DOI:10.5152/forestist.2024.23057
Forestist 2024: 74(2): 231-243

ISTANBUL UNIVERSITY
CERRAHPAŞA

Original Article

An Investigation into the Carbon and Total Nitrogen Content of Suspended Sediments in Değirmendere Watershed and Its Implications for Erosion Risk

Necla Koralay[1], Ömer Kara[1], Kamil Çakıroğlu[2]

[1]Department of Forest Engineering, Karadeniz Technical University Faculty of Forestry, Trabzon, Türkiye
[2]Department of Forest Engineering, Bartın University Faculty of Forestry, Bartın, Türkiye

ABSTRACT

Soil erosion presents a global challenge, leading to severe repercussions such as soil degradation, compromised water quality, reduced agricultural output, and ecological harm, endangering life's sustainability on Earth. To preserve soil fertility and water quality within a watershed, it is crucial to compute soil loss quantities, sediment delivery ratios (SDRs), and nutrient concentrations within suspended sediments (SS). The Değirmendere watershed in Türkiye's Trabzon province was selected for research area. The study employed the RUSLE method in coupled with Geographical Information Systems to quantify soil loss and SDR. Direct measurement techniques were used to calculate the annual SS, as well as carbon (C) and total nitrogen (TN) content within the SS. Over a span of twelve months spanning January to December 2019, water samples were collected. The outcomes revealed that the watershed experiences annual amount of soil erosion is 592,140 tons year^{-1} with an average rate of 5.61 tons ha^{-1} year^{-1}. The sediment delivery ratio (SDR) was calculated to be 0.38. Other analysis indicated that the annual estimated sediment load and the directly measured annual quantities are 225 013 and 97 660, respectively. Both directly measured and predicted suspended sediment contain 0.15% TN and 1.13% C. The estimated sediment load is nearly two and a half times greater than the direct stream measurement ($y = 2.304x$). The outcomes of this research carry important implications for upcoming studies focused on the preservation of soil and water, a crucial measure in reducing soil erosion and improving water quality. The study provides guidance for future investigations concerning soil and water conservation.

Keywords: RUSLE, sediment delivery ratio, soil erosion, water quality, watershed management

Introduction

Soil erosion on the Earth's surface is a worldwide environmental issue that has adverse impacts on agricultural output, water quality, as well as terrestrial and aquatic ecosystems. Soil erosion is one of the most important causes of land degradation that is seriously affected by natural and anthropological activities (Fayas et al., 2019; Zhang et al., 2021). Erosion is a natural phenomenon that occurs worldwide in areas, including Türkiye, with a generally high slope, insufficient vegetation, and a lack of protection practices to reduce the risk of soil erosion (Issaka & Ashraf, 2017; Vieira et al., 2022). The factors most influencing erosion in Türkiye are vegetation destruction (34.82%) and slope from topographic factors (47.55%). Fifty-nine percent of Turkiye consists of areas with more than 12% slope. Severe and very severe erosion is observed in 11.5% of these areas since the vegetation was also destroyed and heavy rainfall occurred. When we evaluate land use, the main source of erosion in Turkiye is seen as agricultural (38.71%) and pasture areas (53.66%) (Erpul et al., 2020). In Türkiye, the average annual soil loss is reported as 8.24 tons per hectare per year (Erpul et al., 2018). The amounts of soil erosion in Türkiye vary from region to region. In 2018, Kara et al. calculated the annual average soil loss in the Foldere watershed as 3.76 tons per hectare per year. Erkal (2012) determined the annual soil loss of the basin soils in the Afyonkarahisar Çobanlar basin as 0–196 tons ha^{-1} year^{-1} using the RUSLE method. Yıldırım and Erkal (2009) found the soil loss for the study area in Afyon Plain to be 15 tons ha^{-1} year^{-1} according to the RUSLE method. Ozsoy (2007) determined the annual soil loss of the land in the Mustafakemalpaşa Basin using the RUSLE soil loss method as tons ha^{-1} year^{-1}. Ozcan et al. (2015) found the annual average soil loss in Kayseri Alidağı to be 9.42 tons ha^{-1} year^{-1}in their study using the USLE/RUSLE method. The study conducted by Tufekçioğlu et al.(2018) revealed that the average surface soil erosion in the Çoruh River Basin is approximately 3.9 tons ha^{-1} year^{-1}. Within the Eastern Black Sea Region (EBSR) that is a geographical region located in the northeastern part of Türkiye, with a coastline along the Black Sea, this figure notably increases to 11.60 tons per hectare per year (Erpul et al., 2020). In terms of specific

Cite this article as:
Koralay, N., Kara, Ö., & Çakıroğlu, K. (2024). An investigation into the carbon and total nitrogen content of suspended sediments in Değirmendere watershed and its implications for erosion risk. *Forestist*, 74(2), 231-243.

Corresponding Author:
Necla Koralay
e-mail:
nkoralay@ktu.edu.tr

Received: September 19, 2023
Revision Requested: October 31, 2023
Last Revision Received: November 21, 2023
Accepted: January 8, 2024
Publication Date: March 21, 2024

land uses within the EBSR, the soil loss per hectare in agricultural areas, pasturelands, and forests amounts to 17.3 tons, 20.93 tons, and 2.08 tons per hectare per year, respectively (Erpul et al., 2018).

Soil particles have a significant effect on water quality. The nutrient-rich topsoil is carried away with soil erosion in surface waters (Ganasri & Ramesh, 2015). Over time, erosion causes streams, lakes, and seas to be exposed to eutrophication. Soil particles carried by water usually consist of small soil aggregates such as clay and silt; these aggregates fill the habitats of aquatic beings living in streams (Ozdemir & Tatar, 2016; Tahiru et al., 2020). This causes damage to the fish by blocking the gills and destroying habitats. A high amount of turbidity occurs as soil particles increase in surface waters. This, consequently, diminishes the penetration of light through the water, curtailing the living spaces of photosynthetic aquatic organisms present in the water.

Water pollution is an important problem in terms of domestic, industrial and agricultural uses, forest ecology, and disease prevention in worldwide. The amount of usable water people can use constitutes 0.5% of the water in the world (DSI, 2022). Countries are classified based on the annual per capita available water. Accordingly, countries with an annual per capita available water of less than 1000 m^3 are considered water-poor, those with 1000–2000 m^3 are experiencing water scarcity, and those with more than 2000 m^3 are considered water-rich (Koralay, 2015). In Türkiye, a country that suffers from water scarcity, the annual amount of usable water per capita was 1652 m^3 in 2000, 1544 m^3 in 2009, and 1346 m^3 in 2020 (DSI, 2022).

Surface water resources, especially rivers, are under increasing threat from pollution in Türkiye (Akın & Akın, 2007; Burak et al., 2022). The quality of water resources is affected by natural and human activities, which limits water for human use (Kumar et al., 2019; Tahiru et al., 2020). Thus, it is necessary to protect freshwater resources and ensure their sustainability. One of the biggest factors deteriorating the water quality in a watershed is the increase in the amount of sediment in the water. Sediment substances in surface waters negatively affect water quality by containing nutrients such as carbon, nitrogen, and phosphorus and by forming a pollutant themselves (Owens & Walling 2001; Tahiru et al., 2020). In Türkiye, approximately 154 million tons of soil are transported to water resources with soil erosion (ÇEM, 2022). It also increases the nutrient content of surface waters by transporting nutrients in the transported soil particles and structures. Therefore, determining the spatial variability of erosion severity in a watershed and the presence of nutrients in suspended solids, which are important for water quality, is vital to improving land use management and protecting water quality (Duarte & Gioda, 2014; Fayas et al., 2019; Sigua & Tweedale, 2003). In addition, to carry out soil and water conservation techniques in watersheds adequately and accurately, the severity and spatial distribution of erosion must be determined quickly and easily.

This study aims to estimate the annual average amount of soil erosion and sediment delivery ratio (SDR) according to the RUSLE (Renard et al., 1997; Wischmeier & Smith 1978) method and determine carbon (C) and total nitrogen (TN) content of suspended sediment (SS) in the Değirmendere watershed in the province of Trabzon in Türkiye. The amount of suspended sediment transported to the sea is studied by a direct measurement method to calculate the annual C and TN values from nutrients in suspended sediment. The RUSLE method was used with the ArcGIS (Ganasri & Ramesh, 2015; Ozsahin, 2016) application to calculate the amount of soil loss and create an erosion risk map of the Değirmendere watershed. As a result, the study will be attempted to be identify not just the locations in the Değirmendere watershed where there is amount of soil erosion, but also how soil particles can affect the quality of the water. The findings will serve as a guide for studies on conservation of soil and water to be carried out in watersheds with comparable features throughout the world, including Türkiye.

Material and Methods

Location of the Study Area

The study area, Değirmendere watershed, is situated within the boundaries of Trabzon province in the EBRS of Türkiye. Encompassing an area of 1055.36 km^2, the Değirmendere watershed that stands as the largest watershed in the EBRS. The broader Trabzon region experiences a temperate maritime climate, and historical records reveal instances of loss of life and property due to past floods and landslides (Filiz & Avci, 2013). Notably, this area boasts significance owing to its biological diversity, natural allure, and the presence of river-type hydroelectric power plants (Kılıcaslan, 1996). For these reasons, it was selected as the study area (Figure 1).

The watershed's composition predominantly covers 36.92% forest cover (comprising *Picea orientalis, Pinus sylvestris* L., *Fagus orientalis*, *Alnus glutinosa*, *Quercus*, *Carpinus betulus*), 41.70% pasture, 19.97% agricultural land, 1.28% residential areas, and 0.13% rocky terrain. These land segments comprise 15,525.36 ha of orchards, 15,700.02 ha of mixed forests, 13,458.96 ha of coniferous forests, 8757.16 ha of broad-leaved forests, 4826.70 ha of natural vegetation within agricultural plots, 238.47 ha of mixed planting models, and 47,025.91 ha cover various other land uses (TOBM, 2022). The average slope across the watershed is 50.09%, while elevations range from 0 to 3082 m. The watershed's annual precipitation total was recorded at 828.9 mm (1927–2021) according to data from the Trabzon Meteorological Directorate that is located at the elevation of 25 m (TMM, 2022).

Estimation of Soil Loss

Various approaches are used globally to assess soil loss within watersheds (Prasannakumar et al., 2011; Tessema et al., 2023). Among these, the most widely utilized method is the Revised Universal Soil Loss Equation (RUSLE) due to its simple structure and high accuracy (Efe et al., 2008; Erkal, 2009; Ganasri & Ramesh, 2015; Irvem et al., 2007; Ozcan, 2015; Ozsoy, 2007; Tufekçioğlu et al., 2018; Yıldırım & Erkal, 2009). Furthermore, the RUSLE model allows the estimation of the average annual soil loss in both agricultural and forested watersheds (Prasannakumar et al., 2011; Tosic et al., 2013; Kumar et al., 2019). In this particular investigation, the combination of ArcGIS software, a Digital Elevation Model (DEM) with a resolution of 30 × 30 m, and the RUSLE methodology was employed to quantify soil loss across the Değirmendere watershed while also producing a map indicating erosion risk (Figure 2). The erosion risk map was created using the Spatial Analysis Tool of ArcGIS 10.00 software, the map algebra module, and the Map Calculation (Raster Calculator) command by substituting raster data into the formula shown in Figure 2. As a result of the analysis, the amount of erosion was determined in tons per hectare per year for both unit area and total area (Ganasri & Ramesh, 2015; Ozşahin, 2016).

Rainfall Erosivity Factor

The erosivity factor (R) signifies the potential of precipitation to cause soil erosion in a specific area (Nijimbere & Lizana, 2019; Prasannakumar et al., 2011). To calculate the RUSLE-R value, annual and monthly total precipitation data spanning the period 1927–2021 were collected from the 11th Regional Meteorology Directorate of Trabzon (TMM, 2022). Around 500 virtual meteorological stations were strategically

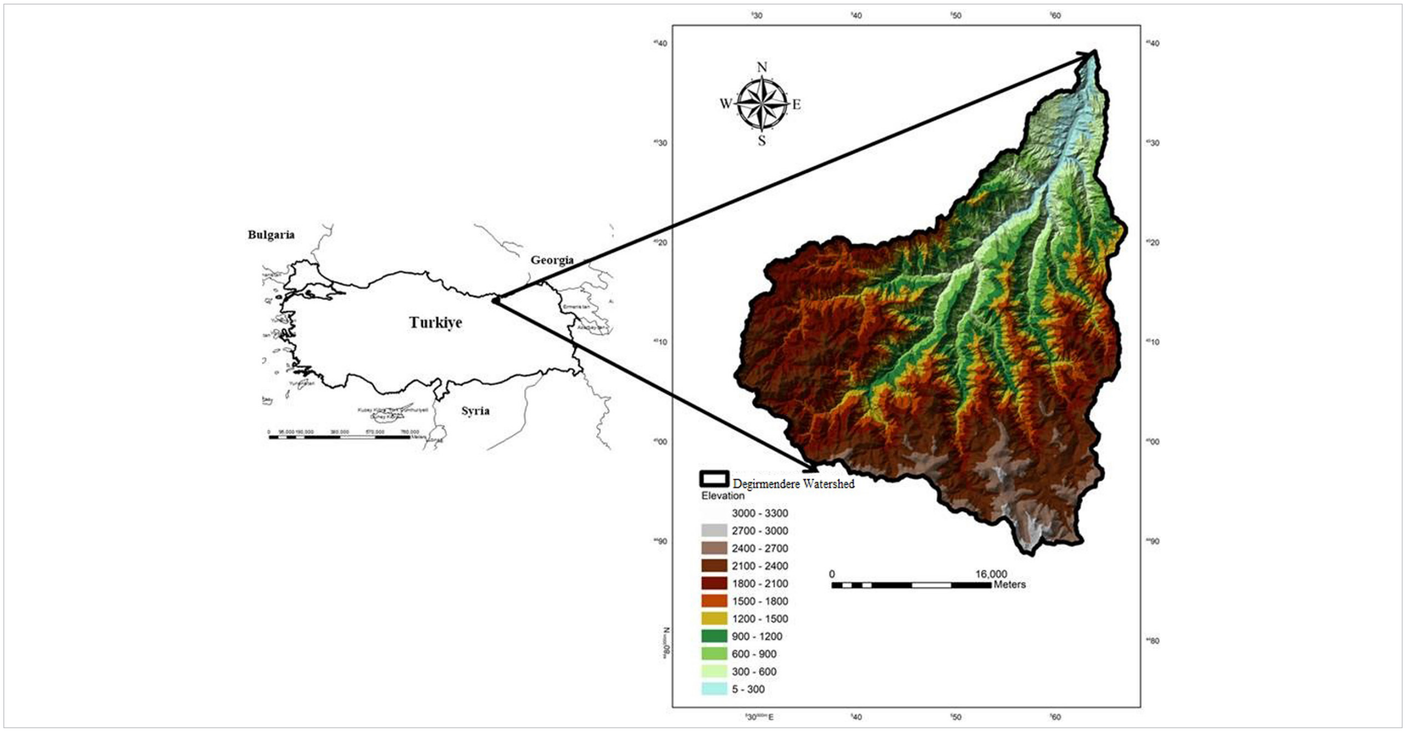

Figure 1.
The Study Area.

positioned according to the grid method at intervals of 1500 m to compute *R* values (Ikiel et al., 2020; Ozdemir & Tatar, 2016). Subsequently, the precipitation values at these points were determined by assuming an increment of 54 mm per 100 meters in annual precipitation, as suggested by Schreiber (Dogru & Gungoroglu, 2022). For these stations, the modified Fournier index (MFI) formula (Arnoldus, 1977) was initially used, followed by the application of the Tufekçioglu and Yavuz (2016) formula to calculate *R*. Using ArcGIS, the *R* values were spatially distributed throughout the region utilizing the inverse distance weighting (IDW) interpolation method (Ibrahim et al., 2012; Fathizad et al., 2014), which offers a more precise, straightforward, and comprehensible interpolation technique (Equations 1–2). The geographic variability of the RUSLE-*R* was verified and characterized through the application of the ArcGIS 10 Geostatistical Wizard. The RUSLE-*R* factor values were attempted to be validated by comparing measured and predicted values, determining prediction errors, and creating a regression equation (Galdino et al., 2016).

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

where MFI is the Modified Fournier Index, P*i* is the precipitation in month *i* (mm), and *P* is the annual precipitation (mm)

$$R = 4.17 \times \mathrm{MFI} - 152 \quad (2)$$

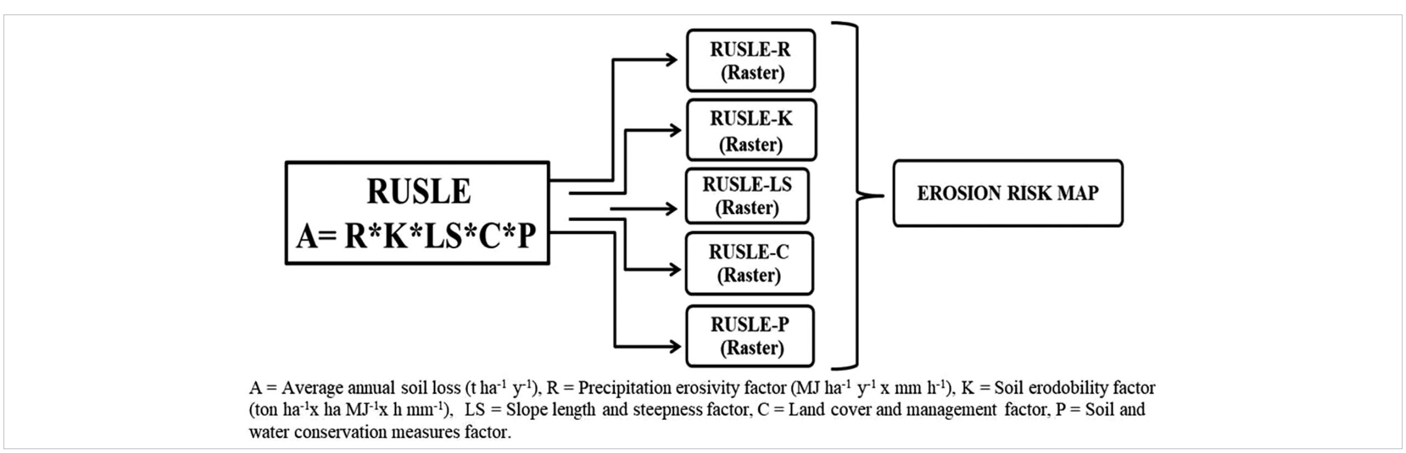

Figure 2.
Calculation of Soil Loss and Mapping of Erosion Risk of Değirmendere Watershed.

Soil Erodibility Factor

The RUSLE-*K*, which is influenced by the physical characteristics of the soil, signifies the resistance of soil to the erosive impact of precipitation and runoff (Fayas et al., 2019; Ikiel, et al., 2020; Ozdemir & Tatar, 2016). In this study, the Değirmendere watershed's map of great soil groups, sourced from the General Directorate of Agricultural Reform, was utilized to compute the K factor (Figure 3a). Given that *K* values are expressed in U.S. customary units, each value was multiplied by 0.1317 and subsequently converted to the International System of Units (SI) (Foster et al., 1981).

Topographic Factor

The RUSLE-*LS* parameter assesses the potential for soil loss within a plot featuring a length of 22.6 m (*L*) and a slope of 9% (*S*) (Nijimbere & Lizana, 2019). To map the RUSLE-*LS* values for the Değirmendere watershed, Equation 3 was applied using the ArcGIS raster calculator tool.

$$LS = ((\text{Flow accumulation} \times \text{Cell size})/22.13)^{0.4}\ ((\text{Sin Slope})/0.0896)^{1.3} \quad \text{(Moore \& Burch, 1986)} \tag{3}$$

Crop Management Factor

The RUSLE-*C* parameter is used to assess the impact of vegetation cover and agricultural practices on soil erosion (Wischmeier & Smith, 1978; Zhang et al., 2021). For the calculation of RUSLE-*C* in the Değirmendere watershed, the CORINE land cover dataset (CORINE 2012-2018) was utilized (EEA, 2000) (Figure 3b).

Conservation Support Practice Factor

RUSLE-*P* is employed to evaluate the impact of soil conservation practices on the annual soil loss amount. The *P* factor value ranges from 0 to 1 (Wischmeier & Smith, 1978). In the case of the Değirmendere watershed, where no soil conservation practices are implemented, the *P* factor is assumed to be 1.

Mapping of Erosion Risk

In ArcGIS 10, each raster data for erosion factors, including *R*, *K*, *LS*, and *C*, was overlaid using the raster calculator tool. The outcomes were categorized into five classes: very low risk (0–2 tons ha^{-1} $year^{-1}$), low risk (2–5 tons ha^{-1} $year^{-1}$), moderate risk (5–10 tons ha^{-1} $year^{-1}$), high risk (10–20 tons ha^{-1} $year^{-11}$), and very high risk (above 20 tons ha^{-1} $year^{-1}$).

Sediment Delivery Ratio

When soil erosion takes place within a watershed, not all eroded soils make their way to the streams. Soil particles have the potential to accumulate on the land surface in areas where the slope and runoff are reduced (Lee & Kang, 2013). Hence, it becomes crucial to assess the amount of soil transported into the streams compared to the soil that remains on the land surface. This evaluation is achieved by calculating the Sediment Delivery Ratio (SDR) within the watershed using Equation (4).

$$SDR = \exp[-\beta L/\sqrt{St}] \quad \text{(Ferro et al. (2001))} \tag{4}$$

where SDR is sediment delivery ratio determined for each cell, *L* is flow accumulation (m), *St* is cell slope (%), and β is the equality coefficient developed depending on the flow and sediment delivery processes.

The Amount of Carbon (C) and Total Nitrogen (TN) of Suspended Solids and Suspended Solids (SS) in Değirmendere Watershed

Throughout the period from January to December 2019, water samples were collected monthly scheduled for the middle of each month from the D1 location situated downstream of the Değirmendere watershed (Figure 3c).

Suspended Solids: The quantity of suspended solids was determined using the gravimetric technique, a direct measurement approach (APHA, 1989). Water samples were collected using 0.5L polyethylene bottles. Whatman Grade 42 filter papers and Equation 5 were employed to quantify the suspended solids content.

$$SS\ (\text{mg/lt}) = ((A - B))/V \times 1000 \tag{5}$$

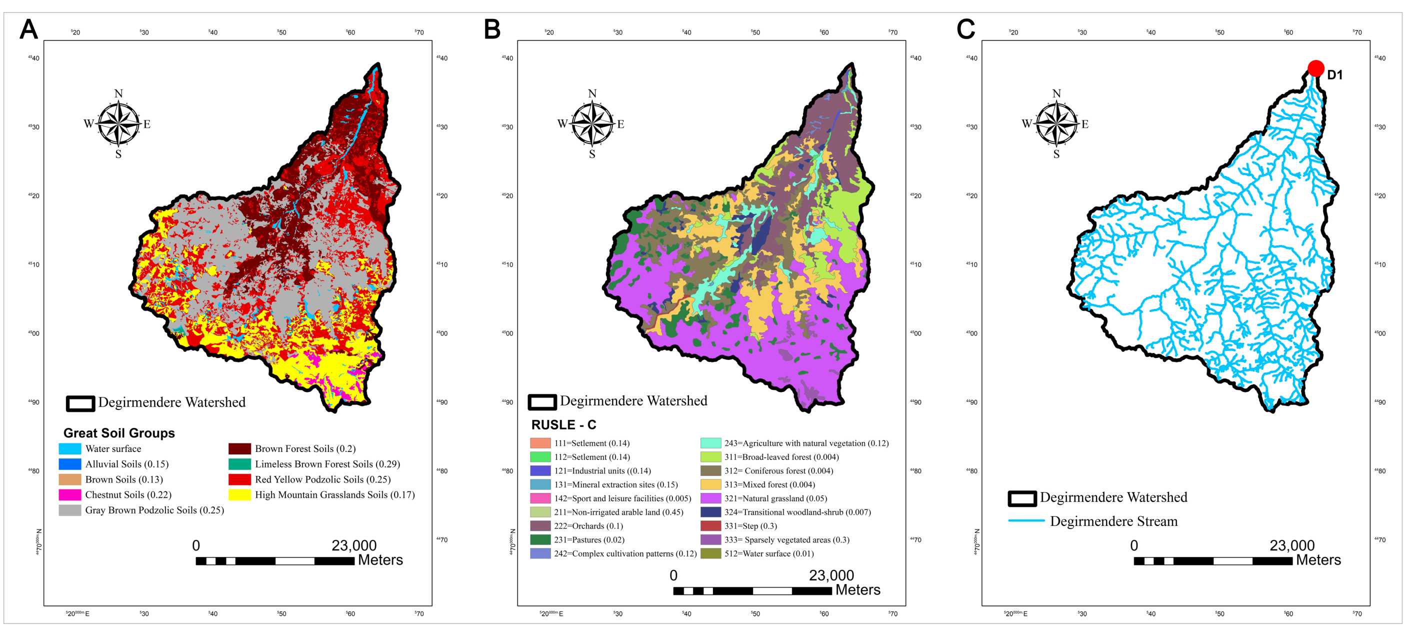

Figure 3.
K Values of Great Soil Groups (A), CORINE Land Cover Map (B), and Water Sampling Point (C).

where A is the total of filter paper and suspended solids (gr), B is the filter paper (gr), V is the volume of water sample taken (100 mL), and 1000 is the coefficient of conversion to mg.

Carbon and Total Nitrogen of Suspended Solids: For the assessment of carbon (C) and total nitrogen (TN) content within the suspended solids (SS) transported to streams in the Değirmendere watershed, 20 L plastic bottles were used. To swiftly segregate water from suspended solids, multipurpose centrifuges were used. The obtained SS, comprised of soil particles, were dried in an air-dried condition for subsequent C and TN measurements. C content was determined using the Walkley–Black method (Walkley & Black, 1934), while TN was quantified using the Kjeldahl method (Bremner, 1965).

Validation of RUSLE Model

The validation of RUSLE A was conducted using the geoistatistical wizard tool of ArcGIS 10. To ascertain the spatial dependence of soil loss, a comprehensive analysis encompassing calculated, measured, and predicted values was undertaken. This involved evaluating prediction error mean, root mean square, regression equations, and regression analysis (Galdino et al., 2016). The Statistical Package for Social Sciences version 22.0 software (IBM Corp.; Armonk, NY, USA) (Cevahir, 2020) was utilized for establishing correlations and determining the levels of statistical significance between soil loss and various parameters. Prior to analysis, a Kolmogorov–Smirnov test was employed to assess the normal distribution of variables. The non-parametric Kruskal–Wallis tests and Tamhane's T2 were employed in this research (Debie & Awoke, 2023; Fang, 2017; Zhang et al., 2021).

For further validation, the directly measured sediment yield from the Değirmendere stream was compared with available literature and used to validate both the SDR and the RUSLE model (Zhang et al., 2021). Notably, the RUSLE model has demonstrated its effectiveness across diverse environmental conditions in various watersheds worldwide, including those in Türkiye. To ensure the validity of the findings, the results obtained were also compared with soil erosion measurements estimated in other watersheds within the same region.

Results

Erosion Risk Map

RUSLE-R

The descriptive statistics of rainfall erosivity revealed a considerable range. The R values span from 163 to 711 MJ ha^{-1} year^{-1} mm h^{-1}. The average R value was calculated to be 435.0495 MJ ha^{-1} year^{-1} mm h^{-1}, with a coefficient of variation (CV) of 28% (Figure 4-5, Table 1). Following Warrick and Nielsen (1980), CV values falling within <12%, 12–60%, and >60% were categorized as low, average, and high, respectively. The weighted R class of the Değirmendere watershed is between 470

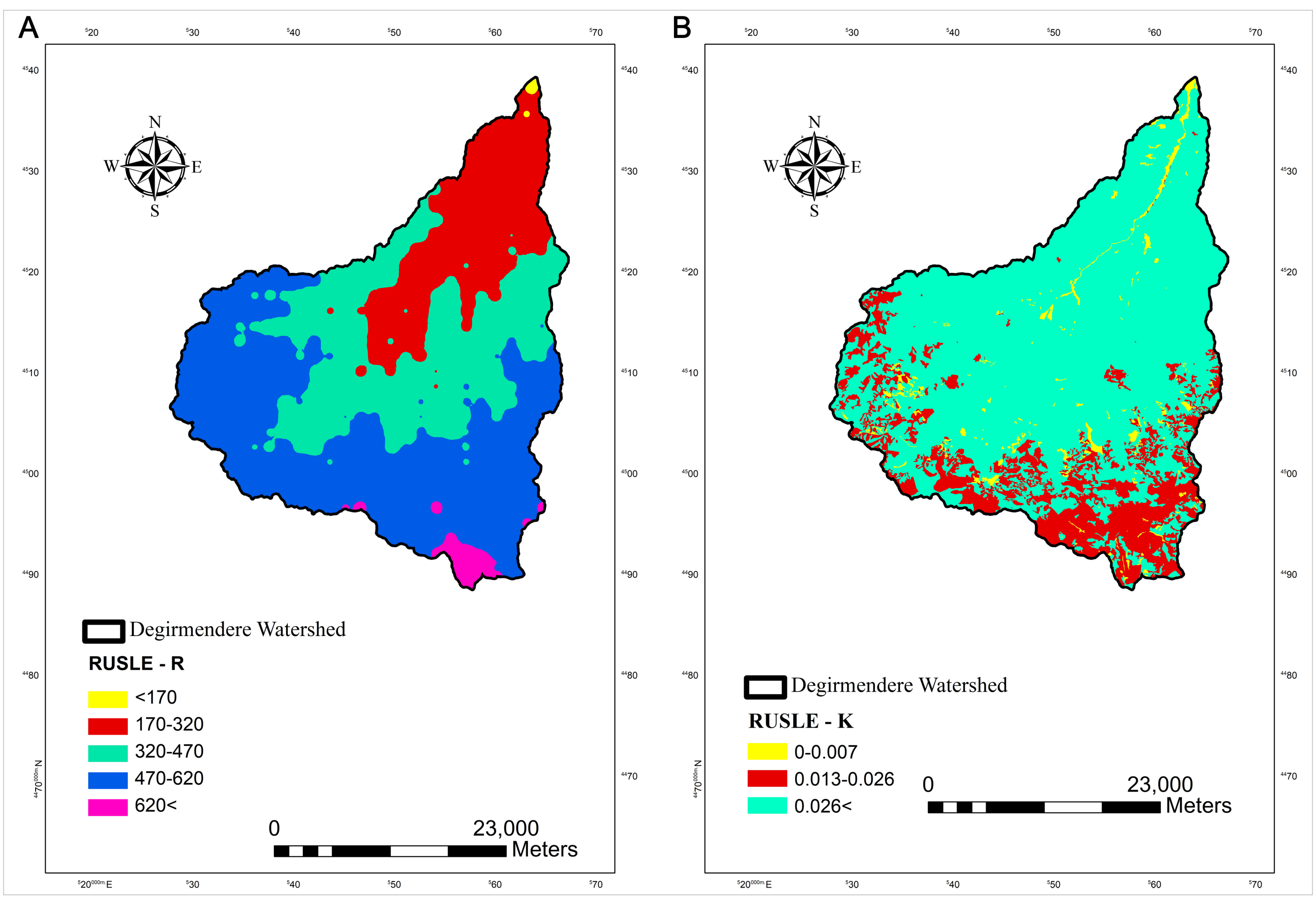

Figure 4.
RUSLE-R (A) and RUSLE-K (B) Map.

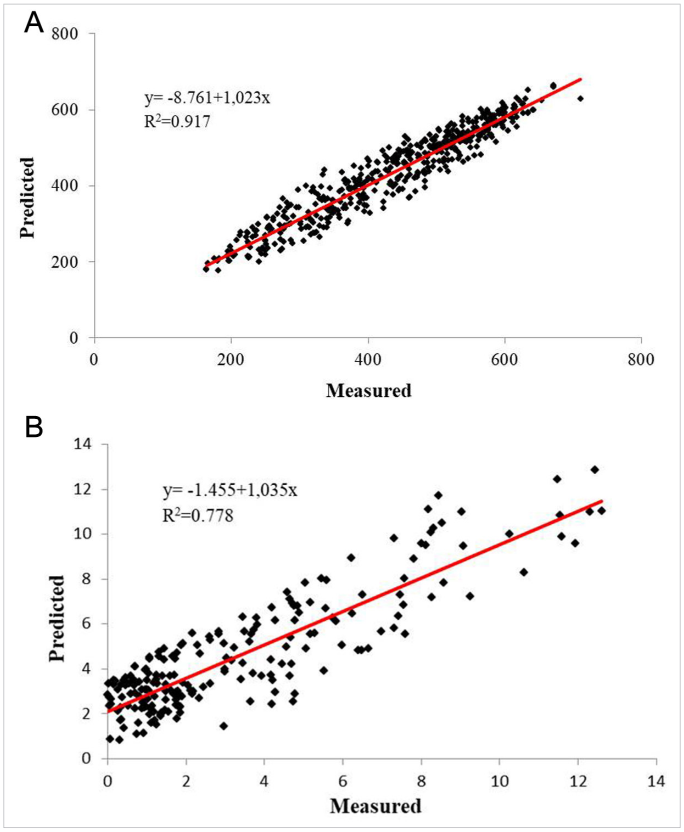

Figure 5.
Measured and Predicted Value of RUSLE-R (A) and RUSLE A (B).

and 620 (accounting for 44.52% of the area). Consequently, when assessing CV and R values with the spatial distribution, the study region demonstrated substantial erosivity. Through the Kruskal–Wallis and Tamhane T2 tests, it was ascertained that notable disparities exist in R values based on land use types ($\alpha = 0.05$, $n = 475$, skewness = −0.317, kurtosis = −0.966). Forested lands were categorized in the mid R group, while agricultural lands exhibited the lowest values and grassland areas registered higher values. The typical R factor was similar with Türkiye's climatic norms. Oğuz et al. (2019) determined the mean *R* value to be 415.32 MJ ha^{-1} year^{-1} mm h^{-1}. Koralay & Kara (2022) discovered an average *R* of 324.65 MJ ha^{-1} year^{-1} mm h^{-1} in the Değirmendere Çatak subwatershed. Parallel outcomes were also observed by Kara et al. (2018), reporting R values at 422.0 MJ ha^{-1} year^{-1} mm h^{-1} in Foldere which is similar in terms of climatic and topographic conditions in the EBSR. Geoistatistical wizard analysis exhibited a correlation coefficient of 0.958 ($\alpha = 0.01$) between predicted and measured values. The prediction errors, in terms of 15 neighbors, indicated a mean of −1.409 and a root mean square of 35.69 (Galdino et al., 2016). Predicted outcomes consistent with measured data, consequently underscoring the reliability of the findings.

RUSLE-K

The *K* values range between 0 to 0.3819 ton ha hour ha^{-1} MJ^{-1}mm^{-1} (Table 1). The areally weighted average for the *K* factor was computed to be 0.03. The predominant range for the *K* factor lies between 0.026 and 0.033, accounting for a significant portion of the area at approximately 79.61%. This revealed that more than two-thirds of the watershed is composed of soils with a higher susceptibility to erosion, as indicated by the soil erodibility classes.

RUSLE-LS

The computed weighted average LS value was determined as 11.9 (Table 1, Figure 6a). Upon assessing the distribution of LS classes across the watershed, it had been revealed that approximately 58.75% of the watershed exhibits high LS values, indicating a heightened vulnerability to soil erosion. This observation underlined the susceptibility of the watershed to soil erosion due to the prevalence of high LS values.

RUSLE-C

The distribution of the *C* factor across different areas was presented in Table 1. Notably, the regions most susceptible to erosion with regard to vegetation cover are the natural pasture and agricultural areas, encompassing approximately 52.03% of the entire watershed (Figure 6b). It was evident that over half of the watershed was characterized by a high susceptibility to erosion in relation to vegetation cover. Conversely, areas under the protective canopy of forests account for 38.75% of the total watershed area.

Soil Loss of Değirmendere Watershed

The distribution of calculated soil loss based on Figure 7(a) was represented proportionally in Table 1. Within the watershed, soil loss was observed at rates of 0–2 and 2.1–5 tons ha^{-1} year^{-1}, accounting for 52.16% and 12.38% respectively. The remaining area, which experiences soil loss exceeding 5 tons ha^{-1} year^{-1}, constitutes 35.45%. The Değirmendere watershed's average soil loss per unit area was determined to be 5.61 tons ha^{-1} year^{-1}, resulting in a total soil loss of 592140 tons year^{-1}.

SDR

The distribution of the estimated sediment delivery ratio within the Değirmendere watershed, as depicted in Figure 7(B), was presented in Table 1. The calculated SDR for the watershed was 0.38, resulting in a sediment yield of 2.1318 tonsha^{-1} year^{-1} and an estimated sediment load of 225,013 tons year^{-1}.

Carbon and Total Nitrogen of Suspended Solids

The results indicate that the lowest recorded TN value was 1.53 tons in August, while the highest TN value was observed to be 22.43 tons in February. In terms of C values, the lowest was recorded as 14.54 tons in August, with the highest being 219.29 tons in April (Figure 8). Examining sediment amounts, the lowest was 663.3 tons in August, whereas the highest sediment amount reached 20387.69 tons in April. The correlation analysis reveals a strong positive correlation between discharge, suspended solids, C, and TN values (Table 2).

The cumulative annual sediment load in the Değirmendere watershed was estimated to be 97660 tons, encompassing 143.22 tons of TN and 1103.39 tons of C.

Validating the Outputs of the RUSLE Model

Descriptive statistics of soil loss revealed notable variability (Table 3). The A values span a range of 0.01–72.355 tons ha^{-1} year^{-1}, with a mean A value of 5.61 tons ha^{-1} year^{-1}. The correlation coefficients of *R*, *K*, *LS*, and *C* with soil loss were found to be 0.01, 0.054, 0.318, and 0.639, respectively. Regression and correlation analysis indicated that *LS* and *C* better explained the variance in soil loss ($\alpha = 0.01$, $R^2 = 63.7\%$) (Figure 9, Table 4). Kruskal–Wallis and Tamhane's T2 tests that were nonparametric tests revealed significant differences in A values based on land use status ($\alpha = 0.05$, $n = 475$). Agricultural areas exhibited the highest A values, followed by pasture areas, while forest areas had the lowest A

Table 1.
Proportional Change of R, K, LS, C, A, and SDR

R′ Classes	Class Mean Values	Area (ha)	% ha	Class Mean Values × Area (ha)
163–170	165	159.14	0.15	26,257.27
170–320	245	22,092.7	20.93	5,412,711.26
320–470	395	34,337.2	32.54	13,563,193.6
470–620	545	46,981.102	44.52	25,604,700.59
620–711	665	1962.46	1.86	1,305,035.9
	Total	105,532.6	100	45,911,898.62
			Weighted average	45,911,898.62/105,532.6 = 435.05 MJ ha^{-1} mm hour^{-1} year^{-1}
K′ Classes	Class Mean Values	Area (ha)	% ha	Class Mean Values × Area (ha)
0–0.007	0.0035	2907.72	2.76	10.18
0.007–0.013	0.01	0.57	0.000544	0.0057
0.013–0.026	0.0195	18,606.2	17.63	362.82
0.026–0.03819	0.0321	84,018.10	79.61	2696.98
	Total	105,532.6	100	3070
			Weighted average	3070/105,532.6 = 0.03 t ha hour ha^{-1} MJ^{-1} mm^{-1}
LS′ Classes	Class Mean Values	Area (Ha)	% Ha	Class Mean Values × Area (Ha)
0–5	2.5	28111.6	26.64	70,279
5–10	7.5	15430	14.62	115,725
10–15	12.5	18,093.9	17.15	226,173.75
15–20	17.5	13,863.5	13.14	242,611.25
20<	20	30,033.6	28.46	600,671.85
	Total	105,532.6	100	1,255,460.85
			Weighted average	1,255,456.653/105,532.5952 = 11.90
C′ Classes	Class Mean Values	Area (ha)	% ha	Class Mean Values × Area (ha)
0.004–0.01	0.007	40,897.10	38.75	286.28
0.01–0.04	0.025	7523.36	7.13	188.08
0.04–0.14	0.09	54,909.60	52.03	4941.86
0.14–0.449	0.3	2202.53	2.09	660.76
	Total	105,532.6	100	6076.99
			Weighted average	6076.99/105,532.60 = 0.058
A′ Classes	Class Mean Values	Area (ha)	% ha	Class Mean Values × Area (ha)
0–2	1	55,049.90	52.16	55,049.90
2–5	2,5	13,068.80	12.38	32,672.00
5–10	7,5	14011.60	13.28	105,087.00
10–20	15	13,742.90	13.02	206,143.50
>20	20	9659.40	9.15	193,187.94
	Total	105,532.6	100	592,140.34
			Weighted average	592,140.34/105,532.60 = 5.61 ton^{-1}/ha year^{-1}
SDR Classes	Class Mean Values	Area (ha)	% Ha	Class Mean Values × Area (ha)
0–0.2	0.1	49,702.80	47.10	4970.28
0.2–0.4	0.3	13,607.90	12.89	4082.37
0.4–0.6	0.5	11,187.30	10.60	5593.65
0.6–0.8	0.7	10,465.50	9.92	7325.85
0.8–1	0.9	20569.10	19.49	18,512.19
	Total	105,532.6	100	40,484.34
			Weighted average	40,484.33641/105,532.60 = 0.38

Note: '*A* = Average annual soil loss (t ha^{-1} y^{-1}), *R* = Rainfall erosivity factor (MJ ha^{-1} y^{-1} × mm h^{-1}), *K* = Soil erodibility factor (ton ha^{-1} × ha MJ^{-1} × h mm^{-1}), *LS* = Slope length and steepness factor, *C* = Land cover and management factor.

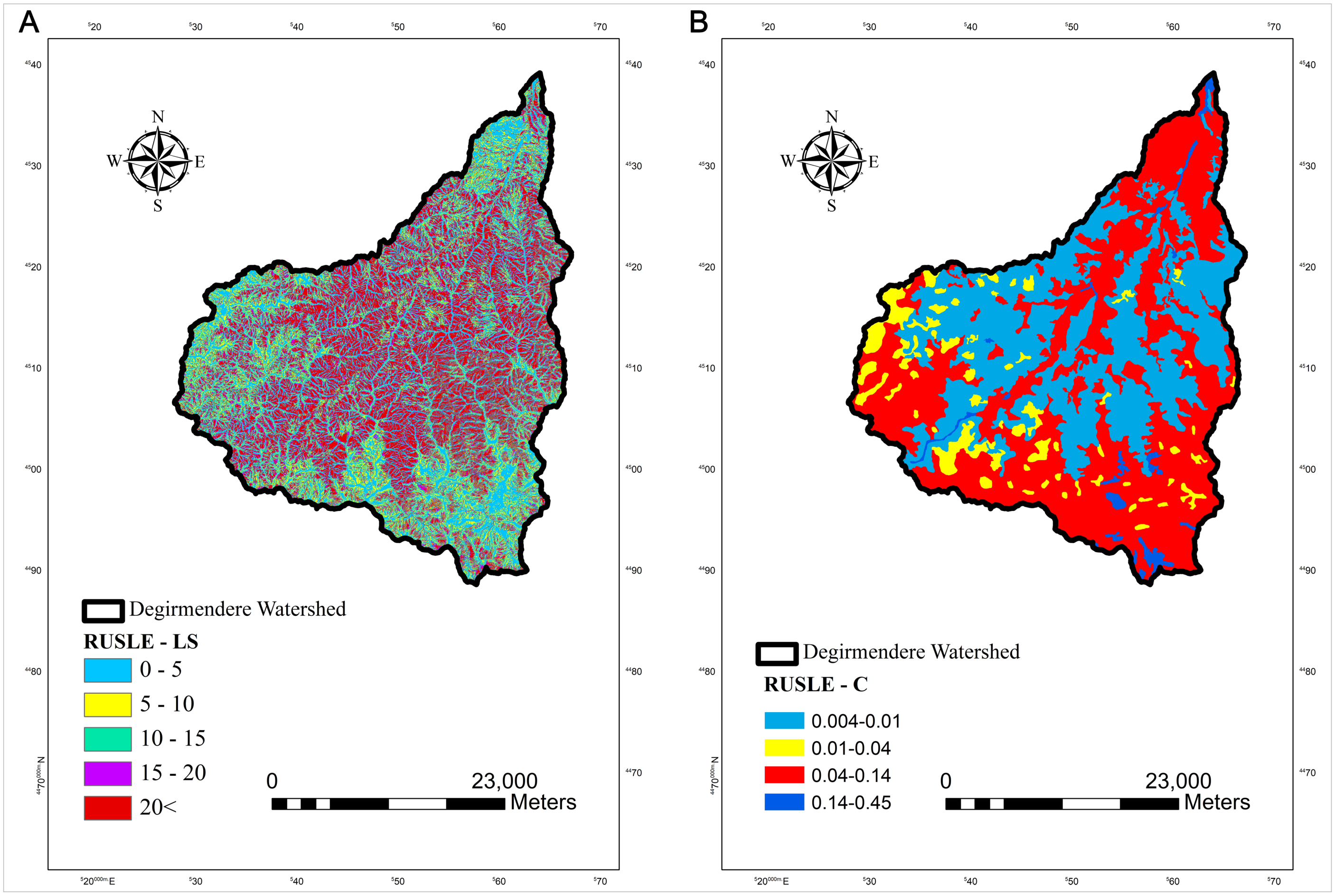

Figure 6.
RUSLE-LS (A) and RUSLE-C (B) Map.

values. The average A factor consistent with expectations for soil loss in Türkiye. Similar A values were found in studies by Tüfekçioğlu et al. (2018) in Çoruh River which was similar in terms of climatic and topographic conditions, Kara et al. (2018) in Foldere, and Ozdemir and Tatar Dönmez (2016) in Işıklı Lake.

Geoistatistical wizard analysis indicated a correlation coefficient of 0.875 ($\alpha = 0.01$) between measured and predicted values, with an R^2 of 0.778. Prediction errors in terms of mean and root mean square were −0.206 and 1.92, respectively, based on 15 neighbors (Galdino et al., 2016). Predicted outcomes closely align with measured data.

Validation of the soil erosion estimated by the RUSLE model was performed using sediment yield (Zhang et al., 2021). The estimated sediment delivery to Değirmendere streams was 225013.33 tons year^{-1}, while the directly measured sediment in the stream amounts to 97660 tons annually. The estimated sediment included 329.982 tons of TN and 2542.26 tons of C, whereas direct measurement yields 143.22 tons of TN and 1103.39 tons of C (Table 5). The estimated sediment was nearly two and a half times greater than the direct stream measurement ($y = 2.304x$). Considering Türkiye's rugged terrain with a significant slope of over 60%, and the prevalent use of RUSLE in watersheds with lower slopes and agricultural lands, variations were expected between estimated and measured data. Furthermore, disparities in the resolution of raster data structures used for RUSLE parameter calculations contributed to the observed differences (Tüfekçioğlu & Yavuz, 2016). The results are statistically coherent and align with existing literature, thereby instilling confidence in their reliability (Zhang et al., 2021).

Discussion and Conclusion

The RUSLE, combined with Geographical Information Systems (GIS), was used to mapping of erosion risk and estimate the soil loss of Değirmendere watershed. The research utilized a time-efficient methodology with global adoption that can be easily applied to track environmental changes (Fang, 2017).

Based on the research data, areas with altitudes higher than 1900 m, characterized by insufficient vegetation in natural pasture areas, exhibit a high erosive impact from R factor that is higher than 470. The findings suggest that altitude ($r = .99$, $p = .01$) has a stronger correlation with rainfall and R. As altitude values increase, C ($r = -0.168$, $p = .01$) values decrease, indicating enhanced vegetation. These regions also demonstrate elevated RUSLE-K values that is higher than 0.02, indicating susceptibility to erosion. Tüfekçioğlu et al., in their study conducted in 2020, revealed that channel and gully erosion occur as a highly dynamic process, with temporal and spatial factors playing a significant role in this process. Additionally, it was observed that there is a substantial increase in erosion in the semi-arid Oltu micro-watershed due to the

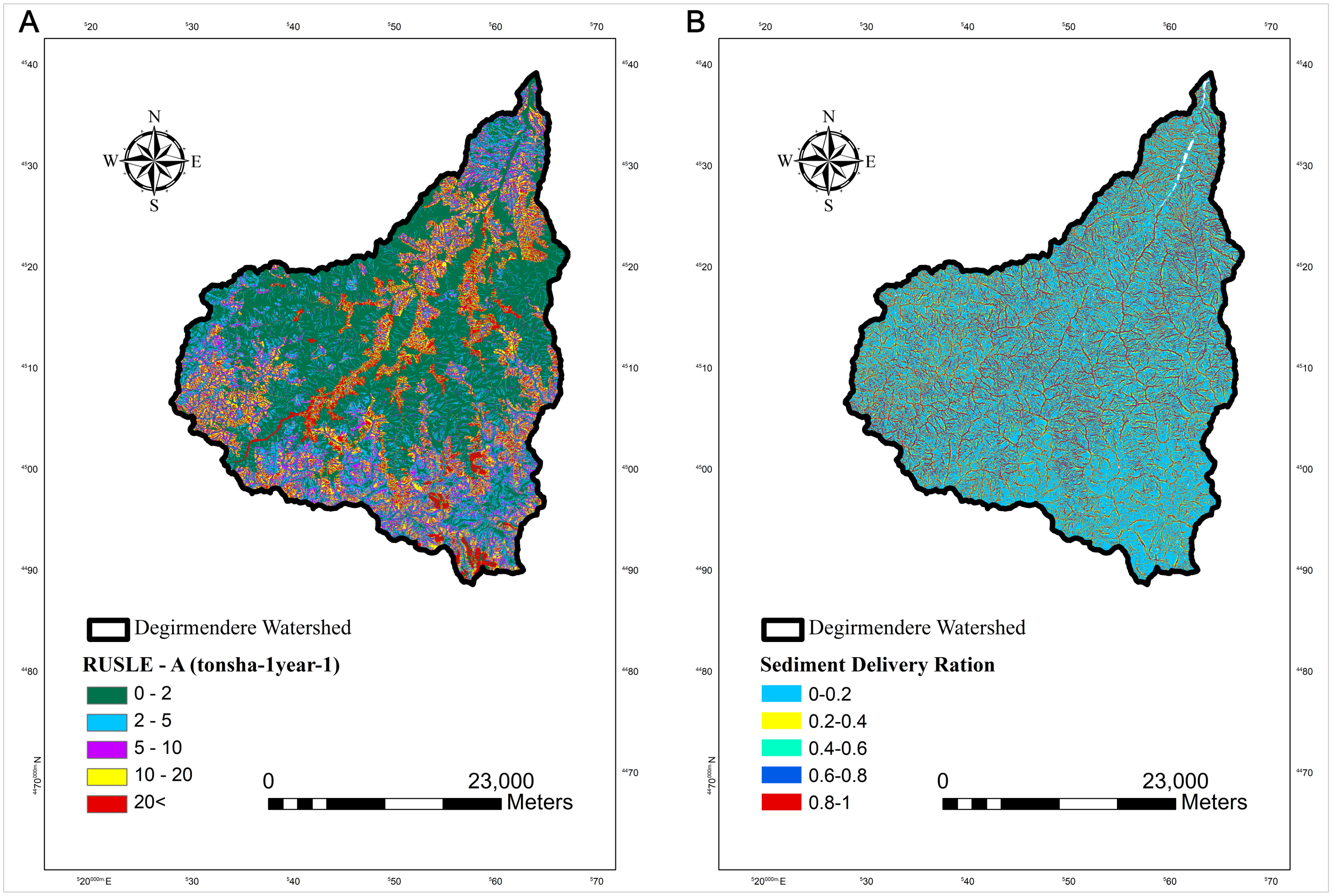

Figure 7.
Erosion Risk (a) and SDR (b) Map.

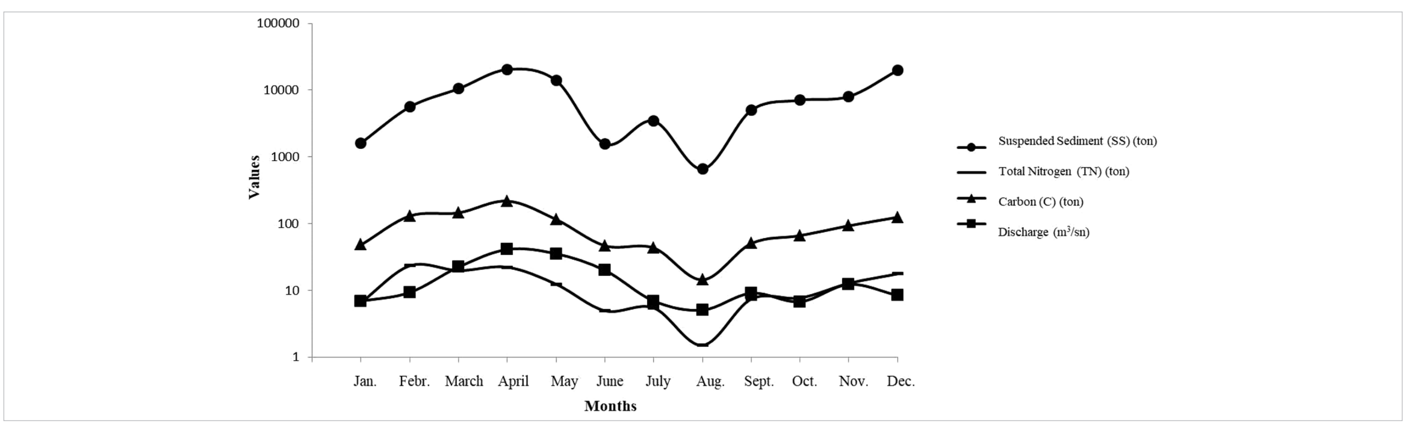

Figure 8.
SS, C, and TN of SS and Discharge Amount by Months.

rising seasonal precipitation. Prasannakumar et al. (2011) noted that extensive soil loss occurs on steep slopes (high *LS*) within grassland, degraded forest, and deciduous forest areas. Likewise, Panagos et al. (2015) highlighted that areas with scattered vegetation at high altitudes in Southern Spain experience very high soil loss (40.16 tons ha^{-1} $year^{-1}$). These insufficiently vegetated areas within the Değirmendere watershed belong to the high erosion risk category.

In general, regions characterized by high *LS* values and altitude, coupled with inadequate vegetation cover, are prone to erosion. Significant discrepancies were observed in *LS* values based on land use status. Similarly, the presence of forest cover in areas with high *R* (320–470) and *K* (0.25) values between altitudes of approximately 500–1900 m contributes to low erosion risk. The removal of vegetation exposes the soil surface to precipitation, leading to direct erosion (Rehman et al.,

Table 2.
Correlation Between SS, C, TN, and Discharge

	S'S	T'N	C'	Discharge
SS'	1	.714**	.846**	.615*
TN'	.714**	1	.925**	.469
C'	.846**	.925**	1	.718**
Discharge	.615*	.469	.718**	1

Note: $N=36$.
'TN = Total nitrogen, C = Carbon, SS = Suspended sediment.
**Correlation is significant at the 0.01 level (two-tailed).
*Correlation is significant at the 0.05 level (two-tailed).

2015). In these regions, *LS* values also tend to be high. Our statistical analysis underscores that *LS* and *C* have the most significant impact on soil erosion, with respective correlations of $r=0.318$ and 0.639. Fu et al. (2005) pointed out that stream edges exhibit low *LS* values due to gentle slopes, whereas high *LS* values are unevenly distributed within watersheds. In their study, Erdem and Türkmen (2020) found that the areas with increased elevation and LS, particularly, correspond to the steep slopes of deep valleys, indicating a high degree of erosion potential. Similarly, in our study, LS values show heterogeneous distribution along both stream sides and the area.

Yavuz and Tüfekçioglu (2019) highlighted that despite low average annual precipitation (585 mm year^{-1}), the study area's elevated topography, limited vegetation, and extensive slope length contribute to surface soil loss. In 2006, Yılmaz determined the annual soil loss of the Camlıdere reservoir watershed located in Ankara as 7.3 tons ha^{-1} using the USLE method. The study identified land cover and topography as the main parameters influencing this situation in the watershed.

Table 3.
Distribution of Soil Loss and RUSLE Parameters Based on Land Use

		Mean	Minimum	Maximum	SD
*R**	Forest	403.18	180.27	539.51	70.32
	Pasture	531.98	250.55	671.37	77.63
	Agriculture	284.26	165.38	710.41	90.5
*K**	Forest	.032	.0001	.0329	.003
	Pasture	.028	.0001	.0329	.006
	Agriculture	.028	.0001	.0329	.008
*LS**	Forest	22.35	.03	55.03	14.76
	Pasture	12.7	.20	55.03	9.89
	Agriculture	17.2	.04	55.03	13.43
*C**	Forest	.004	.0040	.004	.00
	Pasture	.040	.0100	.05	.015
	Agriculture	.114	.0800	.3	.039
*A**	Forest	1.210	.01	5.67	0.99
	Pasture	7.64	.01	34.01	7.01
	Agriculture	14.86	.15	72.35	14.77

Note: **A* = Average annual soil loss (t ha^{-1} year^{-1}), *R* = Rainfall erosivity factor (MJ ha^{-1} year^{-1} × mm h^{-1}), *K* = Soil erodibility factor (ton ha^{-1} × ha MJ^{-1} × h mm^{-1}), LS = Slope length and steepness factor, *C* = Land cover and management factor

In our investigation, the soil in these regions, as indicated by data from the significant soil group, is notably shallow. Consequently, the presence of protective vegetation on the soil surface reduces its susceptibility to erosion. In such locations, soil and water conservation measures can be implemented to safeguard vegetation (Fang, 2017).

As a result, it has been established that vegetation plays a significant role in erosion formation (Fang, 2017; Vieira et al., 2022). High C values and erosion risk are observed in agricultural zones within the Değirmendere watershed, particularly when the elevation is below 800 m, R values are under 320, and the K factor exceeds 0.2. Fu et al. (2005) discovered a greater C factor in regions with extensive cultivated land areas in the Yanhe basin. Our findings suggest that vegetation ($r=.639$) exerts a more substantial influence on soil erosion compared to rainfall ($r=0.01$). C emerges as a stronger indicator for explaining variations in soil loss. Particularly, forested areas stand out as crucial contributors to soil erosion.

According to our results, the most substantial soil loss occurred in agricultural lands (14.86 tons ha^{-1} year^{-1}), followed by pasturelands (7.64 tons ha^{-1} year^{-1}), and the least in forested areas (1.21 tons ha^{-1} year^{-1}). Sthiannopkao et al. (2006) observed that paddy fields suffered the highest erosion, whereas forested areas experienced the least erosion. Furthermore, the soil depth in these regions is notably shallow (0–20 cm) and moderately shallow (20–50 cm). In agricultural areas, even when soil erodibility is low, the absence of protective cover leads to more substantial soil loss compared to forested regions.

Upon comparing our research results with global and Turkish studies, they consistent with the same outcomes and demonstrate compatibility with existing literature. Consequently, adopting soil-protective practices becomes imperative when conducting agriculture in these regions (Fang, 2017; Vieira et al., 2022). Taking into consideration the slope, elevation, aspect, and erosion risk in these areas, soil-conservation practices like contour plowing, strip planting, and alternating planting methods should be implemented. Fang (2017) found that sediment yield reduction was achieved through soil conservation measures such as terrace and contour tillage on slopes, with over 80% of the decreased sediment yield attributed to land use changes.

In the Değirmendere watershed, areas with high erosion risk are generally found in downstream agricultural regions and upper upstream natural pasture areas. Ikiel et al. (2020) noted that the Ergene River and its surrounding agricultural zones consist of regions with moderate to severe erosion risk. They highlighted that erosion risk is elevated in areas with insufficient vegetation cover, higher rainfall, specific soil characteristics, and improper land use driven by human activities and the presence of natural pasture areas. Typically, high erosion risk is concentrated in mountainous areas. Our study is similar to conducted by Ikiel et al. (2020) in terms of the highest occurrence of erosion in natural pasture areas and agricultural fields. The estimated soil loss within the Değirmendere watershed is observed to be below both the Turkish whose average soil erosion value is 8.14 tons ha^{-1} year^{-1} and global average. The distribution of risk in the watershed includes 52.16% areas of very low risk, 12.38% low risk, 13.28% medium risk, 13.02% high risk, and 9.15% very high-risk zones. Nonetheless, the soil depth in the region remains shallow. In addition to this, the amount of erosion has been found to be high in agricultural and natural pasture areas. In these areas, terraces can be created by determining slope and slope length levels, providing a reducing effect on slope and breaking the slope length. Since these areas are typically comprised of agricultural fields in the downstream

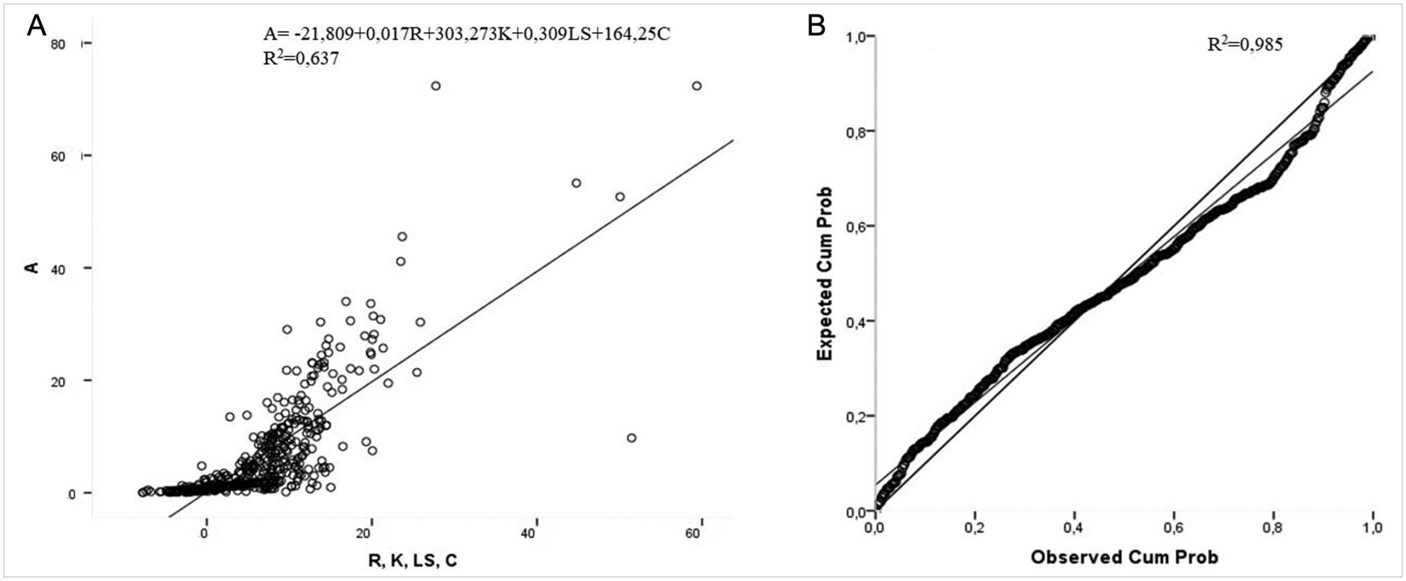

Figure 9.
Regression analysis between A (Average annual soil loss (t ha-1 y-1)), and R (Rainfall erosivity factor (MJ ha-1 y-1 x mm h-1)), K (Soil erodobility factor (tonne ha-1x ha MJ-1x h mm-1)), LS (Slope length and steepness factor), C (Land cover and management factor) parameters (A) and normal distribution of RUSLE A (B)

part of the watershed, implementing soil and water conservation farming practices, such as contour or strip planting methods, is crucial. Therefore, based on the research findings, protective measures should be initiated within the Değirmendere watershed and in other watersheds worldwide exhibiting similar characteristics of high erosion risk and shallow soil depth.

The Soil Delivery Ratio for Değirmendere is calculated as 0.38 (225013 tons per year), which represents a substantial amount. In previous studies, Tüfekçiolu and Yavuz (2016) and Oğuz et al. (2019) reported SDR values of 0.31 and 0.48, respectively. These results indicate that soil erosion can occur across various parts of the watershed, with the northwest and west sections displaying higher potential erosion rates due to the interaction of factors like topography, geology, slope, and land cover. Areas with limited vegetation, especially those located along sloping riparian regions, are more susceptible to SDR.

Table 4.
Correlations Between Soil Loss and R, K, LS, C

	R	K	LS	C	A
R′	1				
K′	−.103*	1			
LS′	−.212**	.127**	1		
C′	−.160**	−.262**	−.102*	1	
A′	.010	.054	.318**	.639**	1

Note: ′*A* = Average annual soil loss (t ha^{-1} year^{-1}), *R* = Rainfall erosivity factor (MJ ha^{-1} year^{-1} × mm h^{-1}), *K* = Soil erodobility factor (ton ha^{-1} × ha MJ^{-1} × h mm^{-1}), *LS* = Slope length and steepness factor, *C* = Land cover and management factor
**Correlation is significant at the 0.01 level (two-tailed).
*Correlation is significant at the 0.05 level (two-tailed).
N = 475.

In terms of direct measurement methods, the highest sediment load was recorded in April (20388 tons), coinciding with increased stream flow following snowmelt. While the rainy season witnessed the highest sediment transport, August exhibited the lowest sediment transport (663 tons). Notably, April also recorded the highest transported TN (22 tons) and C (219 tons). In contrast, August demonstrated the lowest TN (1.5 tons) and C (14.5 tons) transport. These findings suggest that higher discharge levels corresponded to increased amounts of suspended sediments (SS) (r=0.615), carbon (C) (r=0.718), and total nitrogen (r=0.469). Duarte & Gioda (2014) highlighted that SS and phosphorus levels tend to be higher during rainy periods compared to dry periods. They emphasized that sediment's chemical composition affects rock structures, clay minerals, soil structure, and the degradation of forests and agricultural areas. Quilbe et al. (2006) determined the average total dissolved nitrogen to be 8.1 kgha^{-1}year^{-1}, emphasizing that nutrient and sediment transport via runoff is prominent during spring due to precipitation and flow rates, leading to water erosion.

Sigua & Tweedale (2003) highlighted that 79% of the total nitrogen content in the Indian River Lagoon basin can be attributed to runoff from agricultural and urban sources. Additionally, nitrogen originating from the nutrient cycle within suspended solids constitutes approximately 4% of the total nitrogen present in the watershed. Sthiannopkao et al.

Table 5.
Distributions TN, C, Discharge, and SS

	Mean	Minimum	Maximum	SD
TN*	.2033	.09	.42	.12
C*	1.57	.63	3.01	.84
Discharge	15.43	5.12	41.40	12.11
SS*	8138.33	663.29	20387.69	6782.13

Note: *TN = Total nitrogen, C = Carbon, SS = Suspended sediment

(2006) asserted that erosion carries away the fertile topsoil layer, leading to diminished soil fertility, and the sediment transported by erosion contains both nutrients and agricultural chemicals, ultimately degrading water quality. These findings lend support to earlier research, suggesting a potential link between elevated carbon andconcentrations in sediment and the prevalence of agricultural lands within the watershed lacking sufficient vegetative cover. Thus, both the existing literature and correlation analysis reinforce these findings.

In accordance with global and Turkish water quality control regulations, no specific classification has been established for C and TN values within suspended sediments and bed loads. Comparisons are often made between measured values in various river systems. Eutrophication-related SS values for dam reservoirs, as stipulated in water pollution control regulations, are set at 15 mg/L (SKKY, 2004). However, the measured SS amounts exceed this threshold by a significant margin. Consequently, the C and TN levels we observed within suspended sediments hold notable implications for eutrophication. Considering the impact of climate change, similar watersheds worldwide should initiate measures to curtail soil loss, sediment transport, and the transfer of C and TN within sediments.

As soil erosion intensifies, soil loses its capacity to store carbon, which is pivotal in combatting global climate change, while also experiencing reduced productivity. Our findings indicate that the excessive levels of C and TN transferred to surface water within the Değirmendere watershed contribute to soil degradation, elevate carbon emissions, and collectively contribute to climate change. Consequently, to address soil erosion, it is crucial to implement effective soil conservation strategies and prevent soil transfer into streams on a global scale. Otherwise, the inevitable outcome will be eutrophication in streams, lakes, and seas, coupled with the progressive accumulation of transported soil and other watershed activities. The eventual result will be decreased soil fertility within the watershed and deteriorating water quality. These factors combined will potentially trigger a chain reaction, amplifying the effects of climate change.

This paper investigated the C and TN content of SS, total soil loss and SDR of the Değirmendere watershed in Trabzon, Türkiye. The study has shown that the soil particles carried into the streams create turbidity and contain C and TN nutrients which is adversely affected the water quality. The use of the RUSLE and GIS together is important because the easy access to information and saving time. As a result of the study, the quantitative information on soil erosion and water quality, which emerged at the scale of the watershed, sheds light on decision-makers for planning a watershed in terms of soil and water protection. In addition, this study shows that the severity and spatial distribution of watershed erosion can be determined quickly and easily so soil and water conservation such as rotational grazing in natural pasture areas and strip planting method in agricultural fields studies can be carried out adequately and accurately.

Ultimately, the RUSLE model employed in this study is a potent instrument for forecasting soil erosion brought on by water and assessing the efficacy of soil conservation techniques. Population growth and global climate change will increase the pressure on the natural ecosystem in the future. Thus, soil protection practices will become more important. The findings may therefore be used by farmers, land managers, and conservationists to spot regions that are susceptible to soil erosion, established precautions, and maintain the soil's long-term productivity.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept – N.K., Ö.K., K.Ç.; Design – N.K., Ö.K., K.Ç.; Supervision – N.K., Ö.K.; Resource – N.K., Ö.K., K.Ç.; Materials – N.K., Ö.K., K.Ç.; Data Collection and/or Processing – N.K., Ö.K., K.Ç.; Analysis and/or Interpretation – N.K., Ö.K., K.Ç.; Literature Search – N.K., Ö.K.; Writing – N.K., Ö.K.; Critical Review – N.K., Ö.K.

Declaration of Interests: The authors have no conflicts of interest to declare.

Funding: The authors declared that this study has received no financial support.

References

- Akın, M., & Akın, G. (2007). The importance of water, water potential in Turkiye, water basins, and water pollution. *Ankara University Journal of Language, History, and Geography Faculty*, *47*, 105–118.
- APHA (1989). *Standard methods fort the examination of water and wastewater* (20th ed, vol. *2*, p. 540). APHA, American Water Works Association, World Economic Forum.
- Arnoldus, J. M. J. (1977). Methodology used to determine the maximum potential average annual soilloss due to sheet and rill erosion in Morocco. *Food Agriculture Organization, Soils Bulletin*, *34*, 39–51.
- Bremner, J. M. (1965). Inorganic forms of nitrogen. In C. A.Black et al. (Eds.), *Methods of soil analysis, Part 2. Agronomy*, (Vol. *9*, pp. 1179–1237). Am.Soc. of.Agron., Inc. [CrossRef]
- Burak, S., Zeki, S., Ülker, D., & Bayırhan, İ. (2022). The legal framework of water quality management in Turkiye. *Turkish Journal of Water Science & Management*, *6*(1), 121–144.
- ÇEM (2022). *General Directorate of Combating Desertification and Erosion*.
- Cevahir, E. (2020). *A guide to quantitative data analysis with SPSS* (1st ed, p. 161). Kıbele Publications.
- Debie, E., & Awoke, Z. (2023). Assessment of the effects of land use/cover changes on soil loss andsediment export in the Tul Watershed, Northwest Ethiopia using the RUSLE and InVEST models. *International Journal of River Basin Management*, 1–16. [CrossRef]
- Dogru, B., & Gungoroglu, C. (2022). An application for increasing the efficiency in the mapping of the precipitation values of different meteorological stations. *Turkey Geographic Information Systems Journal*, *4*(1), 15–22. [CrossRef]
- DSI (2022). *General Directorate for State Hydraulic Works*.
- Duarte, A. F., & Gioda, A. (2014). Inorganıc composition of suspended sediments in the Acre River,Amozon Basin, Brazil. *Latin American Journal of Sedimentology and Basin Analysis*, *21*(1), 3–15.
- Erdem, M., & Türkmen, F. (2020). Assessment of erosion risk in the Circip stream basin using the RUSLE model, Turnasuyu-Ordu. *Academic Agricultural Journal*, *9*(1), 129–136.
- Erpul, G., İnce, K., Demirhan, A., Küçümen, A., Akdağ, M. A.,Demirtaş, İ., Sarıhan, B., Çetin, E., & Şahin, S. (2020). *Water erosion province statistics and soil erosion control strategies (Sustainable Land/Soil Management Practices and Approaches)*. General Directorate of Combating Desertification and Erosion Publications.
- Erpul, G., Sahin, S., Ince, K., Kücümen, A., Akdag, M. A., Demirtas, I., & Cetin, E. (2018). *Turkiye Atlas of Water Erosion*. General Directorate of Combating Desertification and Erosion Publications.
- EEA (2021) *European Environment Agency*. https://land.copernicus.eu/pan european/corine-land-cover/lcc-2012-2018?tab=download.15.06.2021
- Fang, H. (2017). Impact of land use change and dam construction on soilerosion and sediment yield in the black soil region,northeastern China. *Land Degradation and Development*, *28*(4), 1482–1492. [CrossRef]
- Fathizad, H., Karimi, H., & Alibakhshi, S. M. (2014). The estimation of erosion and sediment by using the RUSLE model and RS and GIS techniques (case study: arid and semi-arid regions of Doviraj, Ilam Province, Iran). *International Journal of Agriculture and Crop Sciences*, *7*(6), 304–314.
- Fayas, C. M., Abeysingha, N. S., Nirmanee, K. G. S., Samaratunga, D., & Mallawatantri, A. (2019) Soil loss estimation using rusle model to prioritize erosion control in KELANI river basin in Sri Lanka. *International Soil and Water Conservation Research*, *7*(2), 130–137. [CrossRef]
- Ferro, V., Bagarello., V., Stefano, C. D., Giordano, G., & Porto, P. (2001). Monitoring and predicting sediment yield in a small Sicilian basin. *American Society of Agricultura Engineers*, *44*, 585–595. [CrossRef]

- Filiz, M., & Avcı, H. (2013). Landslides and Theır effects at the Trabzon Provınce. *SDU International Technologic Science*, *5*(3), 31–38.
- Foster, G. R., McCool, D. K., Renard, K. G., & Moldenhauer, W. C. (1981). Conversion of the universal soil loss equation to SI metric units. *Journal of Soil and Water Conservation*, *36*(6), 355–359.
- Fu, B. J., Zhao, W. W., Chen, L. D., Zhang, Q. J., Lü, Y. H., Gulinck, H., & Poesen, J. (2005). Assessment of soil erosion at large watershed scale using RUSLE and GIS: A case study in theLoess Plareau of China. *Land Degradation and Development*, *16*(1), 73–85. [CrossRef]
- Galdino, S., Sano, E. E., Andrade, R. G., Grego, C. R., Nogueira, S. F., Bragantini, C., & Flosi, A. H. G. (2016). Large-scale modeling of soil erosion with RUSLE for conservationist planning of degraded cultivated Brazilian Pastures. *Land Degradation and Development*, *27*(3), 773–784. [CrossRef]
- Ganasri, B. P., & Ramesh, H. (2015). Assessment of soil erosion by RUSLE model using remote sensing and GIS-A case study of Nethravathi Basin. *Geoscience Frontiers*, *7*(6), 953–961. [CrossRef]
- Ibrahim, A. L., Yaakub, S. Y., Khan, N. L. M., & Huey, T. T. (2012). Application of geographic information system in soil erosion prediction. The 33rd Asian Conference on Remote Sensing, 26-30 November, Pattaya, Thailand.
- Ikiel, C., Ustaoglu, B., & Koc, D. E. (2020). Erosion susceptibility analysis of Thrace Peninsula. *Journal of Geomorphological Researches*, *4*, 1–14.
- Issaka, S., & Ashraf, M. A. (2017). Impact of soil erosion and degradation on water quality: A review. *Geology, Ecology, and Landscapes*, *1*(1), 1–11. [CrossRef]
- Kara, O., Cakıroglu, K., & Koralay, N. (2018). Determination of soil erosion according to RUSLE Method in Foldere Watershed. *Journal of Bartın Faculty of Forestry*, *20*(3), 638–652. [CrossRef]
- Kılıcaslan, A. (1996). The tourism potantials of the Trabzon-Değirmendere regions and it's planning. *Turkish Geography Journal*, *31*, 183–197.
- Koralay, N. (2015). *The effects of river type hydroelectric power plants on water quality in the Solaklı Stream Watershed* (Master Thesis). Karadeniz Technical University, Institute of Science.
- Koralay, N., & Kara, O. (2022). Creating erosion risk map and determining sediment delivery ratio of the Trabzon Değirmendere- Çatak subwatershed. *Turkish Journal of Forestry Research*, *9*, 41–54. [CrossRef]
- Kumar, T., Jhariya, D. C., & Pandey, H. K. (2019). Comparative study of different models for soil erosion and sediment yield in Pairi Watershed, Chhattisgarh, India. *Geocarto International*, *35*(11), 1245–1266. [CrossRef]
- Lee, S. E., & Kang, S. H. (2013). Estimating the GIS-based soil loss and sediment delibery ratio to the sea for four major basins in South Korea. *Water Science and Technology*, *68*(1), 124–133. [CrossRef]
- Moore, I. D., & Burch, G. J. (1986). Physical basis of the length–slope factor in the universal soil loss equation. *Soil Science Society of America Journal*, *50*(5), 1294–1298. [CrossRef]
- Nijimbere, G., & Lizana, C. R. (2019). Assessment of soil erosion of Burundi using remote sensing and GIS by RUSLE model. *RUDN Journal of Ecology and Life Safety*, *27*(1), 17–28. [CrossRef]
- Oguz, I., Susam, T., Kocyigit, R., Bıçak, H., Demirkiran, O., & Demir, S. (2019). Estimation of soil erosion and river sediment yield in rural basin of north Anatolia, Turkiye. *Applied Ecology and Environmental Research*, *17*(4), 7741–7763. [CrossRef]
- Owens, P. N., & Walling, D. E. (2002). The phosphorus content of fluvial sediment in rural and industrialized river basins. *Water Research*, *36*(3), 685–701. [CrossRef]
- Ozcan, A. U., Uzun, O., Başaran, M., Erpul, G., Akşit, S., & Palancıoğlu, H. M. (2015). Soil erosion risk assessment for volcano cone of Alidaği Mountain by using USLE/RUSLE, GIS and geostatistics. *Fresenius Environmental Bulletin*, *24*, 2090–2100.
- Özdemir, M. A., & Tatar Dönmez, S. (2016). GIS-based RUSLE method of the erosion risk analysis in Işıklı lake basin. *Harita Teknolojileri Elektronik Dergisi*, *8*(1), 1–21. [CrossRef]
- Özşahin, E. (2016). Effects of land use and land cover changes on erosion in the Ergene Basin (Trakya). *Anadolu Journal of Agricultural Sciences*, *31*(1), 117–126. [CrossRef]
- Ozsoy, G. (2007). *Determination of erosion risk using remote sensing (RS) and geographic information system (GIS)* (Doctoral Thesis). Uludağ University Institute of Science.
- Panagos, P., Borrelli, P., Meusburger, K., Alewell, C., Lugato, E., & Montanarella, L. (2015). Estimating the soil erosion cover-management factor at the European scale. *Land Use Policy*, *48*, 38–50. [CrossRef]
- Prasannakumar, V., Vijith, H., Abinod, S., & Geetha, N. (2012). Estimation of soil erosion risk within a small mountainous sub-watershed in Kerala, India, using revised universal soil loss equation (RUSLE) and Geo-Information Technology. *Geoscience Frontiers*, *3*(2), 209–215. [CrossRef]
- Quilbé, R., Rousseau, A. N., Duchemin, M., Poulin, A., Gangbazo, G., & Villeneuve, J. (2006). Selecting a calculation method to estimate sediment and nutrients loads in streams: Application to the beaurivage river (Quebec, Canada). *Journal of Hydrology*, *326*(1–4), 295–310. [CrossRef]
- Rehman, O. U., Rashid, M., Kausar, R., Alvi, S., & Hussain, R. (2015). Slope gradient and vegetation cover effects on the runoff and sediment yield in hillslope agriculture. *Turkish Journal of Agriculture – Food Science and Technology*, *3*(6), 478–483. [CrossRef]
- Renard, K. G., Foster, G. R., Weesies, G., McCool, D., & Yoder, D. (1997). *Predicting soil erosion by water: A guide to conservation planning with the revised universal soil loss equation (RUSLE)*. US Government Printing Office.
- Sigua, G. C., & Tweedale, W. A. (2003). Watershed scale assessment of nitrogen and phosphorus loadings in the Indian River Lagoon Basin, Florida. *Journal of Environmental Management*, *67*(4), 363–372. [CrossRef]
- SKKY (2004). *Water pollution control regulation*.
- Sthiannopkao, S., Takizawa, S., & Wirojanagud, W. (2006). Effects of soil erosion on water quality and water uses in the upper Phong watershed. *Water Science and Technology*, *53*(2), 45–52. [CrossRef]
- Tahiru, A. A., Doke, D. A., & Baatuuwie, B. N. (2020). Effect of land use and land cover changes on water quality in the Nawuni Catchment of the White Volta Basin, Northern Region, Ghana. *Applied Water Science*, *10*(8), 198. [CrossRef]
- Tessema, I., Simane, B., & Angassa, K. (2023). Soil erosion estimation and risk assessment at watershed level: A case study of Neshe Dam Watershed in Blue Nile River basin, Ethiopia. *International Journal of River Basin Management*, 1–14. [CrossRef]
- TMM (2022). *Trabzon 11th Regional Directorate of Meteorology*.
- TOBM (2022). *Trabzon forest regional directorate management plans*.
- Tüfekçioğlu, M., & Yavuz, M. (2016). Estimating surface soil erosion losses and mapping erosion risk for Yusufeli micro-catchment (Artvin). *Artvin Coruh University Journal of Forestry Faculty*, *17*(2), 188–199.
- Tüfekçioglu, M., Yavuz, M., Vatandaslar, C., Dinc, M., Duman, A., & Tüfekcioğlu, A. (2018). Assessing and mapping erosion risk for Veliköy sub-watershed within Coruh River Basin in Turkiye. *Journal of Natural Hazards and Environment*, *4*(2), 210–220. [CrossRef]
- Tüfekçioğlu, M., Yildirim, C., & Duman, A. (2020). Determination of soil loss occurring via gully and streambanks using "erosion pin method" in Oltu Micro-catchment within Coruh river basin. *Turkish Journal of Forest Science*, *4*(2), 333–350. [CrossRef]
- Vieira, L., Pessoa, L. A., Carvalho Pereira, V. E., Gois, K. S., & Couto, E. Vd. (2022). Integrating water, sediments, and land use analysis for pollution assessment in a countryside urban-farming watershed landscape in southern Brazil. *International Journal of River Basin Management*, 1–14. [CrossRef]
- Walkley, A., & Black, I. A. (1934). An examination of the degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science*, *37*(1), 29–38. [CrossRef]
- Warrick, A. W., & Nielsen, D. R. (1980). Spatial variability of soil physical properties in the field. In D. Hillel (Ed.), *Applications of soil physics* (pp. 319–344). Academic Press.
- Wischmeier, W. H., & Smith, D. D. (1978). *Predicting rainfall erosion losses-a guide to conservation planning*.
- Yavuz, M., & Tüfekçioğlu, M. (2019). Estimating surface soil losses in the mountainous semi-arid watershed using RUSLE and geospatial technologies. *Fresenius Environmental Bulletin*, *28*(4), 2589–2598.
- Yıldırım, U., & Erkal, T. (2009). *Erosion risk estimation of the western part of the Afyon Plain using the RUSLE method*. Afyon Kocatepe University, project final report, Project no: 07.FENED.06.
- Yılmaz, E. (2006). *Erosion problem and risk analysis in the Çamlıdere reservoir basin* (Master's Thesis). Ankara University Institute of Social Sciences.
- Zhang, J., Wang, N., Wang, Y., Wang, L., Hu, A., Zhang, D., Su, X., & Chen, J. (2021). Responses of soil erosion to land-use changes in the largest tableland of the Loess Plateau. *Land Degradation and Development*, *32*(13), 3598–3613. [CrossRef]