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Assessing soil erosion in inaccessible mountainous areas in the tropics: The use of land cover and topographic parameters in a case study in Thailand

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ABSTRACT

Land degradation processes in hilly areas are often directly related to land cover changes. At the same time, many hilly areas in the tropics are inaccessible and thus lack proper data. As a result, data scarcity is a crucial problem when trying to assess soil erosion. In this paper a method is described showing the use of digital elevation, remote sensing and field measurement techniques for deriving necessary land cover parameters as required for erosion modeling. The study shows that correction of topography-induced illumination variation in remote sensing data helps improve classification accuracy while field measurements help in accurate estimation of cover factor. Similarly, the incorporation of DEM-derived parameters such as upslope catchment area and flow direction network in erosion modeling helps not only to improve the estimation of soil losses but also to identify the dominant erosion process active in the area. This makes the formulation of sound conservation measures for minimizing soil losses and reducing off-site erosion effects in low lying areas much easier.

1. Introduction

Driving forces of land degradation processes on hill slopes in the tropics are often directly related to changes in land cover or to extreme climatic conditions. While land use changes due to population pressure or other factors enhance the degradation process, excessive and prolonged rain can also have a devastating effect on the land, especially in the tropics. Conversion of natural forest to agricultural land to support growing population is reported to cause major changes in soil physical properties such as increase in bulk density, destruction of soil structure, and decrease of organic carbon content (Matson et al., 1997; Murty et al., 2002). These changes not only affect soil fertility but also soil hydraulic properties and water retention characteristics (Zhou et al., 2008). Reduction of organic matter in cultivated lands reduces soil aggregate stability (Six et al., 2000). The overall effect is an increase in surface runoff and soil erosion. Soil erosion not only can result in decreasing agricultural productivity but also can cause flash floods in low-lying areas or siltation problems that reduce the lifespan of reservoirs built for hydro-electric power generation or for irrigation purposes.

In order to model soil erosion, various data such as on land cover, soil, topography and rainfall are required. While canopy cover will give information on rain interception and surface roughness caused by vegetation helps in calculating transport capacity of runoff, information on cover type is useful to estimate the ratio of actual to potential evapotranspiration rates and effective soil hydrological depths (EHD). The term, EHD, indicates the depth of soil within which the moisture storage capacity controls the generation of runoff (Morgan, 2001). It is a function of the plant cover, which influences the depth and density of roots. All these are important input parameters in calculating runoff and soil loss. These data may not be easily available especially in inaccessible mountainous areas in the tropics. In the tropics, data scarcity is often a crucial problem, and the use of remote sensing techniques has become very important in generating land cover parameters (Loveland et al., 2000; Sellers et al., 1996; Su, 2000). Similarly, topographic parameters can be derived using freely available digital elevation data from the Shuttle Radar Topography Mission (SRTM) or from Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data.

In rugged mountainous areas illumination variation can cause problems in classification results. The effect of the inherent illumination variations in the image has to be first corrected since it leads to non-normal distribution of training samples, while a normal distribution is required for Maximum Likelihood classification (Shrestha and Zinck, 2001). In land cover change detection analysis preprocessing techniques such as geometric and atmospheric normalization are generally applied to satellite data in order to make the images obtained on different dates comparable (Chen and Wang, 2010; Hall and Hay, 2003; Johnson and Kasischke, 1998), but topographic normalization to

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remove illumination variation in the image is not commonly done before running classification. In order to remove topography-related constrains, techniques such as intensity normalization, and topography normalization using solar azimuth and solar elevation are available (Colby, 1991; Gupta et al., 2007; Shrestha and Zinck, 2001). In order to select the best method, it will be necessary to assess the effectiveness of these techniques to increase classification results. In modeling the erosion process the cover factor (C factor) (Wischmeier and Smith, 1978) is often used; it can be generated directly from the Normalized Difference Vegetation Index (NDVI). For converting NDVI to C-values available methods include using a Linear Least Square (de Jong, 1994) or an exponential function (Van der Knijff et al., 1999) both of which were derived based on data from semi-arid environments. For application in the tropics, converting NDVI to C-values following one of the established methods developed in semi-arid environments without field verification can be misleading and may not represent the real situation. Moreover, in the tropics plant residues are often left on the field after crop harvest acting as a green mulch. The plant residues also create obstructions for surface runoff and can reduce erosion. Thus, it will be essential to assess C values taking into account all the above mentioned conditions.

In order to prevent land degradation and formulate conservation plans, it is essential to know not only the magnitude of the erosion problem but it is also essential to know where these problems occur and which process is dominant. Runoff generation is a function of rainfall amount, vegetation interception loss and infiltration into the soil. When surface runoff flows down the slopes, it accumulates along the way thus increasing its eroding power. This is especially the case when no soil conservation measures are implemented to control surface runoff. As a result, rills and gully initiation start, which is more damaging to the land than sheet erosion alone. For mapping gullies, topographic parameters play an important role. The locations where gullies start are controlled by slope gradient while the presence of concavities controls their trajectory until sediment deposition starts (Desmet et al., 1999). The importance of topographic attributes in generating high surface runoff and gully initiation is reported in several studies (Cerdan et al., 2002; Daggupati et al., 2013, 2014). From a soil and water conservation point of view it will be interesting to see if areas having high erosion rates are also coinciding with areas prone to gully initiation. It will be thus very important to locate the areas susceptible to gully erosion so that effective measures can be implemented in time.

Overall objective of the study is to analyze the soil erosion process in steep inaccessible mountainous terrain in the tropics, where data scarcity is often a crucial problem. Specific objectives are (i) deriving land cover parameters from remote sensing and field measurement techniques, (ii) understanding the key factors responsible for generating surface runoff and soil erosion, and (iii) identifying critical areas for gully initiation using topographic parameters and erosion assessment so that planning for implementing conservation measures can be made (more) effective. To achieve these objectives, an area in the northern part of Thailand is selected as case study location. The area suffers from haphazard land cover changes including slash and burn agriculture with consequent effects on surface runoff and erosion.

2. Material and methods

2.1. Study area

The study area is located in the Nam Chun watershed in Petchabun Province, about 400 km north of Bangkok, Thailand (Fig. 1). It lies between 16° 40′ and 16° 50′ North latitudes and between 101° 02′ and 101°15′ East longitudes covering 67 km^2. The climate is tropical with distinct differences between dry (Oct–April) and wet (May–September) seasons. Average annual rainfall based on data from the meteorological station in Lomsak for the period 1953–2006 is 1095 mm, of which 80% falls during the monsoon period (May to September). Average annual temperature is 28 °C with the highest temperature reaching 38 °C in April and lowest of 17 °C in December. The watershed consists of high plateau areas, rugged mountain ridges with steep slopes and low lying narrow valleys. Elevation varies from 185 to 1490 m asl. The soils are mainly in the clay loam to silty clay loam texture classes. The presence of high clay content in the soils could indicate that the erodibility of the soil is not so high as far as its physical characteristic is concerned (Morgan, 1995).

There is one main road from Lomsak to Phitsanulok which passes through the Nam Chun watershed and overall accessibility to the study area is limited. The area has suffered from severe deforestation in the last decades due to population growth as well as due to the government campaign of fighting insurgents. The forest areas were cleared to create land for cultivation to feed the growing population, which caused land degradation problems such as accelerated soil erosion, gully formation, and land sliding. Main land use types consist of forest, degraded forest, cropland, grassland and orchard. Slash and burn is the common approach to clear forest area by the local population. Forests are more degraded in the low mountain area than in the high mountain area because of easy accessibility from the settlement areas located in the lowlands. Main agricultural crops are maize and beans in the upland sloping area and rice and vegetables in the lowland area. Agricultural practices on the steeper slopes cause soil erosion as no conservation practice is applied by the farmers except that they leave the crop residues after harvest. The crop residues protect the soil against splash detachment and create surface roughness. The dominant fruit tree type is tamarind but other fruit types grown are mango, papaya and banana. After a disaster caused by landslides and flashflood in August 2001, as a result of excessive rainfall, which destroyed lots of properties and caused loss of human lives in Nam Chun watershed and in various places in Thailand, reforestation programs have been implemented, and tree species such as teak, eucalyptus, *Gliricidia* and *Leucaena* were planted. Tamarind trees are cultivated in the hill slope areas and are intercropped with maize, soybeans and mung beans. For grasslands, the upper catchment is dominated by the species *Imperata cylindrica*.

Similar situations occur in most of the hill slope areas in Thailand. The area can also be considered a case study watershed for understanding the main processes involved in the generation of excessive runoff from the upland areas causing the severe flood disaster during the 2001 monsoon period in Thailand.

2.2. Deriving land cover parameters

2.2.1. Field estimation of cover factor

Fieldwork was carried out in September 2006 and September 2007. Field investigations and sampling were conducted along the main road passing through the Nam Chun watershed and in adjacent areas that could be reached on foot. For each land cover type, representative sample locations were identified and their geographic coordinates recorded using a GPS receiver (Garmin). These locations were later used as training samples (in total 138 samples) in order to carry out supervised image classification. An additional separate set of 104 samples was collected for the purpose of assessing image classification accuracy. Stratified random sampling was applied to select the sampling locations for which the main land use/cover types were used as strata.

In addition to collecting data for land cover classification, field estimations of cover factor C (Wischmeier and Smith, 1978) were carried out in different land cover types. It was based on prior land use (PLU), canopy cover percentage assessed for different cover types (CC), surface cover percentage (SC) and surface roughness (SR) as explained in the method for RUSLE (Renard et al., 1997).

The prior-land-use subfactor (PLU) expresses the influence on soil erosion of subsurface residual effects from previous crops and the effect of previous tillage practices on soil consolidation. For the case study area