Modelling land degradation in the mountainous areas

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Abstract: Land degradation is a crucial issue in mountainous areas and is manifested in a variety of processes. For its assessment, application of existing models is not straightforward. In addition, data availability might be a problem. In this paper, a procedure for land degradation assessment is described, which follows a four-step approach: (1) detection, inventory and mapping of land degradation features, (2) assessing the magnitude of soil loss, (3) study of causal factors, and (4) hazard assessment by applying decision trees. This approach is applied to a case study in the Middle Mountain region of Nepal. The study shows that individual mass movement features such as debris slides and slumps can be easily mapped by photo interpretation techniques. Application of soil loss estimation models helps get insight on the magnitude of soil losses. In the study area soil losses are higher in rainfed crops on sloping terraces (highest soil loss is 32 tons/ha/yr) and minimal under dense forest and in irrigated rice fields (less than 1 ton/ha/yr). However there is high frequency of slope failures in the form of slumps in the rice fields. Debris slides are more common on south-facing slopes under rainfed agriculture or in degraded forest. Field evidences and analysis of causal factors for land degradation helps in building decision trees, the use of which for modelling land degradation has the advantage that attributes can be ranked and tested according to their importance. In addition, decision trees are simple to construct, easy to implement and very flexible in adaptations.

Keywords: landslides, soil erosion, erosion modelling, decision trees, land degradation hazard assessments, Himalaya

1. Introduction

Land degradation is a crucial issue in mountainous areas because of slope steepness. In the Himalayan region, degradation is mainly caused by landslides, mudslides, collapse of man-made terraces, soil loss from steep slopes, and decline of forest/pasture areas (ICIMOD, 1994). Although Bruijnzeel and Bremmer (1989) state that the erosion issue in Nepal is more related to nature than to human influence, land degradation is also influenced by cultivation practices and by how the farmer uses the land. This is especially important in Nepal, where more than 80% of the land surface is occupied by mountains with rugged topography and steep to very steep slope gradients, often exceeding 100%. Because of the scarcity of flat land, steep slopes are reclaimed by means of terraces. Terracing conserves soil and moisture, helps promote rock weathering and eventually increases crop growth. But, however careful the farmers are in maintaining the terraces, land degradation takes place on a yearly basis.

To protect the land from further degradation and make the mitigation measures effective, it is essential to know the spatial distribution of the areas susceptible to degradation and assess hazard severity. Techniques to evaluate land degradation range from simple methods for hazard assessment (Bergsma, 1992) to sophisticated models for estimating soil losses and for hazard prediction (Nearing et al., 1989). Results from advanced modelling are often impressive but also difficult to interpret. A general problem for applying such models is data availability. Frequently, missing data have to be generated on the basis of assumptions, including pedotransfer functions. It is essential to devise a method for hazard zonation, which can be applied in a data-poor environment.

The objective of this paper is to present, discuss and apply a four-step approach to assess land degradation, including: (1) detection, inventory and mapping of existing degradation features, (2) assessing the magnitude of soil loss under different land use and land cover types, (3) detailed study of the causal factors, including field evidence related to degradation features, and (4) modelling land degradation hazard using decision trees. This approach was applied to a case study in the Middle Mountain region of Nepal.

2. Materials and methods

1) Study area

The study area is located in the watershed of the river Likhu Khola, 60 km north of the Kathmandu valley, in the Middle Mountain region of Nepal. The 160 sq.km watershed lies between 27°48'15" - 27°53'55" N and 85°13'01" - 85°27'51" E (Fig. 1). Climate varies from subtropical at valley bottoms and footslopes, through warm temperate at mid-elevations, to cold temperate in the higher mountains. In the lowlands (530 – 950 m asl), the average summer temperature is 26° C, with hot months from April to September, and the average winter temperature is 15° C (Trisuli station). At higher elevations (2000 - 2600 m asl), the average summer temperature is 19° C and the average winter temperature is 11° C, with extreme values as low as -4° C in December (Kakani station). The annual precipitation varies from 1000 mm in the lowlands (Chhahare, 780 m asl) to 2800 mm at higher elevations (Kakani, 2064 m asl). Most of the rain falls during the months of May to September. Land use is mainly rainfed agriculture on sloping terraces and irrigated rice cultivation on level terraces. Steep slopes are mainly used for forest.

Two sample subwatersheds were selected to study the effect of slope aspect on degradation processes. The south-facing subwatershed of Mahadev Khola covers a surface area of 346 ha and elevation varies from 655 to 1510 m asl. The north-facing subwatershed of Jogi and Bhandare Khola covers a surface area of 256 ha and elevation varies from 600 to 1225 m asl.

2) Methods applied

Interpretation of aerial photos and enhanced images was applied for identifying and mapping mass movement features. The terms defined by Cruden and Varnes (1996) were used to describe mass movement processes. The term landslide was used to denote the movement of a mass of rock, debris or earth down a slope. Landslides were classified by considering the type of material (rock, debris, fine earth) and the type of movement (fall, slide, flow). Slide was further classified into rotational and translational, depending on the concavity and the shallowness of the slide body. Debris were dominantly coarse materials, larger than 2 mm.

To estimate the magnitude of sheet erosion, the soil loss assessment model developed by Morgan et al. (1984) was selected because of its simplicity, flexibility and strong physical base. The model separates the soil erosion process into a water phase and a sediment phase. In the water phase, the annual precipitation is used to determine the rainfall energy available for splash detachment and the volume of runoff. The rainfall energy is computed from the hourly rainfall intensity for erosive rains, based on the relationship established by Wischmeier and Smith (1978). The annual volume of overland flow is predicted using the model of Kirkby (1976), which assumes runoff to occur whenever the daily rainfall exceeds a critical value corresponding to the storage capacity of the surface soil layer. In the sediment phase, splash detachment is modelled as a function of rainfall energy, soil detachability and rainfall interception by crops. The transport capacity of the overland flow is determined using the volume of overland flow, slope steepness and the effect of vegetation or crop cover management (Kirkby, 1976).

Splash detachment is computed by:

$$F = K\,(E \exp^{-aP})^{b}.10^{-3}$$

where,

F = rate of splash detachment (kg m^{-2})

K = soil detachability index (g J^{1}), defined as the weight of soil detached from the soil mass per unit of rainfall energy per unit area

E = rainfall energy (J m^{-2})

P = percentage rainfall intercepted by crops

Values of exponents: $a = 0.05$, $b = 1.0$

The transport capacity of the overland flow is computed by:

$$G = C^{*} Q^{2} * \sin S^{*} 10^{-3}$$

where,

G = transport capacity of the overland flow (kg m^{-2})

C = crop cover management factor

Q = overland flow

$\sin S$ = sine of the slope gradient

Predicted detachment was compared with the transport capacity of the runoff, and the lower of the two values was adopted as the annual rate of soil loss, denoting whether detachment or transport was the limiting factor. Detailed explanation of the model application is given in Shrestha (1997).

In addition, causal factors for each of the land degradation processes (debris slides, slumps and soil erosion) such as topography (slope gradient, aspect), lithology, soil, effect of rainfall, proximity to streams and human intervention were studied. Finally, decision trees, were used for modelling land degradation hazard. Decision trees are useful tools, because they perform classification through a sequence of simple, easy-to-understand tests, whose semantics are intuitively clear to domain experts. An example of decision tree for assessing land degradation hazard due to slumping in rice fields is given in Fig. 1.

Fig. 1: Decision tree for assessing slumping hazard

3. Results and discussion

On average, soil losses were moderate in both areas, when compared to a tolerable threshold of 25 tons/ha/yr in mountainous areas where soil loss is high in natural conditions (Morgan, 1986) (Table 1). Soil erosion rates were higher on south-facing slopes than on north-facing ones. Soil losses were highest in rainfed crops on both north-facing and south-facing slopes (averages of 18 and 32 tons/ha/yr respectively), moderate in rangeland (averages of 1 and 8 tons/ha/yr), and minimal under dense forest and in irrigated rice fields (less than 1 ton/ha/yr). Soil loss by sheet erosion was common on sloping terraces under rainfed cultivation practices. In contrast, the amount of sediments from the rice fields was minimal, since runoff water had to pass through a large number of terraces before entering the river system. This favoured sequential trapping of sediments along the stepped terraces.

Table 1: Estimation of soil loss (Shrestha, 1997)

Landuse	South-facing subwatershed of Mahadev Khola (soil losses in tons/ha/yr)			
	Area (ha)	Range	Average	St.dev.
Rainfed crops (maize, millet)	56	6.1-56.2	32.0	11.0
Rangeland	96	1.6-19.8	8.1	4.3
Degraded forest	91	0.1-8.6	2.5	2.1
Dense forest	13	0.1-0.4	0.3	0.1
Irrigated Rice	84	0.1-0.8	0.3	0.2

In the study area, the main mass movement types included rotational debris slides, translational debris slides and slumps. Debris slides dominated in the south-facing watershed. For slumps however, slope aspect seemed not to play a role since slumping was more related to land use (rice cultivation) (Fig. 2). Hazard assessment, by application of decision trees, showed that nearly half of the watershed resulted to be susceptible to slumping (51%) and sheet erosion (46%), while one fourth (26%) was exposed to debris slides hazard. Sloping terraces were highly susceptible to sheet erosion, while level terraces were very highly susceptible to slumping (78%).

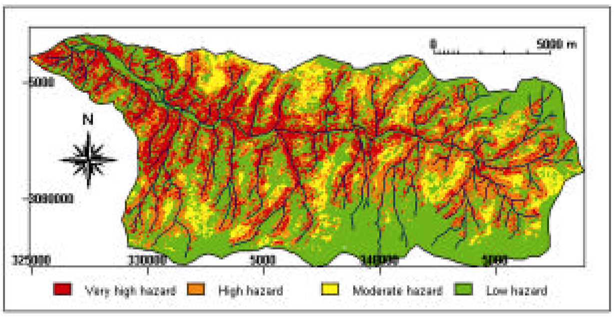

Fig. 2: Hazard assessment for slumping

4. Conclusions

Land degradation hazard assessment is crucial for land use planning activities. Mountainous areas are frequently affected by more than one type of degradation occurring simultaneously, the modelling of which is a tedious task. Although physically based models claim to give good results, insufficient data availability often hampers their application in many developing countries. In addition, suitable models do not exist for all degradation types. In such conditions, modelling by decision trees provides an alternate solution for land degradation assessment. Decision trees are simple to construct and easy to implement in a GIS environment. It is especially useful in a data-poor environment, since the model is flexible and allows the use of field evidence in building decision trees.

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