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Preparing soil protection map using GIS: A case study from Türkiye

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Abstract

Ecosystem services that exist spontaneously in forest ecosystems and benefit society are planned with a certain approach. Forest ecosystem services need to be classified, measured, mapped, planned, and managed. Due to its mountainous terrain, our country has a high disaster risk potential in terms of floods, avalanches, stone and rock rolling, landslides, and soil loss. Soil erosion is recognized as one of the most important environmental problems. Land use changes occur as a result of applications made by people other than natural factors, which increases the amount and risk of soil loss. In this study, the areas that will serve as soil protection were determined and mapped according to certain parameters. The mapping process incorporated various parameters such as slope, bedrock, crown closure, and tree root system. According to the results, approximately 41% of the area consists of areas very sensitive to erosion.

1. Introduction

Erosion is regarded as the second most significant environmental issue globally, following the rapid expansion of the population (Nikkami 2012). The phenomenon of erosion is observed in regions where there is a confluence of intense precipitation, limited vegetation cover, and areas with a sharp slope. The absence of effective erosion control measures results in soil depletion and constrains the agricultural potential of the affected regions (Yitbarek 2012). The impact of climate change on soil erosion risk is significant, as alterations in precipitation patterns have been observed to play a key role. The impacts of climate change have been observed to cause alterations in the frequency and severity of extreme weather events, such as heightened precipitation, prolonged drought, and modifications in land use practices. These changes have been found to have a significant impact on soil erosion processes (Borrelli et al. 2020). Forests play a significant role in ameliorating the adverse impacts of climate change on soil erosion. Hence, forest planners and managers formulate tactics that can safeguard the soil in situ whilst assessing the requisites for other ecosystem services.

Ecosystem services are classified into four categories in terms of their direct and indirect benefits to society: regulating (climate, water regime, ecosystem health), supportive (soil formation, food chain, basic production), production (food, fresh water, firewood, genetic resources), and cultural (recreation, ecotourism, education, cultural heritage) services (Haines-Young and Potschin 2018; ME, 2005). Soil erosion is one of the important factors affecting the sustainability of ecosystems and thus the provision of ecosystem services (Rodrigues et al. 2020). In determining the prominent areas in soil protection and erosion prevention services, it is necessary to determine not only the actual erosion areas but also the areas with hidden risks (Bozali 2020). In this study, while determining the areas to be allocated for soil protection service, the slope, the bedrock structure, the root system of the trees, and crown closure were mapped with the Geographical Information System (GIS).

2. Materials and Method

2.1. Study area

The research was conducted within the İpekyolu Forest Planning Unit, situated in the Maçka Forest Directorate of the Eastern Black Sea Region. This region is known for its mountainous terrain and is located within the country (Figure 1). The region encompasses a combined expanse of 5985.9 hectares, with 3949.8 hectares being covered by forests and the remaining

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2036.0 hectares being devoid of forestation. The dominant tree species within the planning unit are spruce, beech, and Scots pine, as determined by the prevailing habitat conditions. The study area also encompasses a variety of tree species, including alder, hornbeam, fir, and oak.

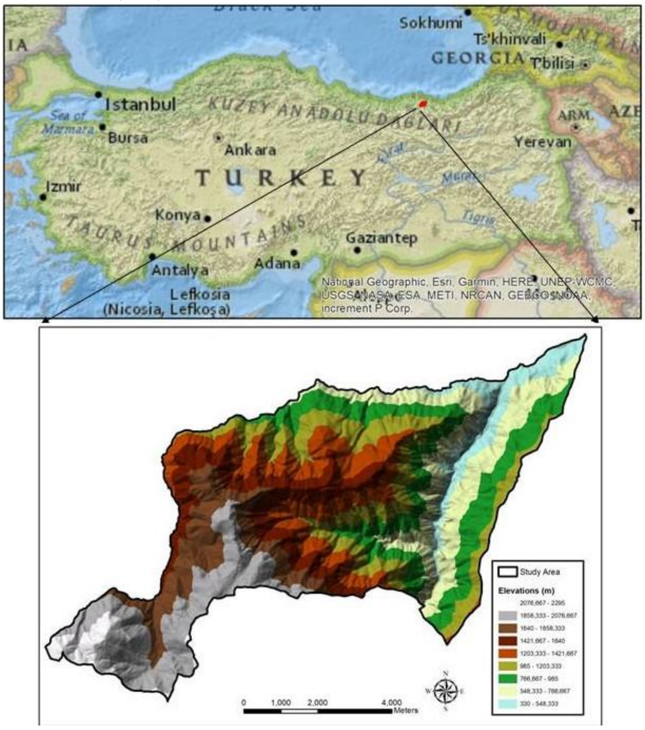

Figure 1. Study area

2.2. Dataset

The digital map of stand types and digital elevation model (DEM) data were acquired from the Maçka Forest Directorate. Furthermore, the geological configuration of the region has been digitized, and the bedrock units have been established utilizing the 1/100,000 scaled geological maps provided by the Mineral Research and Exploration General Directorate.

2.3. The map of soil protection function

The allocation of areas for soil protection service was determined by considering factors such as slope, bedrock, crown closure, and tree root system. The assessment of the soil protection function in the plan unit was based on the slope criterion. Specifically, areas with a land slope greater than 30% were identified as having a significant soil protection function, and slope groups were established accordingly, as presented in Table 1.

Table 1. Erosion risk groups according to slope classes

Slope (%)	Risk Class	Sensitivity
0-30	III	Low
31-60	II	Medium
> 60	I	High

The susceptibility of bedrock groups to erosion and the associated risk groups for the study area were given in Table 2.

Table 2. Erosion risk groups according to bedrock classes

Bedrock	Risk Class	Sensitivity
Sandstone, Schist, Sediment	I	High
Ophiolite, Sedimentary Rock	II	Medium
Gabbro, Limestone, Marble Clay	III	Low

The categorization of erosion risk groups is established in the following manner. The first risk group comprises areas with a high susceptibility to erosion and a significant amount of soil mobility. Simultaneously, the soils that have developed on this particular group of bedrock exhibit a high degree of susceptibility to erosion. Risk group II refers to regions where the likelihood of erosion is moderate and the bedrock group exhibits a moderate susceptibility to erosion. According to the classification system, risk group III denotes regions that exhibit minimal or negligible erosion hazards, and the bedrock group in these areas is comparatively less vulnerable to erosion.

The amount of vegetation and litter in forests serves to mitigate the adverse impacts of erosion. The sensitivity of the plan unit to erosion has been assessed based on its crown closure and root system (Table 3).

Table 3. Erosion risk groups according to crown closure-tree root system

Crown Closure	Risk class based on root structure		
	Tap-root	Heart root	Fringe root
Bare-land	-	-	-
Sparsely distributed	II	II	I
Low coverage	II	II	II
Medium coverage	III	III	II
Full coverage	III	III	II

Maps delineating the areas susceptible to erosion were generated individually based on slope (S), bedrock structure (B), crown closure-tree root system (C) for the study area. Erosion sensitive areas were determined by overlapping the maps, and a soil protection function map was created. The following equation was used while determining the first-, second-, and third-degree erosion sensitive areas within the scope of the soil protection function (SCF).

$$SCF=3S+2B+1C$$

It is predicted that the importance of the slope in the areas that will serve as soil protection is greater than in the others, and therefore it will have the highest weight ratio. Therefore, a hierarchical order was established, whereby slope (3) was given greater priority than bedrock structure (2), and crown closure-tree root system (1). The numerical values 1, 2, and 3 utilized in the equation denote the weight ratios. After determining the minimum and maximum limits of the equation, three groups were formed, and the areas to be allocated for SCF were determined. The equation employs the values 33 and 100 as the lower and upper bounds, respectively.

The difference between the upper limit value and the lower limit value was divided into 3 groups and the limit range values were determined for SCF (Table 4).

Table 4. Limit values of soil protection function risk groups

SCF Value	Risk Class	Description
198-332	III	Low susceptibility to erosion
333-466	II	Medium susceptibility to erosion
467-600	I	High susceptibility to erosion

3. Results and Discussion

Maps depicting the risk of erosion based on slope, bedrock, and crown closure-root system criteria were produced using ArcGIS 10.6 software, as illustrated in Figure 2, Figure 3, and Figure 4. These maps were then incorporated into the risk category database. The study has shown the spatial distribution of erosion risk categories based on three distinct criteria, as presented in Table 5. The production of the ultimate risk map involved the overlaying of slope, bedrock, and crown closure-root system maps, resulting in the generation of a soil conservation map, as depicted in Figure 5.

When evaluated in terms of risk groups, approximately 44% of the area is in the high-risk group in terms of slope, and 38% is in the high-risk group in terms of crown closure-root system. Furthermore, it can be observed that a significant proportion of the region, specifically 76%, is situated within the basaltic geological formation.

Table 5. The areal distribution of the erosion risk classes in the study area based on slope, crown closure-tree root system and bedrock

	Slope	
Erosion risk	Area (ha)	%
High	2627.84	43.90%
Medium	2702.50	45.15%
Low	655.54	10.95%
Total	5985.88	100.00
	Crown closure-tree root system	
High	2246.80	37.53%
Medium	341.83	5.71%
Low	2205.92	36.85%
Bare-land	1191.33	19.91%
Total	5985.88	100.00
	Bedrock	
Basalt	4558.38	76.15%
Dacite	1427.50	23.85%
Total	5985.88	100.00

Based on the results, it was determined that 45.07% of the study area exhibited a moderate susceptibility to erosion, while 13.49% demonstrated a lower susceptibility to erosion. The remaining 41.4% of the area was classified as highly vulnerable to erosion.

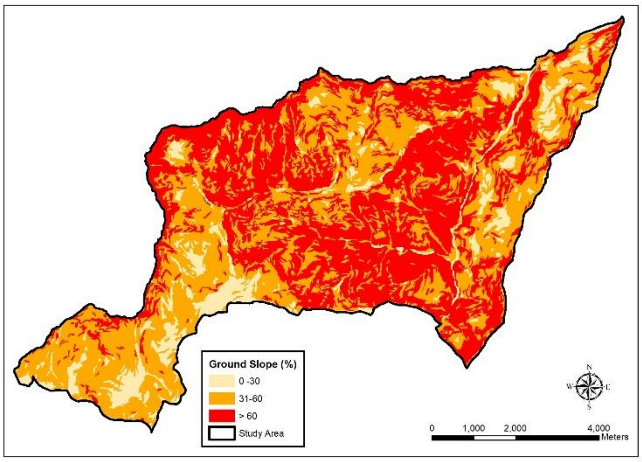

Figure 2. The slope classes map of the study area

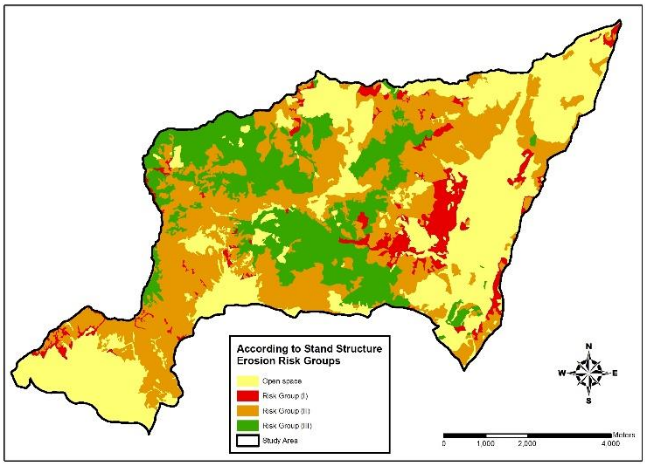

Figure 3. The crown closure-tree root system and slope classes map of the study area

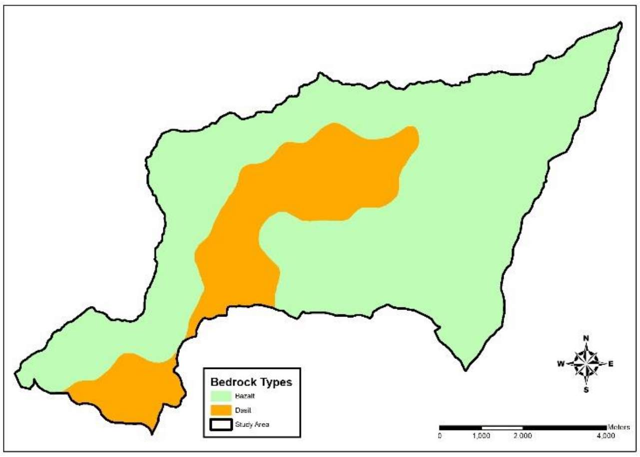

Figure 4. The bedrock classes map of the study area

Table 4. The areal distribution of the erosion risk classes in the study area

Erosion risk	Area (ha)	%
High	2480.98	41.45
Medium	2697.54	45.07
Low	807.36	13.49
Total	5985.88	100.00

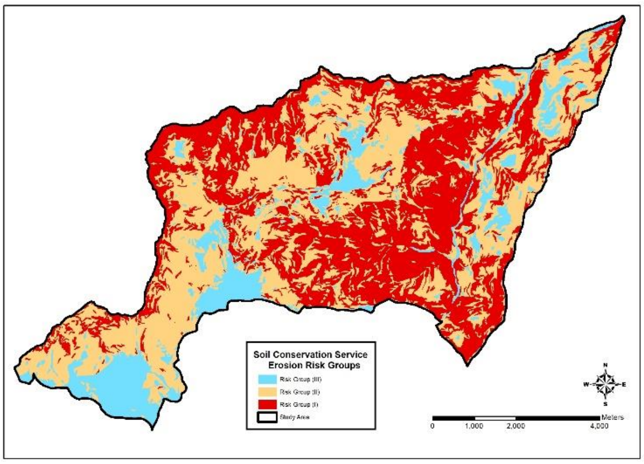

Figure 5. Soil protection map

4. Conclusion

This proposed methodology aims to incorporate slope, bedrock, crown closure, and root system criteria into the identification of soil protection areas in our country. This approach goes beyond the traditional reliance on the slope criterion alone. It enables the identification of not only visibly eroded regions but also those with concealed susceptibility to erosion. This study has facilitated the development of a methodology that forest managers can employ to pinpoint regions that will function as safeguards for soil during the formulation of forest management strategies.

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