ANALYSIS OF LONG-TERM EVI FOR VARIATIONS IN THE PHENOLOGICAL TRENDS OF MAJOR VEGETATION TYPES IN WESTERN HIMALAYA

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ABSTRACT: Over the past few years, extreme weather events due to global climate change and anthropogenic pressure are among the main drivers of changing vegetation cover and productivity in western Himalaya. Changes in vegetation cover, their life-cycle events and how they are influenced by climatic variations is studied by phenological trends. In a region where field-based study is challenging due to high altitude and heterogenous relief, quantifying changes in vegetation photosynthetic activity using remote sensing can provide crucial information regarding variations in vegetation cover and its linkages with climate change and anthropogenic impacts. We conducted this study to detect variations in phenological trends over Uttarakhand Himalaya using MODIS EVI time-series data (2000–2014) and examined temporal patterns in five different vegetation types over different locations. To classify vegetation cover of Uttarakhand in different forest types, we used Vegetation Cover and Land Use map of Uttarakhand. Random points were generated in these forest types and EVI values were extracted from all the layers of our stacked MODIS data. In total most of the vegetation types showed an overall negative trend in mean EVI (browning) with time and are in agreement with previous studies that report only increasing brownness detected at broader scale using much coarser spatial resolution time-series. Sal mixed moist deciduous, in particular, showed a little more negative trend at all the locations as compared to others. Negative EVI trend (browning) in this region could possibly be attributed to the fire activities and land use change at forest fringe as well as temperature induced drought stress and cooling spring temperatures. Wet grassland, on the other hand, showed a positive trend in EVI (greening) which could be attributed to climate warming and wetting at higher altitude. Climate change could result in a replacement of high quality forest with low-quality forests, which are likely to lead to a significant biodiversity loss. An interplay between anthropogenic and climatic factors was also possible to affect the regional phenology.

1. INTRODUCTION

Himalayan mountain system in the Indian sub-continent, characterized by high relief and strongly structured climatic gradients, houses dense and diverse forest cover with several biodiversity hotspots but is also among the most ecologically sensitive environments. The rate of increase in temperature over Himalayan ecosystem is three times more as compared to the global average (Xu et al., 2009). Over the past few years, extreme weather events such as heatwave, extreme rainfall, etc due to global climate change is among the main drivers of changing vegetation cover and productivity in western Himalaya. Changes in vegetation cover, their life-cycle events and how they are influenced by climatic variations is studied by phenological trends. Phenology, the timing of periodic recurrent reproductive biological phenomenon, provides a critical signal of climate variability and change effects on plants. With research advances it has become evident that the responses of plant phenology to climate variability and change are both location and species specific. We conducted this study to analyse phenological trends over Uttarakhand Himalaya using MODIS EVI time-series data. Enhanced Vegetation Index (EVI) provide detailed insight into biotic activities and have been applied in broad range of studies such as global climate change, phenological and crop growth monitoring, yield prediction, climatic and biogeochemical modelling, to name a few (Justice et al., 1998, 2002; Running et al., 2004).

Studies from different regions of the world reported distinct findings. Van Leeuwen et al., 2013 stated negative trend in NDVI of arid, sub-arid and sub-humid vegetation of Andes mountains. However, studies in temperate areas such as European Alps and Rockies mountains showed greening in response to accelerated warming of these regions (Macias-Fauria et al., 2012; Keenan et al., 2018; Park et al., 2019). A very recent study by Filippa et al., reported greening trends in undisturbed vegetation of European Alps where 63% of the vegetated areas showed significant greening trend during the studied period.

During the last few decades, the emergence of remote sensing techniques has greatly influenced the methods of traditional plant phenology observations. In particular, the study of landscape-scale plant phenology is making use of data from satellite remote sensing whereby the timing of phenological events is detected in the temporal profile of greenness-related vegetation indices, such as the normalized difference vegetation index (NDVI) and the enhanced vegetation index (EVI) (Liu, Piao, et al., 2018b; Piao et al., 2006). Recently, remotely sensed solar-induced chlorophyll fluorescence (SIF) data have come up as useful tools to study seasonal variations in gross primary productivity (GPP) (Meroni et al., 2009). Besides, near surface remote sensing has also boomed in the past decade and can be useful for phenology studies due to its repeated, high frequency image collection (every half to one hour) using commercial networked cameras (Nasahara and Nagai, 2015). Using unmanned aerial vehicles (UAV) with spectroradiometer onboard, which can provide multispectral or hyperspectral images varying from the plant level to the landscape scale and thus establish a direct spatial linkage between field- and satellite- based observations (Klosterman et al., 2018)

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). It can be supported by some other studies done by Barnett, Adam, & Lettenmaier (2005) saying that Mountain ecosystems in sub-tropical latitudes in Asia, such as the Himalaya, essentially represent such understudied, ecologically sensitive and vulnerable areas. Understanding and studying the Himalayan forest health, in term of phenological trends, in view of climate changes is therefore crucial in order to develop appropriate forest management strategies for the region.
The long term phenological study over the Uttarakhand Himalaya explains the scenario of last few years and helps to detect climate change (rainfall and temperature) and its impact on vegetation species. The study aims to detect if there are signs of browning in major vegetation types of Uttarakhand region from the period 2001- 2014 using trend analysis method. This could be accomplished by analysis of long-term EVI.

2. STUDY AREA AND DATASET

2.1 Study area

The study was carried out over the Uttarakhand state of India (longitude 77° 34’ 27” East to 81° 02’ 22” E and latitude 28° 53’ 24” North to 31° 27’ 50” N), which has total geographical area of 53,483 km^2, of which 92.57% is covered by hill and 7.43% is the plain area. 63% of

Uttarakhand is covered by the forest. The information about the state is taken from Uttarakhand Forest Department (Government of Uttarakhand). Physiographically, the state can be divided into three zones namely, the Himalaya (elevation from 10,000 to 25,000 feet), the Shiwalik (elevation 6,500 to 10,000 feet) and the Tarai region with the elevation from 1,000 to 10,000 feet. The climate of different cities of the state varies with the altitude and location. At the highest elevations glaciers being located, thus having coolest weather and are covered by ice and bare rock. The state has a temperate climate, marked by seasonal variations in temperature, but is also affected by tropical monsoons. The average annual rainfall is 1,550 mm brought by the southwest monsoon, which blows from July through September. Uttarakhand lies on the south slope of the mighty Himalayan range, and the vegetation vary greatly with elevation, from glaciers at the highest elevations to tropical forests at the lower elevations. The western Himalayan Alpine Shrub and the Meadows ecoregion lies between 3000-3500 meters elevation. From 3000-2600 metres lies the Western Himalayan Subalpine conifer forest, transitioning into the Western Himalayan Broadleaf Forest, which covers from 2,600 to 1500 metres elevation. Below 1500 metres elevation lies the drier Terai-Duar Grassland belt, and the Upper Gangetic Plain moist deciduous forest.

2.2 Datasets

2.2.1 Satellite data: In this study, the freely available temporal (8-day) composites of MODIS (Moderate-Resolution Imaging Spectroradiometer) data (MOD09A1 product) for the period of 14 years from 2001-2014 were acquired for the complete Uttarakhand. Data was obtained through the online data pool at the NASA Land Processes Distributed Active Archive Centre (LP DAAC), USGS/Earth Resources Observation and Science (EROS) Centre, Sioux Falls, South Dakota (https://lpdaac.usgs.gov/get_data) with the help of United States Geological Survey (USGS) Earth Explorer (EE) tool (https://earthexplorer.usgs.gov/). The MOD09A1 product contains 1-7 bands of 500-metre spatial resolution in an 8-day gridded level-3 product. Each of its pixel contains L2G observations during an 8-day period particularly by high observation coverage, low view angle, the absence of cloud or cloud shadow and aerosol loading. The MODIS datasets provided in Hierarchical Data Format (HDF) were exported to GeoTIFF format in ENVI 5.0 and reprojected from the Integerized Sinusoidal (ISIN) projection to a geographic projection (lat/long, World Geodetic System 1984- WGS84). The single tile covering the complete Uttarakhand is taken for each 8-day composite date for the time period of 14 years. These MODIS datasets in GeoTIFF format were imported to ERDAS Imagine 8.7 for calculating Enhanced Vegetation Index (EVI). The entire time series of the 8-day MODIS intervals acquired for the 14-year period consisted of 644, 8-day composite images (365 days yr^{-1}/8-day composite ≈46 composite images yr^{-1}).

2.2.2 Ancillary data: The ancillary data was also needed for the purpose of result analysis. Here, we used Forest Cover and Land use map for different vegetation area extraction e.g. pine; sal; etc (Figure.1). The Vegetation cover and Land use classified map, generated by Roy et al., (2012) for National Assessment Program (Biodiversity at landscape level in India), was used for extracting the homogenous vegetation pixels for major types of vegetation in Uttarakhand.

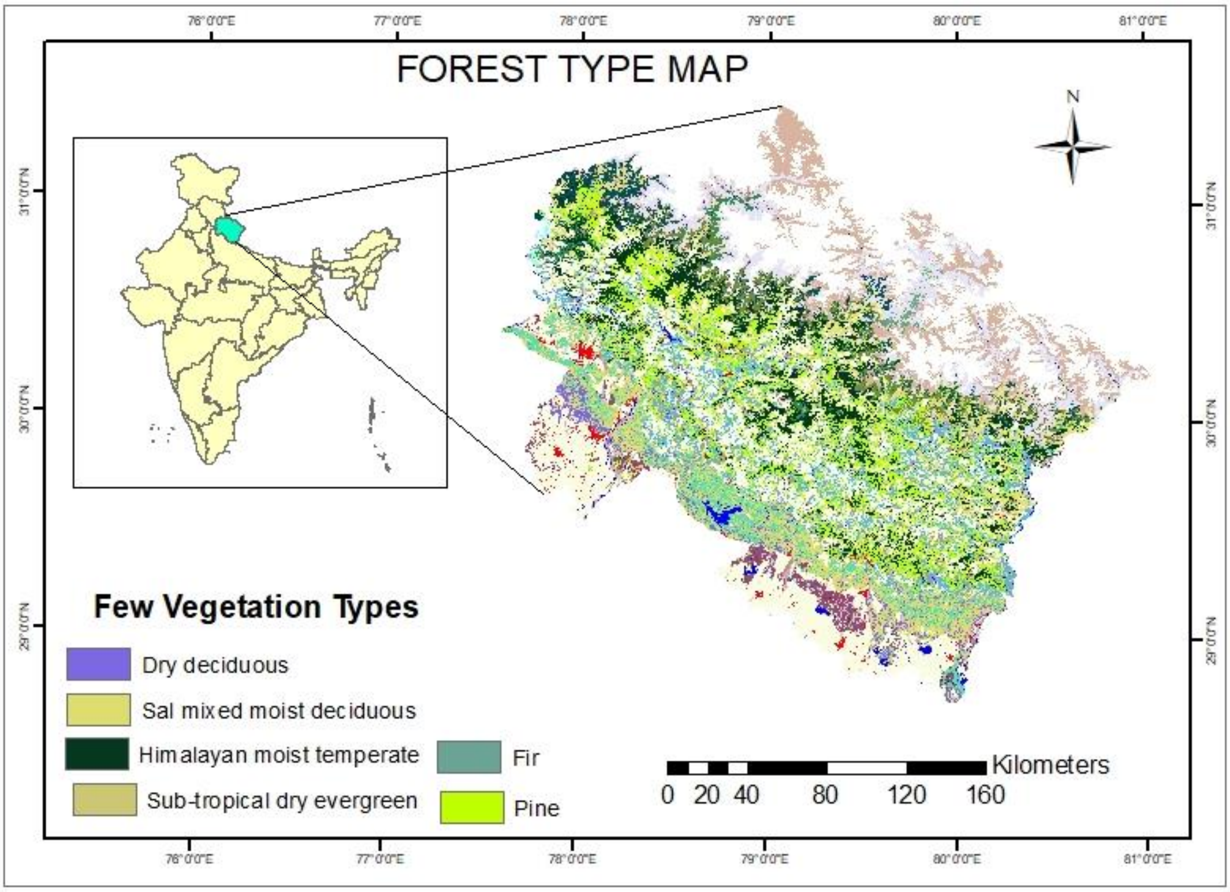

Figure.1 Vegetation cover and Land use map of Uttarakhand region

3. METHODS

Overall, the research methodology can be divided into four major components: data creation, points generation, development of framework and statistical analysis (Figure.2)

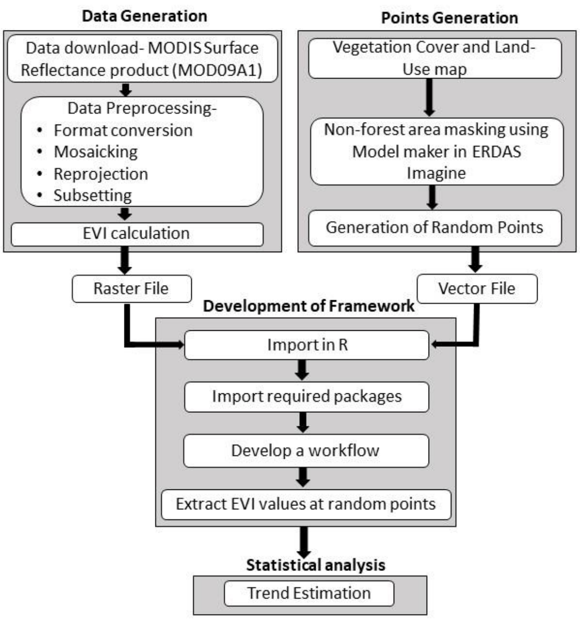

Figure.2. Flow chart of steps followed for estimation of phenological changes

3.1 Database generation

MODIS 8-day composite reflectance data from 1 January 2001 to 31 December 2014 was downloaded and preprocessed (format conversion, Mosaic, Reproject and Subset) and then vegetation indices (EVI) for the whole time period were generated. A total of 644 images of MODIS data were pre-processed and generated a time-series for the complete Uttarakhand.

3.2 Random Points Generation

A vegetation cover and land use map (Roy et al, 2012) was used to mask non-forest area. This was done using Model maker in Erdas Imagine. The prepared file, having required vegetation classes, was then used as an extent to generate random points.

3.3 Phenological Estimation using R studio

For estimating the phenological changes in different vegetation area in spatial domain, different classes of forest are extracted from the MODIS 14 years EVI. Different packages required for the study were installed and a workflow was generated having all the desired codes for value extraction in R. The MODIS EVI-stack raster file was then read in R. Another file in vector format (Random points) was also read in R and overlaid with the raster one. The EVI value of random points falling at the classified five categories of vegetation were extracted and plotted. This time series plot was used to determine whether or not any vegetation type is showing browning over the period of our study.

4. RESULTS

EVI time series datasets give enhanced vegetation signal with improved sensitivity to high biomass regions. Each type of forest has different greening and browning structure. Here, the seasonal graph of different forest types can be explained in two stages- gradual increment (greening) and decrement (browning) with respect to time. The selected vegetation types showed different trends over the study period. Sal mixed moist deciduous and himalayan moist temperate showed browning trends whereas pine and wet grassland showed greening trend at selected locations over the time period of a decade (Figure.3)

Figure. 3 Images of different forest types taken from Google Earth at different time locations.

4.1 Selected random points location

The vegetation cover and land use classified map was used to select major vegetation types of

Uttarakhand region. The random points were generated within the boundary of selected vegetation at different locations (three locations with varying altitude for each vegetation type). Only the points falling in pure unchanged forest patches were taken based on high resolution AWiFS data of 2016.

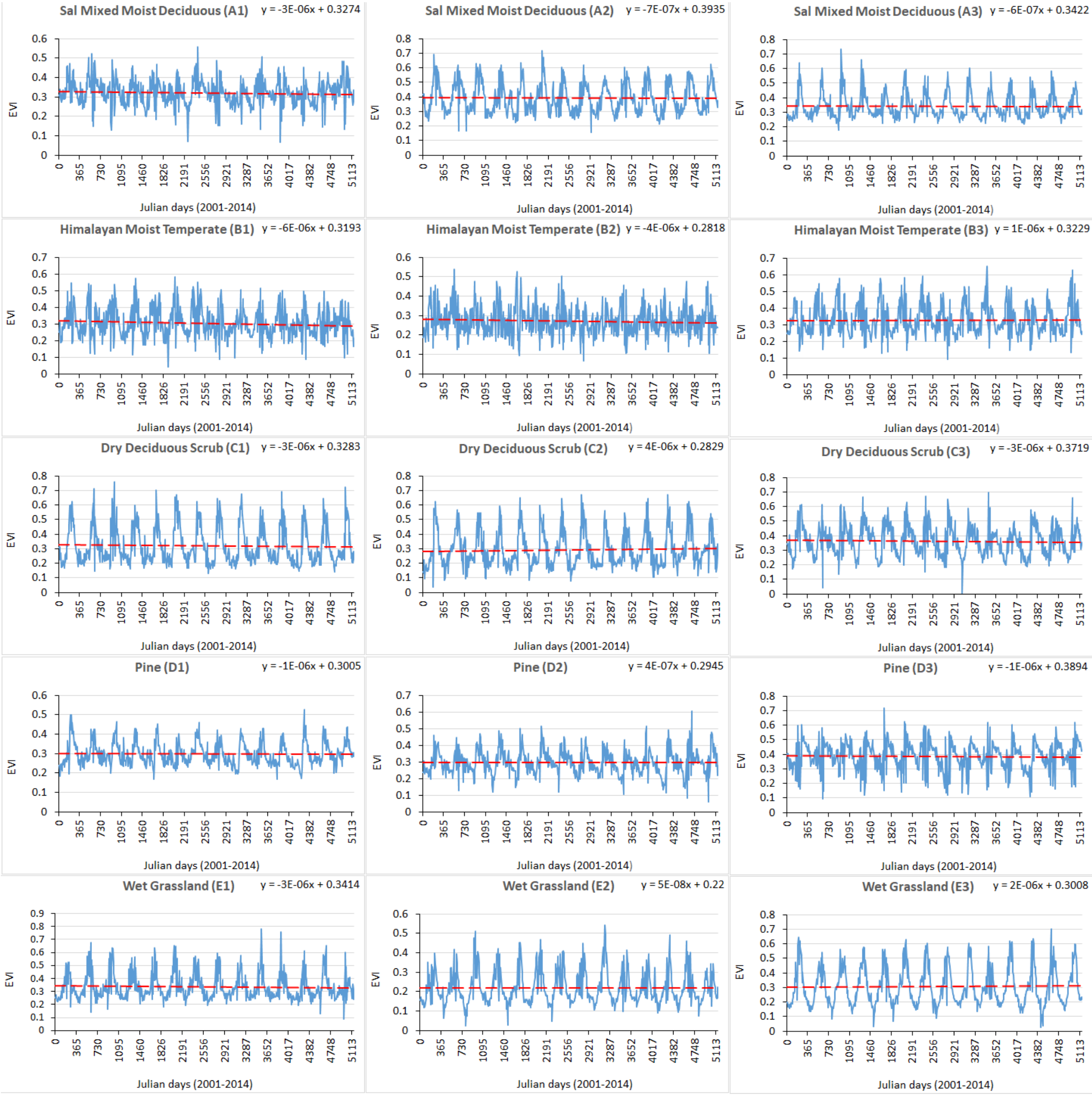

Figure.4 shows the temporal EVI profile, along with trendline- equation, of five different vegetation types (A. to E.) of Uttarakhand region over the period of 14 years from 2001-2014. Forest type with different locations are as follows- A1- Sal Mixed Moist Deciduous (Lat: 30.6934°, Long: 78.2388°, Alt: 2071 m); A2- Sal Mixed Moist Deciduous (Lat- 28.94581°, Long- 80.04622°, Alt- 213 m); A3- Sal Mixed Moist Deciduous (Lat- 30.49872°, Long- 77.84822°, Alt- 578 m); B1- Himalayan Moist Temperate (Lat- 29.9767°, Long- 78.9664°, Alt- 2441 m); B2- Himalayan Moist Temperate (Lat- 31.071804°, Long- 77.95337°, Alt- 3115 m); B3- Himalayan Moist Temperate (Lat- 29.308781°, Long- 80.1373°, Alt- 2015 m); C1- Dry Deciduous Scrub (Lat- 30.2484°, Long-78.3792°, Alt- 966 m); C2- Dry Deciduous Scrub (Lat- 30.712°, Long- 77.777895°, Alt-1385 m); C3- Dry Deciduous Scrub (Lat- 29.232819°, Long-80.238471°, Alt- 1155 m); D1- Pine (Lat- 30.9614°, Long- 78.039°, Alt-1383 m); D2- Pine (Lat- 29.846889°, Long- 79.358103°, Alt- 1415 m); D3- Pine (Lat- 29.255021°, Long- 80.206724°, Alt- 1377 m); E1- Wet Grassland (Lat- 29.5581°, Long- 80.2288°, Alt- 1605 m); E2- Wet Grassland (Lat- 30.45892°, Long- 79.358848°, Alt- 2866 m); E3- Wet Grassland (Lat- 31.170285°, Long- 78.111841°, Alt- 2268 m).

4.2 Temporal EVI Profile

The Temporal EVI values are directly related to seasonal changes in vegetation growth. The EVI values increases during the greening phase and starts decreasing during senescence phase in relation to the canopy integrated chlorophyll content. It shows the differences in the vigour of growth during the different times of the year. Over the studied area, the larger EVI values ranged between 0.4 and 0.6 for dense forest region were as small as 0.1 to 0.4 for lower vegetation area. The curves are plotted for five different vegetation types over the period of 14 years from 2001 to 2014 at different locations with varying altitude (Figure.4). In Sal Mixed Moist Deciduous, the gradual decrease in curve towards the end of each year, at all the three locations and altitude, shows the senescence occuring for a longer period of time as compared to growth period. Also, the decreasing average EVI shows that the senescence is increasing in period over the years. Negative trend of EVI in Himalayan Moist Temperate forest at higher elevation showed the browning of forest over the years. Although the forest showed positive EVI trend at lower elevation, the trend is very weak to be considered as significant. Hence, for most of the time, EVI values are low in Himalayan moist temperate. In Dry-deciduous scrub, the EVI values range from 0.2 to 0.8, which suggest presence of mixed vegetation there. Also, dry-deciduous scrub, at higher elevation (i.e. 1385 m) showed increasing EVI trend (greening) whereas the same forest type at other two locations having lower altitude showed negative EVI trend (browning). Similarly, in Pine forest, EVI values having short range of EVI i.e. 0.2-0.5, showed signs of greening at higher altitude (i.e. 1415 m) whereas pine at other two locations with lower altitude showed decreasing EVI trend (browning). EVI values in wet grassland are in the range 0.2-0.6 having growing period for longer duration of the year. Wet grassland showed positive EVI trends at higher locations (i.e. at 2866 m and at 2268 m) whereas negative EVI trend at lower elevation. Years like 2010 and 2011 showed higher peak values of EVI i.e. 0.8 which could possibly be due to occurence of some climatic events favourable to the vegetation growth during these years.

5. DISCUSSION

With numerous reports and studies speaking about browning of the Indian Himalayan vegetation, the work tries to assess the said reports with long term data on selected forests in the Himalayan region. The forest types were categorised on the basis of the dominant vegetation types in the region. The sample points were located in pure undisturbed forest area, to minimize the effect of land use change on the phenological variation in the site. This study concludes important aspects of variations in phenological trends of major vegetation types over a time span of 14 years. We observed a statistical decrease in the average EVI in some forest types over the time period, on the other hand, some vegetation types showed increasing trends at higher latitudes. Sal mixed moist deciduous forest showed negative trend in EVI over all the locations. Similarly, Himalayan Moist Temperate Forest also showed negative EVI trend. Other forest areas, such as Dry deciduous scrub, Pine and Wet Grassland, at lower latitude and lower altitude showed negative EVI trend which in turn indicates towards browning of the region. This could be attributed to slight delay in green-up and beginning of growing season and early leaf senescence, which could be a result of extreme weather events such as heatwave, heavy rainfall, flood, etc in Western Himalayan region. The vegetation of Himalayan region is mainly impacted by the heat stress which is projected to continue to increase by 15% by 2100 compared to the current time (Lamsal et al., 2017). Negative trends in overall greenness in these areas during the study period could also be attributed to the human-induced LULC changes due to clearance of natural vegetation for urban development and agricultural expansion. However, vegetation at higher latitude and higher altitude showed greening pattern with a slight increase in EVI trends. A positive average EVI trend in Dry Deciduous Scrub, Pine and Wet grasslands, at higher elevation indicated towards greening of the areas. Since, higher elevations are comparatively sensitive towards climate warming, the alpine vegetation greenness gained improvement. The same is reported by some other studies also. Studies by Leeuwen et al., (2013) and Piao et al., (2011) on Qinghai-Xizang plateau have also reported the similar results. Some studies even reveal that the face of the Himalaya will change considerably in the future with projected warming, making it a substantially greener vegetative area. With the northward shift of existing suitable climate for the vegetation species, it can be anticipated that at higher altitudes and latitudes, greening would increase in the near future.

The browning of selected forest areas observed in this study is in support of other studies which pointed out the browning of the region in the past. Kumar, S and Chopra, N, 2017 reported phenological events to be occurring early in Banj Oak (*Quercus leucotrichophora* A. Camus) dominated forest in Central Himalaya. Another study reported that altered water availability significantly affected the leaf emergence, leaf damage and leaf senescence in three Himalayan Oak species (Chand et al., 2017). Field based observations on Rhododendrons in the Himalaya show that some species are flowering a month earlier than in the past (Shreshtha et al., 2012). A research by Munsi et al., 2010 on the Uttarakhand region during 1976 to 2000 observed some significant changes in the LULC using landscape approach. Lambin et al., 2001 and Turner et al., 2007 reported that global environmental changes in recent decades have affected the distribution and dynamics of terrestrial ecosystems worldwide. Results from studies conducted at multiple spatio-temporal scales show that anthropogenic climate change has influenced plant species ranges, vegetation phenology (Cleland et al., 2007, Parmesan and Yohe, 2003), and even altered vegetation-climate relationship significantly (D'Arrigo et al., 2004, de Jong et al., 2013).

The observations in this study show that the long term EVI provides an indication of the subtle changes in the phenology in these forest in the Western Himalaya. The insights from these phenological trends will provide critical inputs in developing scientific understanding of long term changes in the phenological attributes of the vegetation in Western Himalaya. Also, further research with ground validation, climatic data and time-series with better spatial resolution would be helpful in understanding the variations in phenological patterns and identifying the reasons behind those changes.

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