International Journal of the Physical Sciences Vol. 6(5), pp. 1015-1025, 4 March, 2011
Available online at http://www.academicjournals.org/IJPS
DOI: 10.5897/IJPS11.133
ISSN 1992 - 1950 ©2011 Academic Journals

Full Length Research Paper

Production of landslide susceptibility map of Samsun (Turkey) City Center by using frequency ratio method

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Accepted 21 February, 2011

Due to the increased need for housing, Samsun province center had been quickly opened for construction in the last 25 years; because of the rapid population growth, construction facilities have progressed towards the southern hillside of the city. Large amount of landslides had been observed and classified in this region by the relevant institutions. To prevent life and property losses, it is required to evaluate past landslides and thus, to determine the probable landslide areas in the construction regions. Therefore, this study aims to create a landslide susceptibility map of Samsun province center. Frequency ratio method which is widely used in the literature has been used to create the landslide susceptibility map. Some characteristic properties of the region such as the geological formation, altitude, slope, aspect, curvature, plan and profile curvature, distance from roads and streams have been considered for the landslide susceptibility evaluation.

Key words: GIS, Landslide, susceptibility map, frequency ratio method.

INTRODUCTION

Disaster is defined as "a situation or an event which overwhelms local capacity, necessitating a request to a national or international level for external assistance; an unforeseen and often sudden event that causes great damage, destruction and human suffering" (Vos et al., 2010). Disasters are events that cause physical, economic, and social losses for people. For example, in 2009, 335 natural disasters were reported worldwide. They killed 10655 persons, affected more than 119 million others and caused over US$ 41.3 billion economic damages (Vos et al., 2010). The Centre for Research on the Epidemiology of Disasters (CRED), with the sponsorship of the United States Agency for International Development's Office of Foreign Disaster Assistance (USAID/OFDA), has maintained EM-DAT, a worldwide database on disasters since 1988. It contains essential core data on the occurrence and impacts of more than 18000 disasters in the world dating from 1900 to the present (Vos et al., 2010). EM-DAT distinguishes two generic categories for disasters (natural and technological), the natural disasters category is divided into 5 subgroups, which in turn cover 12 disaster types and more than 30 sub-types (Figure 1). Starting from this classification, we can define natural disasters as a "results of biological, meteorological, hydrological, climatologic and geophysical based events which are unpredictable and cannot be prevented.

In addition to earthquakes, floods and storms, landslides are also one of the most commonly experienced natural disasters in the world. In the world, floods constitute 45% of the natural disasters which have occurred in the first half of the year 2010, storms constitute 19%, landslides (mass movements) 10%, drought 9%, earth-quake 7%, extreme temperature 7%, volcano 2% and wildfire constitutes 1% of them (CRED, 2010). Most of the time, landslides bring about large-scale socio-economic destructions such as casualties, economic damages, environmental impacts, the loss of cultural and natural heritage etc. In February 2010, massive mudslides on Portugal's Atlantic island of Madeira (located approximately 900 km southeast of Portugal) have killed 38 people (Assilzadeh et al., 2010). 388

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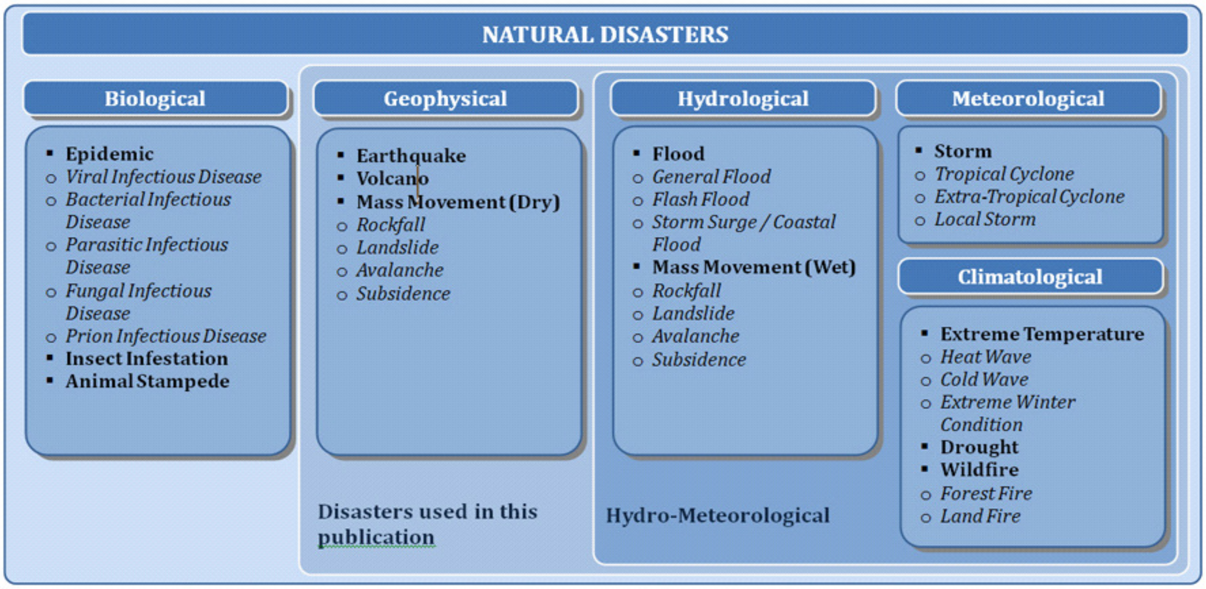

Figure 1. Classification of natural disasters (Vos et al., 2010).

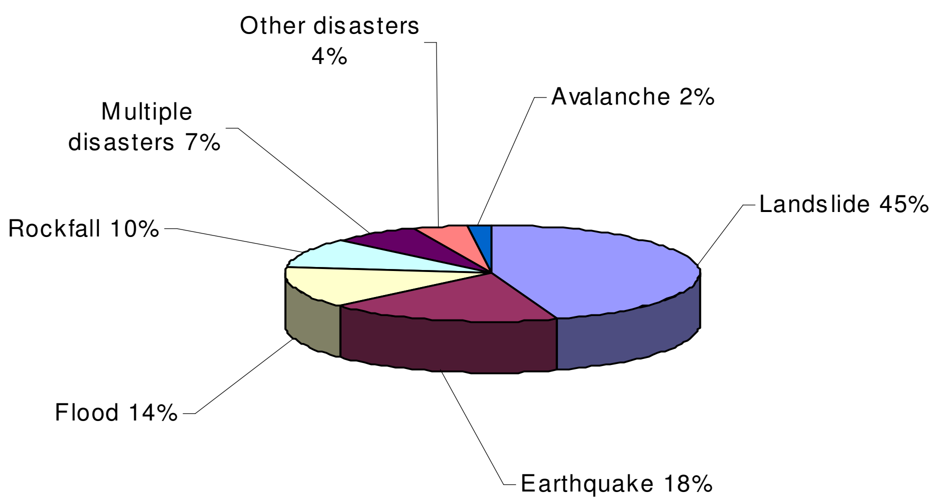

Figure 2. The distribution of disaster events by type in Turkey (Gökçe et al., 2008).

people had lost their lives in the landslide that occurred in the Bududa region of Uganda in March 2010 (CRED, 2010). More recently, over 1500 people have been evacuated from Pemberton, BC, Canada due to an August 6, 2010 landslide that blocked Meager Creek. In August 2010, floods and landslides across Asia have killed hundreds (Assilzadeh et al., 2010).

Landslides are one of the foremost natural disasters that cause loss of life and property in Turkey, as well as in all other parts of the world. If the natural disasters that have occurred in the last 50 years in our country are analyzed, one can observe that landslides with the ratio of 45% are the most frequent natural disasters (Figure 2). In a past evaluation conducted for the landslide disaster, it is seen that almost all of the provinces have been affected from landslides to a certain extent (Gökçe et al., 2008). The destructive effect of landslides tragically has manifested itself lastly on 26 August 2010. 13 people had lost their lives as a result of a landslide that was brought about by downpours in Gündoğdu City in the province Rize. Samsun is one of the foremost provinces, in which landslides often take place, in Turkey. After we had analyzed the data that were obtained from the Directorate of Public Works and Settlement of Samsun, we saw that a total of 219 landslide incidents have occurred in the last 25 years throughout Samsun. 61 of those landslides have occurred in the city center of Samsun.

In a past study held in Samsun and had been performed to find the distribution of damage and for microzonation of the landslides, city center had been grouped into three areas: 1) dangerous areas for construction (where the current buildings must be evacuated), 2) unfavorable areas for construction (where the current constructions must be frozen) and 3) the favorable areas, where new construction facilities can be permitted under certain conditions (Doyuran et al., 1985). Furthermore, there had been excavations during the constructions about 40 to 50 years ago, and the extracted soil had been spilled into the city center in a haphazard manner. This spilled soil has caused the landslides to occur especially on the slanted areas. These areas had also been classified as potentially unfavorable areas for construction. However, in the last 25 years, construction facilities have been developing along these unfavorable areas such as Atakum seaboard and southern ridges, the Mert River and the southern part of the Kürtün River, where landslide events mostly occur in.

Furthermore, these areas had been permitted for housing up to 15 floors. Again, a new boulevard had been constructed along the route from Old Samsun Airport to the Hospital of Thoracic Diseases, this route and its surroundings have been classified as unfavorable areas for construction by Doyuran (1985). Nevertheless, construction facilities had been increased rapidly in this region as well. In the same way, gas stations had been given license in the regions, which were marked on the landslide inventory map of General Directorate of Mineral Research and Exploration Institute as being potentially risky areas that may be exposed to slope movements. This situation especially draws the attention in the southeastern slopes of the Kürtün River.

When it is taken into account that landslides are one of the most significant natural disasters that lead to loss of life and property in our country and also that the rapid increment of the unfavorable constructions, re-evaluation of the landslides in Samsun City center is a strong necessity to prevent the potential losses by precautions to be taken before the occurrence of the landslides. Social and economic losses that are caused by landslides can be minimized by an effective planning and management. These are the realities which have started this current study for the re-evaluation of the landslides in Samsun. In general, for landslide evaluation tasks, different types of maps that contain different information are prepared by conducting field and laboratory studies for the geological and the geotechnical purposes. These maps are used for various tasks such as choosing settlement areas, infrastructure works, the construction facilities of other engineering structures etc. In this context, landslide susceptibility maps are one of the most significant geology-based maps. In this study, a landslide susceptibility map of Samsun City center has been developed. The main goal of landslide susceptibility analysis is to minimize the side effects of the landslides by determining hazardous and perilous areas. Natural hazard maps contain information about the formations of the natural disasters such as landslides, floods, earthquakes and volcanic eruptions which had been lived in the past and contain future predictions estimated from the past events (Varnes, 1984; Yalçin, 2007; Reis et al., 2009).

Various methods and techniques such as frequency ratio, logistic regression, spatial regression, geographically weighted regression, and analytical hierachy process, ordered weighted averaging, fuzzy logic and artificial neural networks are used for the production of landslide susceptibility maps by using Geographical Information Systems (GIS). The frequency ratio method is one of the methods that are commonly used in the literature (Lee and Evangelista, 2005; Lee and Tu Dan, 2005; Lee and Pradhan, 2006; Lee and Sambath, 2006; Lee and Pradhan, 2007; Yilmaz, 2007; Akgün et al., 2008; Yilmaz, 2009; Jadda et al., 2009; Reis et al., 2009; Erener and Düzgün, 2010). Landslide susceptibility map of Samsun City center was produced by using the frequency ratio method in this study as well, because the frequency ratio method has a simple and understandable probabilistic model with an acceptable accuracy (Jadda et al., 2009) and it is very easy to apply (Yilmaz, 2009). In practice, the parameters of slope, aspect, curvature, plan and profile curvature, lithology and proximity to roads and rivers have been taken into account.

STUDY AREA

Samsun City is cited on the coastal region between Kürtün and Mert Rivers (Figure 3). The city is developing as being parallel to the coastline in the east-west direction. The study area covers about 57 km^2 with the geographical coordinates between northern latitudes 41° 15' 5" and 41° 20' 37" and between eastern longitudes 36° 15' 46" and 36° 22' 30".

General geology of the study area

There are 5 different formations seen in the study area (Figure 4). According to the studies performed by the Turkish General Directorate of Mineral Research and Exploration Institute, the following units, from older to younger formations are seen in Samsun province (Öztekeşin, 2008).

Tekkeköy formation (Tt): Tekkeköy formation is the oldest volcanic unit in the region from Middle to Upper Eocene age and it crops out between Erikli fault and Black Sea region along the NE to SW direction. The formation is volcanic and volcano sedimentary sequence.

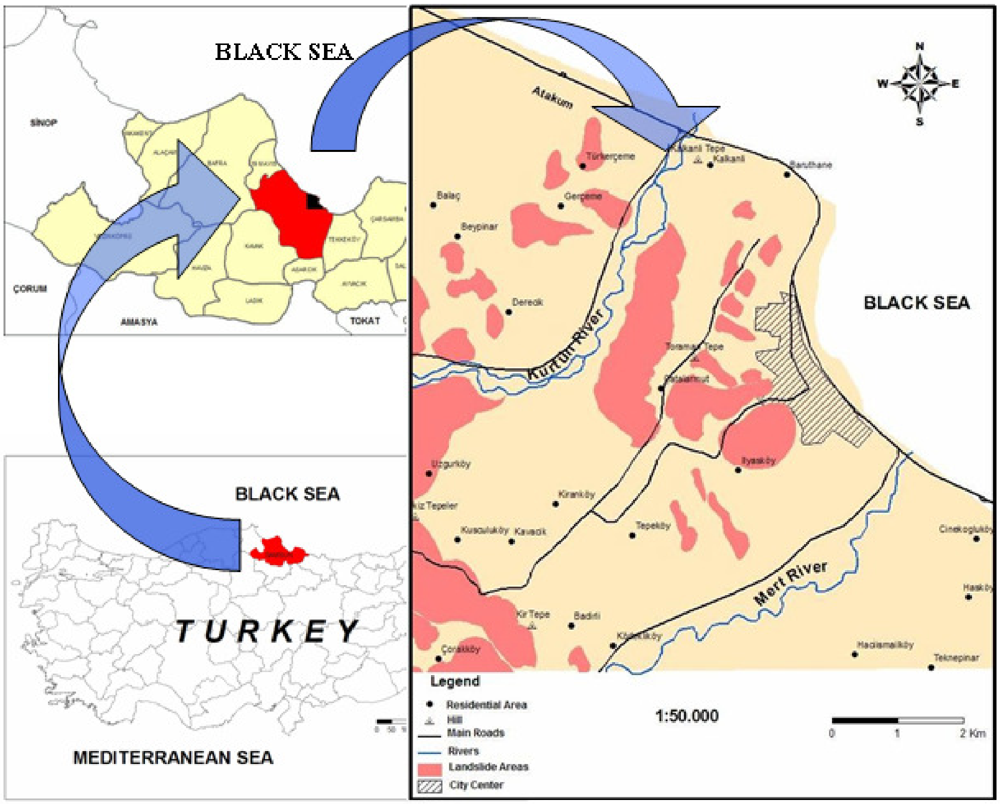

Figure 3. The location map of the study area.

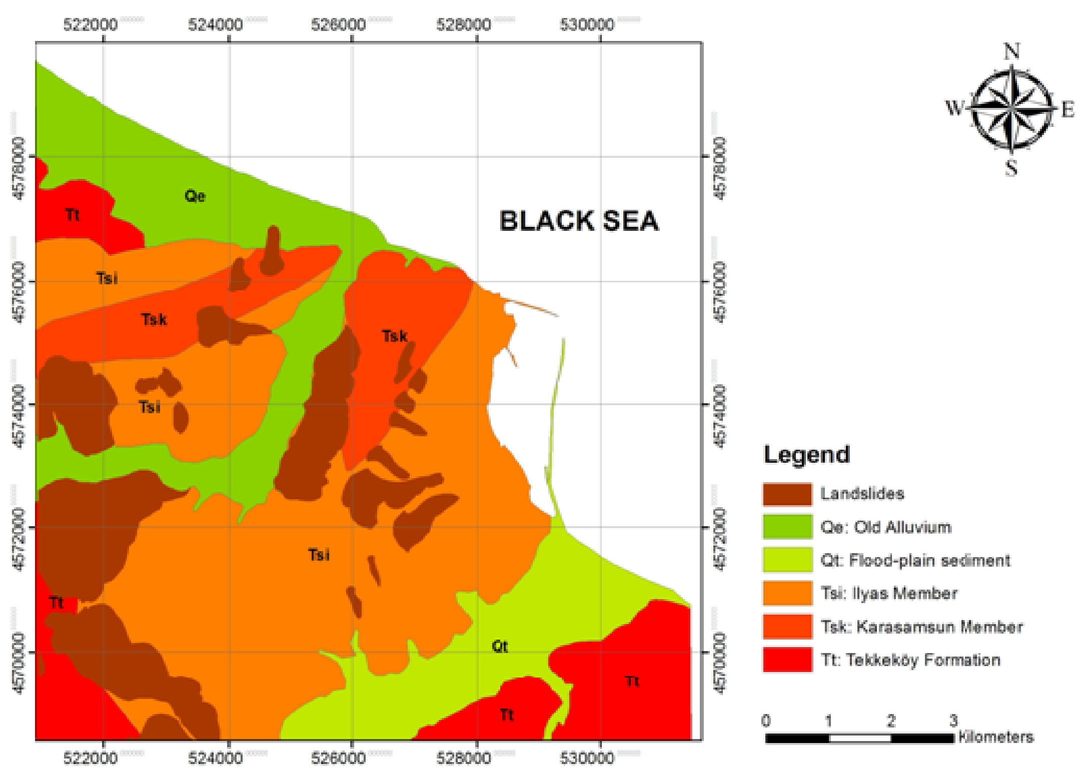

Figure 4. The geological map of the study area.

In the bottom, it consists of sandstone, marl, tuff interbedding, basalt and agglomerates. The formation is in the form of thin layers of sandstone and marl, and in the form of thick layer of tuff, at the lower levels of the bottom. There are 2 tuff layers with the thickness of about 20 to 25 m at the 200 m level of the unit. This sequence goes to upper levels with basalt, agglomerate and tuff figures. The agglomerates are formed by andesite, basalt, dacite, sandstone and blocks in a tuff matrix. The existence of basalt lavas and agglomerates at the upper levels shows that the medium is shoaling partly.

Samsun formation (Ts): The Samsun formation crops out the centre of Samsun City and is contained by the study area. In the bottom of the formation, it consists of grey-blue marls and is mainly marine originated. These lower levels have been given the name Ilyas member (Tsi). The formation contains sandstone, siltstone, marl, clay and gypsum in the transition zone and terrestrial conglomerate at the top. This part has given the name Karasamsun member (Tsk).

Ilyas member (Tsi): A simplified geological map of the study area is shown in Figure 4. This area is located between the main rivers Mert and Kürtün. The unit is formed in the lagoonal marine medium and consists of grey-blue marls, clay, sandstone, siltstone, pebblestone and gypsum. According to the fossil groups in the region, the age of the Ilyas member belongs to Upper Miocene to Lower Pliocene. The fossil groups contain *Globigerine praebulloides Blow*, *Giobigerinoides ruber* (*Dorbigny*), *Globigerinoides* sp., *Globigenina* sp., *Globigerinita* sp., *Pulleniatina* sp., *Amphistegina* sp., *Spiroloculina* sp., *Pyrgo* sp., *Lenticulina* sp., *Nodosaria* sp. (Doyuran, 1985). The thickness of the member is about 130 m.

Karasamsun member (Tsk): The age of Karasamsun member has been defined as Lower Pliocene age, since it has gradual transition with Ilyas member. The Karasamsun member is more resistant to erosion than the other members. It mostly crops out around Karasamsun Ridge, Kalkanli and Köydüzü Ridges, Karasamsun District, Çatalarmut Village and Toraman Hill. It was deposited in the stream medium, from terrestrial conglomerate which forms the topmost levels of the Samsun formation. The base of the unit is gradually transient with the transition level of the topmost parts of the Ilyas member. Alluvial deposits are seen over the base of the unit. The unit consists of sandstone, siltstone and marl with lenses, in places mid-tight attached and also well-cemented conglomerates. The conglomerate is mainly formed by andesite-basalt type volcanic, small amounts of limestone, sandstone and marl. In places, the thickness of cross-layered siltstone, sandstone and marl lenses are ranging from 5-10 mm to 1-2 m and their length varies between 1 to 20 m. The thickness of the member is about 70 m and gradually increases towards the Black Sea.

Old alluvium (Qe): It is deposited from coastal plains of Atakum and Kürtün River. The unit consists of silt and irregularly composed sand of marine shells in the coastal plains of Atakum, and sand, gravel and silt along the Kürtün River.

Flood-plain sediment (Qt): It consists of gravel along the Mert River and very fine tiny sand and silts. Its thickness ranges between 10 to 20 m.

Hydrogeology of the study area

The unit which shows the aquifer properties in the study area is alluvial features formed at the discharge areas of Mert and Kürtün Rivers and the areas at the Atakum coastal plain. There are several drilling works performed in the study area in different years for the works on drinking water resources. According to these works, the hydro-geological assessment of the study area can be summarized as follows, the alluvium thickness of Mert River is between 20 to 30 m, Kürtün River is between 18 to 20 m, and the thickness of the alluvium of the Atakum plain is between 17 to 24 m. Aquifers in the study area contain significant amounts of groundwater. Static levels of the groundwater are changing between 1.50 to 9.50 m (Öztekeşin, 2008).

According to the computations performed by the Regional Directorate of State Hydraulic Affairs, the following results had been obtained for the amount of groundwater reserves in the study area. The groundwater reserve of the alluvium of the Mert River is 4×10^6 m^3/year, Kürtün River is 1.5×10^6 m^3/year and the Atakum plain is 1.5×10^6 m^3/year. There are 5 main geologic units in the area; Ts and Tsk being inefficient in cracks and fractures, and Qe and Qt observed well underground water. Furthermore, by analyzing 83 drill wells drilled for drinking water, it was seen that the groundwater table is compatible with the topography of the area.

MATERIALS AND METHODS

The fundamental data that is required for producing the landslide susceptibility map of the study area has been obtained from a Standard Topographic Map (Samsun-F36-b4) with the scale of 1/25 000. Rivers, roads network and contour lines in the topographic map have been digitized by using ArcGIS 9.3.1 software. At first, the digital elevation model (DEM) of the study area has been created. The DEM model has been converted to the ESRI GRID format and then slope, aspect and curvature maps of the study area have been produced. The proximity maps which show the distances from the landslide areas to respectively, rivers and roads have been created by digitization of 1/25 000 scaled standard topographic map of the study area. The digital landslide inventory map and the geology map of the study area with the scales of 1/25 000 have been obtained from the General Directorate of Mineral Research and Exploration Institute. These maps have been converted to the ESRI GRID format. In order to produce the landslide susceptibility map, the produced maps have been compared one by one to

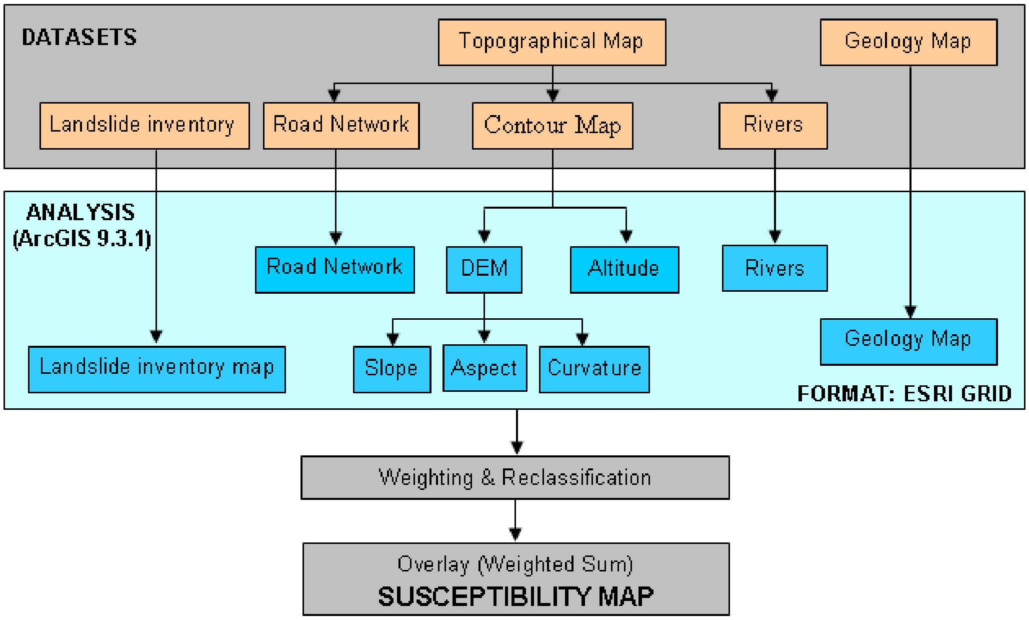

Figure 5. The flow chart showing the methodology of the landslide susceptibility analyses.

landslide inventory map, and thus the relations of the local areas of each layer to landslides have been found. The method that has been used in this study is shown in Figure 5 with the general plan.

Data preparation for the landslide influencing factors

The first step in landslide susceptibility assessments is to acquire information about the landslides that have occurred in the past. In landslide susceptibility studies, generally, it is assumed that the future landslides must occur with the effects of the same factors as previous landslides (Carrara et al., 1995; Chung and Fabbri, 1999; Lee et al., 2004; Yilmaz, 2009; Jadda et al., 2009). This is a reasonable assumption, since most of the factors does not change significantly by the time. According to this assumption, the landslide inventory maps are one of the foremost data that are needed and significant for landslide susceptibility studies, since they show the distribution and characteristics of the past and the current landslides, in their geo-related locations. In other words, landslide inventory maps show the noticeable landslides in the areas they represent (Hansen, 1984; Wieczorek, 1984; Einstein, 1988; Van Westen, 1994; Parise, 2001; Griffiths et al., 2002; Çevik and Topal, 2003; Yalçin, 2007; Reis et al., 2009). Required data for producing the landslide susceptibility maps can be collected from different sources to be decided according to the size of the area to be mapped, the data to be collected on the field, the quality of the data and the level of the details of the project. For example, one can use remote sensing images to acquire the necessary information about landslides together with the available historical information of the past landslides to produce the susceptibility map (Yalçin, 2007; Reis et al., 2009). In this study, we have acquired most of the necessary information from 1/25.000 scaled digital landslide inventory map which was produced by the General Directorate of Mineral Research and Exploration Institute. There are a total of 46 landslide areas shown on the landslide inventory map that we have used. We have converted these regions to the format of the ESRI GRID with equal cell sizes of 30 × 30 m^2 by using ArcGIS 9.3.1 software. We have used 30 of the landslide regions to compute the susceptibility estimations to be used for future predictions. We have used the rest of the 16 regions of 46, for the accuracy test of the computed estimation results.

Lithology is one of the crucial parameters that affect the landslide formation (Kumtepe et al., 2009) and it plays a significant role in the landslide susceptibility studies, since different lithologic units have different susceptibilities for active geomorphologic processes such as landslides. Geomorphologic processes partly depend on the lithology and the weathering characteristics of the fundamental materials that form the lithology (Pachauri et al., 1998; Dai et al., 2001; Çevik and Topal, 2003). Lithologic units in the study area have been obtained from a 1/25.000 scaled digital geology map produced by the General Directorate of Mineral Research and Exploration Institute. Five different lithologies are located in the study area. The Ilyas member is the one in which, the mass movements are the most frequent than the other four lithologic units. It is generally represented with grey-blue marlstone and a transition level formed by the sequence of different lithofacies, above that marlstone. It is located in a vast area, which comprises the settlement areas between the Mert and Kürtün Rivers. The grey-blue marlstone sequence, which constitutes a significant part of the unit, generates yellow clays by partially disintegrating. This unit, which is commonly observed in Samsun settlement area, generally constitutes dip slopes. This unit that leads to the landslides with glide and shallow slip surfaces with the impact of both surface water and groundwater. It also causes the major geological problems in the settlement area (Doyuran et al., 1985).

The most essential component of the landslide susceptibility analyses is the slope angle (Dai et al., 2001; Lee and Min, 2001; Saha et al., 2002; Ercanoğlu et al., 2004; Erener and Düzgün, 2010). It is seen in many studies aimed at producing landslide susceptibility maps that, slope angle is primarily taken into consideration (Dai et al., 2001; Lee and Min, 2001; Saha et al., 2002; Çevik and Topal, 2003; Ercanoğlu et al., 2004; Yalçin, 2008; Yilmaz, 2009; Erener and Düzgün, 2010). The previous studies and the field observations indicate that, increasing slope enhances susceptibility towards the landslide (Yalçin, 2007). In this study, first of all, contour lines in 1/25.000 scaled standard topographic map have been digitized by using ArcGIS 9.3.1 software. Afterwards, DEM of the study area has been built by using contour lines. The produced DEM has been converted to the ESRI GRID format with 30×30 m^2 equally sized cells and the slope map of the study area has been produced from the DEM. The percentile distributions of the landslides correspond to each slope value which have been determined by comparing the slope map to the landslide inventory map (Table 1). Before the comparison, the slope map has been reclassified in 5° intervals. The detected maximum slope value in the study area is 40°. The maximum number of the landslides is seen in the slope groups of 5 to 10° interval, with the percentage of 68.58% and 10 to 15° interval with the percentage of 16.07%.

Although the relation between the aspect and the mass movement has been investigated for a long time, no general decision could have been given regarding to the aspect-landslide relationship (Carrara et al., 1991; Ercanoğlu et al., 2004) however, it is emphasized in many papers that the aspect is one of the significant factors for producing the landslide susceptibility maps (Dai et al., 2001; Çevik and Topal, 2003; Lee et al., 2004; Yalçin, 2008). Physically, the aspect is related to the parameters such as discontinuities that can control the formation of the landslides, precipitation, wind impact and exposition to sunlight (Gökçeoğlu and Aksoy, 1996; Dai et al., 2001; Çevik and Topal, 2003; Ercanoğlu et al., 2004; Yalçin, 2008). Morphological structure and the meteorological properties of the investigated area are very important for the occurrences of the landslides. For example, the landslides are mostly seen in the slanted areas, which have a common orientation relative to the physical properties of some meteorological events such as the general precipitation direction in the region, inclination angle of the sunlight to the area, etc. Materials in slopes with a wider aspect are saturated faster than the other slopes', depending on the infiltration capacity of the soil, that is controlled by many factors such as slopes with intensive precipitation, topographic slope and type, permeability, porosity, moisture, organic material content and vegetation of the soil and precipitation season. Accordingly, that leads to the development of pore-water pressure in slopes (Gökçeoğlu and Ercanoğlu, 2001; Yalçin, 2007). In this study, the aspect map of the study area has been produced from DEM model of the area in order to find the relations between the aspect and the landslides. We have grouped the aspect map into nine categories and then computed the landslide percentage of the each aspect group (Table 1). Accordingly, we have detected that 17.61% of landslides in the study area have occurred at the slopes of the northern aspect, 16.11% of them at the slopes of the southern aspect, 15.63% at the slopes of the northwestern aspect and 12.92% at the slopes of the southwestern aspect.

Another parameter that is frequently used for landslide susceptibility studies is elevation (Juang et al., 1992; Pachauri and Pant, 1992; Çevik and Topal, 2003). It is stated that, the landslides have more tendency to occur at the higher elevations (Pachauri and Pant, 1992; Ercanoğlu et al., 2004). In our study area, the elevation values are between 0 to 364 m. We have divided the elevation values to 7 categories with 50 m. intervals and then computed the correlations between the landslides and each elevation category (Table 1). It was ascertained in the study area that, the highest percentage about 32.80% of the landslides did occur in the areas where the elevation ranges between 100 to 150 m, due to the characteristics of the lithologic unit. Saturation level of the materials in the slanted areas is one of the most crucial parameters that control the stability of the slopes. Proximity of the slopes to drainage networks is also an essential factor for stability. Rivers disrupt the stability either by eroding buttress or saturating the parts of the materials, which constitute slopes, up to river level with water or affecting in both ways (Gökçeoğlu and Aksoy, 1996; Dai et al., 2001; Saha et al., 2002; Çevik and Topal, 2003; Yalçin, 2007, 2008; Reis et al., 2009). The Kürtün and Mert Rivers are the ones that flow constantly in the study area. The graphic data that belongs to both rivers have been transferred to the GIS database by digitization from 1/25.000 scaled standard topographic map. After converting the river data from vector to raster format, a proximity map pertaining to rivers has been produced. The percentile distributions of the buffer zones, in which the landslides in the study area took place, has been ascertained by analyzing the proximity map and the landslide inventory map (Table 1).

In addition to proximity to rivers, stability problems are experienced also at roads and slopes, which are affected by the road construction (Pachauri and Pant, 1992; Pachauri et al., 1998; Ayalew and Yamagishi, 2005; Akgün et al., 2008; Yalçin, 2008; Reis et al., 2009). The roads built on the slopes, cause the loss of load both in topography and slope buttress. The change of the topography and the loss of load events lead to increase of strain behind the slope, and this strain causes the development of cracks. Instabilities occur in the slope because of the negative effects such as water infiltration afterwards (Yalçin, 2007, 2008; Reis et al., 2009). The road network in the study area has been digitized from 1/25.000 scaled standard topographic map. After converting the road network to raster format, buffer zones have been generated with 100 m intervals. Later on, the percentile distributions of the buffer zones, in which the landslides in the study area took place, has been determined by analyzing proximity map and landslide inventory map (Table 1).

Curvature values represent the morphology of the topography (Lee and Min, 2001; Lee et al., 2004; Erener and Düzgün, 2010). Curvature maps are obtained with the second derivative of the surface, in our case it is represented by DEM. Curvature values shows the speed of the change of the slope at the derivative point (in our case at the cell) of the surface (Erener and Düzgün, 2010). Positive and negative curvatures indicate that, the surface is upwardly convex or concave in the given cell, respectively. Zero curvature values indicate that, the surface is flat in the respective cell. From a practical point of view, curvature values can be used to describe the physical characteristics of a drainage basin to understand landslide processes. The plan curvature values were provided to find the divergent and convergent flow areas on the ground and also it is the curvature of the slope parallel to the contour-lines. The convergent flow areas generally indicate the higher erosion risk and movement potential, while the divergent flow areas indicate the lower erosion risk and movement potential. The profile curvature is a curvature that is perpendicular to the counter-lines and it affects the acceleration and deceleration of the flow and so does provide a measure for the landslide damage potential (Erener and Düzgün, 2007; Erener and Düzgün, 2010). Curvature maps of the study area have been built from the DEM of the study area. After analyzing the curvature values in the area, it was ascertained that, the 51.43% of the past landslides have occurred in the concave surfaces 48.20% of them have occurred in the convex surfaces.

IMPLEMENTATION OF THE FREQUENCY RATIO METHOD

In the landslide susceptibility studies, generally, the following reasonable assumption is widely accepted: "the future landslides must occur because of the same factors related to the landslides which occurred in the past" (Chung and Fabbri, 1999; Lee et al., 2004; Yilmaz, 2009; Jadda et al., 2009). For this reason, the frequency ratio method was used for putting forward the correlation between landslide locations in the past and each factor that affects landslides (Lee and Min, 2001; Lee et al., 2004; Erener and Düzgün, 2010). The frequency ratio method has a probability model that is intelligible and very easily applied and due to this characteristic, it was widely used in the literature. The frequency ratio approach is essentially a relative comparison of the probability values of the independent factors of an event under question. Each relative frequency is compared to others and it is clear that, relative frequencies are probabilities that the frequencies of some events are scaled by the total number of the events to give a relative value.

Table 1. Computation of the frequency ratios of the landslide influencing factors.

B=13888	D=63862	Landslide occurrence		Pixels in domain		Frequency ratio
Factor	**Category**	**A number**	**PLO (%)**	**C**	**PIF (%)**	
Altitude	0-50	545	3.92	11912	18.65	0.21
	50-100	3223	23.21	16297	25.52	0.91
	100-150	4555	32.80	15886	24.88	1.32
	150-200	2851	20.53	11554	18.09	1.13
	200-250	1806	13.00	5252	8.22	1.58
	250-300	736	5.30	2125	3.33	1.59
	300-364	172	1.24	836	1.31	0.95
Slope	0-5	1534	11.05	22574	35.35	0.31
	5-10	9524	68.58	30540	47.82	1.43
	10-15	2232	16.07	7605	11.91	1.35
	15-20	413	2.97	2011	3.15	0.94
	20-25	75	0.54	666	1.04	0.52
	>25	110	0.79	466	0.73	1.09
Aspect	Flat	7	0.05	3926	6.15	0.01
	North	2446	17.61	11096	17.37	1.01
	Northeast	1197	8.62	7978	12.49	0.69
	East	1378	9.92	10604	16.60	0.60
	Southeast	1297	9.34	10544	16.51	0.57
	South	2237	16.11	6297	9.86	1.63
	Southwest	1795	12.92	3448	5.40	2.39
	West	1361	9.80	2708	4.24	2.31
	Northwest	2170	15.63	7261	11.37	1.37
Formation	Tt	3180	22.90	6210	9.72	2.35
	Qt	0	0.00	3668	5.74	0.00
	Tsi	9156	65.93	37561	58.82	1.12
	Tsk	1041	7.50	9164	14.35	0.52
	Qe	511	3.68	7259	11.37	0.32
Curvature	Concave	7143	51.43	26003	40.72	1.26
	Flat	51	0.37	5728	8.97	0.04
	Convex	6694	48.20	32131	50.31	0.96
Plan curvature	Concave	6820	49.11	24615	38.54	1.27
	Flat	155	1.12	6687	10.47	0.11
	Convex	6913	49.78	32560	50.98	0.98
Profile curvature	Concave	6530	47.02	30540	47.82	0.98
	Flat	39	0.28	5253	8.23	0.03
	Convex	7319	52.70	28069	43.95	1.20
Distance to road	0-100	7486	53.90	34809	54.51	0.99
	100-200	3796	27.33	15469	24.22	1.13
	200-300	1725	12.42	7825	12.25	1.01
	300-400	506	3.64	2937	4.60	0.79
	400-500	207	1.49	1487	2.33	0.64
	500-1000	168	1.22	1335	2.09	0.58

Table 1. Continued.

Distance to streams	0-500	2345	16.89	14527	22.75	0.74
	500-1000	3132	22.55	11748	18.40	1.23
	1000-1500	2844	20.48	11456	17.94	1.14
	1500-2000	2213	15.93	11526	18.05	0.88
	2000-2500	1847	13.30	8316	13.02	1.02
	2500-3000	1209	8.71	3387	5.30	1.64
	3000-3500	298	2.14	2902	4.54	0.47

The weighting procedure makes the frequency probability functions, since the total value of the relative frequencies is uniform. A frequency ratio is the ratio of two weighted frequencies namely two probability values. The probabilities can be defined appropriately according to the nature of the problem under question such as frequency, conditional, odds probabilities etc. In this study, since the first aim is to find the effects of each factor with their subgroups to the landslide occurrence event, an appropriate probability value which represents the effect of each subgroup must be defined.

For example, if we want to find the effect of the areas which have slope values between 0 to 10%, this can be found by defining the problem with an appropriate probabilistic interpretation. We can ask a question to find the effect of the areas within the given slope ranges: “What is the probability of a randomly selected cell area to be a landslide area and also between the given slope ranges? The answer is of course a conditional probability, that a selected cell is both landslide cell and between the given ranges and it is equivalent to Equation (1) (Bonham-Carter, 1994; Lee et al., 2004; Lee and Evangelista, 2005; Yilmaz, 2009). In order to find the frequency ratio of each factor that affects landslides in the study area, each factor has been grouped into categories and the number of cells where landslide has occurred in each subcategory of each factor has been determined. The following equation has been used for the frequency ratio computation.

$$FR = \frac{PLO}{PIF} \qquad (1)$$

Here, PLO is the percentage of landslide occurrence in each sub-category of a factor that affects landslide and PIF is the percentage of each category of a factor that affects landslide (conditional probability of the question mentioned in the previous paragraph). PLO is computed as A/B and PIF as C/D in Table 1. Where B refers to the total number of landslide cells and D refers to the total number of cells in the study area (Erener and Lacasse, 2007). Higher values of the frequency ratios greater than one indicate high correlations with the landslides and lower values indicate low correlations. The frequency computed for subcategories of each factor that affects the landslides are taken into account for producing the susceptibility maps via the frequency ratio method (Erener and Düzgün, 2007; Erener and Lacasse, 2007; Reis et al., 2009). The frequency ratios computed for each category have been assigned to relevant layer in the ArcGIS 9.3.1 software and afterwards the Landslide Susceptibility Indexes (LSI) have been found by overlapping all layers to each other. The LSI value varies between 2.2 to 14.1 in our case study. Later on, the total frequency value has been divided into 5 classes with equal intervals each representing “non-susceptible and low, moderate, high and very high susceptible” areas. The final susceptibility map with the 5 risk areas is shown in Figure 6.

RESULTS

This study comprises the studies intended for producing the landslide susceptibility map of Samsun City center. In this study, the landslide susceptibility map has been produced by using the frequency ratio method. In practice, usually 9 different factors that affect the landslides are taken into consideration. The susceptibility map has been classified into 5 risky areas: the “non-susceptible, low, moderate, high and very high susceptible” areas. The landslide inventory map and the landslide susceptibility map have been compared to each other, in order to test the reliability of the produced landslide susceptibility map. For this, the distributions of the current landslide areas with respect to the susceptibility classes have been determined as percentile and as area.

In the same way, 16 landslides shown in the landslide inventory map have not been included into the prediction computations. These 16 landslides have been used for the accuracy test of the produced susceptibility map. According to the accuracy test performed by the comparison of the susceptibility classes to the 16 control landslide test areas, it has been ascertained that 38.2% of the current landslides (4.76 km^2) are located in the very high susceptible areas and 53.1% of them (6.61 km^2) are located in the high susceptible areas. When the 16 control group landslides were analyzed, it was seen that 14.2% of the current landslides (0.39 km^2) are located in the very high susceptible areas and 58.7% of them (1.63 km^2) are located in the high susceptible areas. As a result, it has been ascertained that the produced landslide susceptibility map is consistent with the control landslides on the basis of the very high and the high susceptible areas with 72.9% percentage in total.

DISCUSSION

The factors that generate the mass movements have been divided into 4 groups including 1) soil conditions, 2) geomorphologic processes, 3) physical processes and 4) human impacts. When the geological survey reports pertaining to 21 of total 61 landslides that took place in

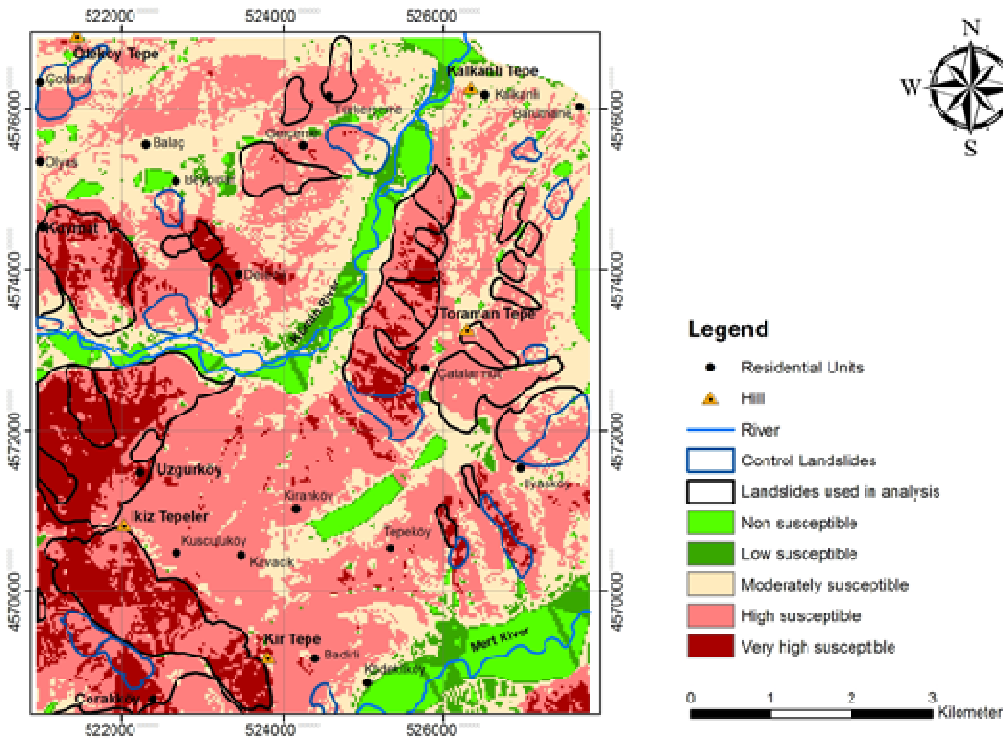

Figure 6. The landslide susceptibility map of the study area.

Samsun City center has been analyzed, it has been discovered that the factors, which affect the formation of the landslides, does not appear in the reports explicitly and clearly. It is also seen that the landslides has only been categorized as “old” and “new” landslides in the landslide inventory map procured by the General Directorate of Mineral Research and Exploration Institute. As a result, in the study it is seen that the human impacts for the landslide areas (such as, buttress excavation) are about 54%.

The mass movements in Samsun City center are primarily stemmed from soil conditions. 66% of landslides are in the areas at the Ilyas member geological unit of Samsun formation. The clays and the gypsum plasters that form this formation are the reason of this situation. The physical and mechanical behaviors, activity, swelling potential, the liquidity index, collapsing risk parameters, the angle of internal friction etc. of clays within the Ilyas member should be analyzed by the mineralogical and the geotechnical researches. Furthermore, the slip surfaces should be determined also, with the seismic surveys in those future studies.

REFERENCES

Akgün A, Dağ S, Bulut F (2008). Landslide susceptibility mapping for a landslide-prone area (Findikli, NE of Turkey) by likelihood-frequency ratio and weighted linear combination models, Environ. Geol., 54(6): 1127-1143.

Assilzadeh H, Levy JK, Wang X (2010). Landslide Catastrophes and Disaster Risk Reduction: A GIS Framework for Landslide Prevention and Management, Remote Sensing, 2(9): 2259-2273.

Ayalew L, Yamagishi H (2005). The application of GIS-based logistic regression for landslide susceptibility mapping in the Kakuda–Yahiko Mountains, Central Japan. Geomorphol., 65(1-2): 15–31.

Bonham-Carter GF (1994). Geographic Information Systems for Geoscientists, Modeling with GIS. Pergamon Press, Oxford, 398.

Carrara A, Cardinali M, Guzzetti F, Reichenbach P (1995). GIS technology in mapping landslide hazard. In: Carrara A, Guzzetti F (Eds.), Geographical Information Systems in Assessing Natural Hazards. Kluwer Academic Publisher, Dordrecht, Netherlands, pp. 135-175.

Carrara A, Cardinalli M, Detti R, Guzzetti F, Pasqui V, Reichenbach P (1991). GIS techniques and statistical models in evaluating landslide hazards. Earth Surface Process. Landforms, 16(5): 427–445.

Çevik E, Topal T (2003). GIS-Based Landslide Susceptibility Mapping for a Problematic Segment of the Natural Gas Pipeline, Hendek (Turkey), Environ. Geol., 44(8): 949-962.

Chung CF, Fabbri AG (1999). Probabilistic prediction models for landslide hazard mapping, Photogrammetric Engineering and Remote Sensing, 65(12): 1389–1399.

CRED (2010). Disaster Data: A Balanced Perspective, CRED Crunch, p. 21.

Dai FC, Lee CF, Li J, Xu ZW (2001). Assessment of landslide susceptibility on the natural terrain of Lantau Island, Hong Kong, Environ. Geol. 40(3): 381-391.

Doyuran V, Lünel T, Altıner D, Koçyiğit A (1985). Microzonation studies for Samsun metropolitan area, Turkey Bull. Geol. Soc., 28: 93-103

Einstein HH (1988). Special lecture: landslide risk assessment procedure. In Proceedings of 5th International Symposium on Landslides, Lausanne, Switzerland, 2: 1075–1090.

Ercanoğlu M, Gökçeoğlu C, Van Asch ThWJ (2004). Landslide Susceptibility Zoning North of Yenice (NW Turkey) by Multivariate Statistical Techniques, Natural Hazards, 32: 1–23.

Erener A, Lacasse S (2007). Landslide Susceptibility Mapping Using

GIS, The Union of Chambers of Turkish Engineers and Architects (UCTEA) Geographical Information Systems Congress, October 30 – November 02, KTU, Trabzon (In Turkish).
Erener A, Düzgün HSB (2007). Geographic weighted regression method in the assessment of landslides, The Chamber of Map and Cadastre Engineers (CSCE) 11.Turkey Scientific and Technical Conference, April 02–06, Ankara (In Turkish).
Erener A, Düzgün HSB (2010). Improvement of statistical landslide susceptibility mapping by using spatial and global regression methods in the case of More and Romsdal (Norway), Landslides, 7(1): 55-68.
Gökçe O, Özden Ş, Demir A (2008). Spatial and Statistical Distribution of Disasters in Turkey Inventory of Disaster Information, Ministry of Public Works and Settlement General Directorate of Disaster Affairs, Department of Disaster Survey and Damage Assessment, Ankara (In Turkish).
Gökçeoğlu C, Aksoy H (1996). Landslide susceptibility mapping of the slopes in the residual soils of the Mengen region (Turkey) by deterministic stability analyses and image processing techniques, Eng. Geol., 44(1-4): 147–161.
Gökçeoğlu C, Ercanoğlu M (2001). Uncertainties on the parameters employed in preparation of landslide susceptibility maps, Bull. Earth Sci. Appl. Res. Centre Hacettepe Univ., 23: 189-206 (In Turkish).
Griffiths JS, Mather AE, Hart AB (2002). Landslide susceptibility in the Rio Aguas catchment, SE Spain. Quarterly J. Eng. Geol. Hydrogeol., 35(1): 9–17.
Hansen A (1984). Landslide hazard analysis. In: Brunsden, D., Prior, D.B. (Eds) Slope instability. Wiley, New York, pp. 523–602.
Jadda M, Shafri HZM, Mansor SB, Sharifikia M, Pirasteh S (2009). Landslide Susceptibility Evaluation and Factor Effect Analysis Using Probabilistic-Frequency Ratio Model, Eur. J. Sci. Res. 33(4): 654-668.
Juang CH, Lee DH, Sheu C (1992). Mapping slope failure potential using fuzzy sets, J. Geotech. Eng., 118(3): 475–494.
Kumtepe P, Nurlu Y, Cengiz T, Sütçü E (2009). Landslide Susceptibility Analysis of Vicinity of Bolu, UCTEA Geographical Information Systems Congress, November 02-06, İzmir (In Turkish).
Lee S, Choi J, Min K (2004). Probabilistic landslide hazard mapping using GIS and remote sensing data at Boun, Korea. Int. J. Remote Sensing, 25(11): 2037-2052.
Lee S, Evangelista DG (2005). Landslide Susceptibility Mapping using Probability and Statistics Models in Baguio City, Philippines, ISPRS 31st International Symposium on Remote Sensing of Environment, 20-24 May, Saint Petersburg, Russia.
Lee S, Min K (2001). Statistical analyses of landslide susceptibility at Yongin, Korea. Environ. Geol., 40(9): 1095–1113.
Lee S, Pradhan B (2006). Probabilistic landslide hazards and risk mapping on Penang Island, Malaysia, J. Earth Sys. Sci., 115(6): 661–672.
Lee S, Pradhan B (2007). Landslide hazard mapping at Selangor, Malaysia using frequency ratio and logistic regression models, Landslides, 4(1): 33–41.
Lee S, Sambath T (2006). Landslide susceptibility mapping in the Damrei Romel area, Cambodia using frequency ratio and logistic regression models, Environ. Geol., 50(6): 847-855.
Lee S, Tu Dan N (2005). Probabilistic landslide susceptibility mapping in the Lai Chau province of Vietnam: Focus on the relationship between tectonic fractures and landslides, Environ. Geol., 48(6): 778-787.
Öztekeşin K (2008). Drinking Water Potential of Samsun City (Metropolitan Municipality). The Union of Chambers of Turkish Engineers and Architects (UCTEA) Samsun City Symposium, 27-29 November, Samsun (In Turkish).
Pachauri AK, Gupta PV, Chander R (1998). Landslide zoning in a part of the Garhwal Himalayas, Environ. Geol., 36(3-4): 325–334.
Pachauri AK, Pant M (1992). Landslide hazard mapping based on geological attributes, Eng. Geol., 32(1-2): 81–100.
Parise M (2001). Landslide mapping techniques and their use in the assessment of the landslide hazard. Phys. Chem. Earth, 26(9): 697–703.
Reis S, Yalçın A, Atasoy M, Nişancı R, Bayrak T, Sancar C, Ekercin S (2009). Production of landslide susceptibility maps by using GIS and remote sensing: Example of Rize province, Turkey's National Association of Photogrammetry and Remote Sensing 5th Technical Symposium, 4-6 February, Ankara (In Turkish).
Saha AK, Gupta RP, Arora MK (2002). GIS-based Landslide Hazard Zonation in the Bhagirathi (Ganga) Valley, Himalayas, Int. J. Remote Sensing, 23(2): 357-369.
Van Westen CJ (1994). GIS in landslide hazard zonation: a review, with examples from the Andes of Colombia. In: Price, MF, Heywood DI (Eds). Geographical information systems in landslide hazard zonation GIS applications for mountain areas. Taylor and Francis, London, pp. 135–165.
Varnes DJ (1984). Landslide Hazard Zonation: A Review of Principles and Practices, Commision on Landslides of the IAEG, UNESCO, Natural Hazards Paris 3: 61.
Vos F, Rodriguez J, Below R, Guha-Sapir D (2010). Annual Disaster Statistical Review 2009: The Numbers and Trends, Centre for Research on the Epidemiology of Disasters (CRED), Université catholique de Louvain, Brussels, Belgium.
Wieczorek GF (1984). Preparing a detailed landslide-inventory map for hazard evaluation and reduction. Bull. Assoc. Eng. Geol., 21(3): 337–342.
Yalçın A (2007). The Use of Analytical Hierarchy Process and GIS in Production of Landslide Susceptibility Maps, J. Faculty Eng. Archit. Selcuk Univ., 22(3): 1-14.
Yalçın A (2008). GIS-based landslide susceptibility mapping using analytical hierarchy process and bivariate statistics in Ardesen (Turkey): Comparisons of results and confirmations, Catena, 72(1): 1–12.
Yılmaz I (2007). GIS based susceptibility mapping of karst depression in gypsum: A case study from Sivas basin (Turkey), Eng. Geol., 90(1-2): 89-103.
Yılmaz I (2009). Landslide susceptibility mapping using frequency ratio, logistic regression, artificial neural networks and their comparison: A case study from Kat landslides (Tokat-Turkey), Comput. Geosci., 35(6): 1125-1138.