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Fine-resolution remote-sensing and modelling of Himalayan catchment sustainability

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Abstract

A number of studies have reported on environmental degradation in the Nepal Himalaya as a result of large-scale deforestation and the associated agricultural extension. In contrast to many previous regional scale studies, we consider land cover and its environmental impact on an individual catchment-scale, using fine-resolution Quickbird data and a soil erosion model. First, using a detailed land cover map generated from Quickbird imagery, we establish basic relationships between land cover, dwelling density and topographic variability, which exist in a typical mid-elevation Nepalese catchment, the Pokhare Khola. These data suggest a strongly subsistence type of household economy based predominantly on terraced arable farming. We demonstrate using multitemporal vegetation indices that this farmland has existed in the region since the late 1980s, and that widespread deforestation has not taken place since then, possibly as a result of specific forest conservation policies of the government coupled with efforts by local communities. Further, through the use of soil erosion modelling we demonstrate the role that the terraced farming practices can play in reducing runoff and hence soil nutrient loss, thereby enabling restoration of vegetation in the previously deforested land terrains. Finally, by combining this information with regional land cover data, we show that the findings of this research can be scaled up to draw conclusions about environmental degradation across the Nepal Himalayan region.

Keywords: Remote-sensing; Quickbird; Deforestation; Environmental degradation; Soil erosion modelling; Nepal Middle Hills

1. Introduction

Environmental degradation poses a serious threat to the long-term sustainability of ecologically fragile mountainous Himalayan watersheds characterised by subsistence farming (Tiwari, 2000). Socio-economic and environmental changes have impacted heavily on land use in the region, mainly manifested by the extension of cultivation into marginal land and forested areas. Such changes have depleted and eroded the natural resources around populated areas, thereby reducing groundwater recharge and increasing surface runoff. The problem is well pronounced in mid-elevation (i.e. 1000–3000 m) areas of Nepal, where steep slopes and narrow valleys are conducive to high levels of erosion, particularly following a period of large-scale deforestation from approximately 1950–80. During this time, forested areas were placed under government ownership, which loosened controls on natural resource management and thus led to large-scale devastation of forest cover (Bajracharya, 1983). A key consequence of this land cover change was an increase in the rate of soil erosion in the region, which is now known to be very high in comparison to other parts of the world (Sen et al., 1997). This in turn has led to a gradual decrease in soil productivity, agricultural production and the incomes of subsistence farmers of the region.

Several studies have documented the extent of land use change in the area (Balla et al., 2003; Gautam et al., 2003; Rao & Pant, 2001), reporting on trends of deforestation and, in more

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recent decades, a reversal of this trend following forest conservation efforts by local communities and external agencies. Others have focussed on the controlling factors of the observed environmental change using bio-economic modelling (e.g. Sankhayan et al., 2003; Sitaula et al., 2005). Some studies have reported on the effects of degradation in the region, mostly focussing on river and reservoir siltation (Sthapit & Balla, 1999) and increases in the incidence and severity of flooding (Tiwari, 2000) although others have also considered the long-term effects on economic prosperity (Semwal et al., 2004). With the exception of a few studies (e.g. Saxena et al., 2005; Thapa, 1996), little attention has been paid to the management and conservation of agricultural lands, which account for a substantial proportion of all land resources in the region.

Until recently, detailed assessments of Himalayan catchment dynamics have depended mostly on the feasibility of extensive field investigations and surveys. Now, however, readily available and affordable fine-resolution satellite sensor imagery offers an alternative method for extracting such information, for analysis by itself or as input to models for simulating the impact of altering the environmental conditions within a catchment. Repeated satellite images can be used both for the visual assessment of land resources as well as the quantitative evaluation of land cover changes over time (Tekle & Hedlund, 2000). Furthermore, hydrological models can now be employed to evaluate the impact of land cover change on a catchment, such as the expansion of agriculture into previously forested areas. This approach allows us to better quantify the trends observed across the wider Himalayan region.

The impact of terrace farming practices on ecologically sensitive land is currently poorly understood in the Himalayan region. Thus, the aim of this paper is to provide an up-to-date analysis of the key issues surrounding environmental degradation in the Himalaya. We aim to demonstrate, for the first time, how the integration of fine-resolution remote-sensing data with GIS-based soil erosion modelling can be used to establish trends in land cover and land use, and evaluate how changes in both impact on land sustainability. This requires the fulfilment of several key objectives:

1. To use Quickbird remote-sensing data to map land cover in the Pokhare Khola catchment, Nepal, and analyse the extent to which it has changed over recent decades, by comparison with historical imagery and map sheet information.
2. To compare these catchment-scale land cover trends with regional trends, derived from various sources including previous studies, satellite data at a more coarse resolution (but with greater coverage) and classified historical map sheet data.
3. To couple the fine-resolution land cover maps with elevation data to demonstrate new potential for modelling the impact of deforestation and terrace agriculture on soil erosion in Himalayan catchments.

2. Study area

The Pokhare Khola catchment is situated in the Dhading district of the central development region of Nepal, and covers an area of approximately 5.28 km^2 (Fig. 1). Geographically, it lies between 27°46′28″ N and 27°48′06″ N latitude and 84°53′32″ E and 84°55′11” E longitude. The climate is classified as sub-tropical, and temperatures reach a maximum of 31 °C in summer months and 8 °C during winter. The average annual rainfall is 1370 mm, most of which falls during the monsoon period between May and September. The catchment is steepest in the south, reaching an elevation of 1079 m and drains to the north through its lowest point at approximately 380 m. Here, the water drains into the Trishuli River and travels westwards taking drainage into the lowlands. The catchment land cover is a mixture of forest, scrub and subsistence terrace farming. There are two predominant crop seasons, namely, rainy and winter seasons. While paddy and maize are the dominant rainy season crops, wheat and vegetables are grown in the winter season. Most families also keep livestock, mainly cows, goats and oxen, as complementary and supplementary activities to agriculture for their livelihood.

3. Data sources

Satellite image interpretation is based primarily on Quickbird data acquired on 21 February 2003, at 0.6 m spatial resolution in the panchromatic band and 2.8 m spatial resolution in four spectral bands. Neither scene was hampered by the presence of cloud cover and both were geo-referenced to UTM Zone 45 (WGS 84). In addition to the Quickbird data, which covered little more than the Pokhare Khola catchment, historical data from the 21st December 2001 and 22nd October 1986 were also acquired from the SPOT 4 HRVIR sensor (10 m spatial resolution multispectral) and SPOT 1 HRV sensor (20 m spatial resolution multispectral). Both images were supplied as L1G data, which are geo-referenced and radiometrically corrected. The scenes were cloud free and largely unaffected by shadow. SRTM DEM data were acquired (post-spacing of 90 m) to facilitate a regional assessment of topographic variability, but the coarse resolution of the data was insufficient for a detailed catchment-scale analysis. Thus, an ASTER DEM was also generated (post spacing of 15 m) using ERDAS software, which was used to establish topographic trends on a much finer scale in the Pokhare Khola. Comparisons between the two DEM datasets showed an average absolute height disparity of 56 m, but visual inspection of the two datasets revealed a high relative correlation, suggesting an accurate replication of the catchment topography by the ASTER stereo model. This finding contrasts with previous reports of large ASTER DEM errors in areas of extreme topography (Kääb et al., 2003).

In addition to satellite sensor imagery, eight map sheets of the catchment and its surrounding areas were acquired and scanned at a resolution of 300 dpi, equivalent to approximately 2 m pixel size. These map sheets were presented at a scale of 1:25 000 with primary elevation contours of 20 m, in a Modified Universal Transverse Mercator projection. They were compiled by the Survey Department of the Government of Nepal in 1994, in co-operation with the Government of Finland, using 1:50 000 scale aerial photography acquired in 1992.