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ORIGINAL PAPER

Using high resolution images and elevation data in classifying erosion risks of bare soil areas in the Hatila Valley Natural Protected Area, Turkey

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Abstract Soil erosion is one of the most important environmental problems. In the case of small scale areas where soil properties and climate have relatively uniform characteristics, vegetation cover and topography (i.e. ground slope) are the main factors that affect the amount of soil erosion. Lack of vegetation cover on bare soil areas, including forest road side slopes, especially in mountainous regions with steep slopes, may significantly increase the erosion rate. Determining and classifying erosion risks in such areas can help preventing environmental impacts. In this study, remotely sensed data and elevation data were used to extract and classify bare soil erosion risk areas for a study area selected from Hatila Valley Natural Protected Area in northeastern Turkey. High resolution IKONOS imagery was used to apply land use classification in ERDAS Imagine 9.0. To generate erosion risk map of the bare soil areas, classified image was superimposed on top of slope map, generated based on a Digital Elevation Model (DEM) in ArcGIS 9.2. The results indicated that 1.43, 5.85, 34.62, 53.16, and 4.94% of the bare soil areas in the study area were under very low, low, medium, high, and very high erosion risks, respectively. The overall classification accuracy of 82.5% indicated the potential of the proposed methodology.

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1 Introduction

Soil erosion and surface runoff result in serious environmental impacts on water conservation and water resources, especially through sediment delivery that dramatically influences water quality and aquatic habitat. Soil erosion types are related to time such as past soil erosion, present soil erosion, and future soil erosion (Akay et al. 2008; Akay and Sessions 2005; Lal 1998; Masoudi et al. 2006). In Turkey, topsoil of the land faces moderate (20%), severe (36%), and very severe (22%) soil erosion incidents because of excessive amount of surface runoff (GDREC 2008). In order to ensure sustainable management of natural resources and to implement necessary soil conservation techniques, the areas with soil erosion risk should be determined and classified according to potential erosion risk levels (Yuksel et al. 2008a).

The main factors that affect the amount of soil erosion are vegetation cover, topographic features, climatic variables, and soil properties (Yuksel et al. 2008b). Removal of vegetation cover due to human activities, residential growth, and large-scale developments increases the soil erosion rate (Jinren and Yingkui 2003). The most important topographic features reflecting the erosion rate include ground slope, slope length, and shape (Lal 1994). The climatic variables such as amount and intensity of precipitation and temperature most affect the soil erosion (Yuksel et al. 2008b). The aggregate stability, texture, depth, organic matter, and stoniness are the main soil properties that affect soil erodibility (CORINE 1992). In a case where soil properties and climate presents relatively uniform characteristics, vegetation cover and topographic features are the main factors that affect the amount of soil erosion.

Existence of vegetation cover significantly reduces the soil erosion by intercepting raindrops, providing better water-holding capacity, reducing runoff, and improving infiltration. Lack of vegetation cover on bare soil areas significantly increases the erosion rate otherwise. To determine and classify erosion risks for bare soil areas including forest road side slopes, it is crucial to generate a reliable land use data (Yuksel et al. 2008b). Image classification as a digital image processing technique in Remote Sensing (RS) technology can provide accurate and low-cost land use data using high-resolution satellite imagery (Yuksel et al. 2008c). The previous studies such as Zhu and Blumberg (2001) and Abrams (2003) successfully used satellite imagery (ASTER) with high resolution to generate accurate and inexpensive land use data.

Forest roads provide access to forest lands for timber management, fire control and a variety of recreational activities (Gucinski et al. 2000); however, bare soil is generally exposed to rain on forest road prism. Especially, the side slopes of the low-volume forest roads are widely recognized as the major source of soil disturbance among forestry activities (Akay 2007). The road prism changes the natural pattern of the ground surface and water drainage system, which tends to increase soil erosion and landslide activities following road construction (Fannin and Lorbach 2007). Besides, road running surface continuously produces sediment yield depending on the traffic density (Reid and Dunne 1984). In order to reduce the amount of soil erosion, environmentally sound road construction methods, using hydraulic excavators and advanced rock drilling and blasting techniques, should be applied and road side slopes should be immediately regenerated after road construction (Winkler 1998).

Topography is one of the most important factors affecting the soil erosion, especially, where ground slope exceeds a critical angle (Lal 1994). Bare soil areas in mountainous regions with steep slopes even increase the potential risk for soil erosion. The ground slope data can be used to generate an erosion risk map of the bare soil areas (Nobrega et al. 2006). By using Geographical Information Systems (GIS) techniques, a slope data can be produced accurately and quickly based on topographic maps and DEM (Mitasova et al. 1996). Sazbo et al. (1998) and Bojie et al. (1995) indicated that the GIS techniques can be successfully used to develop erosion risk maps based on DEM, slope, aspect, and land use data. Masoudi et al. (2006) developed a model for assessing the erosion risk based on risk maps generated through a GIS analysis. They found that about 63% of the Qareh Aghaj subbbasin (1,265,000 ha) in Iran was under potential risk areas.

GIS based risk assesment studies have been previously conducted in various other fields. Huang and Cai (2007) conducted a study where GIS based stochastic model was developed to simulate land use change in Shiqian County, Southwestern China. In a more recent study, Zhijun et al. (2009) investigated the risk degree of fire disasters by succesfully implementing the GIS techniques. Dai et al. (2009) integrated RS technology and GIS for analysing urban surface temperature in Shanghai, China based on thermal satellite images (Landsat TM6 and ETM).

RS technology and GIS techniques can be efficiently used to provide the spatial distributions of soil erosion, which is very important to determine the areas with high erosion risks and to prevent soil erosion incidents in such areas (Mitasova et al. 1996). In this study, remotely sensed data and elevation data were used to extract and classify bare soil erosion risk areas for a study area selected from Hatila Valley Natural Protected Area in northeastern Turkey. High resolution IKONOS imagery was used to apply land use classification in ERDAS Imagine 9.0. Then, erosion risk map was generated by using DEM and slope map in ArcGIS 9.2.

2 Materials and methods

2.1 Study area

The study area is selected from Hatila Valley Natural Protected Area located near the city of Artvin in northeastern Turkey (Fig. 1). Hatila Valley National Park (NP), founded as a national park based on the IUCN-II conservation criteria in 1994, covers approximately 17,000 ha with old-growth forests, endemic herbaceous plants, and large carnivores. It is also categorized as temperate forests of the Caucasus as one of the 21 priority protected areas of the Earth (WWF and IUCN 1994; Baskaya 2005). Therefore, the study area is highly crucial in terms of conservation point of view.

The study area of 13,010.89 ha has a steep and rough terrain with an average slope of 56% and an altitude from 500 to 3195 m. The main land use types include forest, rangeland, bare soil, and forest roads. The average annual temperature and precipitation are 11.9°C and 719.7 mm, respectively. The climate type of the area is semi-humid, where winters are mild and wet, and summers are relatively cool and dry. The forest vegetation type is Picea orientalis (L.) Link, Pinus sylvestris L., Abies nordmanniana (Stev.) Spach subsp. nordmanniana, Fagus orientalis Lipsky, Quercus petraea (Maattuschka) Liebl. subsp. iberica (Steven ex Bieb.) Krassiln, and Carpinus betulus L. (Varol et al. 2003). Main soil types include sandy clay loam, clay loam, and sandy loam.

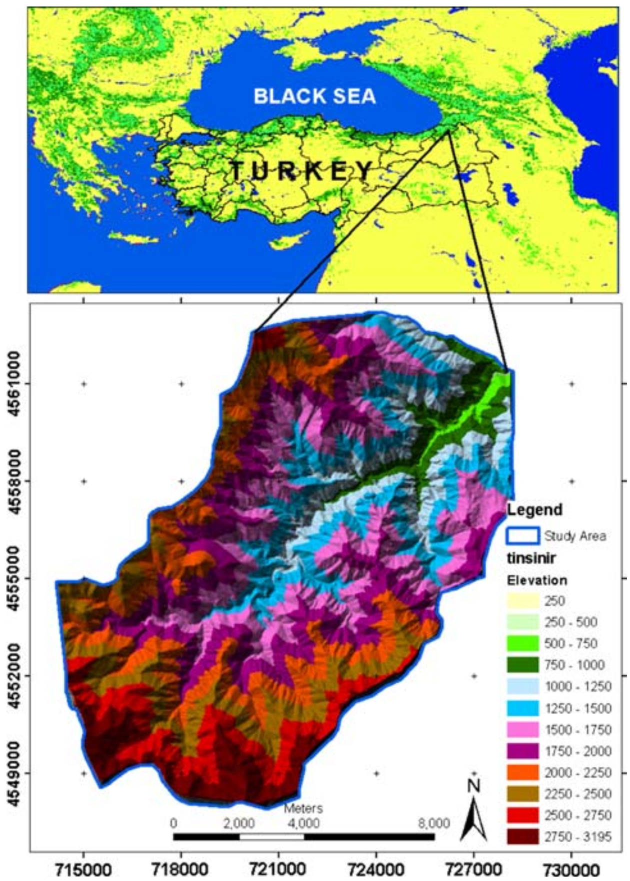

Fig. 1 The location of the study area with elevation classes

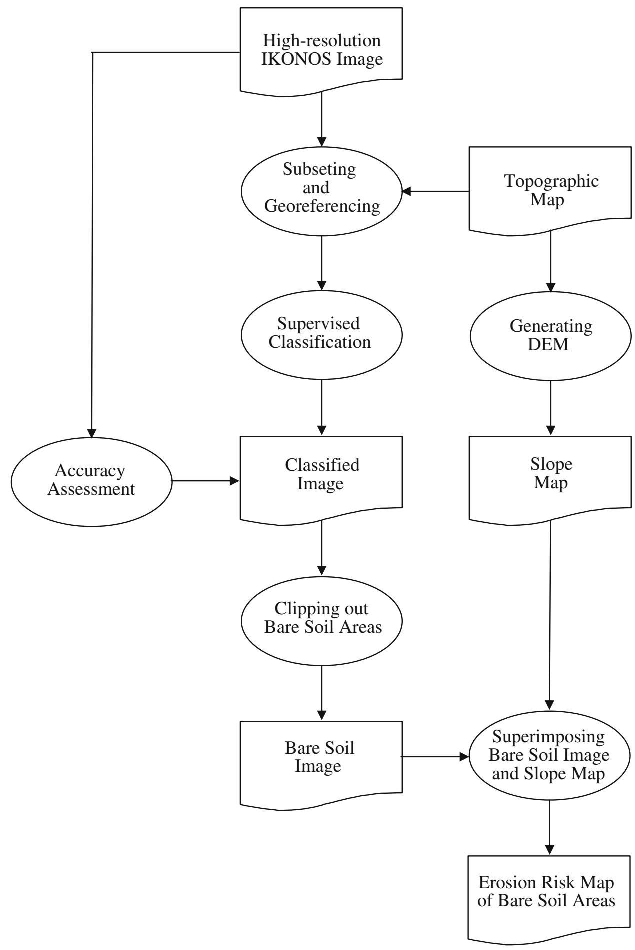

Fig. 2 The flowchart indicating image processing stages

2.2 Image processing

The image processing was conducted in three stages including preprocessing, land use classification, and slope classification. The logic behind the image processing techniques was indicated in Fig. 2.

2.2.1 Preprocessing

The IKONOS 2 image of the study area was acquired on the 29th of March, 2007. The IKONOS satellite was launched in 1999 to provide the publicly available high resolution satellite images. The IKONOS 2 product consists of four panchromatic images at 1-m resolution and one multispectral image at 4-m resolution. The panchromatic image, which was Red, Green and Blue bands, was imported into ERDAS Imagine 9.0 using the layer selection and stacking dialog. Then, the study area was extracted from the image by using "Subset" tool. To remove image distortions introduced by the collection geometry, the subset image was georeferenced based on a topographic map with 1:25,000 scale and then re-projected into the UTM projection zone 37 and ED 50 datum. Sixty-three ground control points (GCPs) were collected for the rectification process, using DGPS.

2.2.2 Land use classification

In land use classification process, Supervised Classification method was performed by using "User-Defined Polygon" function to reduce the chance of underestimating class variances. 71 spectral signatures were selected from the study area by drawing a polygon around training sites of interests. Land use classes of these training points were extracted with respect to topographic maps and field visits. In selection process, "Signature Alarm" and "Signature Mean Plot" tools were used to accurately representing the land use classes. Supervised classification was performed using the parallelepiped non-parametric rule provided by ERDAS 9.0. Then, "Recode" function was used to combine the classes into four main classes; (1) bare soil including forest road side slopes, (2) rangeland and shrubs, (3) forest, and (4) shadow. The satellite image indicated that the shadow areas were located in mountainous areas due to topography and trees, which did not cause serious effects on bare soil areas. Thus, it was also classified as separate class in classification process. The low-volume forest roads in the study area could not be distinguished from the bare soil areas due to close reflectance values with bare soil areas; therefore, they included into the bare soil class. In order to provide a better classified image to be processed, the small sized pixel groups of the land use classes were eliminated by consecutively performing "Clump" and "Sieve" functions in ERDAS 9.0. The groups of contiguous pixels in the land use classes were first grouped together using "Clump" function, and then, the clumps that contain 50 pixels or less were filtered out from the classified image.

To assess the accuracy of the classification process, "Accuracy Assessment" tool in ERDAS 9.0 was used based on 120 sample points which were selected (30 points from each class) from referenced satellite image. The referenced values were recorded on the "Accuracy Assessment Table" based on the topographic map and field reconnaissance. Then, overall accuracy of the classified image was evaluated by using user's accuracy (a measure of commission error) and producer's accuracy (a measure of omission error) of each class.

2.2.3 *Slope classification*

The DEM of the study area was generated by digitizing the contour lines with 10 m intervals on the topographic map in ArcGIS 9.2. In order to classify the bare soil erosion risk areas, slope map of the study area was generated by processing DEM data in ERDAS 9.0. The ranges of the slope classes and their associated potential erosion risks for bare soil areas were obtained from a similar study conducted by Nobrega et al. (2006); very low (0–10%), low (10–25%), medium (25–50%), high (50–100%), and very high (>100%). Then, forest, rangeland, and shrub areas as well as shadow areas were masked out from the classified image to increase of detection of bare soil areas. Finally, bare soil layer was superimposed on top of slope map to generate erosion risk map of the bare soil areas.

3 Results and discussion

The supervised classification method was implemented to classify study area into four main classes (Fig. 3). Table 1 indicates the area of each class determined based on the classification process. The accuracy assessment of the classified image resulted in the overall classification accuracy and kappa value of 82.5% and 0.77, respectively (Table 2).

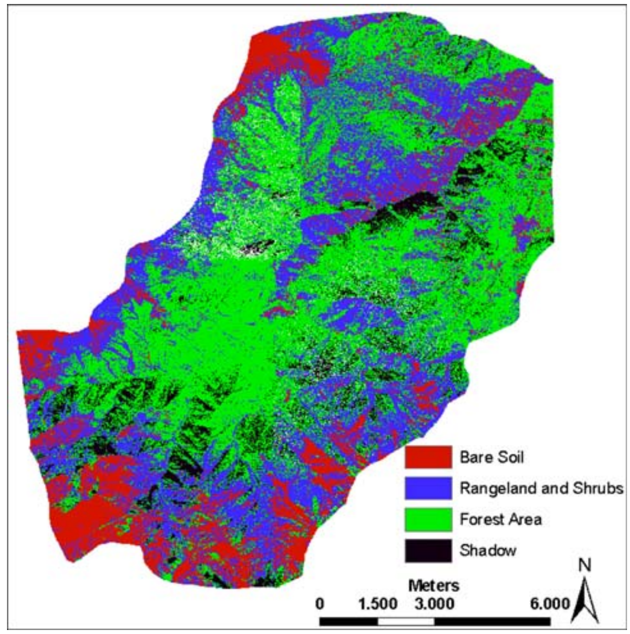

Fig. 3 The study area after supervised classification

Table 1 The area of each class from classification results

Class names	Area (ha)	Percentage
Bare soil	1867.45	14.35
Rangeland and shrubs	4195.15	32.24
Forest	5894.75	45.31
Shadow	1053.52	8.10
Total	13010.89	100.00

Table 2 The results from the accuracy assessment process

Class names	Reference totals	Classified totals	Producer accuracy (%)	User accuracy (%)
Bare soil	33	30	84.85	93.33
Rangeland and shrubs	16	30	93.75	50.00
Forest	44	30	65.91	96.67
Shadow	27	30	100.00	90.00
Totals	120	120		

* Overall classification accuracy = 82.5%

* Kappa statistics = 0.77

Supervised classification gave satisfactory results in terms of distinguishing bare soil areas and shadows; however, accuracy for forest, rangeland and shrubs were relatively low due to large variation of spectral signatures. The highest producer's and users accuracy was reached in

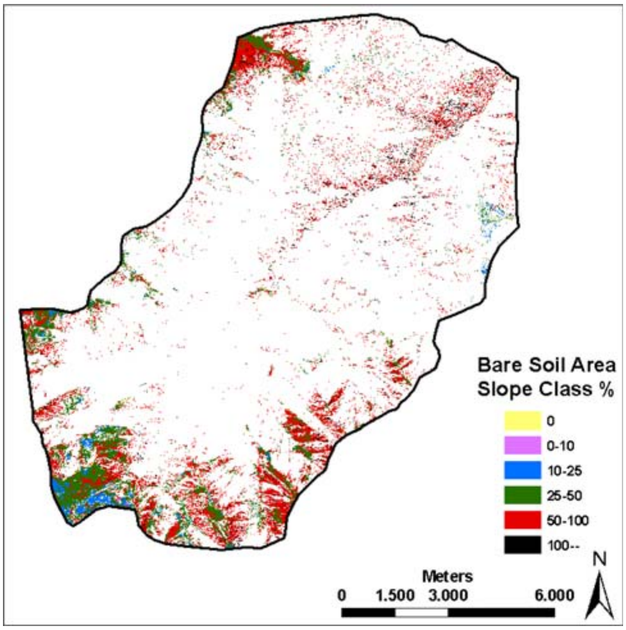

Fig. 4 Erosion risk map of the bare soil areas

Table 3 Erosion risk levels of bare soil areas according to slope classes

Slope classes (%)	Erosion risk	Area (ha)	Percentage (%)
0–10	Very low	26.78	1.43
10–25	Low	109.31	5.85
25–50	Medium	646.41	34.62
50–100	High	992.65	53.16
>100	Very high	92.32	4.94

classification of shadow areas and forested areas, respectively. The results indicated that supervised classification overestimated shadow areas and range lands and shrubs, while underestimated bare soil areas and forested areas. After accuracy assessment, bare soil image was generated by masking out the other classes from the classified image (forest, rangeland and shrub areas, and shadow areas).

The slope map of the study area was generated by using DEM and classified according to potential erosion risks classes. The bare soil image was superimposed on top of slope map to generate the erosion risk map of bare soil areas (Fig. 4). The summary table (Table 3) indicated that more than 58% of bare soil areas had a higher than 50% slope (i.e., high to very high erosion risk), which may significantly increase soil erosion due to runoff (Lal 1994). About 35% had a 25–50% slope with medium erosion risk. The rest of the study area lies on terrain with less than 25% slope, ranging from low to very low erosion risk.

4 Conclusions

There has been an increasing interest in utilizing RS and GIS technologies in assessing environmental impacts. These technologies have been successfully used in wide range of different impact assessment studies such as forest degradation, water resources, soil conservation, etc. In this study, remotely sensed data and elevation data were used to extract and classify bare soil erosion risk areas for a study area selected from Hatila Valley Natural Protected Area in northeastern Turkey. The results from this study suggested that using RS and GIS technologies based on a high-resolution satellite imagery provides effective and accurate way of producing bare soil erosion risk map in considerably short time. Besides, generating erosion maps can assist to locate the areas with high erosion risk, so that decision makers can develop necessary soil conservation plans and apply specific erosion control methods for such areas.

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