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Spatio-temporal analysis of trends in seasonal vegetation productivity across Uttarakhand, Indian Himalayas, 2000–2014

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ABSTRACT

Himalayan mountain system in the Indian sub-continent are among the most ecologically sensitive environments and are also a repository of biodiversity, water and ecosystem services. Over the last two decades, land transformation related to exploitative land uses is among the main drivers of changing vegetation cover and productivity in western Himalayas. In a region where field based research is challenging due to heterogenous relief and high altitude, quantifying changes in vegetation photosynthetic activity using remote sensing can provide essential information regarding trends in vegetation cover and its linkages with anthropogenic impacts. We conducted seasonal trend analysis (STA) on MODIS NDVI time-series data (2000–2014) over Uttarakhand Himalayas and examined spatio-temporal patterns in vegetation trends and its association with altitudinal gradient and land use land cover (LULC) dynamics. In STA the first step determines the annual mean and seasonal NDVI patterns and the second step analyzes the non-parametric trend in magnitude and timing of the annual mean and seasonal NDVI cycle. To provide insights on the role of changing land use to detected changes in vegetation trend, we linked MODIS derived trends to land transformation processes using multi-temporal high spatial resolution imagery in Google Earth (GE). In total 3286.82 km^2 (6.9% vegetated area of Uttarakhand) showed significant trend ($p < 0.01$) in mean annual greenness. While areas <800 m elevation showed dominant negative trend in mean annual greenness (browning)), those between 800 and 1600 m showed mostly positive trend (greening) and majority of areas >1600 m were characterized by negative trend in mean annual greenness. Majority of intensively cultivated irrigated croplands in the Himalayan foothills as well as areas around growing urban centers showed widespread browning, which was contrastingly different from rainfed cultivation areas that showed dominant greening trend. Browning trend was observed to be consistent with increasing altitude, particularly in closed needle leaf forests and alpine shrublands, except areas where human impacts has led to more mixed patterns. Trends in the annual seasonal timing of NDVI indicated an earlier green-up for most parts of the Uttarakhand Himalayas. These results highlight fine scale spatial variations in seasonal vegetation trends and are in partial agreement with previous studies that report only increasing brownness detected at broader scale using much coarser spatial resolution time-series.

Introduction

Global environmental changes in recent decades have affected the distribution and dynamics of terrestrial ecosystems worldwide (Lambin et al., 2001; Turner, Lambin, & Reenberg, 2007). Results from studies conducted at multiple spatio-temporal scales show that anthropogenic climate change has influenced plant species ranges, vegetation phenology (Cleland, Chuine, Menzel, Mooney, & Schwartz, 2007; Parmesan & Yohe, 2003), and even altered vegetation-climate relationship significantly (D'Arrigo et al., 2004; de Jong, Verbesselt, Zeileis, & Schaepman, 2013). Despite mounting evidence on impact of global environmental change on flora, fauna and ecosystem function at different scales, many regions of the globe particularly with high biodiversity and ecological significance remain poorly studied (Ives, 2004; Korner, 2004). Mountain ecosystems in sub-tropical latitudes in Asia, such as the Himalayas, essentially represent such understudied, ecologically sensitive and vulnerable areas (Barnett, Adam, & Lettenmaier, 2005). The Himalayan region, characterized by high relief and strongly structured climatic gradients (Rangwala & Miller, 2012), houses dense

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and diverse forest cover with several biodiversity hotspots, especially in the western part (Xu et al., 2009). Recent findings based on analyses of climatic data in this region suggest spatially variable but significant increase in temperature trend over the last three decades (Immerzeel, van Beek, & Bierkens, 2010; Shrestha, Wake, Mayewski, & Dibb, 1999). Large parts of the Himalayan mountain region are also facing intense anthropogenic pressure due to increasing population, resource exploitation and unsustainable environmental policies (Ives, 2004; Pandit, Sodhi, Koh, Bhaskar, & Brook, 2007; Semwal et al., 2004). In this sensitive ecosystem, combined effects of climate change and unsustainable human practices have resulted in degradation of ecosystem function and services, thus increasing both environmental and socio-economic vulnerability (for e.g. food insecurities) (Ives, 2004; Tiwari & Joshi, 2012a).

Like other sub-tropical mountain systems, environmental changes in the Himalayas are widely associated with vegetation related changes such as changing vegetation phenology and species ranges (Shrestha, Gautam, & Bawa, 2012; Telwala, Brook, Manish, & Pandit, 2013), declining forest cover and biodiversity (Pandit et al., 2007; Tiwari, 2008; Xu et al., 2009). Vegetation is an important component of biosphere, which not only fundamentally regulates the global carbon cycle, energy budget, biogeochemical cycle, but also helps to maintain climatic stability and provides essential services locally (Jackson et al., 2008). There has been increasing realization regarding vegetation sensitivity to climate change, especially in mountain areas (Gottfried et al., 2012; Walther, Beiβner, & Pott, 2005) and consequently the need for monitoring and quantifying their spatio-temporal dynamics (Gottfried et al., 2012). Analyses of long-term vegetation cycles and trends for the Himalayan region can provide important understanding of vegetation responses to both environmental and anthropogenic drivers of change (Panday & Ghimire, 2012; Shrestha, et al., 2012).

The emergence and development of satellite remote sensing has provided an increasingly powerful tool to monitor and characterize vegetation dynamics over large spatial and temporal scales, enabling studies to directly relate changes in vegetation properties to their drivers (Nash, Bradford, Wickham, & Wade, 2014; Tucker et al., 2001; Zhang et al., 2003). Satellite derived vegetation indices such as the Normalized Difference Vegetation Index (NDVI) has been widely used as an indicator for monitoring vegetation dynamics because of its existing correlation with Leaf Area Index (LAI), chlorophyll abundance and gross primary productivity (GPP) (Goetz & Prince, 1999; R. B. Myneni, Hall, Sellers, & Marshak, 1995). NDVI time-series data have been utilized by several studies, especially in the high and mid latitude areas, to describe temporal trends in vegetation at regional scale by quantifying inter-annual and seasonal vegetation dynamics (Barichivich et al., 2014; Myneni, Keeling, Tucker, Asrar, & Nemani, 1997). Studies have demonstrated that NDVI trends were influenced by changes in climate and/or land cover properties. Seasonal trends in time-series vegetation indices have been analyzed using a variety of curve-fitting procedure (fourier analysis, harmonic regression, logistic function), which essentially involves fitting a predefined theoretical function based on empirical data values (Bradley, Jacob, Hermance, & Mustard, 2007; Eastman et al., 2009; Mishra, Crews, & Neuenschwander, 2012). In time-series analysis of remotely derived vegetation indices, the detection of true change in trend depends on the ability of the method to remove high frequency variability associated with noise and to account for the variability associated with multi-year trend (Akaike & Kitagawa, 1999).

Understanding of seasonal and inter-annual vegetation dynamics is critical to environmental decision makers for detecting early warning signals of general trends of degradation or improvement in land conditions, as well as its specific locations (Menzel, 2002). In this study, NDVI time-series data derived from NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) were analyzed for the last 14 years (2000–2014) for the Himalayan mountain region within the state of Uttarakhand, in northern India using Seasonal Trend Analysis (STA) technique. STA is an improved method to analyze seasonal trends in time-series data that can potentially identify vegetation changes while characterizing interaction at different temporal scales. Changes in vegetation condition can be influenced by climatic fluctuation (e.g. rainfall) and disturbance (e.g. fire) and anthropogenic activities (e.g. urbanization, agricultural expansion). The present study, focused on anthropogenic land cover conversion post-2000 when Uttarakhand gained statehood, thus accelerating urban and agricultural expansion and infrastructural development at unprecedented scale (Tiwari & Joshi, 2012a, 2012b). The objectives of this study were:

i. to characterize the spatial distribution of seasonal trends detected using 14-year NDVI time-series data
ii. to access the spatial association of detected seasonal trends with elevation and LULC properties and elevation, and
iii. to analyze the relationship between the observed spatial variations of seasonal trends and associated environmental and anthropogenic drivers within Uttarakhand Himalayas.

Study area

Uttarakhand lies on the southern slopes of Himalayan range and has a total area of 53,484 sq km of which 93% is mountainous and 65% is covered by forests (Negi, 2009). The study area shows great variation in climate and vegetation properties (Fig. 1b) depending on elevation that ranges from 200 m in the Gangetic plains to more than 7800 m in the Himalayan ranges (Fig. 1c). Uttarakhand receives a mean annual rainfall of 1546 mm, of which more than two-thirds is during monsoon season (June–September). The spatial distribution of rainfall shows marked spatial variation due to steep altitudinal gradient from south to north (Singh & Mal, 2014) which also controls the distribution of vegetation types. Western Himalayan alpine shrubs and meadows occupy areas with elevations between 3000 m and 4800 m, and areas above 4800 m are non-vegetated. The Temperate Western Himalayan Subalpine Conifer Forest grows just below the tree line. At 3000 m–2600 m elevation they transition to Temperate Western Himalayan Broadleaf Forest which lie between 2600 m and 1500 m. The Himalayan Subtropical Pine Forests dominate areas with elevation below 1500 m (Singh & Singh, 1987). Upper Gangetic Plain Moist Forests and Terai-Duar Savannas dominate the lowland areas of Uttarakhand and majority of these vegetation have been cleared for agriculture with few remaining patches (Tiwari & Joshi, 2012a). The highly biodiverse forested area in Uttarakhand are protected and conserved by the state and national government in form of six national parks, six wild life sanctuaries and two conservation reserves. Uttarakhand is one of the major contributors of the tourism sector in India, attracting significant numbers of domestic and international tourists. During the last few decades Uttarakhand Himalayas has experienced rapid urbanization. The total population of the state increased by 15.83% between 2001 and 2011 and urban population increased from 25.67% in 2001 to 30.23% in 2011 (India, 2011). The high growth rate can be attributed to post statehood (2000) emergence of rural growth centers and rapid expansion of existing urban areas, agricultural expansion and intensification, improved transportation connectivity, development of tourism, improved accessibility to market and lack of suitable land use regulations (Tiwari & Joshi, 2012b). Recent estimates suggest that 5.85% of the natural forested area was lost due to urban growth in the state between 1981 and 2011 (Tiwari & Joshi, 2012c).