Utilization of Frequency Ratio Method for the Development of Landslide Susceptibility Maps: Karaburun Peninsula Case, Turkey

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Abstract

Geographical information systems (GIS) facilitates both current landslide mapping processes and prediction of potential landslides that may be experienced in the future. Within the scope of the study, landslide susceptibility maps were developed in order to reduce the damages of possible landslides in Karaburun Peninsula of İzmir province. To fulfil this aim, landslide inventory map was produced from related databases in the first place followed by the development of parameter (elevation, aspect, slope, curvature, land use, vegetation cover, lithology, distance to roads, distance to rivers and distance to fault lines) maps. Frequency ratio method was utilized for developing the landslide susceptibility maps and Reciever Receiver Operating Characteristic (ROC) analysis was performed for accuracy testing. The resulting landslide susceptibility map revealed that 36% and 52% of the study area had high and medium risk categories, respectively. 10% of the region has low landslide risk. These results provide important inputs to guide sustainable strategic and physical planning processes in the region, which has been formerly declared as a special protection area, and is a popular destination for both tourism activities and energy facilities.

1. Introduction

The dynamic internal structure of the Earth has been through a continuous change, which is influenced by both natural and anthropogenic factors, since its creation. These natural factors commonly cause a variety of natural phenomena such as earthquakes, volcanic eruptions, floods, landslides, extreme weather events etc., while anthropogenic activities usually disrupt natural balances and turn natural events into disasters causing deaths and destructions (Alcantara-Ayala 2002). From this point, comprehensive disaster analyses and determination of natural hazards and risks are of critical significance to mitigate the potential losses especially in areas intensely inhabitated.

Landslides and rockfalls are amongst the main natural events that may pose high risks to the humans and settelements. A diversity of factors such as geological, geomorphological, climatic and meteorological influences, as well as the human activities initiate landslides. There are also triggering factors which cause the gravity-driven downslope movement of the large masses (soil, rock, debris etc.) (Ercanoğlu et al. 2008). Landslides occur in a wide range of different geographies in the world and significantly affect the landscapes (Gariano and Guzetti 2016). Yet, while changing the physical structure of the environment, landslides can also end up with severe economic losses, infrastructure damages, injuries and fatalities (Prakash et al. 2020). According to UNISDR, 4.8 million people were affected from landslides worldwide and 18414 fatalities were recorded between 1998-2017 (United Nations Office for Disaster Risk Recudtion [UNISDR] 2017).

A number of studies about natural disasters covering different research periods in Turkey also point out that landslides take the first place in terms of event number in the country. According to the evaluation based on the number of the influenced housing, landslides rank second after earthquakes in terms of the losses they caused (Çan et al. 2013). Landslides are very commonly observed in the Black Sea, Central and Eastern Anatolia regions in the country and result in severe physical and economic impacts as well as deaths and injuries. According to the Disaster and Emergency Management Presidency (AFAD), 13494 lanslides and 2596 rock fall events were reported in the country between 1965 and 2015, while 151 events happened in 2018 (AFAD 2015). The 2019 disaster statistics, on the other hand revelaed that 245 landslide/rock fall events took place in Turkey (AFAD 2020).

Within this context, development of landslide susceptibility maps, which deals with the spatial likelihood of the mass movements associated with their occurrence in a particular area (Nsengiyumva and Valentino, 2020), is vital to make efficient physical planning, manage potential risks for the existing settlements and structures, construction works (dams, roads, etc.), and delicate landscapes. Thus, loss and damage risks are properly and timely mitigated (Highland and Bobrowsky 2008). For this reason, researches and studies focusing on landslides hazard and risk modelling via different approaches and techniques have been an important research area. Statistical methods (Mersha and Meten 2020; Pasang and Kubíček 2020; Thanh et al. 2020; Zhang et al. 2020), machine learning algorithms (Bui et al. 2020; Fang et al. 2021; Merghadi et al. 2020; Sahin 2020; Wang et al. 2020) and hybrid models (Chen and Chen 2021; Chen and Li 2020) are commonly utilized by a good number of researchers to develop susceptibility maps, make predictions for potential flows and compare the efficiency and accuracy of different techniques.

For example, Kirshbaum et al. (2020) examined the landslides in the High Mountain Asia region mostly initiated by extreme precipitation, and used satellite and Global Climate Model data and applied Landslide Hazard Assessment for Situational Awareness (LHASA) model to determine the potential landslide hazard in the future within the study area. Slope, lithology, land cover change, distance to road networks, and distance to fault zones data were utilized for the development of the landslide susceptibility map. Lui et al. (2021) utilized three machine learning techniques to model the landslide susceptibility triggered by rainfall in Veikledalen Valley, Norway. The authors used slope angle, aspect, plan curvature, profile curvature, flow accumulation, flow direction, distance to rivers, total water content, saturation, rainfall and distance to roads data as the triggering factors. Lacroix et al. (2020) aimed to determine the relation between the irrigation and the landslide activities on the southwestern coats of Peru. The authors used Hexagon spy satellite and SPOT 6/7 images to detect the land use and morphological changes (elevation change patterns) between 1978 and 2016, and benefited from KH9, Landsat 5 and Landsat 8 imagery to determine the horizontal displacements in the study area. The results showed that large slow-moving landslides occurred within the irrigated areas. Lee and Pradhan (2007) used parameters such as slope, aspect, curvature, precipitation distribution, lithology, vegetation index, land cover, distance from drainage, etc. and applied both frequency ratio (FR) and logistic regression (LR) methods to develop landslide hazard map in Selangor, Malaysia, which is prone to severe landslide activities especially triggered by intense rainfall. In their study, the authors both used satellite images and conducted field surveys to detect the landslide locations, and after the analyses concluded that FR method provided more accurate results compared to LG in their study area.

Besides the techniques adopted, the parameters used for assessing the landslide hazards are of vital importance and may vary according to the aim of the study and the characteristics of the geographic context. Gökçeoğlu and Ercanoğlu (2001) focused on the commonly used geological, geomorpholological, hydrological, and antropogenic data sets and evaluated 21 studies conducted for the development of landslide susceptibility maps. The authors found that slope data was used in all 21 studies, lithology in 20, distance to main faults in 11, curvature and elevation in 10, and drainage network, vegetation and land use potential datasets in 8 studies. In a nother similar study, 117 studies in the literature were examined to determine the parameters used to develop landslide susceptibility maps. According to the results, it was detected that 94.02% of the studies have used curvature, 67.52% lithology, 63.25% aspect, 51.28% drainage characteristics, and 50.43% elevation (AFAD 2015).

Within this context, the aim of this study is to develop a GIS-supported landslide susceptibility maps in Karaburun Peninsula, İzmir, using FR method. As Thanh et al. (2020) also underlined, FR is a very popular bivariate statistical method for the assessment of the landslide susceptibility, since it is easy to use and provide good results. Reciever Operating Characteristic (ROC) analysis was performed for the determination of accuracy of the landslide susceptibility map.

2. Material And Methods

2.1. Study Area

The study area is Karaburun Peninsula located between 26° 21'–26° 38' N longitudes and 38°25'–38° 40' E latitudes to the west of İzmir province, which is the third biggest city in Turkey (Fig. 1). Karaburun has a coastal length of 130 km (Isik Pekkan et al. 2021), covers a surface area of 420 km^2 and extends to the Aegean Sea (Prefecture of Karaburun 2019).

The annual average temperature in the study area varies between 15-20 C^o and the annual average precipitation is around 650-700 mm. The peninsula is an important area for a good number of wind farm projects, since the wind speed reaches to 50 km/hours in the region (Prefecture of Karaburun 2019). The terrain of the peninsula is quite rugged and the highest spot in the region is Akdağ mountain with an elevation of 1212 m. Mountains of limestone and andesite surround the sea-level plains and tectonic pits (İzmir Kalkınma Ajansı (İZKA) 2013; Kalafatçıoğlu 1961). This topographic structure results in the formation of a diversity of attractive bays along the coastal areas of Karaburun, which makes the area a popular tourist destination. Road, tourism facility, wind farm construction activities have therefore become very intensive for the last 10 years. The low-density population in the region increases especially during the tourism seasons (Prefecture of Karaburun 2019).

Karaburun is also a very significant area in terms of its unique landscape characteristics and hosts marine, coastal, mountain, forest and wetland ecosystems (Isik Pekkan et al. 2021). Accordingly, the region was declared Special Environment Protection Site on 15.03.2019 by the Ministry of Environment and Urbanization. Considering both this new conservation status of the peninsula and the delicate characteristics and increasing demand in the area for tourism and wind farm establishments, it has become an essential requirement to conduct more comprehensive researches in the study area.

From this perspective, disaster based studies, risk and hazard determination works are also important in the area, so that proper planning and implementation works can be made to protect the existing characteristics and mitigate the potential negative impacts on the ongoing and planned activities. The landslide susceptibility maps are also necessary to determine the landslide hazards in the region

2.2. Material and Data

The main material used in this study is the spatial data of the Karaburun Peninsula. ArcGIS, Microsoft Excel and IBM SPSS Statistics software were used for data processing, analyses and visualitation processes. The spatial data of the study were transformed into Shape file (*.shp) format.

Table 1 summarizes the spatial data and the type of the spatial analysis used as well as the parameter maps developed within the aim of the study

Table 1

Spatial data of the study

Parameter Map	Name of Data	Type of Data	Original Name	Type of Analysis
Landslide Inventory	Landslide	Vector	Landslide	Classification
Elevation, slope, aspect, curvature	Digital Elevation Model	Raster	ASTER Global Digital Elevation Model V003 / 30 m spatial resolution	Topographic analysis
Land use	Land use map	Raster	Corine Land Cover Change /100 m spatial resolution	Classification
Lithology	Lithology	Vector	Geologial formation	Classificaiton
Distance to roads	Distance to roads	Raster	Road	Proximity analysis and classification
Distance to rivers	Distance to rivers	Raster	ASTER Global Digital Elevation Model V003 / 30 m spatial resolution	Hydrological and proximity anaylsis, classification
Distance to fault lines	Distance to fault lines	Raster	Fault	Proximity analysis and classification
Vegatation cover	Vegetation cover	Raster	Landsat 8 TM / 30 m spatial resolution	NDVI index, classsification

The primary data of this study is the existing landslide areas (landslide inventory), which was obtained from the earthsciences portal of General Directorate of Mineral Research and Exploration (MTA) and used for the production of statistical data from particular parameters which initiate the landslides. Since only 3 landslide areas exist in Karaburun Peninsula according to the records, all 33 former landslide areas within İzmir province were used to obtain significant statistical results. Still, the amount of existing landslide areas is considered low compared to the size of the study area, especially when the approaches in other similar studies are exmained (Basharad 2016; Chen 2014; Chen 2016; Akgün et al. 2008).

2.3. Methods

This study is based on the development of landslide susceptibility maps of Karaburun Peninsula, Izmir province, using method namely FR .Weighted parameter maps were overlaid via GIS capabilities to produce the landslide susceptibility map of the study area. Fig. 2 summarizes the workflow of the study.

For the development of the parameters maps in the study area various methods were used. NDVI technique was applied to determine the vegetation cover (Esendal et al. 2018). Buffer analysis was performed for the determination of the buffer zones around linear fetaures such as roads, rivers and fault lines. Topographic analysis were made to produce elevation, slope and slope maps. Land use parameter map was produced by the reclassification and organization of the CORINE map of the study area. Table 1 also summarizes the main methods utilized for the development of the parameter maps.

Detailed information related to parameter map development and FR method utilization processes are provided in the following sections.

2.3.1. Development of Parameter Maps

Although landslide susceptibility map development studies have become widespread, there is still no consensus on the determination of the necessary parameters and the methods (Gökçeoğlu and Ercanoğlu 2001). Therefore, previous studies were examined and referred for the determination of the parameters (Akgün et al. 2008; Chen et al. 2014; Gökçekoğlu et al. 2001; Huang and Zhao 2018; Kelarestaghi and Ahmadi 2009; Özdemir and Altural 2013; Pachauri and Pand 1992; Sarkar and Kanungo 2017; Youssef et al. 2015). The parameters for this study was determined as elevation, aspect, slope, curvature, land use, vegetation cover, lithology, distance to roads, distance to rivers and distance to fault lines.

Parameter data were obtained from various resources and classified in the first place to statistically evaluate the relation between these data and the characteristics of the existing landslide within the study area to produce the landslide susceptibility map. The resolution was resampled to 30 meters. The existing landslide areas located to the north of the study area around Çandarlı Bay region, which cover a considerably large surface, were extracred from the process due to their possible negative influence on the results of the statistical analyses. Therefore, a total of 33 previous landslide areas were used for the study. After the parameter maps were developed, they were reclassified in accordance with the sublayers in the maps based on the information in the literature. Each reclassified parameter map was masked with the polygons comprising the 33 landslide areas in the study area and the number of the pixels in each masked area was calculated to determine the frequency values.

2.3.2. Frequency Ratio Method (FR)

FR method provides objective weighting of the parameter maps together with their sublayers in determining the landslide susceptibility areas and is based on the principle of computing the observation frequency of parameter sublayers in landslide areas. FR method enables to associate the sublayers of the parameter maps in the study area with the ones that of existing landslide areas. FR method runs on a probability model that defines the likelihood of an event happening (Ataol and Yeşilyurt 2014, Pham, et al. 2015, Soyoung, et al. 2013, Silalahi, et al. 2019). The formula used for FR method is given below;

$$FR = PLO \setminus PIF$$

1

where PLO represents the percentage of the presence of landslides within each sublayer that affect the landslide, and PIF is the percentage of each sublayer affecting the landslide in the parameter map.

The FR calculated via this formula is used for assigning the weights for parameter maps (Erener and Lacasse 2007; Demir 2018). Landslide susceptibility map is developed by the addition of the weighted parameter maps, in which lower values show the low landslide susceptibility, while high ones correspond to the high landslide susceptibility. These values are reclassified with equal intervals to obtain the final state of the landslide susceptibility map.

Regardingly, in this study, the number of pixels corresponding to the landslide area of each sublayer in the relevant parameter map was determined and then the FRs of the sublayers in the landslide areas were calculated using this value.

Receiver Operating Characteristic (ROC) analysis was used for the determination of the accuracy of the landslide susceptibility maps produced with FR. ROC analysis is one of the methods used to organize the classifications obtained by statistical processes and to evaluate their performance. Frequently used for medicine bioinformatics, finance and GIS studies, ROC analysis provides the comparison of the statistical models with the real data. When the area below the curve is close to 1, the specificity of the model increases (Mas et al. 2013, Fawcett 2006).

3. Results

3.1. Parameter and Landsclide Susceptibility Maps

In accordance with the methodology explained in the relevant sections, 10 parameter maps (elevation, aspect, slope, curvature, land use, vegetation cover, lithology, distance to roads, distance to rivers and distance to fault lines) were developed in the first place for Karaburun Peninsula. The parameter maps were used for the development of the landslide susceptibility map of the study area. Fig. 4-13 illustrate the parameter maps of the study and Fig. 14 shows the final map (landslide susceptibility map) developed with FR method.

Table 2
Frequency table

Parameter	Classification Value	Frequency Value
Elevation	0-100	8.5
	100-200	27.6
	200-300	95.1
	300-400	83.5
	400-500	100.0
	500-600	75.1
	600-700	11.2
	700-800	6.4
	800-900	0.7
	900-1000	3.1
	1000-1100	2.7
	1100-1200	5.5
	1200-1300	6.9
	1300-1400	16.4
	1400-1500	34.1
	1500-1600	86.5
	1600-1700	34.0
	1700-1800	0.0
	1800-1900	0.0
	2000-2100	0.0
	2100-2200	0.0
	2200-2300	0.0
Aspect	North	6.3
	Northeast	0.1
	East	100.0
	Southeast	63.1
	South	42.1

Parameter	Classification Value	Frequency Value
	Southwest	46.6
	West	49.9
	Nortwest	51.1
Slope	0-10	90.4
	10-20	100.0
	20-30	52.2
	30-40	41.7
	40-50	37.7
	50-60	0.0
	60-70	0.0
	70-80	0.0
Curvature	(-29)-(-1)	68.7
	(-1)-(-0.5)	100.0
	(-0.5)-0	93.4
	0-0.5	95.8
	0.5-1	93.9
	1-27	61.6
Land use	Urban Areas	35.9
	Transport	48.9
	Construction and Mining Areas	0.0
	Agricultural Areas	18.3
	Forests	3.8
	Grasslands	100.0
	Coastal Areas	0.0
	Bareen Rocky Lands	0.0
	Water Resources	1.0
Vegetation cover	Water Body	49.1
	Urban Area, Semi Desert	5.8

Parameter	Classification Value	Frequency Value
	Urban Area, Dry Soil, Clay Surface	7.3
	Moist Soil, Bare Soil	46.9
	Forest, Grassland	100.0
	Forest, Farmland	41.2
	Dense Vegetation	8.3
Lithology	Quatermary	2.2
	Neogene	0.3
	Paleogene	100.0
	Mesozoic	1.5
	Paleozoic	1.0
	Precambrian	5.9
Distance to roads	0-100	70.9
	100-200	81.0
	200-300	86.1
	300-400	83.2
	< 400	100.0
Distance to rivers	0-100	43.9
	100-200	60.3
	200-300	68.0
	300-400	67.5
	< 400	100.0
Distance to fault lnes	0-50	99.4
	50-100	94.5
	100-150	100.0
	150-200	99.5
	200-250	95.7
	250-300	97.0
	300-350	93.3

Parameter	Classification Value	Frequency Value
	350-400	88.4
	400-450	88.9
	450-500	80.6
	< 500	43.4

The table above shows the calculated frequency values. A susceptibility map was produced using these values in the Karaburun Peninsula. When the frequency values were examined, it was seen that the frequencies were evenly distributed or concentrated in a single class in some parameters. This reduces the effect of these parameters on the susceptibility map. Field studies on each of these parameters or other studies to increase accuracy are required.

According to the landslide susceptibility map (Figure 14) of İzmir province and Karaburun Peninsula, 10% of the study area falls into low risk category and 50% into medium risk category. 40% and 50% of the existing landslide areas comprise medium and high risk zones, respectively. The results show that Karaburun peninsula is mostly made up of high (36%) and medium (52%) risk categories. Still, 10% of the region has low risk characteristics in terms of landslide susceptibility.

Higher elevations within the peninsula have medium landslide susceptibility. Karaburun and Mordoğan districts are mainly made up of medium susceptibility areas.

3.2. Accuracy Results

In a good number of studies ROC method have been used for the determination of the accuracy of the landslide susceptibility maps. In this study, ROC analysis, which is particularly used in biostatistics for the evaluation of performance of the diagnosis and the test was adopted. In ROC, the area below the curve shows the quality of the relation between the test and the diagnoses. The area below the curve line is between 0.5 and 1, where 1 refers to a perfect specificity and 0.5 random specificity (Ayalew and Yamagishi 2005; Reyhanlıoğlu Keçeoğlu et al. 2016).

Figure 15 illustrates the ROC results of the landslide susceptibility maps of the study area. Table 3 summarizes the information related to the ROC analyses.

Table 3
Information realted to ROC curve

	Area	Asymptotic Sig.[b]	Asymptotic 95% Confidence Interval	
			Lower Bound	Upper Bound
Landslide susceptibility map (FR method)	0.783	0	0.777	0.788

According to ROC analysis, the accuracy of the landslide susceptibility map developed with FR method was found 78.3%.

4. Conclusions

In this study, FR method was utilized for the production of the landslide susceptibility map, and thus to spatially predict the landslide risks in Karaburun Peninsula, İzmir province. The study area is a delicate region in terms of landscape characteristics and a popular tourist destination. Landslide susceptibility map development efforts are based on the analysis of natural, environmental and triggering parameters by using different statistical methods. In the study, most common 10 parameters (elevation, aspect, slope, curvature, lithology, land use, vegetation cover, distance to the roads, distance to fault lines and distance to the rivers), which were frequently used in previous studies, were analyzed using FR method. The data and the methods of the study were determined in accordance with the literature review. All the parameter maps were organized to have the same standards in terms of study area boundaries, type, scale, raster resolution and coordinate system. In addition, experts were consulted to determine the relation between the landslides and the triggering parameters. Regarding the process and the produced landslide susceptibility map, the followings were concluded.

- In FR method, the influence of “distance to rivers” parameter was found considerably low. This is thought to be mostly because the winter flows are very common in the region. The streams in the region are generally dry for most of the year. Increase in the pore water pressure is one of the reasons that cause landslides. This is assumed to be the reason for the landslides in the study area to occur mainly in the coastal areas.
- According to the MTA database, only 3 former landslides were recorded in Karaburun Peninsula. Due to this low number, all the existing landslide data for whole İzmir province were used to obtain statistically significant results. On the other hand, AFAD also keeps the inventory of the landslides in the country. From this point, it is necessary to use the data of both institutions to obtain more accurate results. Field surveys, satelleite imagery, UAV and LIDAR applications are also utilized for the determination of the landslides. Thefore, it is essential to update, integrate and enrich the exsting landslide inventory with the support of the advanced technologies. Thus, it will be possible for researches to develop more accurate and precise maps.
- A good number of wind farm establishments exists within the study area, mostly erected on the higher elevations. Accordingly, many roads have been built to provide transportation to the wind farms. However, the road data used in this study excludes these mentioned roads, which in fact may be important triggering factors and should be obtained and analysed for further works. The authors believe that these ignored roads are likely to increase the landslide susceptibility in the region.
- The landslide susceptibility map revealed that the Karaburun Peninsula mostly comprised medium risk lands. In this study yhe number of landslide inventory is rather low compared to similar studies. Srill, it is of significance to allow for the landslide risks for strategic and physical planning processes in the region as well as a range of economic, social and environmental works.

Declarations

Ethics approval

Not applicable

Consent to Participate

Not applicable

Consent to Publish

Not applicable

Author Contributions

All authors contributed to the study conception and design. Conceptualization, data collection, analysis, and first draft writing stages were performed by Muhittin Ozan KARAMAN. Saye Nihan ÇABUK and Emrah PEKKAN supervised and contributed to the context and medthod development, evaluation of the results, and final writing. All authors read and approved the final manuscript.

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Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

Availability of data and materials

Not applicable

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Figures

Figure 1

Study area

Figure 2

Workflow of the study

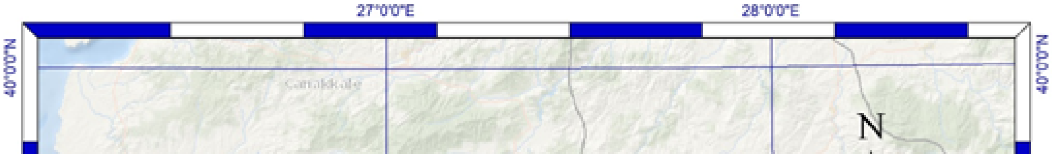

Figure 3

Lanslide inventory map

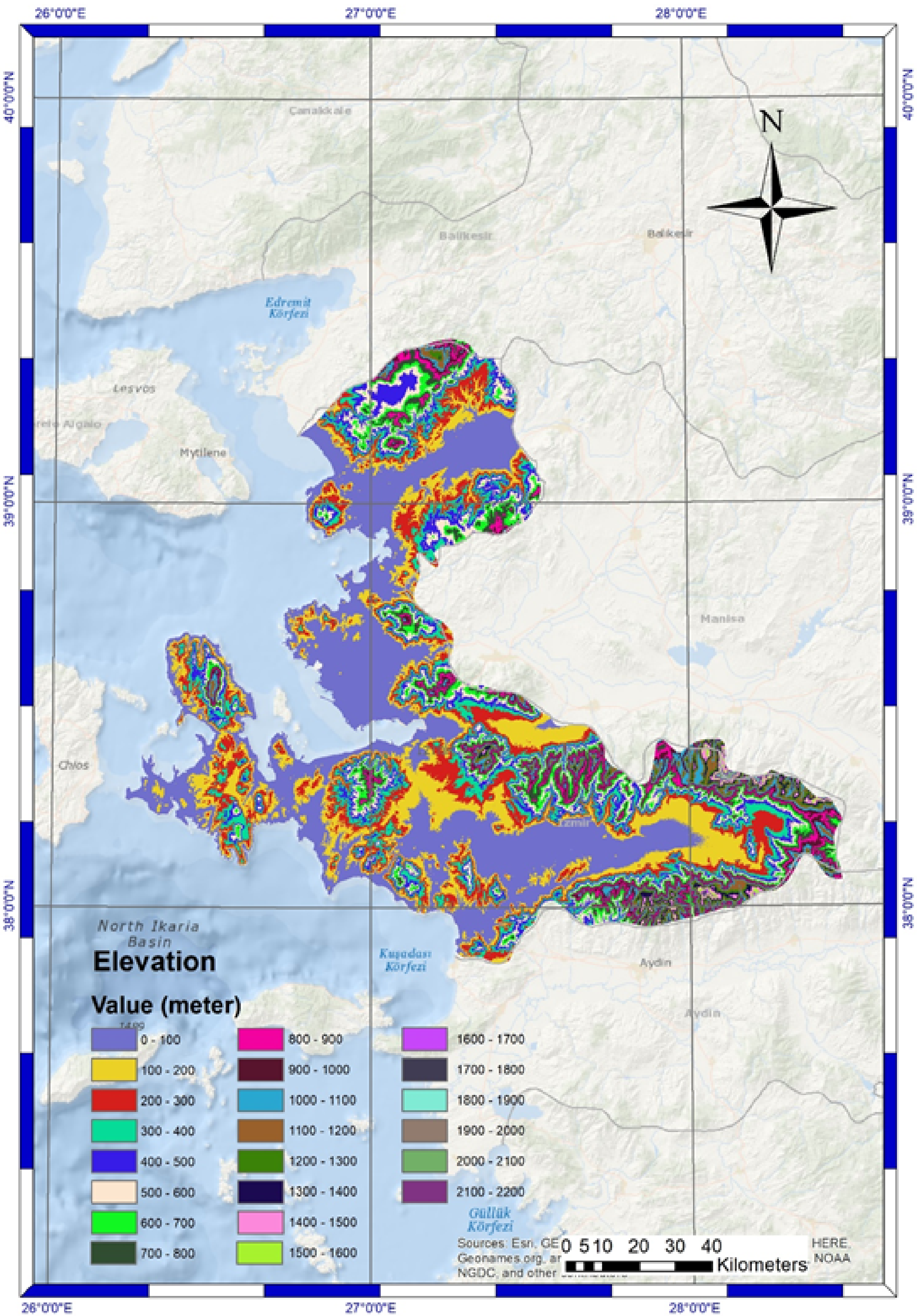

Figure 4

Elevation map

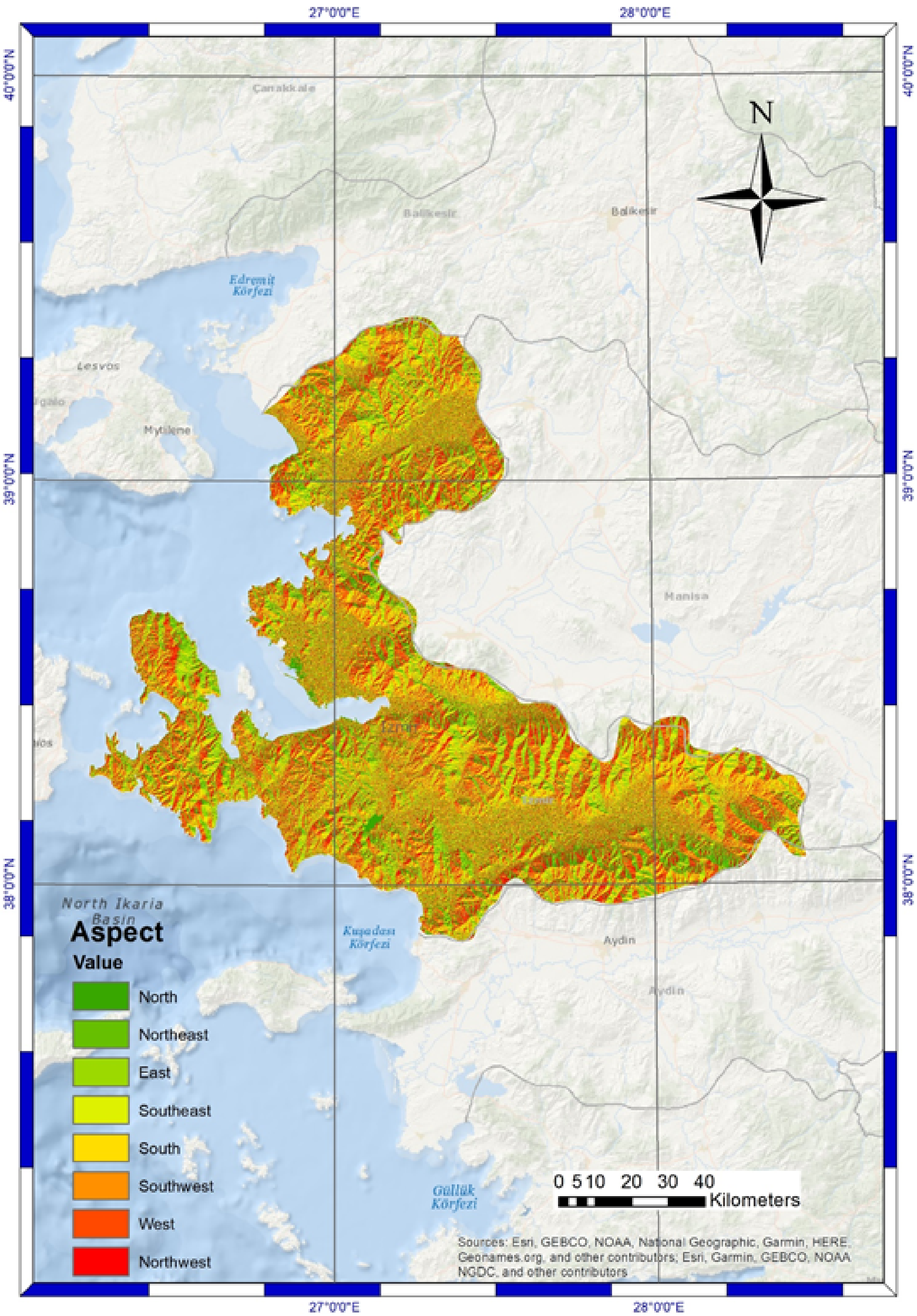

Figure 5

Aspect map

Figure 6

Slope map

Figure 7

Curvature map

Figure 8

Land use map

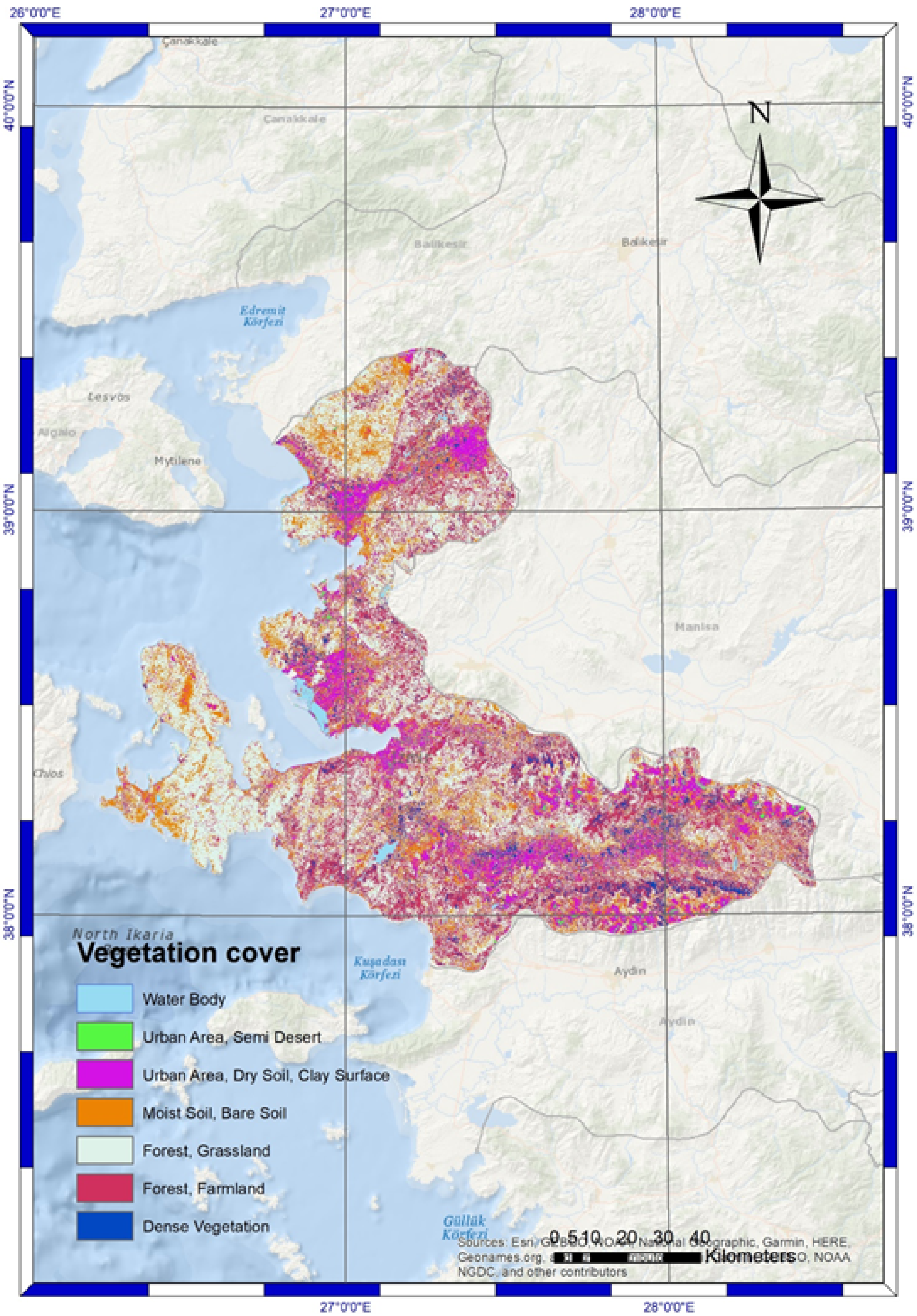

Figure 9

Vegetation cover map

Figure 10

Lithology map

Figure 11

Distance to roads map

Figure 12

Distance to rivers map

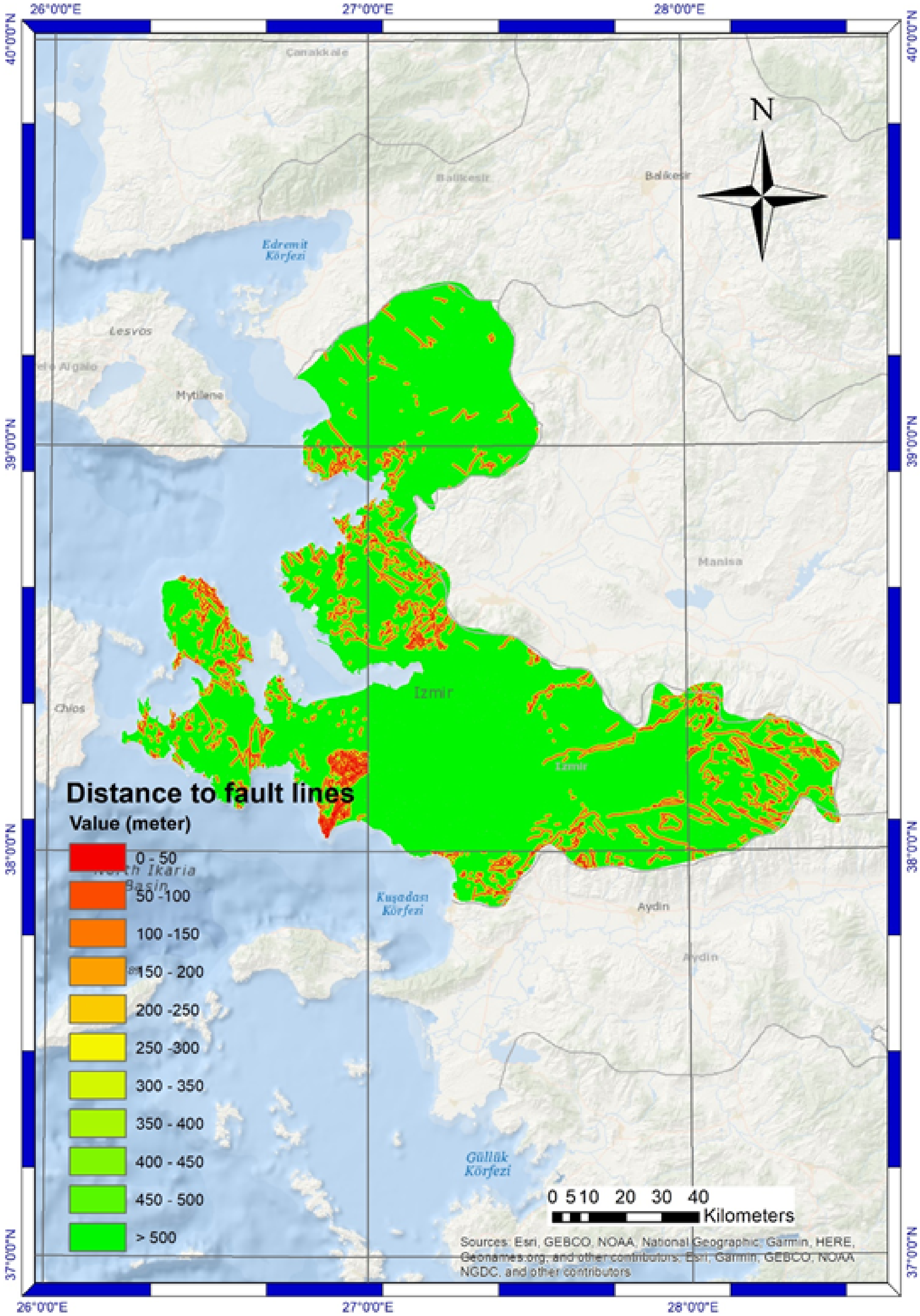

Figure 13

Distance to fault lines map

Figure 14

Karaburun Peninsula landslide susceptibility map developed with FR method

Figure 15

ROC curves for landslide susceptibility map