Road accessibility, population proximity and temperature increase are major drivers of forest cover change in the Hindu Kush Himalayan Region

The Hindu Kush Himalayan (HKH) region has been identified as one of the most important landscapes that needs to be preserved towards a global sustainable ecological balance. The HKH region holding around 210 million population is subjected to forest cover changes of various magnitudes on different spatial and temporal scales[1]. Apart from the natural factors, including climate, extensive deforestation, logging, lopping, heavy grazing, over-harvesting, land conversion, etc. are the major activities triggered by poverty, over population; and lack of awareness, that are all leading to forest depletion in this region[2–4]. In Asia, the most important driver of deforestation has been subsistence agriculture, followed by commercial agriculture, urbanization, infrastructure and mining activities[5,6].

The explanation of climatic, topographic and anthropogenic drivers for forest gain and loss is well known. However, their contribution to forest cover change varies across locations, scale and time. Though various deforestation studies have been carried out in the HKH region, the major drivers responsible need to be identified for effective management[7–9]. Recently, Behera *et al.*[10] have analysed the tree canopy cover (TCC) resilience and proneness in relation to the drivers in the HKH region. However, loss and gain of TCC has not been explained. The objectives of the present study are to use the freely available satellite remote sensing-derived TCC data to find the TCC loss and gain over the past decade; and to explain the phenomenon on the basis of climatic, topographic and demographic drivers. For this purpose regression analysis at appropriate significance level has been applied.

The HKH region with an estimated area of 4.3 m ha occupies 2.9% of global land and 18% of the global mountain area; it is spread over eight countries (Figure 1). The HKH region is divided into three parts according to the climatic and topographic conditions. The western, central and eastern Himalayan regions of HKH are characterized by mean annual temperature of 9.9°C, 8.9°C and 13.6°C respectively; and mean rainfall for June through September, estimated from 30-year rainfall data of 1961–1990 is 86, 546 and 1042 mm respectively[11]. Cold and hot deserts cover most of the area, leaving major portions uninhabited. The topographic and climatic variability of the HKH region is complex, supporting only 18% of the area under forest canopy.

We collected information on topographic, anthropogenic and climatic drivers from different data portals at varied resolution for the period 2000–2010 (Table 1; Figure 1). We generated secondary data such as slope and terrain ruggedness index (TRI) values from DEM data; and the distance to road, distance to built-up area and decadal change in population, from the primary data (Table 1; Figure 1). Data on loss and gain of TCC for the period 2000–2012 were downloaded from the Earth Engine Partners database (Table 1). The TCC loss data represent total loss on an annual timescale. The pixels were encoded with values from 0 (no change) to 12 (year of loss) for each year from 2000 to 2012. The TCC gain data were encoded as 0 (no change) and 1 (gain) for each year from 2000 to 2012 (Figure 2). We calculated and used TCC loss and gain data for the period 2000–2012 in the present study.

All the drivers and TCC data were resampled to a spatial resolution of 5 km

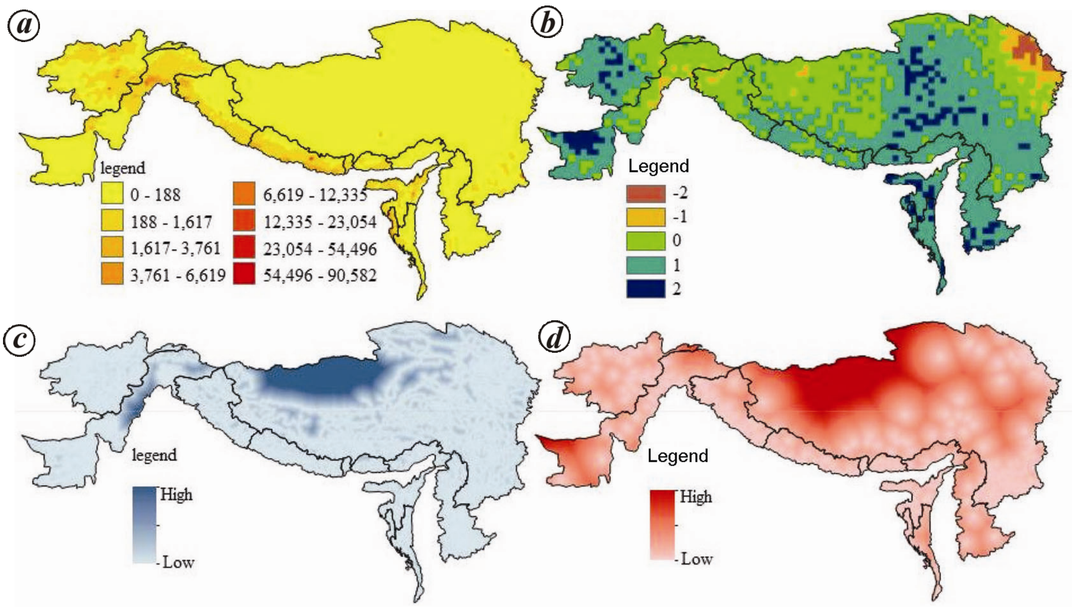

Figure 1. Drivers play a significant role in tree canopy cover change. ***a***, Change in population count. ***b***, Change in mean annual temperature. ***c***, Distance to road. ***d***, Distance to built-up area.

Table 1. Driver data used for analysis (modified from Behera *et al.*[10])

Data	Year	Resolution	Data source	Processing steps
Tree canopy cover Tree loss and gain Tree loss year	2000 and 2010 2000–12 2000–12	30 m	Earth engine partners	TCC loss and gain maps were statistically generated. Grid cells with 0% TCC are termed as 'no' TCC areas and those with 1–100% TCC are termed as forest cover.
Mean annual temperature Total annual precipitation	2000–10	0.5 deg	CRU data	Mosaicked and extracted for the HKH region.
Forest fire	2000–10	500 m	MODIS (Reverb)	Total fire occurrences were calculated during the decadal period by simple addition.
DEM (SRTM) slope Terrain Ruggedness Index (TRI)	2000	90 m	CGIAR-CSI	Slope and TRI were derived from DEM using *Erdas* IMAGINE package
Cropland	2000 and 2010	500 m	MODIS	Some observed noise in the data was removed using knowledge-based masking. Cropland data were further converted to points for Euclidean distance analysis.
Distance to cropland Population count Population density	2000 and 2010	5 km	EDIT	Each cell shows population count and density used for change detection during 2000–10.
Built-up locations (distance to built-up locations)	2000	Vector	SEDAC	Built-up location data were used to estimate the Euclidean distance of each location from the nearest built-up locations.
Road locations (distance to road locations)	1980–2010	Vector	SEDAC	The data layer was used to find the Euclidean distance of each location from the nearest road (line)

EDIT, European Distributed Institute of Taxonomy; SEDAC, Socio-economic Data and Applications Centre; CSI, Consortium for Spatial Information; DEM data, http://srtm.csi.cgiar.org/; SEDAC, http://sedac.ciesin.columbia.edu/; MODIS DATA, http://reverb.echo.nasa.gov/reverb/; EDIT, http://edit.csic.es/HumanPopulation.html; CRU, http://www.cru.uea.ac.uk/cru/data/hrg/.

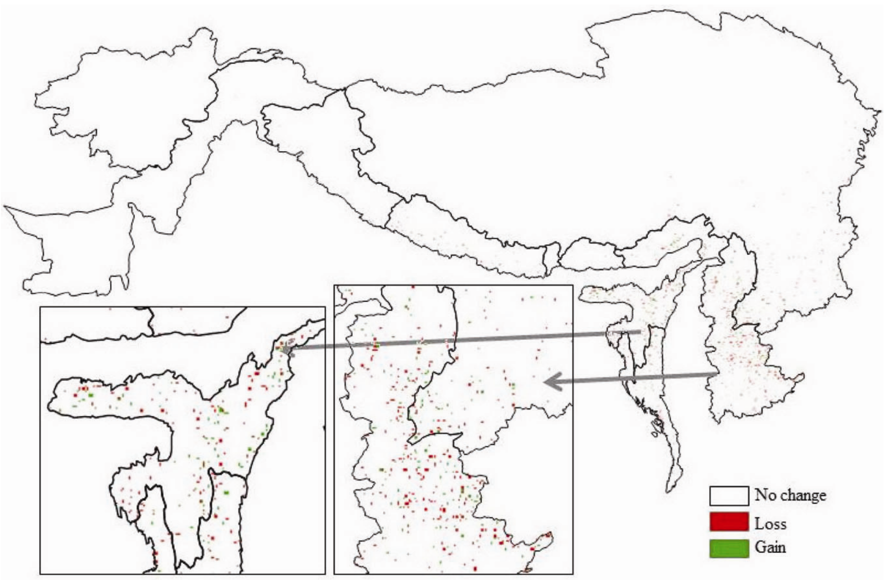

Figure 2. TCC loss and gain during 2000–10. Part of North East Indian states, Western Myanmar and a small part of China are highlighted, where deforestation and plantation are going on hand in hand.

to achieve optimum computation time and space (Figures 1 and 2). Changes in the driver data (between time T_1 and T_0) were estimated by simple subtraction (Table 1; Figure 1). However, the topographic variables, distance data to built-up area and road available for the year 2000 were also used (Table 1). The grid cells with 0% TCC were classified as

Table 2. Driver-wise β-coefficients and their corresponding significance levels as derived using logistic regression for TCC gain and loss; β-coefficients at <0.005 level are considered significant

	Gain		Loss	
Driver	β-Coefficient	Significance level	β-Coefficient	Significance level
Distance to road location	–1.398	0.055	–2.841	0
Distance to built-up location	–0.747	0	–0.572	0
Change in mean annual temperature	0.518	0	0.247	0.001
Change in population count	0	0.16	0.012	0
Change in total precipitation	0	0	0	0
Change in population density	0	0.981	0.0001	0.6
Elevation	0	0	0	0
Slope	0.088	0.01	0.049	0.081
TRI	0.003	0.021	0.002	0.1
Change in distance to cropland	0.414	0.03	0.367	0.06
Total fire occurrence	0.093	0.762	0.46	0.017

having 'no' forest cover, and those with 1–100% TCC were classified as having forest cover. To analyse the change in TCC in relation to the drivers, TCC loss and gain and other driver data of the raster grids were converted to vector points. Due to the large number of TCC loss and gain point occurrences, only 1% of the 'no change' points was selected (randomly) for regression analysis. Due to this data limitation (i.e. availability of data on forest cover change and no change), a binary logistic regression analysis was performed to determine the relationship between forest cover changes and drivers in terms of β-coefficients with the respective significance values (Table 2). The logistic regression can be mathematically formulated as:

$$Y = (\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_n),$$

where Y is the dependent variable, β_0 is the intercept and $\beta_{1,2\ldots n}$ are the coefficients associated with the variables $X_{1,2,\ldots n}$. The sign (–/+) and magnitude of the β-coefficients define their direction (direct and inverse, i.e. positive and negative) and relationship. For example, if $\beta_1 = 0.5$ and $\beta_2 = 0.3$, then Y will be influenced more by X_1 (corresponding to β_1) than by X_2 (corresponding to β_2), and Y will increase with increasing X_1 and X_2. A positive β-coefficient signifies a directly proportional relationship, and a negative β-coefficient defines an inversely proportional relationship, i.e. with a positive β-coefficient, the driver triggers a positive change and vice versa.

About 816,325 and 805,075 sq. km of the total study area (4,323,750 sq. km) was found under TCC in 2000 and 2010 respectively[12]. Between these years, 13,225 and 1975 sq. km of forest cover was lost and gained respectively, leading to an overall loss of 11,250 sq. km and a gain of 6050 sq. km (Figure 2). Table 2 presents the β-coefficient and significance values corresponding to TCC loss and gain for each driver. The change in mean annual temperature and distance to built-up area were the two significant drivers associated with TCC gain. The changes in mean annual temperature and population count and the distances to built-up area and roads were observed to be significant drivers of TCC loss. The other drivers were either insignificant (>0.005) or had β-coefficient values of 0 and were therefore rejected (Table 2).

The TCC loss in relation to distance to road with a negative β-value (–2.841) was highly significant, indicating that road networks have a dominant role in deforestation as they increase accessibility. A rapid expansion of the population enhances and/or leads to the establishment of sprawling built-up areas. The negative β-coefficient (–0.572) associating TCC loss with distance to built-up area explains the inverse proportional relationship between these two and the effect of the proximity of built-up areas. However, distance to built-up area is also observed to have a negative β-coefficient value (–0.747) for TCC gain, indicating that there are afforestation activities around built-up areas[12].

The mean temperature has increased during the past decade in the HKH region. Thus, there is a positive β-coefficient (0.518) related to TCC gain with change in mean annual temperature. This may be explained by the fact that more areas will be available/suitable for afforestation due to increased temperatures at higher elevation, which would otherwise have been cold deserts lacking vegetation. This elevation range shift has been reported[13]. However, the low, positive β-coefficient (0.247) relating TCC loss with change in mean annual temperature is not very significant (significance level, 0.001). This may be explained by the fact that increasing temperatures will lead to loss of TCC at lower elevation. Burgess *et al.*[14] mention that, conversely, a loss of forest cover leads to a temperature rise. The change in total population over the last decade was observed to be positively correlated with ($\beta = 0.012$) TCC loss (Table 2).

The rate of TCC loss during 2000–2010 in the HKH region was observed to be around 937.5 ha/year. The TCC change caused by the explanatory variables was efficiently modelled by the binary logistic regression model. The sign and magnitude of the β-coefficients helped qualify and quantify the impacts of the individual drivers on the TCC change process. Although a positive correlation was observed for change in mean annual temperature, with both a loss and gain occurring, it was concluded that change in mean annual temperature is an insignificant driver of TCC change in the decade studied. However, the impacts of anthropogenic variables are clearly seen from the negative and high values of the β-coefficients associated with distance to roads and built-up area, and the positive β-coefficient associated with change in total population. Thus the present study shows the usefulness of statistical modelling approach in identifying the major drivers of TCC change.

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MANCHIRAJU SRI RAMACHANDRA MURTHY[1]
PULAKESH DAS[2]
MUKUNDA DEV BEHERA[2,*]

[1]*International Centre for Integrated Mountain Development, GPO Box 3226, Kathmandu, Nepal*
[2]*Centre for Oceans, Rivers, Atmosphere and Land Sciences, Indian Institute of Technology, Kharagpur 721 302, India*
**For correspondence.*
e-mail: mdbehera@coral.iitkgp.ernet.in

Histopathological changes in golden hamsters induced by *Leishmania tropica*

Several hundred million people are living in areas where they can be infected with leishmaniasis, a disease caused by over 20 species of pathogenic intracellular protozoan parasites of the genus *Leishmania* and transmitted through the bite of a female phlebotomine sandfly. *Leishmania* parasites infect phagocytes, dendritic cells and fibroblasts[1]. The essential vertebrate host target cell is the macrophage, where the intracellular amastigotes of *Leishmania* reproduce, eventually rupture the cell and spread to other uninfected macrophages[2]. Then these infected cells migrate to all host tissues. *Leishmania* parasites have a high chance for damaging some tissue functions. The clinical spectrum of leishmaniasis varies from an auto-resolving cutaneous lesion, to a distorting mucocutaneous disease, to a fatal visceral illness[3]. One of the important factors determining the pattern of pathology is the species of *Leishmania*[4]. However, the vectors, nutritional status, genetic background of the host and socioeconomic and environmental factors also have an important impact on the outcome of the disease[3,4]. Patients, infected by the same species of *Leishmania*, may give rise to various symptoms[5] and may respond differently to treatment[6,7]. Lately, the BALB/c strain of mice has attracted much attention because it produces visceral leishmaniasis which may be used as a model for studying human visceral leishmaniasis[8]. We address some histopathological features of viscerlizing of *L. tropica* in golden hamsters as a model to study human visceral leishmaniasis.

Leishmania tropica was isolated in Baghdad teaching hospital, Baghdad, Iraq from a skin lesion on the left arm of a 21-year-old male[9]. Males of golden hamster ($n = 60$), aged 8–10 weeks, were supplied by the National Center for Drug Control and Researches (NCDCR), Baghdad. The golden hamsters were divided into two groups, each consisting of 30 hamsters which were inoculated as follows: one was inoculated with 5×10^7 promastigotes of virulent isolate of *L. tropica* which was already cultivated in biphasic medium[10]. The other was the control group with hamsters inoculated with 0.2 ml of phosphate buffer saline.

All hamsters were injected intradermally in the left rear footpad using 1 ml

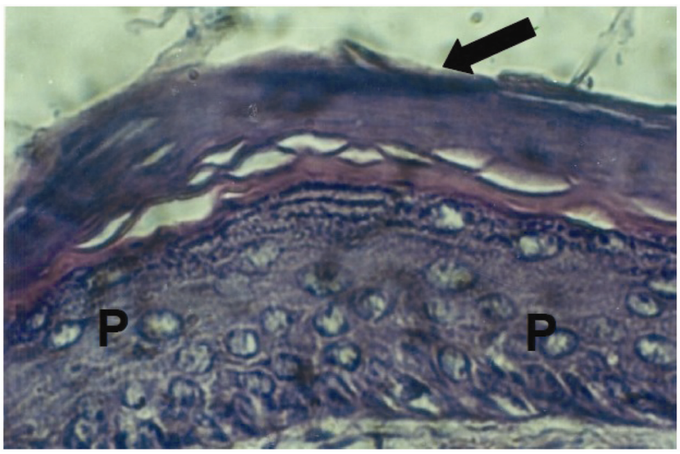

Figure 1. Section in footpad of infected group, showing hyperkeratosis (black arrow) and hyperplasia (P), 60 days post-infection, hematoxylin and eosine stain (400X).