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DETERMINATION OF THE IMPACT OF FOREST FIRES ON SOIL EROSION RISK BY USING THE ICONA MODEL: A CASE STUDY OF AYVALI DAM WATERSHED

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ABSTRACT: Soil erosion in dam watersheds is a crucial phenomenon since dams have become a critical component of economic development for many countries. Therefore, the expected increase in both forest fires and heavy rains in the Mediterranean region poses a threat to the dam watersheds. The increase of these two phenomena will cause a serious increase in soil erosion after forest fires in dam watersheds. Therefore, revealing the possible effects of forest fires on soil erosion risk will be extremely beneficial for taking proactive measures in the management of dam watersheds. So, the goal of this study is to reveal the soil erosion risk and to determine the effect of possible forest fires on the soil erosion risk in the Ayvalı dam watershed. The ICONA model was used to reveal the soil erosion risk in the study area. The effect of forest fires was determined by scenario analysis. In the forest fire scenario, it is assumed that all forests in the study area are burned. Considering this scenario, a new soil erosion risk map was produced with the model. Then these two maps were compared. The results showed that 70.33% of the study area faced very high erosion risk, while 21.65%, 7.19%, 0.77%, and 0.05% of it had high, medium, low, and very low erosion risk, respectively. This potentially very high risk results from the steep slopes, high soil erodibility, and sparse vegetation density in the study area. As a result of the fire scenario, it was determined that while the areas with the very high risk increased by 18.11%, areas with high, medium, low, and very low risk decreased by 48.55%, 26.36%, 35.43%, and 100%, respectively. The findings can be a guide for decision-makers to prioritize necessary precautions depending on the soil erosion potential before and after forest fires.

Keywords: Forest fires, soil erosion risk, ICONA model, dam watersheds, Mediterranean region

ORMAN YANGINLARININ TOPRAK EROZYON RİSKİ ÜZERİNDEKİ ETKİLERİNİN ICONA MODELİ KULLANILARAK BELİRLENMESİ: AYVALI BARAJ HAVZASI ÖRNEĞİ

ÖZET: Barajlar birçok ülke için ekonomik kalkınmanın kritik bir bileşeni haline geldiğinden, baraj havzalarındaki toprak erozyonu çok önemli bir olgudur. Dolayısıyla, Akdeniz bölgesinde gerek orman yangınlarında gerekse şiddetli yağışlarda beklenen artış baraj havzaları için tehdit oluşturmaktadır. Bu iki olgudaki artış baraj havzalarında orman yangınları sonrası toprak erozyonunda ciddi bir artışa neden olacaktır. Bu nedenle orman yangınlarının toprak erozyonu riski üzerindeki olası etkilerinin ortaya konulması, baraj havzalarının yönetiminde proaktif önlemlerin alınması açısından son derece faydalı olacaktır. Bu bağlamda bu çalışma Ayvalı baraj havzasında toprak erozyonu riskini ortaya koymayı ve olası orman yangınlarının toprak erozyon riski üzerindeki etkisini belirlemeyi amaçlamaktadır. Çalışma alanındaki toprak erozyonu riskini belirlemek için ICONA modeli kullanılmıştır. Orman yangınlarının etkisi senaryo analizi ile belirlenmiştir. Orman yangını senaryosunda, çalışma alanındaki tüm ormanların yandığı varsayılmıştır. Bu senaryo dikkate alınarak ICONA modeli ile yeni bir toprak erozyonu risk haritası oluşturulmuştur. Daha sonra bu iki harita karşılaştırılmıştır. Sonuçlar, çalışma alanının %70,33'ünün çok yüksek erozyon riskine maruz kalırken, %21,65, %7,19, %0,77 ve %0,05'inin sırasıyla yüksek, orta, düşük ve çok düşük erozyon riskine maruz kaldığını göstermiştir. Çalışma alanındaki bu çok yüksek erozyon riski yüksek eğim, yüksek toprak aşınabilirliği ve seyrek bitki örtüsü yoğunluğundan kaynaklanmaktadır. Yangın senaryosu sonucunda çok yüksek riskli alanlar %18,11 artarken, yüksek, orta, düşük ve çok düşük riskli alanların sırasıyla %48,55, %26,36, %35,43 ve %100 azaldığı tespit edilmiştir. Elde edilen bulgular, orman yangınları öncesi ve sonrasında toprak erozyonu potansiyeline bağlı olarak gerekli önlemlerin önceliklendirilmesi konusunda karar vericilere yol gösterici olabilir.

Anahtar kelimeler: Orman yangınları, toprak erozyon riski, ICONA modeli, baraj havzaları, Akdeniz bölgesi

INTRODUCTION

The Mediterranean basin together with the regions such as South Africa, the western USA, the Arabian Peninsula, and the northeast parts of Brazil has influenced by the climate change and the region has problems with water supply (Şen, 2021). In the twenty-first century, global climate models project that this region will become one of the climate change hotspots (Lionello & Scarascia, 2018). As a result, it is predicted that more frequent and severe seasonal droughts in summer and autumn will be experienced in the region (Giertz et al., 2006; Kovats et al., 2014).

The strategy used to reduce the temporal and spatial variability of natural water resources for many years has been to construct dams on rivers (Ehsani et al., 2017). Dams that allow to accumulation of water during the rainy season for meeting water demand in dry periods have become an important part of human life (Bunyasi et al., 2013; Daus, 2021). Agricultural production increases rapidly in the regions where the dams are built and the obtained products meet the required raw material demand for the industry. So, dams contribute to the development of the agricultural industry (Shabanzadeh-Khoshrody et al., 2016). In addition, the energy shortage is alleviated by the electricity produced from the dams (Kum, 2016). Dams also reduce floods and torrents, and consequently, rapid population growth is experienced around them (Boulange et al., 2021). As a result, dams have become a critical component of economic development for many countries (Goldsmith & Hildyard, 1984; Zarfl et al., 2015).On the other hand, it is stated that dams which have an extremely important place in human life cause environmental problems in many studies, and whether or not to build new dams lead to social and political debates (Mirchi et al., 2014; Poff & Schmidt, 2016). However, planned dams for both water security and economic development in many countries clearly reveal the views of decision-makers about this controversial issue (Mulligan et al., 2020). Thus, it becomes necessary to ensure that the services provided by the dams are much more compared to their damages. The focus to ensure this condition is to deal with sedimentation (George et al., 2017). In other words, it is to minimize soil erosion and consequently reduce sediment yield in the dam watersheds.

In general, it is difficult to implement measures for reducing soil erosion in a whole watershed because of limited human and financial resources (Rahmati et al., 2019). In this context, determining the areas with the highest erosion risk in a watershed becomes crucial in using the resources most effectively and efficiently (Zhou et al., 2008; Jaiswala et al., 2015; Dutal & Reis, 2020). Many models have been used to determine the soil erosion in a watershed. Some of these models such as RUSLE, WEPP, and SWAT reveal soil erosion quantitatively, while others such as CORINE and ICONA reveal soil erosion qualitatively (Yüksel et al., 2008a; Babalık et al., 2021a; Esmaeili Gholzom et al., 2022). Among these models, ICONA is a nonrigid model that can be used for areas with limited data (ICONA, 1997). The model released by the Spanish Institute of Natural Conservation is used effectively in many Mediterranean countries and Europe together with remote sensing and geographic information systems (Sahin & Kurum, 2002; Ediş et al., 2021). In the model, four main inputs namely lithofacies, slope, vegetation density, and land use are taken into consideration and the soil erosion can be determined with high accuracy in a short time (Esmaeili Gholzom et al., 2022).

The factors causing soil erosion can be generally listed as slope, altitude, land-use change, sparse vegetation density, inadequate soil erosion control precautions, and improper land-use practices (Reis et al. 2017a; Yüksek et al., 2020). In addition, another factor that has an impact on soil erosion is forest fires (Lourenço et al., 2012; Francos et al., 2018; Lucas-Borja et al., 2019). Forest fires burn the vegetation and litter and make the soil surface bare and consequently, the soil erodes easily during rainfall (Ice et al., 2004). Another effect of fires is that they harden the soil surface and increase the soil water repellency (Weninger et al., 2019). In such a case, since the speed and amount of runoff increase on these hardened surfaces, it becomes more dangerous for the areas with loose soil (Agbeshie et al., 2022).

According to climate change projections, it is expected to increase in both forest fire events and short duration and heavy rainfalls in the Mediterranean region (Oguz et al. 2019; Babalık et al., 2021b; IPCC, 2022). The increase of these two phenomena will cause a serious increase in soil erosion after forest fires in the region. This situation clearly shows that revealing the possible effects of forest fire on soil erosion risk in especially fire-sensitive areas will be extremely beneficial for taking proactive measures in the management of dam watersheds. In this context, the goal of present study is (1) to reveal the soil erosion risk in the Ayvalı dam watershed by using the ICONA model and (2) to determine the effect of possible forest fires on the soil erosion risk.

MATERIAL AND METHODS

Study Area

Ayvalı dam which was built between the years of 1993 and 2006 for irrigation, drinking water, and flood control purposes on the Erkenez stream is 20 km away from Kahramanmaraş city center. The volume and area of the lake are 80 hm³ and 2.73 km^2 respectively at the normal water level. It was planned to meet the drinking, domestic, and industrial water needs of Kahramanmaraş city until 2040 (URL-1). Ayvalı dam watershed has an area of 2800 ha and is located between 37° 32' 00" - 37° 39' 22" N latitudes and 37° 6' 52" - 37° 15' 50" E longitudes. The mean slope of the study area is 30%. The altitude in the study area varies from 600 m to 2000 m. The study area has a Mediterranean climate type. The annual average precipitation is about 720 mm. In general, precipitation falls in the winter months while the summer months are dry. While the annual average temperature is 16.7 °C, the temperature is maximum in July (45.2 °C) and minimum in February (–9.6 °C) (GDMS, 2022).

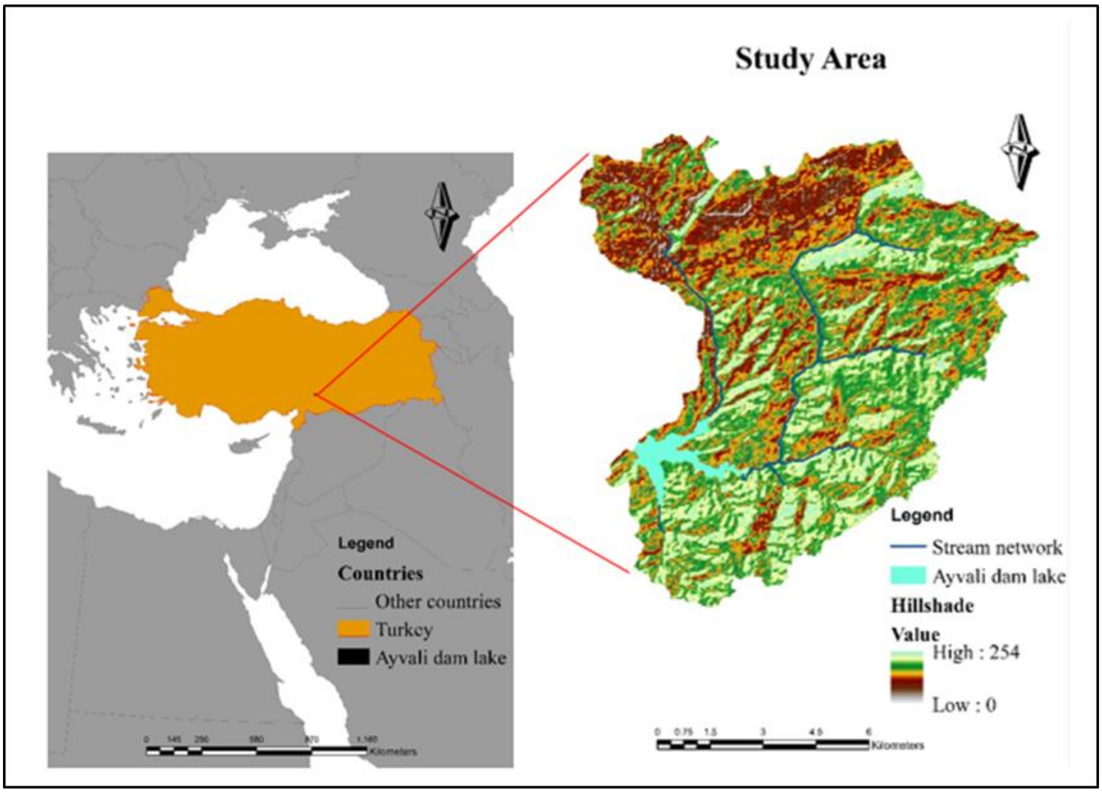

Figure 1. Ayvalı dam watershed

Ayvalı dam watershed is located in the Mediterranean flora region, which is one of the three major flora regions of Turkey (Anşin, 1983). There is various vegetation type such as woody, herbaceous and bush in the study area. The dominant species of the region is Turkish red pine (*Pinus brutia* Ten). However, a major part of the forest areas generally has a sparse vegetation cover due to anthropogenic impacts (Okatan et al., 2000). Dominant rangeland condition is also poor in the study area. According to the CORINE map, while 22.2% of the study area consists of forest areas, 12.1%, 46.3%, and 19.4% of the study area consist of agriculture, shrub, and rangeland and others, respectively.

Methods

Mapping soil erosion risk with the ICONA model considers a multi-step process (Figure 2). The first step is to generate the four inputs including lithofacies, slope, vegetation, and land use/land cover maps. In order to generate soil erodibility and soil protection maps, these maps are combined. Soil erodibility map is produced by combining slope and lithofacies maps, while soil protection map is produced by combining vegetation cover with land use/land cover. In the last step, a soil erosion risk map is obtained by combining soil protection and soil erodibility maps (ICONA, 1997).

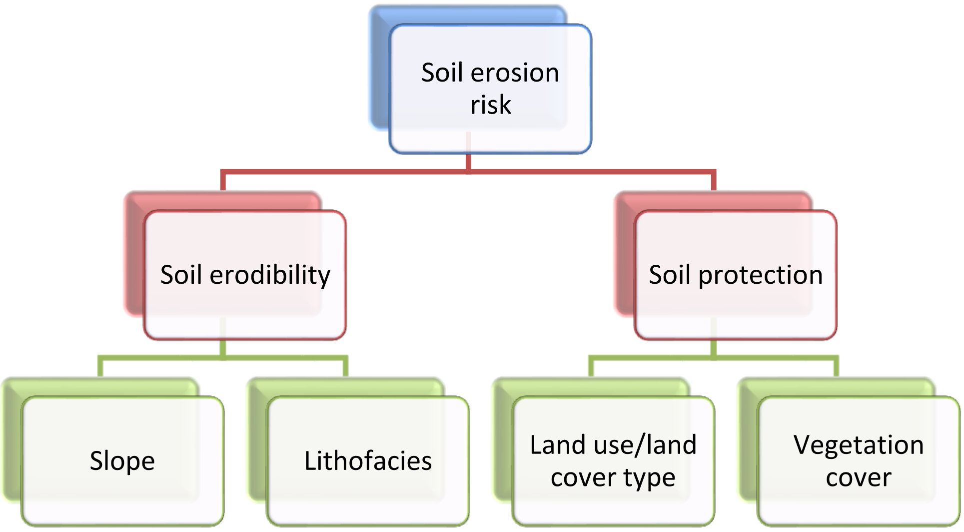

Figure 2. Flowchart of the ICONA model

In this study, ASTER GDEM V3 (ASTER, 2018) was used to produce the slope map. The slope map was divided into different slope classes as (1) flat to gentle (0-3%), (2) moderate (3-12%), (3) steep (12-20%), (4) very steep (20-35%), and (5) extreme (>35%).

The lithofacies map presents different types of bedrocks or soils depending on their resistance to chemical and physical weathering (ICONA, 1997). This map can be created on soil or bedrock types (Bayramin et al., 2003). In this study, bedrock was taken into account to produce the lithofacies map. While the bedrock types were determined with the geological maps taken from the General Directorate of Mineral Research and Exploration, the lithofacies class of each bedrock in the ICONA model was determined with the help of Table 1.

Table 1. Classification of bedrocks in ICONA model

ICONA classes	Lithofacies characteristic
a	Very high resistant to weathering
b	High resistant to weathering
c	Moderate resistant to weathering
d	Low resistant to weathering
e	Very low resistant to weathering

The land use/land cover map was mainly created by considering the CORINE map, as well as the forest management plan and Google Earth. In the study area, eleven land use classes such as non-irrigated arable land, complex cultivation patterns, fruit trees, coniferous forest, mixed forests, land principally occupied by agriculture, with significant areas of natural vegetation, transitional woodlands-shrub, natural grasslands, bare rocks, sparsely vegetated areas, and water bodies were determined. Then, a land use/land cover map was produced depending on the corresponding classes of each land use in the ICONA model (Table 2).

Table 2. Land use classes in ICONA model (ICONA, 1997)

Land use classes in ICONA model	Corresponding land uses in the CORINE classification (Gündüzoğlu, 2019)
(1) Dry farming	Non-irrigated arable land and complex cultivation patterns
(2) Orchard	Fruit trees
(3) Irrigation	-
(4) Forest	Coniferous forest and mixed forests
(5) Shrub land	Land principally occupied by agriculture, with significant areas of natural vegetation and transitional woodlands-shrub
(6) Rangeland and others	Natural grasslands, bare rocks, sparsely vegetated areas, water bodies, and burned areas

The Normalized Difference Vegetation Index (NDVI) provides information on the greenness level of vegetation, photosynthetic activity, biomass (Reed et al., 1994), and spatial and temporal distribution of land degradation in various ecosystems (Holm et al., 2003). Therefore, NDVI was used as an indicator of vegetation cover in this study. NDVI was calculated using the 4th and 5th bands of the Landsat 8 satellite image obtained from the NASA Earth Explorer website. The satellite image was selected among the months of the wet periods in the study area. Before the calculation process, radiometric corrections of both bands were made. NDVI values were divided into predefined classes ((1) <%25; (2) %25-50; (3) %50-%75; (4) >%75) based on the ICONA model.

The soil erodibility map was created by overlapping the slope and the lithofacies maps. In this process, the soil erodibility matrix was used (Table 3). According to this matrix, possible results are very low erosion (EN), low erosion (EB), moderate erosion (EM), high erosion (EA), and extreme erosion (EX). In this context, if the slope is low and bedrock is the most resistant to weathering in a certain area, the soil erodibility level is low. Conversely, soil erodibility is considered extreme when the slope is markedly steep and bedrock is the least resistant to weathering.

Table 3. Erodibility matrix in ICONA model

Slope class	Lithofacies class				
	a	b	c	d	e
1	1 (EN)	1 (EN)	1 (EN)	1 (EN)	2 (EB)
2	1 (EN)	1 (EN)	2 (EB)	3 (EM)	3 (EM)
3	2 (EB)	2 (EB)	3 (EM)	4 (EA)	4 (EA)
4	3 (EM)	3 (EM)	4 (EA)	5 (EX)	5 (EX)
5	4 (EA)	4 (EA)	5 (EX)	5 (EX)	5 (EX)

A soil protection map was produced by overlaying land use/land cover and vegetation cover maps. The values in the soil protection map are determined by the soil protection matrix (Table 4). According to this matrix, the soil protection map is divided into 5 classes namely very low protection (MB), low protection (B), medium protection (M), high protection (A), and very high protection (MA). Land use/land cover varies from relatively sparse vegetation cover dominated by anthropogenic effects to more dense uncultivated land cover types such as a forest. If the land use is of the type dominated by anthropogenic effects and the vegetation is sparse, the soil protection is classified as low. Conversely, high soil protection is reached when land use is of the uncultivated land cover and vegetation is dense.

Table 4. Protection matrix in ICONA model

Land Use	Vegetation Cover			
	1	2	3	4
1	5 (MB)	5 (MB)	4 (B)	4 (B)
2	5 (MB)	5 (MB)	4 (B)	3 (M)
3	3 (M)	2 (A)	1 (MA)	1 (MA)
4	4 (B)	3 (M)	2 (A)	1 (MA)
5	5 (MB)	4 (B)	3 (M)	2 (A)
6	5 (MB)	4 (B)	3 (M)	2 (A)

Finally, the soil erosion risk map is generated by superimposing the soil erodibility and soil protection maps. The soil erosion risk is determined according to the soil erosion risk matrix (Table 5). According to this matrix, the soil erosion risk map is divided into 5 classes such as very low risk (1), low risk (2), medium risk (3), high risk (4), and very high risk (5). The soil erosion risk is low in the case of a low soil erodibility combined with high soil protection, while the soil erosion risk is high when low soil protection is combined with a high soil erodibility.

Table 5. Soil erosion risk matrix in ICONA model

Erodibility class	Protection class				
	EN	EB	EM	EA	EX
MA	1	1	1	2	2
A	1	1	2	3	4
M	1	2	3	4	4
B	2	3	3	5	5
MB	2	3	4	5	5

The accuracy of the ICONA soil erosion risk map was checked with the field observations, as well as previous studies in the Ayvalı dam watershed.

The effect of forest fires on soil erosion risk was determined by scenario analysis. According to this scenario, it was assumed that all forests in the study area were converted into bare land after a forest fire. The ICONA erosion risk map of the watershed was used as a base scenario. Land use/land cover and vegetation density maps were reproduced depending on the scenario to reveal the impact of forest fires on soil erosion risk. These new maps and the slope and lithofacies maps without any changes were used to produce a new soil erosion risk map representing the forest fire scenario. Then, this map was compared with the base soil erosion risk map. In the study, ArcGIS software was used in all processes.

RESULTS AND DISCUSSION

Figure 3 shows the distribution of slope classes in the study area. Areas with very steep and extremely steep slopes are generally concentrated on the hills of Ahır Mountain which covers a certain part of the study area. A large part of the study area (88.59%) had a slope greater than 12%, while 0.58% and 10.83% of the study area had flat to gentle and moderate slopes, respectively (Table 6). This slope condition indicates that soil erosion can easily occur in the study area. It is well known that the steeper the slope, the higher the soil erosion risk (Wischmeier & Smith 1978; Krishna Bahadur, 2012; Karagül & Çitgez, 2019; Sahour et al., 2021).

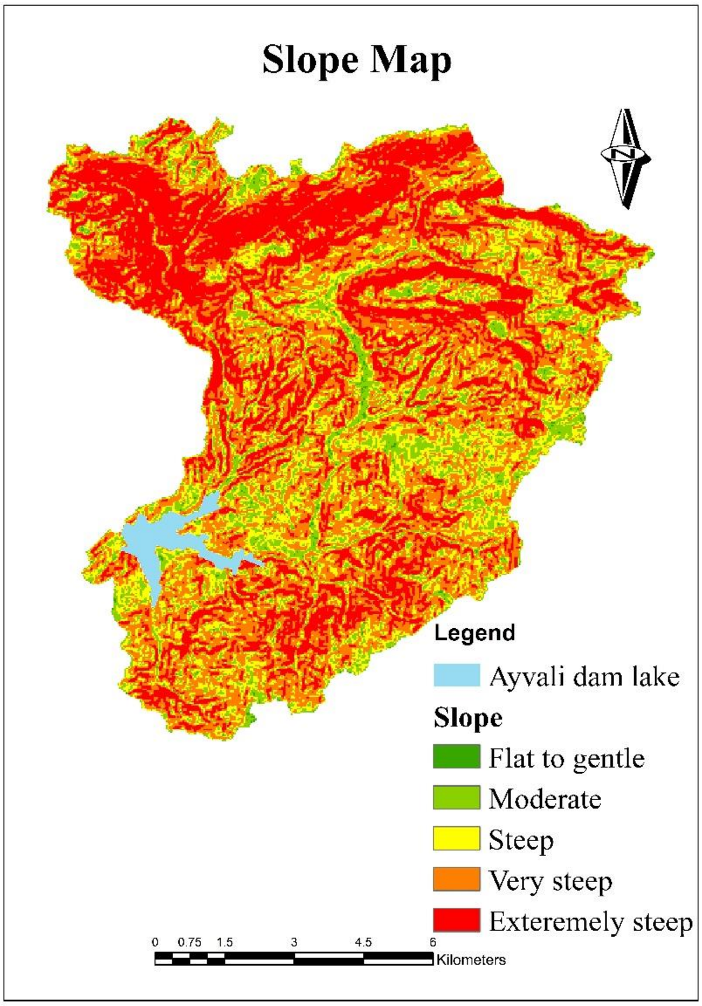

Figure 3. The slope map of the Ayvalı dam watershed

Table 6. The distribution of slope classes in the Ayvalı dam watershed

Slope Classes	**Area (ha)**	**Area (%)**
Flat to gentle	60.13	0.58
Moderate	1123.77	10.83
Steep	2006.93	19.34
Very steep	3842.01	37.02
Extremely steep	3346.41	32.24

The lithofacies map is presented in Figure 4. Table 7 reveals that 64.62% of the study area comprises low resistant bedrocks. In addition, 9.39% of the area had very low resistant materials, while 25.98% of it had moderate resistant bedrock. In general, it can be said that the bedrocks which are very sensitive to erosion are dominant in the major part of the study area. Therefore, this situation increases soil erosion risk in the watershed (Bayramin et al., 2003).

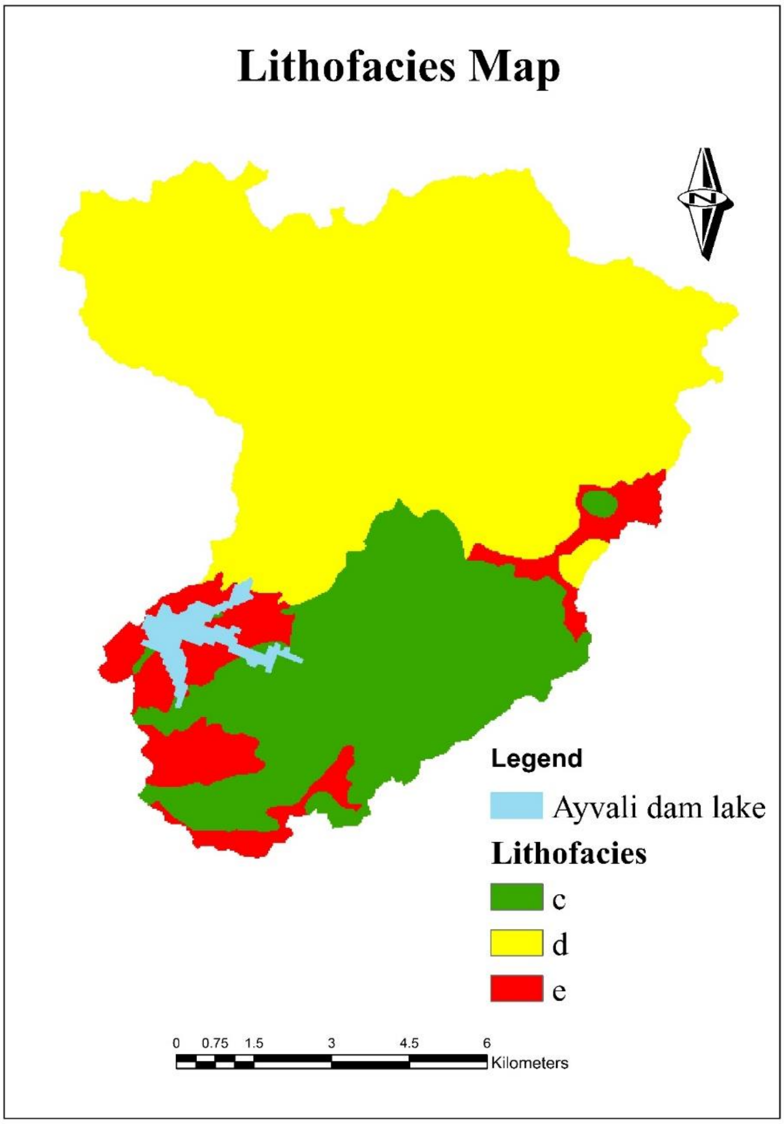

Figure 4. The lithofacies map of the Ayvalı dam watershed

Table 7. The distribution of lithofacies classes in the Ayvalı dam watershed

Lithofacies Classes	Area (ha)	Area (%)
(c) Moderate resistant to weathering	2696.94	25.98
(d) Low resistant to weathering	6707.39	64.62
(e) Very low resistant to weathering	974.93	9.39

The soil erodibility map was produced based on the slope and lithofacies maps (Figure 5). Table 8 suggests that 83.10% of the study area is faced with high to very high soil erodibility. It was also found that 0.50% of the study area had very low erodibility, while 2.95% of it had low erodibility. This is an expected result considering the slope and bedrock conditions in the study area and clearly shows that the study area is highly prone to soil erosion (Kefi et al., 2011; Reis et al., 2017b). In addition, when compared to the bedrock, it was observed that the erodibility map had a pattern that is more similar to the slope map. Therefore, as reported by

Sahour et al. (2021), it can be said that slope is a more effective factor than bedrock in determining soil erodibility.

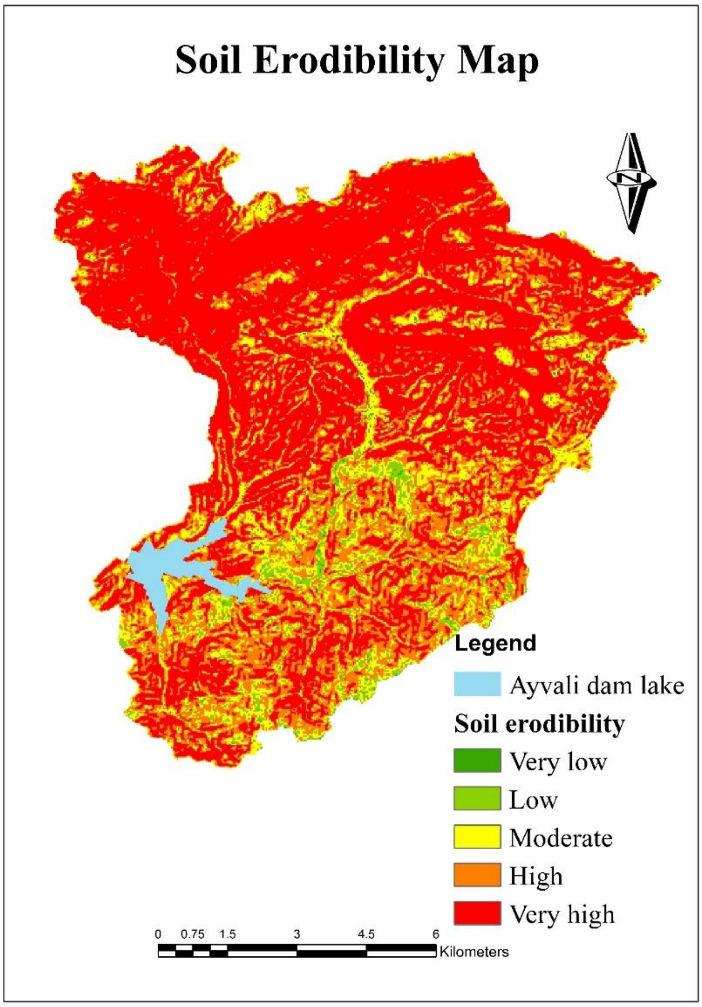

Figure 5. The erodibility map of the Ayvalı dam watershed

Table 8. The distribution of erodibility classes in the Ayvalı dam watershed

Erodibility Classes	Area (ha)	Area (%)
Very low	51.77	0.50
Low	306.67	2.95
Moderate	1396.02	13.45
High	2576.68	24.83
Very high	6048.12	58.27

The land use/land cover map is shown in Figure 6. Table 9 exhibits that shrubs cover the largest area (46.3%) followed by forests (22.2%), rangelands and others (19.4%), dry farming (11.9%), and orchards (0.2%) in the study area. Land use type influence the level of soil erosion (Yuksel et al., 2008b; Cebecauer & Hofierka, 2008; Göl, 2009; Göl et al., 2010; Korkanç, 2018). In general, soil erosion tends to increase from forest lands to cultivated lands (Schiettecatte et al., 2008; Reis et al., 2021).

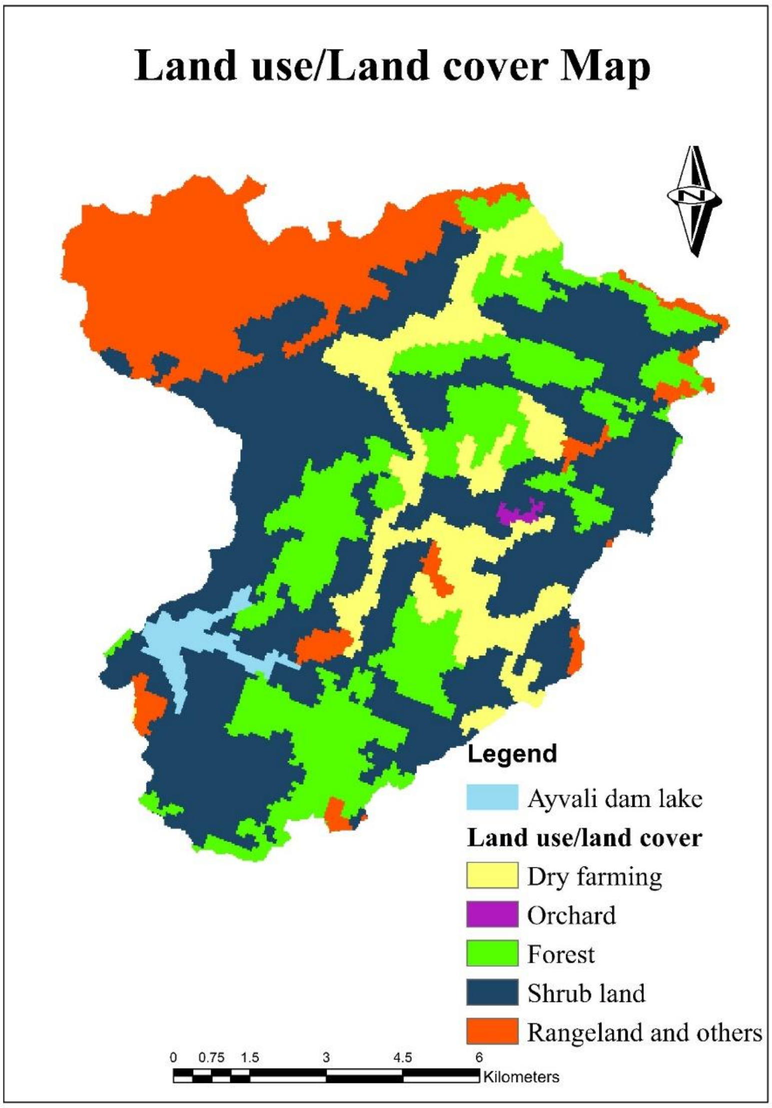

Figure 6. The land use/land cover map of the Ayvalı dam watershed

Table 9. The distribution of land use/land cover classes the Ayvalı dam watershed

Land use	Area (ha)	Area (%)
Dry farming	1238.73	11.9
Orchards	22.74	0.2
Forests	2300.12	22.2
Shrub	4805.80	46.3
Rangelands and others	2011.87	19.4

When the vegetation cover map is examined (Figure 7), it is remarkable that a large part of the study area (63.30%) has a vegetation density varying from 0 to 25%. It was found that 36.66%

of the watershed had a vegetation density of 25-50% while areas with 50-75% vegetation density were covered in only 0.04% of the study area (Table 10). It is reported that vegetation has a protection effect on the soil and consequently reduces erosion (Vrieling, 2006; Luo et al., 2014; Dengiz et al., 2014; Mirzaei et al., 2018). Therefore, it can be said that the low vegetation density was among the determinants behind the high soil erosion risk in the study area.

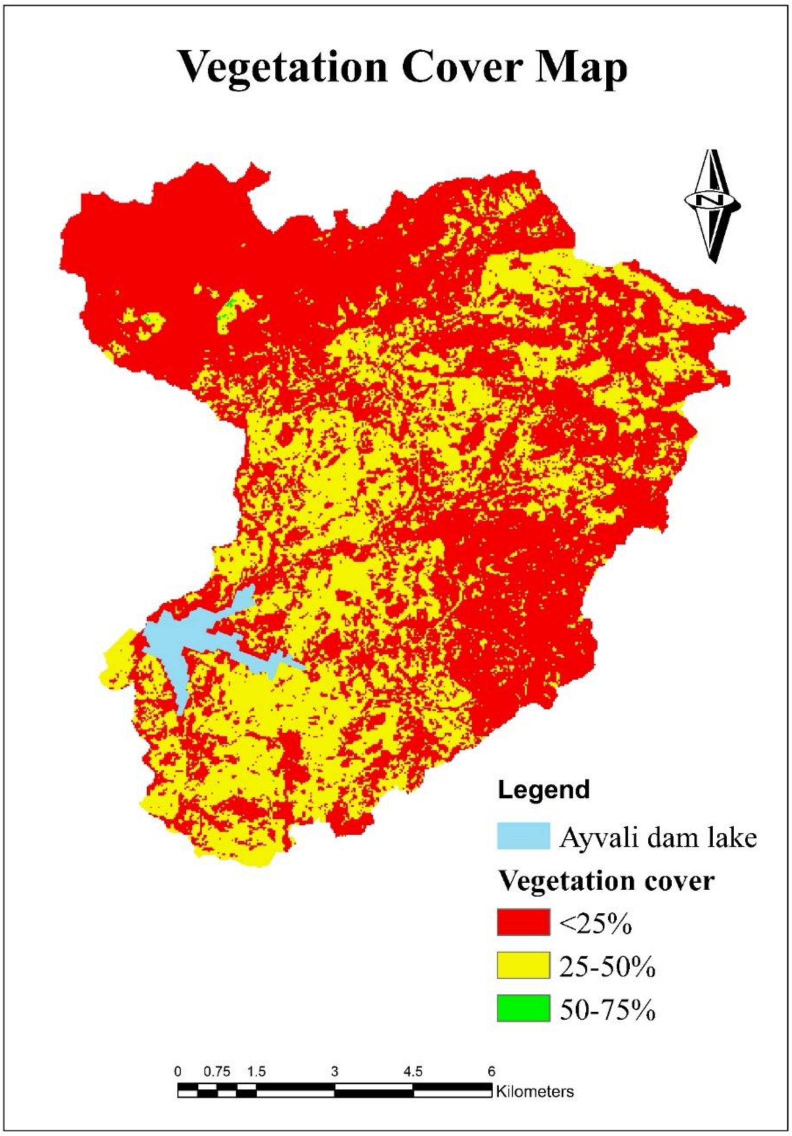

Figure 7. The vegetation cover map of the Ayvalı dam watershed

Table 10. The distribution of vegetation cover classes in the Ayvalı dam watershed

Vegetation cover	Area (ha)	Area (%)
<25%	6569.69	63.30
25-50%	3805.43	36.66
50-75%	4.13	0.04
>75%	-	-

Figure 8 shows the soil protection map produced by overlaying the land use/land cover map and the vegetation cover map. It was determined that the soil was highly protected in 0.004% of the study area while it was moderately protected in 14.54%, and very low-protected in 58.88% of the study area. There was no area with very high protection in the study area (Table 11). Therefore, it was understood that the soil protection level was generally low in a major part of the study area. This may be due to the satellite image which belongs to the winter season and the low vegetation density in the forest areas. However, it is not forgotten that the acquisition date of satellite images is extremely important for a realistic representation of soil protection (Farhan & Nawaiseh, 2015).

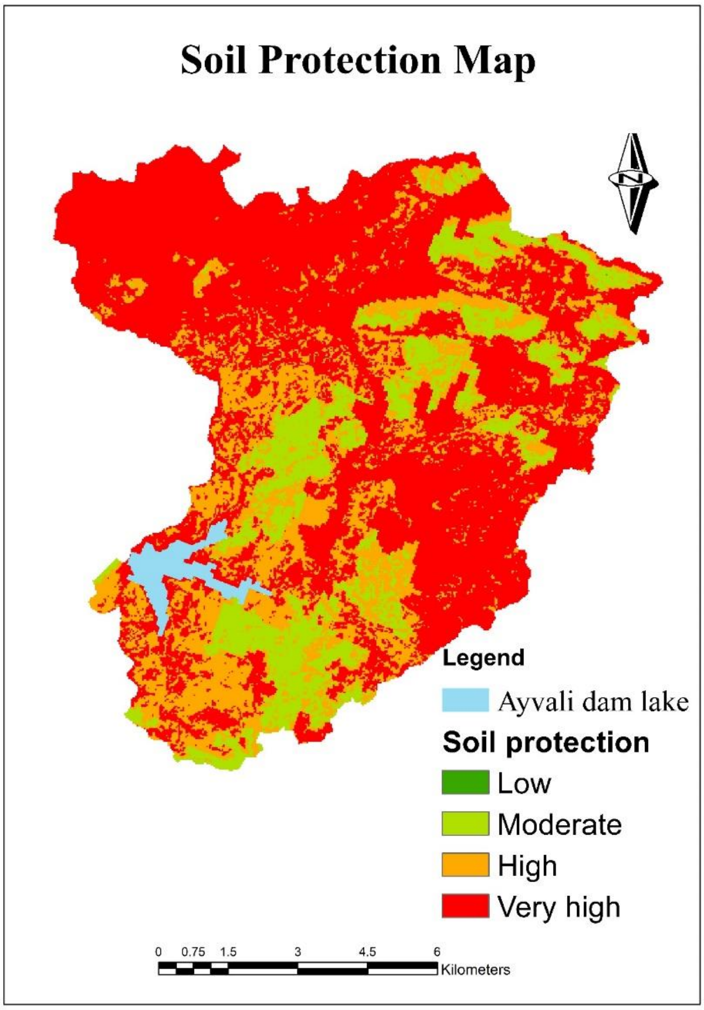

Figure 8. The soil protection map of the Ayvalı dam watershed

Table 11. The distribution of soil protection classes in the Ayvalı dam watershed

Soil protection	Area (ha)	Area (%)
Very high	-	-
High	0.45	0.004
Moderate	1509.54	14.544
Low	2758.15	26.574
Very low	6111.12	58.878

The soil erosion risk in the study area is presented in Figure 9. Table 12 suggests that 70.33% of the study area is subject to very high erosion risk, while 21.65%, 7.19%, 0.77%, and 0.05% of it are subject to high, medium, low, and very low erosion risk, respectively. The concentration of soil erosion risk under high and very high risk classes is a natural result of the ratio of steeply sloping areas in the study area and the vegetation density in these sloping areas. In addition to these conditions, since the bedrocks generally have a low resistance to weathering in the study area, it is inevitable that the soil erosion risk will be very high in a large part of the study area. Kefi et al. (2011) and Farhan & Nawaiseh (2015) stated that areas with very high erosion risk have steep slopes, low vegetation density, and high soil erodibility. In these areas, the runoff can easily reach a higher velocity due to the steep slope (Wolka et al., 2015). This situation causes to increase in the detachment and transportation possibility of soil particles under very low soil protection circumstances. In addition, it can be said that the soil erosion risk situation in the study area coincides with the Mediterranean ecosystems where soil erosion susceptibility is generally high (Berney et al., 1997; Terranova et al., 2009).

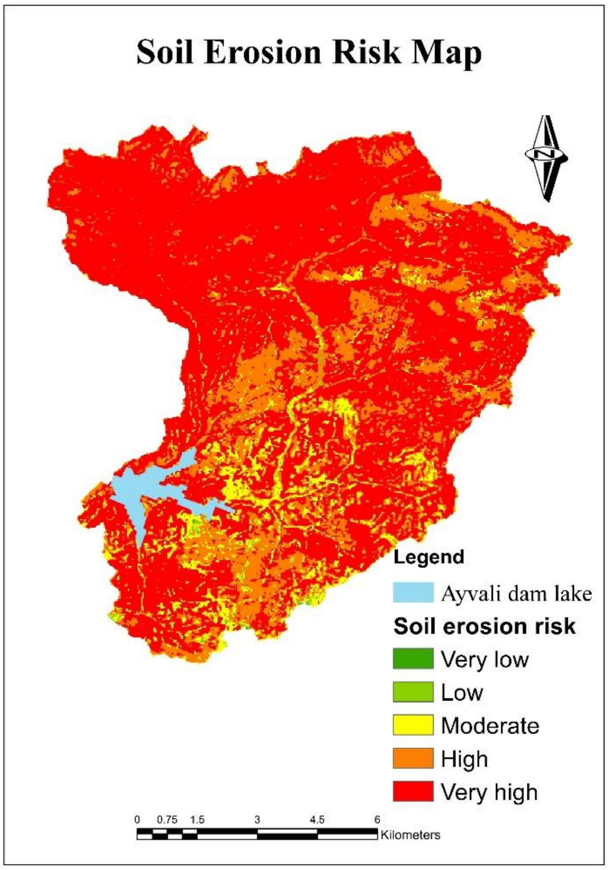

Figure 9. The soil erosion risk map of the Ayvalı dam watershed

Table 12. The distribution of soil erosion risk classes in the Ayvalı dam watershed

Erosion susceptibility	**Area (ha)**	**Area (%)**
Very low	5.48	0.05
Low	80.17	0.77
Moderate	746.45	7.19
High	2247.36	21.65
Very high	7299.79	70.33

It is crucial to test the accuracy of the soil erosion risk map. While reliable validation requires ground measurement of soil erosion, this is a difficult task, especially for watershed-scale studies (Verieling et al. 2006; Okou et al., 2016). For this reason, the validation process was skipped in many studies (Shrimali et al., 2001; Bayramin et al., 2003; Lu et al., 2004; Li et al., 2016; Reis et al., 2017b; Ediş et al., 2021). However, previous studies and field surveys in the area of interest were taken into account for validation (Kefi et al., 2011; Esmaeili Gholzom, 2022). In this context, the erosion status map generated by the General Directorate of Rural Services was used for the present study. According to this map, 26.7% of the watershed is subject to very severe erosion, while 30.8%, 41.9%, and 0.5% are subject to severe, moderate, and low erosion. According to this map, erosion is quite severe, especially in the northwest of the study area. In addition, Okatan et al. (2000) carried out a study in the Kızıldere stream watershed, which is one of the subwatersheds in the study area. Kızıldere stream watershed is located in the west and northwest of the study area. In their study, it was reported that the Kızıldere stream watershed is very sensitive to erosion.

In the present study, it was determined that a large part of the study area was subject to very high erosion and the very high erosion risk was concentrated in the northwest of the study area. Therefore, it can be said that the soil erosion risk map has satisfactory accuracy in light of these studies. In addition to these, as a result of field observations, it was observed that a major part of the study area is sensitive to erosion (Figure 10).

Figure 10. The soil erosion problems in the study area, a) a view from the northwest part of the study area, b) a view from the north part of the study area, c) the soil erosion under forest vegetation, and d) agricultural practices on the steep slopes.

When the distribution of soil erosion risk to land use types was examined, it was found that 72% of dry farming and 86.2% of the orchard were in the very high erosion risk class. In addition, soil erosion risk was very high in 81.5% of the shrubs and 89% of rangelands and others (Table 13). Table 13 shows that the areas of these land use types also decrease as the soil erosion risk decreases, In similar studies, these land use types generally are located in the areas with moderate and very high erosion risk (Beyramin et al., 2003; Stanchi et al., 2013; Esmaeili Gholzom et al., 2022). While 0.2% of forest areas were in the very low erosion risk class, 1.6%, 10.59%, 57.5%, and 29.7% of forest areas were in low, medium, high, and very high erosion risk classes, respectively. This result is not in line with similar studies. In these studies, forest areas are generally located in areas with very low and moderate soil erosion risk (Beyramin et al., 2003; Oruk et al., 2012; Luo et al., 2014; Esmaeili Gholzom et al., 2022). This contrary situation in the study area can be attributed to both low vegetation density and very high erodibility in forest areas (del Campo et al., 2022). In this context, when the forest management plan was examined, it was determined that 58.4% of the forest areas have crown closure with 0 and 1, while 24.97% of them have crown closure with 2. The ratio of crown closure with 3 in forest areas was determined as 16.99%. Therefore, it is clear that under these erodibility and vegetation density conditions, forest areas cannot fully protect the soil and consequently prevent soil erosion.

Table 13. The distribution of soil erosion risk to land use types

Land use	Erosion risk classes	Area (ha)	Area in the land use (%)	Area in the study area (%)
Dry farming	1	0	0	0.00
	2	11.86	1.0	0.11
	3	76.22	6.2	0.73
	4	258.76	20.9	2.49
	5	891.88	72.0	8.59
Fruit trees	1	0.00	0.0	0.00
	2	0.09	0.4	0.00
	3	0.00	0.0	0.00
	4	3.06	13.4	0.03
	5	19.59	86.2	0.19
Forests	1	5.48	0.2	0.05
	2	37.84	1.6	0.36
	3	251.48	10.9	2.42
	4	1321.69	57.5	12.73
	5	683.63	29.7	6.59
Shrub	1	0.00	0.0	0.00
	2	21.12	0.4	0.20
	3	379.65	7.9	3.66
	4	490.30	10.2	4.72
	5	3914.73	81.5	37.72
Rangelands and others	1	0.00	0.0	0.00
	2	9.26	0.5	0.09
	3	39.10	1.9	0.38
	4	173.56	8.6	1.67
	5	1789.96	89.0	17.25

On the other hand, when the distribution of soil erosion risk to slope classes was analyzed, 78.8% of the areas with a very low slope were subject to the low soil erosion risk, while 53.4% of the areas with low slopes were subject to medium soil erosion risk. It was found that 64.4%, 85%, and 81.9% of the areas with medium, high, and very high slopes, respectively had very high erosion risk (Table 14). This situation implies that vegetation cover is not enough to protect the soil in especially steep, very steep, and extreme slope classes. This finding is consistent with the results of Kefi et al. (2009) and Wolka et al. (2015) who reported that high slope and low soil protection conditions cause high soil erosion.

Table 14. The distribution of soil erosion risk to slope classes

Slope Class	Erosion risk classes	Area (ha)	Area in the land use (%)	Area in the study area (%)
Flat to gentle	1	5.48	9.12	0.05
	2	47.37	78.8	0.46
	3	7.28	12.1	0.07
	4	0.00	0.00	0.00
	5	0.00	0.00	0.00
Moderate	1	0.00	0.0	0.00
	2	32.81	2.9	0.32
	3	490.75	43.7	4.73
	4	600.22	53.4	5.78
	5	0.00	0.00	0.00
Steep	1	0.00	0.00	0.00
	2	0.00	0.00	0.00
	3	248.43	12.4	2.39
	4	466.39	23.2	4.49
	5	1292.12	64.4	12.45
Very steep	1	0.00	0.00	0.00
	2	0.00	0.00	0.00
	3	0.00	0.00	0.00
	4	576.31	15.0	5.55
	5	3265.70	85.0	31.46
Extremely steep	1	0.00	0.00	0.00
	2	0.00	0.00	0.00
	3	0.00	0.00	0.00
	4	604.44	18.1	5.82
	5	2741.97	81.9	26.42

In the study area, it was found that 82.3% of dry farming and 86.2% of orchard areas were located in areas where the slope is more than 12% (Table 15). This situation causes increasing soil erosion risk in the study area. Millward & Mersey (1999) stated that the use of areas with slopes of more than 12% for agricultural purposes accelerates soil erosion. The fact that 64.7% of the shrubs and 78% of rangelands and others were located in areas with very steep and extreme slopes is another important factor that increases soil erosion risk in the study area. A similar result was found in Esmaeili Gholzom et al. (2022) and it was stated that these fragile ecosystems (Stanchi et al., 2013) were subject to high soil erosion risk due to high slope and soil conditions.

Table 15. The distribution of land use types to slope classes

Land use	Slope Class	Area (ha)	Area in the land use (%)	Area in the study area (%)
Dry farming	1	12.22	0.99	0.12
	2	206.63	16.7	1.99
	3	302.54	24.4	2.91
	4	497.31	40.15	4.79
	5	220.03	17.76	2.12
Fruit trees	1	0.09	0.4	0.00
	2	3.06	13.4	0.03
	3	7.19	31.6	0.07
	4	11.15	49.0	0.11
	5	1.26	5.53	0.01
Forests	1	11.59	0.50	0.11
	2	171.22	7.44	1.65
	3	338.04	14.7	3.26
	4	842.36	36.6	8.12
	5	936.91	40.7	9.03
Shrub	1	26.16	0.54	0.25
	2	570.65	11.87	5.50
	3	1098.24	22.85	10.58
	4	1946.35	40.5	18.75
	5	1164.40	24.2	11.22
Rangelands and others	1	10.07	0.50	0.10
	2	172.21	8.56	1.66
	3	260.92	12.97	2.51
	4	544.85	27.1	5.25
	5	1023.82	50.9	9.86

When forest areas were investigated, it was seen that only 0.5% of these areas were located in areas with flat to gentle slopes, while 7.44%, 14.7%, 36.6%, and 40.7% of these areas were located in areas with moderate, steep, very steep, and extreme slopes, respectively (Table 15). Therefore, most of the forests in the study area were located in areas where the slope is quite high. The presence of forest areas on steep slopes has a reducing effect on soil erosion (Yazici & Turan, 2016; Aydın et al., 2018; Reis & Dutal, 2019; Esmaeili Gholzom et al., 2022). However, the vegetation density of forests must be at the highest level to provide soil protection services under these slope conditions (Gaatib & Larabi, 2014). The fact that forest areas in the study area cannot completely provide soil protection services due to low vegetation density supports this idea. However, the forests in the study area could prevent more concentration of soil erosion risk in the very high soil erosion risk class but they could not ensure that most of the forest areas are in the very low and low soil erosion risk class.

Effects of Forest Fire on Soil Erosion Risk

The erosion risk map depending on the forest fire scenario is shown in Figure 11. According to this scenario which assumes that all forest areas in the watershed will be destroyed as a result of forest fire, 83.6% of the watershed have a very high soil erosion risk while 11.14%, 5.30%, and 0.50% of it have high, medium, and low soil erosion risk, respectively (Table 16). In addition, the area with a very low risk does not exist in the study area.

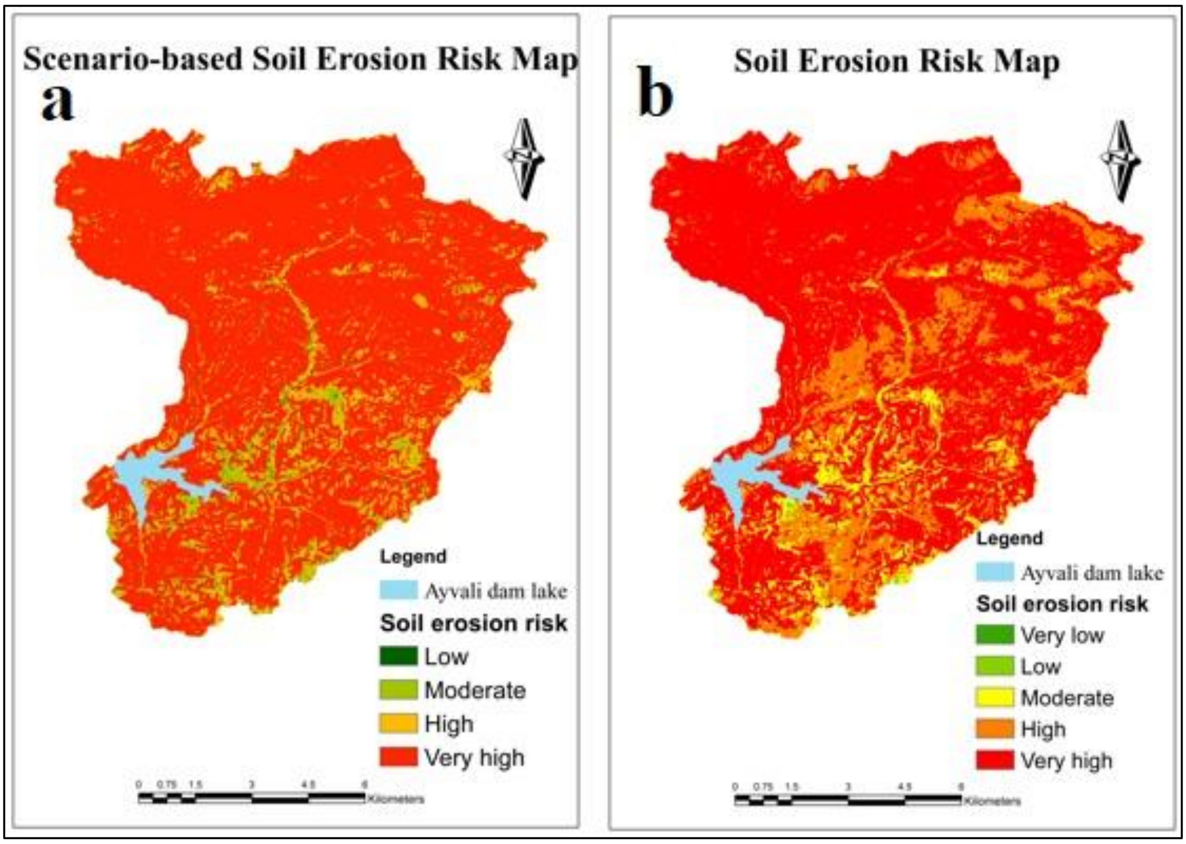

Figure 11. Soil erosion risk maps, a) based on the forest fire scenario and b) actual situation

Table 16. The distribution of soil erosion risk classes before and after the forest fire in the Ayvalı dam watershed

Erosion susceptibility	Area (ha) after the forest fire	Area (%) after the forest fire	Area (ha) before the forest fire	Area (%) before the forest fire
Very low	-	-	5.48	0.05
Low	51.77	0.50	80.17	0.77
Moderate	549.71	5.30	746.45	7.19
High	1156.31	11.14	2247.36	21.65
Very high	8621.47	83.06	7299.79	70.33

As a result of the fire scenario, it was determined that while the areas with the very high risk increased by 18.11%, areas with high, medium, low, and very low risk decreased by 48.55%, 26.36%, 35.43%, and 100%, respectively (Figure 12). Currently, the areas with high risk constitute 21.65% of the watershed (2nd largest area in the watershed) while 57.5% of forest areas are located in these areas (Table 12, Table 13). Therefore, the increase in the areas with very high risk is mainly due to the transformation of the areas with high risk into the areas with very high risk. This situation suggests that the forests in the study area have a reducing effect on soil erosion even though they have low density. As it is known, forest areas reduce the speed of raindrops, provide a protective cover to the soil during periods of heavy rainfall, reduce runoff and protect soil pores (Roose 1996; Kefi et al., 2011). Therefore, the conversion of forest areas to bare areas due to forest fires increases soil erosion risk. In addition, it should not be forgotten that the change in the soil erosion risk will vary depending on the size of the burned areas as well as the topographic, edaphic, climatic, and geological characteristics.

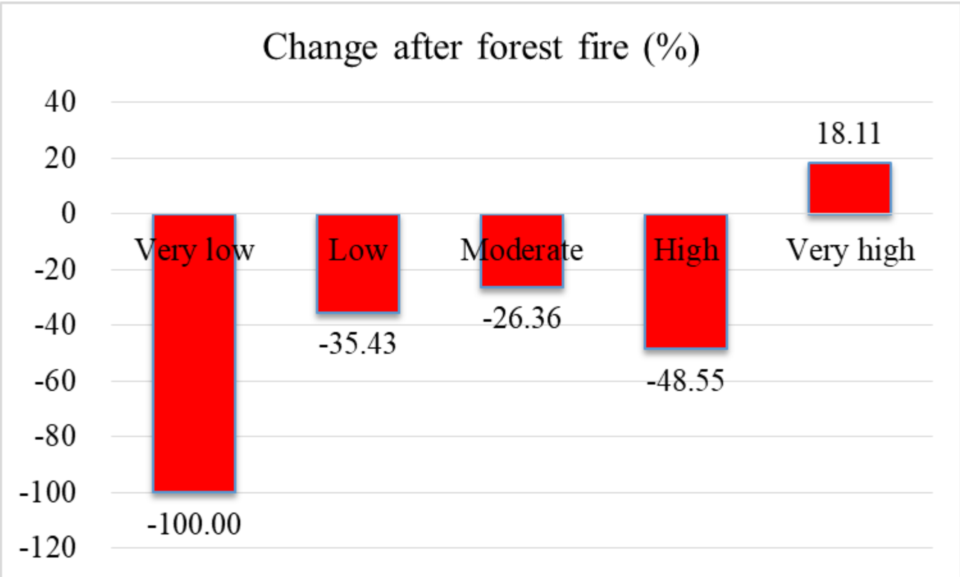

Figure 12. The change in the soil erosion risk classes after forest fire

CONCLUSIONS

In this study, the effect of forest fires on soil erosion risk was determined in the Ayvalı dam watershed. For this purpose, the current erosion risk map of the watershed was first produced by using the ICONA model. Then, a new soil erosion risk map was generated considering the forest fire scenario based on the assumption that all forest areas in the watershed were burned. Finally, the changes in soil erosion risk were determined by comparing these two maps. The results of the study can be listed as follows.

1. According to the ICONA model, 70.33% of the study area faces very high erosion risk, while 21.65%, 7.19%, 0.77%, and 0.05% face high, medium, low, and very low soil erosion risk, respectively. These results show that the study area is extremely sensitive to soil erosion.
2. It was found that scenario-based forest fire would cause an increase of 18.11% in the very high soil erosion risk class, while a decrease of 48.55%, 26.36%, 35.43%, and 100% in the high, medium, low, and very low soil erosion risk classes, respectively. This means that a major part of the study area is concentrated in a very high soil erosion risk class. Therefore, it indicates that forest fires can significantly increase soil loss in the watershed. In this context, it is necessary to be prepared for forest fires and to take preventive measures in the study area where the soil erosion risk is currently very high.
3. The study area is extremely sensitive to erosion in terms of parent material, slope, land use/land cover type, and vegetation density. It was revealed that the sparse forest cover on the sloping and erosion-sensitive bedrocks could not adequately prevent soil erosion in the study area. Therefore, silvicultural interventions should be carried out to increase the density of forest areas in the study area.
4. Climate is one of the most influential factors on soil erosion. Therefore, it can be said that the ICONA model which does not take into account the climate factor provides useful outputs for a general understanding of the distribution of soil erosion risk in a watershed.
5. It is thought that this study can be a guide for decision-makers to prioritize necessary precautions based on the soil erosion potential before and after forest fires and will make a small contribution to the related literature.
6. Finally, similar studies can be carried out using quantitative models that include soil erosion processes in order to more accurately and reliably reveal the effects of forest fires on soil erosion risk.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

ETHICS COMMITTEE APPROVAL

This study does not require any ethics committee approval.

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