Chapter 7

Sustainable Land Use Planning Model in Rural Basins

Ertuğrul Karaş

Additional information is available at the end of the chapter

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Abstract

Soil erosion is a common problem that complicates watershed management in Turkey and around the world. The main objective of soil conservation work carried out in basins is to ensure sustainable watershed management. The first operation is to define the current situation in the basin. The initial and fundamental objective of erosion estimation based on existing data is generally deciding how to overcome the problem. However, the treatments carried out in most soil conservation studies are similar to each other. Any common, known, or defined methodology about erosion problems in watersheds has not been improved—until now. Considering this problem, the Sustainable Land Use Planning (SLUP) model was developed to determine soil conservation precautions, to set priorities for decision makers and to produce a common solution for rural watershed in Turkey. While the estimated average soil loss was determined to be 7.66 t ha^{-1} per year, some land use changes were proposed and land use management priorities were set in the direction of the model results to gain sustainable management in the Çelikli basin. At the end of the study, it was showed that the soil loss can be reduced about the rate of 91.2% applying the SLUP model.

Keywords: land use planning, soil erosion, soil conservation, SLUP model

1. Introduction

Soil is an indispensable resource for the continued existence of living organisms on Earth. Today, food security and the environmental sustainability of limited natural resource management have become more important. Population growth and complex situations in the use of natural resources have required skilled land use. As a result, soil erosion, which was an accepted part of the soil degradation process, is observed in various ways and degrees under the influence of factors such as climate, topography, and land use. The biggest change in natural resources in the last 100 years has occurred as a result of changes in land use type and technological improvements. The major factors in accelerated soil degradation processes are improper land use, deforestation, soil erosion, overgrazing, vehicle off-roading, and inappropriate irrigation. The daily displacement of the upper layers of land due to heavy rains, accumulation of the carried soil, plant nutrients in storage structures, sedimentation, and processes such as eutrophication threatens the sustainability of natural resources. No matter the factors, soil degradation processes need to be correctly defined and must be established for the natural balance between living organisms. Today, the estimation of soil loss is one effort to reduce the effects that lead to soil degradation.

USLE, developed by Wishmeier and Smith [1], is globally the foremost and preferred popular model in predicting soil loss. The main objective of RUSLE and WEPP models, which were developed based on USLE, is to estimate soil loss from a given land. Research carried out at the parcel level, the contribution of many scientists [2–5], is maintained with the support of technology. Today, it is possible to achieve results in a very short time, to forecast the impact of alternative applications, and to analyze and evaluate the results with the help of computers that process data on the Geographic Information System (GIS) environment. With detailed analysis of each factor considered, the effectiveness of these model results is faster and easier. Environmental factors such as land use and soil characteristics can be easily obtained by means of this technique [6]. Thus, the identification of sensitive areas of erosion can offer unique opportunities for exposing priorities and providing measures to decision makers.

Numerous studies have been carried out over the last two decades using USLE-GIS integration in various part of the world [7–31]. So far, the efforts carried out on the estimation of soil loss have not yet adopted a common point in terms of analysis and evaluation. To keep soil loss under a defined threshold is the point of the alliance. In particular, these efforts have intensified in the last half century and have provided much more to the adoption of the concept of soil loss tolerance [1, 3, 32–47]. This is defined as the maximum permission level of soil loss from an area that will not cause any yield reducing. Soil loss tolerance values have been compared with rates of soil formation in many studies [48–65].

The first study interested in the SLUP model was applied in the Güvenc basin [66]. In this study, the areal distribution of soil erosion classes and soil conservation precautions was also obtained. According to the results, 64.68% of the basin had a non-existent or too low erosion degree, 9.18% had a low-moderate erosion degree, 7.53% had a moderate-high erosion degree, 4.33% had a high erosion degree, and 14.33% had a very high level erosion degree. It was shown that soil loss can be lowered from 16.30 to 1.44 t ha^{-1}, reduced by approximately 91%, with the proposed approach across the entire basin.

Almost all of the soil conservation studies, carried out in the basins throughout the world up to now, have been focused on the estimation of soil loss. Despite some efforts, any approach that may be a solution offer to soil conservation measures to be taken in the basins has not been developed yet. This is considered as a major absence and requirement. The purpose of this study is to introduce the model called "Sustainable Land Use Management", which was developed to ensure the most appropriate land use management plan by reducing soil loss in the basins considering the problems and requirements mentioned above.

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2. Materials and methods

2.1. The study area

This study was conducted in a catchment known as Celikli, located in the Tokat region of north-east side of central Anatolia, Turkey (**Figure 1**). The basin is 1041.2 ha in area and has an average elevation of 1300 m above sea level. It is situated in the area transitioning from central Anatolia to the middle Black Sea region (latitude 40° 06 31 N, longitude 36° 21 40 E).

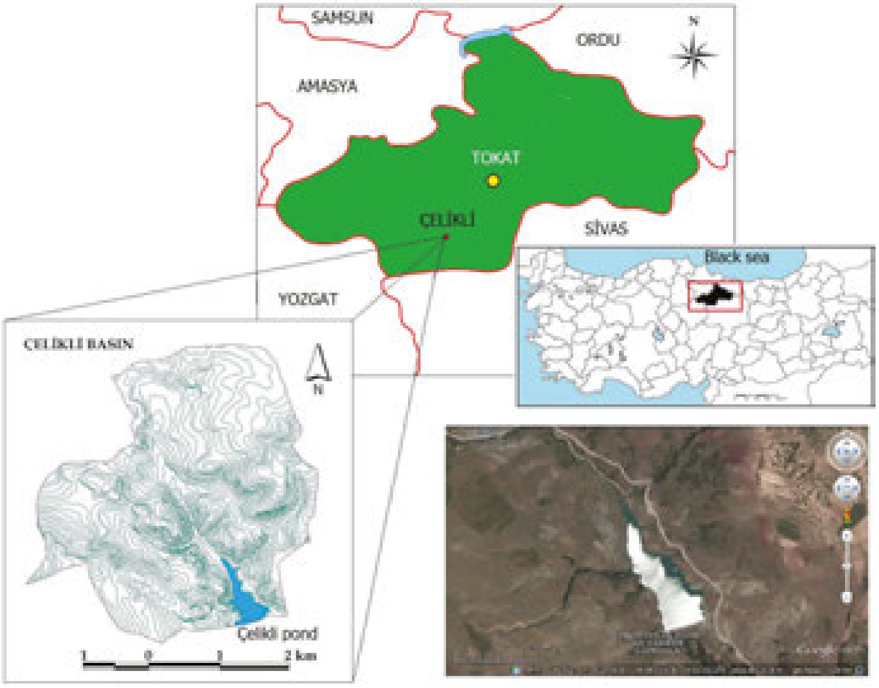

Figure 1. The location, topographic map and Google Earth view of the Çelikli basin.

The study area has semi-arid climatic conditions. The average annual temperature is 8.1°C, and the mean annual precipitation is 535.9 mm, 84.7% of which falls between October and May [67].

2.1.1. Land use

Current land use for the basin was prepared by a detailed land investigation. The determined land use groups were given in **Table 1** and **Figure 1**. While dry farming areas occupy nearly 68% of the area, pasture and shrub land use have approximately 25 and 5.45%, respectively. Pasture land use, which is not appropriate for tillage due to insufficient soil depth, was left for native usage. In the last 60 years, most of the pastures and some forested areas were converted to agricultural land by ploughing. Consequently, native land use of the basin was considerably changed from pasture and forest to agriculture land use [67].

Land use	Area (ha)	Area (%)
Dry farming	706.9	67.88
Pasture	258.9	24.86
Shrub	56.7	5.45
Bare rock	8.5	0.82
Water surface	10.2	0.98
Total	1041.2	100.00

Table 1. Land use distribution of the basin.

Investigation of pasture composition was done to determine the coverage percentage, dry grass yield, and to describe the species of pasture plants on the selected 27 sample points in the basin. The analysis showed that the coverage rate was about 50% of this pasture area. Although some points are majority Graminea family, most have a mixed composition with Fabaceae, Labiatae, Convolvulaceae, Labiatae, and other species. Vegetation quality of pastures in the basin is generally determined as low [67].

Land Use Capability Class (LUCC) of the basin soils given in **Table 2** was also determined with the detailed investigations. LUCC is a classification process made considering soil, topography, climate, environment, crop cover and hydrological conditions. Limiting factors, such as soil properties and slope, are taken into account in favourableness of an area for determining of the most suitable management form such as agricultural, forestland, and pasture. In general, lands are classified as eight groups varying from1 to 8. There are six different LUCC (II, III, IV, VI, VII, and VIII) in the basin except for I and V [67].

Land use capability classes	Area, (ha)	Area (%)
II	11.1	1.07
III	84.3	8.10
IV	52.1	5.00
VI	541.6	52.02
VII	333.4	32.02
VIII	8.5	0.82
Water surface	10.2	0.98
Total	1041.2	100.00

Table 2. Land use capability classes and areal distribution in the basin.

Around 84% of the basin soil is Class VI or VII. Classes II, III, and IV cover 14.07% of the basin and are available for agricultural aims. Although they have some restrictive factors, those areas can be used for agricultural production by carefully choosing plants, applying some special

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conservation practices, and careful management techniques. About 84.86% of the basin soils (VI, VII, and VIII) are unsuitable for agricultural production, which are favourable mainly for grassland, forestland, or wildlife habitats in terms of LUCC.

When we look at the maps of land use and LUCC together in **Figure 2**, we can see that most of the basin soil is used for agricultural production (68%), although only 14% of the land is appropriate. The areas suitable for agricultural production (Classes II, III, and IV) are on the north-east side of the basin. Class VI is extensively used for agricultural aims. This current situation reveals that the area is unsuitable and unsustainable for basin management.

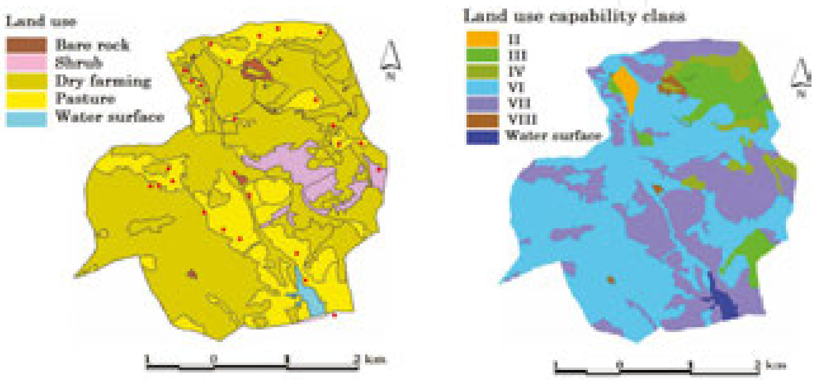

Figure 2. The maps of land use and land use capability class of the basin.

2.1.2. Soil sampling and analysis

Georeferenced soil samples were taken from top soil (0–0.3 m) and subsoil (0.3–0.6 m) in July 2002. In soil samples, organic matter [68], soil pH [69], lime ($CaCO_3$) [68], electrical conductivity

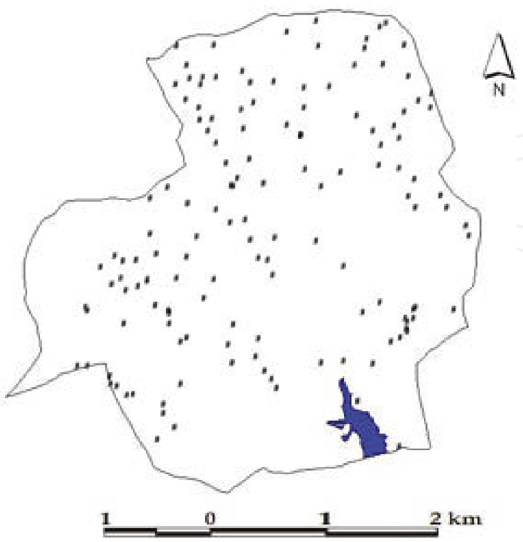

Figure 3. Soil sampling points in the basin.

(EC) [70], Cation exchange capacity [71], textural distribution [72], saturated hydraulic conductivity [73], and volumetric water content [74] were analyzed. Erodibility was calculated by a soil erodibility nomograph [75]. The sampling points are shown in **Figure 3**.

2.1.3. Soil map

Two satellite images (IRS-1C, with a 5.8 × 5.8 m pixel size and LANDSAT-TM with 30 m × 30 m pixel size) were used to prepare a soil map of the basin, in addition to a cadastral map with a scale of 1/5000. The combined image of the basin obtained from these two images is given in **Figure 4**.

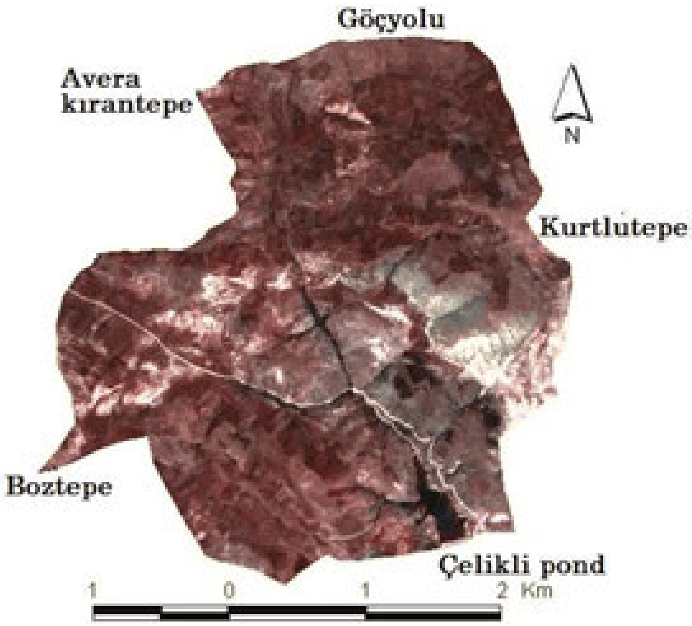

Figure 4. Satellite image of the basin.

The detailed soil map was prepared with a scale of 1/5000 and 9 soil series were identified. A description of soil profiles, environmental properties, and physical and chemical characteristics of the soil samples was taken from these profiles. The defined soil series in the basin is given in **Table 3**.

The soil series in the basin given in **Table 3** and **Figure 5** were classified according to the basis of soil taxonomy. Three ordos (Entisol, Mollisol, and Alfisol), three subordos (Orthent, Ustoll, and Ustalf), four big groups (Ustorthent, Haplustoll, Haplustalf, and Argiustoll), and three subgroups (Typicustorthent, Lithicustorthent, and Verticargiustoll) were determined using climatological and geological data [67]. Kevenli, Yelten, and Göçyolu are the soil series, which have the most widest in terms of area occupying 29.3, 28.33, and 13.59% of the total area, respectively. Although their average depths are changing from 24 to 67 cm, many soil properties are very close to each other such as exchangeable cations and texture distribution. Other six soil series (Yedikır, Yayla, Alıçlı, Uluyol, Kurtlutepeönü, and Akardere) in the basin include 30.76% of the total area varying from 1.60 to 10.52%

Soil series	Area (ha)	Area (%)
Kevenli	305.2	29.30
Yelten	295.0	28.33
Göçyolu	141.5	13.59
Yedikır	109.5	10.52
Yayla	69.8	6.70
Alıçlı	54.7	5.26
Uluyol	20.8	1.99
Kurtlutepeönü	18.0	1.72
Akardere	16.6	1.60
Water surface	10.2	1.98
Total	1041.2	100.00

Table 3. Soil series in the basin.

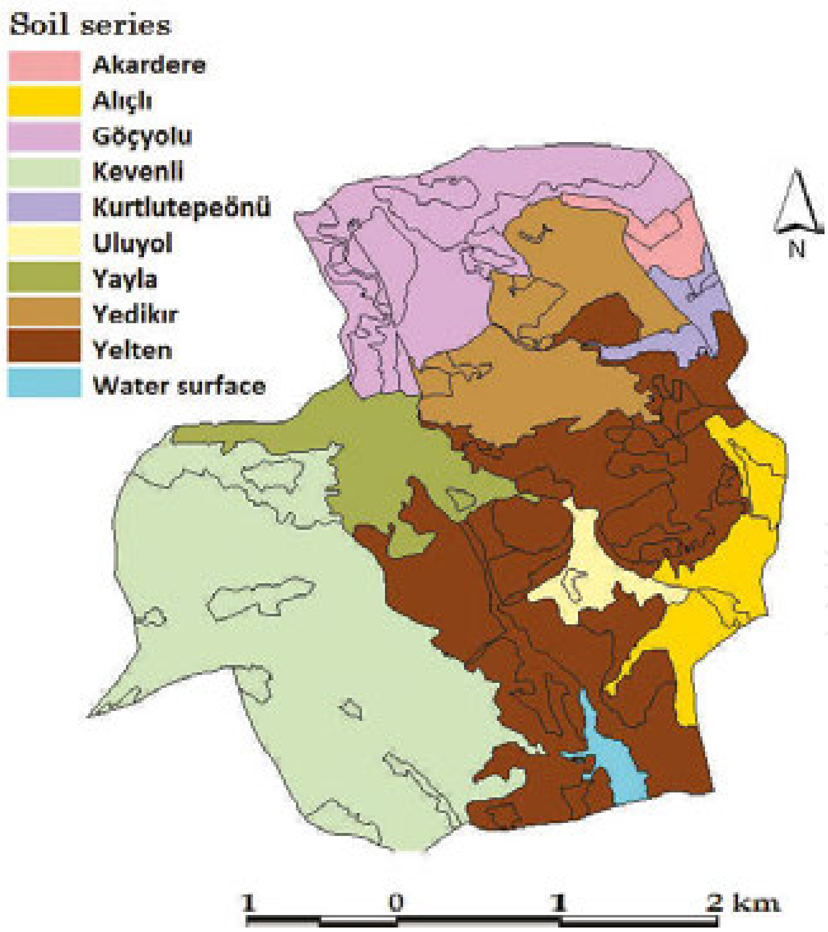

Figure 5. Soil series map of the basin.

Some physical and chemical properties of the soil series in the basin are given in the **Table 4**. Although the soil depths are between 24 and 90 cm, the basin soils have a generally shallow depth, low organic material, low lime content, and slightly alkaline character. Most of the soils have a silty clay loam (SCL) texture, and plant available water content for the mean depth (46 cm) is about 75 mm due to weak soil profile development.

Soil series	Depth cm	Salt %	pH	$CaCO_3$ %	Org. Matter %	%			Texture	Cation Exc. Cap. me/100g	Exchangable cations me/100g			
						Sand	Clay	Silt			Ca + Mg	K	Na	Total
Kevenli	67+	0.024	7.79	3.2	1.2	48.8	26.3	24.9	SCL	33.52	31.73	0.66	0.03	32.42
Yelten	31+	0.019	7.37	1.1	1.6	46.9	28.3	24.8	SCL	30.57	28.28	0.49	0.02	28.79
Göçyolu	24+	0.018	6.78	0.0	2.2	60.7	18.2	21.1	SL	26.95	26.14	0.51	0.01	26.66
Yedikır	66+	0.033	7.14	1.1	1.3	33.6	41.2	25.2	C	44.68	40.03	0.77	0.01	40.81
Yayla	51+	0.019	7.91	7.7	1.2	46.0	28.7	25.3	SCL	21.75	20.89	0.63	0.02	21.54
Alıçlı	51+	0.034	7.69	8.9	2.0	53.1	26.2	20.7	SCL	40.81	38.71	0.70	0.01	39.42
Uluyol	65+	0.017	7.89	12	0.9	59.5	21.9	18.6	SCL	21.58	20.28	0.47	0.01	20.76
Kurtlute peönü	67+	0.012	6.91	0.0	0.7	51.6	21.8	26.6	SCL	22.39	21.80	0.40	0.02	22.22
Akardere	90+	0.040	7.64	3.0	2.1	23.5	57.0	19.5	C	57.55	52.25	0.72	0.44	53.41
Mean	48.6	0.024	7.46	4.1	1.5	47.0	30.0	23.0	SCL					

Table 4. Some physical and chemical properties of soil series in the basin.

2.2. USLE model

Soil loss is estimated using the following equation in USLE [1]:

$$A = R \times K \times L \times S \times C \times P \tag{1}$$

where A is average annual soil erosion per unit area (t ha^{-1} year^{-1}), R is rainfall erosivity factor (MJ mm ha^{-1} h^{-1} year^{-1}), K is soil erodibility factor (t ha^{-1} h ha^{-1} MJ^{-1} mm^{-1}), L is slope length factor, S is slope steepness factor, C is cover and management factor, and P is management practice factor. L, S, C, and P are all dimensionless.

2.2.1. Rainfall erosivity factor (R)

The rainfall erosivity factor (R) shows the effect of rainfall impact on the amount and rate of runoff calculating the rainfall energy (EI) obtained from a maximum 30-min intensity (I_{30}) having at least 12.7 mm of precipitation during a period of 15 min. The interval duration between two storms must be at least 6 h [1]. After the calculation of the rainfall intensities, rainfall kinetic energy is calculated using the following equations [76]:

$$E_i = 0.019 + 0.0873\, log_{10} i \tag{2}$$

$i \leq 76$ mm h^{-1}

$$E_i = 0.283 i > 76\ mm\ h^{-1} \tag{3}$$

where E_i is the kinetic energy of 1 unit of rainfall (MJ ha^{-1} mm^{-1}) and i is the rainfall intensity (mm h^{-1}).

The product of the total kinetic energy of rainfall (E) and its peak 30-min intensity (I_{30}):

$$R = E \times \left(\frac{i_{30}}{100} \right) \tag{4}$$

where R is the rainfall erosivity factor (MJ ha^{-1} cm h^{-1}); I_{30} is the peak 30-min intensity of rainfall (cm h^{-1}); and E is the total kinetic energy of rainfall (J m^{-2}).

R factor value for the whole basin was used as 54.68 MJ ha^{-1} cm h^{-1}, taken from research carried out in the Tokat province from 1996 to 2005 [77].

2.2.2. Soil erodibility factor (K)

The soil erodibility indicates the erosion susceptibility of the soils, which is a function of soil texture, permeability and organic matter. It is explained using a soil erodibility monograph for farmland and construction sites mathematically [75].

The soil erodibility factor (K) was determined for each soil sample based on analysis of soils in the laboratory. The equation referenced is as follows:

$$K = \left(\left(2.17 \times 10^{-4} \right) \times \left(M^{1.14} \right) \times \left(12 - a \right) + 3.25 \times \left(b - 2 \right) + 2.5 \times \left(c - 3 \right) \right) \times d \tag{5}$$

where M = (percentage of silt and fine sand) × (100-percentage of clay); a is the organic matter content (%), b is the soil structure (1–4), c is the permeability grade (1–6), and d is the coefficient of converting (d = 1.292).

Soil samples collected from the predetermined points were marked using GPS. The K factor values of the soils were determined for each soil series from 142 samples; the K factors varied between 0.18 and 0.30. The basin K factor map is given in **Figure 6**.

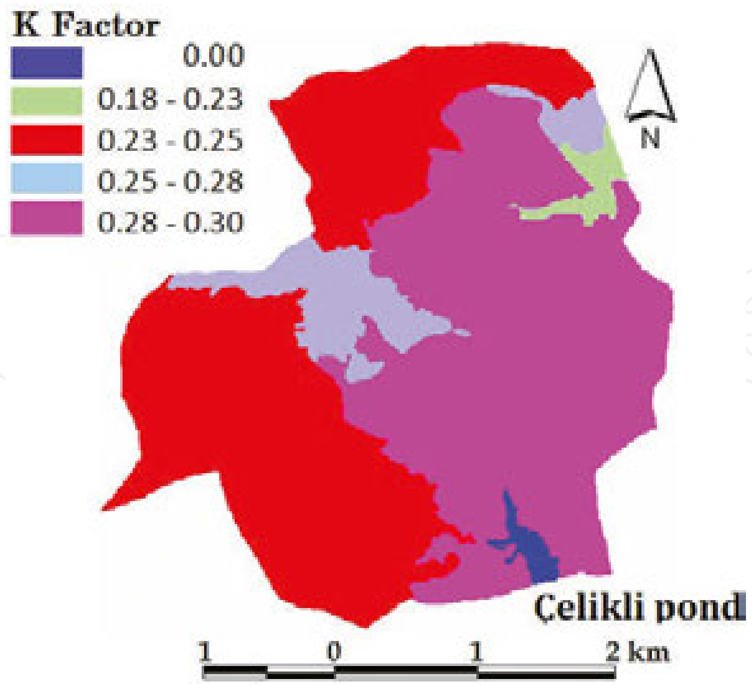

Figure 6. *K* factor map of the basin.

2.2.3. Slope length and steepness factor (LS)

Slope length and steepness (LS) factor reflects the impact of topography on soil erosion. With a unit plot of length 22.13 m, the USLE used the equation:

$$\boldsymbol{L} = \left(\frac{\lambda}{22.13}\right)^m \tag{6}$$

where L is slope length factor, $\boldsymbol{\lambda}$ is slope length, and m is a coefficient that changes according to slope [if the slope (S) >4%, $m = 0.5$, for $S = 4\%$, $m = 0.4$, and if $S \leq 0.3$ and $m = 0.3$].

The equation used to calculate slope steepness factor (S) in the USLE is given below:

$$S = \frac{0.43 + (0.30 \times s) + (0.043 \times s^2)}{6.574} \tag{7}$$

where S is slope steepness factor and s is slope (%).

Basin slope distribution and slope map are given in **Table 5** and **Figure 7**, respectively.

Slope/land use		Agricultural		Pasture		Shrub		Bare rock	
%	**Slope definition**	**ha**	**%**	**ha**	**%**	**ha**	**%**	**ha**	**%**
0–2	Flat	32.9	4.66	5.3	2.03	0.0	0.00	0.0	0.00
2–6	Slight	320.9	45.40	55.2	21.3	3.1	5.49	3.6	41.9
6–12	Middle	266.0	37.60	97.3	37.5	20.9	36.8	3.2	37.5
12–20	Steep	72.6	10.20	71.5	27.6	26.0	46.4	1.0	12.0
20–30	Very steep	12.0	1.70	25.9	10.0	6.1	10.7	0.6	7.37
30–45	Rough	2.1	0.30	3.4	1.32	0.3	0.47	0.1	1.05
>45	Very rough	0.3	0.04	0.4	0.14	0.0	0.02	0.0	0.00
Total		706.9	100	258.9	100	56.7	100	8.5	100

Table 5. Slope distribution of the land use groups.

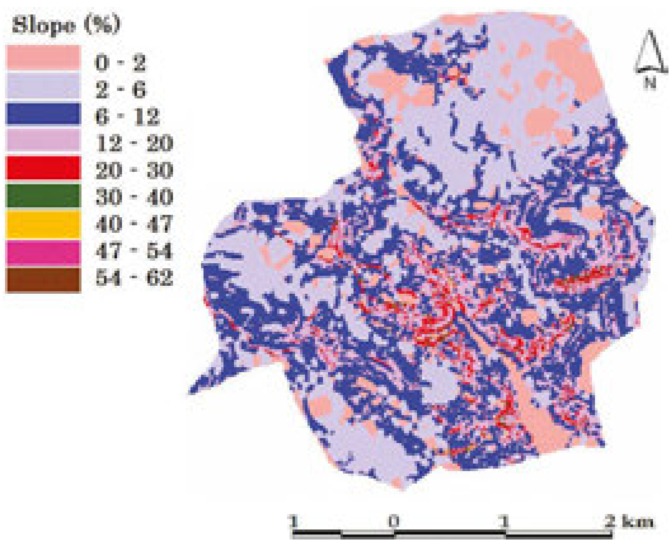

Figure 7. Slope map of the basin.

An equation was developed to compute length-slope factor:

$$LS = \left(\frac{A_s}{22.13}\right)^m \times \left(\frac{sin\beta}{0.0896}\right)^n \quad (8)$$

The basin LS factor map was prepared using ArcView Spatial Analyst extension [78] and the digital elevation model (DEM), which was prepared with 10 m interval digitized contours from a 1/25,000 scale topographic map. The grid cell size for this study was chosen as 10 m for purposes of calculation. Therefore, a grid cell area was 100 m^2. Flow accumulation and slope steepness values proposed by Moore and Burch [79] were used to calculate the LS factor as grid format. The equation given below calculates the combined LS factor for the basin.

$$LS = \left[\left(Flow\,accumulation \times \frac{cell\,value}{22.1}\right)^{0.4}\right] \times \left[\left(\frac{\sin slope}{0.0896}\right)^{1.3}\right] \quad (9)$$

Basin LS factor values change between 0 and 39.91. The DEM and LS factor maps of the basin are given in **Figures 8** and **9**.

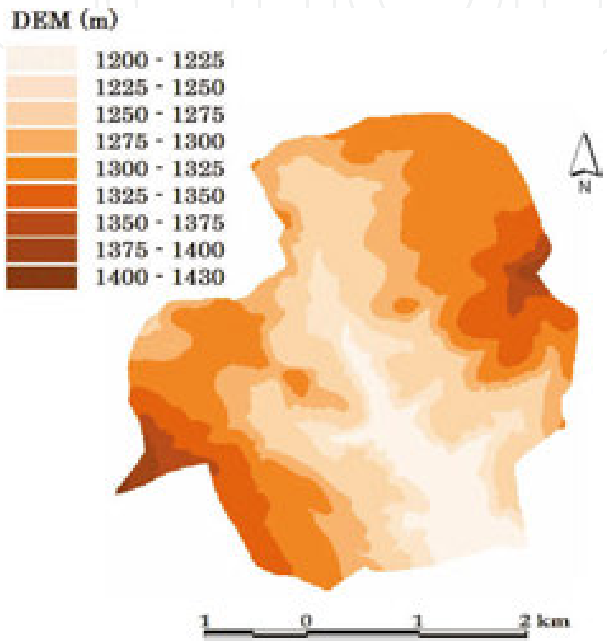

Figure 8. Digital Elevation Model (DEM) of the basin.

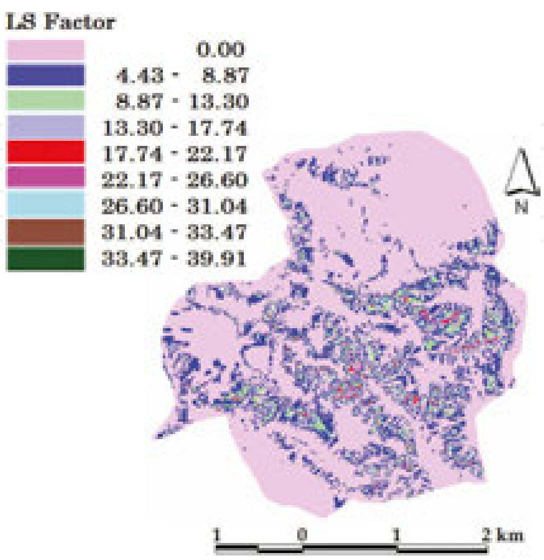

Figure 9. LS Factor map of the basin.

2.2.4. *Cover and management factor (C)*

C is the crop (cover) management factor, which is an indicator that shows the effectiveness of different crop management systems as comparatively for preventing of reducing of soil loss. It is a relative measurement of soil loss considering between a crop management system and continuously fallow and tilled land. Whereas the USLE was developed for use on agricultural fields, the proper *C* factor values are chosen for nonagricultural conditions.

For this study, *C* factor values were taken from the results of the USLE project [77] carried out at the basin for agricultural areas and based on data published in [80] for pasture and shrub. *C* factors for the basin are given in **Table 6** and **Figure 10**.

Land use	Quality	Changing interval	Selected value
Agriculture (dry)	Poor	0.10–10.40	0.25
Pasture	Poor	0.01–0.05	0.03
Shrub	Poor	0.003–0.40	0.038
Bare Rock	–	0.00	0.00
Water Surface	–	0.00	0.00

Table 6. *C* factor values used for the land use.

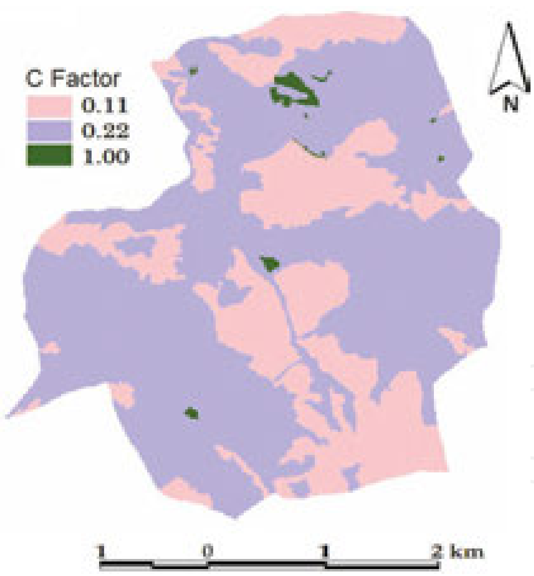

Figure 10. *C* factor map of the basin.

2.2.5. *Management practice factor (P)*

The effects of soil conservation practices that will reduce soil loss are determined by the management practice factor (*P*), which represents cropland practices such as contour farming, strip cropping by reducing runoff speed.

There were not any conservation measures for agricultural areas such as contour farming or strip cropping. For that reason, the *P* factor was accepted as 1.00 for the entire basin [67].

2.2.7. Soil loss tolerance

Soil loss tolerance (*T*) is the permission level of soil loss that will not cause to reduce in productivity as economically [3, 75]. The amount of tolerance value (*T*) that permitted must be equal to or less than the soil erosion rates [81]. Soil loss tolerance values were determined from according to rooting depth [37], and categorized into five classes, as shown in **Table 7**.

Rooting depth, cm	Soil loss tolerance (t ha^{-1} $year^{-1}$)	
	Renewable soil	Non-renewable soil
0–25	2.2	2.2
25–50	4.5	2.3
50–100	6.7	4.5
100–150	9.0	6.7
>150	11.2	11.2

Table 7. Implication of soil loss tolerance.

Soil depth and tolerance maps for the basin are in five groups changing from 2.2 to 11.2 t ha^{-1}; their depths are considered in **Figure 11**.

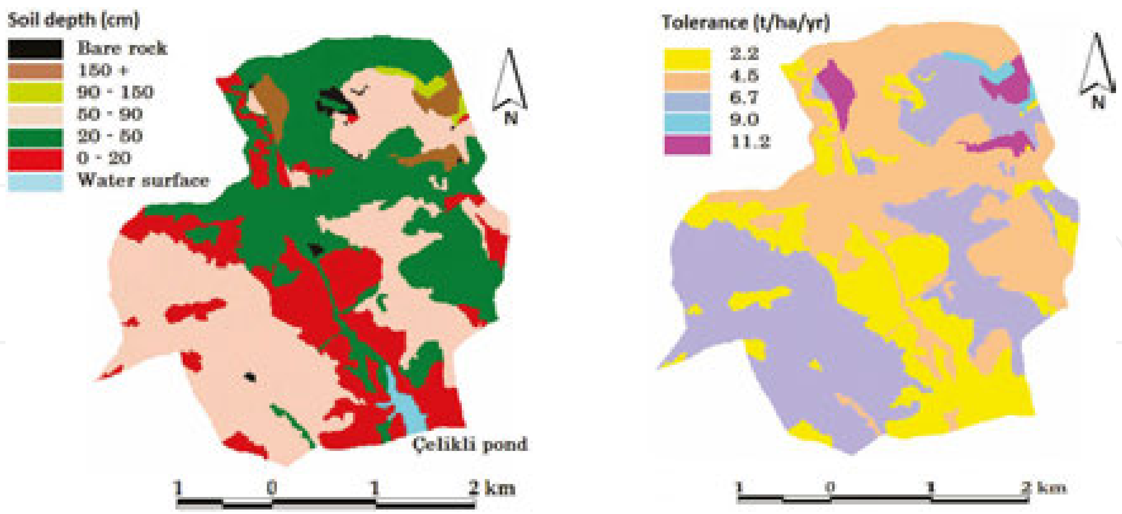

Figure 11. Soil depth map and soil loss tolerance map of the basin.

After calculation of the USLE, soil loss and tolerable soil loss rates can be compared to in terms of a specific management system considering their alternative to determine soil conservation measurements in farm planning.

2.2.8. Sustainable land use planning (SLUP) model

A method proposed by Karaş [82] was firstly applied in the Güvenç pond basin in Turkey. The described approach in **Table 8** was used for both the soil erosion rates and soil loss tolerance values. The presented table mainly includes all land use types. The principal idea of the table is to apply the required soil conservation precautions (SCP) for land use types according to existing soil erosion and present conditions using only one or a combination of as many precautions as possible. Applying all types of SCP has certain costs. Therefore, SCP practices were ordered from the cheapest to the most expensive. All of the SCP practices were compared to the soil loss tolerance (*T*) values. Customarily, unused (bare land) and agricultural areas are the most exposed to soil erosion. For example, the first and second SCP at the agricultural land use includes cultural methods, which contain practices such as conservation tillage, strip cropping, and contour farming. If soil erosion is still greater than the soil loss tolerance despite cultural precautions of the agricultural land use, third-degree SCP needs to be applied. Physical applications include terracing or the design and installation of a combined practice to remove settled solids and associated pollutants in all runoff of larger storms. However, if there are no possible events to prevent or reduce soil erosion to the level of *T* values using the first three SCP, the fourth-degree SCP, which includes changing land use type (natural transformation to pasture, rangeland, and forest), needs to be applied. If it is not possible to reduce soil erosion under a level of *T* values via the first four SCP practices, the fifth-degree SCP (including the fourth-degree precautions + physical structures) needs to be applied. Physical structures include graded stabilization structures, stream bed improvement, gabion threshold construction, and grassed waterways.

Erosion degree	**The value of (A/T)**	**Erosion escription**	**Proposed soil conservation precautions**
1	≤1.0	None exists or too few	First-Degree Precautions (FDP) Consider cropping systems that will provide maximum protection for the soil. Use minimum tillage systems where possible. Soil management (increasing organic matter content, using soil stabilisers), crop rotation on agricultural areas, suitable tillage, minimum tillage, conservation tillage, mulching, mulch tillage, ridge tillage, strip tillage, fertilising, controlled grazing, pasture management) using suitable mechanisation tools for cultivation.
2	1.0 T – 2.0	Low – Moderate	Second-Degree Precautions (SDP) Use support practices, such as cross slope farming, that will cause the deposition of sediment to occur close to the source. (In addition to FDP applications, contour farming, inter cropping, mixed cropping, agro forestry and shrub establishment of agricultural areas, continued covering, and developing rangelands)

Erosion degree	The value of (A/T)	Erosion escription	Proposed soil conservation precautions
3	2.0–4.0	Moderate–high	Third-Degree Precautions (TDP) Cultural Precautions + Physical Structures (In addition to SDP, strip cropping, cross slope, wind breaks, drainage, terracing on shrub land and rangeland) terracing, contour strips, installation of trench and holes for pasture management
4	4.0–6.0	High	Fourth-Degree Precautions (FoDP) Changing land use type (natural transformation to pasture, rangeland and forest)
5	>6.0	Very high or severe	Fifth-Degree Precautions (FiDP) Including FoDP + Physical structures Physical structures (graded stabilisation structures, stream bed improvement, construction of gabion threshold, grassed waterways, etc.) Proper forest management, Reforestation / afforestation, shifting cultivation, controlled cutting.

Descriptions: *A*—potential soil loss; *T*—soil loss tolerance value

Table 8. Soil conservation precautions according to land use and potential soil loss.

3. Results and discussion

3.1. Soil loss

Potential Soil Loss (PSL) for the basin was estimated to be between 0 and 152.77 t ha^{-1}, applying the USLE equation in the GIS environment. The PSL values for existing land use types were also obtained. The results show that the PSL is of 9.87 t ha^{-1} for agricultural land use, 3.01 t ha $^{-1}$ for pasture, and 4.16 t ha^{-1} for shrub. The mean calculated potential soil loss is 7.66 t ha^{-1} for the entire basin. Detailed statistical results obtained for each land use type are given in **Table 10**.

Total soil loss for the general basin is about 7972.86.42 t year^{-1}. While 87.51% of the total soil loss is lost from agricultural areas, pasture and shrub land use also contribute to the rate of 9.51 and 3.58%, respectively. When considered in terms of soil depth in the basin, mean soil loss tolerance values are around 4.5 t ha^{-1}, which are accepted as the threshold level of the basin. This means that 89.79% of the total soil loss occurs over the threshold value.

According to the obtained results, agricultural lands are under a high potential soil loss risk. While the agricultural land use occupies 68% of the total area, 87.51% of total soil loss is sourced from this area. In the basin, the agricultural areas are mainly converted from forest and pasture, which are the native land use. Therefore, most of the soil loss is lost from this area. Furthermore, most of the agricultural land use areas are now class VI in terms of land use capability. Actually,

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these areas should definitely not be ploughed. The soils in Class VI are generally unsuitable for agricultural production due to their severe limitations such as topographic soil conditions. These areas are generally appropriate for grassland, forestland, or wildlife habitat.

Although only 14% of the soils in the basin are appropriate for agricultural aims, 68% of the basin is used for the agricultural production. In agricultural land use, 31.37% of the area produces 72% of the total soil loss, which represents the soil loss over 11.2 t ha^{-1} in **Table 9**.

Land use	**Descriptive statistic**	**Soil loss (t ha^{-1} $year^{-1}$)**						
		0.0–2.2	**2.2–4.5**	**4.5–6.7**	**6.7–9.0**	**9.0–11.2**	**>11.2**	**General**
Agriculture	Mean (t ha^{-1} $year^{-1}$)	0.52	3.31	5.55	8.00	10.06	22.69	9.87
	Cell number*	18,192	10,048	8361	6946	4971	22,172	70,690
	USLE(t ha^{-1} $year^{-1}$)	94.59	332.58	464.03	555.68	500.08	5030.82	6977.78
	Area (%)	25.73	14.21	11.83	9.83	7.03	31.37	100.00
Pasture	Mean	0.62	3.25	5.48	7.74	10.04	14.70	3.01
	Cell number	14,506	5274	2659	1584	854	1013	25,890
	USLE(t ha^{-1} $year^{-1}$)	89.93	171.00	145.71	122.60	85.74	148.91	763.89
	Area (%)	56.03	20.37	10.27	6.12	3.30	3.91	100.00
Shrub	Mean	0.90	3.32	5.55	7.64	10.01	14.32	4.16
	Cell number	1887	1475	1157	713	267	171	5670
	USLE(t ha^{-1} $year^{-1}$)	16.98	48.97	64.21	54.47	26.72	24.49	235.84
	Area (%)	33.28	26.01	20.41	12.57	4.71	3.02	100.00
Bare rock	Mean	0.0	–	–	–	–	–	0.00
	Cell number	850	–	–	–	–	–	850
	USLE(t ha^{-1} $year^{-1}$)	0.0	–	–	–	–	–	0.00
	Area (%)	100.00	–	–	–	–	–	100.00
Water surface	Mean	0.0	–	–	–	–	–	0.00
	Cell number	1030	–	–	–	–	–	1030
	USLE(t ha^{-1} $year^{-1}$)	0.0	–	–	–	–	–	0.00
	Area (%)	100.00	–	–	–	–	–	100.00
Basin general	Mean	0.58	3.29	5.54	7.77	10.05	22.28	7.66
Cell number	36,465	16,797	12,177	9243	6092	23356	104,130	
USLE(t ha^{-1} $year^{-1}$)	211.50	552.62	674.60	718.18	612.25	5203.71	7972.86	
Area (%)	35.02	16.13	11.69	8.88	5.85	22.43	100.00	

*grid cell size 10 m × 10 m = 100 m^2.

Table 9. Soil loss according to land use groups in the basin.

The calculated potential soil loss (PSL) using the USLE for the basin is given in **Figure 12**. PSL values were divided into the appointed soil loss tolerance (*T*) values for each soil series to determine the soil erosion degree and the proposed soil conservation precautions on current land use, as explained in **Table 9**. The prepared erosion class map is given in **Figure 13**.

Erosion degree	*A*/*T* rate	Description	Area (ha)	Area (%)
1	0–1	None exist or too few	548.4	52.67
2	1–2	Low–moderate	212.8	20.44
3	2–4	Moderate–high	172.0	16.51
4	4–6	High	63.9	6.13
5	>6	Severe	44.2	4.25
Total			101.3	100.00

Table 10. Areal distribution of soil erosion in Çelikli basin.

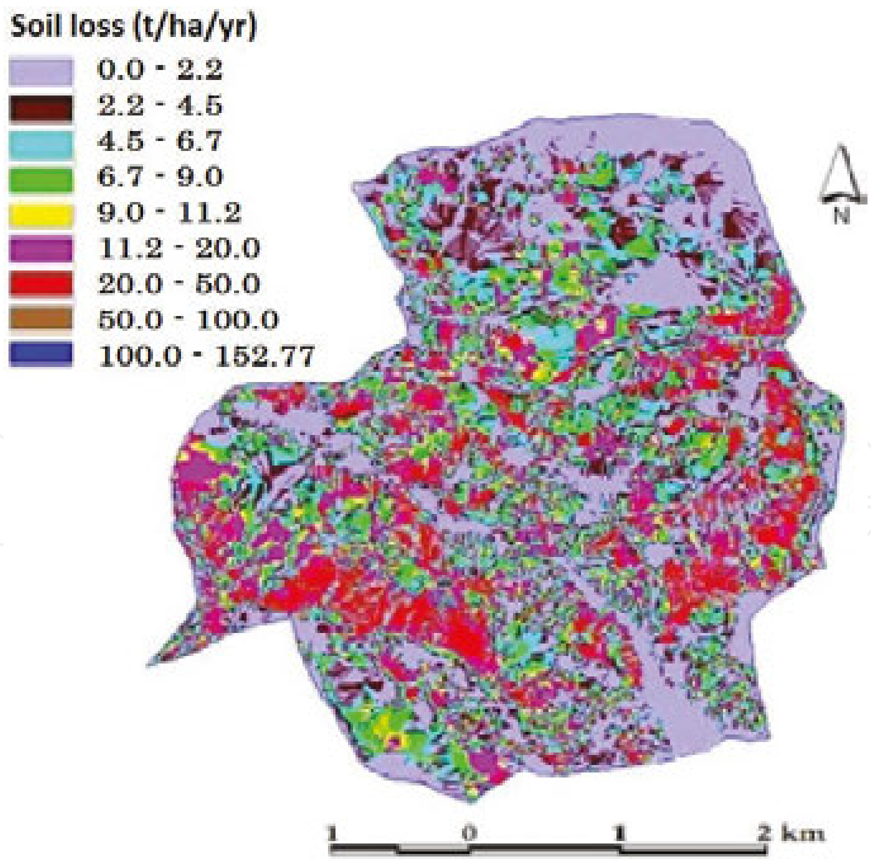

Figure 12. Soil loss map of the basin.

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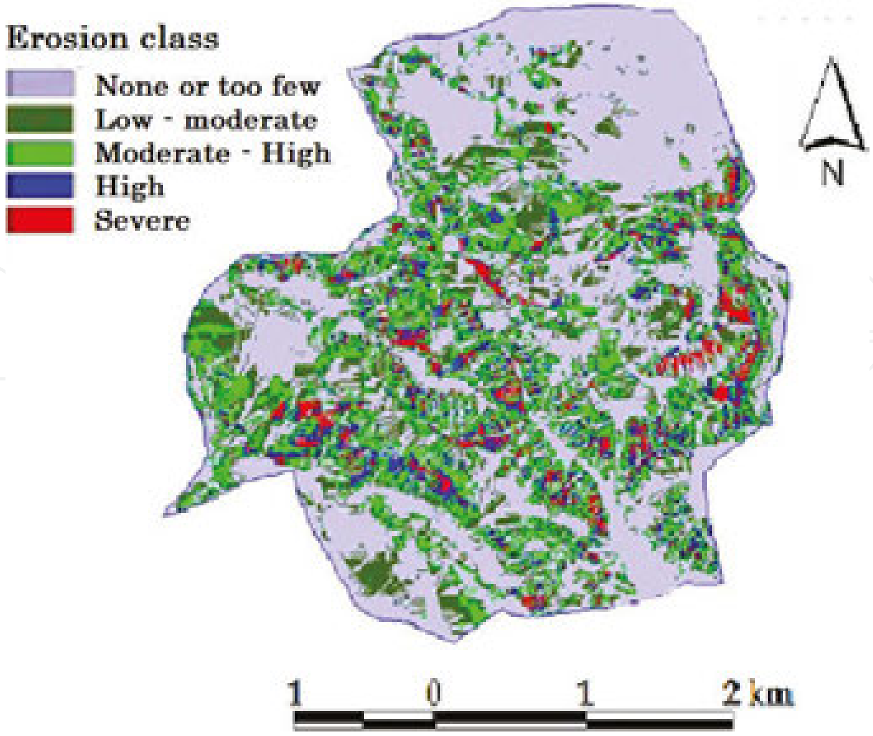

Figure 13. Erosion class map of the basin.

Areal distribution of soil erosion in Çelikli basin is given in **Table 10**. Currently, according to the results, soil loss in the 50% of basin has none exist or too few.

While pasture land use produces a total of 763.89 t of soil loss, only about 9.58% of total soil loss came from the pasture areas. Most of the pasture areas are around Çelikli pond and on the northern side of the basin. About 56.03% of soil loss in pasture land use is under 2.2 t ha^{-1}. Soil losses in 20.37% of the pasture areas are between 2.2 and 4.5 t ha^{-1}, which provides 171 t of loss.

Shrub area has 234.8 t of soil loss, which is the 2.95% of total loss. Shrub areas were formerly forested areas, and all of them now include brushwood from cutting down the forests for fuel during the last century. In these areas, the biggest soil loss is between 4.5 and 6.7 t, which is 27% of total soil loss.

3.2. Land use planning of the basin

The natural land usages of the basin are primarily pasture and forest. Areas in the basin under severe erosion risk are mainly agricultural, shrub, and pasture land uses, respectively. Actually, the pasture and forest were the native land use 100 years ago. As mechanization tools were developed, land conversions started to convert to meet agricultural aims and rural needs by cutting down trees for fuel and by cultivating the soil. In that basin, the carrying capacity for grazing was calculated by considering the number of animals. There were a total of 5000 animals in the basin, including 3000 native cows and 2000 sheep and goats, with a 258.9 ha pasture area [67]. In Turkey, a native cow and a sheep are accepted as 0.5 and 0.1 of a big cow as a native unit (BBHB), respectively. Therefore, the grazed animal numbers were calculated as 1700 BBHB for the whole basin. When we calculate for the carrying capacity for each BBHB, the required pasture area is about 6.12 ha per head. Consequently, the needed area for pasture is about (1700 × 6.12) 10,404 ha. This result shows that the existing pasture area is not sufficient for grazing. The number of grazing animals is over the carrying capacity due to insufficient cover rate and forage yield. It is necessary to increase about 40 times the current pasture area for adequate grazing, or to expand it around 20 times by getting additional improvement measures (such as seedlings, fertilizing, controlled grazing) and applying some rain water harvesting techniques (such as constructing micro-basin water harvesting ridges, negarim type micro-basins, flood water harvesting pools, contour trenches, or bunds and terracing), and some planting measures (such as constructing consecutive brushes and trees as barriers for reducing surface runoff).

In agricultural areas, the wheat-fallow system is applied due to insufficient rainfall. The average wheat yield was determined as 1720 kg per ha for the selected 137 points. The average production cost for wheat is around 2960 kg ha^{-1} in dry areas [83]. Thus, the net income for the Çelikli basin is under the production cost, which is not sustainable for dryland areas. The low productivity is not economical when compared with the obtained income considering soil loss. Moreover, the main source of soil erosion is agricultural fields, which occupy around 88% of total basin area. Currently, 78.34% of arable lands are not appropriate for agricultural usage by ploughing due to improper land use. Therefore, those areas should be converted to pasture land, as they were 100 years ago, for reducing soil loss and meeting the grazing capacity of the basin. This means the pasture areas will increase about 2.13 times, reaching 812.68 ha, which is 78% of the entire basin.

Shrub areas generally have low density coverage and are open to intensive rainfall conditions. Thus, to reduce soil loss they need conservation measures like being converted to forest by increasing the cover density.

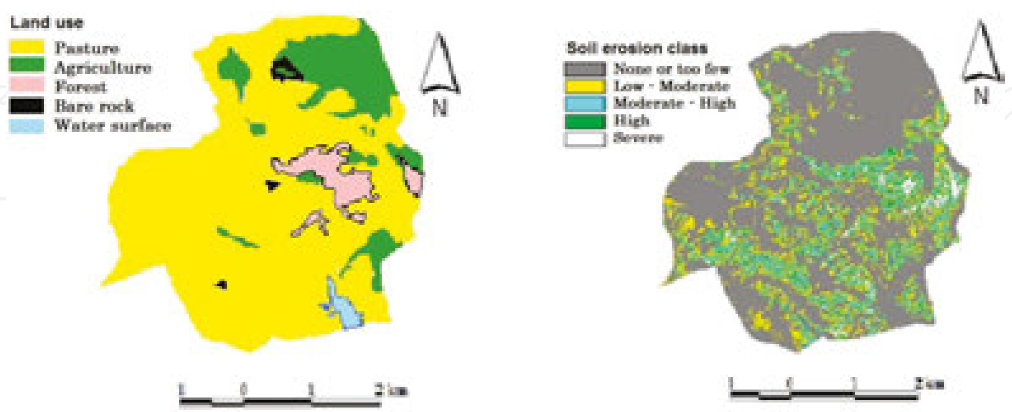

Figure 14. The proposed land use for sustainable management and soil erosion classes in the basin.

Currently, agricultural areas that have LUCC II, III, and IV are appropriate for arable land in the basin. They still unproductively use the wheat-fallow system for agricultural aims. Animal

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production is a main income for the farmers living in the region. Some forage plants, such as vetch (*Vicia sativa*), forage pea (*Pisum sativum*), and sainfoin (*Onobrychis sativa*), can be grown under the dry conditions in the region. Agricultural production by ploughing risks soil erosion, causing movement of the soil and encouraging soil loss. When natural vegetation is removed for agricultural aims by ploughing, soil surface is exposed to intensive rainfall. Alternatively, the forage crops have the basic requirements for feeding the animals and are grown in the Çelikli province.

The research, carried out in the region, showed that sainfoin is one of the most favourable plants, which permanently covers the soil surface. Sainfoin is a perennial legumes-forage crop, which can be grown in poor soil and dry regions, where the rainfall is 300–400 mm per year for grazing animals. While it can obtain a harvest in dry regions in general, hay production can be changed between 2000 and 6000 kg per ha with a fertilization and maintenance. It is accepted as a rotation crop in arid regions and convenient for reducing soil erosion from the fields and ensuring nitrogen [84]. Sainfoin is advised to grow in areas that have low phosphorus soils [85]. It protects animals against bloat due to having tannins and it helps to increase protein absorbsion. It also keeps the soil in place thanks to main and side roots [86].

The land use proposed by the SLUP model was applied in the basin by considering the land use changes, the applications previously mentioned for agricultural, forest, and pasture land use. A final soil loss map of the basin and soil loss distribution is given in **Figure 14** and **Table 11**.

Agricultural land use in class VI was converted to pasture by reducing 79.13% of the total arable land. Current land use (wheat-fallow) was changed to permanent forage crops (sainfoin, *O. sativa)* applying no tillage or minimum tillage, strip cropping with contour farming, and using suitable mechanization tools for cultivation to reduce soil losses. The *C* factor was 0.25 for *O. sativa*. The *P* factor was 0.37 for strip cropping with contour farming. While the *P* factor was 1.0 with fall plough, the soil tillage method factor was 0.25 for no tillage farming. Therefore, the *P* factor was decreased from 1.00 to 0.0925. Soil losses on the agricultural land decreased from 9.87 to 0.24 t ha^{-1}, and the reduction rate was approximately 97.56% considering those applications.

In pasture areas, first- and second-degree precautions were applied to reduce soil loss in addition to the installation of some permanent vegetation, such as buffer strips (e.g. Saltbush) situated in short intervals, including physical structures (such as terracing, contour strips, and installing trenches and holes) to intercept storm water runoff and minimize soil erosion. In pasture land use, overgrazing management and improvement studies (seeding, fertilizing) on poor areas are proposed for sustainable management. Pasture areas increased by converting them from agricultural land at a rate of 216% in the basin. The *C* factor for pasture area was selected as 0.025. Soil loss in pasture land use was decreased from 3.01 to 0.83 t ha^{-1} by means of grazing management, improvement studies, and including some physical precautions.

Shrub land areas were another source of soil loss. This land was a forest before the trees were cut down. After planning, the shrub land was converted to its natural cover plant. The *C* factor was selected as 0.001 applying forest management. Therefore, soil loss in this land decreased from 4.16 to 0.05 t ha^{-1}. Overall, soil loss was lowered from 9.87 to 0.67 t ha^{-1} with the SLUP model across the entire basin, reducing it by approximately 91.25%. After planning, land use changes are given in **Table 12**.

Land use	Descriptive statistic	Soil loss (t ha^{-1} year^{-1})						
		0.0–2.2	**2.2–4.5**	**4.5–6.7**	**6.7–9.0**	**9.0–11.2**	**>11.2**	**General**
Agriculture (forage crop)	Mean (t ha^{-1} year^{-1})	0.23	2.43	–	–	–	–	0.24
	Cell number*	14,713	37	–	–	–	–	14,750
	USLE (t ha^{-1} year^{-1})	33.84	0.90	–	–	–	–	33.81
	Area (%)	99.75	0.25	–	–	–	–	100.00
Pasture	Mean	0.59	2.9	5.16	7.47	10.09	24.54	0.83
	Cell number	75,119	6403	148	77	23	59	81,830
	USLE (t ha^{-1} year^{-1})	443.20	185.69	7.64	5.75	2.32	14.48	659.08
	Area (%)	91.59	8.02	0.19	0.10	0.03	0.07	100.00
Forest	Mean	0.05	–	–	–	–	–	0.05
	Cell number	5670	–	–	–	–	–	5670
	USLE (t ha^{-1} year^{-1})	2.84	–	–	–	–	–	2.84
	Area (%)	100.00	–	–	–	–	–	100.00
Bare rock	Mean	0.0	–	–	–	–	–	0.00
	Cell number	850	–	–	–	–	–	850
	USLE (t ha^{-1} year^{-1})	0.0	–	–	–	–	–	0.00
	Area (%)	100.00	–	–	–	–	–	100.00
Water surface	Mean	0.0	–	–	–	–	–	0.00
	Cell number	1030	–	–	–	–	–	1030
	USLE (t ha^{-1} year^{-1})	0.0	–	–	–	–	–	0.00
	Area (%)	100.00	–	–	–	–	–	100.00
Basin general	Mean	0.49	2.90	5.16	7.47	10.09	24.54	0.67
	Cell number	97,382	6440	148	77	23	59	104,130
	USLE (t ha^{-1} year^{-1})	479.88	186.59	7.64	5.75	2.32	14.48	696.66
	Area (%)	93.51	6.18	0.14	0.07	0.02	0.06	100.00

*grid cell size 10 m × 10 m = 100 m^2.

Table 11. Soil loss according to proposed land use groups in the basin.

Land use	Current land use (ha)	Proposed land use (ha)	Difference (ha)
Agriculture (wheat-fallow)	706.9	–	−706.9
Agriculture (forage crops)	–	147.5	+147.5
Pasture	258.9	818.3	+559.4
Shrub	56.7	–	−56.7
Forest	–	56.7	+56.7
Bare rock	8.5	8.5	–
Water surface	10.3	10.3	–
Total	1041.3	1041.3	

Table 12. Land use changing before and after planning in the basin.

4. Conclusion

Sustainable land use planning (SLUP) model was applied in a semi-arid basin, having different land use. Main problem in the basin had soil erosion due to land use problems such as improper land use, deforestation, and overgrazing. The grazing capacity for feeding animals is not sufficient due to poor vegetation and cover rate. It is necessary to increase the pasture area about 40 times for adequate grazing, or to expand it around 20 times by getting additional improvement measures and applying some rain water harvesting techniques and some planting measures. When it was evaluated the basin in terms of land use capability classes, some land use problems were determined. Although only 14.07% of the basin is available for cultivation, around 68% of the basin has been used for agricultural aims for years. The USLE and GIS were used to estimate soil loss in the basin. While the average soil loss was calculated as 7.66 t ha^{-1} for the entire basin, soil loss for agricultural, pasture, and shrub had 9.87, 3.01 and 4.16 t ha^{-1}, respectively, varying between 0 and 152.77 t ha^{-1} yearly. Total soil loss for the general basin is about 7972.86 t per year. While 87.52% of the total soil loss is lost from agricultural areas, pasture and shrub land use also contribute to the rate of 9.58 and 2.95%, respectively. When considered in terms of soil depth in the basin, mean soil loss tolerance values are around 4.5 t per ha, which are accepted as the threshold level of the basin. This means that 89.79% of the total soil loss occurs over the threshold value.

The land use proposed by the SLUP model was applied in the basin by considering the land use changes, the applications previously mentioned for agricultural, forest, and pasture land use. A final soil loss map of the basin and soil loss distribution was prepared. Agricultural land use in class VI was converted to pasture by reducing 79.13% of the total arable land. Current land use (wheat-fallow) was changed to permanent forage crops (sainfoin, *O. sativa)* applying no tillage or minimum tillage, strip cropping with contour farming, and using suitable mechanization tools for cultivation to reduce soil losses. While *C* factor was 0.25 for sainfoin, *P* factor was 0.37 for strip cropping with contour farming. While the *P* factor was 1.0 with fall plough, the soil tillage method factor was 0.25 for no tillage farming. Soil losses on the agricultural land decreased from 9.87 to 0.24 t ha^{-1}, and the reduction rate was approximately 97.56% considering those applications.

In pasture areas, first- and second-degree precautions were applied to reduce soil loss in addition to the installation of some permanent vegetation to intercept storm water runoff and minimize soil erosion. It was also applied an overgrazing management and improvement studies (seeding, fertilizing) on poor areas are proposed for sustainable management. Pasture areas were increased by converting them from agricultural land at a rate of 216% in the basin. The *C* factor for pasture area was selected as 0.025. Soil loss in pasture land use was decreased from 3.01 to 0.83 t ha^{-1} by means of grazing management, improvement studies, and including some physical precautions.

Shrub land areas were another source of soil loss. This land was a forest before the trees were cut down. After planning, the shrub land was converted to its natural cover plant. The *C* factor was selected as 0.001 applying forest management. Therefore, soil loss in this land decreased from 4.16 to 0.05 t ha^{-1}.

Overall, soil loss was lowered from 7.66 to 0.67 t ha^{-1} with the SLUP model across the entire basin, reducing it by approximately 91.25%.

Author details

Ertuğrul Karaş

Address all correspondence to: ekaras@ogu.edu.tr

Department of Biosystem Engineering, Faculty of Agriculture, University of Osmangazi, Eskişehir, Turkey

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