Climatic control of Vegetation Trend Shifts in Northwest and Central India

Bikash Ranjan Parida

Centre for Land Resource Management (CLRM)
School of Natural Resource & Management
Central University of Jharkhand, Brambe
Ranchi-835205, Jharkhand, India
Email: bikash.parida@cuj.ac.in

ABSTRACT

The relationships between climatic conditions and vegetation changes are not firmly established at different geographic settings. It is well established that climate phenomena strongly affects the terrestrial ecosystems. In this context, many studies have presented how climatic variations have caused major alterations in the composition and distribution of terrestrial ecosystems worldwide. There is a need to understand how ecosystem processes are influenced by the entire suite of perturbations, from climate variability owing to changes in temperature, precipitation, solar radiation, and other disturbances. The overarching objective of this study was to determine spatiotemporal responses of the terrestrial vegetation in Northwest and Central India to climate change. The GIMMS $NDVI_{3g}$ dataset at 0.083° spatial resolution from the AVHRR instruments were used for the years 1982–2015 to capture Normalized Difference Vegetation Index (NDVI) changes over terrestrial ecosystems. In conjunction with satellite dataset, the monthly gridded climatic dataset such as precipitation, temperature, surface solar radiation, and microwave-based soil moisture were used to determine the major driving climatic variables of large-scale change of vegetation growth. All satellite and climate fields were aggregated to a common 0.083° spatial grid to apply statistical analyses and these computations were executed using the R package “raster”. The greening and browning trends were investigated using non-parametric methods, namely, Mann-Kendall test and Theil-Sen (TS) median slope.

The prominent large-scale greening trends of vegetation during the period 2000-2015 were identified in Northwest India (i.e. Gujarat, Rajasthan states) including the Central India (i.e. Madhya Pradesh). These areas are mainly confined to arid, semi-arid and sub-humid regions. Despite climatologically drier regions, the strong greening trends of vegetation were evident over these regions. This can be explained by the various driving factors such as increased rainfall and decreased temperature trends in response to climate change.

KEY WORDS:

NDVI, climatic data, vegetation growth, greening trends, climate change

1. INTRODUCTION

The main component of the terrestrial biosphere is vegetation and it plays an active role in the climate system through the exchange of energy, carbon, water and momentum between the biosphere and the atmosphere (Foley et al., 2000). In this context many studies have presented how climatic variations have caused major alterations in the composition and distribution of terrestrial ecosystems worldwide [Chapin et al., 2010]. Commonly, precipitation and temperature are two important climate drivers that affect plant growth and distribution albeit other climate drivers viz. solar radiation, atmospheric CO_2 concentrations, nutrients, etc are also regulate the vegetative phenology. Over Indian continental regions, average temperatures during the summer monsoon season (June-September) have increased by 0.25 °C since the mid 1990s (Milesi et al., 2010) and are projected to rise up to 2.8-3.8 °C in the future in response to the build-up greenhouse gases in the atmosphere (Lakshmi Kumar et al., 2013). The most pronounced changes in summer monsoon temperature in the recent decades (2001-2015) are observed across all parts of India.

From a climatic point of view, India receives about more than 75% of rain during monsoon (June–September) season. A shift in precipitation pattern can have a profound impact on agriculture, forestry and water resources, etc. Vegetation growth pattern and responses are highly dependent on monsoon-dominant climate over the Indian subcontinent (Revadekar et al., 2012). The seasonal trends of monsoon rainfall in India during past three decades (1980-2010) are different over the eastern and western parts of the country. Previous findings suggested that the increasing rainfall trends are more profound over the west of 80° E, whereas largely negative or decreasing trends towards the eastern region.

Remotely sensed vegetation indices like normalized difference vegetation index (NDVI) is used to monitor vegetation growth and known as a surrogate measurement of plant photosynthetic activity (Myneni et al., 1997). Vegetation growth pattern is commonly used to monitor productivity of natural and agricultural lands. The trends such as “declining or browning” and “increasing or greening” have been used widely. These trends are not constantly monotonic but can change from positive to negative trend and vice versa. Further, changes of NDVI trend can be either gradual or abrupt and more rarely, no change (de Jong et al., 2013) and the shift from one to another one can be computed using the change points in trends (Wang et al., 2011). Regardless of changes in NDVI trend spatially and temporally, the critical issue is detecting the changes for understanding the process in the context of broader global change. So, the main objectives of this study were to investigate the vegetation trend shift and associated climate controls and to analyze inter-annual and seasonal variation in the vegetation trend shift over the period 1982-2015. The trend was determined separately for two periods such as 1981-2000 and 2000-2015 as the latter period experienced higher global warming which could have significant signals of trend shift.

2. DATA & METHODS

2.1 Study Region

The study area covers various regions of India and the detailed analysis has been carried out only to specific regions that have been sensitive to climate. For this article, Northwest India and part of Central India have been included for analyzing the vegetation trend shift associated with climate control. The Northwest (Gyjarat and Rajasthan) and Central India (Madhya Pradesh) comprises a large amount of diversity in vegetation including diversified crops due to factors such as climate, soil type, and irrigation access. The Northwest is located in arid to semiarid region and majority of areas are drought-prone, whereas Madhya Pradesh (MP) is located in the sub-tropical region of Central India. In both regions, there are two major growing seasons: the monsoon season (kharif) that spans from June to October and the winter season (rabi) that spans from November to March (Ministry of Agriculture, 2014). The primary monsoon season crops are paddy, jowar, maize, cotton, groundnut, soybean, and pulses. The primary winter crops in Northwest are wheat and groundnut, whereas in MP, wheat, sorghum, pulses, and mustard are grown. The main source of rainfall in both regions is the monsoon, usually lasts from June to September, though off-season precipitation occasionally falls in December to January (Ministry of Agriculture, 2014). Both regions have experienced extreme temperatures both during summer and winter. The temperature starts rising from March and its start falling from October.

2.2 Satellite and Climate Data

Satellite-based AVHRR GIMMS NDVI$_{3g}$:

The improved calibrated and extended long-term satellite vegetation records of NDVI from the GIMMS has been used. The third generation of the GIMMS NDVI (NDVI$_{3g}$) data builds on its predecessor NDVIg with a native resolution of 0.084° (Tucker et al., 2005). The latest version of NDVI$_{3g}$ data has been better calibrated against other NDVI data sets. The vegetation greenness index NDVI was used because it acts as a substitute measurement of chlorophyll and thus plant photosynthetic activity that detects the presence of growing vegetation (Myneni et al., 1997). The annual composite of NDVI has been obtained by taking 12-month mean values from the corresponding months in each calendar year.

IMD-based Rainfall and Temperature:

The India Meteorological Department (IMD) rainfall data were available at the National Data Center (NDC), Pune. The National Climate Centre constructed gridded rainfall data with a spatial resolution of 0.25° latitude and longitude grid and they are interpolated from the 7000 rain-gauge stations. This is the latest dataset for India developed by IMD and detailed description and quality control were mentioned in Pai et al. (2014).

In this study, we used both NDVI and IMD data from 1981-2015 for analyzing its trend and establishing relationships between vegetation and climate.

2.3 MANN–KENDALL TREND TEST FOR NDVI

The NDVI data are used to compute Mann–Kendall trends (Mann, 1945) on a pixel basis from 1981 to 2015. The trend calculation is applied on annual aggregated data with pixel values that are more than 0.2. The non-parametric test is based on the rank correlation coefficient (τ; herein after referred to as Kendall's τ). The other procedure called pre-whitening as described in Yue et al. (2002) has been applied to remove lag-1 autocorrelation from the data. The Kendall's τ at pixel basis within 90% significance level has been analysed. The climate data such rainfall and temperature are used to compute the linear slope that uses the Theil–Sen approach (1968). Theil–Sen slope estimator was formulated by Thiel (1950) but modified by Sen (1968) and computes the median of the slopes between observation values. The trends of NDVI and climate data were determined separately for the two focal periods, namely, 1981 to 2000 and 2000 to 2015 on a pixel basis. The trend of pixels corresponds to urban areas and barrel land has been masked so that only vegetation pixels have been analyzed. Two focal periods have been determined in order to see the climate controls on vegetation as the period after 2000 have been experienced more warming than the 1980s or 1990s. All the statistical computation were performed in the in the R raster and gimms package which has been publicly available (Detsch, 2016).

3. RESULTS AND DISCUSSIONS

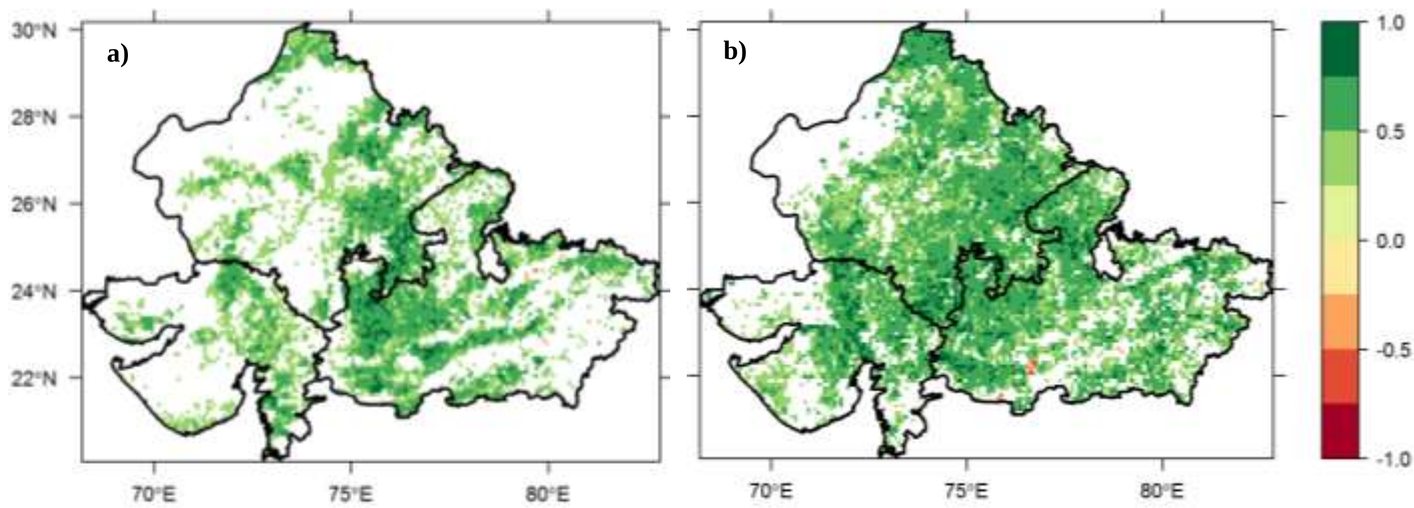

Figure 1: Spatial patterns of "significant" values of τ during (a) earlier period (1982–2000) and (b) the latest period (2000-2015) for NDVI3g. The τ-values are shown only for those pixels that passed 90% level of significance.

Figure 1 illustrated the Mann-Kendall trends separately for the earlier period (1982-2000) and the recent period (2000-2015) based on the latest NDVI3g data. In the earlier period (a), we found that most of the areas observed as greening trends but these trends have been more pronounced in the latest period (b). This indicates that activities of vegetation has been enhanced profoundly over Northwest (Gujarat and Rajasthan) as well as central India (MP). Despite global warming and changes in temperature in the recent decades are observed across all parts of India, the increased temperature has no such adverse impact on vegetation growth especially over both Northwest and central India (MP). The percentage area under three categories, namely, browning, no trend, and greening trends at 90% level of significance has been determined (Table 1). The results indicate that greening trend during earlier period was 46% which has been increased to 70% of area during the latest period.

Table 1: The % of area under browning, no trend, and greening trends at 90% level of significance, which has been calculated based on the Mann-Kendall τ-values of annual aggregated NDVI. Area of three states (GJ, RJ, MP) is 0.832 million km^2.

Duration	Browning (%)	No trend (%)	Greening (%)
1982-2000	0	54	46
2000-2015	0	30	70

In order to understand the climate controls on such large-scale greening trends in the latest period over these regions, we further investigated climatic controlling factors such as precipitation and temperature. Figure 2 illustrated the sen's slope for the rainfall (a, b) and temperature (c, d) based on the latest IMD data. In the earlier period, we found that most of areas have either decreasing or no trend of rainfall (-50 to 5 mm per year). However, the decreasing trend has been changed to large-scale increasing trend (> 5 mm per year) of rainfall in the latest period over for the western and Central India (Figure 2b). The corresponding % of area under the increasing trend of rainfall was 28% during the earlier period (1982-2000), whereas in the latest period, the increasing trend was 86% (Table 2).

Figure 2 (c, d) represents spatial pattern temperature trends for the two focal periods. The results show that increasing temperature trend up to 0.5 °C/decade over all regions during the first period. Notable, this increased trend of temperature shifted to decreasing trend (i.e. 0 to 0.5 °C/decade) for the latest period. The area under the decreasing or no trend of temperature in the latest period over for the western and Central India covers up to 78% (Figure 2d and Table 2).

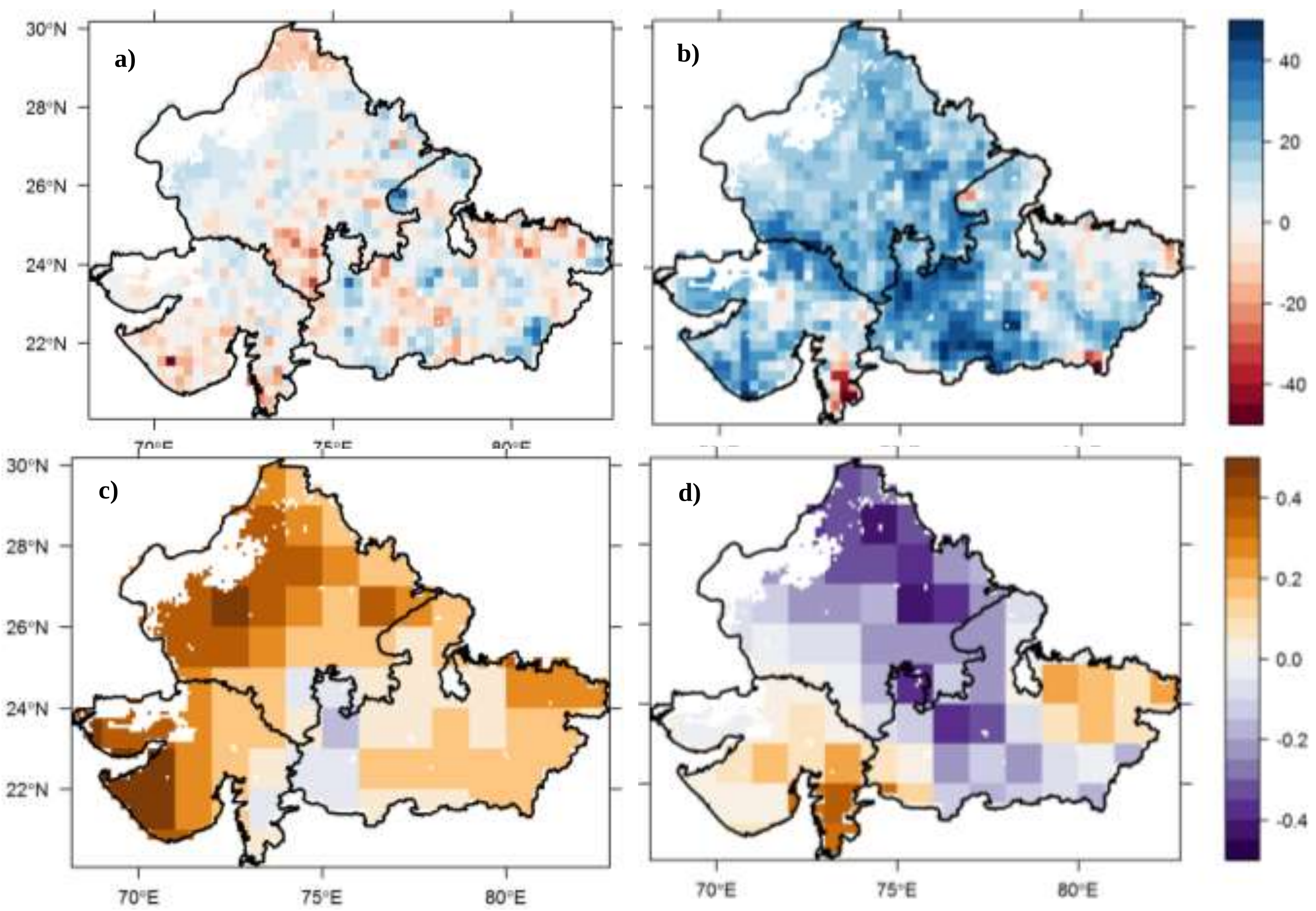

Figure 2: Spatial patterns of "significant" values of sen's slope (mm/yr) during (a) earlier period (1982–2000) and (b) the latest period (2000-2015) for rainfall. Spatial patterns of "significant" values of sen's slope (°C/decade) for temperature are shown in (c) for earlier period (1982–2000) and (d) for the latest period (2000-2015). The slope values are shown only for those pixels that passed 90% level of significance.

Table 1: Area % of sen's slope under decreasing trend, no trend, and increasing trend for precipitation (mm/yr) and temperature (°C/decade) at 90% level of significance.

Sen's slope	Duration	Decreasing (%)	No trend (%)	Increasing (%)
precipitation	1982-2000	12.5	59.5	28
	2000-2015	2.5	11.5	86
temperature	1982-2000	1.5	16.8	81.7
	2000-2015	47.2	30.4	22.4

From these results, we found that there is a large-scale shifts in greening of vegetation over the period 1982to 2016 over these regions. From a more quantitative perspective, Table 1 indicates that a considerably larger amount of "significant" greening trends becomes apparent from the earlier period (i.e. 46% of area) to the latest period (i.e. 70% of area). These greening of vegetation can be explained by either increased rainfall or decreased temperature trends over these regions. Among these climatic controls, precipitation may have been playing greater role as these regions characterized by drier (western) or sub-tropical (MP) climate. There could be other climatic or non-climatic controls on such large-scale change in vegetation, which has not been analyzed in this article.

4. Conclusions

None of the any studies have been conducted over these regions using the latest identified $NDVI_{3g}$ dataset to understand the climatic controls on vegetation growth. Here, the trends were determined using the long-term time series satellite data and climate data. We infer based on the quantitative perspective that either increased rainfall or decreased temperature may have caused such large-scale greening of vegetation over western and Central India (MP). Notably, the rainfall plays greater role on this shifts as these regions are characterized by drier to sub-tropical climate.

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