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Original Research Article

Assessment of the soil protection function of forest ecosystems using GIS-based Multi-Criteria Decision Analysis: A case study in Adıyaman, Turkey

Nuri Bozali

Karadeniz Technical University, Faculty of Forestry, Trabzon, Turkey

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ABSTRACT

Forest ecosystems provide many ecosystem services including soil erosion prevention. Forest areas prone to soil erosion risk should be carefully determined and the appropriate management interventions should be designed to ensure the soil protection service of the forest ecosystems. In Turkey, the soil protection function of forests is determined by considering mainly the topographical condition (i.e., slope) of forest landscape. In this study, GIS-based Multi-Criteria Decision Analysis (MCDA) was developed and used to determine forest areas for soil protection function based on erosion risk factors including bedrock, crown closure, ground slope and rainfall. The priorities of the risk factors were determined using Analytical Hierarchy Process (AHP) technique and the spatial data layer of each factor was used to generate the map of soil protection function for a case study area located in the city of Adıyaman, Turkey. The results indicated that the most effective factor on erosion risk was slope, followed by bedrock type. It was found that 36.25% of the study area was under low erosion risk, while 21.47% was classified as high and very high risk. On the other hand, the areas subject to soil protection function was found to be 12.05% of the area when using the classical method which was based on solo ground slope factor. Obviously, the difference (9.42%) comes from the combined use of various other erosion risk factors such as crown closure, bedrock and ground slope. The methodology presented provides decision makers with a practical and an effective prediction approach of soil erosion to develop and take necessary action for minimizing soil loss in forest ecosystems.

1. Introduction

Soil degradation caused by erosion is one of the most important environmental problems in the world. The earth is eroded over time by natural factors such as wind, snow, rain, hail, waves and surface waters. In addition to these natural factors, anthropogenic activities such as unsuitable land use practices also increase the risk of soil loss. In fact, soil loss due to erosion continues to be a major threat to the environment in many regions of the world (Pradhan et al., 2011; Nikkami, 2012). The development and severity of the erosion process is mainly influenced by natural disturbances and anthropogenic activities. The most effective natural factors include climate, soil erodibility, topography, and vegetation cover (Antal et al., 2008). The primary human-made factor that increases the erosion risk is the land use preferences contrary to suitable land use practices

E-mail address: nuribozali@ktu.edu.tr.

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(Borrelli et al., 2017). When the amount of soil loss rises above the tolerable threshold, ecosystem services of the soil cannot be maintained due to reduction in the rate of soil production.

Soil protection function of forest ecosystems have been increasingly deteriorating in Europe, which poses a major threat to the terrestrial ecosystems in continental climate regions (Sun et al., 2013). In particular, soil erosion caused by water is one of the most common forms of soil degradation. The potential risk of soil erosion is closely related to the increased precipitation events considered as the major climatic factor (Zhao et al., 2019). Soil erosion is also influenced by the soil erodibility of the bedrock, which is defined as the vulnerability of soil particles to movement by water. The soil structures and permeability along with the soil properties (i.e., percentage of silt, sand, and organic material) are the leading soil parameters that reflect soil erodibility (Zhao et al., 2009).

Ground slope is the main topographic factor that increases the amount of soil erosion as the kinetic energy and carrying capacity of surface water run-off becomes greater in steep grounds. When slope angle exceeds a critical value, soil erosion becomes severe and increases logarithmically (Kosmas et al., 1999). Vegetation cover is another main factor directly influencing the rate of soil loss since reducing the protection of soil cover accelerates removal of soil particles (Tsegaye, 2019). As one of the most important natural resources, the forest ecosystems provide a variety of ecosystem services including carbon storage, biodiversity maintenance, soil erosion control, timber harvesting and recreation (Kimmins, 2008). Erosion control is considered to be one of the most important functions of forest ecosystems as the severity of the soil erosion can be acute in deforested areas (Harmel et al., 2006). The mechanical effects of tree stems, branches and leaves play an important role in reducing the erosion in the forested lands. Thus, the surface flow rate and amount of water in forests are much less than that in bare soils.

About 20% of the forests in Europe is allocated to protect water supplies, prevent soil erosion, and deliver other ecosystem services (San-Miguel-Ayanz, 2015). For example, an action plan was developed in 1852 in Europe to protect some natural forest areas against wind and erosion (Wisniewski and Kistowski, 2015). In the middle of the 19th century, some European countries made legal arrangements to encourage the establishment of protected forests. In the 20th century, specific functions of forest ecosystems were defined as productive, economic and protection (including soil protection) (Wisniewski and Marker, 2019). Some previous studies reported that surface run-off, landslide, and erosion are reduced markedly on forests allocated to soil protection (Stoffel et al., 2006; Zhang et al., 2011). The forests with soil protection function provide strong ability in preventing washing and drifting of soil particles, reduction of organic matter, and the formation of undesirable surface formations that may occur due to the erosion process (Wisniewski and Marker, 2019). The soil protection forests also help protect the areas around the protection zones from water, snow and wind erosions, as well as rock and stone fallings and landslide formations. To maintain such important ecosystem service, it is essential to determine the spatial pattern of soil protection zones and implement specific forest management strategies in those areas.

An accurate map of soil protection function can be generated based on various thematic data layers representing erosion risk factors. GIS techniques have key advantages in generating erosion risk maps by evaluating many data layers (Yuksel et al., 2008; Eroğlu et al., 2010; Sivrikaya et al., 2014; Akay and Taş, 2019). In recent years, GIS techniques have been integrated with MCDA to provide quick and effective method for erosion risk mapping (Zhao et al., 2009). Analytical Hierarchy Process (AHP), as one of the most common MCDA methods, has been used to solve spatial problems in various forest management applications (Akay and Şahin, 2019). Developed by Myers and Alpert (1968) and modelled by Saaty (1977), the AHP method evaluates a set of evaluation criteria and searches for the optimal solution among a set of alternative options.

The soil protection is important phenomena in Turkey because nearly 83% of the land is subject to erosion of various degrees (Keleş et al., 2005). In current practices of forest management in Turkey, the soil protection function of forest ecosystems is determined mainly based on solo ground slope of forest landscape by arbitrary classifying the slope factor. Therefore, it is important to assess and determine soil protection function of forest ecosystems accurately so as to allocate areas properly for soil protection and other forest uses and help maintain forest ecosystem services over time. In this study, a GIS-based AHP method was developed and used to produce map of soil protection function based on erosion risk factors such as bedrock, crown closure, ground slope and rainfall. The study was implemented in a forest management unit located within the province of Adıyaman, Turkey.

2. Material and methods

2.1. Study area

The study area is located in the northern part of Adıyaman Forest Enterprise Chief (FEC) in the South Eastern Anatolian Region within the central district of Adıyaman (Fig. 1). Adıyaman FEC is between 37° 24 ‘30 ″- 37° 59′ 27″ North latitudes and 38° 02 ‘33 ″- 38° 31′ 25″ East longitudes. The total area of FEC is about 189,318 ha, 14.26% of which is covered with forest. The main tree species are red pine, black pine, juniper and oak.

According to the Macro Climate Region Map of Turkey, Adıyaman FEC is located in the continental climate zone where summers are very hot and dry, winters are much colder. According to the meteorological data obtained from the nearest meteorological station, the average temperature, total annual precipitation, and average relative humidity are 17 °C, 935.4 mm, and 49%, respectively.

Fig. 1. Study area in the border of Adıyaman FEC.

2.2. GIS database

The map of soil protection function was generated based on the digital data layers (10 m × 10 m) of specified erosion risk factors (i.e., bedrock, crown closure, ground slope and rainfall). ArcGIS 10.5 (Esri, Redlands, CA, USA) was used to produce these data layers based on the geology, forest cover type and topographical maps. The bedrock layer was generated based on geology map (1:100,000) obtained from the General Directorate of Mineral Research and Exploration (Fig. 2). The crown closure layer was produced based on stand characteristics derived from the forest cover type map (1:25,000) of the FEC (Fig. 3).

The forest cover type map, gathered from Forest Management Department of General Directorate of Forestry, was generated using both field survey and remote sensing data including high resolution aerial photos. Thus, the accuracy, as a crucial part of data quality, was checked by field measurements using GPS techniques and high resolution aerial photographs, different classification methods that provide better accurate data. While remote sensing and GIS provide quick and functional approach in creating vegetation cover data for larger landscapes in a cost-time effective way, ground measurements and aerial photo interpretation provide true/near true and reliable data to compare and consolidate the data for better accuracy. In fact, this is one of the important aspect of our approach in determining soil protection map.

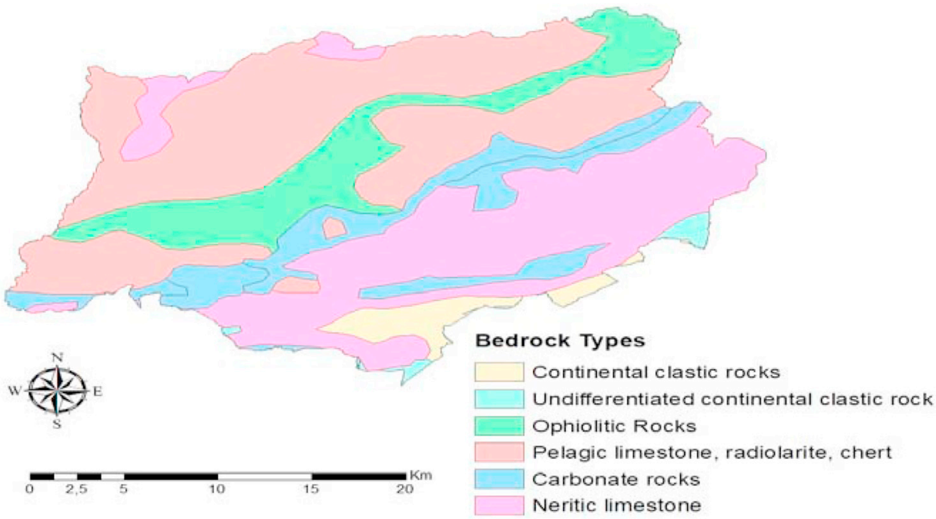

Fig. 2. Bedrock type map of the study area.

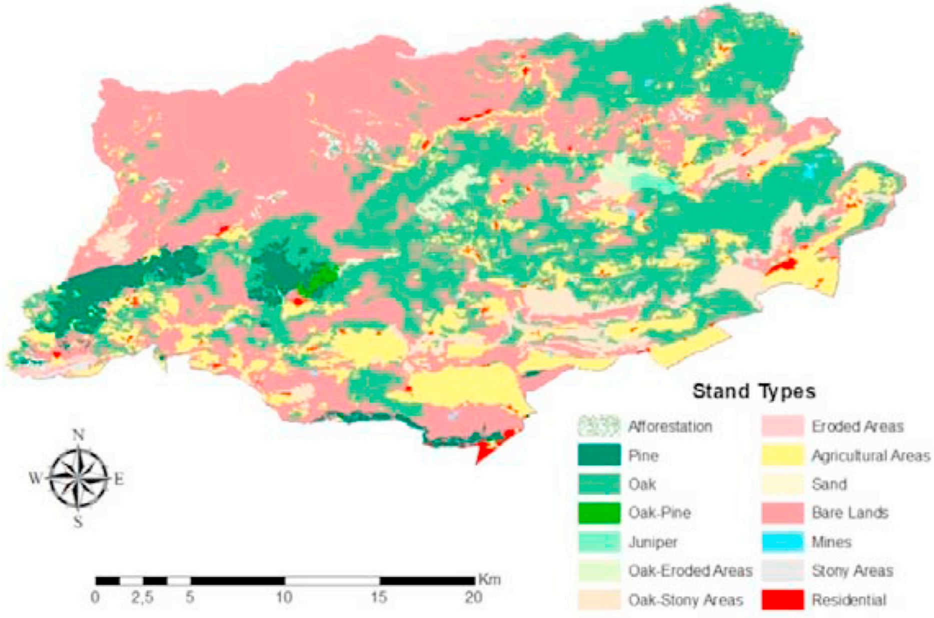

Fig. 3. Stand type map of the study area.

The topographic map (1:25,000) obtained from Adıyaman FEC was used to generate slope layer based on digital elevation model (DEM) of the study area (Fig. 4). The average annual rainfall layer was produced by using an interpolation method depending on the DEM and the meteorological data from the nearest meteorology station. The average annual rainfall in the study area was estimated using Equation (1) (Akay et al., 2008). The slope layer was also used to produce erosion risk map using classical method in which the forests are assigned to soil protection function if ground slope exceeds critical value of 59% (GDF, 2014).

$$P_h = P_0 \pm (54\ h/100) \quad (1)$$

P_h = Estimated average annual rainfall in the study area (mm)
P_0 = Annual rainfall at the nearest meteorology station (mm)
h = Elevation difference between meteorology station and study area (m)
54 = Increase in annual rainfall for every 100 m increment in elevation

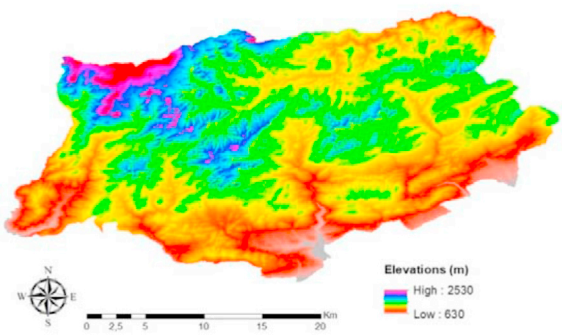

Fig. 4. DEM of the study area.

2.3. Classification of erosion risk factors

In determining the prominent areas for soil protection function, it is necessary to determine both the areas with actual erosion visible in the area and the areas with potential erosion risks (Asan and Özdemir, 2002). While this is an ideal situation, there was no opportunity to observe any indications of actual erosion over the landscape. Thus, the areas to be allocated to the soil protection function were evaluated according to the potential erosion risk factors such as bedrock, crown closure, ground slope and rainfall. In order to rate the erosion susceptibility of the risk factors, each data layer representing a risk factor in GIS database was reclassified and grouped into the subclasses.

The bedrock type affects the erodibility of soil characteristics. While soil types are used directly to characterize erodibility, it is also possible to differentiate the soil types in terms of susceptibility to erosion by taking into account bedrock types as soil types are formed based on bedrock types. The bedrock types forming the soils highly susceptible to erosion are granite, quartz diorite, young sediments and schists, syenite, trachite, acid volcanic rocks, continental clastic rock, undifferentiated continental clastic rock, sandy-clayey quaterner deposits, volcanic tuffs, marl, neogene powder, sand stones, and dust stones (Dyrness, 1976; Balcı ve Öztan, 1987). Some of the metamorphic rocks, ophiolitic rocks, diorite, and cracked limestone are moderately susceptible to erosion. The bedrocks less sensitive to erosion are some sea sediments, pelagic limestone, neritic limestone, basalt, andesite, gabbro, peridotite, serpentine, carbonate rocks, micaschists, gneiss, radiolarite, chert, and conglomerate. In this study, bedrock types observed in the study area were classified according to their erosion susceptibility rates (Table 1).

The crown closure is defined as the proportion of ground area covered by tree crowns. Forests minimize the soil erosion as tree crowns provide a surface cover which is able to reduce rainfall kinetic energy by intercepting precipitation (Li et al., 2019). Therefore, the surface flow and erosion decreases as the crown closure increases. In forest management strategies in Turkey, the crown closure is classified in five classes; bare-land (agricultural lands, rangeland, bare lands, etc.), sparsely distributed stands (<10%), low coverage stands (11–40%), medium coverage stands (41–70%), and fully covered stands (>70%). In this study, the crown closure layer is categorized according to these five classes.

The gradient of ground slope is considered another major factor governing the amount of surface flow and soil erosion. The soil erosion rate increases as the ground slope increases for a constant rainfall conditions (Qing-quan et al., 2001). If the slope increases from 5% to 10%, the amount of erosion increases by three times, and if it increases to 15%, erosion increases by five times (Bozali, 2013). Some previous studies indicated that the forests where the ground slope exceeds 30% were evaluated as the areas where the soil protection function is prominent (Asan and Özdemir, 2002). In this study, however, ground slope layer was categorized intp three classes as low (<30%), medium (30–60%), and high (>60%) accounting for various rates or degrees of susceptibility of forests to erosion.

The erosion is primarily caused by water run-off, especially after heavy rainfall on steep slopes (Reddy et al., 2019). The splashing function of raindrops is the main driving factors of soil erosion caused by rainfall. The decreased rainfall reduces the erosivity which leads to reduction in the amount of soil loss to erosion (Hua et al., 2019). The rainfall layer was then produced by using an interpolation method based on DEM and the meteorological data taken from the forest management plan. The meteorological data cover the period of 1994–2013 based on the nearest meteorological station located in Adiyaman at 678 m of elevation.

Besides, soil erosion is accelerated by human activities. Disturbances and destructions can be observed in all areas where human intervention to nature exist, accelerating the process of soil erosion. Human-induced factors on soil erosion are generally degradation of vegetation, technical mistakes in soil tillage and cultivation, inappropriate land uses, rapid population growth and lack or poor national agricultural development policies (Çepel, 2003). Among them, degradation of vegetation and inappropriate land uses were observed to a certain extent as part of human induced-factors on soil erosion in the region.

2.4. The method: Analytical Hierarchy Process (AHP)

The AHP is one of the widely preferred multi-criteria decision making techniques used to search for the optimal solution among alternatives by evaluating a set of criteria (Coulter et al., 2006). It focuses on the analysis of various environmental parameters and conducts ranking using a number of criteria to solve a very complex decision-making process (Saaty and Vargas, 2001). The hierarchy of a parameter, running from higher to lower level, is based on its interrelationship between other parameters. Both subjective and objective factors may well be used in the decision-making processes. Moreover, the AHP utilizes a pairwise comparison of the parameters affecting the process of determining soil protection function. The

Table 1
Erosion risk groups according to bedrock structure.

Bedrock types	Risk group	Description
Sandstone, Slate, sediment	I	High susceptibility to erosion
Ophiolite, Slope Rubble, Sedimentary rock, Carbonate	II	Medium susceptibility to erosion
Gabbro, Limestone, Marble, Clayey Limestone	III	Low susceptibility to erosion

pairwise comparison is carried out using a matrix of the parameter and assigning a relative weight to each parameter regarding its influence on other parameters expressed in a numerical scale and also consistency ratio (Saaty, 1980). The value of each member (a_{ij}) of the comparison matrix is calculated as the ratio of the weight of attribute *i* to the weight of attribute *j*, scaling from 1 to 9.

Many researchers indicated that climate, topography, soil features, parent rock and ground vegetation are the main factors effecting the erosion (Li et al., 2017; Zhao et al., 2019; Das et al., 2020). Based on the previous researches (Bou Kheir et al. , 2001; Le Bissonnais et al., 2002; Abaoui et al., 2005; Bayramin and Erpul, 2006; Bachaoui et al., 2007; Berkane and Yahiaou, 2007; Bou Kheir et al., 2008; Nekhay et al., 2009; Tian et al. , 2009; Terranova et al., 2009; Nigel and Rughooputh, 2010; Park et al., 2011; Pradhan et al., 2012; Arekhi et al., 2012; Vijith et al., 2012; Naqvi et al., 2013; Guidoum et al., 2013; Alexakis et al., 2013; Arar and Chenchouni, 2014), the thematic layers of slope gradient, annual precipitation, lithofacies, vegetation index, drainage density, and land use have been considered as the main layers required for mapping the soil erosion hazard. In this study, the soil erosion risk factors including bedrock, crown closure, ground slope and rainfall were used as the main criteria in determining soil protection function. To calculate a weighted average for each criterion (and sub-criterion), pairwise comparisons were conducted by single decision maker approach based on empirical study results and statistical findings that revealed the effects of criteria on soil erosion. The weight matrix was then calculated using pairwise comparison matrix. The map of soil protection function was produced by using GIS techniques integrated with AHP method (Fig. 5).

The relative importance between two criteria was measured based on a numerical weight scaled from 1 to 9 (Saaty, 1980) (Table 2). In the solution process, importance of sub-criteria was evaluated with respect to the soil erosion risks. A higher score was given to a criterion indicating more susceptibility to the erosion and a lower score was given to a criterion showing less susceptibility to the erosion. The relative importance or weights were determined based on expert screening (Luo et al., 2020) including researchers in forest management planning, forest management plan auditors and practitioners.

Various approaches have been taken into consideration to reduce and prevent direct and indirect effects of erosion. Not can all approaches be applied in an entire region prone to erosion, due mainly to the limited financial or human resources. Thus, areas that require special attention for soil protection may have to be determined. The choice of a particular method depends highly on the purpose, available data, time and cost. In this study, evaluations were conducted by taking the opinions of *experts* rather than a formal questionnaire with ordinary people as the issue is quite technical. We approached as many available experts as possible and analyzed their opinions. Here, a multi-parametric approach based on expert knowledge and AHP method was used. In fact, both qualitative and quantitative approaches can be utilized here. In the qualitative approach, expert knowledge is used to provide an indicator of relative risk. In the quantitative approach, however, estimates on erosion risks are made based on measured data and modeling.

A weight value was given to each of the criteria affecting soil erosion and thus identifying areas for soil conservation. These weight values were then determined according to the relative importance of the criteria. The priorities of the criteria such as

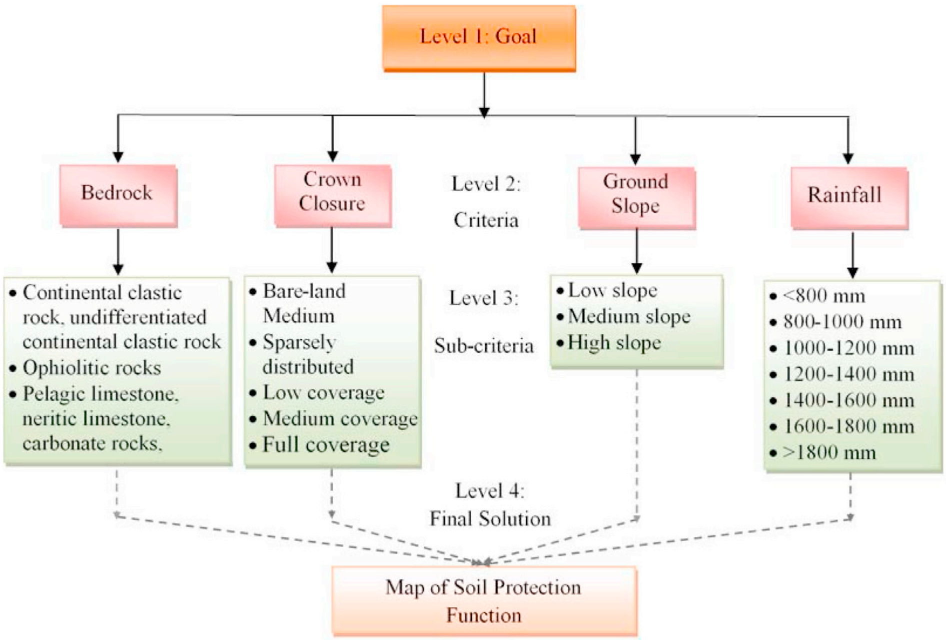

Fig. 5. The hierarchy of AHP method.

Table 2
The relative importance values.

Importance Scale	Definition
1	Equal importance
3	Weak importance of one over another
5	Essential or strong importance
7	Demonstrated importance
9	Absolute importance
2, 4, 6, 8	Intermediate values between the two adjacent judgments

slope, bedrock, proximity and precipitation, effecting soil erosion, were determined with face-to-face interview conducted with the experts. The results of the interview showed the priority as slope, bedrock, crown closure and precipitation in descending order of importance. Relative weights of the sub-criteria were then similarly determined.

A pairwise comparison matrix *A* was generated to compute the weights for different criteria (or sub-criteria). Each entry ($a_{ji}= 1/a_{ij}$) of the matrix *A* represents the importance of the *j*th criterion relative to the *i*th criterion. If $a_{ji}>1$, the *j*th criterion is more important than the *i*th criterion.

In the next step, normalized pairwise comparison matrix was generated. The column vector of *B* was produced by using fallowing formula (Gülci, 2014):

$$b_{ji} = \frac{a_{ji}}{\sum_{j=1}^{n} a_{ji}} \tag{1}$$

where b_{ji} is each entry at the column and n is the number of criteria. Then, weighted averages of the criteria (w_j) were computed by averaging the entries on each row using formula below (Gülci, 2014):

$$w_j = \frac{\sum_{i=1}^{n} c_{ji}}{n} \tag{2}$$

To control the consistency of the evaluations, the ratio of Consistency Index (CI) and Random Index (RI) were computed. The small value of this ratio (<0.1) reveals that consistent results can be achieved from the AHP method. The weighted averages of the sub-criteria were assigned to the data layer of the corresponding criteria by using “Raster Calculator” tool under “Spatial Analyst” extension of ArcGIS 10.5. Then, “ExtAhp 2.0” plug-in was used to combine the weighted averages of the criteria and generate the map of soil erosion potential. Then, the map of soil erosion potential was reclassified into five classes (e.g., very high, high, moderate, low, very low) to indicate the spatial distribution of erosion risk. This classification system was the most common one among the previous studies. At the final stage, the AHP based risk map was compared to the risk map generated by the classical method in which the forest lands exceeding a critical ground slope (i.e. 59%) is assigned with soil protection function. This has been used as a practical method by the planning experts in allocation forests into soil protection function in forest management plans in Turkey (Anonymous, 2008).

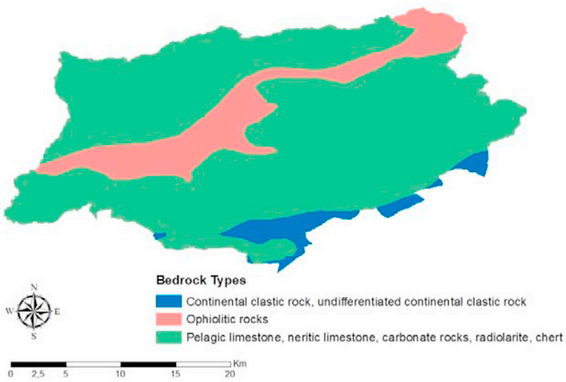

Fig. 6. The bedrock classes map of the study area.

3. Results and discussion

3.1. Data layers of risk factors

The bedrock types used in the study area were classified into three classes according to their erosion susceptibility rates (Fig. 6). Table 3 indicates the areal distribution of these bedrock classes in the study area. It was found that most of the soils in the study area were formed from the bedrock that are subject to soil erosion at low susceptibility rate (i.e. pelagic limestone, neritic limestone, carbonate rocks, radiolarite, chert). The rest of the bedrocks was subject to moderate (ophiolitic rocks) and high (continental clastic rock, undifferentiated continental clastic rock) erosion risks, respectively.

The crown closure layer was classified into five classes based on the forest cover type map created as part of forest management plan (Fig. 7). Table 4 indicates the areal distribution of crown closure classes in the study area. The results indicated that more than half of the study area was covered with the stands of fully covered crown closure, while about 40% of the area was covered with bare-land and sparely distributed crown closure.

The ground slope as a main factor for the determination of soil protection was classified into three classes (Fig. 8). It was found that 44.12% of the study area was on medium slope, while 43.83% was on low slope class (Table 5). On the other hand, about 12.05% of the area was classified as high slope classes.

The rainfall layer, produced by using an interpolation method, indicated that the annual rainfall varied between 809 mm and 1835 mm in the study area (Fig. 9). Then, rainfall layer was classified by 200 mm intervals starting from 800 mm. It was estimated that average rainfall was 1000–1200 mm -more than half of the study area (Table 6). On the other hand, estimated rainfall was 800–100 mm and 1200–1400 mm in about 24.83% and 16.74% of the study area, respectively.

3.2. The weighted averages of the criteria

In order to assess the soil protection function of the study area, GIS-based Multi-Criteria Decision Analysis (MCDA) using AHP method was used to generate soil erosion risk map. In AHP solution process, the weighted averages of the criteria and sub-criteria were used to generate the data layers of the erosion risk factors including bedrock, crown closure, ground slope, and rainfall. In calculating the weighted averages, the priority of factors was determined as slope > bedrock > crown closure > precipitation.

The weighted averages of sub-criteria for bedrock were calculated using Equations (1) and (2) (Table 7). The continental clastic rock had the highest weighted averages followed by ophiolitic rocks. Due to their lithopedological properties, the sedimentary bedrocks (such as continental clastic rock) are sensitive to soil erosion and have a low weathering resistance (Li et at., 2017). The ophiolitic bedrocks with high exchangeable Mg content is also susceptible to the erosion because of surface sealing, decreased infiltration, and increased runoff (Gundogan et al., 2010).

Table 8 indicates the weighted averages of sub-criteria for crown closure. It was found that forests with full crown closure had the highest weighted averages, followed by moderate crown closure. On the other hand, bare-lands had the lowest weighted averages, followed by sparsely distributed lands. It was stated by the previous studies that vegetation cover significantly reduces the soil erosion by intercepting raindrops and reducing runoff, while lack of vegetation cover increases the soil erosion rate significantly (Eroğlu et al., 2010).

The weighted averages of sub-criteria for ground slope were indicated in Table 9. The results revealed that the high slope had the highest weighted averages, followed by medium slope areas. The slope gradient is one of the major driving factors affecting soil erosion. The surface flow on the terrain with various topographical conditions can be significantly high on steeper slopes. The weighted averages of sub-criteria for rainfall showed that risk of erosion increases with higher rainfall (Table 10). Previous studies reported that when the rainfall intensity is greater than the soil infiltration rate, the surface water flows down to the hillslope and causes excessive soil erosion (Liu et al., 2001).

3.2.1. The map of soil erosion protection function

In this stage, first of all, the weighted averages of the sub-criteria were assigned to the data layer of the corresponding erosion factors by ArcGIS 10.5. Fig. 10 indicates the weighted averages of erosion factors with respect to their erosion risk levels. Then, decision maker's pairwise comparisons were used to calculate a weighted average for each criterion. The pairwise comparison approach has been widely used to tackle the subjective and objective judgments about qualitative and/or quantitative criteria in MCDA such as AHP (Kou et al., 2016). While there are different measurement scales such as ratio scale, geometric scale and logarithmic scale, here decision maker judgments with ratio scale were used to create preference

Table 3
The areal distribution of the bedrock classes in the study area.

Bedrock Classes	Area (%)
Continental clastic rock, undifferentiated continental clastic rock	4.46
Ophiolitic rocks	14.22
Pelagic limestone, neritic limestone, carbonate rocks, radiolarite, chert	81.32

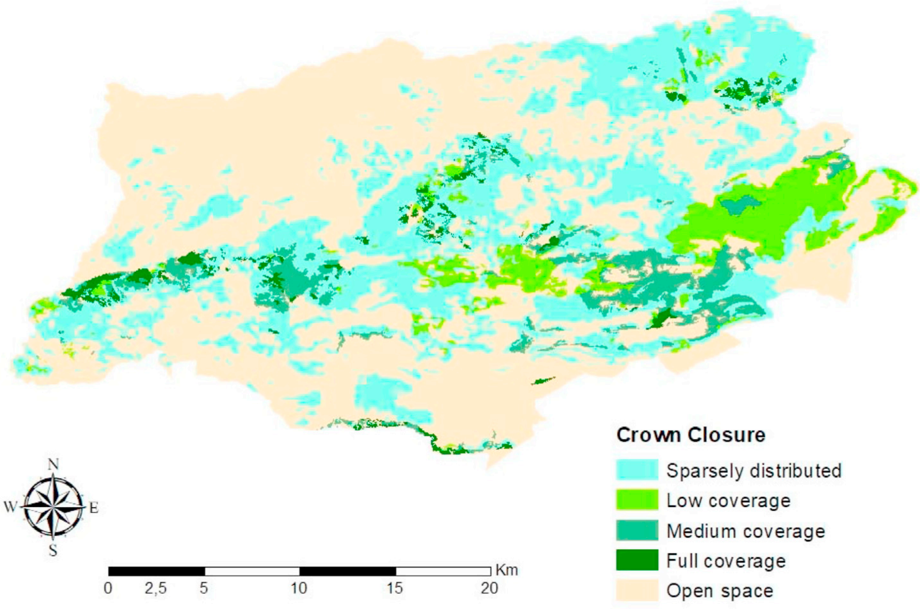

Fig. 7. The crown closure classes map of the study area.

relations in calculating the weighted averages. Table 11 shows the weighted average values of criteria representing the erosion risk factors of ground slope, bedrock type, crown closure and rainfall in order of importance.

The result indicated that the most effective criterion on the erosion was ground slope, followed by bedrock types and crown closure. It was found that rainfall had the least effective criterion on soil erosion risk. As it was predicted, the importance of slope in areas that would serve as soil protection function was higher than other risk factors -ground slope had the highest weight ratio. The criteria effective for soil erosion such as slope, bedrock, crown closure and precipitation were then used to determine the risk groups by overlaying the maps produced independently from each other. Specifically, the data layers with weighted averages of the risk factors were combined and overlaid on top of each other using “ExtAhp 2.0” plug-in ArcGIS 10.5. In this way, the areas for soil protection function were identified and mapped using the GIS functions. Fig. 11 indicates the map of soil protection function with respect to soil erosion risks. Based on the GIS-based AHP method, 21.47% of the study area was classified as high and very high risk, while 36.25% was under low erosion risk (Table 12). According to the classical method which considers solo ground slope factor, only 12.05% of the study area was assigned to soil protection function (Fig. 12). Obviously, the difference (9.42%) comes from the combined use of various other erosion risk factors such as crown closure, bedrock and ground slope.

In summary, slope factor is the most influential criterion in creating soil erosion risk map as also indicated by other similar research endeavors. As slope decreases, for example, the erosion risk level decreases accordingly. Second important aspect was the vegetation cover. For example, erosion risk is seemingly less in areas with forest cover. The important point here is to identify areas with hidden risk for erosion rather than actual erosion on the landscape.

4. Discussion and conclusions

One of the major problems that forest planners encounter during the preparation of forest management plan in Turkey is the lack of scientifically sound criteria and indicators for determining and allocating areas for various forest uses. In particular, areas appropriate for soil protection function are determined based on only the slope parameter as a criterion. Within the scope of this study, however, GIS-based Multi-Criteria Decision Analysis (MCDA) was proposed to assist decision makers in determining the areas to be allocated properly for soil protection function by considering not only ground slope but also the other important factors such as bedrock, crown closure and rainfall. Analytical Hierarchy Process (AHP) technique was used to generate the map of soil protection function and present erosion sensitive areas according to the risk groups identified in the study. By using specified criteria and indicators (i.e., sub-criteria), the proposed method is able to identify areas for soil protection function according to the erosion risk groups.

In previous studies, generally the amount of soil loss from a unit area was calculated using erosion prediction models such as Universal Soil Loss Equation (USLE), Revised Universal Soil Loss Equation (RUSLE), and Water Erosion Prediction Project (WEPP). With the criteria and indicators set out in this study, however, the areas with various erosion risks can technically be determined in a given planning unit. In fact, soil losses as a result of water erosion occur depending on many factors. In order to determine soil conservation activities, it is not only necessary to know these factors but also the methods of controlling

Table 4
The areal distribution of the crown closure classes in the study area.

Crown Closures	Area (%)
Sparsely distributed	32.64
Low coverage	7.17
Medium coverage	5.73
Full coverage	1.70
Bare-land	52.76

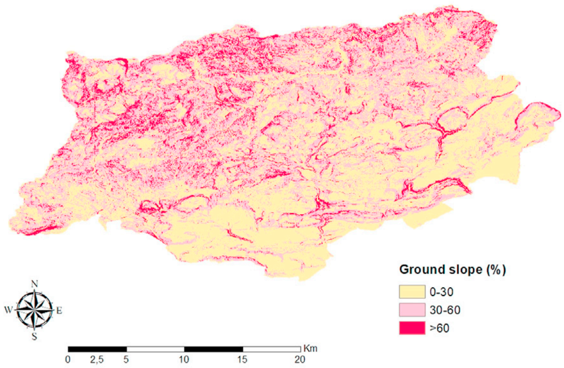

Fig. 8. The ground slope classes map of the study area.

Table 5
The areal distribution of the ground slope classes in the study area.

Ground Slope	Area (%)
Low (0–30%)	43.83
Medium (30–60%)	44.12
High (>60%)	12.05

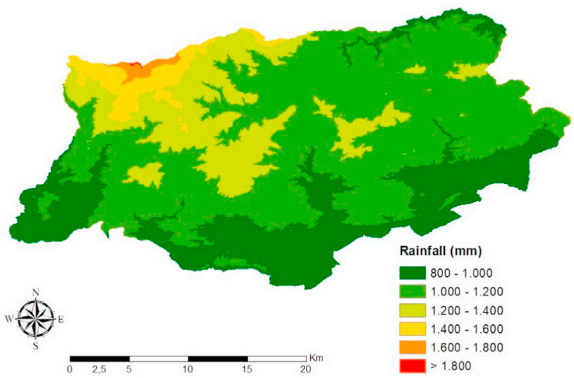

Fig. 9. The rainfall classes map of the study area.

Table 6
The areal distribution of the rainfall classes in the study area.

Rainfall (mm)	Area (%)
800–1000	24.83
1000–1200	54.20
1200–1400	16.74
1400–1600	3.52
1600–1800	0.67
>1800	0.04

Table 7
The weighted averages of the bedrock classes.

Bedrock Classes	Given Score	Continental clastic rock, undifferentiated continental clastic rock	Ophiolitic rocks	Pelagic limestone, neritic limestone …	Weighted Averages
Continental clastic rock, undifferentiated continental clastic rock	9	1	1.5	3	0.50
Ophiolitic rocks	6	0.66	1	2	0.33
Pelagic limestone, neritic limestone, carbonate rocks, radiolarite, chert	3	0.33	0.5	1	0.17

these factors. For example, Turan and Dengiz (2015) used seven criteria (texture, soil depth, precipitation, land use, elevation, slope and vegetation) with sub criteria affecting soil erosion to determine erosion risk classes using GIS, AHP, satellite image, digital soil map and topographic map. They determined the priorities of each criterion similar to our study and concluded that 45.9% of the basin area is under high erosion risk. In fact, in determining vegetation cover we used accurate data such as forest cover type maps generated based on remote sensing, ground measurements and field observations. Moreover, a practical method not requiring costly detailed soil data (e.g., depth, pH and texture) was also used here. Another similar work by Kanar and Dengiz (2015) determined soil erosion risk assessment using CORINE and LEAM models. Additionally, Vulević et al. (2015) prioritized soil erosion vulnerable areas using MCDA technique using similar parameters. They found that slope, vegetation, soil properties and precipitation, in descending priorities, were the main factors of soil erosion classification. Again they have used broad vegetation classification data and yet detail soil properties, which are costly and time consuming parameters in developing a practical method.

Das et al. (2020) conducted a similar study involving the use of AHP in determining soil erosion hazard zones in a case study area of India. They indicated that areas with more slope, relative relief, drainage density, and lineament density, and frequency are highly vulnerable to soil erosion. The presence of forest cover indicated low soil erosion hazard. Similar other research conducted by Boufeldja et al. (2020) determined erosion sensitive areas using erosivity, erodibility, topography, vegetation cover and support practice as the main criteria. According to the AHP pairwise comparison table, the parameters such as annual rainfall, soil texture, land use/land cover and the slope, in descending order, were the most influencing ones. Contrary to our results, slope was the less effective parameters as the topography of the region was generally flat. On the same line, Kachouri et al. (2015) developed an AHP based method to assess soil erosion hazard using six parameters (slope gradient, annual precipitation, lithofacies, vegetation index, drainage density, and land use). They indicated that slope was the most influential factor and the approach described was able to determine soil erosion hazard qualitatively over a comparatively large area. Finally, Tairi et al. (2019) assessed soil erosion risk areas based on AHP using five parameters (slope, drainage density, land use, soil erodibility and erosivity of precipitation). They also indicated that slope was the most influential factor followed by erosivity of the rains and ground vegetation. All these similar research results indicate that determining soil erosion hazard or risk areas in preparing multiple use forest management plan considering soil protection function is quite crucial and topography, climate and ground vegetation are the primary factors in such endeavor.

In fact, some erosion risk assessment models such as CORINE, CONA, LEAM developed to determine the susceptibility of landscape for erosion can be used to validate the maps generated in this study. As well, some soil erosion models such as USLE, RUSLE and WEP were developed to determine erosion processes and erosion rates as well as to estimate and evaluate the soil loss. Thus, such modeling approach may be used for large landscapes to compare and validate the maps generated here using GIS based on AHP technique. In the meantime, however, it is difficult to use such models to validate the results as they require the use of details soil properties of the case study area that are currently unavailable and costly to acquire. Alternatively, for example, Tanyaş et al. (2015) estimated some parameters of RUSLE since they require extensive field and laboratory studies and used 30 years old bathymetry measurements to validate the results of the RUSLE soil erosion model used in their study. They concluded that full use of models such as RUSLE is limited in the absence of full database, C factor is important and validation may be necessary as they have found slight differences between measurements and model results. As explained above, we used forest cover type generated by both field measurements and remote sensing in determining vegetation cover (i.e., C factor) accurately. Besides, the underlying objective of the study was to develop and use a more practical method for forest management planning experts without detail measurements of the criteria and sub-criteria used to delineate areas for soil conservation.

Furthermore, additional data such as wind speed would be interesting to use in the model, provided that there would be spatially located data. This study considered slope, bedrock, crown closure and precipitation factors. Only can the crown closure be related to or affected by anthropogenic disturbances. Vegetation cover can be fragmented, degraded or destroyed by people creating a very susceptible landscape to erosion. Such disturbances will show their effects accelerated particularly in high slope areas. According to the forest management plan of the case study area, some degraded or bare forest stands, susceptible to erosion, originate from anthropogenic disturbances such as unconscious harvesting, illegal harvesting or encroachment for other land uses (Anonymous, 2014). Thus, it is crucial to help minimize the antropojenik disturbances to soil erosion.

In conclusion, a forest management planning unit can well be practically classified as very high, high, moderate, low, and very low erosion risk areas for better allocation of areas to soil conservation functions. The method developed here is flexible

Table 8
The weighted averages of crown closures.

Crown Closures	Given score	Bare land	Sparsely distributed	Low coverage	Medium coverage	Full coverage	Weighted Averages
Bare-land	1	1.000	0.333	0.200	0.143	0.111	0.040
Sparsely distributed	3	3.000	1.000	0.600	0.429	0.333	0.120
Low coverage	5	5.000	1.667	1.000	0.714	0.556	0.200
Medium coverage	7	7.000	2.333	1.400	1.000	0.778	0.280
Full coverage	9	9.000	3.000	1.800	1.286	1.000	0.360

Table 9
The weighted averages of the ground slope.

Ground Slope Classes	Given score	Low (0–30%)	Medium (30–60%)	High (>60%)	Weighted Averages
Low (0–30%)	5	1.000	0.714	0.556	0.24
Medium (30–60%)	7	1.400	1.000	0.778	0.33
High (>60%)	9	1.800	1.286	1.000	0.43

Table 10
The weighted averages of the rainfall classes.

Rainfall (mm)	Given Score	800–1000	1000–1200	1200–1400	1400–1600	1600–1800	>1800	Weighted Averages
800–1000	4	1.000	0.800	0.667	0.571	0.500	0.444	0.10
1000–1200	5	1.250	1.000	0.833	0.714	0.625	0.556	0.13
1200–1400	6	1.500	1.200	1.000	0.857	0.750	0.667	0.15
1400–1600	7	1.750	1.400	1.167	1.000	0.875	0.778	0.18
1600–1800	8	2.000	1.600	1.333	1.143	1.000	0.889	0.21
>1800	9	2.250	1.800	1.500	1.286	1.125	1.000	0.23

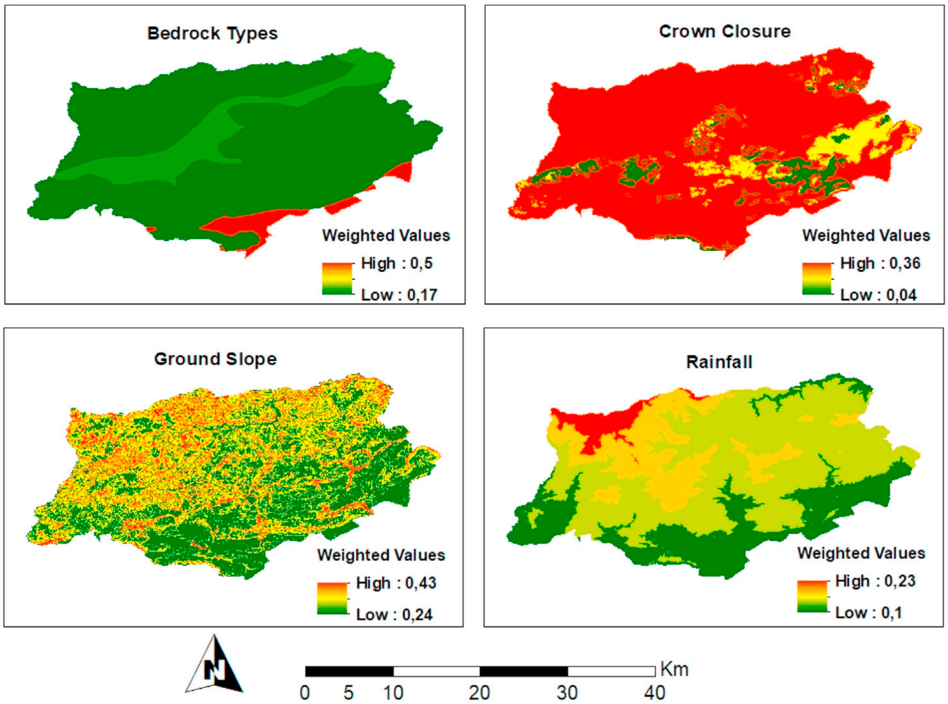

Fig. 10. The weighted averages of erosion factors with respect to the erosion risk levels.

Table 11
The weighted values of criteria.

Criteria	Given score (priority)	Rainfall	Crown closure	Ground slope	Bedrock types	Weighted Values
Ground slope	9	1.000	1.286	1.500	1.800	0.333
Bedrock types	7	0.778	1.000	1.167	1.400	0.229
Crown closure	6	0.667	0.857	1.000	1.200	0.222
Rainfall	5	0.556	0.714	0.833	1.000	0.185

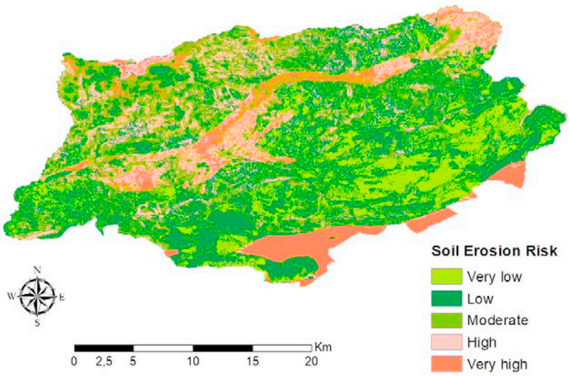

Fig. 11. Soil erosion risk map generated by GIS-based AHP method.

Table 12
The weighted values of criteria.

Erosion Risk	Area (%)
Very low	18.14
Low	36.25
Moderate	24.14
High	12.88
Very high	8.59

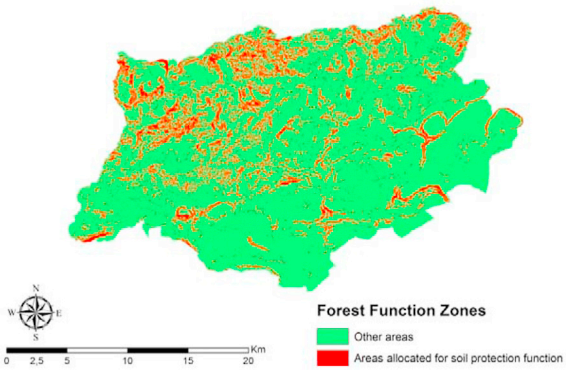

Fig. 12. The soil protection areas generated by classical method with ground slope.

and practical enough to accommodate or integrate the areas that are subject to actual erosion determined by visual observations in the field and the areas with potential erosion risks in a given planning unit. In this way, the areas to be allocated for soil protection function in each planning unit would be determined based on both observed and theoretical erosion risks factors which lead to permanent allocation of areas to soil protection function in preparing forest management plans. In fact, various forest uses such as production, water preservation, soil protection and recreation should be carefully determined and specific forest management strategies should be developed for each forest use in order to maintain the key ecosystem services provided by the forest ecosystems.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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