Polish J. of Environ. Stud. Vol. 19, No. 5 (2010), 881-886

Review

Using the Geographical Information System and Remote Sensing Techniques for Soil Erosion Assessment

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Received: 5 January 2007
Accepted: 10 September 2009

Abstract

The objective of this study is to establish a geographical information system method for spatial assessment of soil erosion based on the universal soil loss equation (USLE), and to evaluate the utility of GIS with regard to soil erosion mapping. The study area, Goynuk, covers 1,437 square kilometers and is located in the southeastern part of Bolu, Turkey. In this study, USLE factors including rainfall erosivity (R-factor), soil erodibility (K-factor), slope and slope length (LS-factor), vegetative cover (C-factor), and conservation practice (P-factor) were studied and reviewed. Each factor, which consists of a set of logically related geographic features and attributes, was used as an input for analysis. A land use map of the study area was generated from (Landsat TM 2000) satellite imagery. A digital elevation model (DEM) interpolated from elevation contours was used to generate the slope and LS-factor. Spatial vegetative cover, extracted from Landsat TM imagery, was used to determine the spatial C-factor and P-factor, values of which are based on experimental results from the literature. USLE model calculation applied to the resultant polygonal layer gave values of soil loss in tons/ha/year. These are then ranked into three classes as low, moderate, and high. The study indicated that highly eroded areas are bare lands and steep conditions, whereas less eroded areas are low slope classes. As a conclusion the study confirms that the use of GIS and remotely sensed data can greatly enhance spatial modeling for soil erosion.

Keywords: soil erosion, universal soil loss equation, geographical information systems, remote sensing

Introduction

Soil erosion is one of the most serious environmental problems in the world today because it threatens agriculture as well as the natural environment. Soil erosion is a natural and land resource problem that occurs on a global scale and can lead to significant economic, environmental, and social impacts. Soil erosion involves the detachment of sediment and soil from the soil surface by raindrop impact, flowing water, and wind. Erosion by water is influenced by ecological processes and human social practices [1]. The human impacts on soil erosion can be interpreted from land use changes over long periods and large areas [2].

The prevention of soil erosion, which means reducing the rate of soil to approximately that which would occur under natural conditions, relies on selecting appropriate strategies for soil conservation. The factors which influence the rate of erosion are rainfall, runoff, soil, slope, and plant cover, and the presence or absence of conservation measures [3]. Erosion control requires a quantitative and qualitative evaluation of potential soil erosion considering these factors.

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Research on soil erosion and its effects on agricultural productivity started in the 1930s. During 1940 and 1956, research scientists began to develop a quantitative procedure for estimating soil loss in the "Corn Belt" of the United States [4].

Based on the assembled data in previous studies, Wischmeier, Smith, and others developed the universal soil loss equation (USLE). An Agriculture Handbook (No. 537) describing USLE was published in 1965 and revised in 1978 [5, 6].

Through widespread acceptance, USLE has become the major conservation planning tool used in the world. Although originally developed for agricultural purposes, its use has been extended to other land uses. As additional research, experiments, data, and resources became available, research scientists continued to improve USLE, which led to the development of the revised universal soil loss equation (RUSLE). RUSLE has the same formula as USLE, but with several improvements in determining factors. These include some new and revised isoerodent maps; a time-varying approach for soil erodibility factor; a sub factor approach for evaluating the cover-management factor; a new equation to reflect slope length and steepness; and new conservation-practice values [7]. A new Agriculture Handbook (No. 703) that describes RUSLE in great detail was published in 1997 by the U.S. Department of Agriculture [4].

Both USLE and RUSLE can be expressed as follows:

$$A=R\cdot K\cdot LS\cdot C\cdot P \text{ (tons/ha/year)}$$

...where:
A – soil loss
R – rainfall erosivity factor
K – soil erodibility factor
LS – slope and slope length factor or topographical factor
C – vegetative cover factor
P – conservation practice factor

Study Area

The study area of 1,437 square kilometers is located in the southwestern part of the Bolu district in northwestern Turkey (Fig. 1). The region receives an average annual rainfall of about 614 kg per square meter, and has an average annual temperature of about 10.8ºC. Its highest temperature is 36.5ºC, whereas it experiences a low of down to -17.6ºC. Elevations range from 400 m to 1,700 m, and the district is 720 m above sea level. The indicated study area contains agriculture, forestry, mining, and urban areas as significant land cover types.

The data obtained from the General Directorate of Rural Affairs in Turkey indicates that the major soil types of the

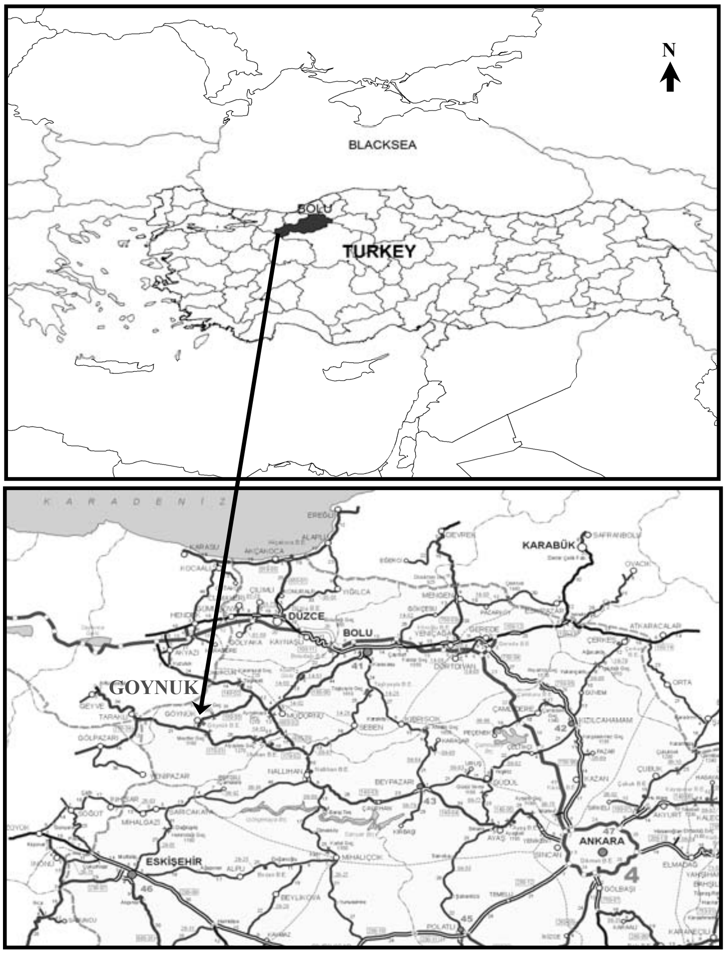

Fig. 1. Location map of the study area.

region are brown forest soils (93.2%), non-calcareous brown forest soils (2.8%), alluvial soils (2.1%), colluvial soils (1.7%), and rendzina soils (0.2%). The depth of the non-calcareous brown forest soil group ranges between 40-70 cm and natural plant cover generally consists of deciduous forest trees. The depth of the brown forest soil group ranges between 50-90 cm.

Data Source and Methodology

The overall methodology involved the use of RUSLE in a GIS environment, with factors obtained from soil surveys, topographic maps, satellite imagery and the results of the reviewed literature. Each GIS layer was developed for each factor and combined with a cell-by-cell basis in using the ArcGIS software. Calculations were done using capabilities available within the Spatial Analyst extension in ArcMAP module of the ArcGIS.

Data sources used in this study include the digital elevation model (DEM), soil data, land use/cover data, rainfall index map, table of crop and management factor (C-factor) in the Agriculture Handbook by the USDA, and the other literature cited.

A digital elevation model (DEM) interpolated from elevation contours was used to generate the slope and LS-factor. Digitized contours of the study area from the topographical maps (1:100,000 scale) published by the General Commander of Mapping were interpolated using a linear triangular irregular network. A slope map was then derived from this DEM, an important input for calculating slope steepness and slope length of different parts in the study area.

The land use/cover map of the study area was generated from (Landsat TM 2000) satellite imagery (Fig. 2). For detailed information on different land uses/land cover, satellite imagery of the study area for the year 2,000 was used. Initially, the satellite imagery was rectified.

Erdas Imagine software was used to extract land use/cover data using the supervised method of remotely sensed data. By this method, the data extracted from the imagery is compared with the real field data for the existing

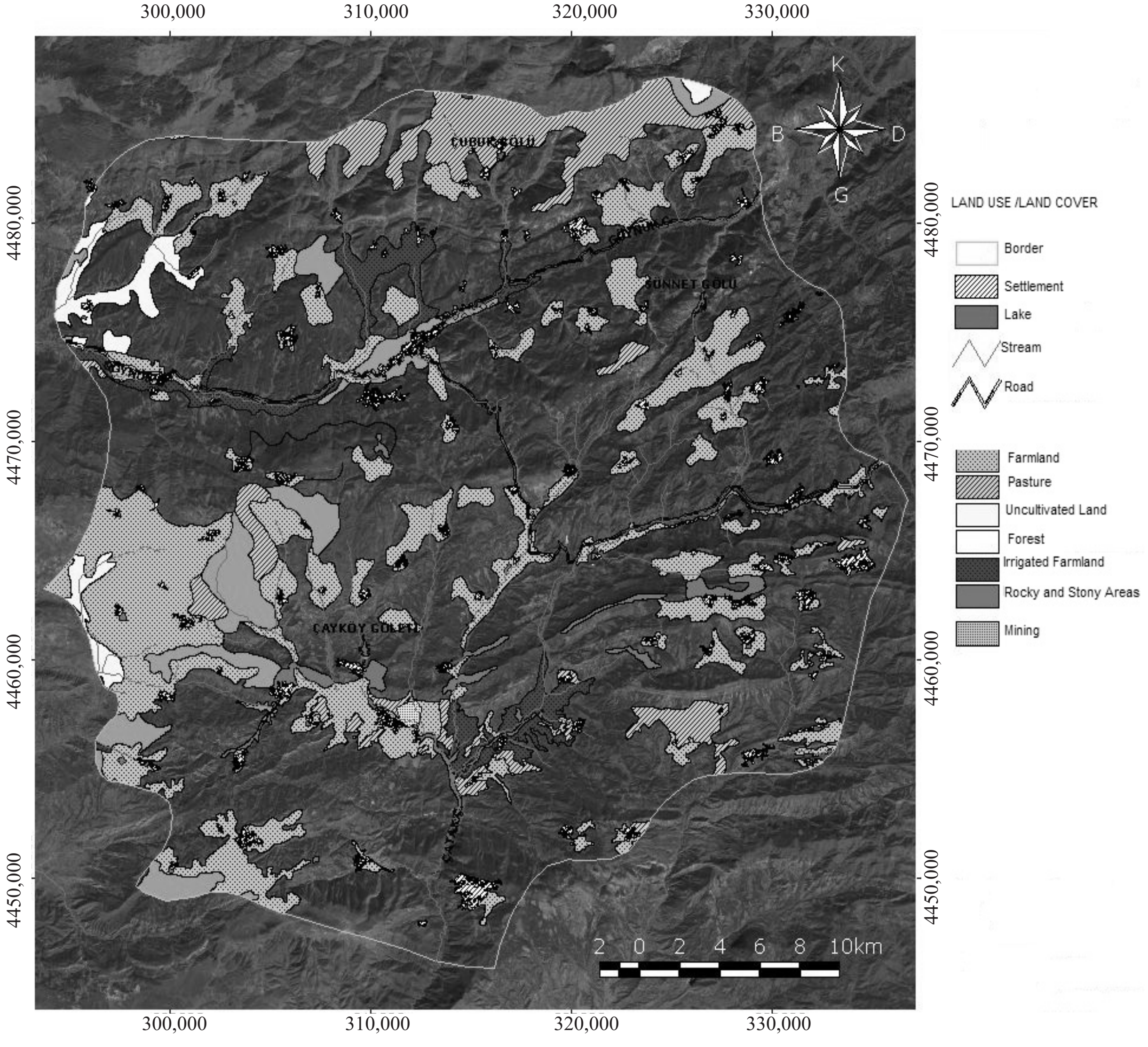

Fig. 2. Land use/Land cover on the Landsat TM 2000 satellite imagine map of the study area.

Table 1. Attribute values of the USLE factor layers.

R-factor	*K*-factor		*C*-factor		*P*-factor
50	Soil types	*K* value	Land cover	*C* value	1
	Alluvial	0.15	Orchard	0.30	
	Colluvial	0.18	Pastureland	0.05	
	Brown forest	0.10	Water body Settlement	0.00	
	Non-calcareous brown forest	0.29	Deciduous forest	0.004	
	Rendzina	0.12	Cropland	0.24	
			Mixed forest	0.007	

land use/land cover (supervised method). A 1:25,000-scaled land use/cover map was digitized, including primarily forest, deciduous forest, mixed forest, secondary forest, pastureland, orchard, cropland, settlement, and water body classes.

Supervised classification is more closely controlled by the specialist than unsupervised classification.

In this process, you select pixels that represent patterns you recognize or can identify with help from other sources. Knowledge of the data, the classes desired, and the algorithm to be used is required before you begin selecting training samples. By identifying patterns in the imagery you can “train” the computer system to identify pixels with similar characteristics. By setting priorities for these classes, you supervise the classification of pixels as they are assigned to a class value. If the classification is accurate, then each resulting class corresponds to a pattern that you originally identified. Unsupervised classification is more computer-automated. It allows you to specify parameters that the computer uses as guidelines to uncover statistical patterns in the data.

A field observation trip has been carried out in order to collect the ground control points by using topographical maps of the study area. By integrating supervised classification and visual interpretation techniques, a land use/cover data base was built from Landsat TM imagery [8].

Determining RUSLE Factor Values

R-factor value for the study area was determined to be 50 by Dogan 1999. Therefore the *R*-factor was assumed to be a constant and had a value of 50 for this study [9].

K-factor values were generated from soil maps (1:100,000 scale) and were assigned values according to major soil types as determined by the Soil Survey Department for USLE experiments. *K*-factor values were obtained from the lists of the major soil types after experimental research conducted by the General Directorate of Rural Affairs in Turkey (Table 1). *K*-factor values were obtained by adding the *K*-factor value as an attribute to the soil theme’s table.

LS-factor the slope length factor and slope degree factors are typically combined together and defined as the topographic factor that is a function of both slope and length of the land. The technique for estimating the RUSLE *LS*-factor used in this study was proposed by Moore and Burch [10]. They derived an equation for estimating *LS* based on flow accumulation and slope steepness [10]. The equation is:

$$LS = (FlowAccumulation \cdot CellSize/22.13)^{0.6} \\ (Sin(Slope0.01745)/0.09)^{1.3} \cdot 1.6$$

This equation used for computing *LS* requires flow accumulation data. Flow accumulation can be computed from either a DEM using the hydrologic extension or other watershed delineation technique, or an expression that can be developed in the raster calculator. Flow accumulation is used to estimate slope length [4].

The modified equation for computation of the *LS*-factor in ArcGIS at a point on a hillslope was derived by Mitasova et al. [11].

$$FlowAccumulation\ (FlowDirection[elevation]) \tag{1}$$

This equation was developed on the raster calculator from the spatial analyst toolbar in ArcGGIS 8.3 to provide flowaccumulation data [11]. Then Equation 2 was developed to provide *LS* factor data.

$$LS = \left(\frac{flowacc \times resolution}{22.1}\right)^{0.6} \cdot \\ \left(\frac{Sin(slope) \times 0.01745}{0.09}\right)^{1.3} \tag{2}$$

C-factor: spatial vegetative cover extracted from Landsat TM imagery was used to determine the spatial *C*-factor values that are based on experimental results from the literature.

P-factor: for all vegetation cover types no erosion control was found, therefore the *P*-factor was assigned the value 1.

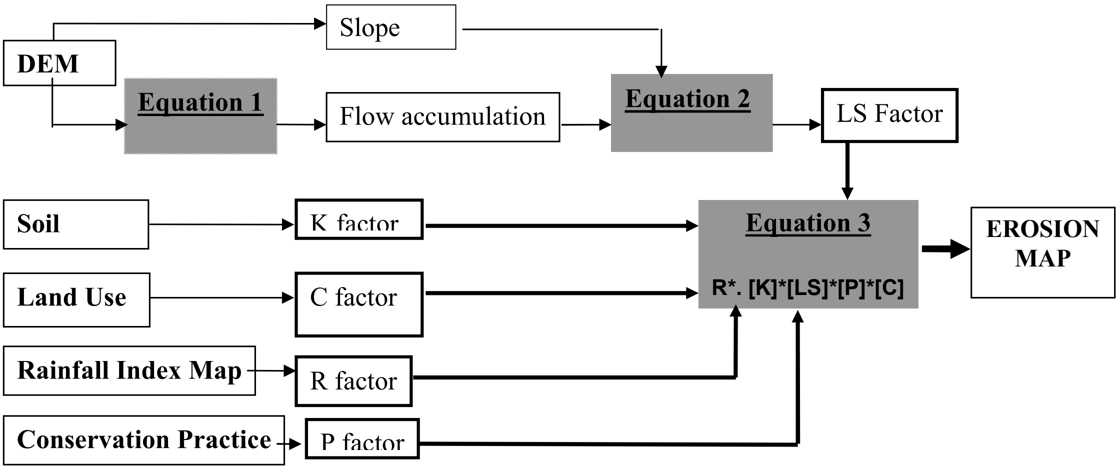

Fig. 3. Methodology flow chart.

Five GIS layers were produced from the attribute values of the model factors. Four data layers in the GIS, namely rainfall, soil, land cover, and the *LS* layer having cells of equal size [30], were overlaid to compute the annual soil loss at each cell. The overlay analysis is based on the expression below:

$$R^{*}.\ [K]^{*}[LS]^{*}[P]^{*}[C] \qquad (3)$$

Equation 3 was developed using the raster calculator in ArcMap. The schematic chart of the spatial overlay showing spatial data and associated attribute data is illustrated in Fig. 3.

Conclusions

The USLE was used to predict soil erosion in the Bolu Goynuk. The derived erosion map from spatial overlays of USLE factors is shown in Fig. 4.

Fig. 4 shows the levels of erosion hazard in Goynuk, expressed in three classes ranging from low risk areas,

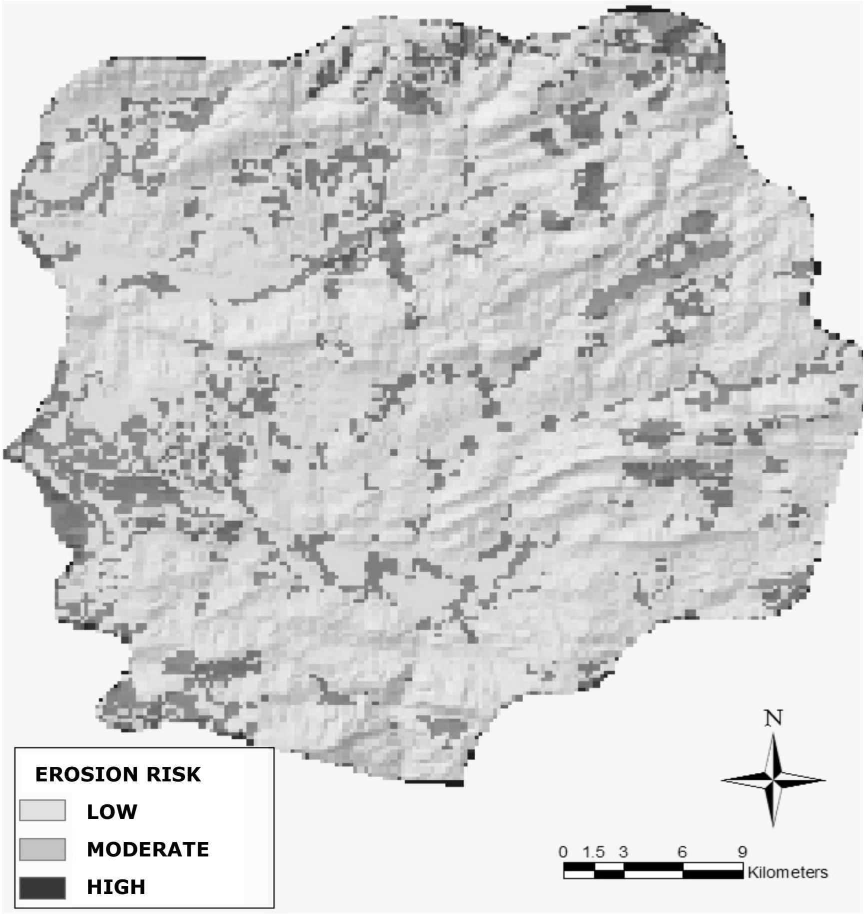

Fig. 4. Erosion risk map of the study area.

where average annual soil loss rates are less than 3.0 tons/ha/yr, to high risk areas with over 19 tons/ha/yr of annual soil loss.

Most areas have minor soil erosion of less than 3 tons/ac/yr (77%). The areas of highest erosion occurred in places where the slopes are the steepest. The estimated erosion values are primarily below the usual "tolerable soil loss" of 3 tons/ac/yr (acceptable soil loss tolerances from literature range from 2.5-12 tons/ha/year [12].

About 18 percent of the study area is experiencing a soil loss greater than 10 tons/ha/yr. The resulting GIS map showed that about 5 percent of the study area is ranked in the moderate level erosion category.

By overlaying the erosion hazard map on maps of land cover, soil erodibility, topographic factors and rainfall erosivity, it was possible to reveal the relationship between those factors and areas of high erosion risk. According to the overlay analysis, erosion hazard is low under vegetation cover. This cover type mostly consists of mountain forests. Erosion hazard is high on both the agricultural fields and pastures. As the rainfall erosivity factor is kept constant, spatial change in soil erosion rates cannot be investigated. High soil erodibility like non-calcareous brown forest and alluvial soils reflect the high risk areas where average annual soil loss rates are greater than 3 tons/ha/yr.

In the study area, spatial variation of soil loss is observed and from this data erosion controlling strategies need to be taken. For example, some land-forming practices such as developing terraces on steep slopes to reduce the slope lengths (LS factors) will slow down the runoff velocities and reduce erosion.

The USLE model is a statistically-based soil erosion model that is easy to parameterize and thus requires less data and time to run. Integrating the model with GIS can help land managers identify problem areas and adopt best management practices. Another advantage of the GIS USLE approach is its ability to predict soil loss over large areas due to its interpolation capabilities [13]. GIS is very useful compared to traditional methods because it can divide the land surface into many cells, which permits analysis to be performed on both large regions as well as small areas.

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