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ORIGINAL ARTICLE

Use of USLE/GIS technology integrated with geostatistics to assess soil erosion risk in different land uses of Indagi Mountain Pass—Çankırı, Turkey

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Abstract The universal soil loss equation (USLE) is an erosion model to estimate average soil loss that would generally result from splash, sheet, and rill erosion from agricultural plots. Recently, use of USLE has been extended as a useful tool predicting soil losses and planning control practices by the effective integration of the GIS-based procedures to estimate the factor values on a grid cell basis. This study was performed for five different lands uses of Indağı Mountain Pass, Cankırı to predict the soil erosion risk by the USLE/GIS methodology for planning conservation measures in the site. Of the USLE factors, rainfall-runoff erosivity factor (USLE-R) and topographic factor (USLE-LS) were greatly involved in GIS. These were surfaced by correcting USLE-R site-specifically using DEM and climatic data and by evaluating USLE-LS by the flow accumulation tool using DEM and watershed delineation tool to consider the topographical and hydrological effects on the soil loss. The study assessed the soil erodibility factor (USLE-K) by randomly sampled field properties by geostatistical analysis. Crop management factor for different land-use/land cover type and land use (USLE-C) was assigned to the numerical values from crop and flora type, canopy and density of five different land uses, which are plantation, recreational land, cropland, forest and grassland, by means of reclassifying digital land use map available for the site. Support practice factor (USLE-P) was taken as a unit assuming no erosion control practices. USLE/GIS technology together with the geostatistics combined these major erosion factors to predict average soil loss per unit area per unit time. Resulting soil loss map revealed that spatial average soil loss in terms of the land uses were 1.99, 1.29, 1.21, 1.20, 0.89 t ha^{-1} $year^{-1}$ for the cropland, grassland, recreation, plantation and forest, respectively. Since the rate of soil formation was expected to be so slow in Central Anatolia of Turkey and any soil loss of more than 1 ton ha^{-1} $year^{-1}$ over 50–100 years was considered as irreversible for this region, soil erosion in the Indağı Mountain Pass, to the great extent, attained the irreversible state, and these findings should be very useful to take mitigation measures in the site.

Keywords USLE/GIS technology · Geostatistics · Erosion risk assessment · Land use

Introduction

The universal soil loss equation (USLE) (Wischmeier and Smith 1978) and its principal derivative, the revised universal soil loss equation (RUSLE) (Renard et al. 1997), predict the long-term average annual rate of erosion on a field slope based on rainfall pattern, soil type, topography, crop system and management practices. The technology has been broadly used throughout the world for nearly 40 years since it is relatively simple and robust and represents a standardized approach although having many shortcomings and limitations (Desmet and Govers 1996). One of its limitations is that it estimates the soil loss that

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results only from rill and sheet erosion and does not intend for further soil losses by gully, wind, or tillage erosion. The USLE/RUSLE equation was produced for selected cropping and management systems, but is also applicable to non-agricultural conditions such as construction sites. Recently, it has been successfully used at national, regional and watershed level (Van der Kniff et al. 2000; Grimm et al. 2003; Erdogan et al. 2006). The equation compares soil losses of a given unit to ''tolerable soil loss'' rates to determine alternative management and crop systems and to adequately design conservation measures for the projected scale.

Extension of using the USLE/RUSLE for a greater scale than the field scale necessitated the use of geographic information system (GIS) such that GIS-based procedures were employed to determine the factor values for predicting erosion in a grid cell (Kinnell 2001). Eedy (1995) reported the advantages of GIS in environmental assessment, and Burrough (1986) introduced the principles of GIS tools for collecting, storing, manipulating, and displaying spatial data. Thus, remote sensing (RS) and GIS have resulted in great progress in the research of soil erosion and soil and water conservation since the end of 1980s. Estimation of soil erosion and its spatial distribution using RS and GIS techniques were performed with reasonable costs and better accuracy in larger areas to face up to land degradation and environmental deterioration (Lal and Blum 1997; Millward and Mersey 1999; Wang et al. 2003). An interactive web-based approach to use RUSLE and GIS for estimating soil erosion was developed by Ouyang and Bartholic (2001). Likewise, Martin et al. (2003) used GIS/USLE model to estimate sheet erosion from a watershed. In the study, GIS was easily and successfully integrated with the USLE to identify discrete locations with relatively precise spatial boundaries that had a high sheet erosion potential together with the areas where management practices might be suitable to prevent soils from eroding. Also it is recommended that the GIS/USLE modeling approach would offer quick and inexpensive tool for estimating sheet erosion within watersheds using publicly available information. As GIS tools usually facilitated derivation of the topographic factor from DEM data and computation of soil losses (Cerri et al. 2001; Bartsch et al. 2002; Wang et al. 2003), remote sensing data helped to develop the cover-management factor and land cover classifications (Millward and Mersey 1999; Wang et al. 2003; Ma et al. 2003). On the other hand, most attempts to use GIS in conjunction with the USLE to model spatial changes in soil loss have often proceeded without addressing the problems related to the assumptions that are incurred in scaling up the USLE applications from plots to large areas. The GIS/USLE application by Ventura et al. (1988) and Hession and Shanholtz (1988), for example, failed to mention a need for distinguishing areas that experience net erosion and net deposition before applying this equation. Difficulties and limitations experienced when applying erosion models together with GIS were broadly discussed by Wilson and Lorang (2000).

In addition to the integration of USLE with the GIS, geostatistical interpolation or kriging of soil and vegetation variables has become an important alternative to other mapping techniques (Beurden and Riezebos 1988). In erosion risk assessment, the authors showed that kriging was an efficient option for mapping of USLE-K factor compared to that of the conventional choropleth mapping. Traditionally, based on properties of the typical pedon which is believed to represent soil series, *K* values were assigned to each soil mapping unit, assuming that one soil erodibility value represents the entire area of each soil series, and therefore, these approaches did not account for spatial variability of soil properties and processes (Goovaert 1999) and accordingly soil erodibility (Parysow et al. 2003; Wang et al. 2001). To model spatial variability different kriging methods have been developed for estimating sought variables at unsampled locations using sample data available only at a subset of locations. Lu et al. (2004) applied RUSLE, remote sensing, and GIS to the mapping of soil erosion risk in Brazilian Amazonia. Soil loss was estimated by integrating a sample ground data set, TM images, and a slope map as a function of six input factors, including rainfall erosivity (*R*), soil erodibility (*K*), slope length (*L*), slope steepness (*S*), cover-management (*C*), and support practice (*P*) (Wang et al. 2003). Authors compared two geostatistical methods with a traditional stratification to map the factors and to estimate soil loss and concluded that two geostatistical methods performed significantly better than traditional stratification in terms of overall and spatially explicit estimates. Together with GIS, Basaran et al. (2006) used the geostatistical techniques to determine the spatial variation of soil qualities. They transferred the information on soil parameters obtained by the use of variogram models and geostatistical methods to the GIS to have kriging map depicting the spatial variation of soil erodibility factor (USLE-K).

The objective of this case study of applying the USLE/RUSLE technology was to quantitatively perform erosion risk assessment at the watershed composed of different land use types and topographical units in the semiarid part of Turkey. It is expected that this methodology of integrating USLE with both GIS and geostatistics should offer an useful tool to assess erosion risk and plan conservation measures at the watershed scale.

Materials and methods

Study area

Study site is located at an altitude between 1,196 and 1,410 m above sea level in the north of Ankara, Indagi Mountain Pass of Çankırı province. The region has an arid climate with a long-term annual average precipitation of 499 mm, and average temperature is 21.1°C in summer and –0.5°C in winter. The watershed is composed of five land use types which are cropland (34.3%), grassland (23.8%), plantation (19.3%), forest (15.4%), and recreation (7.2%) (Fig. 1). Of these land uses, cropland, plantation, and recreational land have been converted from the grassland or woodland which were original land uses in the ecosystem of Indagi Mountain Pass. The woodland comprises of *Pinus nigra* Arn. and *Quercus pubescens* Willd. Principal tree species of the plantation, which was replaced by the original woodland 40 years ago, is *Pinus nigra* Arn., which is also the principal tree species of the recreational land in the site. The observations also showed that there were remnants of quite old *Pinus nigra* Arn. and *Quercus pubescens* Willd. in the cropland, grassland, and recreational land either in isolation or in groups. Age determination indicated these remnant trees were 155 years old. Forests of *Pinus nigra* Arn. are protected in the mid of the treeless plains and floristically in very poor conditions in the central Turkey (Akman 1995). Aytug (1970) reported the fact that such species as *Quercus pubescens* Willd., *Quercus cerris* L., *Pyrus elaeagnifolia* Pall., and *Cistus larifolius* L. exists in the Anatolia could be proof of existence of *Pinus nigra* Arn. since it descended from them, and that *Pinus nigra* Arn. vanished in time. These old remnant trees found in the cropland, grassland, and recreational land in addition to those present in the woodland and plantation indicated that original land use over the whole study area was natural forest.

Dominant grass species in the grassland are Achillea biebersteinii Afan., Bellis perrennis L.,Centaurea depressa Bieb, Tanacetum armeneus (D.C) Schultz Bip., Salvie virgata Jacq.,Trifolium campestre Schreb., Verbascum glomeratum Boiss., and Dactylis glomerate L. Agricultural crops are mostly wheat (Tritucum aestivum L.) and barley (Hordeum vulgare L.).

The geological strata in the study area belong to Pliocene Ilgaz formation and Miocene Mamak formation. While the former mainly contains sandstone, claystone, conglomerate, breccia, and marn, the latter is composed of magmatic rocks like serpentine, andesite, and basalt. Sandstone, conglomerate, and breccia of the Ilgaz formation are calcium carbonate- and iron oxide-cemented rocks. In situ observations showed that serpentines of the Mamak formation greatly underwent the carbonization by hydrothermal alteration. The soil forming factors relief, parent material, climate, organisms, and time control the spatial variation of soil properties within landscapes. A large heterogeneity in terms of the soil formation may occur at greater depths and this study did not aim to cover the soil property change with the soil depth at which geology changed. Therefore, notwithstanding the underlying geology, the more homogenous soil properties found close to the soil surface were considered in this study.

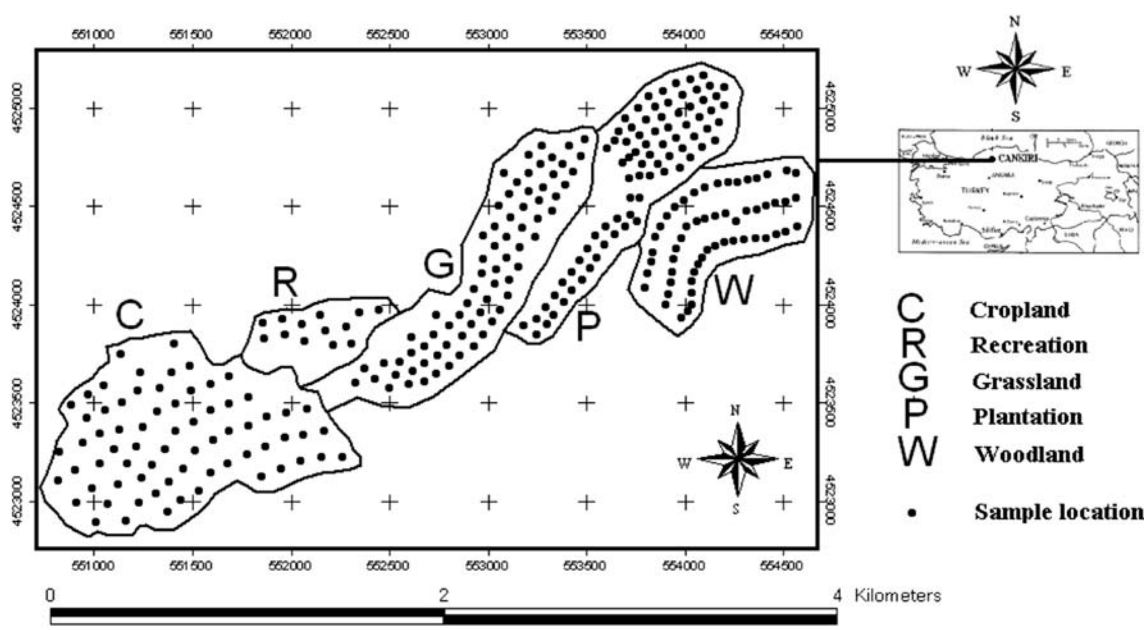

Fig. 1 Map of study area

Procedure

A well-known USLE (Wischmeier and Smith 1978) was used for this study because it is one of the most appropriate model-based approaches that could be applied to the authoritatively available data in Turkey. USLE quantitatively estimates soil erosion with the following empirical equation:

$$A = R \cdot K \cdot L \cdot S \cdot C \cdot P \quad (1)$$

where A mean annual soil loss (t ha^{-1} y^{-1}), R rainfall erosivity factor (MJ mm ha^{-1} h^{-1} y^{-1}), K soil erodibility factor (t ha h ha^{-1} MJ^{-1} mm^{-1}), S slope factor, L slope length factor, C cover management factor, and P supporting practice factor. Assuming no support practice in the study area (P = 1), it was not used in calculations.

Following are the details of the methods used to determine the model factors in turn written in Eq. (1):

USLE-R

Rainfall erosivity, defined as the potential ability of rain to cause erosion and given as the product (EI_{30}) of the total energy of rainstorm (E) and the maximum 30-min intensity (I_{30}) (Wischmeier and Smith 1978; Foster et al. 1981), was taken directly from isoerodent map of Turkey (Dogan 2002), which gives erosive potentials of rainfalls and erosion index values of USLE for Ilgaz meteorological station.

$$E = 0.119 + 0.0873 \cdot \log_{10}(I) \quad (2)$$

$$E = 0.283 \quad (3)$$

Eqs. (2), (3) are for the conditions where $I(\leq 76$ mm h^{-1} and $I(< 76$ mm h^{-1}, respectively, and E have units of MJ ha^{-1} mm^{-1}. With Eq. (4), we had the units of MJ mm ha^{-1} h^{-1} y^{-1} for the annual erosivity (Renard et al. 1997):

$$R = \frac{\sum_{i=1}^{j} (EI_{30})_i}{N} \quad (4)$$

where $(EI_{30})_i$ is EI_{30} for rainfall event i and j is number of rainfall events in an N year period.

Additionally, the methodology described by Toy and Foster (1998) to convert the point data of R taken directly from the isoerodent map of Turkey (Dogan 2002) to the USLE surface of the watershed was used considering the effect of elevation on actual amount of precipitation. Accordingly, the point data were applied to the DEM of the study area by Eq. (5) to compute R values of unknown elevations in ArcView 3.2:

$$R_{new} = R_{base} \left(\frac{P_{new}}{P_{base}}\right)^{1.75} \quad (5)$$

where, R_{new} is the new value for R at the desired new location, R_{base} is the R value at base location, P_{new} is the average annual precipitation at new location, and P_{base} is the annual precipitation at the base location. The study area has a meteorological station at the altitude 885 m (Ilgaz Meteorology Station), and altitude in the area is between 1,196–1,410 m. R values of unknown elevations were computed by using DEM in Arcview 3.2 and Eq (5) by assuming a 50 mm increase of precipitation with each 300 m increment in altitude.

USLE-K

The soil erodibility factor of USLE determined by the nomograph (Wischmeier et al. 1971) comprised five soil and soil-profile parameters which were percent-modified Si (0.002–0.1 mm), percent-modified S (0.1–2 mm), percent organic matter (OM), and classes for structure (s) and permeability (p) (Renard et al. 1997). Structure and permeability indices used to calculate soil erodibility factor were taken from Soil Survey Staff (1951). Algebraic approximation (Wischmeier and Smith 1978) of the nomograph where the Si fraction does not exceed 70% is,

$$K = \left[2.8 \times 10^{-5}(12 - \mathrm{OM})M^{1.14} + 4.3 \times 10^{-1}(s - 2) + 3.3 \times 10^{-1}(p - 3)\right]/100, \quad (6)$$

where M is the product of the primary particle size fractions (% modified Si or the 0.002–0.1 mm size fraction) (% Si + % S). USLE-K of Eq. (6) was expressed in SI units of t ha h ha^{-1} MJ^{-1} mm^{-1}.

Spatial correlation and spatial patterns of USLE-K were evaluated by the geostatistics and Arcview 3.2. The basic theory of the geostatistics firstly presented by Matheron (1965) has been well established by Journal and Huijbregts (1978) and applied to soils by Burgess and Webster (1986) and Trangmar et al. (1987). Experimental semivariogram for the separation distance (lag) h was calculated by Eq. (7):

$$\gamma \times (h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [z(x_i) - z(x_i + h)]^2 \quad (7)$$

where $z(x_i)$ was the value of measured soil properties at spatial location x_i and $N(h)$ was the number of pairs with separate distance (lag) h. The data was fitted to the spherical model for experimental semivariograms. Also, the empirical semivariogram was directionally calculated at the angles of 0° (N–S), 45° (NE–SW), 90° (E–W), and

135° (SE–NW) for USLE-K. This directional examination of the variogram surfaces indicated no severe anisotropy, and therefore, only omni-directional variogram was obtained by using the best fitting model by the cross-validation method and modeled with isotropic functions to determine spatial dependent variance within the study area. The values of USLE-K at the observation points were used for prediction values at unknown points using the ordinary kriging interpolation method by the model and parameters of the semivariogram generated. The software package GS + 7 (Gamma Design Software) was used to perform geostatistical computation. The map of USLE-K was generated in the geostatistical tool of the Arcview 3.2 using the variogram models and parameters to obtain a high quality map.

USLE-LS

USLE-LS factor was computed using the interaction between topography and flow accumulation (Moore and Bruch 1986a, b). In this case, USLE-LS relied not only on percentage and length of the slope but also on the flow expected to occur over the land. Slope percentage layer was derived from digital elevation model (DEM) of the study area and slope length was assumed to be fixed as 15 m for each pixel (Ogawa et al 1997). Following was calculation of USLE-LS by Eq. (8):

$$LS = \left(\frac{\chi\eta}{22.13}\right)^{0.4} \cdot \left(\frac{\sin\theta}{0.0896}\right)^{1..3} \quad (8)$$

where, χ is flow accumalation and was derived from DEM using a GIS accumulation algorithm (Lee 2004), η is cell size, and θ is slope in degrees. Flow accumulation was computed using the watershed delineation tool of Arcview 3.2. Since USLE is only suitable for estimating erosion due to interrill and rill processes, there is an upper bound on the slope length that should be used. To enforce an upper bound using the above approach, we needed to modify the flow accumulation map.

USLE-C

Crop management factor depends on vegetation cover, which dissipates the kinetic energy of the raindrops before impacting the soil surface. Therefore, vegetation cover and cropping systems have a large influence on runoff and erosion rates. Soil erosion can be limited with proper management of vegetation, plant residue and tillage (Lee 2004). *C* values were decided with the use of land cover data described by Wischmeier and Smith (1978) and Özhan et al. (2005). The latter study was involved in determining cover and management factors for USLE for forest ecosystems in the Marmara region of Turkey. A map of USLE-C was generated through reclassification of each land-use/land-cover type into its corresponding C values given in Table 1.

USLE-P

Due to the fact that there were no erosion control practices in the research area, USLE-P factor was assumed as a unit value (USLE-P = 1).

Finally, a map showing potential soil erosion was produced using USLE and integrating layers of R, K, LS, and C with ArcView 3.2 software (Wall et al. 1997).

Results and discussion

The layer of the USLE-R factor calculated by Eqs. (2), (3), (4) (Dogan 2002) and mapped by Eq. (5) using the DEM of the watershed is shown in Fig. 2.

In the research area, USLE-R values were within the range of factor changes between 37–43 MJ mm ha^{-1} h^{-1} year^{-1}. Comparatively, depending on the DEM, USLE-R values increased from the north-east towards the south-west of the watershed, and the values were approximately 37–40 MJ mm ha^{-1} h^{-1} year^{-1} and 40–43 MJ mm ha^{-1} h^{-1} year^{-1}, respectively. When compared to the USLE-R values mapped for Europe (Van der Kniff 2000), which were $0 <$ USLE-R < 900 MJ mm ha^{-1} h^{-1} year^{-1}, these values showed that the watershed climatologically had a very low erosion potential. However, in spite of showing very low erosivity values, it has been long recognized that the climatic characteristics of these regions together with topographic, soil, and land use factors have escalated water erosion. The substantial sign of the potential risk in these semiarid regions of Central Anatolia is very high climatic unevenness in which extreme events occur and rainy and vegetative seasons hardly concur. Bayramin et al. (2006) pointed out that erosivity risk classes increased when the occurrence of unusual storm conditions was considered by the frequency analysis performed with the modified fournier index (MFI) for the semi-arid area of Beypazari, Ankara, Turkey. Additionally, since events of unusual storm conditions with high runoff and soil erosion potential

Table 1 Crop management factor for different land-use/land cover type (Wischmeier and Smith 1978 and Özhan et al. 2005)

Land use capability	*C* values
Forest	0.04
Recreation	0.06
Plantation	0.09
Grassland	0.11
Cropland	0.38

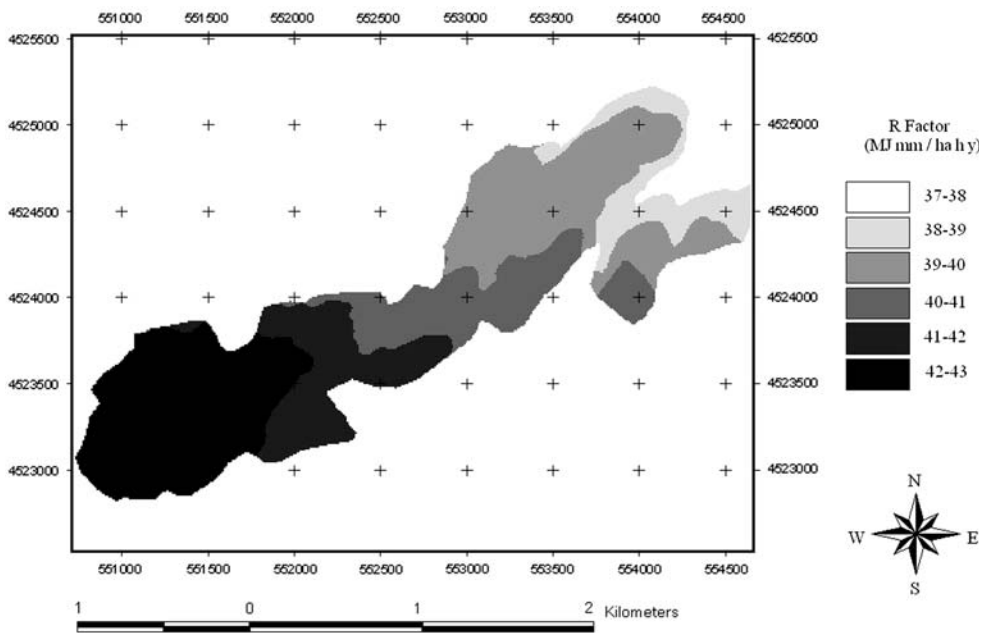

Fig. 2 R factor layer

are very important for soil erosion research, knowledge of the temporal distribution of heavy rainstorms is also necessary for evaluating the amount of runoff and soil loss (Boardman 1988; Poesen et al. 1996; Klik and Truman 2003).

Figure 3 and Table 2 show the geostatistical model and parameters for isotropic semivariogram of the USLE-K. The selected model consists of two functional structures. The first structure is the nugget effect, caused by either measurement error or variation of the property which cannot be detected with current scale at our sampling. The second structure, semivariance increases as separation distance between sample locations increases, rising to an approximately constant value called sill. Empirical semivariogram of the USLE-K factor was defined using spherical model. The nugget effect was 0.0023 and sill value was 0.0036. The maximum spatial correlation was found 800 m.

The kriging map produced using the parameters of the geostatistics is given by Fig. 4.

The map indicated that USLE-K factor varied between 0.059 and –0.24 t ha h ha^{-1} MJ^{-1} mm^{-1} in the area and the spatial pattern of USLE-K changed with the land use types. Especially, the higher values were in the western part of the watershed, where the cropland was located and the eastern part where the plantation and woodland were sited had the lower values of USLE-K factor. Unlike USLE-R distribution, USLE-K distribution in the area was so wide that it could make significant changes in the soil losses. For example, the ratio of the lower bound of the highest USLE-K class (0.220 t ha h ha^{-1} MJ^{-1} mm^{-1}) to that of the smallest class (0.059 t ha h ha^{-1} MJ^{-1} mm^{-1}) was 3.7. Therefore, soil management in the fragile ecosystems of the semi-arid regions appears to be a very critical to the system sustainability. In relation to USLE-K, many studies have shown that the organic matter had great importance

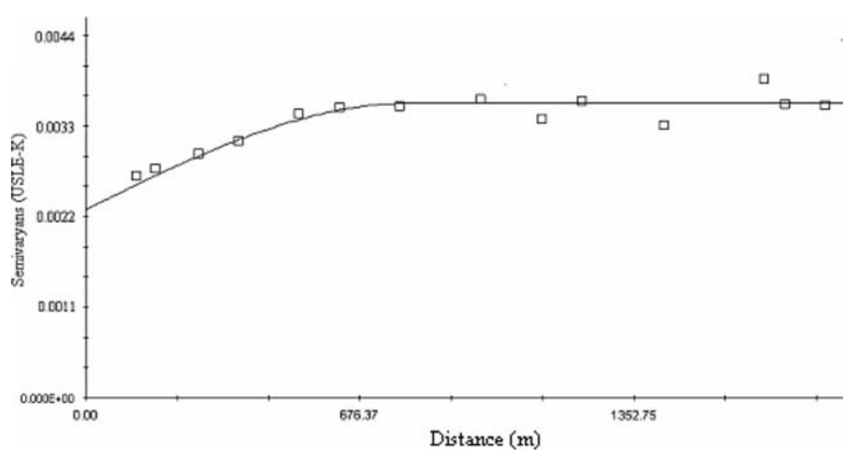

Fig. 3 Semivariogram of USLE-K

Table 2 Descriptive statistics, semivariogram model and parameters for USLE-K

USLE-K								
Descriptive statistics				Semivariogram models and parameters				
Depth	Mean	SD	CV	Model	Nugget	Sill	Range	R^2
0–10 cm	0.14	0.06	37.5	Spherical	0.0023	0.0036	800 m	0.610

due to its effects and regulatory roles over numerous physical soil features like pH, bulk density, hydraulic conductivity, aggregate stability and erosion susceptibility. Loss of organic matter could cause soil aggregates to break down easily and accordingly to become more erodible (Wu and Tiesson 2002). Parallel to the increases in soil organic matter, soil porosity increased, while bulk density and soil erodibility decreased (Cerda 1996).

USLE-LS layer calculated by Eq. (8) using DEM of the watershed and considering the interactions between topography and flow accumulation is shown in Fig. 5, and its distribution as a percentage is given in Table 3. The Indagi Mountain Pass had USLE-LS values which ranged from 0–2 to 14–17. However, USLE-LS value of 0–2 prevailed in the whole area (69.7%); for example, 98.0% of the cropland and 75% of the grassland land satisfied the condition of 0 < USLE-K < 2. In the rest of the grassland, 24.0 and 1.0% had the value of 2–5 and 5–7, respectively.

In the recreational land, USLE-LS factor varied between 0–7, and when portioned, 44.8, 54.7, 0.6% of which had the values of 0–2, 2–5, and 5–7, respectively. The plantation and forest had the relatively greater USLE-LS values compared to the rest. 52.0, 24.0, 13.0, and 11.0% of the plantation had the values of 0–2, 2–5, 5–7, and 7–10, respectively. And values of the forest were between 0–14, and 32.4, 34.1, 20.5, and 10.4% of the forest had the values of 0–2, 2–5, 5–7, and 7–10, respectively. The coverage of the classes of >10 were insignificant and summed 0.4%. The spatial analysis of USLE-LS (Fig. 5) suggested that topography of the watershed mostly favored less erosion, meaning that in only very small part of the watershed the steeper slopes collecting more runoff would result in greater erosion.

Figure 6 shows the map of USLE-C generated by reclassification of each land-use/land-cover type using values given in Table 1 (Wischmeier and Smith 1978; Ozhan et al. 2005). The watershed was composed of five land use types, which were cropland (34.3%), grassland (23.8%), plantation (19.3%), forest (15.4%), and recreation (7.2%) (Fig. 1) and coverage area of these were 34.3, 23.8, 19.3, 15.4, and 7.2%, respectively, having the USLE-C values of 0.38, 0.11, 0.09, 0.04, and 0.06 (Fig. 6).

Relatively, since greater USLE-C values matched with the greater USLE-K values in the cropland although USLE-LS values were smaller, one could expect that the potential soil losses in the Indagi Mountain Pass would be higher in this type of land use and vice versa, because smaller USLE-C values (e.g. C_{forest} = 0.04) corresponded

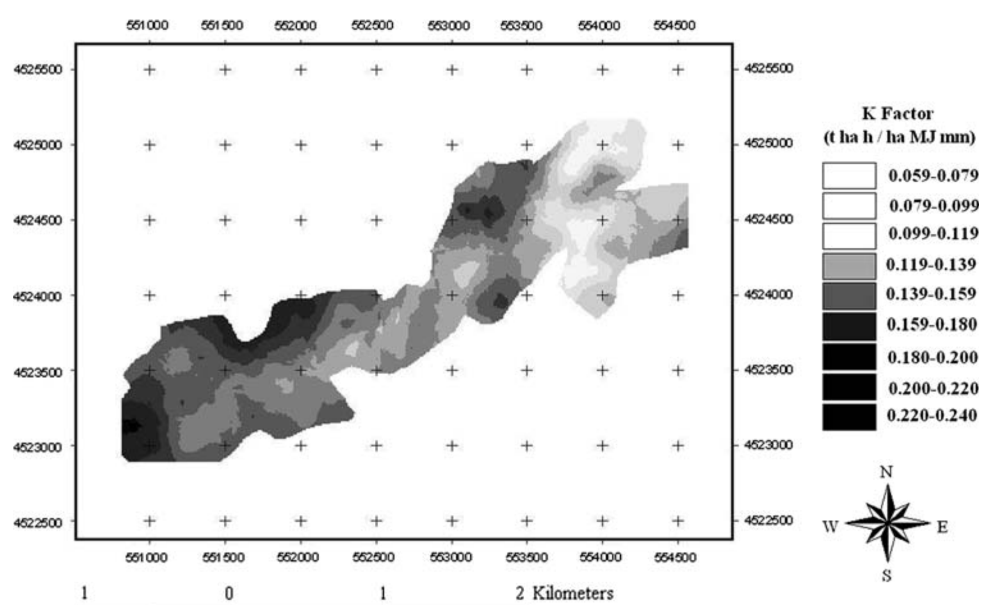

Fig. 4 K factor layer

Fig. 5 LS factor layer

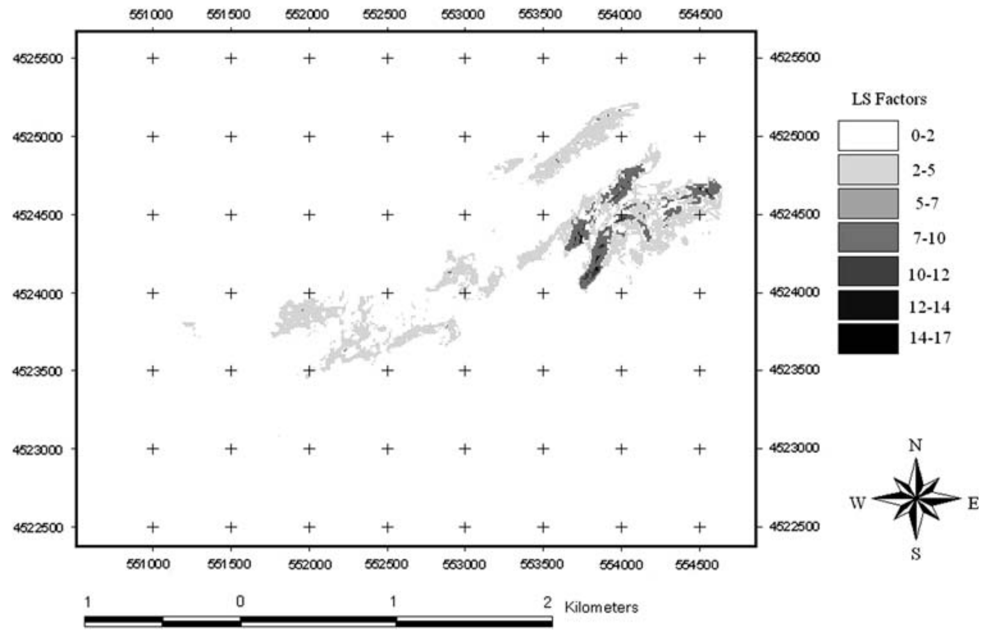

Table 3 USLE-LS distribution (%) detailed in terms of land use type over the study area

LS factors	Cropland	Recreation	Grassland	Plantation	Forest	Total
0–2	98.0	44.8	75.0	52.0	32.4	69.7
2–5	2.0	54.6	24.0	24.0	34.1	20.2
5–7		0.60	1.0	13.0	20.5	6.0
7–10				11.0	10.4	3,7
10–12					1.8	0.3
12–14					0.8	0.11
Total	100.00	100.00	100.00	100.00	100.00	100.00

to the smaller USLE-K values although USLE-LS values were greater, there could be less soil loss in the land use of the forest.

The map of the potential soil losses predicted by Eq. (1) is given by Fig. 7, and annual soil losses (A, ton ha^{-1} $year^{-1}$) in terms of the different landuse/land-cover types are given in Table 4.

As a base of discussing the potential soil erosion, the amount of 1 ton ha^{-1} $year^{-1}$ was taken as an upper bound of soil erosion rate in determining the soil loss classes. This limit is the one still tolerable to sustain the soils of the watershed since the rate of soil formation was expected to be so slow in semiarid environments like Central Anatolia of Turkey. Therefore, any soil loss of more than 1 ton ha^{-1} $year^{-1}$ over 50–100 years is considered as irreversible (EEA 1999; Renard et al. 1997).

As a total, the irreversible soil losses occurred in the 44% of the area although the soil losses were below the bound in 56% of the area (Table 4). More significantly, the results indicated that, out of 44%, 34.9% of the irreversible soil losses happened in the class of $1 < A < 3$, implying the significance of soil conservation measures in this fragile ecosystem not to aggravate the problem.

With respect to the land uses, areas of the cropland and grassland had the most irreversible soil losses, and percentages of soil losses more than 1 ton ha^{-1} $year^{-1}$ were 17.5 and 12.0%, respectively (Table 4). In the ecosystem, conversion of the original land uses, which were woodland and grassland, into the cropland had a significant effect on the soil organic matter (OM). Basaran et al. (2007) found that relative to OM of the forest and grassland, OM of the cropland decreased by 46 and 38%, respectively, for the 0–10 cm depth in their study in the same ecosystem. This decrease was respectively by 39 and 29% when OM of the recreational land was compared to those of the forest and grassland. Evrendilek et al. (2004) and Celik (2005) reported similar results for changes in OM along adjacent Mediterranean forest, grassland, and cropland ecosystems in Turkey. Sparling et al. (1992), Haynes (1999), and Shepherd et al. (2001) explained in detail that cultivation detached soil aggregates and exposed previously inaccessible organic matter to microbial attack and accelerated the decomposition and mineralization of OM. As previously explained, USLE-K was directly affected by OM and indirectly by the effect of OM on the soil structure and soil permeability classes (Eq. (6)). The results showed that although the topography of the cropland (USLE-LS) was relatively unlikely for higher erosion rates, the degraded soil properties ($0.139 \leq$ USLE-K ≤ 0.240) along with less protective vegetative cover (USLE-C = 0.38) caused the irreversible soil losses in the cropland. Additionally, the

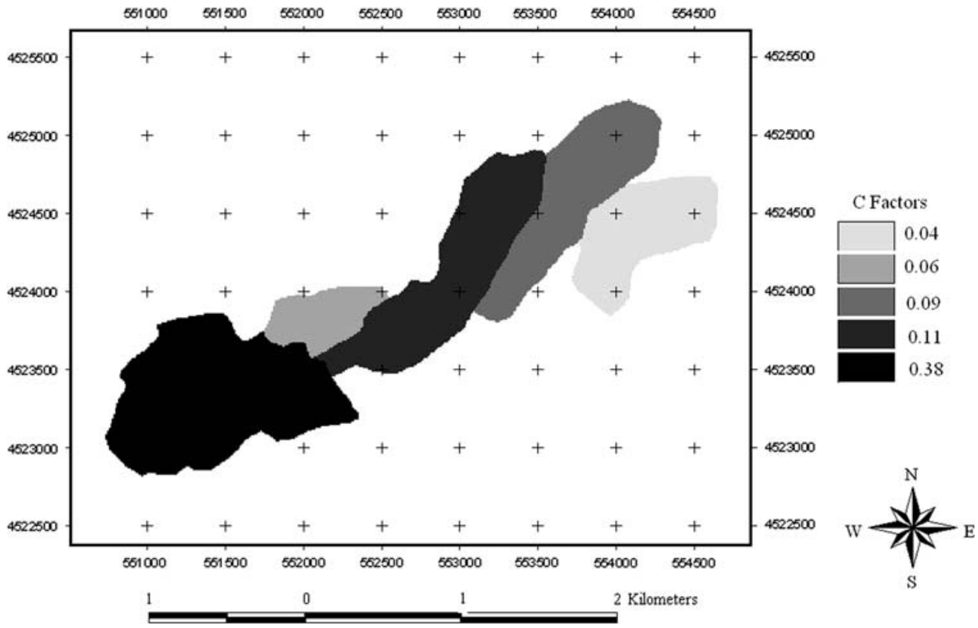

Fig. 6 C factor layer

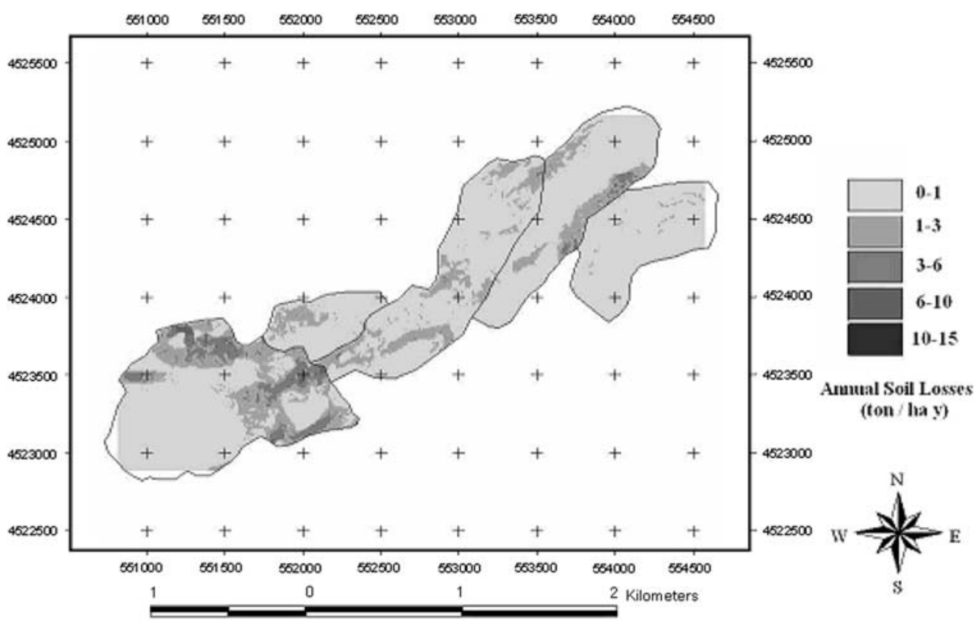

Fig. 7 Map of annual soil loss according to USLE

Table 4 Annual soil loss predicted in the land uses of the Indağı region (t ha^{-1} year^{-1})

Soil loss (t ha^{-1} year^{-1})	Cropland (%)	Grassland (%)	Plantation (%)	Forest (%)	Recreation (%)	Total
0–1	16.8	11.8	12.4	11.3	3.7	56.0
1–3	10.2	11.6	5.6	4.1	3.4	34.9
3–6	5.4	0.4	1.3	–	–	7.1
6–10	1.9	–	–	–	0.1	2.0
Total	34.3	23.8	19.3	15.4	7.2	100.00

poor management of the grassland by overgrazing in the ecosystem degraded both soil properties and quality of the grass, resulting in higher risk of the potential soil loss (0.119 ≤ USLE-K ≤ 0.159 and USLE-C = 0.11).

The plantation, forest, and recreational land had less irreversible soil losses than the cropland and grassland; the coverages of these were 6.9, 4.1, and 3.5%, respectively. With reasonable measures of conserving soil from the water erosion, these lands could be easily and successfully contained for the ecosystem sustainability.

Finally, the application of the USLE/GIS/Geostatistics methodology to the ecosystem of Indagi Mountain Pass helped to locate the erosion-prone areas where the concentrated flow created the irreversible soil losses, using the data on climate, soil, topography, and land use. Particularly, rather than the topographical properties of the ecosystem, landuse/land-cover type and its effects on soils had a greater influence on the magnitude of soil losses since USLE-R factor did not change significantly in the study area.

Conclusion

The USLE/GIS/Geostatistics technology was used to predict potential soil erosion in the semiarid Indağı Region, Çankırı located in the Central Anatolia, Turkey. Of model parameters, USLE-R was computed from the erosivity map of Turkey. Additionally, in view of the effect of elevation on actual amount of precipitation, USLE-R values were site-specifically corrected using the DEM and the climatic data. Spatial correlation and spatial patterns of USLE-K determined by nomograph (Wischmeier et al. 1971) using five soil and soil-profile parameters were evaluated by the geostatistics and Arcview 3.2. The topographical and hydrological effects on the soil loss were characterized by USLE-LS factor evaluated by the flow accumulation tool using DEM and watershed delineation techniques of Arcview 3.2. By assuming no support practice in the study area ($P = 1$), the annual soil losses (A, ton ha^{-1} $year^{-1}$) with respect to the different land-use/land-cover types of the region were estimated as a product of R, K, LS, and C layers. With the use of the USLE/GIS/Geostatistics methodology, the spatial distribution of different erosion prone areas were identified in the Indağı Region, Çankırı in order to successfully and timely take erosion control measures in the severely affected areas. In terms of the land uses, especially the cropland and grassland were found to be more susceptible to the soil losses by water erosion than forest, plantation, and recreational land. This was ascribed to the degraded soil chemical and physical properties resulted from the land use change in the cropland and poor management by overgrazing in the grassland. Accordingly, in this fragile semi-arid ecosystem, rather than the topographical properties of the ecosystem, landuse/land-cover type and its effects on soils had a greater influence on the magnitude of soil losses since the climate changed only with the elevation slightly.

However, there is a need to have direct field measurements of soil erosion in the watershed to confirm and validate the results of USLE prediction. Therefore, future works are required for monitoring of sediment load in rivers and measurement of sediment deposition in lakes and reservoirs that exist in the watershed.

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