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RESEARCH ARTICLE

GIS-BASED LANDSLIDE SUSCEPTIBILITY MAPPING BY ANALYTICAL HIERARCHY PROCESS: A CASE STUDY, BURDUR PROVINCE

[1]Kerem Hepdeniz and *[2]İbrahim İskender Soyaslan

[1]Mehmet Akif Ersoy University Bucak EG Technical Sciences and Vocational School of Higher Education, Department of Architecture and Urban Planning, Burdur, Turkey
[2]Mehmet Akif Ersoy University, Faculty of Engineering and Architecture, Civil Engineering Department, Burdur, Turkey

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ABSTRACT

The creation of landslide susceptibility maps is a critical step in helping organizers, local authorities, and policy makers with disaster planning. As such, the reliability of these landslide susceptibility maps is essential for decreasing loss of life and property. Increasing populations and settlements in sloped areas have generally enhanced the effect of landslides. In this study, a geographic information system and analytical hierarchy process were used to determine landslide susceptibility zones in Burdur province. For this purpose, ten parameters; distance to fault, wetness index, slope aspect, distance to stream, rainfall, distance to road, curvature, land cover, slope gradient and lithology were selected as conditioning factors associated with active landslides. The results of this study indicate that 11.63% of the investigation area has a high susceptibility and 1.57% has a very high susceptibility. The findings of this study are important for long-term land use planning, emergency decisions, minimization of potential landslide hazards, and saving lives.

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INTRODUCTION

A landslide, defined as the movement of a mass of rock, debris, or earth down a slope (Cruden, 1991), is a destructive natural disaster that affects a large number of people and has a negative effect on settlements, stream drainage, transportation, agriculture, forest land, and water resources. In the last 50 years, 13.494 landslides occurred in Turkey, where they are the second most frequent natural disaster, after earthquakes, and result in significant loss of life and property (Ercanoglu *et al.,* 2008; AFAD, 2015). In order to mitigate and control the problems caused by landslides, inventory mapping, susceptibility mapping, hazard mapping, and risk assessment have to be undertaken (Upreti and Dhital, 1996). These studies are also very important for future projects such as urban development and regional land-use planning projects (Ercanoglu *et al.,* 2008). However, there are no standard procedures in place for evaluating landslide susceptibility or landslide hazard and risk (Kayastha *et al.,* 2013). Many researchers have used different techniques, such as pair wise comparison (Westen, 1993; Süzen and Doyuran, 2004; Chaudhary), frequency ratio (Lee and Talip,2005; Yalcin *et al.,* 2011; Choi *et al.,* 2012; Mohammady *et al.,* 2012; Ozdemir and Altural, 2013; Hong *et al.,* 2015), logistic regression (Ohlmacher and Davis, 2003; Lee *et al.,* 2007; Bai *et al.,* 2010; Mancini *et al.,* 2010; Pradhan, 2010; Wang *et al.,* 2013; Shahabi *et al.,* 2014; Trigila *et al.,* 2015; Patriche *et al.,* 2016; Chen *et al.,* 2017), and fuzzy logic–artificial neural network (Ercanoglu and Gokceoglu, 2002; Pistocchi *et al.,* 2002; Oh and Pradhan, 2011; Ilanloo, 2011; Barrile *et al.,* 2016) to assess landslide susceptibility. In this study, geographic information system (GIS) techniques were combined with analytical hierarchy process (AHP), developed by Saaty (1980) (Saaty, 1980), to obtain a landslide susceptibility map for a landslide-prone area in Burdur province, Turkey, using distance to fault, wetness index, aspect, distance to stream, rainfall, distance to road, curvature, land cover, slope, and litho logy criteria.

Corresponding author:* **İbrahim İskender Soyaslan,
Mehmet Akif Ersoy University, Faculty of Engineering and Architecture, Civil Engineering Department, Burdur, Turkey.

MATERIALS AND METHODS

The study area is located between 36.53° and 37.50° north latitude and 29.24° and 30.53° east longitude (Figure 1). The average topographic elevation is about 1000 m; Koçaş Mountain, at an altitude of 2598 m, is the highest point in

Burdur province. The area of Burdur province is 6887 km^2, and it has many lakes. The topography of the province is very rough and mountainous. Approximately 5% of the study area has a slope angle greater than 40°. The soils are generally clayey and calcareous.

AHP was used to obtain standardised weights for the different layers, and the landslide susceptibility maps were generated by GIS techniques such as interpolation, buffer zone, and raster calculator. A summary flowchart of the methodological approach is provided in Figure 2.

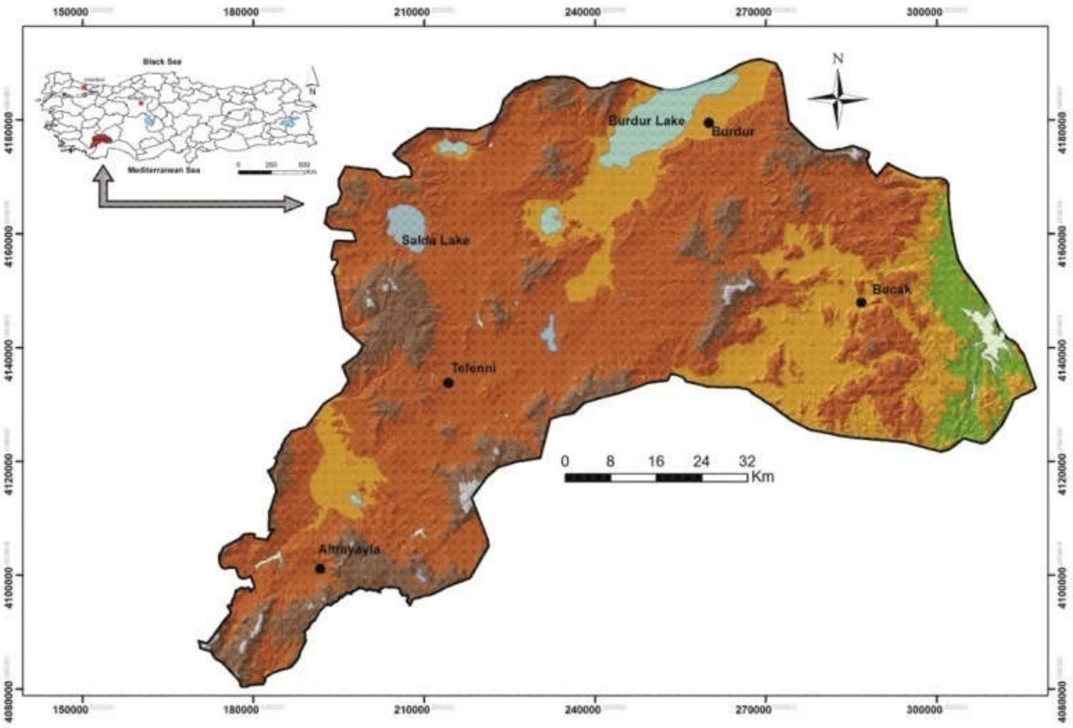

Figure 1. Location map of the study area

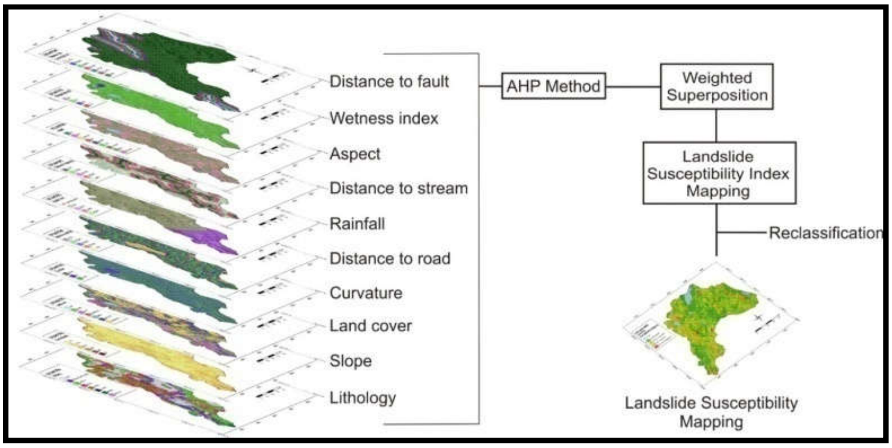

Figure 2. Generalized flow chart of the methodology employed in the study

A continental climate is dominant, and winters are generally harsh, while summers are arid and warm. Average monthly temperatures vary from 2.5°C to 24.3°C; July is the warmest month and January is the coldest. Annual rainfall varies from 398 mm to 804 mm; August is the driest month, with 8 mm of rainfall, and December is the rainiest, with 63 mm between 1926 and 2016 years (MGM, 2015). In this study, Digital Elevation Model (DEM), acquired from Aster–GDEM and with a resolution of 30 m, was used. Slope, aspect, and curvature maps were generated from DEM. Roads and streams were digitised from scanned 1/25.000scale topographical maps. Lithology, active fault, and land use maps were obtained from the Mineral Research and Exploration General Directorate (MTA) (1997). All digitised vector maps were converted to a raster format using Arc GIS 10 software.

AHP is one of the most simple methods of multi-criteria decision analysis (Saaty, 1980), such as site selection, regional planning, suitability analysis and landslide susceptibility analysis (Shahabi *et al.,* 2014). Decomposition, comparative judgement, and synthesis of priorities are the three principles of the method (Malczewski and Rinner, 2015). The pair wise comparison is the basic measurement made in the context of the AHP procedure, using a scale from 1/9 to 9, where 9 is the most important and 1/9 is the least important (Saaty, 1977). By this techniques, each parameter which is important for landslide susceptibility maps were organized into a matrix (Table 1). One of the strengths of the pair wise comparison method is that it allows the determination of rating inconsistencies by the consistency index (CI), which is related to the eigenvalue method:

$$CI = \frac{\lambda max - n}{n-1} \quad ....(1)$$

Where λ_{max} is the maximal eigenvalue and n is the order of the comparison matrix. The consistency ratio (CR), which is the ratio of CI and RI, is given by

$$CR = \frac{CI}{RI} \quad ....(2)$$

Where RI is the average random consistency index, calculated by Saaty (1977) (34), shown in Table 2.

In this research, RI10= 1.49 because of using 10 criteria. A CR<0.10 indicates a reasonable level of consistency in the pairwise comparisons. However, if CR >0.10, the ratio is indicative of inconsistent judgements.[33]. (Table 3). The eigenvectors of each matrix (Table 4) landslide susceptibility index (LSI) were calculated by a procedure based on the weighted linear sum:

$$LSI = \sum_{p=1}^{n} Wj\ Wij \quad ....(3)$$

where Wj = weight value of causative factor, Wij = weight value of class i of causative factor j, and n = the number of causative factors.

Table 1. Pairwise comparison matrix and significance weight of the landslide causative factors (continues)

Distance to roads									
[1] 0-1000	1								0,564
[2] 1000-2000	1/4	1							0,186
[3] 2000-3000	1/5	1/3	1						0,108
[4] 3000-4000	1/6	1/4	1/2	1					0,080
[5] >4000	1/7	1/5	1/3	1/2	1				0,062
Curvature									
[1] Concave	1								0,690
[2] Flat	1/9	1							0,067
[3] Convex	1/3	6	1						0,243
Land cover									
[1] Forest	1								0,157
[2] Cultivated area	1	1							0,157
[3] Settled	1/7	1/7	1						0,038
[4] Meadow	3	3	8	1					0,454
[5] Sparse vegetation	1	1	6	1/4	1				0,135
[6] Irrigation area	1/4	1/4	3	1/6	1/3	1			0,059
Slope									
[1] 0-10	1								0,036
[2] 10-20	2	1							0,049
[3] 20-30	4	3	1						0,097
[4] 30-40	6	4	2	1					0,146
[5] 40-50	8	6	3	2	1				0,244
[6] >50	9	7	4	3	2	1			0,428
Geology									
[1] Alluvial deposits	1								0,040
[2] Pebble stone-sandstone	8	1							0,468
[3] Limestone	7	1/4	1						0,175
[4] Melange	6	1/5	1/3	1					0,109
[5] Peridotite	3	1/6	1/4	1/3	1				0,067
[6] Travertine	1	1/9	1/7	1/6	1/3	1			0,037
[7] Volcanic sediment	1	1/9	1/7	1/6	1/3	1	1		0.037
[8] Talus	**3**	**1/6**	**1/4**	**1/3**	**1**	**3**	**3**	**1**	**0,067**

Table 2. Random consistency index

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14
RI	**0**	**0**	**0,58**	**0,90**	**1,12**	**1,24**	**1,32**	**1,41**	**1,45**	**1,49**	**1,51**	**1,53**	**1,56**	**1,57**

Table 3. Causative factors

Causative factors	N	Λ_{max}	CI	CR	RI
All	10	11.2110	0.13455	0.08911	1.49
Distance to fault	7	7.47673	0.07945	0.06019	1.32
Wetness index	4	4.26315	0.08771	0.09746	0.90
Aspect	9	9.63846	0.07980	0.05504	1.45
Distance to streams	5	5.12289	0.03072	0.02743	1.12
Distance to roads	5	5.33475	0.08368	0.07472	1.12
Curvature	3	3.08243	0.04121	0.07106	0.58
Land cover	6	6.24347	0.04869	0.03927	1.24
Slope	**6**	**6.16087**	**0.03217**	**0.02594**	**1.24**
Geology	**8**	**8.71887**	**0.10269**	**0.07283**	**1.41**

Table 4. Total weights of the subcriteria

Criteria (C)	Subcriteria (Sc)	Weight (Cwi)	Sunweight (SCwi)	Total weight (Twi)
Distance to fault	0-1000	0,026	0,211	0,005486
	1000-2000		0,135	0,003510
	2000-3000		0,073	0,001898
	3000-4000		0,059	0,001534
	4000-5000		0,057	0,001482
	5000-6000		0,036	0,000936
	>6000		0,429	0,011154
Wetness Index	0-5	0,034	0,07	0,002380
	5-10		0,096	0,003264
	10-15		0,23	0,007820
	15-20		0,604	0,020536
Aspect	Flat	0,031	0,036	0,001116
	North		0,062	0,001922
	Northeast		0,031	0,000961
	East		0,057	0,001767
	Southeast		0,03	0,000930
	South		0,041	0,001271
	Southwest		0,293	0,009083
	West		0,292	0,009052
	Northwest		0,158	0,004898
Distance to stream	0-1000	0,024	0,518	0,012432
	1000-2000		0,203	0,004872
	2000-3000		0,129	0,003096
	3000-4000		0,09	0,002160
	>4000		0,060	0,001440
Rainfall	0-500	0,05	0,078	0,003900
	500-550		0,133	0,006650
	550-600		0,267	0,013350
	600-650		0,522	0,026100
Distance to road	0-1000	0,055	0,564	0,031020
	1000-2000		0,186	0,010230
	2000-3000		0,108	0,005940
	3000-4000		0,08	0,004400
	>4000		0,062	0,003410
Curvature	Convex	0,085	0,69	0,058650
	Flat		0,067	0,005695
	Concave		0,243	0,020655
Land cover	Forest	0,187	0,157	0,029359
	Cultivated area		0,157	0,029359
	Settled		0,038	0,007106
	Meadow		0,454	0,084898
	Barren land		0,135	0,025245
	Irrigated area		0,059	0,011033
Slope	0-10	0,187	0,036	0,006732
	10-20		0,049	0,009163
	20-30		0,097	0,018139
	30-40		0,146	0,027302
	40-50		0,244	0,045628
	>50		0,428	0,080036
Lithology	Alluvion	0,321	0,04	0,012840
	Pebble-Sandstone-Mudstone		0,468	0,150228
	Limestone		0,175	0,056175
	Melange		0,109	0,034989
	Peridotite		0,067	0,021507
	Travertine		0,037	0,011877
	Volcanite		0,037	0,011877
	Slope wash		0,067	0,021507

Landslide conditioning factors

There are no general rules regarding the selection of factors in landslide susceptibility mapping (Ayalew and Yamagishi, 2005). The nature of the location area determines the selection of landslide-causing parameters, and these parameters are incorporated to enhance the accuracy and reliability of the susceptibility mapping method (Shahabi *et al.,* 2014; Dragicevic *et al.,* 2015). Ten possible landslide causing layers; distance to fault, wetness index, aspect, distance to streams, rainfall, distance to roads, curvature, land cover, slope, and lithologywere analyzed for landslide susceptibility mapping. *Distance to Fault;* Faults are the weakness zones of the earth's surface, and they are important factors in landslide susceptibility mapping (Esmaeil *et al.,* 2014).

During an earthquake, lateral and vertical forces unbalance the stability of slopes and cause landslides; as a result, landslide probability increases closer to a lineament (Lee and Evangelista, 2006; Owen *et al.,* 2008; Moore *et al.,* 1988). Burdur is located on the first degree earthquake zone and active fault maps were obtained from the Mineral Research and Exploration General Directorate (MTA) (1997). In this study, faults were buffered in seven different zones, and each zone was weighted by AHP (Figure 3a). *Topographic Wetness Index;* Topographic wetness index, also known as compound topographic index (Moore *et al.,* 1998), is one of the most important factors in landslide susceptibility mapping. It combines local upslope contribution area and slope and it is calculated using the expression

$$W=\ln (As/\tan b) \quad ....(4)$$

where W is the wetness index, As is the specific catchment area, and b is slope angle (Ercanoglu *et al.,* 2008). Topographic wetness index is generally used as a part of shallow landslide susceptibility mapping; areas with high index values indicate greater potential susceptibility of landslide (Figure 3b). *Aspect;* Aspect has a forced effect in a landslide event and determines parameters such as exposure to solar radiation, drying winds, and rainfall. Thus, it has an indirect effect on vegetation to grow, which in turn affects soil stability. In this study, DEM was used to generate aspect values and then reclassify them into nine categories: flat (-1), north (0°–22.5°, 337.5°–360°), northeast (22.5°–67.5°), east (67.5°–112.5°), southeast (112.5°–157.5°), south (157.5°–202.5°), southwest (202.5°–247.5°), west (247.5°–292.5°), and northwest (292.5°–337.5°) (Figure 3c).

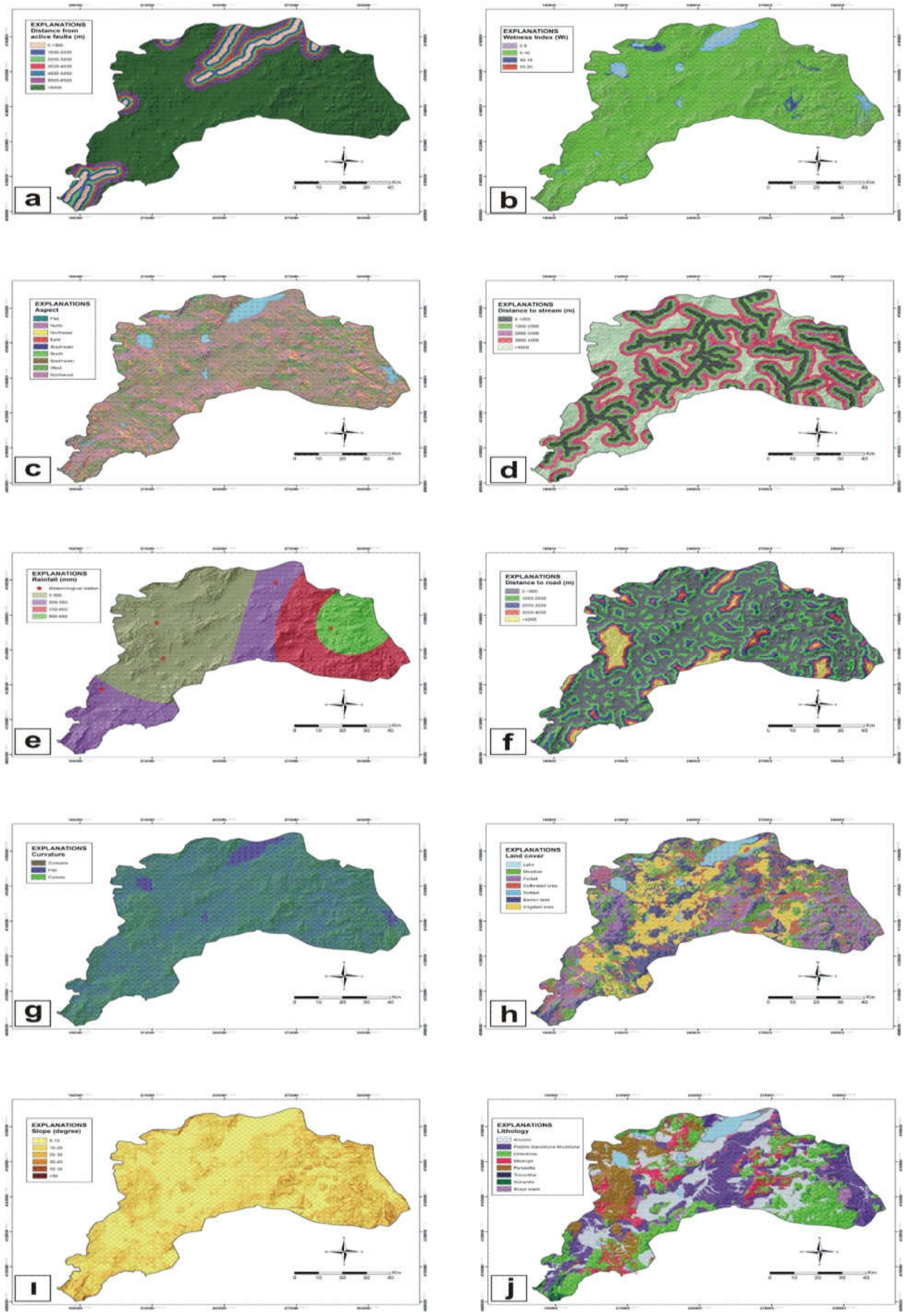

Figure 3. Parameter maps used in the study: a) distance to fault, b) topographic wetness index, c) aspect, d) distance to streams, e) rainfall, f) distance to road, g) curvature, h) land cover, i) slope, j) lithology

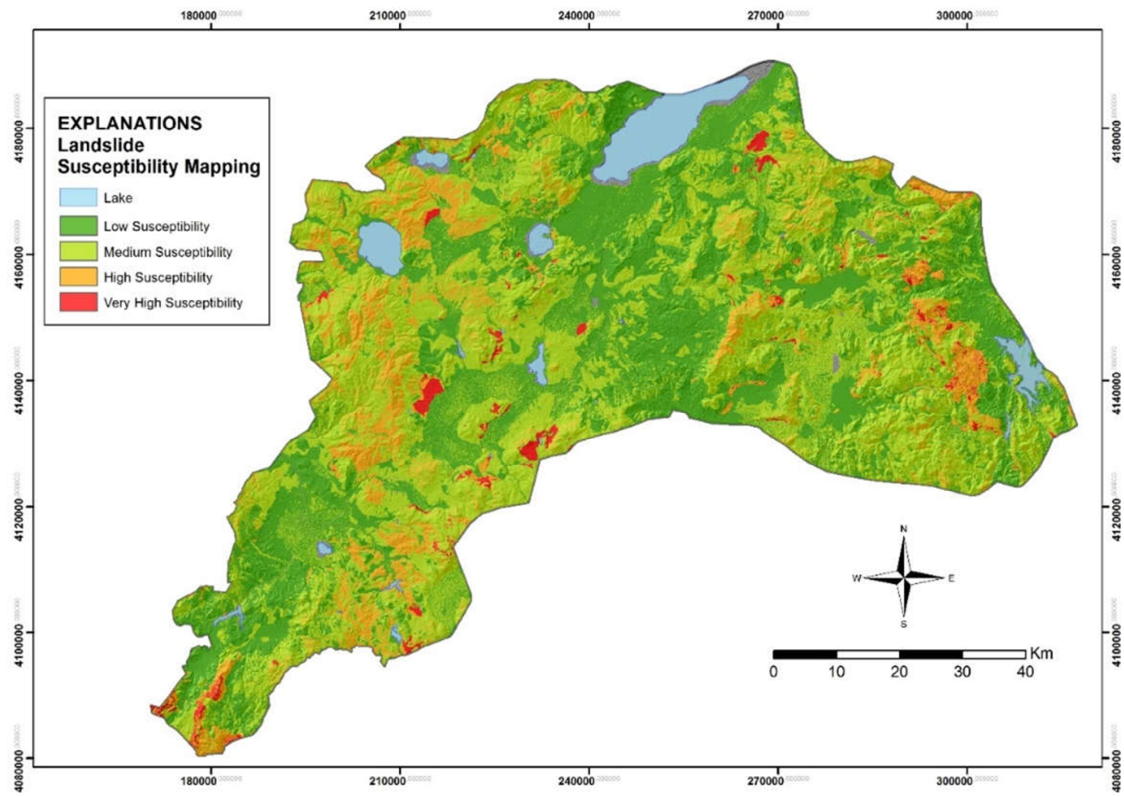

Figure 4. Landslide susceptibility map of Burdur province

Distance to Streams: Drainage density is an additional conditioning factor connected with landslide formation. Surface changes induced by stream erosion and the undercutting of slope toes can affect landslide initiation. The proximity of the slope in relation to streams can negatively affect the stability of the slope. In this study, five different buffer zones were created: 0–1000 m, 1000–2000 m, 2000–3000 m, 3000–4000 m, and >4000m (Figure 3d). *Rainfall;* Most landslides occur following sudden, intense rain and snow melt; increases the degree of saturation, underground hydrostatic level, and water pressure, which increases the potential for landslide occurrence. Annual total precipitation from 1950 to 2014 observed in six meteorological stations located within the research area were used to make a precipitation map, including four categories (Figure 3e).

Distance to Road: Landslides can occur on the sides of slopes intersected by roads (Yalcin *et al.,* 2011). The slope might normally be steady, but the roads might change the dynamics of the topography and reduce the load on the heel of slope, thus destabilising it. In addition, frequency vibrations produced by vehicles can cause landslides. In this study, a distance to road map was created with five different buffer zones at 1000 m intervals, in order to determine the effect of the road on the stability of the slope (Figure 3f). *Curvature;* Curvature represents the morphology and is parallel to the direction of the highest slope (Kayastha *et al.,* 2013). A negative value represents convex, a positive value represents concave, and a value of zero indicates that the surface is linear. Curvature has an effect on the acceleration or deceleration of flow over the surface, and convex slopes can lead to more erosion because of the acceleration of the fluid. The study area was classified as convex, concave, and flat as shown in Figure 3g. *Land Cover;* The effect of land cover in slope stability is one of the most important factors, and it has been studied since the 1960s. Human implementation of the land could play an important role in the occurrence of landslides as land cover absorbs the water of the terrain and reduces the potential for landslide. The land use maps in this study were obtained from MTA (1992), and six different land cover classes were described (Figure 3h). *Slope;* Slope is the main parameter that affects landslide occurrence, and thus, it is widely used in landslide susceptibility analysis. In this study, a slope gradient map was obtained from DEM and divided into six different classes: 0°–10°, 10°–20°, 20°–30°, 30°–40°, 40°–50°, and >50°. Almost 35% of the study area consists of slopes in the 0–10° range, and 28% consists of slopes in the 30–40° range. Less than 1% of the study area has a slope angle >50° (Figure 3i). *Lithology;* This parameter has been regarded as the most crucial factor in landslide susceptibility, and thus, it was assigned the highest weight value among the parameters (Table 5). Numerous studies (Kayastha *et al.,* 2013; Shahabi *et al.,* 2014) (Kayastha *et al.,* 2013, Song *et al.,* 2012, Shababi *et al.,* 2014) have used lithology as an input parameter to designate landslide susceptibility. Eight litho logical units were determined in the study area, which was digitised from 1/100000-scale geological maps from MTA (1997) (Figure 3j).

Analysis of landslide susceptibility

In the AHP method, each layer is divided into smaller factors and these factors are composed according to their importance. Each factor is valued between 1 and 9 in comparison with other factors. The preference values for the study are given in Table 1. A significant advantage provided by AHP is, it can determine the rating inconsistencies by the consistency index (CI). As seen in table 3, all obtained CR values are less than 0.10, which is considered the highest value (34). The values given in the last column of Table 1, yield weight values for each causative factor. These weight values indicate the degree of importance of the factor or class.

According to the results, lithology had the highest value, 0.321; followed by land cover and slope, which were of equal importance with a value of 0.187. Distance to streams (0.024) and distance to fault (0.026) had the lowest values among the criteria. Finally, landslide susceptibility index (LSI) was calculated by a procedure based on the weighted linear sum. The overlay analysis method was then used to generate landslide susceptibility maps in Arc GIS Spatial Analyst, classifying areas into four categories of different landslide susceptibility zones: low, medium, high, and very high. The susceptibility map shows that 38.28% (2679 km^2) of the area has low susceptibility, 48.52% (3395 km^2) has medium susceptibility, 11.63% (815 km^2) has high susceptibility, and 1.57% (110 km^2) has very high susceptibility (Figure 4). It was noted that the very high landslide susceptibility areas are located mainly in the east side of Burdur province, in Bucak County, and around the towns of Tefenni and Karamanlı. According to the resulting map; slope wash, high slope and northward facing slopes are the areas where landslide formation is most common.

Conclusions

As with other natural disasters, it is not easy to estimate where and when a landslide will occur. GIS combined with AHP is an effective technique for identifying landslide hazard zones. This method was implemented in Burdur province with a 30m cell size. In this study, ten criteria—distance to fault, wetness index, aspect, distance to stream, precipitation, distance to road, curvature, land cover, slope, and lithology—were considered and mapped using the GIS techniques of buffer zoning, overlay analysis, and interpolation. According to pair wise comparisons, lithology, land cover, and slope were weighted the highest in influencing landslides. Ultimately, landslide susceptibility zones were determined and classified from low to very high. According to this study, 11.63% (815 km^2) of the investigation area has high susceptibility and 1.57% (110 km^2) has very high susceptibility. This type of preliminary study and comprehensive feasibility analysis of the determined area can be helpful for planners, engineers, and policy makers in mitigating damage risks, planning disaster management, avoiding risk areas when building cities, and building retaining walls in appropriate zones.

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