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Research Article

High Altitudinal Vegetation Dynamics Including Treeline Ecotone in Langtang National Park, Nepal

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Abstract

Identification of high altitudinal vegetation dynamics using remote sensing is important because of the complex topography and environment in the Himalayas. Langtang National Park is the first Himalayan park in Nepal representing the best area to study vegetation change in the central Himalaya region because of the high altitudinal gradient and relatively less disturbed region. This study aimed at mapping vegetation in Langtang National Park and its treeline ecotone using Moderate Resolution Imaging Spectroradiometer (MODIS), Normalized Difference Vegetation Index (NDVI). Two treeline sites with an altitude of 3927 and 3802 meters above sea level (masl) were selected, and species density was measured during the field survey. The linear slope for each pixel and the Mann Kendall test to measure significant trends were used. The results showed that NDVI has significantly increased at the rate of 0.002yr^{-1} in Langtang National Park and 0.003yr^{-1} in treeline ecotone during 2000-2017. The average 68.73% equivalents to 1463 km^2 of Langtang National Park are covered by vegetation. At the same time, 16.45% equivalents to 350.43 km^2 are greening, and 0.25%, i.e., 5.43 km^2 are found browning. In treeline ecotone, the vegetation is mostly occupied by grasses, shrublands and small trees where the NDVI was found from 0.1 to 0.5. The relative changes of NDVI in barren lands are negative and vegetative lands above 0.5 NDVI are positive between 2000 and 2017. The dominant treeline vegetation were *Abies spectabilis, Rhododendron campanulatum*, *Betula utilis* and *Sorbus microphyla,* with the vegetation density of 839.28 and 775 individuals per hectare in sites A and B, respectively. The higher average NDVI values, significantly increased NDVI, and higher density of vegetation in both A and B sites indicate that the vegetation in treeline ecotone is obtaining a good environment in the Himalayas of Nepal.

Keywords: Langtang National Park, NDVI, treeline ecotone, vegetation greenness

Introduction

Vegetation changes have been widely investigated using both ground and satellite-based observation. In-situ monitoring, surface and remote sensing approaches provide information on surface vegetation changes at varying temporal and spatial scales (Chen et al. 2019; Wang et al. 2019). Among these, satellite imagery has potentially emerged to study vegetation changes on a large spatial scale (Kerr & Ostrovsky 2003). The satellite-derived Normalized Difference Vegetation Index (NDVI) is used as a proxy indicator of the vegetation changes. Thus, vegetation dynamics at local, regional, national and global scales are identified using NDVI (Chen et al., 2014; Gang et al., 2016; Kong et al., 2017; Panday & Ghimire, 2012; Piao et al., 2015; Wang et al., 2017; Zhong et al., 2010). The global monitoring of NDVI is used to predict the ecological effects of environmental changes, directly influencing on structure and functioning of the ecosystem (Pettorelli et al., 2005). The NDVI has shown a consistent correlation with vegetation biomass and dynamics in various ecosystems worldwide (Myneni et al., 1995; Running, 1990) because the NDVI correlates directly with the vegetation productivity (Reed et al., 1994). The NDVI provides information about the spatial and temporal distribution of vegetation communities (Reed et al., 1994), CO_2 fluxes (Vourlitis et al., 2003; Wylie et al., 2003), land degradation in a various ecosystem (Bai et al., 2008; Holm et al., 2003; Thiam, 2003), forest carbon dynamics(Dong et al., 2003; Myneni et al., 2001; Piao et al., 2005), land use and land cover (He et al., 2017), identification of drought (Deng et al., 2013; Domenikiotis et al., 2004; Liang et al., 2017; Qian et al., 2016), fire (Maselli et al., 2003), flood (Wang et al., 2003) and frost (Tait & Zheng, 2003).

The NDVI is the ratio of the difference between the near-infrared and red visible bands and the sum of these two bands (Rouse et al. 1974; Tucker, 1979). It depends on chlorophyll pigments in which healthy plants absorb more visible light indicating more photosynthesis activities and productivity. The NDVI values range between -1 to +1, whereas the NDVI value increases with increase in the greenery of the forest, grasses, shrub and croplands (Tucker, 1979). The NDVI is used for vegetation mapping, in which more than 0.1 NDVI represents vegetation (Fang et al., 2004; Zhou et al., 2001). Recently, vegetation studies have also found focusing on the Himalaya (Anderson et al., 2020; Mishra & Mainali, 2017; Paudel & Peter, 2010).

The highest altitudinal limit of the forests separated from alpine or tundra vegetation is commonly referred to as treeline representing high elevation vegetation zones. It is

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found as the upper altitudinal or latitudinal limit in which upright trees reach either two or three meters in height (Gaire et al., 2014; Harsch et al., 2009; Körner & Paulsen, 2004; Schickhoff et al., 2016). The treeline ecotone in the Nepal Himalaya is characterized as climatic (natural), orographic (topography) and anthropogenic (Gaire et al., 2014).

The alpine vegetation is an important indicator of the environmental changes, which shows a quick response to the climate and other bio-physical environmental changes (Shrestha et al., 2012). As the climate has warmed, many treelines around the planet have shifted upwards (Gaire et al., 2014; Greenwood & Jump, 2014; Harsch et al., 2009) and few of them are stable as well. The diverse topography, biodiversity, treeline form and human influences make the Himalaya complex where treeline vegetation are changing their spatial ecological niche (Xu & Grumbine, 2014). The mountain region of Nepal is dominated by high altitudinal needle-leaved open and closed forest which are mainly evergreen forests such as Pine forest (Blue pine, Chir pine), Birch-Rhododendron, Fir-Hemlock-Maple, Oak-Laurel, Mountain Oak-Rhododendron forest, Juniper, Larch and some deciduous evergreen forest (MENRIS/ICIMOD, 2008). These vegetation growths and distribution in treeline ecotone of the alpine regions have been rapidly changing in response to the environment over time, which refers to treeline dynamics or treeline vegetation dynamics. *Abies spectabilis* (Himalayan Silver fir), *Betula utilis* (Himalayan birch) and *Pinus wallichiana* (Himalayan blue pine) are the dominant treeline species in Nepal Himalaya (Chhetri et al., 2017). *Abies spectabilis* cover treeline ecotone ranging from 3800 to 4100 m above sea level (masl) (Chhetri & Cairns, 2015; Chhetri & Cairns, 2016). In the Trans-himalayan regions of Nepal, the treeline ecotone occurs between 3800-4100 m and is dominated by *Betula utilis* and *Abies spectabilis* with few presence of *Pinus wallichiana* (Tiwari et al., 2017a; Tiwari et al., 2017b). In central Nepal, treeline forming vegetation is associated with *Rhododendron campanulatum* (bell rhododendron) and *Juniperus indica* (black juniper). Several previous studies have shown the treeline response to climate changes over the limited area of the Nepal Himalaya (Chhetri & Cairns, 2015; Gaire et al., 2014; Kharal et al., 2017; Shrestha et al., 2017; Sigdel et al., 2018; Thapa et al., 2017; Tiwari et al., 2017a). Few studies of modeling have also been conducted for studying treeline vegetation dynamics and habitat distribution of the plant's species (Chhetri et al., 2018; Chhetri et al., 2017; Schickhoff et al., 2015). All of this above-mentioned research were mainly relying on dendrochronological approach and point-scale research.

Langtang National Park (LNP) is the first Himalayan protected area in Nepal. It experiences a wide range of climate and diverse vegetation types because of high altitudinal gradient ranging from 792 to 7,245 m a.s.l. In the meantime, the area is less disturbed. Very few studies have been carried in this region using satellite- derived NDVI data. The study of spatio-temporal variation of NDVI using MODIS data in Koshi River basin showed increased NDVI (Wu et al., 2020). However, this study covered large areas but not addressed treeline ecotone. In this context, we aimed to study vegetation changes in Langtang National park, and its treeline ecotone (3700-4200m) using MODIS NDVI images. Finding of vegetation greeness in treeline ecotone using NDVI is another objective of this research. Based on vegetation coverage, treeline vegetation dynamics inside the park were identified and verified using in-situ measurement. Identification of vegetation dynamics in treeline ecotone using NDVI is the first attempt in these region. The areas of maximum average NDVI and significant positive NDVI trends are considered a good habitat of vegetation in treeline ecotone (Baniya et al., 2018).

Remote sensing is a widely used technique for detecting treeline dynamics (Zong et al., 2014). The remote sensing derived NDVI has the privilege to quantify continuous vegetation changes within each pixel. A pixel with few trees might be classified as non-forest during land covers classification, even though it has a higher NDVI value than barren lands. Identification of these changes is very difficult in any classified images, while NDVI can locate it more accurately (Zhang et al., 2009). The field study has been conducted to verify remote sensing based NDVI results, vegetation types in treeline ecotone and altitudinal position of the treeline. The density of treeline vegetation was also estimated in two treeline sites; one faced on South-West, and another faced on South-East direction of the Lauribinayak hill in the park and identified numbers of treeline vegetation per unit of area. This study also seeks the relevancy of remote sensing for vegetation change in high altitudinal regions and treeline ecotone of the Nepal Himalaya. The study incorporates both field observation and remote sensing approach.

Materials and Methods

Study area

Langtang National Park is located in North-Central Nepal between 27° 57' and 28° 22'N to 85°12'and 85° 52'E. It represents some of the best examples of graded climatic conditions in the Central Himalaya. It is the first Himalayan park within the sacred Himalayan landscape in Nepal, with 2130 km^2, including a buffer zone. The elevation gradient is distinct in LNP, which ranges between 7145 m a.s.l (Lirung) as the highest and 792 m a.s.l (Bhote Koshi) as the lowest (Chaudhary, 1998). This high altitudinal variation is coupled with unique topography and vegetation. In 2010, the park was mainly occupied by forest (37.59%) with a large area of needle-leaved, i.e., 35.47% and 2.12% broadleaved forest. Similarly, the land use category includes 19.41% snow/glacier, 16.33% barren, 17.62% grasslands, 4.66% agricultural lands, 4.28 % shrublands, and 0.077% rivers in 2010 (Uddin et al., 2015) (Fig. 1). The LNP is extended over parts of three districts, namely Rasuwa, Nuwakot and Sindhupalchowk of Bagmati Province (MoFALD, 2017). The main dominant treeline vegetation in LNP is *A. spectabilis* associated with *R. campanulatum* and *J. indica*. The treeline was mainly found in between 3700 to 4200 m.a.s.l. in the park (Fig. 1).

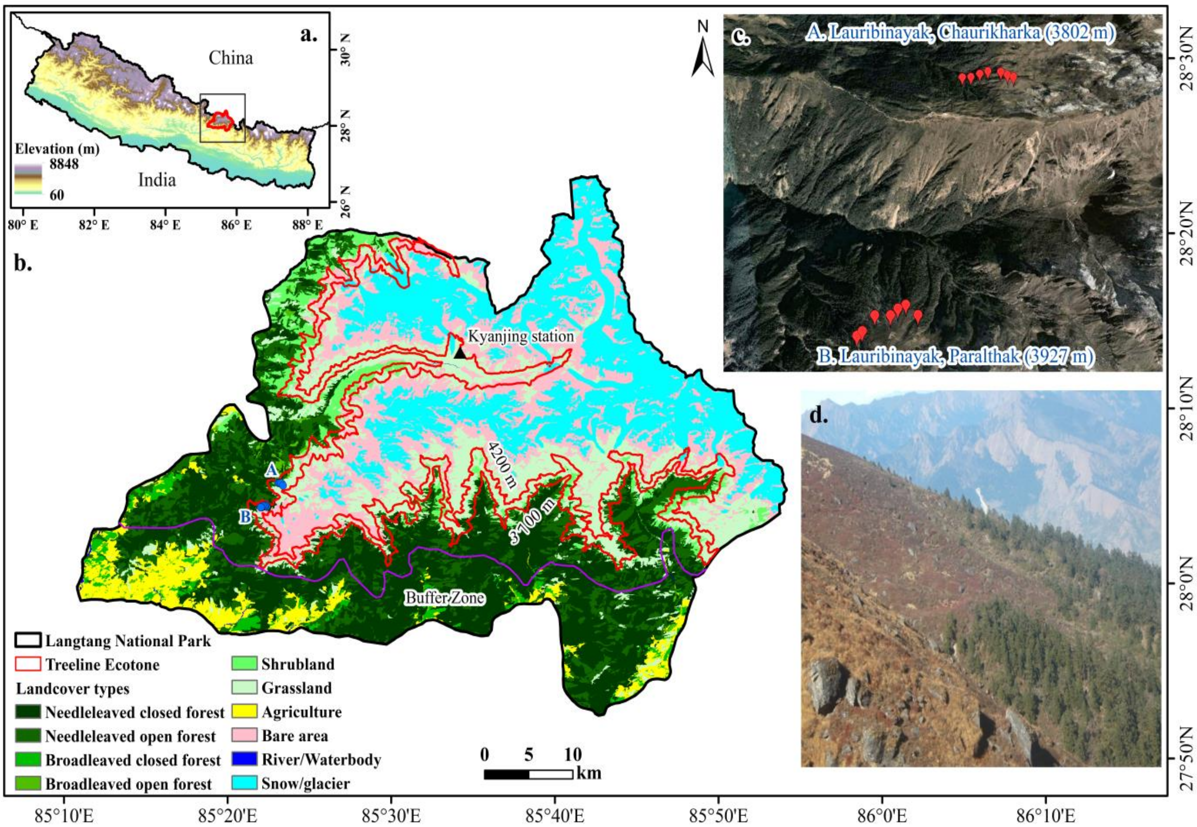

Figure 1 The inset (a) shows the location of the study area with highest altitude of 8848 m (corrected 8848.86 m), i.e., LNP with its land cover (Uddin et al., 2015), treeline ecotone, and filed study sites (b) the left top figure (c) shows the treeline in google image (Sites A and B) whereas left down figure (d) shows treeline in the study area.

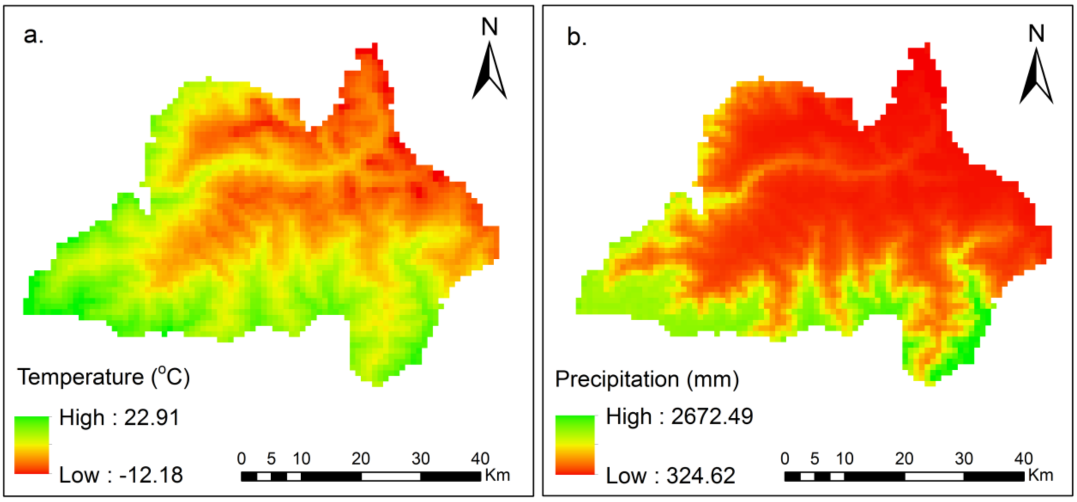

Figure 2 Climatic Research Unit 1km gridded average annual temperature and precipitation during 2000-2017 at Langtang National Park, Nepal.

The average annual temperature and precipitation data obtained from CRU data during 2000-2017 (Harris et al., 2014) and downscaled to 1km (Mosier et al., 2014) in LNP are presented (Fig. 2). The temperature and precipitation are the highest in lower parts of the study area and gradually decreased towards the higher altitude. The nearest meteorological station from the treeline ecotone of the park is situated at Kyanjing (Altitude-3920 m; index no-1031; location- 28°13'N and 85°34'E) showed that the average annual temperature was 6.04°C with a maximum of 12.74°C, minimum of 0.71°C, and the average annual precipitation was 545 mm during 2000-2017(DHM, 2017).

Data and data processing

The MODIS NDVI, i.e., MOD13Q1 Terra product, was used to study vegetation dynamics (Didan, 2015). The data has 16 days temporal and 250 m spatial resolution spanning from 2000 to 2017. The noise of NDVI time series datasets was removed using the Savitzky-Golay filter, which provides a simplified least-squares-fit convolution for smoothing and computing derivatives of a set of consecutive values (Savitzky & Golay, 1964). The auxiliary data such as land use and land cover (Uddin et al., 2015), and Shuttle Radar Topography Mission (SRTM) 30 m Digital Elevation Model (DEM) (Jarvis et al., 2008) were used. A field study was also conducted in September 2020 for the verification of the results. In LNP, two treeline sites, i.e., Lauribinayak- Chaurikharka (Site A) and Paralthak (Site B), were chosen at an average altitude of 3802 m and 3927 m a.s.l, respectively. In the selection of these sites, preference was given in the area that has lesser or no anthropogenic activities and the treeline was selected based on the upper tree limit (at least 2 m in height).

Data analysis

Spatial and temporal vegetation changes in LNP during 2000-2017

The annual average NDVI from 2000-2017 was computed from raster image analysis in ArcGIS 10.2. The linear slope of NDVI for each pixel (Baniya et al., 2018; Fensholt & Proud, 2012; Liu et al., 2015; Piao et al., 2011) and *p* values for the significant changes using Mann Kendall (Kendall, 1975; Mann, 1945) and Sen's slope (Sen, 1968) test were calculated. Then, the net vegetation changes in LNP and treeline ecotone of the park were identified using the following equation (Baniya et al., 2019).

$$\text{Net NDVI changes} = \sum_{i=1}^{n} N_i \ A_i \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where i represents a pixel with a statistically significant trend, n is the total number of such pixels, N_i is the number of pixels in which NDVI is significantly changed, and A_i is the pixel area.

Vegetation coverage in treeline ecotone of LNP

The treeline vegetation in LNP was identified based on average NDVI in treeline ecotone. The mean NDVI below 0.1 is not considered as vegetation (Fang et al., 2004; Zhou et al., 2001). Therefore, the higher NDVI denotes higher vegetation presence, i.e., trees, seedlings, and saplings represent a good habitat for treeline vegetation. NDVI provides the direct evidence of the vegetation at any locality. The following four categories of NDVI were used to find the vegetation coverage in the treeline ecotone of LNP in Central Himalaya of Nepal (Baniya et al., 2018) (Table 1).

The NDVI values greater than 0.1 to +1 were categorized as a normal, good and excellentsurface vegetation coverage, respectively. In this study, treeline ecotone was considered between 3700-4200 m altitude in LNP based on field observation and previous records of treeline altitudinal position found in the Nepal Himalaya (Chhetri & Cairns, 2015; Chhetri et al., 2018; Gaire et al., 2014; Tiwari et al., 2017a).

Table 1 NDVI categories used to identify greenness of vegetation in treeline ecotone of LNP during 2000-2017.

Category	NDVI values	Greeness of vegetation
1	< 0.1	Poor
2	0.1-0.3	Normal
3	0.3-0.5	Good
4	>0.5	Excellent

Measurement of treeline species density

The total number of 14 quadrat (7 in each site of having 20 × 20 m size) were sampled at two treeline sites. The number of treeline species (>2m ht) that occurred within the quadrat was recorded to find the treeline species density. The density was calculated using the following equation for the practical approach of the vegetation description (Kent & Coker, 1995)

A horizontal transect of 100m was drawn in the treeline, and quadrat were sampled randomly based on treeline species presence in Chaurikharkha and Paralthak treeline sites in the Lauribinayak (Fig. 1). The total number of 7 quadrat of 20 × 20 m was sampled in each treeline site. The densities of treeline species were measured to support satellite-derived NDVI and NDVI changes in both treeline sites located in LNP.

$$Density\ (N/ha) = \frac{Number\ of\ treeline\ species\ in\ all\ quadrate}{Total\ number\ of\ quadrate\ studied \times Area\ of\ quadrate\ studied} \times 1000 \ldots..(2)$$

Results and Discussion

Vegetation dynamics based on MODIS NDVI changes

The spatial average NDVI of all pixels during 2000-2017 in LNP was 0.286 and 0.277 in it's treeline ecotone. The spatial average NDVI has significantly increased at the rate of 0.002 yr^{-1} in LNP and 0.003 yr^{-1} in treeline ecotone during the last 18 years. The spatially averaged temporal vegetation has increased in all the park areas and treeline ecotone of LNP. However, the average NDVI was lower in 2000 and 2004 in the park and 2000, 2004 and 2015 in the treeline ecotone. Similarly, both the park and treeline ecotone showed higher average NDVI in 2009 (Fig. 3).

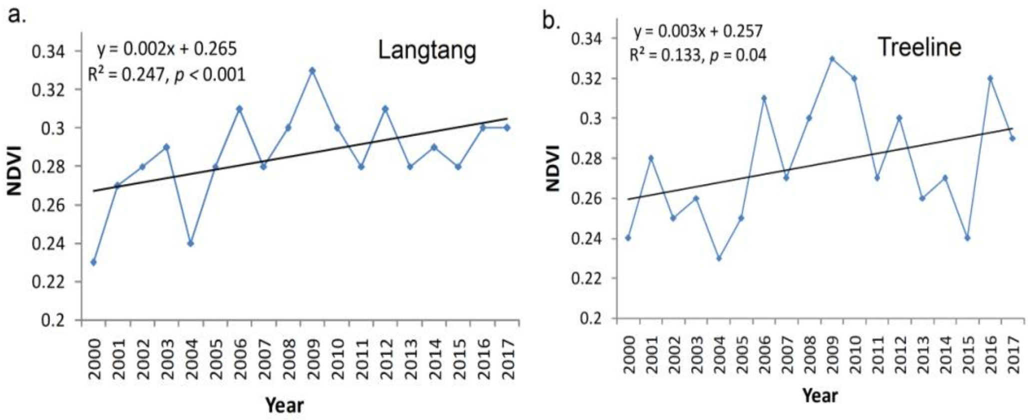

Figure 3 Temporal trends of spatial average NDVI based on Mann Kendell and Sen's slope (a) Langtang National Park and (b) treeline ecotone in Nepal during 2000-2017.

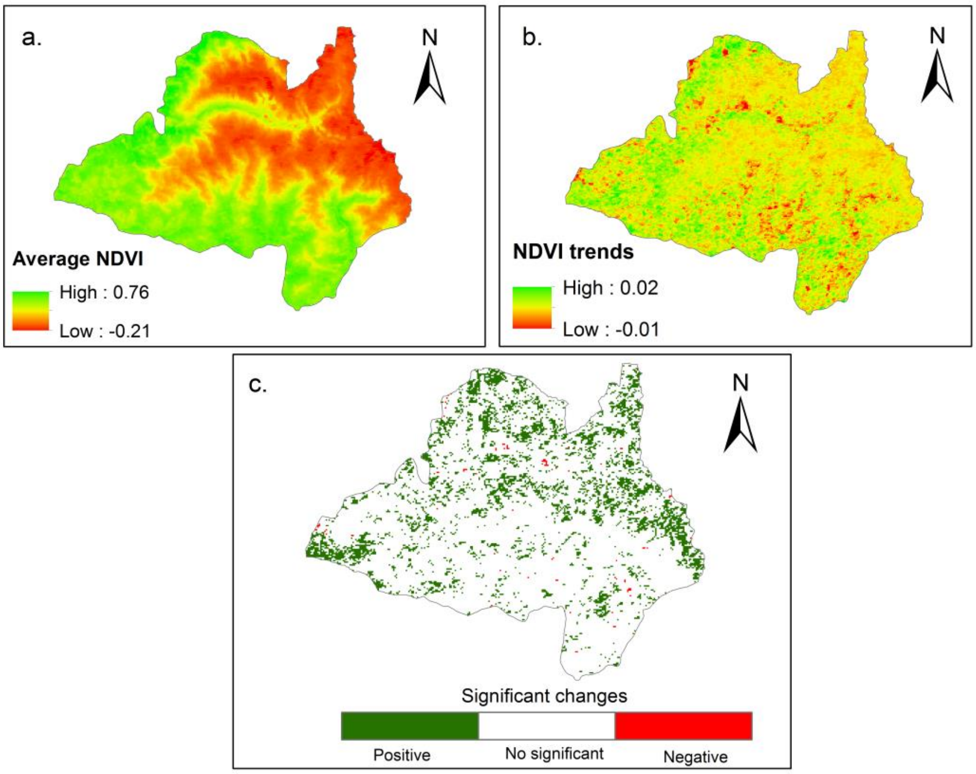

Figure 4 The NDVI and its changes; (a) Spatial distribution of NDVI; (b) Linear NDVI trends and (c) Significant NDVI trends based on Mann Kendall test statistics in each pixel during 2000-2017 in Langtang National Park (Scales: 0-40 Km in each).

A total of 68.73%, equivalent to 1463 km^2 areas of LNP, was occupied by vegetation where the average NDVI is more than 0.1. Generally, the lower reaches, including the buffer zone, have good NDVI distribution. However, the areas above the treeline ecotone had an average NDVI less than 0.1 (Fig. 4a). During the last 18 years, 88.05 % equivalent to 1875.56 km^2 areas of the park showed positive NDVI trends with significant positive trends in 16.45% equivalent to 350.43 km^2. The average NDVI distribution, trends and significant trends are shown in

Fig. 4. The significant positive trends are also found in the barren lands above the treeline ecotone (3700-4200 m) of the park (Fig. 4c). *Rhododendron campanulatum* above treeline were regenerating faster and have had continuous growth (Mainali et al, 2019). A very few areas showed significant negative trends, i.e., only 0.25% (5.43 km²), mainly in the parts of Rasuwa and Sindupalchowk district of the park. Overall, 16.45% of the park is greening, i.e., significantly increased NDVI, while 0.25% is browning, i.e., significantly decreased NDVI during 2000-2017. The maximum positive NDVI trend of 0.02 yr^{-1} and negative NDVI trend of -0.01 yr^{-1} was found in the park during the last 18 years. The greening trends in large area of the park showed higher number of saplings, seedlings and increased vegetation growth which is a signal of vegetation shift or growth in high altitudinal regions in Nepal.

Identification of vegetation coverage in treeline ecotone

The treeline vegetation is dominated by *A. spectabilis* and *R. campanulatum* with associating *B. utilis* and *S. microphyla* in LNP. The treeline vegetation found good in the western regions of the park located in the Rasuwa district, where the NDVI in the majority of the areas was in the range of 0.3 to 0.5. The treeline site, i.e., Lauribinayan Chaurikharka (3802 m) and Paralthak (3927 m), were found to possess good to an excellent greening where the average NDVI was more than 0.3 and significantly increased in the study period (Fig. 5). Similarly, treeline ecotone at Thangsyap showed good surface greening where the NDVI has significantly increased. The treeline at the southern site of the park located in the Nuwakot district does not have good surface coverage; however, some small areas showed significantly increased NDVI. In Fig. 5a, the green circles indicate the areas with positive NDVI pixels, i.e., good coverage of treeline vegetation, whereas the red circles indicate the areas with negative NDVI pixels, i.e.,poor coverage of vegetation. In Fig. 5, points A and B inside the green circles show Lauribinayak Chaurikharka and Lauribinayak Paralthak treeline sites. The treeline in the eastern site of the park located in the Sindhupalchowk district has better vegetation cover and getting improved NDVI compared to the southern parts of the park (Fig. 5).

In the treeline ecotone of the Rasuwa district, some areas located above Deding and Kyanjin in Langtang and Timure have NDVI less than 0.1 representing no vegetation and the tree line above Kyanjin also experienced significantly decreased NDVI. The large portion of treeline areas with mean NDVI between 0.3 to 0.5 and significant NDVI changes showed that these areas have higher regeneration capability, i.e., seedlings and saplings of treeline species. The areas with negative NDVI values were manually checked in Landsat scenes and Google Earth and found that these areas were marked with landslide, avalanches, barren land and tongue of debris-covered glaciers. The significantly increased NDVI (Fig. 5b) showed that large areas of the treeline ecotone are greening and obtaining good vegetation coverage of plant species. The area inside the green circle showed in Fig. 5b were field observation sites where the NDVI has significantly increased that indicates good greening and regeneration potential of treeline vegetation.

The significant NDVI trends were also found above the treeline that reflects the altitudinal shifts of vegetation and land-use conversion from glaciers to the barren land and barren to greening land. The previous study showed that the glacier has been rapidly retreating and decreased in Nepal Himalaya (Bajracharya et al., 2014; Paudel et al., 2016). Consequently, the vegetation shifts to barren lands, and those areas left behind from glacier retreat in the mountain. The high altitudinal vegetation growth and treeline shifting in the mountain (Gaire et al., 2014; Harsch et al., 2009; Schickhoff et al., 2015) supports these results.

The high average NDVI and the areas of positive NDVI trends are considered as good greening of treeline vegetation because the NDVI is the proxy for biomass and productivity (Myneni et al., 1995; Reed et al., 1994) and species richness (Pettorelli et al., 2005). The higher NDVI refers to the dense vegetation and vice versa. The vegetation growth depends on several environmental factors in the Himalaya, such as temperature (Baniya et al., 2018; Gaire et al., 2014; Zhu et al., 2016), CO_2 (Krakauer et al., 2017), soil moisture (Tiwari et al., 2017a), human factors and topography (Chhetri et al., 2017). In the Himalaya, rising atmospheric CO_2 concentration and nitrogen deposition are the most likely climatic causes of detected greening (Mishra & Mainali., 2017). The combination of these multiple environmental factors determined the NDVI level. Therefore, good NDVI in favor of these environmental factors provides good habitat and vice versa. The majority of treeline ecotone showed normal to good surface coverage while few ecotone regions showed excellent vegetation coverage. Some treeline sites in upper parts of Lauribinayak, Safru, Bridim, Timure, Langtang, Helambu and Gumba possess excellent coverage of treeline vegetation reflecting good NDVI distribution and significant positive NDVI trends. However, the growth of treeline vegetation depends on aspect, slope and special ecological niche (Schickhoff et al., 2015). Some of the areas in treeline ecotone experienced negative NDVI, indicating inappropriate growth of treeline vegetation. The Deding sites of the Timure, Kyanjin areas of the Langtang and some pixels in the Gumba regions did not show good greening (Fig. 5). These areas are affected both by natural hazards such as snow and glacier cover, landslide, debris covers and rocks, soil avalanche and anthropogenic disturbance like deforestation, forest fire, transhumance and open grazing (Wang et al., 2019). Since thousands of years ago, mountain people have been practicing animal husbandry, timber logging, fodder and firewood collection and transhumance activities in the Nepal Himalaya. Thus, an anthropogenic treeline was formed and dominated in the mountain in which treeline ecotones are transformed at varying extent. Fire and overgrazing are the main cause of treeline vegetation changes in Nepal Himalaya (Wang et al., 2019). The upper regions of the Kyanjin showed negative NDVI (Fig. 5a) due to the deposits of large debris/alluvial fan and avalanche, confirmed from Google Earth visual inspection.

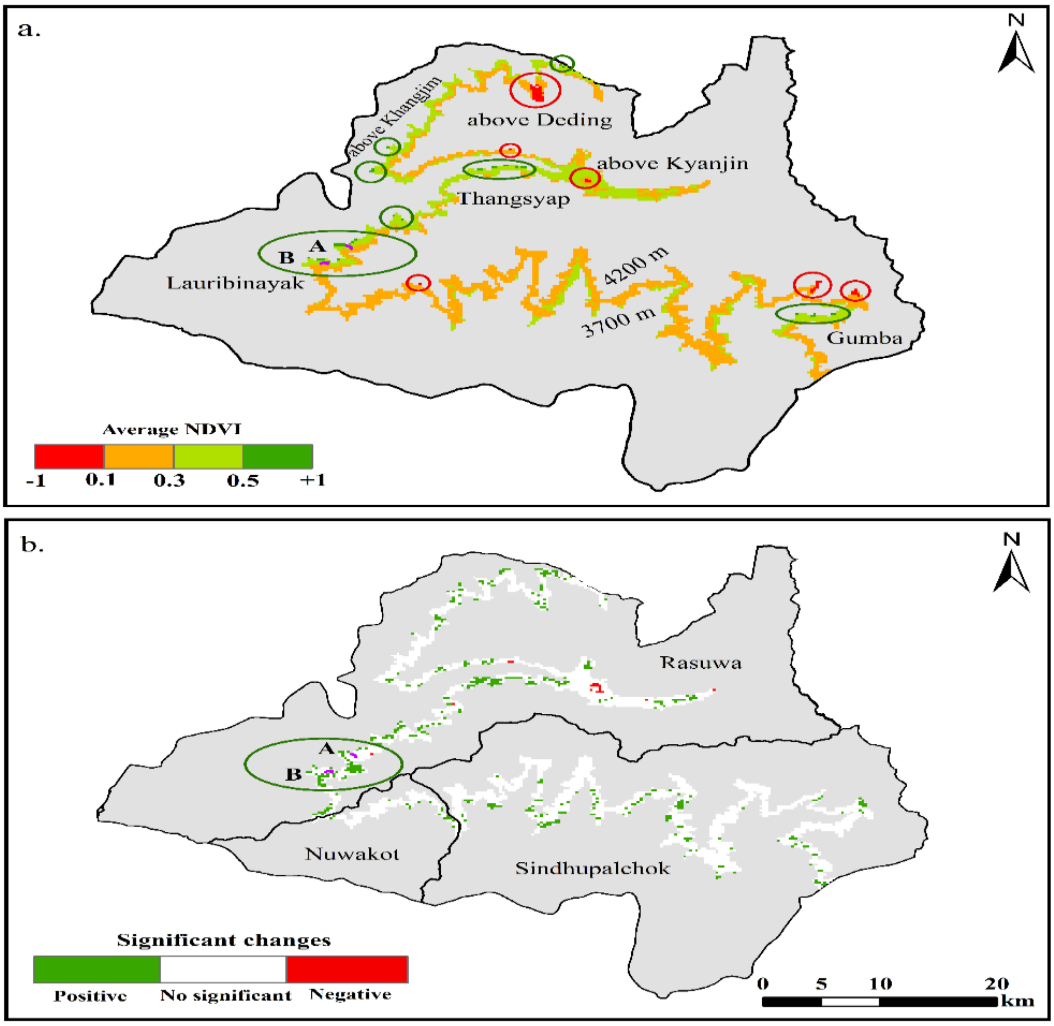

Figure 5: NDVI and NDVI changes in treeline ecotone (a) average NDVI to represent vegetation status and (b) significant NDVI changes in the treeline ecotone

Treeline species density based on the in-situ measurement

The treeline ecotone was dominated by four treeline species types. The total density of treeline species was 839.28 and 775 individuals per hectare in sites A and B, respectively. The treeline vegetation species such as *R. campanulatum* and *A. spectabilis,* is dominant and highest in number at both sites. These treeline sites A and B were found to have good average NDVI (Fig. 5a), significant NDVI change (Fig. 5b) and higher treeline species density. High numbers of seedlings and saplings of *R. campanulatum* were found; however, the saplings of about 1-2 m height of *A. spectabilis* were dominant in both sites. The density of *B. utilis* and *S. microphylla were* lower in both treeline sites. The higher density of *A. spectabilis* and *B. utilis* was found near the timberline (below treeline). Thus, high density of treeline vegetation, good average NDVI and positive NDVI trends in treeline ecotone of altitude between 3700 to 4200 m a.s.l. showed that treeline vegetation is getting good environment in high altitudinal regions of central Himalaya in Nepal. The density of treeline vegetation species has been calculated for two treeline sites (Site A and B) of LNP (Table 2).

The Pine trees (Chir pine and Blue pine), Oak trees, Birch-Rhododendron forest, Alpine pasture, Trans Himalayan steppe, Juniper species, Eastern Himalaya Oak-Laurel evergreen coniferous trees are dominated in the park and high altitudinal regions. The major treeline forming species are Fir (*A. spectabilis*), Birch (*B. utilis*), Rhododendron forest in the western site, and Oak-Laureal forest in the eastern site of the park are dominant. The majority of the treeline forests are needle-leaved and evergreen forests. Above the treeline, the alpine pasture, dwarf Rhododendron and Juniper scrubs are dominated, which are very important for transhumance, i.e., seasonal droving of the cattle grazing. Beyond the alpine pasture, large areas are nival zone where the vegetation does not exist. Below the treeline, Pine forest, lower temperate Oak forest, Fir trees, and hill Sal with *Schima Castapnopsis* forest are dominant; and some of them being broadleaved and deciduous forest which have distinct phenological periods. The higher density of treeline forming species in both sites supported that the areas are good for treeline vegetation growth and more regeneration capability. The large distribution of the vegetation in the park and treeline ecotone corroborated the results obtained from in-situ (Sites A and B) and remote sensing based NDVI observation. The higher vegetation density, species distribution, NDVI and positive NDVI trends verified that treeline ecotone possesses good surface vegetation coverage and getting good environment of plant growth.

Treeline	Coordinates		Quadrate size	No of treeline species occurrence				Total no.	Density (no/ha)
	Latitude	Longitude		*A. spectabilis*	*R. campanulatum*	*B. Utilis*	*S. microphylla*		
Treeline Site A- Lauribinayak, Chaurikharka									
A	28.09388	85.38926	20 m × 20 m	14	16	5	1	36	839.28
B	28.09465	85.38881		12	14	5	3	34	
C	28.09585	85.38481		11	15	6	2	34	
D	28.09564	85.38576		9	11	4	4	28	
E	28.0956	85.38678		13	11	3	2	29	
F	28.09548	85.38766		15	14	3	5	37	
G	28.09331	85.3897		14	17	5	1	37	
Tree line species density in site A (no/ha)				314.28	350	110.71	64.28	839.28	
Treeline Site B- Lauribinayak, Paralthak									
A	28.07333	85.37305	20 m × 20 m	14	18	2	2	36	775
B	28.07444	85.37222		9	15	1	4	29	
C	28.07416	85.37138		11	13	4	3	31	
D	28.07361	85.37055		9	7	6	1	23	
E	28.07388	85.36916		12	11	2	4	29	
F	28.07277	85.36777		13	14	3	2	32	
G	28.07250	85.36722		11	16	5	5	37	
Tree line species density in site B (no/ha)				282.14	335.71	82.14	75	775	

Table 2 Treeline species density (number/ha) in two treeline sites, i.e., Lauribinayak Chaurikharka (Site A) and Lauribinayak Paralthak (Site B) in Langtang National Park of Nepal.

There are some limitations in using MODIS data in LNP, including spatial and temporal resolution (Vermote & Kaufman, 1995) digital quantization error (Viovy et al., 1992), ground and atmospheric attenuation (Tanre et al., 1992), Sensor quality (Kaufmann et al., 2000) and varied topography. MODIS NDVI is time series and quality controlled (Tucker et al., 2005), effective in vegetation study (Baniya et al., 2018). In addition, the Savitzky-Golay filter was used in MODIS data (Savitzky & Golay, 1964) for smoothing possible noise obtained from cloud cover, water, snow and shadow. The field data such as finding treeline and quadrate sampling were used for identifying the density of treeline forming species to verify remote sensing approach for NDVI changes. The two treeline sites were only selected during field study because it was not feasible to visit all the treeline sites in rugged, inaccessible and isolated areas in the mountain. In this study, both remote sensing and field data were coupled to make the results more precise.

Conclusion

This study investigated the vegetation changes in LNP, and its treeline ecotone using MODIS NDVI data. In addition, we also identified surface vegetation coverage in treeline ecotone based on corresponding NDVI values. The field-based treeline species density in two treeline sites were used and supported remote sensing approach. The average NDVI from 2000 to 2017 showed that 68.73%, equivalent to 1463 km² areas of Langtang National Park, were covered by vegetation. The average NDVI has significantly increased in LNP and treeline ecotone during the last 18 years. About 16.45%, equivalent to 350.43 km² area of the park, was greening during 2000-2017. A large fraction of the treeline areas were possessed normal to good vegetation coverage, whereas few areas showed excellent greening. Most of the treeline ecotone had NDVI greater than 0.1 and significantly increased during the study period. The treeline sites A and B host good to excellent vegetation coverage in which the average NDVI was more than 0.3 and significantly increased. The dominant highlands vegetation is reported *A. spectabilis*, *R. campanulatum*, *B. utilis, Blue pine* and *S. microphylla.* The vegetation density showed greening and obtaining good environment in treeline ecotone. Meanwhile, good vegetation presence in treeline ecotone indicate that vegetation is shifting towards in higher altitudinal regions. This study implies the relevancy of remote sensing for high altitudinal vegetation dynamics across the Nepal Himalaya in large spatial scales. In future, species-specific vegetation mapping using high-resolution satellite data is crucial and factor responsible for high altitudinal vegetation growth are to be determined.

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