such as the type and distribution of landslides, the reliability of the inventory map, and the consideration of appropriate environmental variables that cause landslides. Landslide susceptibility assessments are divided into two as quantitative and qualitative. Qualitative methods consist of methods based on expert opinion. Quantitative methods, on the other hand, consist of data-driven methods and geotechnical approaches (Corominas et al. 2014). This study was carried out for slide type landslides in the Büyük Menderes river watershed using artificial neural networks, one of the quantitative methods. The Büyük Menderes Basin is one of the 25 major drainage basins in Turkey, and when the natural disaster potential is evaluated, it differs from other basins both in terms of active tectonics and of the fact that it includes slide type landslides. According to the landslide inventory map, 40 % of the landslides are spatially located in a zone at a distance of 1000 m to active faults. In this study, landslide susceptibility assessment was carried out by using Artificial Neural Network method that is one of the data driven methods. Geology, digital elevation model, slope, topographic wetness index, roughness index, plan, profile and tangent curvatures, proximity to the active faults and rivers were used as landslide conditioning factors. In susceptibility assessments, landslides were separated by 70 % analysis, 15 % test and validation data sets by random selection method. The performance of the

landslide susceptibility map was assessed by the area under the receiver operating characteristic curves, error histogram, and confusion matrix, respectively.

2. Study Area

The Büyük Menderes basin is located between 37 ° 12 " - 38 ° 40" north latitudes and 27 15"-30°15" west longitudes in the Aegean Region (Fig. 1). The Büyük Menderes River begins near Dinar District (Afyon) in Western Anatolia and flows into the Aegean Sea from the Söke Dipburun region. The basin is bordered by Samsun Mountain, Cevizli Mountain, Elma Mountain and Murat Mountain from the north; Sandıklı Mountains from the east; and Madran Mountain, Babadağ and Bozdağları from the south. The basin area is approximately 26,000 km² and accounts for 3.2 % of the surface area of Turkey. In the basin, there are Uşak, Denizli and Aydın city centers and 39 district centers belonging to these cities.

As a result of climate change, one of the biggest problems of the last century, increases in the frequency and intensity of extreme natural events occur. WorldClim (2019) climate scenario data were analyzed for the Büyük Menderes basin because it is the closest prediction model according to the data obtained by the Coupled Model Intercomparison Project Phase 5 (CMIP5) prepared by the World Climate Research Program (WCRP). It is predicted that there will be a 51 mm decrease in average annual rainfall values in 2070 in the Büyük Menderes river basin (Fig. 2a, b).

3. Geological And Geomorphological Features Of The Büyük Menderes Watershed

The Büyük Menderes River played an important role in the formation of the geomorphology of Western Anatolia. The basin contains 3 graben systems. The western most part of the basin is located in the Büyük menderes graben, the middle part in the Denizli graben and the eastern part in the Baklan-Dinar graben system (Fig. 3). The river was generally shaped by the Menderes river system. There are many active fault systems in the basin under the influence of the West Anatolian extensional tectonic regime; this river system is, therefore, located among the high seismic activity zones in Turkey (Fig. 3). There are rock assemblages of various ages and types formed from the Paleozoic until today. In the Büyük Menderes basin, the basic units belonging to the Paleotectonic period consist of the Menderes massif and the İzmir-Ankara suture belt. The units belonging to the Menderes massif are composed of metamorphic rocks which do not have an ordered lithology laterally and vertically. The basement of the Western Anatolian graben system is formed by the metamorphic rock assemblages of the Menderes Massif, which are generally composed of gneiss and schist. Being the oldest unit in the basin, the Carboniferous-aged units are generally composed of gneiss, mica-schist, metaquartzite and partly limestone. There are Mesozoic neritic limestones on the Paleozoic metamorphic units. In some sections, there are clastic rocks in the Flysch facies, and these include serpentinite, chert, diabase and limestone lithology forming blocks of different sizes. The cover units (Paleogene- and Neogene-aged units) overlying Mesozoic-aged units are composed of units containing recrystallized limestones and sandstones. The Cenozoic cover deposits discordantly overlie the Mesozoic units. The Cenozoic period

consists of Neogene-, Miocene- and Pliocene-aged sedimentary and volcanic units. The metamorphism observed in the region was followed by regional thermal doming in the Early Miocene, and this dome was disintegrated as a result of orogenic collapse and led to regional expansion around the massif (Seyitoğlu and Scott, 1991; 1992, Konak, 2002). The Neogene and Quaternary units constitute the metamorphic units of the Menderes massif and the cover rocks on the basement units of the Izmir-Ankara Suture Belt. The Neogene-aged units are generally composed of sedimentary rocks developed in stream and Lake Facies and volcanic rocks of various types. The lower-Middle Miocene-aged rock beds form the bottom of the Neogene sequences (Konak and Şenel, 2002). These units consist of sandstone, shale, limestone and pebble stones deposited in fluvial facies. The composition of the clastic rocks in the unit, especially the pebbles, is variable according to the bedrock they rest on. At the top, the late Miocene-Pliocene sediments overlie them unconformably. This top package consists of limestone, marl and clay stones. The upper Miocene-Early Pliocene units constitute common rock types.

A land structure map was prepared according to the classifications suggested by Jenness (2006) using the topographic Wetness index (Fig. 4). According to this, the basin is a valley consisting of 3.99% small drainage systems, 20.50% lower slope, 13.22% steep slope, 9.85% ridges, 15.51% low slope and 36.93% low-slope plains formed by the Menderes river and its lateral branches. AsterGDEM was used as the Digital Elevation Model of the study area by converting it to 100m spatial resolution (Fig. 1). According to the digital elevation model, the average height value is 800 m, and the altitudes reach over 2500 m in the region between Honaz and Kale and Banaz-Dinar, which forms the northeast part of the basin. As other environmental variables, such parameters as slope; roughness index; topographic wetness index; plan, profile curvature and proximity to active faults and rivers were used for landslide susceptibility assessments (Fig. 5).

4. Landslide Inventory Map

In the Büyük Menderes basin, there are 863 slide type landslides with a total area of 222 km² (Fig. 6a). According to the statistical data of the landslide areas, the lowest value is 0.00 km² and the largest landslide area is 30.20 km². When the landslide areas are listed, the median value, which is the areal mean value, was calculated as 0.21 km². Figure 6b shows that the areal data of the landslides on the landslide inventory map are skewed to the right according to the Chi-Square Distribution. 40% of the landslides are spatially located in a zone 1000 m away from active faults. The landslides are generally seen in the Paleogene-Neogene-aged clastic (Fig. 7a, b) and Triassic-Cretaceous carbonate units (Fig. 7a). The largest landslide in the basin was in the Dinar fault zone around Çivril, in an area of approximately 30 km² on the western slope of Akdağ (Fig. 7b).

5. Artificial Neural Networks

Artificial neural networks (ANN) are defined as a set of mathematical modeling methods that interact with biological nervous system counterparts of many simple elements connected in parallel (Kohonen, 1982).

Since the cell, which is the basic process element of artificial neural networks, is not linear, it is not linear in artificial neural networks that result from the combination of cells. With this feature, ANN are one of the widely used methods in modeling nonlinear complex problems today. In this study, pattern recognition and classification method in artificial neural networks was used for landslide susceptibility assessment; thus, it was conducted using a two-layer artificial neural network model: the hidden layer and the output layer (Fig. 8).

6. Results

The number of hidden layers between input and output layers directly affects the performance of the model (Basheer and Hajmeer, 2000; Karsoliya, 2012). In this study, 7 units in the geological map, 6 categories of categorical land use, DEM and derivative maps (slope, curvature, roughness, plan curvature, profile curvature, TWI, fault and river distance) were evaluated as continuous data, and a total of 21 ANN input layer was created. The dataset of the Büyük menders basin was divided into 3 as 70% analysis, 15% test and 15% validation. The hidden layer numbers varying between two-thirds and two times of the input layer number suggested by Karsoliya (2012) were tested, and result susceptibility analyzes were performed with 20 hidden layers where the best result was obtained. The training algorithm was implemented using the scaled conjugate gradient method for backpropagation and the log-sigmoid transfer function. Considering the root mean square error value in the model, the cross-entropy performance function was used. The landslide susceptibility assessment (Fig. 9a) was evaluated in five categories as very low (36.87%), low (20.79%), medium (16.34%), high (12.65%) and very high (13.35%) (Fig. 9d). According to the success- and prediction- rate curve of the obtained landslide susceptibility map (Fig. 9a, b, c,d), it is seen that 26 % of the study area is in very high group ranges and that 82.01 % of the landslides are also in these groups (Fig. 9d).

The obtained landslide susceptibility map performance and accuracy evaluations were evaluated by many different methods. The blue bars in the error histogram represent the training data, whereas the green bars show the validation data and the red bars show the test data. The histogram is an indicator of the outliers which are the data points where the mismatch is significantly worse than the majority of the data. In the artificial neural network model obtained in this study, no data mismatch between the variables and landslides was found as a result of the error histogram (Fig. 10).

Considering the root mean square error value in the model, the cross-entropy performance function was used. Cross entropy loss or log loss measures the performance of a classification model whose output layer has a probability value between 0 and 1 and is used in the ANN model. Cross entropy loss increases as the predicted probability moves away from the original value. The performance evaluation with cross entropy was calculated as a probability value of 0.038731 in the model network architecture. The analysis captured the strongest probability in the test sets in Epoch 64 (Fig. 11).

When the landslide susceptibility assessment analysis, test, validation and performance evaluations of the landslide sets in the study area are examined, it is seen that the analysis, test and validation of the

landslides are estimated to be above 90% (Fig. 12). The value under the receiver operating characteristic curve of the landslide susceptibility map was calculated as 0.82, 0.84, 0.86 and 0.82 in the analysis, test, validation landslides and in the whole study area, respectively (Fig. 12). According to the accuracy tests of the landslide susceptibility map obtained as a result of the study, it is seen that the model applied in the study has a high predictive power and accuracy.

7. Conclusion

Landslides are among the natural disasters that cause significant loss of life and property in Turkey. Landslide susceptibility maps are used to determine the spatial likelihood of landslides within the scope of landslide risk reduction studies in areas under potential danger of landslides; therefore, as in the world, they have begun to be widely used in Turkey as well. Effective fight against losses caused by landslides requires a proper articulation of environmental variables that prepare and trigger landslides in a particular region. Landslide susceptibility assessments should be carried out separately for each landslide mechanism. The Büyük Menderes Watershed is one of the 25 main drainage basins in our country. Compared to the other basins in Turkey, the basin is an important watershed in terms of active tectonics. In this study, the slide type landslide susceptibility map in the Büyük Menderes River basin with an area size of 26.000 km² was carried out using artificial neural networks method. Rural and urban settlements, agricultural lands and transportation network are often negatively affected by landslides in the basin.

8. Declarations

Competing interest

There are no conflicts of interest to declare.

-Ethical Approval

-Ethical Approval is not required.

-Consent to Participate

Contributions are among the authors permission.

-Consent to Publish

Contributions are among the Publish permission.

Author contributions

Senem Tekin: Collected the datasets and analyzed the data, Methodology, Validation.

Tolga Çan: Conceptualization, Analyzed the data, Methodology, Validation, Writing.

-Funding-Competing Interests

There is no financial support.

-Availability of data and materials

- Availability of data and materials is described in the publication.

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Figures

Figure 1

Location map of the study area.

Figure 2

Current (a) and 2070 scenario (b) Using Worldclim data Annual Precipitation (BIO12) (mm).

Figure 3

Active fault (Emre et al. 2018) and Lithology Map (Konak 2002; Konak and Şenel, 2002).

Figure 4

Land morphology Map of the Büyük Menderes Basin.

Figure 5

Slope (a), roughness index (b), curvature (c), plan curvature (d), profile curvature (e), topographic wetness index (f), proximity to active faults (g), and proximity to rivers (h).

Figure 6

Landslide inventory map (Duman et al., 2009 a, b). (a), Chi-Square Distribution for landslide inventory (b).

(a)

(b)

Figure 7

Landslides observed in Miocene clastics around Babadağ (a) and in Triassic carbonate units (b) on the western slope of Akdağ.

Figure 8

Artificial neural network structure.

Figure 9

Susceptibility map (a, b, c) and Success-Prediction rate curve (d).

Figure 10

Error histogram.

Figure 11

Cross entropy model result.

Figure 12

Receiver Operating Characteristic Curve and Analysis, validation, test and model fitness of all landslides in the study area.