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# Timberline change detection using topographic map and satellite imagery

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**Abstract:** High altitude ecosystems, defined by low temperatures, are known to react sensitively to climate warming. This study reports vegetation ingression and land cover changes in an area of Nanda Devi Biosphere Reserve in Central Himalaya using satellite imagery of 1986, 1999 and 2004. The topographic map of 1960 was taken as benchmark. The SRTM DEM data was used to extract information on elevation, slope and the aspect. The March 1986 satellite imagery showed snow, glaciers and scree as dominant land cover types with a few dense vegetation patches. The 1999 imagery showed marginal increase in vegetation cover while 2004 imagery revealed >20% increase in the vegetation cover and drastic reduction in snow cover, thereby showing vegetation ingression in erstwhile snow/ice areas. The elevation contours, overlaid on the 2004 imagery, showed the timberline at 4300 m, the alpine scrub line at 4900 m and the tundra vegetation line at 5300 m above m.s.l.. The topographic map of 1960 showed scrub, scattered trees and timberline between 3900 and 4000 m above m.s.l.. The study indicates rapid recession of glaciers and snow cover and ingression by vegetation probably due to global warming related rise in temperature.

**Resumen:** Los ecosistemas de alta elevación, definidos por temperaturas bajas, son conocidos por reaccionar de forma sensible al calentamiento climático. En este estudio se reportan la intrusión de la vegetación y los cambios en cobertura del suelo en una área de la Reserva de la Biosfera Nanda Devi en los Himalaya Centrales, usando imágenes satelitales de 1986, 1999 y 2004. Se tomó el mapa topográfico de 1960 como punto de referencia. Se usaron datos del modelo digital de elevación SRTM para extraer información sobre la elevación, pendiente y orientación. Las imágenes satelitales de marzo de 1986 mostraron que los tipos de cobertura terrestre dominantes fueron nieve, glaciares y pedreras, con unos pocos parches de vegetación densa. Las imágenes de 1999 mostraron un incremento marginal en la cubierta vegetal, mientras que las imágenes de 2004 revelaron un incremento > 20% en la cubierta de la vegetación y una reducción drástica en la cubierta de la nieve, mostrando la intrusión de la vegetación en áreas inicialmente cubiertas por hielo o nieve. Las cotas de altura, superimpuestas en las imágenes de 2004, mostraron el límite arbóreo altitudinal a 4300 m, el límite del matorral alpino a 4900 m y el límite de la vegetación de tundra a 5300 m s.n.m. El mapa topográfico de 1960 mostró matorral, árboles aislados y el límite arbóreo entre 3900 y 4000 m s.n.m. El estudio indica una rápida recesión de los glaciares y de la cubierta de nieve, así como la intrusión de la vegetación, probablemente debido a un aumento de la temperatura relacionado con el calentamiento del planeta.

**Resumo:** Os ecossistemas de elevada altitude, definidos por temperaturas baixas, são conhecidos por reagir de forma sensível ao aquecimento do clima. Este estudo relata o acesso da vegetação e das mudanças no coberto do solo numa área da Reserva da Biosfera de Nanda Devi no Himalaya central usando imagens de satélite de 1986, de 1999 e de 2004. O mapa topográfico de 1960 foi tomado como elemento de referência. Os dados SRTM DEM foram usados para

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extrair a informação sobre a elevação, declive e aspecto. A imagem de satélite em Março de 1986 mostrou a neve, glaciares e escarpas rochosas como tipos dominantes da cobertura do solo com algumas manchas de vegetação densa. A imagem de 1999 evidenciou um aumento marginal na cobertura de vegetação enquanto que a imagem de 2004 revelou um aumento superior a 20% na cobertura da mesma e a redução drástica na cobertura de neve, mostrando desse modo a entrada da vegetação em áreas que antes eram da neve/gelo. As linhas nível, sobrepostos na imagem de 2004, mostraram que linha de árvores a 4300 m, a linha de arbustos alpinos nos 4900 m e a linha da tundra acima dos 5300 m m.s.l.. O mapa topográfico de 1960 mostrava os arbustos, árvores dispersas e a linha de árvores entre os 3900 e 4000 m m.s.l.. O estudo indica uma rápida o diminuição dos glaciares e da cobertura de neve e a expansão pela vegetação, provavelmente devido ao aumento da temperatura relacionado com o aquecimento global.

**Key words:** Alpine zone, central Himalaya, climate change, remote sensing, snow and glacier, timberline.

## Introduction

Alpine areas are the areas located between timberline and snowline. Since most plant species have upper altitudinal limits that are set by various climatic parameters and by limitation of resources, alpine ecosystems are known to react sensitively to climate warming. Simulation studies show that climate change impact will result in alpine vegetation ingression at higher altitudes (Noble 1993) by pioneer species (Grabherr *et al.* 1994). Detailed observations on vegetation ingression in alpine regions of Europe are being carried out under the Global Research Initiatives on Alpine (GLORIA) project (Pauli *et al.* 2006). This study reports observations on the vegetation ingression and timberline changes over the last four decades using topographic maps and satellite remote sensing data.

## Materials and methods

### *Study area*

The 263 km² area of Nanda Devi Biosphere Reserve (NDBR), a World Heritage Site, in Central Himalaya (30° 20' - 30° 30' N and 79° 50' and 80° 00' E) was selected for this study. The elevation in the study area ranges from 3000 to 8000 m above m.s.l.. Due to the special protection status, NDBR is free from cattle grazing, firewood and fodder collection, lopping or logging for the past few decades. Thus, the site is ideal for studying the vegetation dynamics that could be attributed to purely natural influences. The main forest trees of the area are fir (*Abies pindrow* Brandis) and birch (*Betula utilis* Jacq.). The scrub vegetation is mainly comprised of assorted species of *Rhododendron* and herbaceous plants.

### *Data*

The topographic map of 1960 on 1:50,000 scale (prepared by Survey of India using aerial photographs), satellite imagery of March 1986 (Landsat TM), March 1999 (IRS LISS-III) and March 2004 (IRS LISS-III and LISS-IV) were used in this study. The green, red, near infrared (NIR) and shortwave infrared (SWIR) spectral bands of LISS-III and Landsat TM data with 23.5 m and 30 m spatial resolution, respectively, were used to monitor the changes in land cover over the years. IRS P6 LISS-IV data with 5.8 m spatial resolution in green, red and NIR bands was used to derive the current land cover map of the area. The Shuttle Radar Terrain Mission (SRTM) digital elevation model (DEM) data was used to derive the elevation map.

Topographic map was digitized to derive the thematic information on the vegetation, snow cover, scree and glaciers. The satellite imagery were geo-referenced with the topographic map using map to image registration technique. The thematic features *viz*. vegetation, snow cover, scree and glaciers for each data period were mapped using digital image analysis and maximum likelihood algorithm. The vegetation was separable with high accuracy from other classes due to its unique tone. The vegetation type and density modulated the tone. The vegetation was further categorized as dense, medium dense and sparse using normalized difference vegetation index

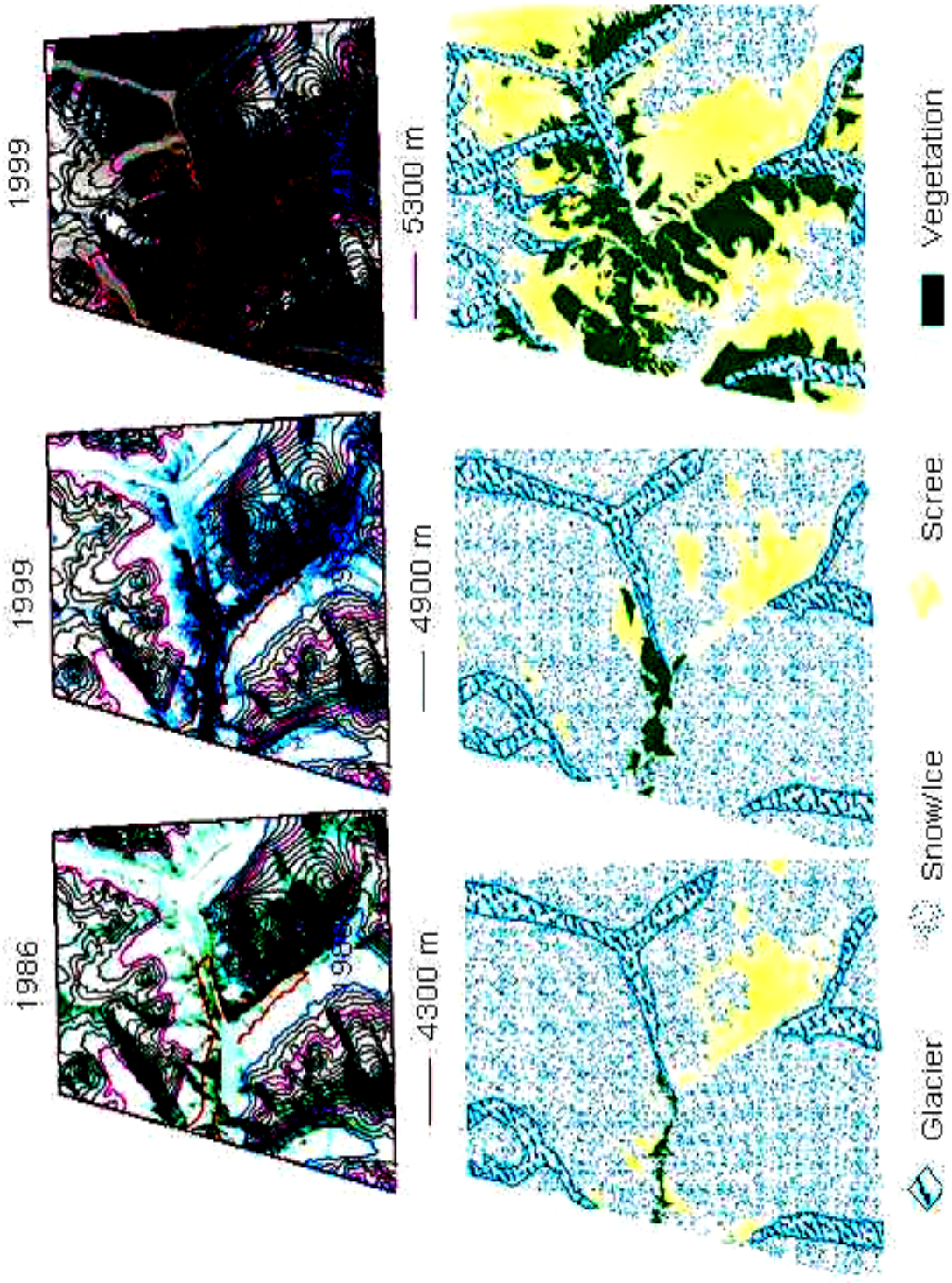


**Fig. 1.** Changes in vegetation and other land cover classes: (a) FCC of temporal satellite imagery overlaid with elevation contours, (b) classified images of the same area showing different land cover classes.

(NDVI). Three categories of vegetation *viz*., forest/woody, scrub and others (grasses and mosses) were delineated. The elevation contours were generated from DEM. The elevation contours were overlaid on thematic layer to detect the elevation-wise vegetation ingression and delineate the timberline, vegetation line and the snow line.

## Results and discussion

Interpretation of the topographic map showed that snow and glacier was the dominant class, followed by scree. Vegetation was marked as isolated scattered trees and scrub patches. Thus, it was not feasible to compute area under vegetation. The change analysis over time domain was done using satellite data. Interpretation of 1986 image showed that snow and glaciers occupied about 90.5% area, followed by scree (9.0%), while vegetation occupied merely 0.5% area. The 1999 image did not show any major change in snow and glacier and a marginal increase in the vegetation (by 1.8%). The 2004 imagery, however, showed notable changes. During this period, scree occupied maximum area (42%) followed by snow/glacier (35%) and vegetation (23%) (Table 1). Since the month of data acquisition was the same (March) in all the years, the change in land cover has more probability of being the true changes rather than the effect of season. Fig. 1 shows the extent of different land cover classes as seen in 1986, 1999 and 2004. The 2004 image clearly showed vegetation expansion by colonization of higher elevations, an area earlier occupied by snow/ice. Recent findings of Adhikari (2003) support this observation. The dense vegetation belonged to *Betula-Abies* community. The density and basal area of the trees was 160 trees $ha^{-1}$ and 4 $m^2$ $ha^{-1}$, respectively.

**Table1.** Changes in area (%) under different cover types from 1986 to 2004.

| Class | 1986 | 1999 | 2004 |
|---|---|---|---|
| Snow/Glacier | 90.5 | 89.9 | 35 |
| Vegetation | 0.5 | 1.8 | 23 |
| Scree | 9.0 | 8.3 | 42 |

The vegetation in Himalaya, especially above timberline, is influenced by several environmental factors such as altitude, slope, aspect, soil depth, moisture regime, wind velocity and exposure to sun (Barry 1994). These parameters play a significant role in determining vegetation colonization, growth and distribution. The significant change in vegetative cover from 1986 to 2004 indicates successful colonization by plant species in the newly available area after snow/ice melting. This could also be attributed to the ban in 1993 on grazing of sheep, goat and horses. The shrinking of snow/ice area could be attributed to global warming related rise in temperature, an observation also made by Gaur *et al.* (2005). The increase in forest density could be attributed to the complete ban on mountaineering and human activity in the NDBR by Government of India in 1982. Samant & Joshi (2003) reported better regeneration of plants, particularly *Betula utilis*, in same area in Himalaya.

Analysis of vegetation growth in relation to elevation showed presence of vegetation in >5000 m altitude areas. In 1986, the same was restricted to <4300 m altitude. The timberline could be delineated at 4300 m in 2004, scrub line at 4900 m and the tundra vegetation line at 5300 m above m.s.l. (Fig. 1). In the 1986 image, the timberline was unidentifiable and areas above 4000 m were covered by snow. Hence, as a baseline, we used the timberline demarcated on the topographic map of 1960. The timberline was between 3900 and 4000 m in the NDBR in 1960. Thus, a shift of >300 m in timberline was observed which is significant. These observations indicate that the high altitude ecosystems in Himalaya are already witnessing changes. A detailed study on timberline, snow line and alpine flora is required. Such a study should also include investigations on species composition, their IUCN status etc. to effectively model the impact of climate change. The experimental plan could be like that of GLORIA project. Other parameters such as aspect, which influence the vegetation growth and development (Kank *et al.* 2005) could also be taken in to account.

## Conclusions

This study indicates that the ecosystems in the Himalaya have shown significant changes since 1960. Vegetation ingression was noticed to higher altitudes areas that were previously under snow and ice. An apparent shift of around 300 m in timberline was observed. Satellite imagery was found to be of particular assistance in this in difficult Himalayan terrain. Regular monitoring of the timberline and associated changes in alpine ecosystems using satellite imagery is recommended for better understanding of the global warming related influences in Himalayas.

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