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Research Article

Erosion analysis of Kuruçay Stream basin (Edremit—Balikesir, Türkiye)

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Abstract

Kuruçay Stream basin, located in the Edremit district in northwest Turkey, is a small, narrow and long basin with an area of 17.3 km^2, extending in the N–S direction, located on the southern slopes of Mount Ida. The study was carried out to determine the soil erosion susceptibility and distribution within the Kuruçay Stream basin, as well as to estimate the annual average amount of soil loss through the Revised Universal Soil Loss Equation (RUSLE) model using Geographical Information Systems (GIS). To apply the equation to the basin, data layers for rainfall erosivity (R), soil erodibility (K), slope length (L) and slope steepness (S), landcover management (C), and support practice (P) factors were generated. The layers were then overlaid, calculations were made and erosion susceptibility classes were generated. Thus, the spatial distribution of erosion susceptibility classes and the annual estimated amount of soil loss were determined. Based on the results, the Kuruçay Stream basin was found to have five distinct erosion susceptibility levels: low, moderate, high, severe, and extremely severe. Accordingly, 76% of the basin has low, 11.3% moderate, 6% high, 2.9% severe and finally 3.7% very severe erosion susceptibility. The Kuruçay Stream basin shows similar characteristics with the neighbouring river basins in terms of erosion sensitivity.

Key words: Basin, geographical information systems, RUSLE, soil erosion

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1. Introduction

Soil erosion poses a significant threat, resulting in the depletion of soil, a critical natural resource. It's commonly categorized into two forms: natural erosion and accelerated erosion (Çepel 1997; Şahin and Sipahioğlu 2007; Blanco-Canqui and Lal 2008; Erkal and Taş 2013; Kızılelma and Karabulut 2014). Natural erosion involves the gradual wearing away and movement of the soil's surface layer by external forces (Lastoria et al. 2008; Rahman et al. 2009; Gitas et al. 2009; Fernandez and Nunez 2011). This type of erosion is a non-hazardous process that occurs very slowly under natural land cover and takes thousands of years to develop. However, accelerated erosion, driven by human activities, poses a significant hazard.

Natural factors like bedrock composition, geomorphological features (such as elevation, slope, and exposure), climate, and vegetation, alongside human activities—particularly improper and intensive land use—contribute to the development of erosion.

Soil erosion stands as one of Türkiye's foremost challenges (Atalay 1983, 2000; Mater 2004; Efe et al. 2008a, 2008b; Atalay and Cürebal 2018; Atalay and Altunbaş 2019; Atalay et al. 2019). This issue has escalated to critical proportions due to misguided and excessive land utilization, disrupting natural equilibrium and rendering land unsuitable for its intended purposes (Efe et al. 2008c; Gerdjikov et al. 2019). Numerous scientific inquiries into erosion and conservation strategies have been undertaken to address this predicament (Wischmeier and Smith 1978; Renard et al. 1991; Lane et al. 1992).

Various methodologies have been developed to quantify soil erosion, primarily aimed at gauging its magnitude and severity to inform sustainable policy decisions (Renard et al. 1997; Zhu and Huang 2006; Gaubi et al. 2017; Nearing et al. 2017). Among these, prominent methods include PSIAC (Pacific Southwest Inter-Agency Committee), MPSIAC (Modified Pacific Southwest Inter-Agency Committee), USLE (Universal Soil Loss Equation), RUSLE (Revised Universal Soil Loss Equation), DGCONA (General Directorate for the Conservation of Nature), WEPP (Water Erosion Prediction Project Erosion Model), SIMWE (Simulate Water Erosion), etc. Recently, prediction techniques incorporating isotopes of certain radioactive elements such as Cesium 137 (Cs-137), Lead 210 (Pb-210), and Beryllium 7 (Be-7) have emerged (Atalay and Cürebal 2018).

The pioneering investigations into erosion were spearheaded by German scientist Ewald Wollny in the latter part of the 19th century. In 1888, Wollny's seminal work titled "Pioneer of Soil and Water Conservation Research" posited that soil physical properties and surface runoff waters significantly influenced erosion (Baver 1939). Although Wollny laid the foundation for erosion studies in 1888, it wasn't until the 1930s that American geographers revisited and refined his ideas. The first quantitative application of erosion studies emerged in the Corn Belt of the USA, where in 1946, a team of researchers in Ohio devised a more practical and applicable equation by incorporating the rainfall factor into their parameters. In 1954, the U.S. Agricultural Research Service established the National Surface Runoff and Soil Loss Data Center at Purdue University. Its primary objective was to monitor and compile data to provide updated information on erosion. By 1965, extensive soil erosion studies across various regions culminated in the development of the Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1978). Subsequent advancements in technology led to the revision of soil erosion methodologies in 1987. The USLE equation underwent, resulting in the formation of the Revised Universal Soil Loss Equation (RUSLE) (Renard et al. 1991).

Some of the improvements in the RUSLE include:

"A greatly expanded erosivity map for the western United States, minor changes in R factors in the eastern United States, expanded information on soil erodibility, a slope length factor that varies with soil susceptibility to rill erosion, a nearly linear slope steepness relationship that reduces computed soil loss values for very steep slopes, a subfactor method for computing values for the cover-management factor, improved factor values for the effects of contouring, terracing, stripcropping, and management practices for rangeland." (Renard et al. 1991).

As Geographic Information Systems (GIS) and Remote Sensing (RS) technologies advanced and became widely adopted, erosion models were seamlessly integrated into these platforms and began to see widespread application. Utilizing erosion models in conjunction with GIS and RS technologies has proven to be an effective method for predicting erosion severity and distribution (Mitasova et al. 1996; Molnar and Julian 1998; Millward and Mersey 1999; Yitayew et al. 1999). In parallel with the growth and widespread use of GIS and RS technologies, the RUSLE equation has emerged as a preferred methodology. In recent years, numerous studies in Türkiye have been conducted utilizing the RUSLE method, including those by Ekinci (2005), Cürebal and Ekinci (2006), Tağıl (2007), Efe et al. (2008a, 2008b), Özşahin (2011), Demirci and Karaburun (2012), Özşahin (2014), Atalay and Cürebal (2018), Erpul et al. (2018), Mutlu and Soykan (2018), Mutlu et al. (2021), Alparslan and Küçükönder (2021), Çilek (2021), Ustaoğlu et al. (2021), Atalay Dutucu and Mutlu (2022), Fıçıcı and Soykan (2022), Aykır and Fıçıcı (2022), Koralay and Kara (2022), Demir et al. (2022), Ikiel (2022), and Özşahin (2023).

This study aimed to assess the factors influencing soil erosion, estimate soil erosion rates, and create a comprehensive map of the Kuruçay Stream basin, situated on the southern slope of Mount Ida in north-western Türkiye. Kuruçay Stream basin was chosen as the study area because it is a basin where the parameters affecting erosion are experienced in different dimensions and erosion analysis has not been studied before. The RUSLE method was selected to achieve this goal. Erosion estimation endeavors utilizing the RUSLE method have been conducted across various countries worldwide. In Türkiye, the RUSLE method is employed by the Ministry of Forestry and Water Affairs in basin-specific studies as part of erosion control initiatives (T.C. Orman ve Su İşleri Bakanlığı, Çölleşme ve Erozyon ile Mücadele Genel Müdürlüğü 2013).

The research addressed the following sub-problems:

1. What is the current erosion status of a stream that is located on the southern slope of a high mass with a relative elevation difference over a short distance, such as Mount Ida, and has undergone a severe erosion process?
2. What is the erosion status of the Kuruçay Stream basin compared to neighboring basins?

2. Materials and methods

2.1. Case study area

Kuruçay Stream basin is located in north-western Türkiye, north of the Aegean region, within the borders of Edremit District (Fig. 1). Spanning a surface area of 17.3 km^2, the basin primarily runs in a north-south orientation. The Kuruçay Stream, the primary watercourse within the basin, stretches a total length of 39 km, with 15.2 km comprising the mainstem. Both the mainstem and its tributaries exhibit seasonal flow patterns. The elevation within the area fluctuates between sea level (0 m) and 1774 m, as the basin is characterized by a narrow and elongated topography.

Geologically, the basin developed on the Mount Ida massif. Consequently, metamorphic rocks are prevalent throughout the area. Gneisses and crystal-

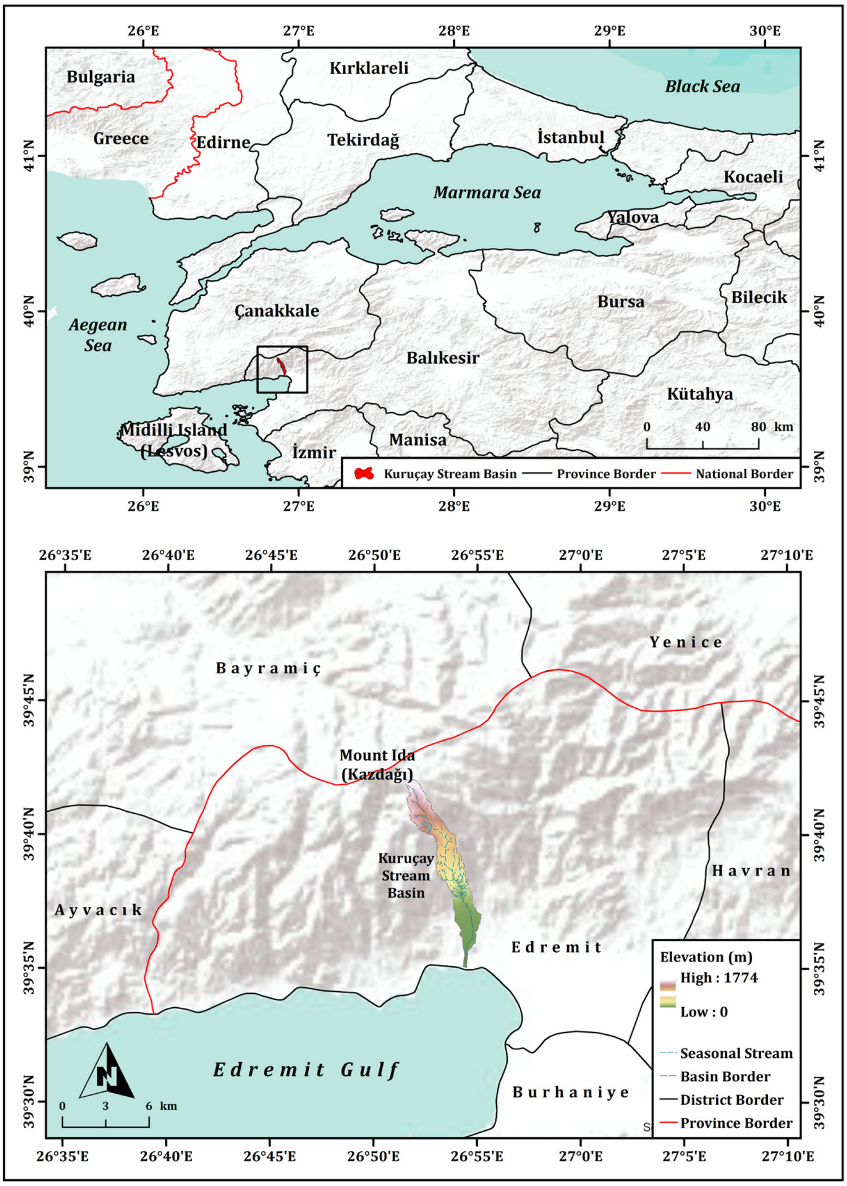

Figure 1. Location of the Kuruçay Stream basin.

lized limestones from the Paleozoic and Jurassic periods dominate the upper and middle reaches of the basin. In contrast, the lower basin's hilly terrain comprises Neogene volcanic rocks such as andesite, tuff, and basalt. Near the coastline, Quaternary alluvial deposits are observed in low-lying areas. Tectonic features within the basin predominantly align in NE–SW and E–W directions, forming a stepped structure extending from the Gulf of Edremit to the summit of Mount Ida.

The study area is characterized by Mediterranean climate. Although there is no meteorological station within the immediate vicinity, 55-year long observations from the Edremit Meteorological Station, the closest station to the study area, were utilized. According to this data, the average annual temperature is 16.6 °C, with a total annual precipitation of 704 mm. Throughout the year, temperatures never drop below 0 °C. The warmest month is July, with an average temperature of 26.9 °C, while the coldest month is January, with an average temperature of 7.3 °C. Precipitation patterns indicate the highest monthly rainfall occurring in December, with 129 mm, while the lowest precipitation levels, at 5 mm each, are recorded in July and August. Silty soils are common in the study area. These soils to cover a wide area in the north of the basin. In the south of the basin, loamy and sandy soils are common. Brutia pine (*Pinus brutia* Ten.) and black pine (*Pinus nigra*) forests are generally seen in the north of the study area. Olive agriculture is common in the south.

2.2. Methods

The "Revised Universal Soil Loss Equation" (RUSLE) developed by the Soil Division of the US Department of Agriculture was used to distinguish and classify potential erosion susceptibility areas in the study area. The RUSLE method consists of five parameters: rainfall erosivity factor (R), soil erodibility factor (K), slope steepness and slope length factor (LS), landcover management factor (C) and support practice factor (P) (Wischmeier and Smith 1978; Renard et al. 1991; Lane et al. 1992; Renard et al. 1997; Nearing et al. 2017; Atalay and Cürebal 2018) (Fig. 2).

RUSLE formula consists of the following parameters (eq. 1):

$$A = R*K*LS*C*P \tag{1}$$

Where:
A = Average Annual Soil Loss (tons/ha/year)
R = Rainfall Erosivity Factor (MJ/ha/year)
K = Soil Erodibility Factor (tons/ha/year)
LS = Slope Steepness and Slope Length Factor (dimensionless)
C = Landcover Management Factor (dimensionless)
P = Erosion Control Support Practice Factors (dimensionless)

During the implementation of the RUSLE method, topographic maps of the basin at a scale of 1:25,000 were digitized and the necessary base data such as elevation (contour curves), rivers, etc. were generated for the analysis.

To generate the rainfall-erosion factor map, data from the Edremit Meteorological Station (21 m) spanning the years 1962 to 2017 were utilized. These data were processed using the Microsoft Office Excel program. The formula developed by Schreiber was employed to estimate the amount and distribution of precipitation across the study area, accounting for the elevation variance from 0 to 1774 meters. This formula was based on the assumption that precipitation increases by 54 mm for every 100 meters of elevation gain (Schreiber 1904) (eq. 2).

$$Ph = Po + 4{,}5*\mathrm{h} \tag{2}$$

Where:
Ph = Average precipitation (mm)
Po = Average monthly precipitation of a point with known data (mm)

In the RUSLE equation, the value obtained by multiplying the total kinetic energy of precipitation by their maximum intensity in 30 minutes (E.I = Erosion Index) plays an important role in the calculation of soil erosion (Wischmeier and Smith 1978). In this study, the Modified Fournier Index (MFI) formula (Arnoldus 1980) was used to find the E.I value.

MFI Formula (eq. 3):

$$MFI = \sum_{i=1}^{12} pi^2/P \qquad (3)$$

Where:
p_i: average monthly precipitation (mm)
P: average annual precipitation (mm)
Rainfall Erosivity Factor Formula (R Factor): (4.17 * *MFI*) – 152

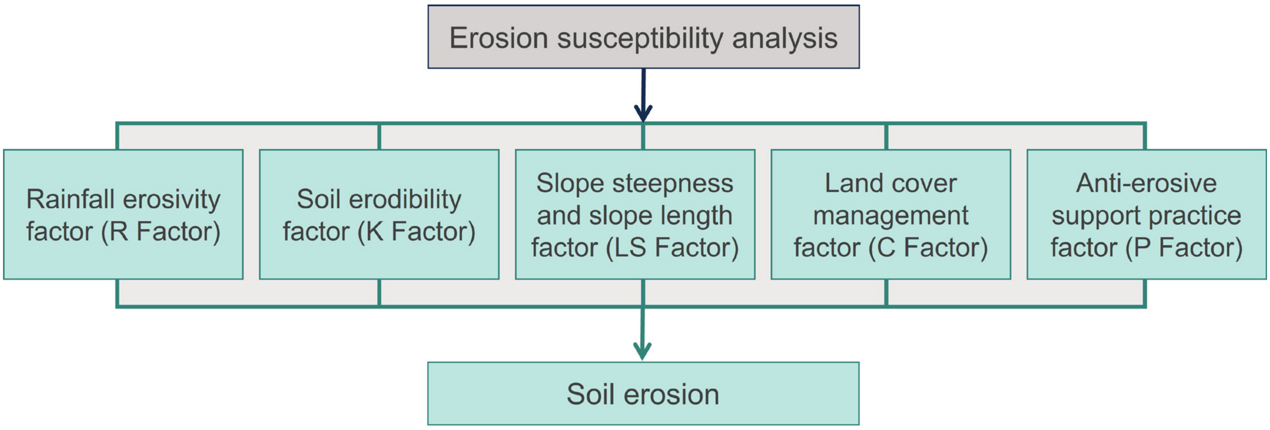

Figure 2. RUSLE method process.

After the Rainfall Erosivity Factor (R Factor) values were calculated, they were interpolated to the Digital Elevation Model (DEM) and mapped.

The soil types of the study area were determined by revising the 1:25,000 scale soil maps prepared by the General Directorate of Rural Services (Balıkesir İli Arazi Varlığı 1999). Since a significant part of the study area consists of hilly areas with limited access conditions, K factor values were obtained from the Ministry of Forestry and Water Affairs, General Directorate of Combating Desertification and Erosion, Soil Information System. After the K factor values were processed into the attribute table, they were converted into 10*10 grid (raster) maps.

Various formulas have been proposed to calculate the LS factor (Millward and Mersey 1999; Moore and Wilson 1992; Cürebal and Ekinci 2006; Efe et al. 2008c; Pandey et al. 2009; Gaubi et al. 2017; Zeng et al. 2017). In this study, the formula developed by (Moore and Burch 1986a, 1986b) and (Mitasova et al. 1996) was used to create the LS factor map. Slope length (L) and slope steepness (S) maps were derived from the Digital Elevation Model (DEM) using formulas outlined by Desmet and Govers (1996) and Mitasova et al. (1996).

The slope map, expressed in degrees, was generated using the Spatial Analyst tool with the Slope analysis option under the Surface menu. Subsequently, a flow direction map was generated from the slope map using the Flow Direction analysis under the Hydrology menu. The Flow Accumulation analysis, also under the Hydrology menu, was then applied to the flow direction map to produce a flow accumulation map. Finally, the LS Factor map was generated using the Map Algebra tool under the spatial analysis toolbox, employing the following formula (eq. 4):

$$LS = 1.6 * \mathit{Power}((\text{“}\mathit{FlowAcc}\text{”} * 10) / 22.1, 0.6) * \mathit{Power}(\mathit{Sin}(\text{“}\mathit{Slope}\text{”} * 0.01745) / 0.09, 1.3) \qquad (4)$$

Where:
Power = Power is a function in the ArcGIS spatial analyst
FlowAcc = Flow accumulation function in the ArcGIS spatial analyst
Slope = Slope gradient values

Cover management factor map was produced using ArcMap (Add Basemap). It was then updated according to 2022 using screen digitizing in Google Earth with the help of Conversion Tools (To Kml /From Kml Tools). Then, the C Factor values which were obtained by reviewing the relevant literature were added to the attribute data and converted into 10*10 grid maps. Since a significant part of the study area consists of hilly areas with limited access conditions, considering the geographical proximity of the study area and the similarity of the features and characteristics of the natural environment, C Factor values were taken from Panagos et al. (2015).

3. Results

3.1. Rainfall Erosivity Factor (R Factor)

The influence of rainfall erosivity factor on soil erosion cannot be underestimated. The quantity, intensity, and duration of precipitation, along with the angle, size, and impact of raindrops on the ground, all contribute significantly to soil erosion processes. Raindrops initiate surface runoff, which, in turn, transports soil particles. These waters, guided by the slope's direction, displace soil particles dislodged by the impact of raindrops. Several empirical formulas have been proposed to quantify these effects, including those developed by Moore (1979), Joint Research Centre (European Commission) et al. (1998), Wischmeier and Smith (1978), Cooley (1980), and Lorito et al. (2004).

The formulas mentioned in the materials and methods section were used to calculate the R factor values in the study area (eq. 3) (Fig. 3; Table 1).

R factor value for a site up to 100 m:

$MFI = 106^2 + 98^2 + 77^2 + 60^2 + 38^2 + \ldots\ldots / 748 = 88.10$

R Factor = (4.17*88.10)-152 = 215.37.

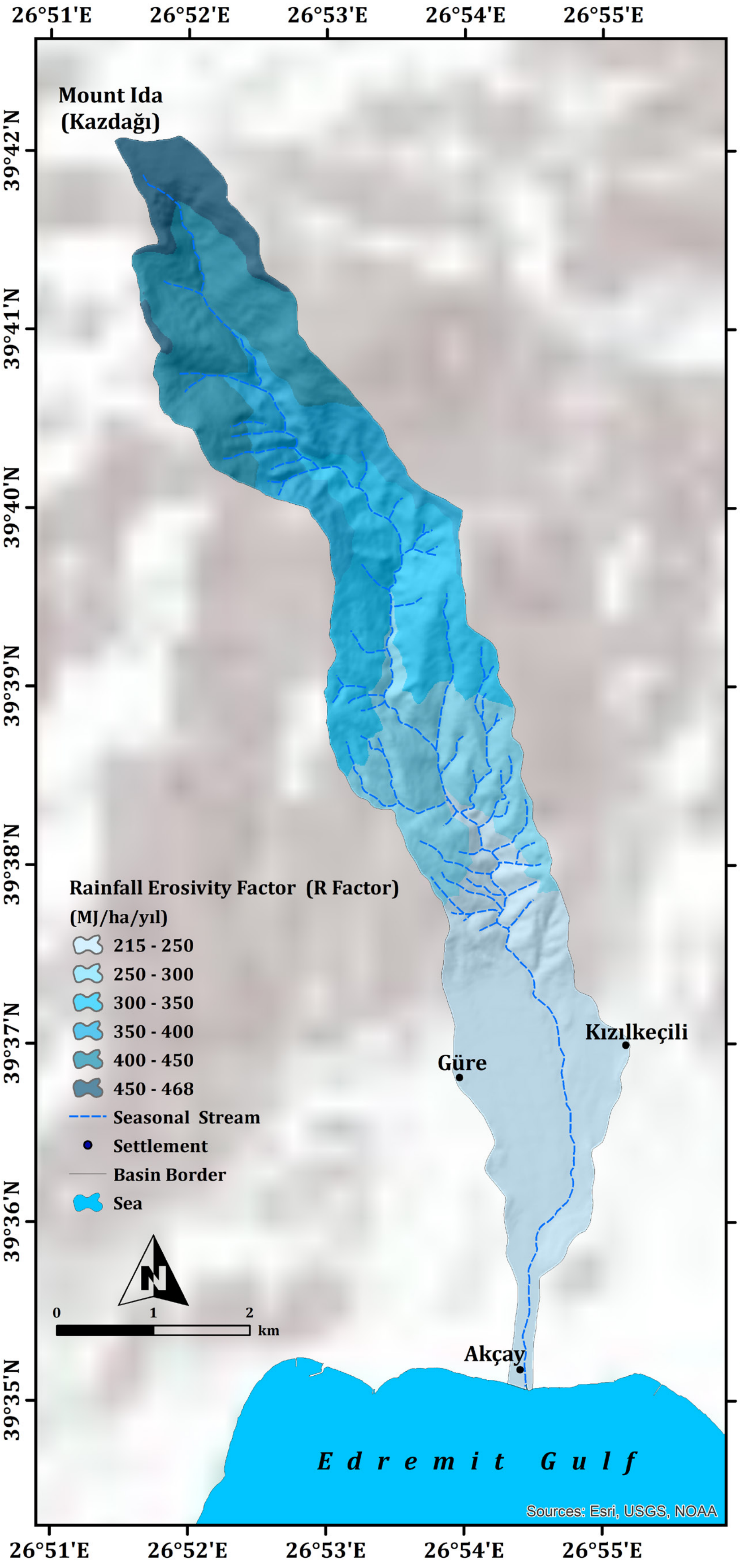

Figure 3. Rainfall Erosivity Factor (R) of Kuruçay Stream basin

Table 1. Kuruçay Stream basin R Factor.

Elevation (m)	Sum of Squares of Monthly Rainfall	Total Precipitation (mm)	MFI	R Factor (MJ/ha/year)
0–100	65866	748	88.10	215.37
100–200	72838	802	90.86	226.89
200–300	80296	856	93.84	239.32
300–400	88240	910	97.00	252.51
400–500	96670	964	100.32	266.32
500–600	105586	1018	103.75	280.65
600–700	114987	1072	107.30	295.44
700–800	124875	1126	110.94	310.60
800–900	135249	1180	114.65	326.10
900–1000	146109	1234	118.44	341.88
1000–1100	157455	1288	122.28	357.91
1100–1200	169287	1342	126.18	374.16
1200–1300	181605	1396	130.12	390.61
1300–1400	194408	1450	134.11	407.23
1400–1500	207698	1504	138.13	424.00
1500–1600	221474	1558	142.19	440.91
1600–1700	235736	1612	146.27	457.95
1700–1774	244526	1644	148.73	468.22

3.2. Soil Erodibility Factor (K Factor)

Soil properties such as structure, texture, grain size, permeability, water holding capacity and profile are the main criteria determining the susceptibility to erosion (Wischmeier et al. 1971; Renard et al. 1997; Millward and Mersey 1999; Mater 2004; Cürebal and Ekinci 2006; Efe et al. 2008c; Atalay 2011; Erpul et al. 2018).

Three distinct soil texture classes are identified in the study area: sandy, loamy, and silty. The soils eroded from the upper and middle reaches of the basin and subsequently deposited downstream are predominantly sandy, covering 1.16% of the basin area, equivalent to 0.2 km^2. Adjacent to the sandy soils, to the north, lie loamy soils, occupying 15.03% of the basin area, totalling 2.6 km^2. The largest portion of the basin is covered by silty soils, constituting 83.81% of the area, covering 14.5 km^2 (Fig. 4; Table 2).

Table 2. Kuruçay Stream K Factor*.

Soil Type	K Value (tons/ha/year)	Area (km^2)	Area (%)
Sandy Soil	0.04	0.2	1.16
Loamy Soil	0.20	2.6	15.03
Silty Soil	0.25	14.5	83.81

* K values in the table were obtained from the T.C. Orman ve Su İşleri Bakanlığı, Çölleşme ve Erozyon ile Mücadele Genel Müdürlüğü, Toprak Bilgi Sistemi.

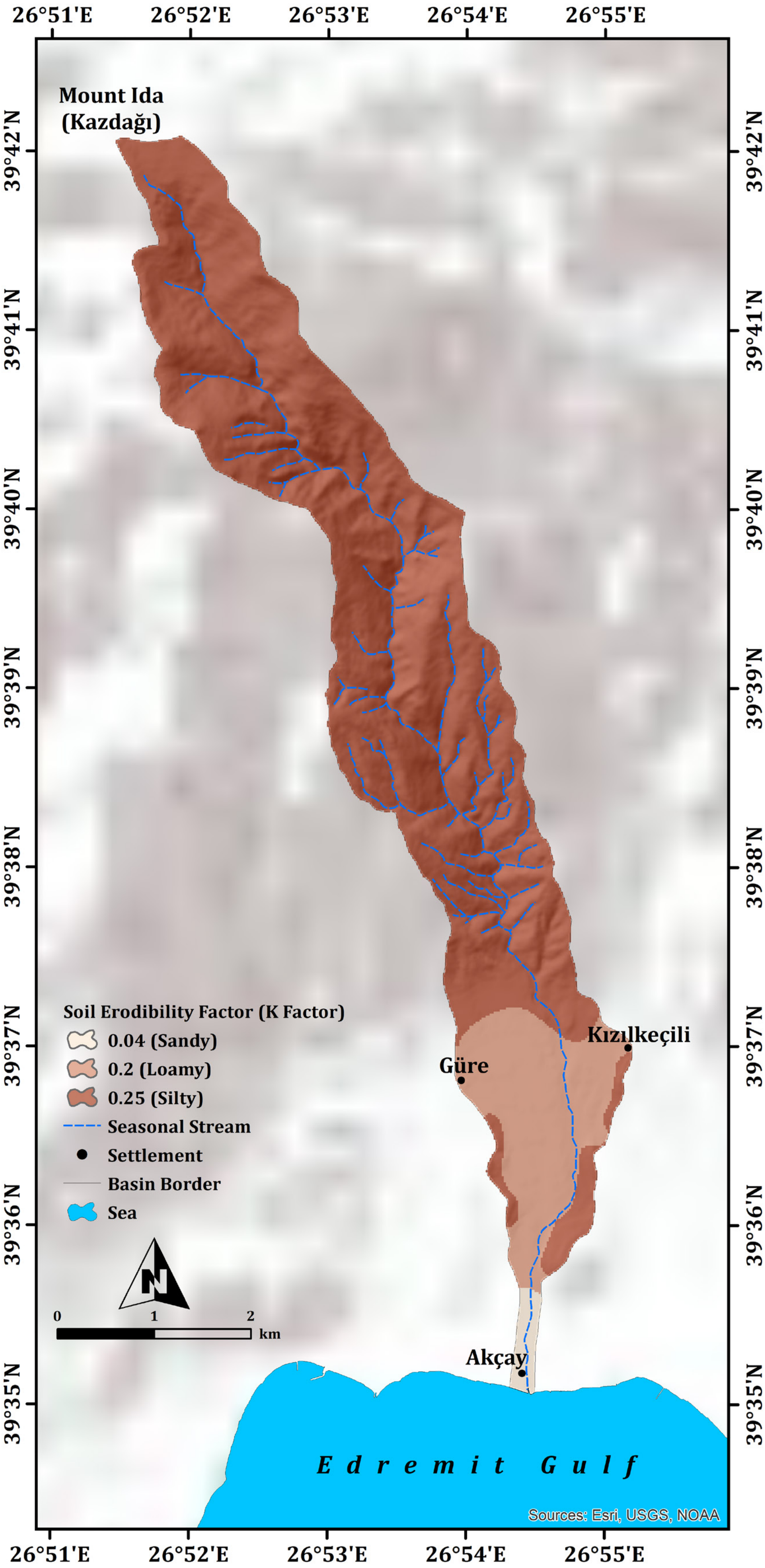

Figure 4. Kuruçay basin Soil Erodibility Factor (K).

3.3. Land cover/Land use and Cover Management Factor (C Factor)

Land use characteristics are the main parameters that shape the relationship between precipitation, infiltration and flow rate and determine the impact of rain droplets on the ground. Land use characteristics and the degree of ground coverage profoundly impact the severity and extent of erosion (Cürebal and Ekinci 2006; Mutlu and Soykan 2018; Mutlu et al. 2021; Fıçıcı and Soykan 2022; Aykır and Fıçıcı 2022; Özşahin 2023). In densely vegetated areas, rainwater is largely retained by trees, shrubs, and herbaceous plants and cannot pass directly into surface runoff. This phenomenon called interception has a slowing effect on erosion.

Kuruçay Stream basin is rich in vegetation. Forested areas covered with dense vegetation constitute 47.40% of the basin with 8.2 km^2. Shrub areas constitute 17.34% of the basin with 3 km^2, olive groves constitute 28.32% of the basin with 4.9 km^2, while agricultural areas constitute 0.58% of the basin with 0.1 km^2. Within the basin, bare rocky surfaces with high slope values, which have poor ability to protect the ground from the impact of rain droplets against erosion, constitute 5.20% of the basin with 0.9 km^2 and settlement areas constitute 1.16% of the basin with 0.2 km^2 (Fig. 5; Table 3).

Table 3. Kuruçay Stream C Factor (Panagos et al. 2015).

Land Use Classes	C Factor	Area (km^2)	Area (%)
Forested areas	0.0002	8.2	47.40
Shrub areas	0.04	3.0	17.34
Agricultural areas	0.38	0.1	0.58
Olive groves	0.2	4.9	28.32
Bare rocky surfaces	0	0.9	5.20
Settlement areas	0	0.2	1.16

Table 4. Kuruçay Stream slope classes.

Slope Classes	Area (km^2)	Area (%)
0–2	1.6	9.0
2–7	2.4	14.2
7–12	1.1	6.6
12–18	2.0	11.4
18–24	3.1	17.8
> 24	7.1	41.1

Table 5. Kuruçay Stream LS Factor.

LS Factor Classes	Area (km^2)	Area (%)
0–1	7.5	43.6
1–10	4.5	26.2
10–25	4.0	23.0
25–70	1.1	6.2
> 70	0.2	1

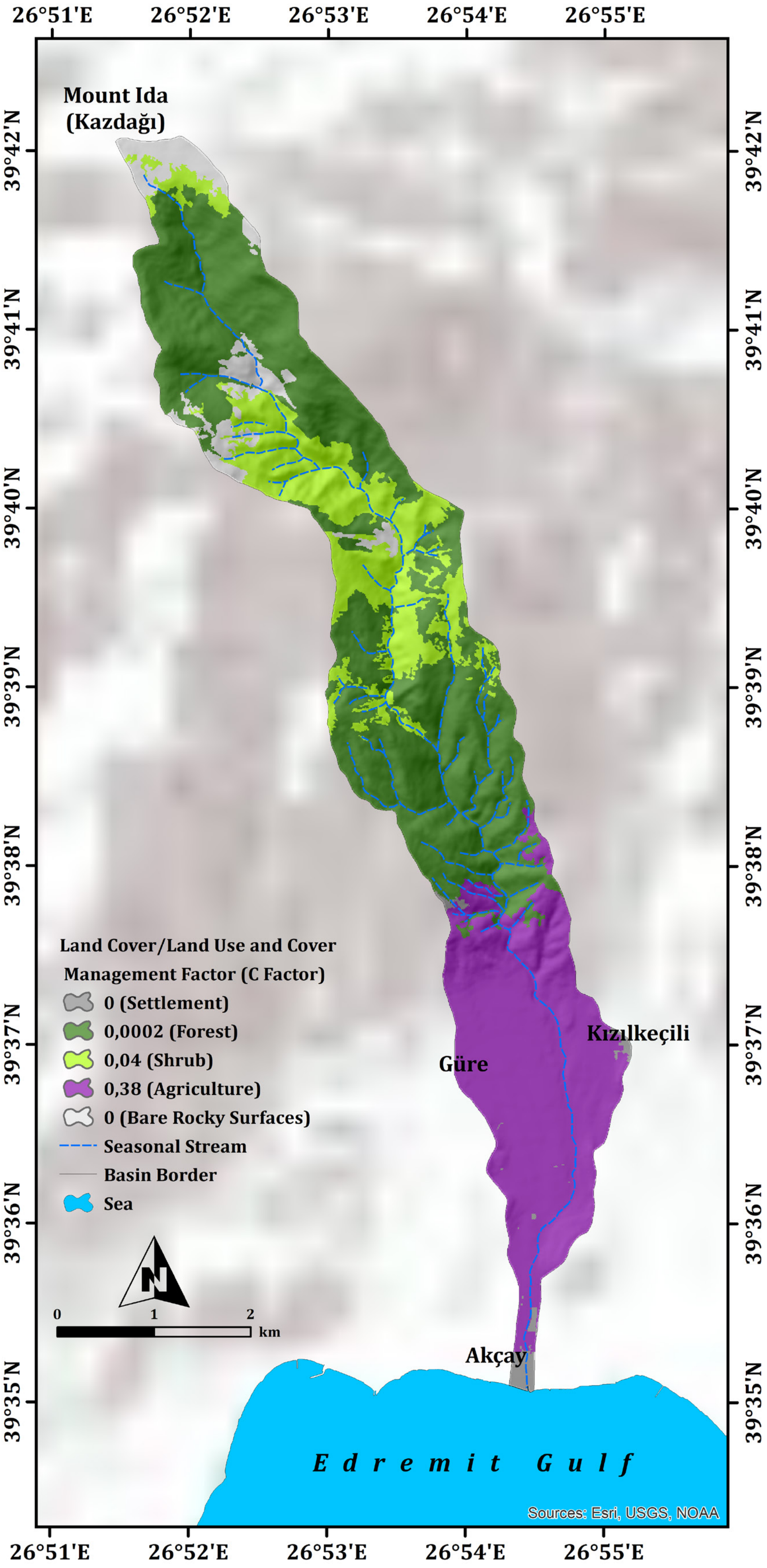

Figure 5. Kuruçay Stream basin Cover Management Factor (C Factor).

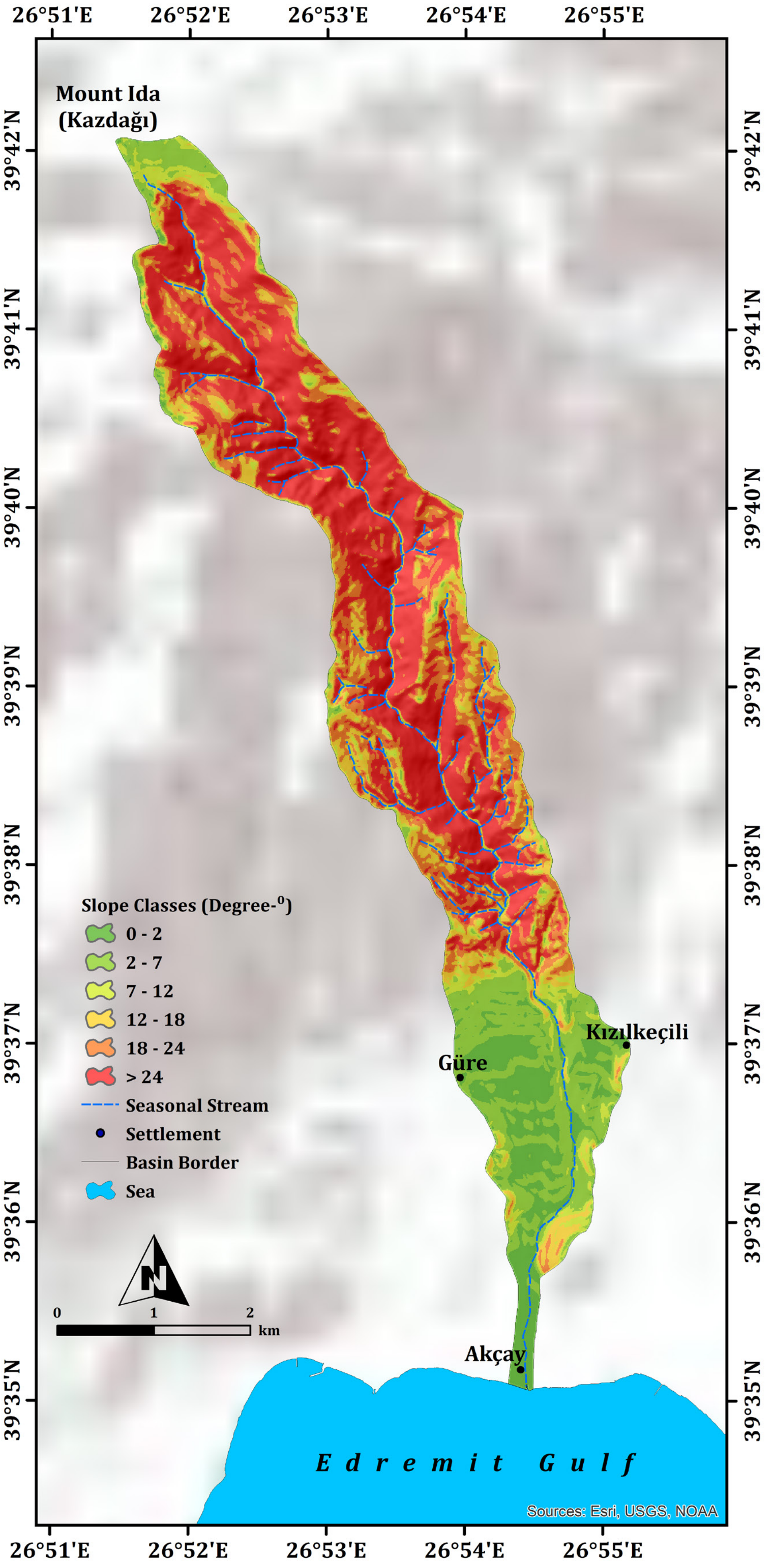

Figure 6. Kuruçay Stream basin Slope.

3.4. Slope length and steepness (LS Factor)

Slope is an important topographic factor affecting erosion. As the slope values increase, the severity and extent of erosion also increase. Slope indirectly affects the severity and extent of erosion by affecting the flow rate of water.

The available literature on erosion was taken into consideration while classifying the slope characteristics of the Kuruçay Stream basin (Cürebal and Ekinci 2006; Özşahin 2011). Slope characteristics show a significant increase in the upper and middle reaches of the basin, but have low values in the lower reaches of the basin. Areas with slope values above 24° degrees constitute more than 1/3 of the basin (Table 4). These areas, which generally correspond to the narrow and deep valleys formed in the upper and middle reaches of the basin, are also the places where erosion and erosion sensitivity is high (Fig. 8). The average slope of the basin is 19.7° degrees (Fig. 6).

The analyses revealed a correlation between increasing LS values and areas characterized by high slopes. These regions also correspond to elevated levels of erosion and erosion sensitivity. Conversely, plains and valley floors characterized by low slope and LS values exhibit lower erosion and erosion sensitivity (Figs. 7, 8).

3.5. Erosion control support practice (P Factor)

The P factor in erosion modelling refers to parameters that describe erosion prevention measures (Lane et al. 1992; Renard et al. 1997). Techniques such as terracing steep slopes and enhancing vegetation density are examples of methods used to influence the P factor. The P factor typically ranges from 0 to 1. A P factor value approaching 0 indicates lower erosion susceptibility, whereas a value nearing 1 signifies increased erosion susceptibility.

The effects of erosion preventive factors in preventing erosion are low in the Kuruçay Stream basin. For this reason, it was excluded from the equation by using a value of 1 for the P factor.

4. Discussion and conclusion

The erosion susceptibility of the Kuruçay Stream basin and the estimated annual soil loss were determined in this study using the RUSLE method. The study area was classified into five distinct erosion susceptibility classes, with threshold values for these classes established based on erosion control action plans issued by the General Directorate for Combating Erosion and Desertification of the Ministry of Forestry and Water Affairs (T.C. Orman ve Su İşleri Bakanlığı, Çölleşme ve Erozyon ile Mücadele Genel Müdürlüğü 2013).

According to these classifications, areas with low level of sensitivity encompass 76% of the basin, covering 13.11 km^2. Moderately sensitive areas constitute 11.3% of the basin, totaling 1.95 km^2. Additionally, areas characterized by high, severe, and very severe erosion susceptibility collectively comprise 12.6% of the basin, covering 2.18 km^2 (Table 6).

Upon examination of the Soil Loss Amount map (Fig. 7), it becomes evident that regions characterized by very severe erosion sensitivity predominantly consist of bare rocky areas with minimal vegetation cover. Areas exhibiting

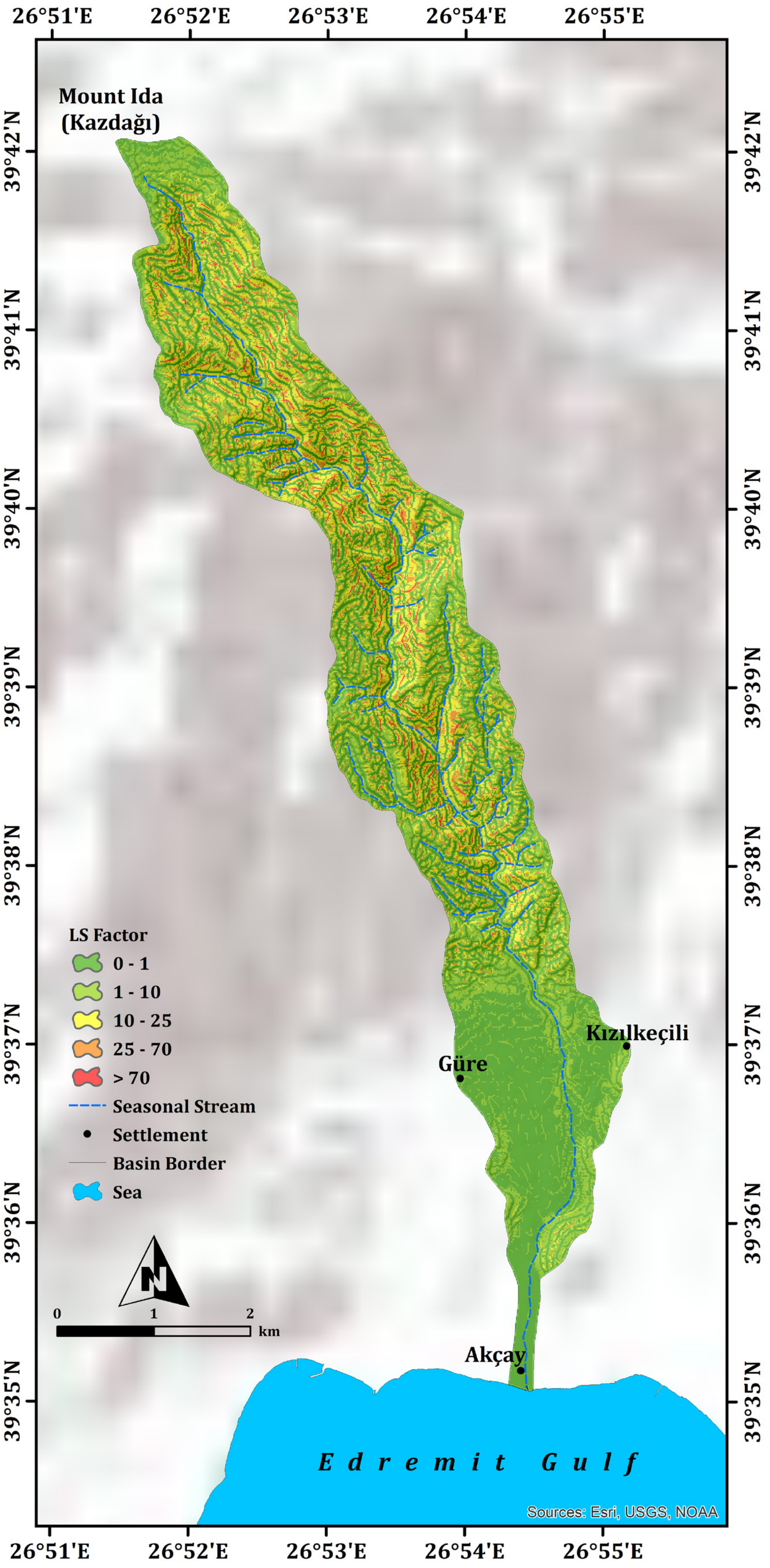

Figure 7. Kuruçay Stream basin LS Factor.

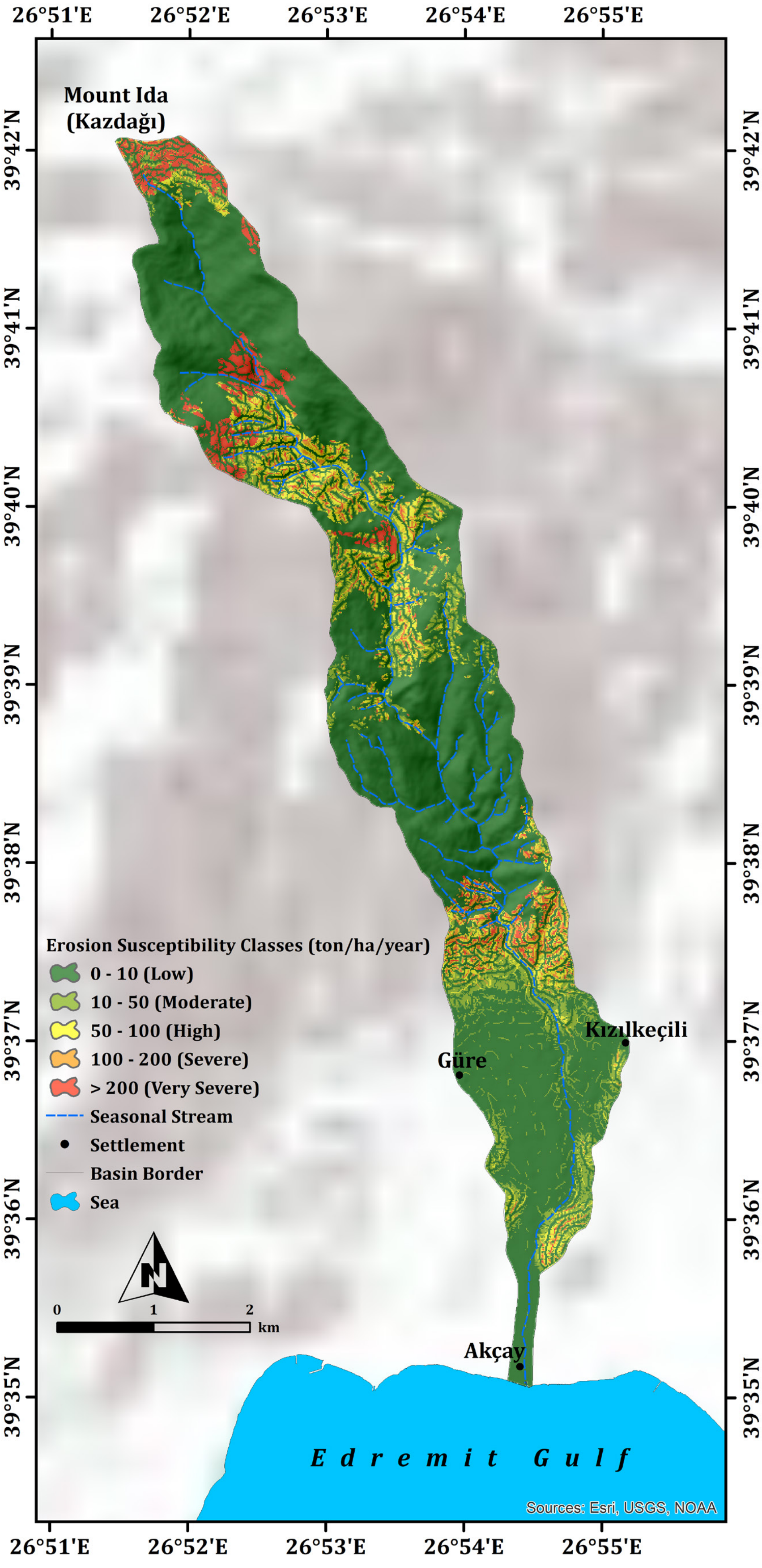

Figure 8. Erosion Susceptibility Classes and Soil Loss Amount map of Kuruçay Stream basin.

Table 6. Erosion Susceptibility Classes of Kuruçay Stream basin.

Erosion Susceptibility Classes	Soil Loss	Area	
	tons/ha/year	km²	(%)
Low	0–10	13.11	76.0
Moderate	10–50	1.95	11.3
High	50–100	1.04	6.0
Severe	100–200	0.50	2.9
Very Severe	> 200	0.64	3.7

slope values exceeding 7°, where olive cultivation activities entail the removal of natural vegetation cover, also exhibit high and severe erosion sensitivity (Figs. 9). Mild to moderate erosion is observed in the remaining portions of the basin (Fig. 8).

Figure 9. Thin layer of A and C horizon soil cover on crystallized limestones in the north part of Kavurmacilar rural neighborhood **A** Overview of the layer; **B** Detail.

When the study area and the nearby river basins are compared in terms of erosion, similar results are observed. While this value is 0.03 tons/ha/year in Kuruçay Stream basin, it is calculated as 0.04 tons/ha/year in Zeytinli Stream basin, 0.04 tons/ha/year in Fındıklı Stream basin, 0.02 tons/ha/year in Kızılkeçili Stream basin, 0.02 tons/ha/year in Şahin Stream basin and finally 0.005 tons/ha/year in Havran Stream basin. The fact that the average annual soil loss in Kuruçay Stream basin and its neighbouring basins are close to each other should be related to the physical characteristics of the basin (geology, geomorphology, climate, soil, etc.).

In order to control erosion in the study area, firstly natural vegetation should be protected. Then, erosion monitoring and prevention systems should be established and people should be made aware of this issue. Otherwise, erosion in the catchment may take on an inevitable dimension. In addition, the RUSLE method provides the opportunity to obtain consistent results in the erosion study carried out by taking into account the neighbouring river basins.

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Additional information

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Data availability

All of the data that support the findings of this study are available in the main text or Supplementary Information.