academicJournals

Vol. 8(10), pp. 388-397, 11 March, 2013
DOI 10.5897/SRE11.792
ISSN 1992-2248 © 2013 Academic Journals
http://www.academicjournals.org/SRE

Scientific Research and Essays

Full Length Research Paper

Assessment of soil erosion in the Ihsaniye watershed area, Afyonkarahisar, Turkey

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Accepted 7 June, 2012

This article discusses research in which the authors apply the Universal Soil Loss Equation (USLE), Geographical Information Systems (GIS) and Remote Sensing (RS) to the mapping of the soil erosion risk in the Ihsaniye watershed, Afyonkarahisar, Turkey. The rainfall-runoff erosivity (R) factor was developed from annual precipitation data and from previous studies. Soil maps and soil survey data were used to develop the soil erodibility factor (K), and a digital elevation model was used to generate the topographic factor (LS). The cover-management factor (C) was obtained from Landsat TM image. A soil erosion risk map with five classes was produced. Almost half of the watershed area falls within the low (63%) and slight erosion categories (8%), and is mostly seen in the southern section. The low and slight erosion risk areas are situated in flat plain and low slope areas. Only 18% of the watershed suffers from high and severe erosion risks in the north-east and the south-west. The results can be used to advise local government with regard to prioritizing the areas requiring immediate erosion mitigation. This research implies that GIS and RS provide promising tools for evaluating and mapping soil erosion risk in the study area.

Key words: Ihsaniye, Afyonkarahisar, universal soil loss equation (USLE), geographical information systems (GIS), soil erosion risk.

INTRODUCTION

Soil erosion is one of the most serious environmental problems in the world today, as it seriously threatens agriculture, natural resources and the environment (Onyando et al., 2005). Soil erosion is a natural process, occurring over geological time, and most concerns about erosion are related to accelerated erosion, where the natural rate has been significantly increased by human activity (Gobin et al., 2004). Accelerated soil erosion is a serious concern worldwide, and it is difficult to assess its economic and environmental impact accurately because of its extent, magnitude, rate and the complex processes associated with it (Lal, 1994). Many human-induced activities such as mining, construction and agricultural activity disturb land surfaces, resulting in accelerated erosion. Soil erosion from cultivated areas is typically higher than that from uncultivated areas (Brown, 1984). The United Nations Environmental Program reported that crop productivity is reduced and becomes uneconomic on about 20 million ha/year due to soil erosion and degradation (United Nation Environmental Program, 1991).

Scientists have been involved in soil erosion research for a long time and consequently many models for soil erosion loss estimation have been developed (Lal, 2001). These models are categorized as empirical, semi-empirical and physical process-based models. Several physical process-based models have been developed in order to quantify erosion in basins, such as the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1965), the Revised Universal Soil Loss Equation

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(RUSLE) (Renard et al., 1997), the Water Erosion Prediction Project (WEPP), (Flanagan and Nearing, 1995; Flanagan et al., 2007), the Limburg Soil Erosion Model (LISEM) (De Roo et al., 1996), and the Soil and Water Assessment Tool (SWAT) (Arnold et al., 1998; Gassman et al., 2007).

Among these models, the USLE has remained the most practical method of estimating soil erosion in the field and for estimating the effects of different control management practices on soil erosion for nearly 40 years (Dennis and Rorke, 1999; Kinnell, 2000), while other process-based erosion models have intensive data and computational requirements (Lim et al., 2005). An environmental characterization of the physical (climate, pedology, topography) and human factors (agricultural and conservation practices) governing water erosion on the watershed unit scale was made based on the USLE (Vezina et al., 2006). Created in the United States, the USLE is an erosion model designed to compute long-term average annual soil loss on a field scale (A) as the product of six major factors: rainfall erosivity (R), soil erodibility (K), slope length (L), steepness (S), cover and management practices (C) and conservation practices (P) (Wischmeier and Smith, 1978).

Erosion prediction models can help address long-range land management planning under natural and agricultural conditions. Even though it is hard to find a model that considers all forms of erosion, some models have been developed specifically to aid conservation planners in identifying areas where introducing soil conservation measures would have the most impact on reducing soil loss (Angima et al., 2003; Rahman et al., 2009).

Spatial technologies such as Geographic Information Systems (GIS), Remote Sensing (RS) and numerical modelling techniques, have been developed as powerful tools for ecological and environmental assessment (Krivtsov, 2004; Rahman and Saha, 2009; Erdogan, 2009, 2010). Combining these technologies not only supplies a platform to support multi-level and hierarchical resource and environmental analysis, but also integrates the information in a comparative theoretical framework (Li et al., 2006; Rahman et al., 2009). The use of GIS and RS techniques makes soil erosion estimation and its spatial distribution feasible at a reasonable cost and with improved accuracy in larger areas (Millward and Mersey, 1999; Wang et al., 2003).

In the last four decades, the integration of USLE with GIS has been used by many researchers. A GIS is a powerful set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world (Burrough, 1986). GIS has had a tremendous impact in many applied fields, because it allows the manipulation and analysis of individual "layers" of spatial data, and it provides tools for analyzing and modeling the interrelationships between such layers (Bonham-Carter, 1996).

Presently, USLE/RUSLE application with GIS and RS techniques have received special attention from researchers in many parts of the world (Millward and Mersey, 1999; Jain et al., 2001; Fıstıkoğlu and Harmancıoğlu, 2002; Doğan, 2002; Lee, 2004; Onyando et al., 2005; Onori et al., 2006; Li et al., 2006; Erdoğan et al., 2007; Bayramin et al., 2008; İrvem et al., 2007; Pandey et al., 2007; Dabral et al., 2008; Özcan et al., 2008; Yue-Qing et al., 2008; Bahadur, 2008; Beskow et al., 2009).

Turkey has a number of socio-economic and environmental problems resulting from soil erosion. Due to irregularities in rainfall and undulating topography characteristics, most parts of Turkey are vulnerable to soil erosion. This is primarily because 60% of Turkey's land has a slope greater than 12%. TEMA (The Turkish Foundation for Combating Soil Erosion, for Reforestation, and the Protection of Natural Habitats) estimates that 90% of the country is affected by soil erosion, equal to an area of 11 million hectares of agricultural land. This widespread problem threatens the sustainability of agricultural production in the Ihsaniye watershed, where diverse and economically important crops are produced.

The goal of this study was to utilize the USLE with GIS environment, and to investigate the spatial distribution of annual soil loss potential in terms of the Ihsaniye watershed, which is a typical rural watershed in the Afyonkarahisar Province. The results of the study provide useful information for local government in terms of prioritizing the mitigation of erosion areas in the Ihsaniye watershed.

Study area

The Ihsaniye watershed is located in the Afyonkarahisar Province of mid-western Turkey. The elevation varies from 1000 to 1685 m above mean sea level, and 76% of the total area falls within 1000 to 1200 m altitude which increases from west to east (Figure 1). About 65% of the total area falls within the category of moderate to moderately steep slope (0 to 6°).The geographical area of the watershed is approximately 818.6 km^2. The watershed area is between 38°46´30´´ and 39°30´30´´ north latitudes and 30°25´30´´ and 30°35´00´´ east longitudes.

The annual average temperature is 10.7°C, with an average summer high of 21.5°C in July, and an average winter low of 0.2°C in January. The annual precipitation averages 402.1 mm, of which 62% occurs between December and May, inclusive. The overall climate of the area can be classified as continental. The topography of the watershed is characterized by undulating, high and low hill slopes, lowland and plain areas. The drainage pattern of the area is dendritic.

Land use in this area includes pasture, cultivated land, fallow land, evergreen forest, barren land, residential and built-up land, etc. The dominant crop in the study area is

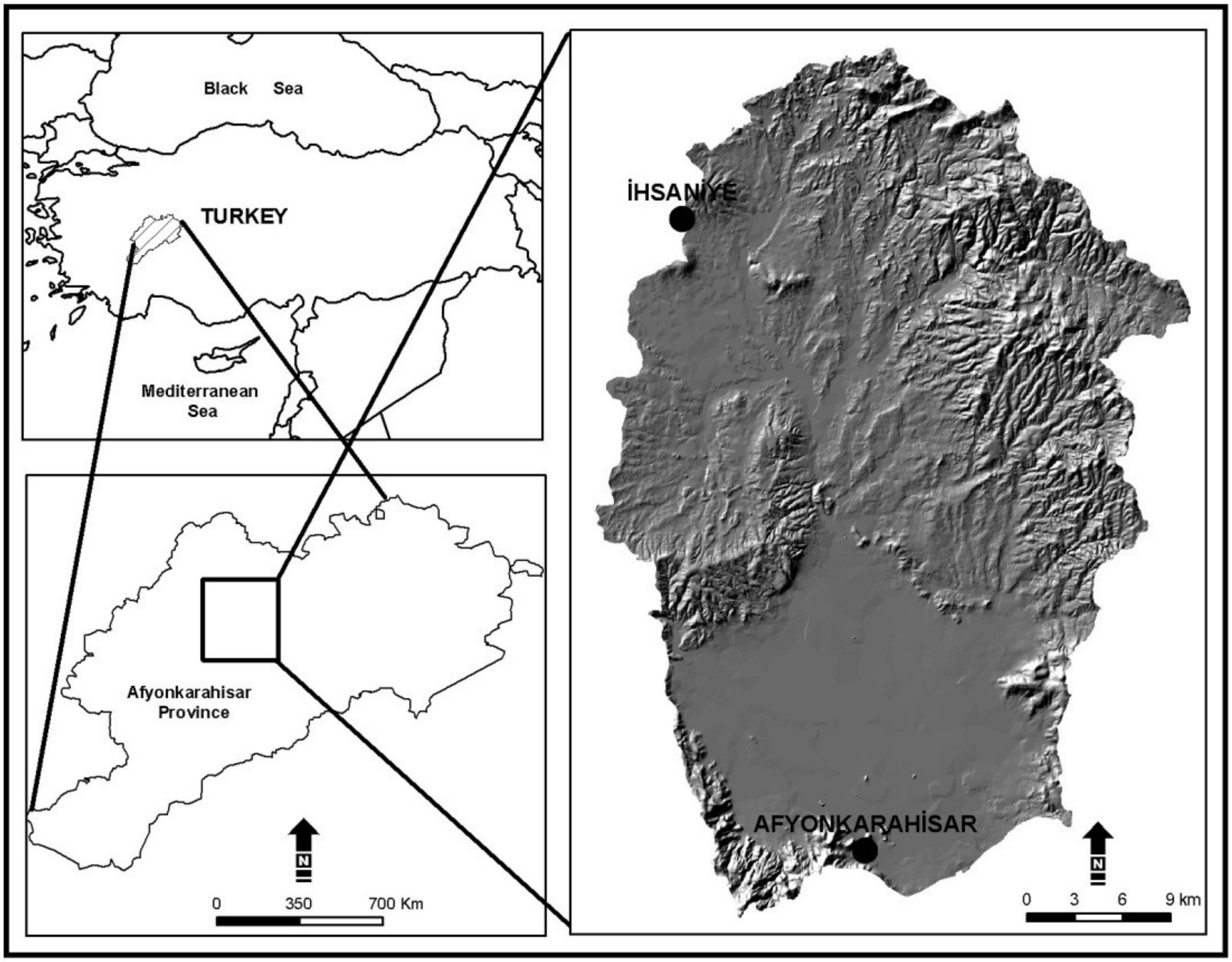

Figure 1. Location of the study area.

wheat. The soil is mainly of a sandy loam type, and the soil depth ranges from 0 to 45 cm. The geology is dominated by sedimentary, igneous and metamorphic rocks, ranging from tuff and agglomerate to andesite and trachyte to recent alluvial deposits. Tuff and alluvial is found in large areas. Tuff is found in northern-side of the study and makes up 36% of the total study area. Alluvium is found in the southern-side of the study area and makes up 29% of the total study area. Schist is found in the eastern-side of the study area and makes up 19% of the total study area. The problem of erosion is prevalent in the study area due to the hilly topography and inappropriate agricultural management practices.

MATERIALS AND METHODS

It is essential to prepare and analyze the different types of data with regard to soil erosion prediction and hazard assessment as there are many factors that affect soil erosion. Different sources and types of data were used in this study. The basic data used in this study included: (i) a Digital Elevation Model (DEM), generated from a 10-m interval contour map of the Ihsaniye watershed; (ii) soil attribute data collected from field studies and the results of laboratory analysis; (iii) satellite image, Landsat Thematic Mapper (TM) taken in May 2007 (path 178 and row 33); (iv) monthly rainfall data from the Afyonkarahisar meteorological station (v) soil and geology maps of the study area which were digitized in order to convert them to a digital format and (vi) field studies and results of other relevant studies. The data preparation and methodology of the layers are shown in Table 1.

For further analysis, all data/layers were projected using the Universal Transverse Mercator (UTM) projection system, at 30 m pixel size. Finally, a grid cell of rainfall, soil, combined slope length and steepness, land use and practice management was prepared.

These layers were overlaid and the soil loss rate was calculated as per the USLE equation. These were further grouped into five main groups to show the severity of the erosion in relation to the spatial distribution.

In the application of USLE on a GIS environment, soil loss was estimated within raster/grid GIS. Raster models are cell-based

Table 1. Data preparation steps for factor maps using USLE methodology.

Factor maps for USLE	Data preparation
Rainfall erosivity (R) factor	Calculated from Kaya (2008) and converted to surface of the study area by Toy and Foster (1998) formula with GIS.
Soil erodibility (K) factor	Collected soil samples from field studies and results of laboratory analysis and Torri et al. (1997, 1998, 2002) formula were used to convert K value by means of kriging interpolation with GIS.
Slope length and steepness (LS) factor	Calculated from the DEM, slope, elevation, flow direction and flow accumulation. Combined from Moore and Burch (1986a, b) formula with GIS.
Cover and management (C factor)	Classify from Landsat TM on May 2007 image with supervised method by ERDAS imagine processing software.
Conservation support -practice (P) factor	Obtained from field survey and relevant studies with GIS.

representations of map features, which offer analytical capabilities for continuous data, and allow the fast processing of map layer overlay operations (ESRI, 1996; Fernandez et al., 2003). The spatial resolution of the data set was 30 m, consistent with the Landsat Thematic image.

USLE was used to evaluate the possibility of water erosion on the Ihsaniye watershed. This model was described by Wischmeier and Smith (1978) and can be expressed by the following equation:

$$A = R \times K \times LS \times C \times P \qquad (1)$$

where A is the average annual soil loss per unit of area (t ha^{-1} yr^{-1}), R is the rainfall–runoff erosivity factor (MJ mm ha^{-1} h^{-1} yr^{-1}), K is the soil erodibility factor (t h MJ^{-1} mm^{-1}), LS is the topographic factor (dimensionless) which includes slope length factor (dimensionless) and slope steepness factor (dimensionless), C is the cover management factor (dimensionless), and P is the support practice factor (dimensionless).The following will describe how data was collected for the mapping of the parameters in Equation 1.

Rainfall erosivity factor (R)

The R factor reflects the effect of the erosivity of the climate at a particular location. The R factor is the principal function with regard to the USLE, which is mainly responsible for soil loss. The numerical values used for the rainfall erosivity factor, quantifies the effect of raindrop impact, and also reflects the amount and rate of runoff likely to be associated with the rain (Renard et al., 1997). Within the USLE, rainfall erosivity is estimated using an EI30 measurement (Wischmeier and Smith, 1978).

For this study, the rainfall and runoff factor (R) was previously determined on a county basis in Turkey (Kaya, 2008). The R factor was calculated for Afyonkarahisar by Kaya (2008) and was used for the study area. This R factor value is point data, and requires converting to the surface of the study area related to elevation. Toy and Foster (1998) was used to apply to the DEM of the study region to spatially create the R surface:

$$R_{new} = R_{base}\left(\frac{P_{new}}{P_{base}}\right)^{1.75} \qquad (2)$$

where R_{new} is the new value for R at the desired new location, R_{base} is the R_{base} at the base location, P_{new} is the average annual precipitation at the new location, and P_{base} is the annual precipitation at the base location. The final R factor map is presented in Figure 2.

Soil erodibility factor (K)

The K factor in the USLE reflects the effect the average long-term soil and soil-profile response to the erosive power associated with rainfall and runoff. The main soil properties affecting K are soil texture, organic matter and structure and permeability of the soil profile. The physical, chemical and mineralogical soil properties and their interactions that affect the value of the K factor are many and varied. Several erosion mechanisms operate at the same time, each one relating differently to a specific soil property (Wischmeier and Smith, 1978; Onori et al., 2006).

For this study, in order to calculate the K factor, geological, topographic, soil and land use map layers were overlaid to choose suitable soil sample location in order to collect soil samples. Based on this, 35 soil samples were collected in the study area in April and November 2007. Samples were 30 to 50 cm deep and were taken from at least one geological, topographical and land use type. The geographical locations of the soils sampled were recorded by means of a global positioning system (GPS). The analysis of these soil samples was done at Eskişehir Anatolian Agricultural Research Institute (Toprak ve Su Kaynakları Eskişehir Araştırma Enstitüsü). The results were converted to K values by the use of the following formula (Torri et al., 1997, 1998, 2002).

$$K = 0.0293\left(0.65 - D_G + 0.24D_G^2\right) \times \exp\left\{-0.0021\frac{OM}{f_{clay}} - 0.00037\left(\frac{OM}{f_{clay}}\right)^2 - 4.02C + 1.72f_{clay}^{\ 2}\right\} \qquad (3)$$

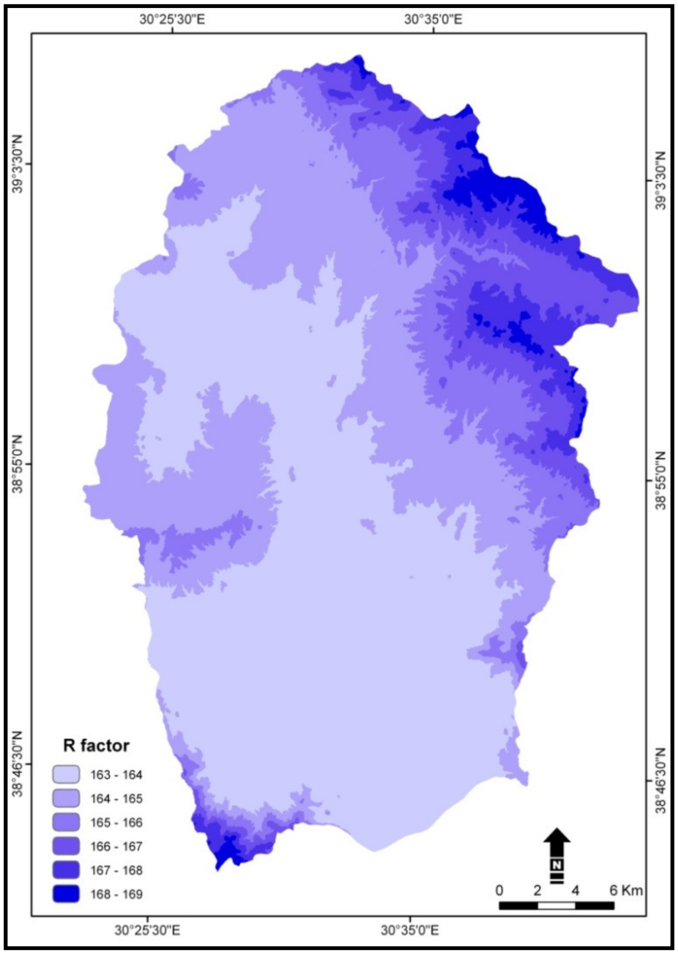

Figure 2. Spatial distribution of R factor in the Ihsaniye watershed.

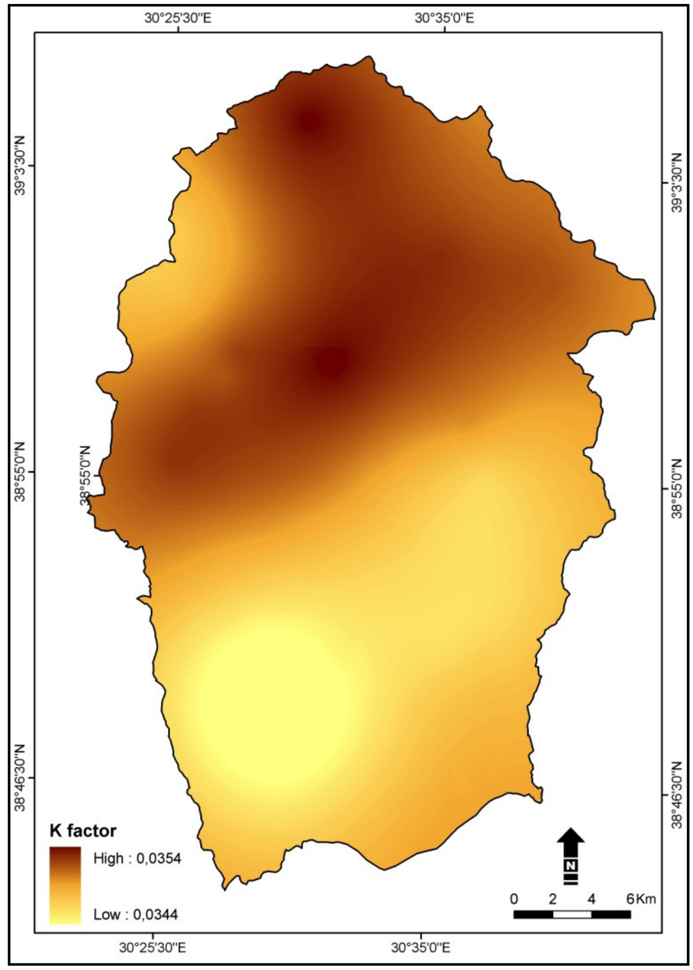

Figure 3. Spatial distribution of K factor in the Ihsaniye watershed.

where DG is defined as

$$D_G = -3.5 f_{sand} - 2.0 f_{sil} t - 0.5 f_{clay} \quad (4)$$

where K is in ton ha h ha^{-1} MJ^{-1} mm^{-1}, OM is percentage of organic matter, f_{sand} is the fraction of sand (particle size of 0.05 to 2.0 mm), f_{silt} is the fraction of silt (particle size of 0.002 to 0.05 mm) and f_{clay} is the fraction of clay(particle size of 0.00 005 to 0.002 mm). Then, each 25 m cell of the grid surface of the study area was assigned a K value by means of a Kriging interpolation. Figure 3 illustrates the K factor spatial distribution.

Slope length and steepness factor (LS)

The L and S factors in the USLE reflect the effect of topography on erosion. Erosion is proportional to slope length (L) and steepness (S). Erosion increases as slope increases. Slope length is defined as the horizontal distance from the origin of the overland flow to the point where either the slope gradient decreases to a point where deposition begins, or runoff becomes focused into a defined channel (Foster and Wischmeier, 1974; Wischmeier and Smith, 1978).

For this study, the LS factor was computed from the DEM using an ArcGIS Spatial Analyst extension. A 10 m DEM of the study area was prepared by 10 m interval digitized contours from a 1:25.000 scale topographic map. LS require a flow accumulation and the slope's steepness. Flow accumulation and slope were derived from the DEM in the raster grid. The flow accumulation gives an area that is calculated from all cells that flow into each down slope cell. The flow accumulation was computed from the DEM using watershed delineation methods. The slope steepness was computed using the DEM in degrees. Moore and Burch (1986a, 1986b) were used for the combined LS factor. The combined LS factor for the watershed was calculated, and its spatial distributions in the different spatial gradients of watershed were presented (Figure 4):

$$LS = \left(FlowAccumulation * \frac{CellSize}{22.13} \right)^{0.4} * \left(\frac{\sin slope}{0.0896} \right)^{1.3} \quad (5)$$

where the flow accumulation denotes the accumulated upslope contribution for a given cell, LS is the combined slope length and slope steepness factor, the cell size is the size of the grid cell (for this study 30 m) and the sine slope is a slope whose degree values are in sine. Figure 4 shows the spatial distribution of the LS factor in the study area.

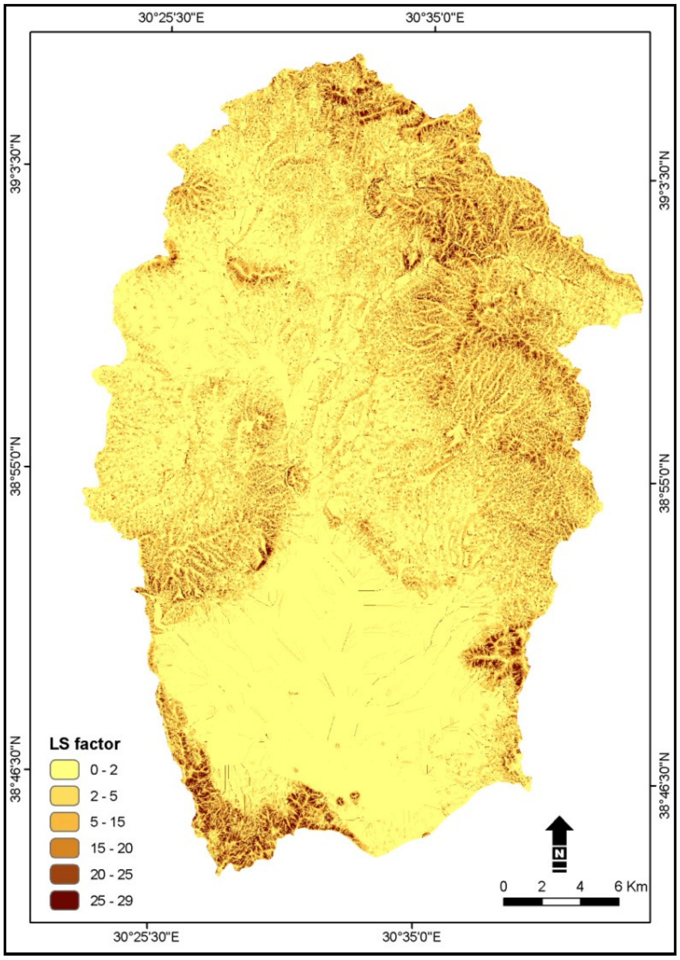

Figure 4. Spatial distribution of LS factor in the Ihsaniye watershed.

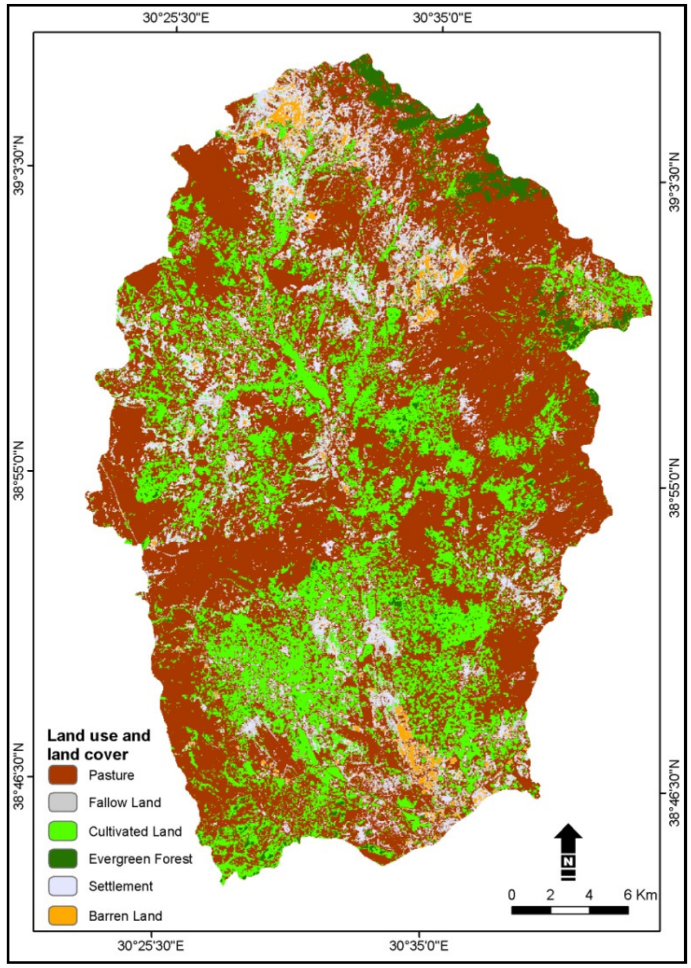

Figure 5. Spatial distribution of land use and land cover in the Ihsaniye watershed.

Cover and management factor (C)

The C factor reflects the effect of cropping and management practices on the erosion rate. The C factor has a close linkage to land use types and is a reduction factor with regard to soil erosion vulnerability. This factor represents the ratio of soil loss from an area with a given cover and type of management, to that from an identical area in tilled continuous fallow on the same soil and slope. This is an important factor in the USLE, since it represents the conditions that can be easily changed to reduce erosion (Wischmeier and Smith, 1978; Beskow et al., 2009).

For this study, the C factor with regard to the study area was obtained from a satellite image. The study area was covered by Landsat TM (path 178 and row 33) on May 2007. The area of interest was first cut from the entire Landsat TM scene, and was then geo-coded by means of the ERDAS imagine processing software (ERDAS, 1998). Supervised classification using the Maximum Likelihood Classifier (MLC) algorithm was used for the digital classification of the satellite data. For the development of this layer, training samples were selected for six land cover categories (Figure 5): pasture, fallow land, cultivated land, evergreen forest, settlement and barren land. The land use classes were allocated C values without consideration of seasonal variance. The C-factor map was developed based on values published in several studies carried out in different areas of Turkey with the same land use as in this study (Fıstıkoğlu and Harmancıoğlu, 2002; Erdoğan et al., 2007; İrvem et al., 2007; Bayramin et al., 2008; Özcan et al., 2008). The land use and cover map is presented in Figure 5.

Conservation support-practice factor (P)

The P factor reflects the effect of contouring and tillage practices on soil erosion. Wischmeier and Smith (1978) define the support factor (P) as the ratio of soil loss with a specific support practice, to the corresponding soil loss with up and down cultivation such as contouring, strip cropping, concave slopes, terraces, sediment basins, grass hedges, silt fences, straw bales and subsurface drainage. The lower the P value, the more effective the conservation practice is deemed to be at reducing soil erosion. If there are no support practices, the P factor is 1.0.

For this study, the values for the P factor were assigned to be 1.0 for the entire area, since there were no erosion control practices in the studied area according to field survey and relevant information.

RESULTS

The average annual soil loss in the Ihsaniye watershed was computed by overlaying the five factor maps

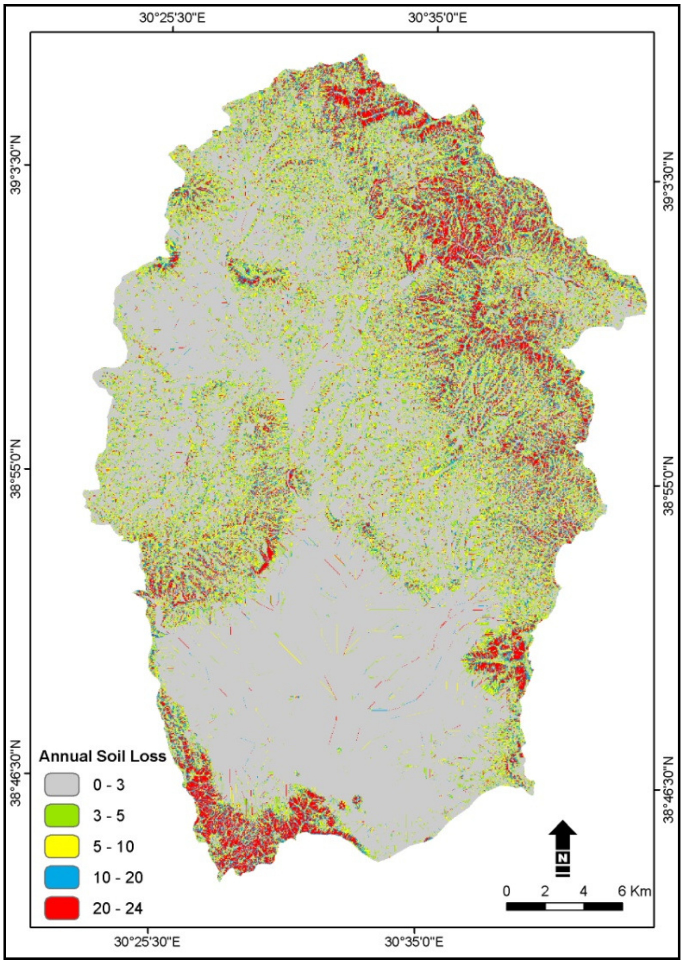

Figure 6. Spatial distribution of soil loss in the Ihsaniye watershed.

(Rainfall erosivity (R), soil erodibility (K), slope length and steepness (LS), cover and management (C), conservation support-practice (P)) using the USLE with ArcGIS Spatial Analyst extension. As seen in Figure 6 and Tables 2 and 3, the average annual soil loss values vary from 0 to 24 ton ha^{-1} yr^{-1}, the mean value is 16 ton ha^{-1} yr^{-1}. About 63% of the watershed area is found out to be within the low erosion class. Areas covered by slight, moderate, high and severe erosion potential zones are 8, 11, 9 and 9% respectively (Table 2).

The quantitative value of prediction soil loss was divided into five ordinal categories as shown in Table 2. Almost half of the study area falls within the low (63%) and slight erosion categories (8%), which is mostly seen in the southern section of the watershed. The low and slight erosion risk areas are situated in flat plain and low slope areas, where the soil erosion by water is not an active feature. However, the remaining areas are located in a basin with high and extreme erosion risk, where the hilly topography, high slopes and inappropriate cultivation practices result in accelerated soil erosion. About 18% of the watershed suffers from high and severe erosion risk. These areas are mostly found in the north-eastern section and south-western corner of the watershed. So management practices should be adopted in the areas of high to extreme erosion risk, in order to reduce soil loss. The rainfall erosivity factor value varies from 163 to 169 MJ mm ha^{-1} h^{-1} yr^{-1} and the mean value is 165 MJ mm ha^{-1} h^{-1} yr^{-1} (Figure 2, Table 4). There is more rainfall erosivity in the south-eastern section and north-western corner of the study area than elsewhere in the study area. There is a close relationship with the decreasing trend of rainfall with elevation. It is found that there is a close relationship between the rainfall characteristics and soil loss. An increase in rainfall intensity and amount is generally accompanied by an increase in soil loss.

The soil erodibility factor value varies from 0.0344 to 0.0354 t ha h ha^{-1} MJ^{-1} mm^{-1}, and the mean value is 0.0349 t ha h ha^{-1} MJ^{-1} mm^{-1} (Figure 3, Table 3). In fact, lower values are found in association with alluvial soils with medium texture in the southern section of the study area, whilst higher values are mainly associated with fine-medium textured soils in the northern section of the study area. From the soil erodibility map derived using a kriging interpolation method, it is clear that higher K values are found in the northern section of the watershed, while lower K values are present in the southern section of the study area. The resulting K values can be easily compared with what is known from Doğan et al. (2000).

Figure 4 reveals the map of the LS generated by the DEM of the watershed and the LS values given in Table 5. The Ihsaniye watershed LS values range between 0 to 2 and 20 to 29. Coverage areas were 62, 14, 15, 3, 2 and 4%, respectively, for the ranges of LS values 0 - 2, 2 - 5, 5 - 15, 15 - 20, 20 - 25 and 25 - 29. A total of 76% of the area has a lower 5 LS value in flat plains and low slope areas, where the soil erosion due to water is not an active feature. However, the north-eastern section and south-western corner of the watershed shows the highest variability in terms of elevation, with the steepest and longest slopes and, as a consequence, the greatest LS values. In terms of soil erosion, it is important to determine whether the same area having a greater LS value, coincides with areas of higher erodibility and lower land cover, in order to identify the greatest risk area where conservation efforts need to be intensified.

Figure 5 shows the map of the C factor generated by the reclassification of each land use cover type using a satellite image. The watershed was composed of six land use types: pasture (58%), cultivated land (24%), fallow land (5%), evergreen forest (2%), settlement (9%) and barren land (2%). Most areas of the watershed take the form of pasture (58%) which is seen in the high elevation values of the watershed. Fallow land and cultivated land (29%) are found in the flat plain and low slope parts of the study area. Evergreen forest (2%) is found in the north-eastern corner of the study area. The other types are found elsewhere in the study area. Table 6 shows

Table 2. Rate and area of loss of each soil risk category.

Erosion risk classes	Rate of erosion (ton/ha^{-1}/yr^{-1})	Ha	%
Low	0 - 3	52490	63
Slight	3 - 5	6553	8
Moderate	5 - 10	8648	11
High	10 - 20	7062	9
Severe	20 - 24	7107	9

Table 3. Values of R, K, LS and C factors.

Estimation	R factor	K factor	LS factor	C factor
Minimum	163	0.0344	0	0.001
Maximum	169	0.0354	29	1.000
Mean	165	0.0349	16.44	0.312
SD	1.33	0.0008	14.32	0.362

Table 4. Categories of R values for the study area.

R interval	Area (ha)	%
163 - 164	38501	47
164 - 165	23075	28
165 - 166	7898	10
166 - 167	6465	8
167 - 168	4391	5
168 - 169	1530	2

Table 5. Categories of the LS values for the study area.

LS interval	Area (ha)	%
0 - 2	50598	62
2 - 5	11838	14
5 - 15	12228	15
15 - 20	2225	3
20 - 25	1374	2
25 - 29	3597	4

Table 6. Land use and land cover categories and adjusted C values for the study area.

Land cover and land use	Area (ha)	%	C factor value
Pasture	47072	58	0.09
Cultivated land	19752	24	0.28
Fallow land	4195	5	0.50
Evergreen forest	2036	2	0.008
Settlement	7520	9	1.0
Barren land	1285	2	1.0

land use and land cover statistics and adjusted C factors. The C factor value varies from 0 to 1 and the mean is 0.312 (Table 6).

DISCUSSION

The average annual soil loss in the Ihsaniye watershed area was computed by overlaying the five factor maps using the USLE with a Spatial Analyst extension. As seen in Figure 6, the average annual soil loss values vary from 0 to 24 ton ha^{-1} yr^{-1}, with a mean value of 16 ton ha^{-1} yr^{-1}. These results are clearly compatible with other studies carried out in Turkey (Fıstıkoğlu and Harmancıoğlu, 2002; Erdoğan et al., 2007; İrvem et al., 2007; Bayramin et al., 2008; Özcan et al., 2008). It should be emphasized that the areas suffering from the greatest amount of erosion would need special priority for the implementation of soil erosion control measures.

The relationship between soil loss and sediment yield requires the assessment of the sediment delivery ratio (SDR). The SDR is defined as the fraction of gross erosion that is transported from a given catchment in a given time period. The SDR can be affected by a number of factors including sediment source, soil texture, proximity to the main stream, channel density, basin area, slope, length, land use/land cover and rainfall-runoff factors (Ferro and Minacapilli, 1995; Ferro et al., 1998). The SDR can be obtained from the total sediment yield divided by the total soil loss. It is estimated that the soil loss using the USLE model in the Değirmen sub-watershed amounted to 38 km^2 within the study area. In this sub-watershed, average soil loss was 8.9 t ha^{-1} yr^{-1}. Average sediment yield was reported as 1.22 t ha^{-1} yr^{-1} at station number 1107 (Akarcay-Afyonkarahisar). Sediment data used in this study were from the General Directorate of Electrical Power Resources Survey and Development Administration (EIE). The inverse relationship between the SDR and the basin area has been attributed to decreasing slope and channel gradients and increasing basin size (Walling, 1994).

Conclusions

This article discusses research in which the authors applied the USLE and GIS to the mapping of soil erosion risk in the Ihsaniye watershed, Afyonkarahisar, Turkey. The strategy adopted here is, firstly, to calculate five USLE factors using distributed GIS data [e.g. rainfall erosivity (R), soil erodibility (K), slope length and steepness (LS), cover and management (C) and conservation support-practice (P)] to adequately represent the surface characteristics and, secondly, to estimate spatial distribution of soil loss in the basin. A soil erosion risk map with five classes (low, slight, moderate, high and severe) was produced based on the simplified USLE within the GIS environment. The methods and results described in this study are valuable for understanding the relationship between soil erosion risk and environmental factors and are useful for managing and planning land use that will avoid soil erosion.

The conclusions of the present study are as follows:

1) The integration of USLE and GIS successfully applied for erosion prediction in this study. The USLE model and GIS techniques were effective in this study to assess soil loss and erosion risk.
2) About 18% of the watershed area, mostly found in the north-eastern section and the south-western corner of the watershed, is under high and severe erosion risk. The results can be used to advice the local government in prioritizing the areas of immediate erosion mitigation.
3) Almost half of the watershed falls within the low (63%) and slight erosion category (8%), which is mostly seen in the southern section of the study area. The low and slight erosion risk areas are situated in flat plain and low slope areas, where the soil erosion by water is not active.
4) These results from this study are closely compatible with other studies carried out in Turkey (Fıstıkoğlu and Harmancıoğlu, 2002; Erdoğan et al., 2007; İrvem et al., 2007; Bayramin et al., 2008; Özcan et al., 2008; Karaburun, 2009).
5) The rate of erosion in this study area related not only with the steep slopes with poor vegetation cover, but also high on barren lands. The predicted amount of soil loss and its spatial distribution can provide the basis for comprehensive management and sustainable land use with regard to the watershed under consideration.
6) There is more rainfall erosivity in the south-eastern section and north-western corner of the study area than elsewhere in the study area. There is a close relationship with the decreasing trend of rainfall with elevation. It is found that there is a close relationship between the rainfall characteristics and soil loss.
7) Finally it is suggested that not only USLE method and other soil erosion predictions methods should also be applied to estimate soil erosion risk in study area and elsewhere in Turkey.

ACKNOWLEDGEMENTS

This work has benefited from the financial support of Afyon Kocatepe University. Project No. 07.FENED.06. The authors would like to thank to Dr Günay Alpul of the Faculty of Agriculture, Ankara University for his stimulation and anonymous reviewers for their insightful and helpful suggestions.

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