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Determining the Effect of Forest Fires on Soil Loss Using RUSLE and a New Approach: The Case of Çınarpınar Forestry Enterprise/Türkiye

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Abstract: Soil erosion by water (WSE) is an environmental, economic, and sociological problem in the world. Nowadays, forest fires have triggered more WSE, especially in the Mediterranean basin. Therefore, the present study aims to determine the impact of forest fires on soil loss susceptibility in the Çınarpınar Forestry Enterprise, Türkiye. The RUSLE model was used to determine soil loss. Two soil loss maps were generated for the actual situation (base scenario) and forest fire scenario. For the forest fire scenario, R, K, and LS factors in the RUSLE model were modified based on the forest fire severity index. Finally, two maps representing base and forest fire scenarios were compared. The actual mean soil loss was found as 5.34 t ha^{-1} $year^{-1}$ in the Çınarpınar Forestry Enterprise while the mean soil loss was determined as 12.44 t ha^{-1} $year^{-1}$ for the forest fire scenario. It was found that forest fires would increase soil loss by more than 2 times in the study area. Areas with very low soil loss susceptibility to forest fires constitute 41.97% of productive forests, while areas with very high, high, medium, and low soil loss susceptibility constitute 3.64%, 9.28%, 27.50%, and 17.61% of productive forests, respectively. It was also found that there is not always a linear relationship between fire severity and soil loss susceptibility under natural conditions. Consequently, it is hoped that this study will help decision-makers in the implementation of the multi-purpose approach, which aims to reduce the risk of both forest fire and soil loss.

Keywords: Mediterranean basin, forest fire severity, RUSLE, soil erosion.

Orman Yangınlarının Toprak kaybı üzerindeki etkisinin RUSLE ve Yeni Bir Yaklaşım Kullanılarak Belirlenmesi: Çınarpınar Orman İşletme Şefliği Örneği/Türkiye

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Öz: Su erozyonu dünya genelinde çevresel, ekonomik ve sosyolojik bir sorundur. Günümüzde orman yangınları, özellikle Akdeniz havzasında, su erozyonunun daha fazla oluşmasını tetiklemektedir. Bu nedenle, bu çalışma Türkiye'de Çınarpınar Orman İşletmesi'nde orman yangınlarının toprak kaybı duyarlılığı üzerindeki etkisinin belirlenmesini amaçlamaktadır. Toprak kaybı RUSLE modeli ile belirlenmiştir. Mevcut durum (ana senaryo) ve orman yangını senaryosu için iki toprak kaybı haritası oluşturulmuştur. Orman yangını senaryosu için, RUSLE modelindeki R, K ve LS faktörleri yangın şiddet indeksine bağlı olarak değiştirilmiştir. Son olarak, ana ve orman yangını senaryolarını temsil eden iki harita karşılaştırılmıştır. Çınarpınar Orman İşletmesi'nde mevcut ortalama toprak kaybı 5,34 t ha^{-1} $yıl^{-1}$ olarak bulunurken, orman yangını senaryosu için ortalama toprak kaybı 12,44 t ha^{-1} $yıl^{-1}$ olarak belirlenmiştir. Orman yangınlarının çalışma alanındaki toprak kaybını 2 kattan fazla artırabileceği tespit edilmiştir. Orman yangınlarına karşı çok düşük toprak kaybı duyarlılığına sahip alanlar verimli ormanların %41,97'sini oluştururken, çok yüksek, yüksek, orta ve düşük toprak kaybı duyarlılığına sahip alanlar verimli ormanların sırasıyla %3,64, %9,28, %27,50 ve %17,61'ini oluşturmaktadır. Doğal koşullar altında yangın şiddeti ile toprak kaybı duyarlılığı arasında her zaman doğrusal bir ilişki olmadığı da ortaya konulmuştur. Sonuç olarak, bu çalışmanın hem orman yangını hem de toprak kaybı risklerini azaltmayı amaçlayan çok amaçlı yaklaşımın uygulanmasında karar vericilere yardımcı olacağı ümit edilmektedir.

Anahtar kelimeler: Akdeniz havzası, Orman yangını şiddeti, RUSLE, Toprak erozyonu.

INTRODUCTION

Soil erosion is the phenomenon including detachment and transportation of soil fragments from their location by various erosive forces and deposition of them in a certain places (Sirjani & Mahmoodabadi, 2014). When this detachment and transportation process is driven by water, it is defined as soil erosion by water (WSE) (Raza et al., 2021). Soil erosion, which is actually a natural geological process, can accelerate with the effect of various factors such as land use, land use change, vegetation density, and unproper human activities (Yüksek et al., 2020; Alaboz et al., 2021; Dursun & Babalık, 2023). This situation is called accelerated erosion (Ganasri & Ramesh, 2016). Accelerated erosion (hereinafter referred to as WSE) brings ecological, economic, and sociological problems (Tanyaş et al., 2015; Thapa, 2020).

WSE causes not only onsite but also offsite damages. Due to WSE, the fertile top layer of the soil is carried away. This leads to a decline in soil fertility and thus crop productivity. In addition, WSE diminishes the water capacity of the dams while it degrades the water quality (Sharda et al., 2013). It causes a rise in sediment and pollutants and a decrease in biodiversity in streams. In streams that carry a high amount of sediment, WSE results in a blockage effect and consequently causes floods (Maina et al., 2019). Moreover, WSE also disrupts ecosystem services such as carbon absorption, as it leads to a decrease in vegetation density due to land degradation (Allafta & Opp, 2022). While 12% of the total terrestrial areas in the world are severely affected by erosion, WSE is responsible for approximately 70% of this ratio (Oldeman, 1994). For example, in Türkiye, 642 million tons of soil are transported to water reservoirs every year due to WSE (Erpul et al., 2018).

Especially in the last decades, WSE has become a global threat because of various reasons (Terranova et al., 2009). Forest fires have been one of the significant factors causing WSE as well as population growth, overgrazing, inappropriate agricultural practices, deforestation, and construction activities (Allafta & Opp, 2022). Most fires in Europe have resulted in increased runoff and peak flows. There has also been an increase in the sensitivity of the soil to erosion. It was stated that the WSE increased by several orders of magnitude depending on fire severity and specific location characteristics such as topography and vegetation (Coschignano et al., 2019; Morris & Moses, 1987).

In this context, considering the effects of forest fires on soil erosion, WSE has become an issue that needs more attention, especially in the Mediterranean basin. A rise in forest fire events is expected due to climate change in this region which is already prone to erosion because of its precipitation, topography, and soil characteristics (IPCC, 2022; Oguz et al., 2019; Terranova et al., 2009). Forest fires in many countries in the region confirm this expectation (FAO, 2006; Tselka et al., 2021). In addition, although forest fires events has decreased in some countries, very severe and widespread forest fires, called mega-fire, have begun to occur (Hirschberger, 2016).

Low-intensity forest fires (such as surface fires) may have little or no impact on soil loss, while high-intensity fires can cause significant increases in soil loss (Agbeshie et al., 2022). On the severity of the forest fire, vegetation condition, topography and climate characteristics are the main determinants (Estes et al., 2017; Fang et al., 2018). In this context, considering the fire severity in determining the effects of forest fires on soil loss is of great importance for more realistic results, since these factors and therefore fire severity are not homogeneous in a particular forest area (Coschignano et al., 2019)

Determination of WSE by conventional methods is quite expensive and time-consuming (Ganasri & Ramesh, 2016). Therefore, various models each of which has its own characteristic, application extent, and application purpose have been developed to predict soil loss. USLE/RUSLE (Universal Soil Loss Equation/Revised Universal Soil Loss Equation), WEPP (Water Erosion Prediction Project), ANSWERS (Areal Nonpoint Source Watershed Environment Response Simulation), LISEM (The Limburg Soil Erosion Model), SWAT (Soil and Water Assessment Tool), and AGNPS (Agricultural Non-Point Sources) are some of these models (Babalık et al., 2021; Dutal, 2022; Dutal & Reis, 2020; Merritt et al., 2003). GIS (Geographic Information System) and remote sensing data were also considered in the development of these models. This orientation has greatly facilitated the implementation of model applications in larger areas in recent years (Reis et al., 2017; Šúri et al., 2002; Yuksel et al., 2008).

Among these models, RUSLE is the frequently used one throughout the world (Bonilla et al., 2010; Jiang et al., 2015; Sharma et al., 2023). Integration with GIS, application in various scales, ease of application, and data requirement are the main reasons why the model is frequently preferred (Farhan & Nawaiseh, 2015). It can also predict the spatial distributions of soil loss amount and erosion risk in ungauged watersheds as it only needs knowledge about the watershed properties and climatic conditions (Kalambukattu & Kumar, 2017). Therefore, the RUSLE model has been the most appropriate model option to be used for the evaluation of soil loss in most developing countries where there is a data shortage for more complex models (Allafta & Opp, 2022).

In natural resource management, the identification of potential risk is at least as valuable as learning from past events. Therefore, determining the potential changes in soil loss which may occur as a result of forest fires for unburned forestlands will guide both proactive and multi-purpose approaches in natural resource management. While studies that reveal potential effect of fires on soil loss in unburned forestlands are limited throughout the world (De Girolamo et al., 2022; Terranova et al., 2009), there is no study on this issue in Türkiye. Studies in Türkiye, have focused on soil loss for burned forest areas by using the fire severity indexes (Bayazıt & Koç, 2022; Değerliyurt, 2014). In addition, comparing different soil erosion scenarios allows decision-makers to use labor and financial resources in the most efficient way to prevent environmental damage and related costs (Singh & Kansal, 2023; Vijith et al., 2018). Thus, present study aims to 1) determine the soil loss amount in the Çınarpınar Forestry Enterprise by using the RUSLE model, 2) map the potential forest fire severity of the study area, and 3) reveal the potential impact of forest fires on soil loss with a scenario-based approach depending on the potential forest fire severity

MATERIAL AND METHOD

Study area: This study was performed within the boundaries of Çınarpınar Forestry Enterprise (ÇFE) in Türkiye (Figure 1). ÇFE is extended from 37°32′ to 37°44′ North latitudes and from 36°31′ to 36°52′ East longitudes. ÇFE is about 25 km away from the Kahramanmaraş city center. In addition, a little part of the reservoirs of Kılavuzlu and Sır Dams is located in the boundaries of ÇFE. Moreover, some of the streams in ÇFE flow into the reservoirs of Kılavuzlu, Sır, and Menzelet dams. The total area of ÇFE is 30591.5 ha. However, the study area is 27274.1 ha as the reservoir areas in ÇFE were not taken into account in the process of soil loss calculation.

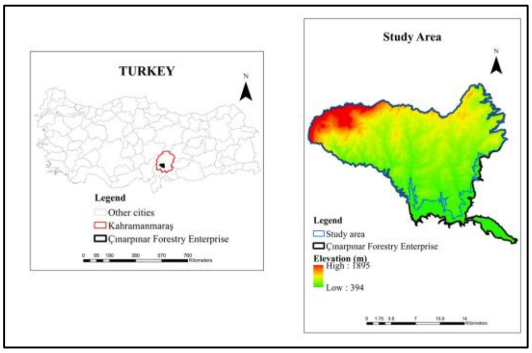

Figure 1. The location of Çınarpınar Forestry Enterprise.

The altitude in the study area varies between 407 and 1895 m (Figure 2). The average slope is 30.5% (Figure 3). The Mediterranean climate is experienced in the ÇFE, with dry and hot summers and warm and rainy winters. While the average maximum precipitation (130.6 mm) falls in December, the average minimum precipitation (2.2 mm) falls in August. The annual average rainfall is 721.6 mm according to the period of 1930-2022. While the mean lowest temperature is 1.4 °C in January, the mean highest temperature is 36.1 °C in August (GDMS, 2022).

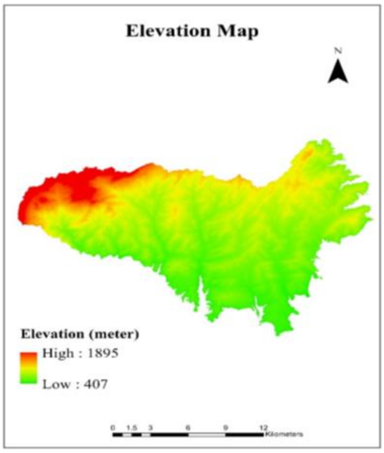

Figure 2. The elevation map of the study area.

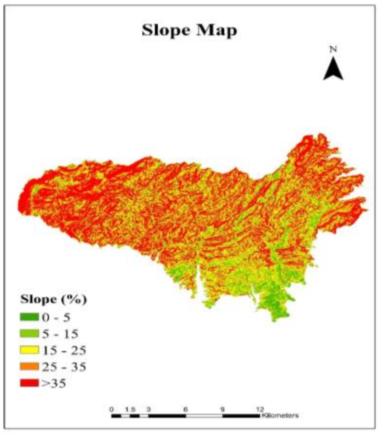

Figure 3. Slope map of the study area.

Approximately 66% of the study area comprises forest areas. However, about 70% of these forest areas are productive forests and the rest is degraded forest areas. Calabrian pine stands (*Pinus brutia*, Ten.), which are extremely sensitive to fire, have the highest ratio in these forest areas. Agricultural areas constitute 16% of the study area and are generally concentrated in regions where the slope is relatively less. Grasslands in forest cover 14% of the study area, while residential areas cover 2% of it (Figure 4).

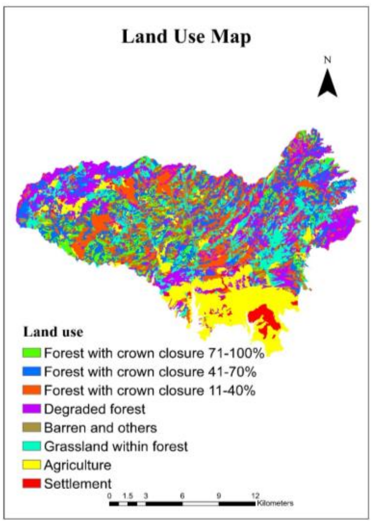

Figure 4. Land use map of the study area..

Method: In the present study, the geographical distribution of the changes in soil loss amount was determined based on the difference between the present soil loss map (base scenario) and the soil loss map based on the forest fire severity potential (fire scenario). Thus, soil protection hotspots against forest fires were revealed. In short, a new approach revealing the possible changes in soil loss based on the potential forest fire severity for unburned forest areas was used in this study (Figure 5). The RUSLE model (Renard et al., 1997) was preferred to determine the soil loss in the ÇFE. It was selected due to its ease to use, data requirement, robustness, GIS integration, and wide use (Allafta & Opp, 2022). The forest fire severity potential was determined depending on the parameters driving the fire behavior. All maps required for this study were produced with ArcGIS software.

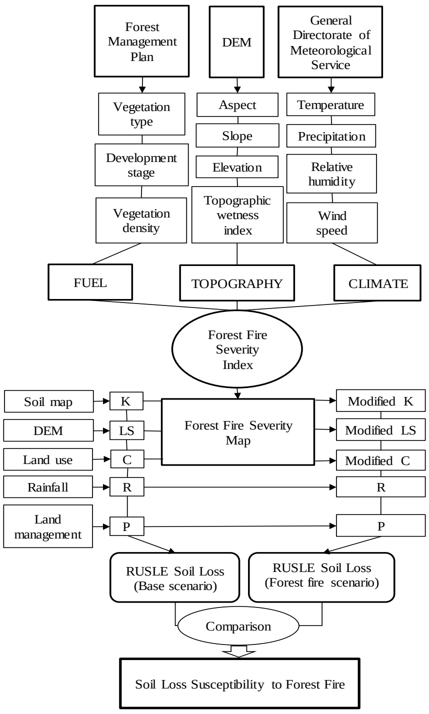

Figure 5. Flowchart of the study.

RUSLE model: The RUSLE is one of the frequently preferred methods for erosion-related studies (Tselka et al., 2021). The model was developed by revising the USLE model. The RUSLE model, which can predict the rill and interrill erosion, is the product of long-lasting experiments (Tselka et al., 2021). It considers five parameters and the soil loss is calculated with the following formula 1.

A=R*K*LS*C*P (1)

Where A is the soil loss amount (ton ha-1 year-1); P is the support practice factor (dimensionless); K is the soil erodibility factor (ton ha h ha-1 MJ-1 mm-1); R is the rainfall and runoff factor (MJ mm ha-1 h-1 year-1); LS is the slope length and steepness factor (dimensionless); C is the cover and management factor (dimensionless).

R factor: R is an indicator of the erosive power of precipitation. The sum of the EI values obtained by multiplying the energy of each precipitation that can cause erosion (>12.7 mm) by its maximum 30-minute intensity in a year period is the R value of that year. The average annual R value is used in the RUSLE model. Since these data, which are necessary for the calculation of the R value, are not available for many regions of the world, the R value is calculated by various methods (Kalambukattu & Kumar, 2017; Lanorte et al., 2019; Thapa, 2020). In this study, the following formula 2 was used to calculate R similar to the studies by Aytop and Şenol, (2022) and Tüfekçioğlu and Yavuz, (2016).

R=(4.17*MFI)-152 (2)

Where MFI represents the Modified Fornier Index and calculated with the formula 3.

$$MFI = \sum_{1}^{12} \frac{Pi^2}{P} \quad (3)$$

Where Pi represents the monthly precipitation of ith month (mm); P is the yearly precipitation (mm).

In the present study, monthly precipitation values for the years 1930-2022 of Kahramanmaraş Meteorology Station (KMS), which is the nearest station to the ÇFE area, were used. R value calculated for KMS is interpolated to the study area. Therefore, the altitude is firstly classified at intervals of 100 m in the study area. Then, the annual precipitation amount for each altitude class was calculated by formula 4.

$$P_L = P_S + 54 * \left(\frac{E_L - E_S}{100}\right) \quad (4)$$

Where PL is the yearly precipitation of each elevation class in the Çınarpınar Forestry Enterprise (mm); PS is the yearly precipitation of KMS (mm); EL is the average elevation of each elevation class in the study area (m); ES is the elevation of KMS (m)

Finally, formula 5 was used to determine the R value for each elevation class.

$$R_L = R_S * \left(\frac{P_L}{P_S}\right) \quad (5)$$

Where RL is the R value of each elevation class in the ÇFE; RS is the R value of KMS

K factor: The K factor varies depending on both the sensitivity of the soil to detachment and the runoff ratio. The higher the K value, the lower the soil's resistance to erosion. It is influenced by texture, structure, permeability, and organic matter (Thapa, 2020). In the present study, K values were determined based on the great soil groups map of the ÇFE. This map is taken from the Ministry of Agriculture and Forestry, General Directorate of Agricultural Reform (TRGM, 2021). Considering the literature (Değerliyurt, 2013; İrvem & Tülücü, 2004; Koralay & Kara, 2020; Özdemir & Tatar Dönmez, 2016; Özden & Özden, 1997), a K value was assigned to each soil group. Before the soil loss calculation process, the K values in Table 1 were converted to the international system.

Table 1. K values assigned to great soil groups.

Great Soil Groups	K-value (ton *acre *hour)*(hundreds of acre foot-tonf *inch)$^{-1}$
Alluviyal	0.18
Koluvial	0.18
Brown Forest	0.20
Non Calcic Brown	0.20
Red-Brown Mediterranean	0.15

LS factor: The impact of topography on soil loss is revealed by the LS factor in the RUSLE model. L represents the distance between the start and end points of the runoff, while S represents the slope gradient of this L surface. A rise in the L value results in increasing the amount of runoff, while a rise in the S value results in increasing the erosivity and velocity of the runoff. Therefore, a rise in these factors means a rise in soil loss.

The LS factor was determined with the following formula 6 (Tselka, 2021).

$$LS = (\frac{a}{a_0})^u * (\sin(b * 0.01745)/0.0896)^n \quad (6)$$

Where "a" is the pixel size times flow accumulation; a_0 is 22.13; u is a variable length-slope exponent; b is the slope in degree; n is the slope gradient exponent. In this study, u and n were set to 0.4 and 1.3, respectively.

DEM data with 30*30 m resolution was used to calculate the LS factor.

C factor: The C factor reflects the degree to which vegetation prevents soil loss. As it is known, vegetation both reduces the erosive effect of raindrops and increases the mechanical durability of the soil through its roots (Depountis et al., 2020). This factor ranges from 0 to 1, based on the density and type of vegetation. As the vegetation density rises, the C decreases. It was determined depending on the land use map in this study. The Çınarpınar forest management plan was taken in to account to generate the land use map. Considering the previous studies (Al-Quraishi, 2003; Değerliyurt, 2013; Swarnkar et al., 2018; Wischmeier & Smith, 1978), the C values for each land use were determined (Table 2).

Table 2. Assigned C values to land uses.

Land Use/Land Cover	C-value
Forest with crown closure 71-100%	0.0006
Forest with crown closure 41-70%	0.003
Forest with crown closure 11-40%	0.006
Degraded forest	0.19
Non-wood, bare, and others	0.20
Grassland in forest	0.08
Agriculture	0.30
Settlement (Medium intensity)	0.20

P factor: It represents the impact of soil protection measures (terracing, contour, etc.) on soil loss. As these practices decrease the runoff rate, they contribute to the reduction of the soil loss amount. P factor has no dimension and ranges between 0 and 1. The value of 1 indicates that there is no protection application. The P value approaches 0 as the intensity of the soil erosion measures increases (Depountis et al., 2020). In this study, the value of 1 was used for the whole study area.

Model validation: When the RUSLE model results were compared with the measured results, the RUSLE model overestimates low soil loss while it underestimates high values (Kinnel, 2005; Rapp et al., 2001). Abu Hammad et al., (2005) stated that RUSLE model results would be 3 times higher than the observed values in the Mediterranean basin. In addition to these findings, Šúri et al., (2002) reported that it would be a more accurate approach to use the RUSLE model in comparison studies than using it for absolute results. Therefore, it can be said that validation of the RUSLE model is not a crucial component for comparison studies. Since two different scenarios (base and forest fire) were compared in the present study, the RUSLE model was not validated. Obtained results were compared with similar studies. It is already seen that the RUSLE model is not validated in most of the scenario-based studies and the results are compared with previous studies (Terranova et al., 2009).

Forest fire severity map: The effects of forest fires on soil properties are not uniform and vary spatially depending on the fire severity (Coschignano et al., 2019). Soil properties change more in areas with higher fire severity, while they change less in areas with lower fire severity (Agbeshie et al., 2022; Schoenholtz, 2004). Therefore, the spatial distribution of fire severity must first be revealed to determine the potential impacts of forest fires on soil loss. Fire severity indicates the changes in vegetation, litter, and soil after a forest fire (Agee, 2007; Han et al., 2021; Keeley, 2009). Nowadays, the spatial distribution of fire severity in burned forest areas can be mapped by using various indices (Gokkaya, 2022; Montealegre et al., 2014; Morgan et al., 2014). However, since this study aims for a scenario-based evaluation of change in soil loss, it is necessary to reveal the potential fire severity of unburned forest areas. In this study, this potential fire severity was determined through the factors that drive fire behavior. These factors are fuel, topography, and weather (Balde et al., 2023; Estes et al., 2017; Sugihara et al., 2006; Zald & Dunn, 2018). However, in this study, the weather parameter was kept constant because there is only 1 meteorology station. In addition, the study area is not too large to cause notable differences in climatic parameters. Therefore, potential fire severity was determined by an index including fuel and topography factors. While the fuel factor consists of vegetation type, vegetation density, and development stage parameters, the topography factor consists of slope, elevation, aspect, and TWI parameters. While the parameters under the fuel factor were obtained from the Çınarpınar forest management plan, the topographic parameters were derived from the DEM data. Table 3 and Formula 7 (adopted from Sivrikaya & Küçük, 2022) were used to determine the fire severity index. A higher fire severity index value indicates a higher fire severity potential while a lower index value indicates a lower fire severity potential.

Table 3. Forest fire severity classes and parameter rates.

Parameter	Unit	Fire sensitivity class/rate									
		Very low		Low		Moderate		High		Very high	
		1	2	3	4	5	6	7	8	9	10
Vegetation type	Class	Fir	Oak, Other deciduous			Cedar				Black pine	Calabrian pine
Development stage	cm					36-51.9	<8	20-35.9			8-19.9
Vegetation density	%				11-40			41-70			71-100
Aspect	class	N	NE,NW	E		FLAT	SE,W		S		SW
Slope	%	0-5			5-15		15-25		25-35		>35
Elevation	m		0-500		500-1000		1000-1500		1500-2000		
Topographic wetness index			11.31-21.70		8.38-11.31		6.48-8.38		5.16-6.48		3.04-5.16

$$FSI=0.6*(0.5485*VT+0.2409*DS+0.2106*CC)+0.4*(0.4353*A+0.3569*S+0.1330*E+0.0748*TWI) \quad (7)$$

Where FSI is forest fire severity index, VT is vegetation type, DS is the development stage, CC is crown closure, A is aspect, S is the slope, E is elevation, TWI is topographic wetness index.

Effect of forest fires on soil loss: To reveal the impact of forest fires on soil loss, some modifications were made in K, LS, and C parameters depending on the fire severity, because it was reported that forest fires cause changes in these parameters of the RUSLE model (Curran et al., 2006; Gimeno-García et al., 2007; González Bonorino & Osterkamp, 2004; Terranova et al., 2009). Considering the previous studies, the modifications depending on the fire severity can be seen in Table 4 (Lanorte et al., 2019; Larsen & MacDonald, 2007; Miller et al., 2003; Terranova et al., 2009). Any information about the effects of fires on the relevant parameters in degraded forest areas and other land uses within the forest borders could not be reached. Therefore, the effect of forest fires in productive forest areas was taken into account in this study. This effect was determined as a result of comparing the soil loss maps produced for base and forest fire scenarios. Considering the changes in soil loss, soil protection hotspots against forest fires were revealed.

Table 4. The parameter modifications in the RUSLE model after forest fires.

RUSLE Parameter	Modification Process	Forest Fire Severity Class				
		Very Low	Low	Moderate	High	Very High
K	Multiplication	1.6	1.7	1.8	1.9	2.0
The exponent "u" in the LS formula	Replacement	0.42	0.44	0.46	0.48	0.50
C	Replacement	0.005	0.015	0.05	0.125	0.2

RESULTS AND DISCUSSION

In the present study, the susceptibility of soil loss against forest fires was determined, and thus the areas that need to be protected the most against forest fires were revealed to minimize the soil loss. For this, a scenario-based approach was adopted. The actual soil loss map of the ÇFE was considered as the base scenario. The potential soil loss that may occur as a result of forest fires was called the forest fire scenario. Soil loss maps generated according to these two scenarios were compared and soil loss susceptibility to forest fire was revealed. The areas with the greatest change in soil loss were considered as the areas where the most precautions should be taken against forest fires. Soil loss was determined by the RUSLE method. To produce the soil loss map for the forest fire scenario, the R, K, and LS parameters were changed depending on the potential forest fire severity map. In this study, a potential fire severity map was produced by using a potential fire severity index depending on the parameters affecting forest fire behavior. Most previous studies evaluated the impact of forest fires on soil loss for burned areas (Depountis et al., 2020; Efthimiou et al., 2020; Lanorte et al., 2019; Tselka et al., 2021). However, studies to determine the areas where proactive measures should be intensified in order to minimize the soil loss that may occur as a result of forest fires have not been emphasized much. Therefore, this study contributed to the limited studies on this subject in the literature with a new approach.

The R value in the study area varied between 215 and 493. While R reached its maximum values in the northwest of the ÇFE in parallel with the elevation, it decreased to minimum values in the southern parts (Figure 6). While the very high and high R classes constituted 12.52% of the ÇFE, the low and very low R classes constituted 55.51% of the ÇFE.

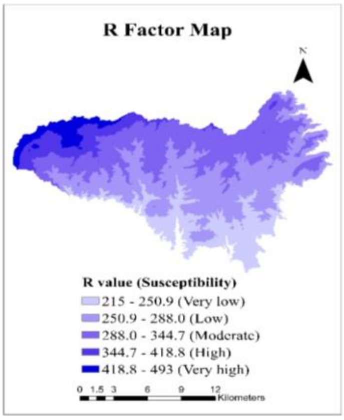

Figure 6. R factor map

The K values depending on the great soil groups were considered to produce the K map was (Figure 7). K values varied between 0.019 and 0.026. While most of the ÇFE (94.56%) is in the easily erodible class, the rest (5.44%) is in the moderately erodible class. These results showed that a large part of the ÇFE is prone to erosion.

The LS factor in the ÇFE ranged from 0.0 to 763.23 (Figure 8). The standard deviation and mean for the LS were found to be 13.69 and 7.54, respectively. Specifically, the LS factor was divided into five classes in the ÇFE. While the very high class constituted 51.52% of the ÇFE, the high, moderate, low, and very low classes constituted 43.33%, 4.58%, 0.50%, and 0.06% of the study area, respectively. LS values were less than 27 in the large part of the study area.

In areas near seasonal streams, LS was more than 75. This result is in accordance with the study by Kalambukattu and Kumar, (2017). While LS was higher in steeply sloping northwest regions of the ÇFE, it was lower in low-lying areas located in the south. This clearly showed the dominant effect of slope on LS. Similar results were found by Farhan and Nawaiseh, (2015) and Allafta and Opp, (2022). In addition, Tüfekçioğlu and Yavuz, (2016), Danacıoğlu and Tağıl, (2017), and Alparslan and Küçükönder, (2021) reported similar results about the effect of slope on LS in their studies in Türkiye.

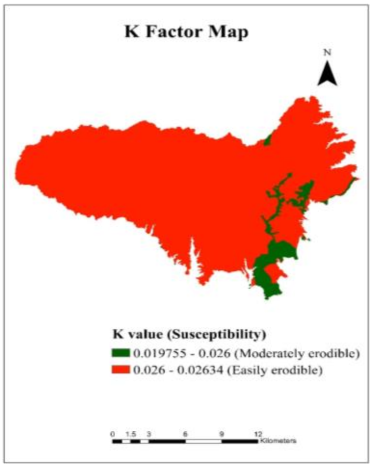

Figure 7. K factor map.

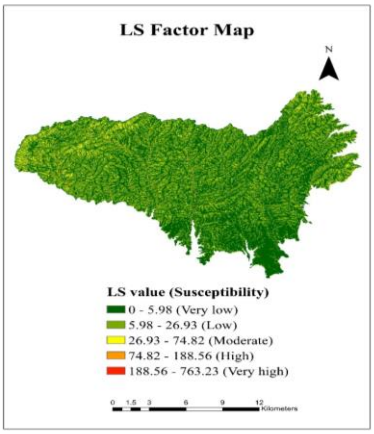

Figure 8. LS factor map.

The C value was determined according to the land uses in the ÇFE. The dominant land use in the study area is forest. While about 70% of these forest areas are productive forests, 30% are degraded forests. Agriculture, residential, and grasslands cover 16.19%, 1.98%, and 13.93% of the study area, respectively. Depending on these land use conditions, the C value in the ÇFE varied between 0.0006 and 0.30. While the central and western parts of the ÇFE had a lower C value, the southern parts where agricultural areas are concentrated had a higher C value (Figure 9).

The value of P factor was accepted as 1 for the whole study area because no soil and water conservation measures were taken in the study area.

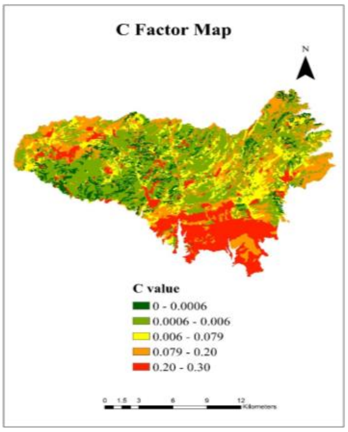

Figure 9. C factor map

The soil loss map produced by combining RUSLE model factors is shown in figure 10. This map was divided into 5 soil loss classes. A very large part of the ÇFE (66.16%) has a very low soil loss. While 9.04% of the ÇFE is subject to very high soil loss (>20 t ha^{-1} $year^{-1}$), 9.17% is subject to high soil loss (10-20 t ha^{-1} $year^{-1}$). Whereas 8.65% of the study area has a moderate soil loss, 6.98% of it has a low soil loss. High and very high soil loss classes are intensified in the northwest and southern parts of the ÇFE, while low and very low soil loss classes are intensified in the central and western parts of the ÇFE.

It was determined that the soil loss amount in the ÇFE ranged from 0 to 1306 t ha^{-1} $year^{-1}$. The mean soil loss was calculated to be 5.34 t ha^{-1} $year^{-1}$. Soil loss in the Mikail basin where 25 km away from the study area was determined to be 335.6 t ha^{-1} $year^{-1}$ by using the RUSLE model (Aytop & Şenol, 2022). Despite the same climatic conditions, the main reason causing this difference in soil loss can be ascribed to land use. A large part of the Mikail basin has a slope of more than 20% similar to the ÇFE. The land use in these steep areas is generally degraded forest and agricultural areas in the Mikail basin whereas steep sloping areas in the study area are generally covered by productive forest. Considering the impacts of slope and land use on soil loss, it is clear why the study area has less soil loss than the Mikail watershed. According to the scenario of an increase in forest areas in the Mikail basin, soil loss decreased by 79% and was found as 69.05 t ha^{-1} $year^{-1}$. This result also proves why the ÇFE has less soil loss. Additionally, soil loss in the Ceyhan basin which includes the study area was calculated to be 7.10 t ha^{-1} $year^{-1}$ (ÇEM, 2018). However, various soil loss values were also found in the Mediterranean basin. For instance, in a study carried out in the Estaña basin in Spain, it was calculated that the soil loss was 2.3 t ha^{-1} $year^{-1}$ (López-Vicente & Navas, 2009). Rellini et al., (2019) calculated soil loss with the RUSLE model in the Portofino promontory in northwest Italy. The soil loss was found 9 t ha^{-1} $year^{-1}$ for this region, where the land use consists of mainly olive groves and maquis. Stefanidis et al., (2021) determined soil loss as 3.4 t ha^{-1} $year^{-1}$ with the RUSLE model in Kassandra

Peninsula in northern Greece. In a study by Efthimiou et al., (2020), the amount of soil erosion in the Rafina basin in Greece was found to be 4.53 t ha^{-1} year^{-1}. Therefore, it can be said that the soil loss value found in the present study is within reasonable limits.

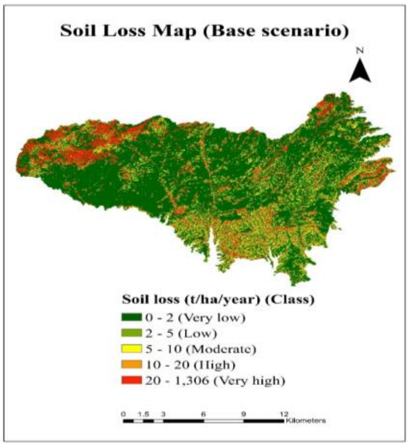

Figure 10. Soil loss map based on the base scenario.

Figure 11 shows the potential forest fire severity map produced by combining the parameters affecting fire behavior. When the map is examined, it is understood that the areas with very high and high fire severity potential are concentrated in the northwest and center of the study area. It was found that 30.77% of the productive forests had a very high fire severity, while 65.12%, 3.74%, and 0.37% of them had high, medium, and low fire severity, respectively. However, it was determined that there is no very low fire severity class in the study area.

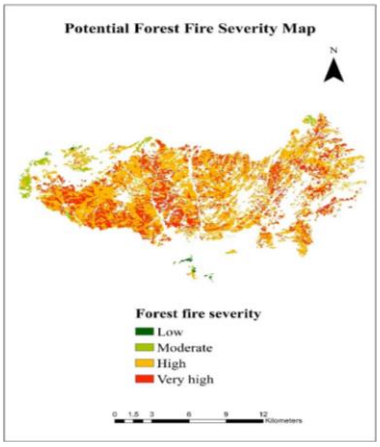

Figure 11. Potential forest fire severity map.

The soil loss map produced by considering the potential forest fire severity map is shown in figure 12. When the map is investigated, it is seen that very high and high soil loss classes are intensified in the west and northwest of the ÇFE. According to this map based on the fire scenario, 27.87% of the ÇFE is subject to very high soil loss, while 17.21%, 11.76%, 7.38%, and 35.78% of it are in the high, moderate, low, and very low soil loss classes, respectively.

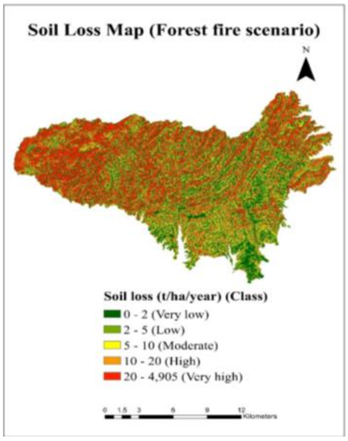

Figure 12. Soil loss map based on the forest fire scenario

It was determined that the highest soil loss value raised to 4905 t ha^{-1} year^{-1} after the fire. The mean soil loss was determined as 12.44 t ha^{-1} year^{-1}. When this value was compared with the actual situation (5.34), the forest fires would increase soil loss by more than 2 times. Similar findings were found in other studies. De Girolamo et al., (2022) determined that the sediment yield increased from 5.86 t ha^{-1} year^{-1} to 12.05 t ha^{-1} year^{-1} after the forest fire in Italy. Valkanou et al., (2022) found that the mean annual soil loss was 253 t ha^{-1} on Evia Island in Greece. They found that this value increased to 543 t ha^{-1} year^{-1} after the forest fire. Shakesby et al., (2015) stated that soil loss increased by 2-4 times after the forest fire. In addition, it was reported that the runoff and sediment yield is approximately 1-4 times higher after a forest fire in Mediterranean ecosystems (Garrido-Ruiz et al., 2022; Shakesby, 2011). These increases in soil loss after forest fires can be attributed to various reasons. Forest fires cause a decrease in soil organic matter, porosity, and saturated hydraulic conductivity, while increasing bulk density (Weninger et al., 2019; Wittenberg et al., 2020). Thus, both the water holding capacity and the infiltration decrease (Martin & Moody, 2001; Stoof et al., 2010). Moreover, it is known that fire increases soil water repellency whereas it decreases aggregate stability (Stoof et al., 2015). Additionally, changes in ground cover also play a significant role in soil loss (Durán Zuazo & Rodríguez Pleguezuelo, 2008; Göl et al., 2010; Korkanç, 2018; Ozalp et al., 2016; Yuksek & Yuksek, 2015; Yazıcı et al., 2018; Dursun & Babalık, 2023). The destruction of vegetation and litter makes the soil vulnerable to raindrops (Lucas-Borja et al., 2018; Shakesby et al., 1993). In addition, the loss of ground cover causes a decrease in interception and depression storage (Evelpidou et al., 2022; Reaney et al. 2014). This situation results in a significant rise in runoff, thus increasing erosion (Yüksek, 2009).

The changes caused by the potential forest fire in the areal distribution of soil loss classes in the ÇFE are presented in Table 5. While the very high soil loss class increased by 208.30%, the high soil loss class increased by

87.68%. However, the very low soil loss class reduced by 45.92%.

Table 5. The changes in soil loss classes after forest fire.

Soil Loss Class	Base Scenario (%)	Forest Fire Scenario (%)	Change (%)
0-2 (Very low)	66.16	35.78	-45.92
2-5 (Low)	6.98	7.38	5.73
5-10 (Moderate)	8.65	11.76	35.95
10-20 (High)	9.17	17.21	87.68
>20 (Very high)	9.04	27.87	208.30

Figure 13 indicates the geographic distribution of the change in soil loss after the fire scenario. In this map, the very high class represents the most susceptible areas to forest fires, while the very low class represents the least susceptible areas. While 3.64% of the productive forests were subject to very high susceptibility, 9.28%, 27.50%, 17.61%, and 41.97% of the productive forests were in the classes of high, medium, low, and very low susceptibility, respectively.

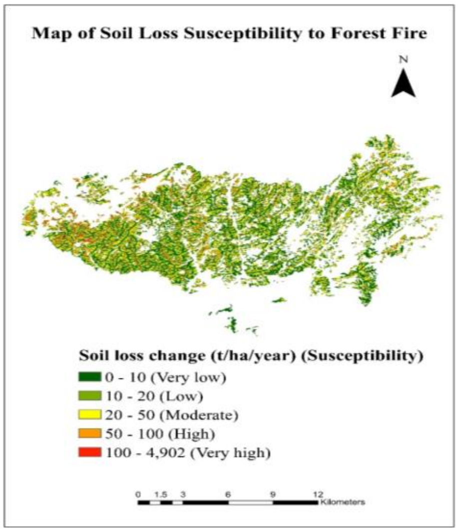

Figure 13. The map of soil loss susceptibility to forest fires.

When Figure 14 is investigated, it is understood that as the fire severity potential increases, the ratio of very low soil loss susceptibility decreases and the ratios of the rest of susceptibility classes increase. Additionally, the distribution of the soil loss susceptibility classes is generally similar in areas with moderate and high fire severity. However, the distribution of soil loss susceptibility classes to the very high fire severity class does not increase linearly.

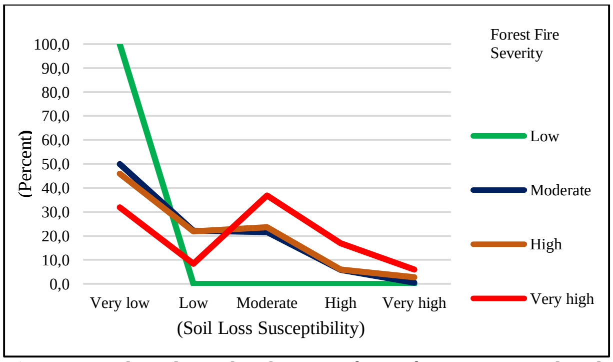

Figure 14. The relationship between forest fire severity and soil loss susceptibility classes.

Table 6 indicates the distribution of soil loss susceptibility classes to potential fire severity classes. Areas with low fire severity potential completely comprise of low soil loss susceptibility class. 50% of areas with moderate fire severity potential have very low soil loss susceptibility. While 45.9% and 31.9% of productive forests with high and very high fire severity potential, respectively have very low soil loss susceptibility, very high soil loss susceptibility constitutes 2.8% and 5.9% of high and very high fire severity classes, respectively. Therefore, soil loss susceptibility may be higher in areas with lower fire severity whereas soil loss susceptibility may be lower in areas with higher fire severity. This clearly implies that there is not always a linear relationship between forest fire severity and soil loss susceptibility in natural conditions. Lanorte et al., (2019) also found a similar relationship between fire severity and soil loss susceptibility.

Table 6. The distribution of soil loss susceptibility classes to potential fire severity classes.

	Soil Loss Susceptibility Classes				
Forest Fire Severity	Very Low	Low	Moderate (%)	High	Very High
Low	100.0	0.0	0.0	0.0	0.0
Moderate	50.0	22.1	21.6	5.8	0.5
High	45.9	21.8	23.6	5.9	2.8
Very High	31.9	8.4	36.9	17.0	5.9

One of the limitations is due to the capacity of the RUSLE model in the present study. While the RUSLE model is used to predict sheet and rill erosion (Ganasri & Ramesh, 2016), it does not take bank, gully, and channel erosion into account (Chalise et al., 2019). Therefore, future studies can be carried out using more comprehensive and process-based models. In this study, K values were indirectly determined depending on great soil groups. For more precise and reliable results, soil samples can be taken to directly calculate K values. However, field work including the identification of litter characteristics can be carried out to determine potential fire severity in future studies.

CONCLUSION

In this study, soil loss susceptibility to forest fires in ÇFE was revealed. For this purpose, a scenario-based approach was employed. Soil loss before the fire was determined by the RUSLE model. A potential fire severity map of the study area was first produced to determine the soil loss amount after the fire. Based on this map, the K, LS, and C parameters of the RUSLE model were revised. Then, the soil loss map was generated for the forest fire scenario. Soil loss susceptibility to forest fires was determined based on the difference between soil losses before and after forest fires. The following results were obtained in this study.

1. The soil loss in the ÇFE varies from 0 to 1306 t ha^{-1} $year^{-1}$. In addition, mean soil loss was found as 5.34 t ha^{-1} $year^{-1}$.

2. The maximum soil loss amount would rise to 4905 t ha^{-1} $year^{-1}$ while the mean soil loss amount would be 12.44 t ha^{-1} $year^{-1}$ after forest fires. Considering this result, forest fires would increase soil loss by more than 2 times in the ÇFE. These results also clearly reveal only one of the forest ecosystem services.

3. Areas with very low soil loss susceptibility to forest fires constitute 41.97% of productive forests, while areas with very high soil loss susceptibility constitute 3.64% of productive forests. Areas with high, medium, and low soil loss susceptibility constitute 9.28%, 27.50%, and 17.61% of productive forests, respectively. In this context, taking necessary precautions against forest fires in high and very high soil loss susceptibility classes, which constitute approximately 13% of productive forest areas, will significantly reduce the soil loss risk caused by forest fires in the ÇFE.

4. It was found that there is not always a linear relation between fire severity and soil loss susceptibility under natural conditions. This showed that the expected impact of fire severity on soil loss could be overshadowed by the natural predisposition of the burned areas.

5. A linear relationship between forest fire severity and soil loss does not always exist in nature. For example, a forest area with a relatively lower fire severity potential may have a higher soil loss potential. Therefore, revealing possible fire-induced changes in soil loss will provide a useful basis for minimizing soil loss, especially in fire-prone areas. In this context, it is thought that the present study will help decision-makers in the implementation of the multi-purpose approach, which aims to reduce the risk of both forest fire and soil loss.

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