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Original Research

Erosion Risk Analysis in Unlendi Dam Basin

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Abstract

In this study, erosion areas, rates and degrees of erosion were determined by Revised Universal Soil Loss Equation (RUSLE 3D) method and Remote Sensing (RS) on the Geographical Information System (GIS) of the Ünlendi dam constructed on the Acıçay stream, Tuzluca-Iğdır. The precipitation data of 14 meteorology stations for rainfall erosion factor (R); large soil groups and characteristics in the basin for soil erosion susceptibility factor (K); the equation for slope length and slope steepness factor (LS); Sentinel-2 satellite image and the equation for vegetation cover factor (C); classification of slopes for erosion control factor (P) were used. Digital Elevation Model in 5x5 meters resolution, factors and erosion maps were created by using GIS. The average soil loss was found to be moderate (24.1 $t.ha^{-1}.y^{-1}$) and above the average of Türkiye (8.24 $t.ha^{-1}.y^{-1}$). In the erosion map, susceptibilities were determined as light in 37.3% (1932 ha); moderate in 14.9% (772 ha); strong in 14.7% (758 ha); severe in 28.4% (1468 ha) and very severe in 4.7% (244 ha). Insufficient vegetation and its destruction, steep slopes, overgrazing in pasture increase the erosion susceptibility. In risky areas, due to the nature of the region, terracing and afforestation studies have been proposed, considering the steepness of the slope.

Keywords: Ünlendi dam basin, GIS, RS, RUSLE-3D, erosion susceptibility, sediment yield

Introduction

Erosion is an ongoing event since the existence of soil and climatic events and is called natural or normal or harmless or geological erosion. The soil eroded as a result of natural forces and events is obtained from the new soil material consisting of the main material in the lower layer. The events in which natural erosion increases as a result of disasters or misuse of people and exceeds tolerance values are called accelerated or harmful or soil erosion or simply erosion. The events in which natural erosion increases as a result of disasters or misuse of people and exceeds tolerance values are called accelerated or harmful or soil erosion or simply erosion [1]. As a result of harmful erosion, the effects of natural and climatic events that normally cause erosion, and as a result, the severity of the erosion event increases, causing loss of life and property [2].

The most important damage of erosion in cultivated and other agricultural lands is that it removes the topmost organic matter-rich fertile soil and renders it unproductive. The negativities related to accelerated erosion are seen as a serious problem in our country and in the world, and measures are taken accordingly. According to the foresight of the United Nations, it is emphasized that yearly, 24 billion tons of soil will be lost on Earth in the near future, and this will be one of the most dangerous environmental disasters for humanity. Another determination to confirm this was reported by the Food and Agriculture Organization

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(FAO) and the global amount of soil erosion was emphasized as 20-30 billion tons year^{-1} [3, 4].

Another damage of accelerated erosion is that soil material carried from sloping and high lands accumulates in stagnant water areas such as lakes, dam reservoirs, hydroelectric power plants, reducing the depreciation life of these structures and causing significant economic losses [5, 6]. 20.6% of Türkiye's lands are under the risk of moderate and very severe erosion. According to the calculations made, it has been reported that the loss of soil carried to the lake and the sea due to erosion is 642 million tons year^{-1} in Türkiye [7].

The fact that the depreciation or economic life of the dams is long [8], which directly concerns and affects human and other living life such as electricity, drinking water, irrigation, and flood prevention, requires long-term engineering studies and a budget is directly proportional to the sediment load carried into the dam reservoir. The higher the sediment load carried, the shorter the economic life of the dam will be. In this case, it is necessary to calculate the sediment load caused by water erosion or to estimate it with the help of different models [9]. Models developed to date are classified in four different groups as experimental, physical, conceptual and hybrid [10]. Since experimental forecasting models can be applied more quickly and easily on a river basin basis [11, 12], they are used to predict water erosion and soil losses or sediment load. Universal Soil Loss Equations (USLE) [10, 11, 13], which is the basis of Universal Soil Loss Equations, and its modified form MUSLE [11, 14, 15, 16, 17] and its revised version RUSLE [2, 3, 5, 11, 14-25] are models that are widely used in the world and in Türkiye. Among these models, RUSLE and MUSLE are more preferred because they use less data in the calculations [26]. In these two estimation models aiming to calculate soil erosion, MUSLE are the experimental equations based on the runoff factor and RUSLE on the precipitation factor [27].

Recently, GIS-supported, and RUSLE-based studies have focused on estimating the amount of sediment transported to the dam basin by streams. As a result, important data have been provided for the control of the amount of sediment carried to the dam reservoir area, the functionality of the dam and the extension of its economic life [28].

The height of Iğdır-Ünlendi dam, where the study was carried out, is 68 meters and the reservoir volume is 97.76 million m^3. It was built to provide drinking (25%) and irrigation (75%) water, and 26.80 million m^3 y^{-1} drinking water is available to the city centre of Iğdır, Tuzluca, Karakoyunlu and Aralik districts, Halfeli, Melekli, Hoşhaber towns and their 70 villages. Estimation of the amount of sediment carried by the stream was made on the Ünlendi dam basin by using RUSLE-3D and GIS.

Material and Methods

Location and General Geographical Features of the Study Area

The Unlendi dam and its basin, which was built on the Acıçay Stream in the study area, is located in the South Southwest (SSW) of the Tuzluca district of Iğdır province. Acıçay Stream flows from the Aras Güneyi Mountains, which have an altitude of 2000-3000 m, towards 1000-2000 m in the Northeast (NE) direction and pours its waters into the Aras River (Fig. 1).

In the upper part of the dam, there are Clastic and Carbonate rocks of Miocene period located between the Quaternary Andesites and Pliocene-Quaternary Basalts. In the upstream part of the dam, there are pelagic limestones from the Mesozoic period. After the dam embankment, the Clastic and Carbonate rocks continue to the north as a narrow strip between the Basalts and cover larger areas in the Tuzluca district.

In the dam basin, Colluvial soils are located in a narrow strip between Basaltic soils. Colluvial soils are young soils with A and C horizons, formed on sedimentary material, and mostly coarse stone and rubble, with decreasing particle diameters down the slope. To the north, after the end of the basin, there are brown soils covering a large part of Tuzluca district.

The dam basin and Tuzluca district to which it is connected have a harsh continental climate. However, the climate is milder in the plains and plains. Air temperatures are between -19 and +37ºC and terrestrial vegetation is dominant [29]. Iğdır province, together with the vicinity of Salt Lake, is the region that receives the least rainfall in Turkey. According to automatic stations data of General Directorate of Meteorology (GDM) for the years 2014-2022, the average precipitation in Tuzluca district is 321.98 mm [30]. Since the Ünlendi dam basin is 1000-1500 meters higher than the Tuzluca district, the precipitation amounts will be higher.

RUSLE Equation

Renewed Universal Soil Loss Equation was used [2, 5, 11, 18-21, 24, 25, 31-33] to identify and group the areas with potential risk in terms of water erosion in the Unlendi dam basin, the study area. The RUSLE equation renewed by Renard et al. [34] is as follows:

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

Where A, annual average soil loss (t ha^{-1} y^{-1}); R, precipitation erosion energy (MJ ha^{-1} y^{-1} * mm h^{-1}); K, soil erosion susceptibility factor (t ha^{-1} * ha MJ^{-1} * h mm^{-1}); LS, slope length and slope steepness factor; C, land cover and management factor; P, soil-water conservation measures factor. The data sources and places of use used in the determination of these factors in RUSLE were given in Table 1.

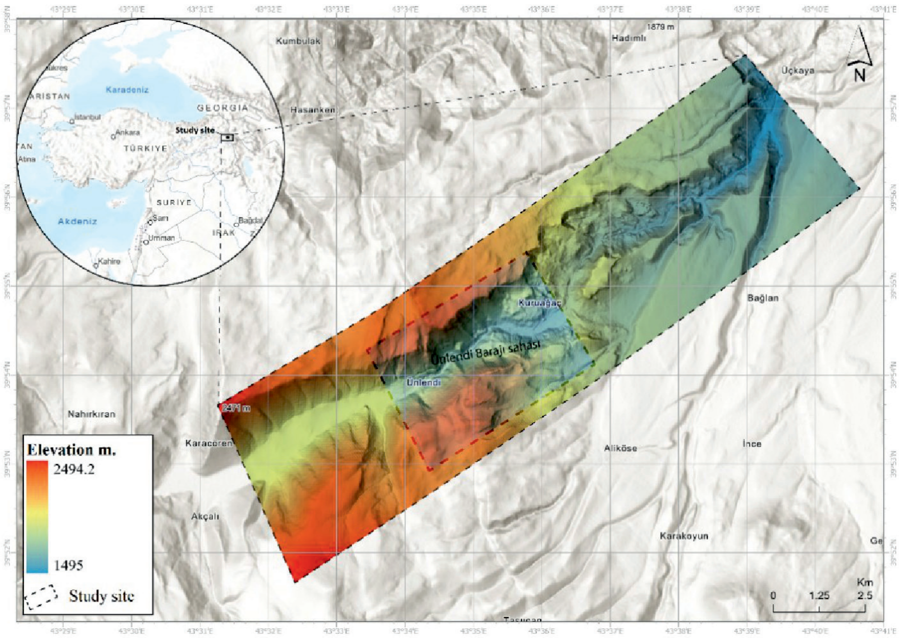

Fig. 1. Ünlendi dam basin.

Calculation of the potential amount of sediment to be transported to the dam upstream in the Ünlendi dam basin built on the Acıçay Stream and the creation of the erosion risk map with GIS were given schematically in Fig. 2 as flowchart.

According to the workflow chart given in Fig. 2, the operations were carried out based on GIS and RS. Different data sources given in Table 1 were used for RUSLE modelling. In this context, the preparation and analysis of the data was carried out with Microsoft Office, Excel, and ArcGIS 10.4 software.

Rainfall Erosion Factor (R)

A high correlation was found between soil losses in a fallow land and the erosion index (EI) obtained by multiplying the 30-minute peak intensities of the total kinetic energy of precipitation [35]. While determining the precipitation erosion factor, the diagrams of the pluviography are taken as a basis. However, in basin studies where there are no pluviography to represent the study area, the Modified Fournier Index (MFI) method [36], which considers the monthly and annual totals of precipitation, is used.

$$MFI = \sum_{i=1}^{12} \frac{Pi^2}{P} \tag{2}$$

Where Pi, monthly precipitation (mm); P, average annual precipitation (mm). Rainfall erosion factor (R) is found using the following equation:

$$R = (4.17 * MFI) - 152 \tag{3}$$

In the calculation of the R factor, precipitation data of 14 meteorological stations (Ağrı, Tuzluca, Diyadin, Karakoyunlu, Iğdır, Taşlıçay, Cumaçay, Çukuralan, Beyköy, Sarıkamış, Digor, Kağızman, Suluçam, Doğubeyazıt) located in the study area and its immediate surroundings were used. According to these station values whose R value was determined; R value was defined for the entire field by using raster interpolation method in ArcMap environment. Then, the

Table 1. Different data sources and places of use used in the study.

Data	Source	Usage places
1-Climate	Precipitation data (GDM)	Precipitation erosion factor (R) (MJ ha^{-1} y^{-1} x mm h^{-1})
2-Soil	Soil maps (GDRS-1/25000) General Directorate of Rural Services	Soil resistance factor (K) (ton ha^{-1} x ha MJ^{-1} x h mm^{-1})
3-Digital elevation model	Digital Surface Model/5 m resolution General Directorate of Maps	Slope length and slope steepness factor (LS)
4-Sentinel-2 Satellite image	https://scihub.copernicus.eu/	NDVI, Ground cover factor (C), Anti-erosion factors (P)

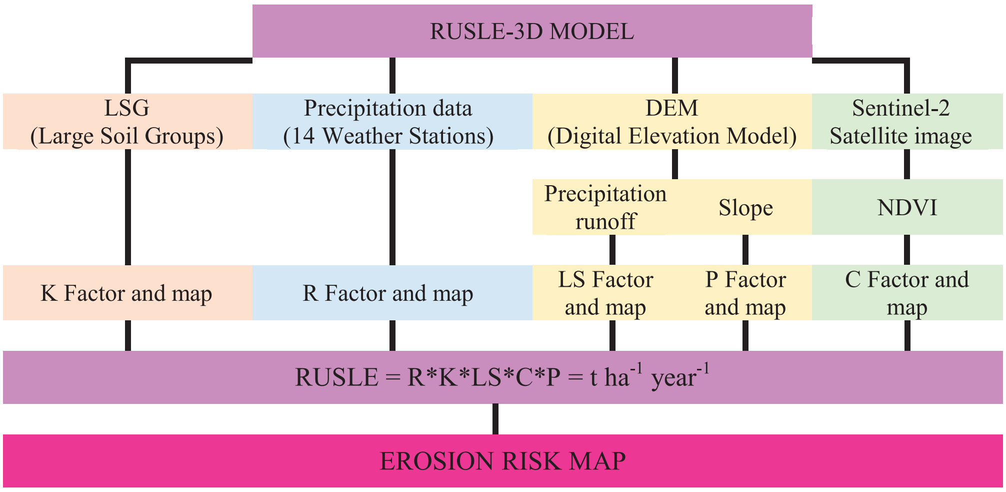

Fig. 2. Workflow chart.

area within the study area was cut and the R value factor was determined, and its map was created.

Soil Erosion Factor (K)

Grain size distribution in the soil, soil structure, porosity, amount of organic matter, soil profile depth and soil permeability are the main soil physical properties that affect erosion risk [37]. Different methods are used to calculate the K factor, which expresses the resistance to weathering and transport events [38] or sensitivity, which varies according to the physical properties of the soils and the seasons [31]. Basically, in RUSLE, it is determined as t ha^{-1} y^{-1} soil loss on a land with a 9% slope and a length of 22.1 m [39].

In order to determine the soil erosion (K) factor, the large soil group map of Iğdır province prepared by Karaoğlu and Erdel [40] was used. According to this map, on both sides and high parts of the dam basin; high slopes, medium deep and shallow, heavy clayey, mostly limeless, poor in organic matter Basaltic, in the bed of Acıçay stream; there are large Colluvial soil groups with A and C horizons formed on the sedimentary material, with little soil and mostly coarse stones and rubble, with decreasing particle diameters down the slope. Basaltic soils, generally, the pasture is shallow (20-50 cm) in high parts, with a slope of 12-20%, stony and open to severe erosion, on the lower slopes it is lithosolic (very shallow), with a slope of 30% and more, open to very severe erosion. Colluvial soils, at the bottom of the basin and in the upstream part, it is medium deep (50-90

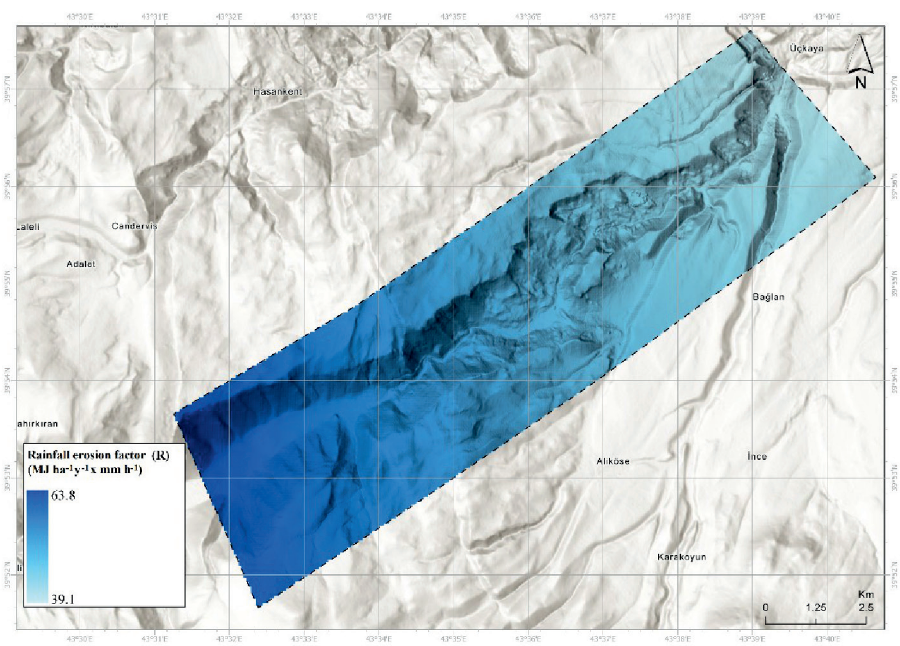

Fig. 3. Rainfall erosion factor (R) map.

Table 2. Erosion control factor (P) values.

Slope (%)	Strip-like	Contouring	Terracing	
			Row	Wide floor
0-7	0.27	0.55	0.10	0.12
7-11.3	0.30	0.60	0.10	0.12
11.3-17.6	0.40	0.80	0.10	0.16
17.6-26.8	0.45	0.90	0.12	0.18
>26.8	0.50	1.00	0.14	0.20

cm), with a slope of 6-12%, open to moderate erosion, meadow vegetation, lithosolic in the upper part of the dam, with a slope of 0-2%, open to very little erosion, suitable for irrigated agriculture [41]. For basaltic soils, the K value is 0.25 in laboratory studies [42] and according to the soil texture (moderate) and the amount of organic matter (no or very little) [41], it can be eroded strongly as the first approach on the soil-erodibility nomograph [35]; for colluvial soils, 0.17 [39] and 0.18 [38] were determined as moderately eroded [39] and a K map was produced.

Slope Length and Slope Steepness Factor (LS)

It is very difficult to calculate the slope length and steepness (LS) factor in RUSLE under field conditions. A Digital Elevation Model (DEM) with 5x5 m resolution was created from the 1/25.000 scale topography map of the dam basin. Slope map was produced using Digital Elevation Model (DEM) in ArcGIS environment and flow direction and current accumulation calculations were made. The formula developed by [43, 44] was used to calculate the slope length and slope steepness (LS) factors.

$$LS = \left(\frac{Akış\ toplamı * Hücre\ büyüklüğü}{22.13}\right)^{0.4} \left(\frac{SinE}{0.0896}\right)^{1.3} \tag{4}$$

Where LS is the slope length and steepness factor; E was given as the slope. The same slope values were used in the slope and LS factor maps. According to the calculations, if the LS value is high, the slope value is high, and these sections are high areas with high valley density. They are also areas where erosion is high [45]. On the contrary, Acıçay creek bed and high plains with lower elevation are areas with low LS and consequently low erosion. LS factor map was prepared with the calculated LS values.

Land Cover Factor (C)

The mitigating effects of surface vegetation on erosion are defined as the land cover (C) factor in RUSLE. The decrease in the amount of erosion is directly proportional to the increasing vegetation density. Depending on the surface coverage rate, the plants make the soil more resistant to erosion by reducing the kinetic energy of the raindrops falling with their above-ground parts, holding the soil with their roots, and promoting aggregation, and reduces erosion by reducing the surface runoff rate [46, 47]. However, sustainable vegetation is destroyed as a result of cultural agricultural activities, residential areas, and expansion, opening and expansion of industrial areas, deforestation, especially fires, and the severity of erosion increases in the remaining bare lands.

The land cover (C) factor can be obtained from satellite data, which has provided reliable previous study results in study areas where it is not possible to obtain data from the land [31]. The data obtained in the Normalized Difference Vegetation Index (NDVI) analysis used to calculate the C factor varies between -1 and +1. Values close to +1 indicate dense vegetation; close to -1 describe conditions such as snow cover, water surface and cloudiness. Values close to 0 are seen in weak vegetation or bare lands [48]. In calculating the C factor, Sentinel-2 satellite image and the equation given by Zhang et al. [49] was used.

$$C = \left(\frac{-NDVI+1}{2}\right) \tag{5}$$

Where C is the land cover factor; NDVI stands for Normalized Difference Vegetation Index. The C map was prepared with the values calculated with the help of this formula.

Erosion Control Factor (P)

In RUSLE, the erosion control factor (P) refers to soil conservation practices applied to reduce soil erosion. Contour farming, terracing, strip-like planting are commonly used control measures [50]. Common control measures and slope-dependent P factor values were given in Table 2. In reducing and preventing erosion, all the measures taken for soil protection are applied to eliminate all the negativities that encourage erosion [51].

P values range from 0 to 1, where a value of 0 indicates very good erosion prevention work below the critical slope (>6%) and a value of 1 indicates erosion prevention work with concentric agriculture in areas with very steep slopes [52].

Results and Discussion

Rainfall (R), soil (K), slope length and steepness (LS), vegetation (C), erosion control (P) factors determined according to the RUSLE method were analysed with ArcGIS 10.4 and maps were created.

Rainfall Erosion Factor (R) Map

The map prepared with the rainfall erosion factor (R) values obtained with the data of 14 meteorology stations located around the Ünlendi dam basin was given in Fig. 3.

The R factor has been determined as 63.8 in mountainous areas at an altitude of 2500 m above the dam; 45-55 in the 2000 m altitude sections where the dam embankment is located; 39 t ha^{-1} y^{-1} in the downstream part of the dam with an altitude of and 1500-2000 m. A high R factor value indicates that soil loss will potentially be high.

Soil Erosion Factor (K) Map

The map obtained with the soil erosion factor K values determined according to the large soil groups physical and chemical properties of the Colluvial located in the Acıçay stream bed and its surroundings; of the Basaltic located in the high parts of the basin is shown in Fig. 4.

The K value was determined as 0.25 in all steeply sloping lands of the dam basin; as 0.18 in the bed area of Acıçay stream and in the higher parts; and 0.17 in

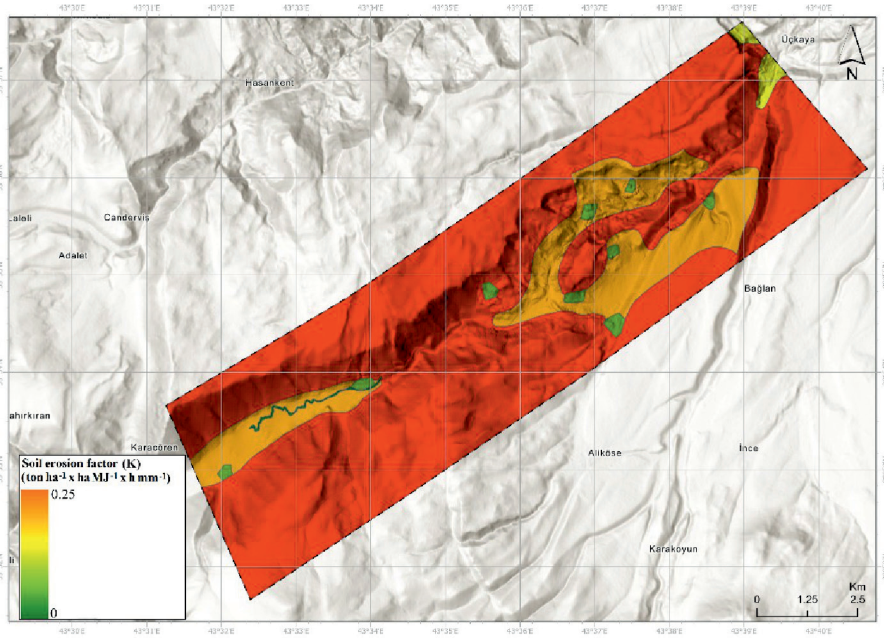

Fig. 4. Soil erosion factor (K) map.

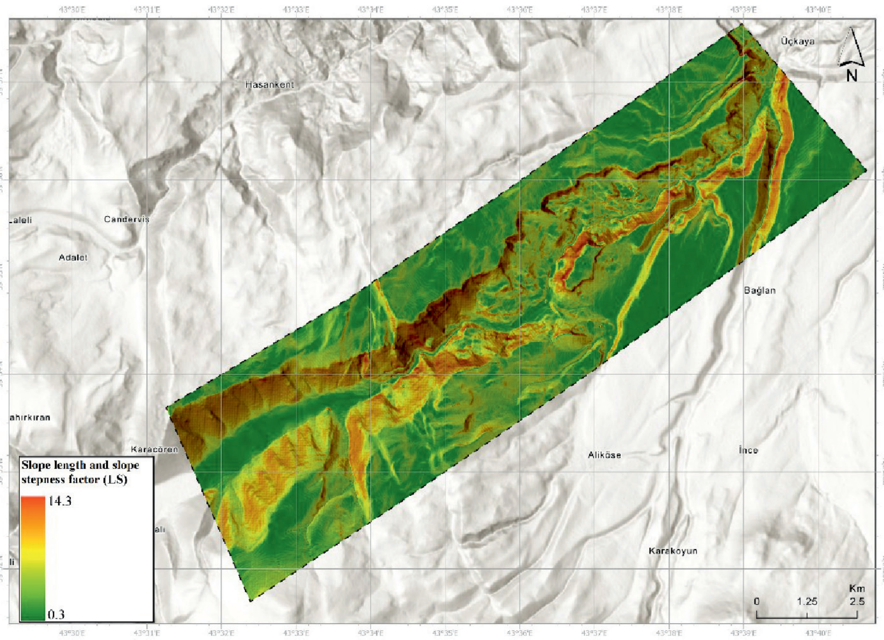

Fig. 5. Slope length and slope steepness factor (LS) map.

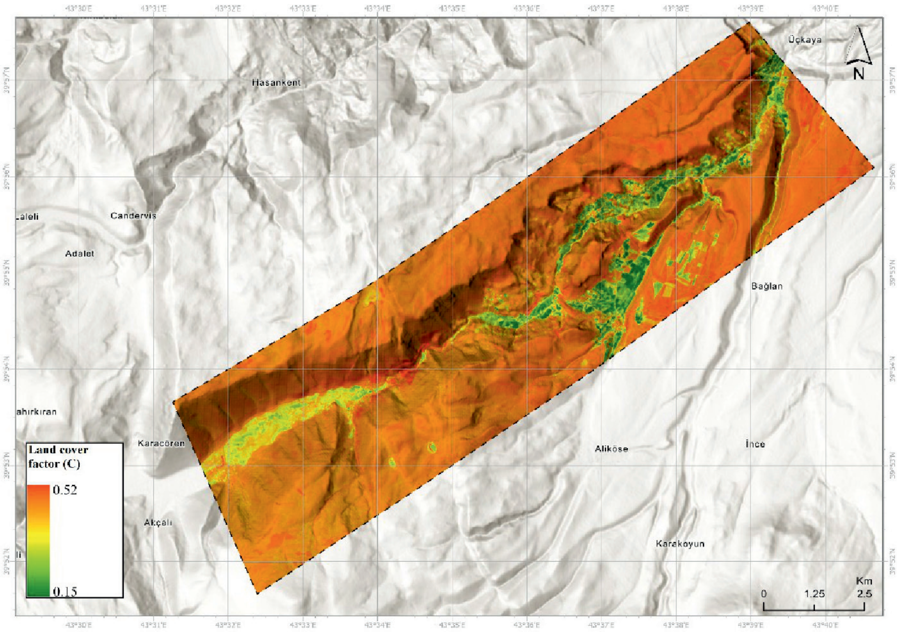

Fig. 6. Land cover factor (C) map.

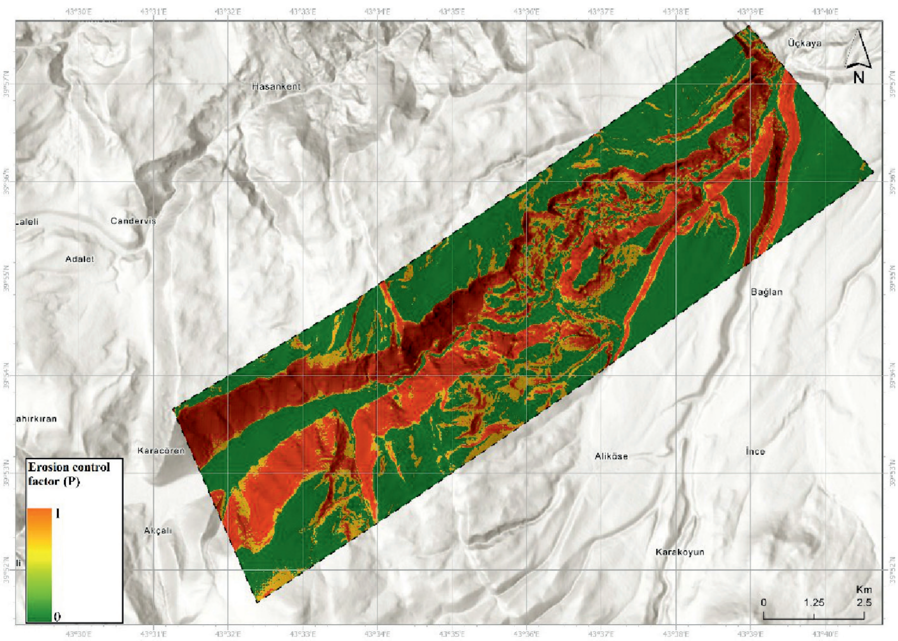

Fig. 7. Erosion control factor (P) map.

the upstream and downstream sections. A high K factor indicates that potential soil losses from high altitude and steeply sloping lands will be high.

Slope Length and Slope Steepness Factor (LS) Map

The LS values map of the Ünlendi dam basin built on Acıçay Stream is presented in Fig. 5.

LS values varies between 14.3 on high and sloping slopes on the upstream side of the dam basin and 0.3 on flat and near flat areas of the basin. As LS values

Table 3. Areal distribution of erosion.

Erosion severity	Soil losses (ton ha^{-1} y^{-1})	Area (km^2)	Ratio %
Slight	5	19.32	37.3
Moderate	10	7.72	14.9
Strong	20	7.58	14.7
Severe	50	14.68	28.4
Very severe	75.9	2.44	4.7
Total	160.9	51.73	100.00

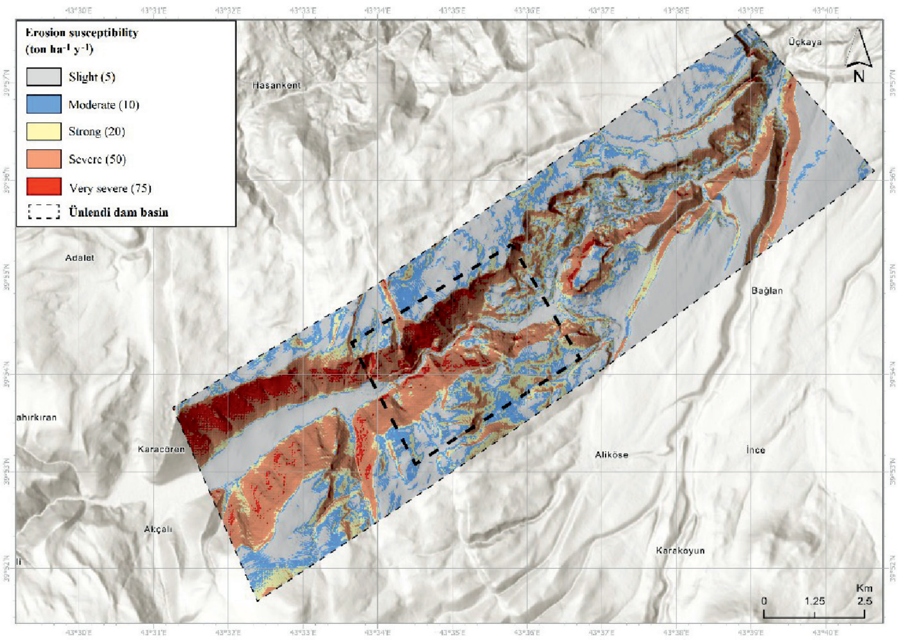

Fig. 8. Erosion susceptibility map.

increase in terms of both steepness and length, estimated soil losses will be higher.

Land Cover Factor (C) Map

The map prepared with the C factor data obtained by the analysis of the Normalized Difference Vegetation Index (NDVI) was given in Fig. 6.

The C factor was determined as 0.30-0.52 in the upstream and high areas where the vegetation is weak; as 0.15 in the downstream part where irrigated agriculture can be done until the dam was built. A small C value indicates that the vegetation is strong and reduces erosion.

Erosion Control Factor (P) Map

The map prepared for the P factor in the Ünlendi dam basin, where there is no erosion preventive study other than the natural vegetation was given in Fig. 7.

The P values were close to 0 and 0 due to vegetation of pasture and slope in the flat and near-flat lands in the high areas; close to 1 and 1 on steep slopes. Values close to 0 indicate less soil losses, close to 1 indicate that soil losses will be higher.

Erosion Susceptibility Areal Distribution and Map

The spatial distribution of the annual amount of soil loss that may occur due to erosion in the Ünlendi dam basin built on Acıçay Stream was shown in Table 3 and its map in Fig. 8.

Estimated soil losses in the Ünlendi dam basin range from light to very severe (5-75.9 t ha^{-1} y^{-1}). Similar to the previous maps, soil losses were calculated lower on flat and near-flat lands, and higher on steeply sloping lands. According to the erosion susceptibility map, in the dam basin, 37.3% (1932 ha) slight, 14.9% (772 ha) moderate, 14.7% (758 ha) strong, 28.4% (1468 ha) severe, 4.7% (244 ha) very severe susceptibilities were obtained.

Conclusions

The Ünlendi dam basin established on Acıçay Stream shows altitude changes from 2000-3000 meters altitude of Aras Güneyi Mountains to 1500 meters altitude where the dam bank was located. The elevation difference of approximately 1000 meters occurs at a horizontal distance of 11 kilometers. High and steep slopes in the upper parts of Acıçay Stream are areas that increase the risk of erosion.

According to the spatial distribution of erosion susceptibility calculated by RUSLE-3D method in the Ünlendi dam basin, the average soil erosion susceptibility is moderate (24.1 t ha^{-1} y^{-1}) and above the average value of Türkiye (8.24 t ha^{-1} y^{-1}) [8]. The inadequacy and destruction of the land cover, steep sloping deep hillsides, high elevation difference between the upper parts of the basin and the dam embankment are the factors that increase the erosion susceptibility.

In risky areas where soil erosion sensitivity is high, erosion should be combated by terracing and afforestation, considering the steepness of the slope. Especially the natural vegetation on the slopes of the Aras Güneyi Mountains facing Acıçay Stream should be protected and encouraged. Such measures to be taken will make significant contributions to both soil protection and reducing the transported sediment yield.

Conflict of Interest

The authors declare no conflict of interest.

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