GIS modelling for locating the risk zone of soil erosion in a deciduous forest

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ABSTRACT: The maps of altitude, geology, vegetation cover and land use were prepared and classified as the main criteria to locate soil and water conservation programs. Analytical Hierarchy Process (AHP) was used to determine the relative priorities of these criteria by pairwise comparison. All the thematic maps were then integrated using the overlay process in Geographical Information System (GIS) and the final map of soil erosion risk was produced. Results indicated that vegetation cover was given the highest weight (0.494). The geology was assigned the second highest weight (0.313), as the main cause of initiation of the erosion of erodible lands. Land-use change has a local influence on soil erosion, so it was assigned the third weight (0.151). Altitude is a low-impact variable for predicting the water and soil conservation areas.

Keywords: forest soil; water; conservation programs; AHP; GIS

Soil and water resource protection are clearly crucial for productive and sustainable economies and environments. Both soil and water resources can be threatened by processes of soil erosion and sediment redistribution (Owens, Collins 2006). In order to preserve sensitive areas, appropriate land use types should be applied according to land cover classification, and illegal opening and cuttings must be prevented (Bozali et al. 2008).

Although soil erosion is a physical process with considerable variation globally in its severity and frequency, where and when erosion occurs is also strongly influenced by social, economic, political and institutional factors. The prevention of soil erosion, which means reducing the rate of soil loss to approximately that which would occur under natural conditions, relies on selecting appropriate strategies for soil conservation, and this, in turn, requires a thorough understanding of the processes of erosion (Morgan 2005). The undesirable effect of erosion may not be significant in a short time, but it will be clear in a long time. Erosion and soil loss are the main adverse effects causing a decrease in soil fertility and yield production, deposition materials in waterways, irrigation channels and rivers, declining dam capacity, flooding and environmental pollution and closing roads (Verstraeten, Poesen 2001). With integration and application of statistical approaches and GIS techniques, specific quantitative models to assess and predict soil erosion are also available (Wu, Wang 2007). The method uses GPS (Geographical Positioning System) and databases to capture field survey information that can be used in GIS to perform analyses that rely on the spatial coincidence of landscape characteristics to determine risks to ecosystems (Kim et al. 2004).

In order to ensure sustainable management of the watersheds, it is required that the soil and water conservation programs should be located. For this purpose, the current conditions of the forests, in terms soil erosion potentials, should be analysed. This study presents a series of field studies and GIS-based spatial analysis, which were performed to investigate the main factors effecting the locating of soil and water conservation programs.

MATERIAL AND METHODS

Description of the study area

Measurements were carried out in Miana forest which is located in the deciduous northern forest of Iran between 52°56'30" to 52° 59'25" east longitude and 36°12’25” to 36°16’35” north latitude. Annual mean temperature is in the range of 12–14°C. Annual mean precipitation is between 900 and 1,000 mm. The forest altitude ranges from 320 to 1,060 m a.s.l. The general slopes are less than 50%. Soil textures range from loam to loamy silt and loamy clay. The study compartments have four types of soils consisting of undeveloped Rendzina, washed brown soil with calcic horizon, calcareous brown soil and brown soil with alkaline pH. The bedrock is limestone, calcareous sandstone, marl lime and calcareous conglomerate. The total area of Miana forest is 1,831 ha. For this area 10,800 m of roads were predicted in 1996.

Data collection

In this study, the main criteria influencing the locating of soil and water conservation programs are elevation above sea level, geology, vegetation cover and land-use factors. AHP developed by Saaty is a method that enables reaching a decision by using quantitative and qualitative data. Weighting was done through pairwise comparison questionnaires filled by forest experts. AHP is based on determining the relative priorities (weighting) of the criteria by pairwise comparison (Table 1). The Expert Choice Software was used for determining the priority of effective criteria on the locating of conservation programs. ArcGIS 9.2 and IDRISI Andes 15.0 software packages were used as basic analysis tools for spatial analysis and data layers manipulation. A Digital Elevation Model (DEM) was generated with 20-m resolution in ArcMap, and some maps were obtained from surface analysis. Data were controlled by GPS in a field survey.

The normalized difference vegetation index (*NDVI*) was calculated using Eq. (1).

$$NDVI = \frac{[NIR - R]}{[NIR + R]} \quad (1)$$

Table 1. Scale for pairwise comparison

Definition	Degree of importance
Equal	1
Moderate	3
Strong	5
Very strong	7
Extreme	9

2, 4, 6 and 8 can also be used as degrees of importance among the mentioned scales

where:

NIR – near infrared band (Band 4),

R – red band (Band 3) of the Indian Remote Sensing (IRS LISS III) digital image.

The spatial resolution of IRS images was 23.5 m and band lengths corresponded to the green, red, near infrared and middle infrared.

RESULTS AND DISCUSSION

During the analysis, vegetation cover was given the highest weight (0.494), because even though the environment may be favourable to erosion, erosion cannot occur unless the soil is bare. The geology was assigned the second highest weight (0.313), as the main cause of initiation of the erosion of erodible lands. Land-use change has a local influence on soil erosion, so it was assigned the third weight (0.151). Altitude is a low-impact variable for predicting the water and soil conservation areas, because it is an aggregate variable for precipitation and slope inclination effects, thus it was assigned the fourth weight (Table 2).

The upper lands of our study area receive more rainfall, so the erosion potential of soil is high. The impact of erosion depends also on the thickness of the topsoil. The upper land of mountainous areas has a thin soil cover while in the plain area the

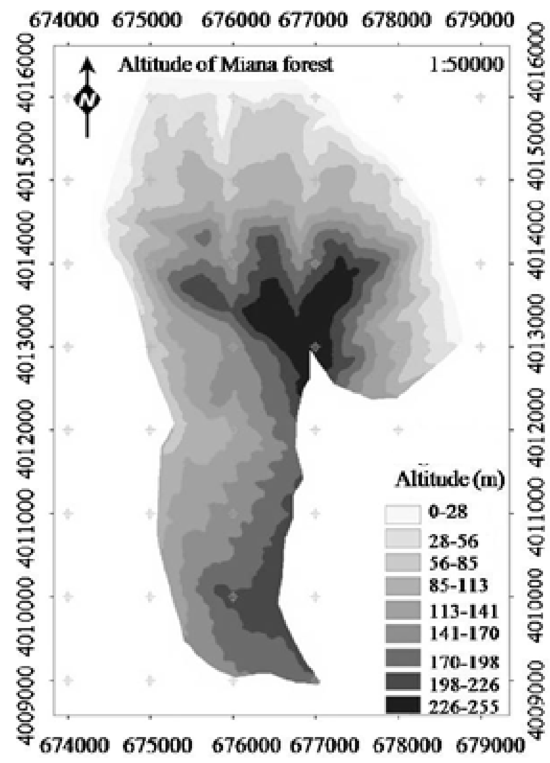

Fig. 1. Altitude fraction map of the study area

Table 2. Judgement matrix and integrated weights of dominant factors in locating the soil and water conservation programs based on AHP

Criteria	Altitude	Geology	Vegetation cover	Land use	Integrated weights
Altitude	1.00	0.14	0.12	0.17	0.042
Geology	7.00	1.00	0.50	3.00	0.313
Vegetation cover	8.00	2.00	1.00	4.00	0.494
Land-use	6.00	0.33	0.25	1.00	0.151

Inconsistency ratio: 0.06

soil is deeper and so the hazard is less felt, because when a layer of a few centimetres of topsoil gets washed away from areas with a deep fertile soil the erosion is not usually perceptible (Masoudi et al. 2006). More rainfall on the rock hill areas resulted in a larger soil loss as reflected also in the increasing rate of soil detachment (Ande et al. 2009). More than 50% of the total area was represented by areas with an altitude range of 113–255 m (Fig. 1).

Geologic structure and lithology are significant factors predisposing certain terrane to land slide. In fact, land sliding may be a dominant erosion process in the northern forest of Iran (McKittrick 1994). Fig. 2 shows that less than 20% of the total area is located within the geology class of L-M1.

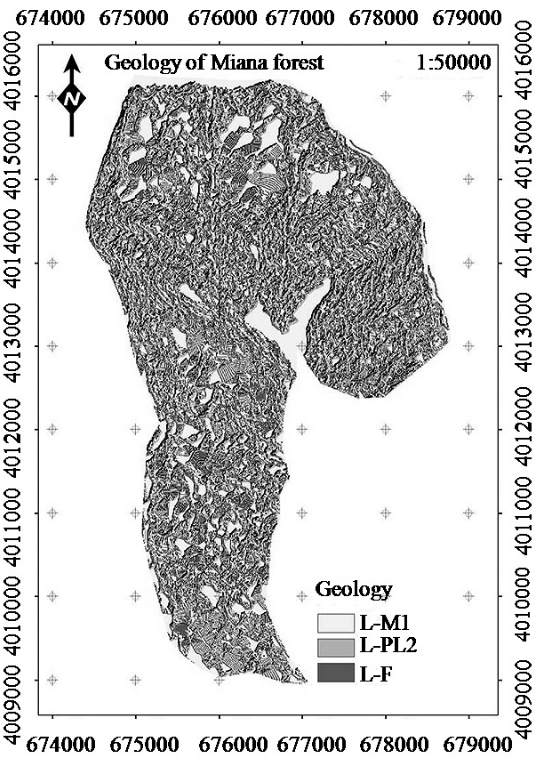

Fig. 2. Geology fraction map of the study area
L-M1: the slope gradient is gentle, soil depth is higher than that of L-Pl2, and soil infiltration is lower than that of L-M1, the bedrock is marl; L-Pl2: the slope gradient is too high, soil depth is moderate, infiltration is good, and the bedrock is conglomerate and sandy lime; L-F: this region is faulty and unstable

Vegetation provides a protective layer or buffer between the atmosphere and the soil by means of its canopy, roots, and litter components (Mohammad, Adam 2010). Many studies have emphasized the importance of vegetation cover in relation to soil loss. Cao et al. (2006) indicated that vegetation cover could significantly reduce the sediment yield from unpaved roads. The aboveground components of the vegetation, such as leaves and stems, partially absorb the energy of the erosive agents of water and wind, so that less is directed at the soil, whilst the belowground components, comprising the rooting system, contribute to the mechanical

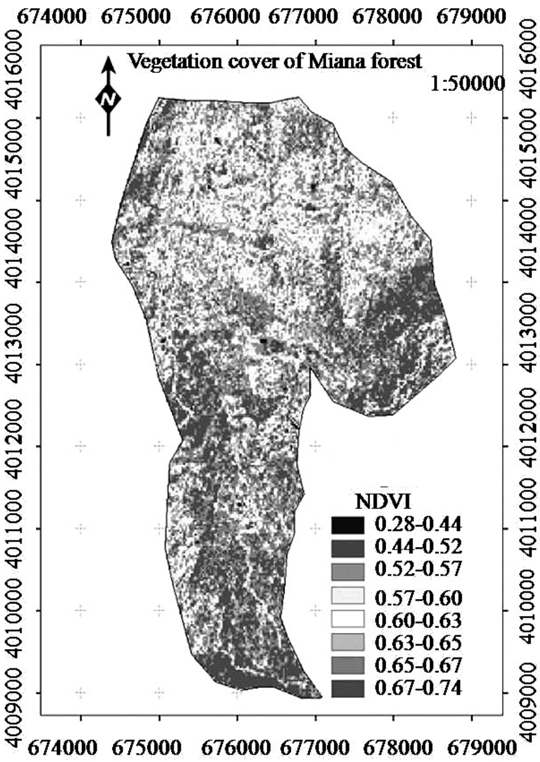

Fig. 3. Vegetation fraction map of the study area
NDVI – normalized difference vegetation index

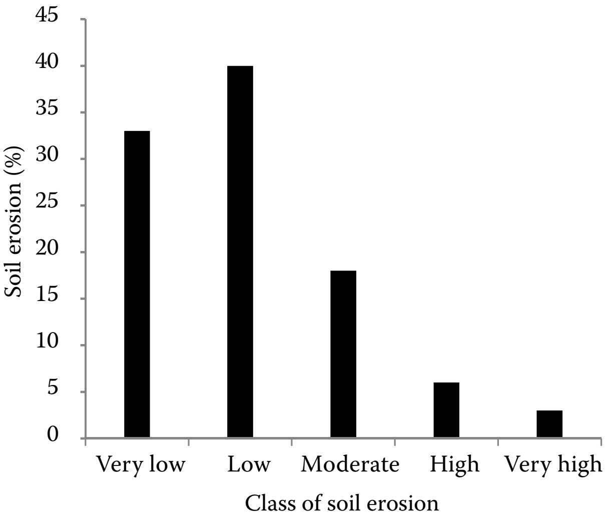

Fig. 4. Land percentage under different risk classes of soil erosion

strength of the soil (Morgan, Rickson 1995; Jasinskas et al. 2011). The study area is covered by forest trees, shrubs, litter and herbaceous cover, so the most part of the area of the region has *NDVI* higher than 0.5 (Fig. 3).

Land-use change in forest areas has potentially multiple effects on the environment. So, in recent years, land-use conversion in forest areas caused by human activities has had critical influences on political, economic and society functions of the government. Land use in forest areas is the main and basic concept of forestry and indeed many forestry programmers in developed countries define it equal to environmental programming (Ebrahimzadeh, Lamso 2010). Land-use conversion is described as an effective process in forest areas.

The reasons for this conversion which is frequency occurred through human activities are the lack of basic program, inattention to sustainable development, lack of sustainable management and no attention to environmental limitations (Zadedalir, Malaki 2007). The effective factors for land-use change can be divided into juridical factor, economic factor and population factor. The population is the most important factor in land-use change and influences the other two factors. The population increase has brought about many problems for forest ecosystems. The results of a study in Iran showed that the land use has an important influence on tourism, because tourism is the basic activity and sensitive from environmental aspects. So, the conservation and maintenance of natural resources are essential to sustain and juice up recreation areas (Esmaeil 2010). Less than 25% of the total area was represented by areas with distances

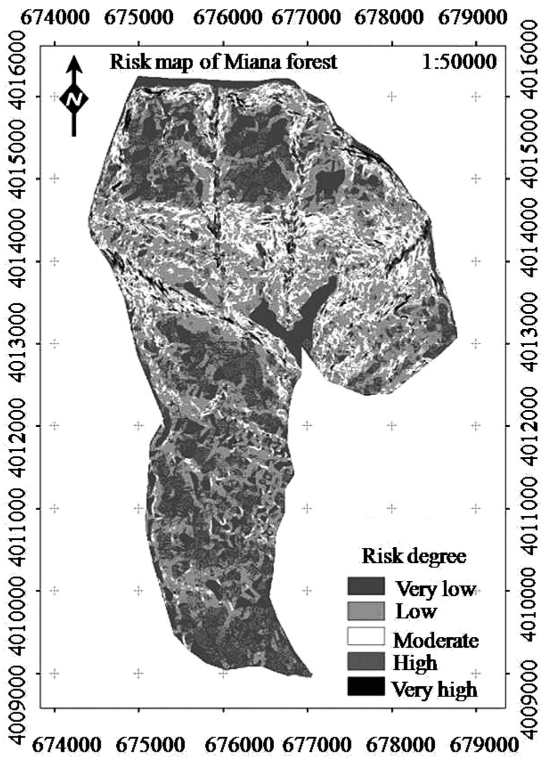

Fig. 5. Soil erosion risk map

shorter than 300 m from settlements (Fig. 4). All the thematic maps were then integrated using the overlay process in GIS. The equation used in GIS for the erosion risk modelling and for mapping the soil and water conservation areas is Eq. (2):

$$ER = 0.494\ V + 0.313\ G + 0.151\ L + 0.042\ A \qquad (2)$$

In general, GIS is a technique that is used to estimate quantitative variables from remotely-sensed data. Less than 2% of the forest area is classified as very highly vulnerable to erosion (Fig. 6). This class is generally distributed in central and northern parts (Fig. 5).

CONCLUSIONS

In this study the maps of altitude, geology, vegetation cover and land use were prepared and classified. Maps were overlaid to obtain the soil erosion risk map. It has been concluded that vegetation cover was given the highest weight. The geology was assigned the second highest weight, as the main cause of initiation of the erosion of erodible lands. Land-use change has a local influence on soil erosion, so it was assigned the third weight. Altitude is a low-impact variable for predicting the water and soil conservation areas.

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