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Research Paper

Long term trend analysis of vegetation dynamics over Rajasthan using satellite derived enhanced vegetation index

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ABSTRACT

Enhanced vegetation index (EVI) time series data from the Moderate Resolution Imaging Spectroradiometer (MODIS) for the years 2001 to 2021 were used to understand the vegetation dynamics in the Rajasthan during last 21 years. Savitzky–Golay filtering technique was used for reconstruction of high-quality data. The non- parametric Mann-Kendall test was used to evaluate the EVI time series trend at 30m pixel resolution. The results showed that there was great variation in EVI spatial distribution, decreasing trend from the southern and south-eastern parts to the western parts of the state. The EVI increased in 93.3% pixels and decreased in 6.6% pixels, indicating that the vegetation is improving rather than degrading. The findings of this research provide a scientific understanding of how vegetation is changing over Rajasthan and could help in the implementation of sustainable ecosystem management.

Keywords: Vegetation dynamics, EVI, MODIS, Remote sensing, Rajasthan

Vegetation is considered as an important part of the terrestrial ecosystem and biosphere. It is a crucial component of soil-water-plant-atmospheric system, having a significant influence on hydrological and biogeochemical cycles, global energy budget and terrestrial carbon storage (Liu and Lei, 2015; Srivastava *et al.,* 2021). It has a clear relationship with climate change so can be used as a proxy for environment, climate and hydrological studies (Zoran *et al.,* 2016; Wu *et al.,* 2017). Long term vegetation condition assessment is important to understand the ecosystem and its functions.

Long term satellite derived remote sensing products provide valuable inputs for precise monitoring of vegetation dynamics and its relation with climate change (Chakraborty *et al.* 2018; Pan *et al.*, 2018). Globally, various satellite time series products such as NOAA (AVHRR), SPOT (Vegetation), and TERRA/AQUA (MODIS) have been used for the detection of land cover change, natural resource monitoring, and assessment of vegetation condition for a region (Lunetta *et al.,* 2006; Priyadarshi *et al.,* 2018). Remote sensing-based vegetation indices precisely estimate crop phenology, vegetation condition, and net and gross primary productivity from red and near-infrared band reflectance (Piao *et al.,* 2020). MODIS-derived vegetation indices with multiple spatial resolutions (250 m, 500 m, 1 km, and 0.05 Deg), are very useful in monitoring of vegetation dynamics and provide scope to understand the vegetation cover changes at regional and global scales.

The enhanced vegetation index (EVI), one of the most significant vegetation index used for growth assessment of surface vegetation and is also one of the most important basic data in ecosystems research. The change in EVI is a crucial indicator of changes in the local environment and ecosystems (Sarkar and Kafatos, 2004; Cao *et al.*, 2015). It can estimate biomass effectively under saturated conditions (Huete et *al.*, 2002; Fraga *et al.*, 2014). In addition, the EVI range is broader and more dynamic, allowing for the collection of more fluctuations than the NDVI because it takes into account the coefficient of resistance components that rectify the impact of aerosols.

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The objective of present study is to characterizing the long term spatiotemporal pattern of vegetation dynamics over Rajasthan during 2001 to 2021. The goals of this research are to (1) evaluate the annual and seasonal variations in EVI over Rajasthan during 2001-2021; (2) use of Mann-Kendall test to analyze EVI trend at 30m pixel. The proposed method is useful for monitoring vegetation condition and its changes over Rajasthan that are essential inputs for managing land resources in a sustainable manner.

MATERIAL AND METHODS

For the present study Rajasthan state was selected which is located between 23° 30′ to 30° 11′ N latitudes and 69° 29′ to 78° 17′ E longitudes. Geographically, it covers 3,42,239 km^2, or roughly 10.4%, of the total area of India. The climate of Rajasthan is characterized by highly erratic and poor distributed rainfall (480 - 750 mm), excessive evaporation losses, strong wind speed and extremes of air temperatures. The Aravalli hills' orientation parallel to the direction of the southwest monsoon has a significant impact on climate in Rajasthan. The Arabian Sea branch of the monsoon winds strikes the eastern slope of these hills, causing the south-eastern portion of the hills to get sufficient rainfall while the north-western part of the hills remains dry.

In the present study, enhanced vegetation index (EVI) was used in order to analyze the vegetation patterns during 2001-2021. The EVI data were obtained from NASA Land Processes Distributed Active Archive Center's MODIS products (MOD13Q1) and it can be expressed as:

$$EVI = G\frac{NIR - RED}{NIR + C1 * RED - C2 * BLUE}$$

Where, G is a gain factor (G = 2.5) and C1 and C2 represent the aerosol coefficient that is utilised from MODIS to remove the presence of aerosol influences on the red band of MODIS (C1 = 6 and C2 = 7.5). L stands for the adjustment that was made to eliminate the impacts induced by canopy background.

In the present study, MODIS MOD13Q1 EVI products were downloaded using Google Earth Engine for a 21-year period (2001–2021). The data were temporally smoothed using the Savitzky-Golay filter (Jönsson and Eklundh, 2004; Chen *et al.,* 2004). Data sets were reprojected from the Geographic coordinates system to UTM 43 coordinate system and resampled to 30 m resolution by using the bilinear interpolation technique in the ArcGIS. The mean monthly EVI was computed by taking mean of the respective month for the period of 21 years (2001-2021).

Mann-Kendall test and Sen's slope estimator have been implemented for trend analysis by using R 4.2.1 software. In time series EVI data, the Mann-Kendall test was used to determine significance and p-value, which give the strength and direction of the trend but cannot quantify the magnitude of the trend. Therefore, the slope of the trend in time series EVI data was calculated using the non-parametric Sen's approach.

RESULT AND DISCUSSION

Annual variation of EVI

The temporal patterns of the EVI are shown in boxplots from the year 2001 to 2021 (Fig. 1). The boxplot corresponding to the annual EVI temporal patterns shows the way measures of central tendency indicate that the EVI fluctuates slightly between the years 2001 and 2021. For instance, EVI values corresponding to the year 2001, showed a slight increase in the Rajasthan state. It is noteworthy to mention that the EVI data points ranging from 2001–2021 contain the mean of all months of EVI values from January to December. It is observed that the maximum (~0.55) and minimum EVI values (~ -0.12) occurred in the years 2017 and 2005, respectively. In addition, maximum fluctuations of the EVI also occurred in the year like 2005, and 2017, while the minimum fluctuation of the EVI is observed in the year such as 2010 and 2018. The median EVI within the basin varies between ~0.17 to 0.23 throughout the time period. In addition, the 25th percentile of the EVI ranges from ~0.05 to 0.09 while the 75th percentile of the EVI ranges from ~0.30 to ~0.38 across the twenty-one years. The unequal distribution of rainfall across Rajasthan was the major cause of this difference in vegetation greenness. Many studies have reported that temporal variation of EVI is closely associated with rainfall (Budde *et al.*, 2004; Doi, 2001; Richard and Poccard, 1998; Wang *et al.*, 2003; Kumari *et al.*, 2021). Although, there is a time lag of one or two months between EVI and rainfall (Moses *et al.*, 2021; Kumari *et al.*, 2021).

Seasonal variation of EVI

Fig. 2 shows the monthly variations of the EVI for the whole Rajasthan state. The boxplot reflects the mean monthly values of the EVI for the study period (2001–2021). It is observed that the EVI has its seasonal peak in January and September, while April is observed to have the lowest EVI values in the study area. Further, it can be seen that monthly EVI values have fewer fluctuations, especially in the summer season, as compared to the monsoon and winter seasons. It is also observed that the vegetation greening (EVI) is higher during the months of September, January and February compared to other months and shows the relation between various cropping season (*viz Kharif*, *Rabi* and *Zaid*) and the EVI index. EVI increased with the peak stage of *Rab*i and *Kharif* seasons and decreased with the crop maturity. However, the minimum values of EVI were lower in the *Rabi* season as compared to *Kharif* which may be due to the unsown area or fallow land.

Spatial variation of EVI

Fig. 3 shows the spatial variation of long-term mean annual EVI for the period of 2001 to 2021. The mean EVI varies from -0.11 to 0.55. It can be seen that greenness cover (EVI value) increased in the Rajasthan state over the period of time. Among all the years, year 2021 has a larger number of green pixels covering the study area, which shows that majority of the area has higher EVI values year. However, the reverse pattern is seen in the year 2001, where the majority of the area is covered with lower EVI values. These maps clearly indicate a decreasing trend of EVI from the southern and south-eastern parts to the western parts of the state. This

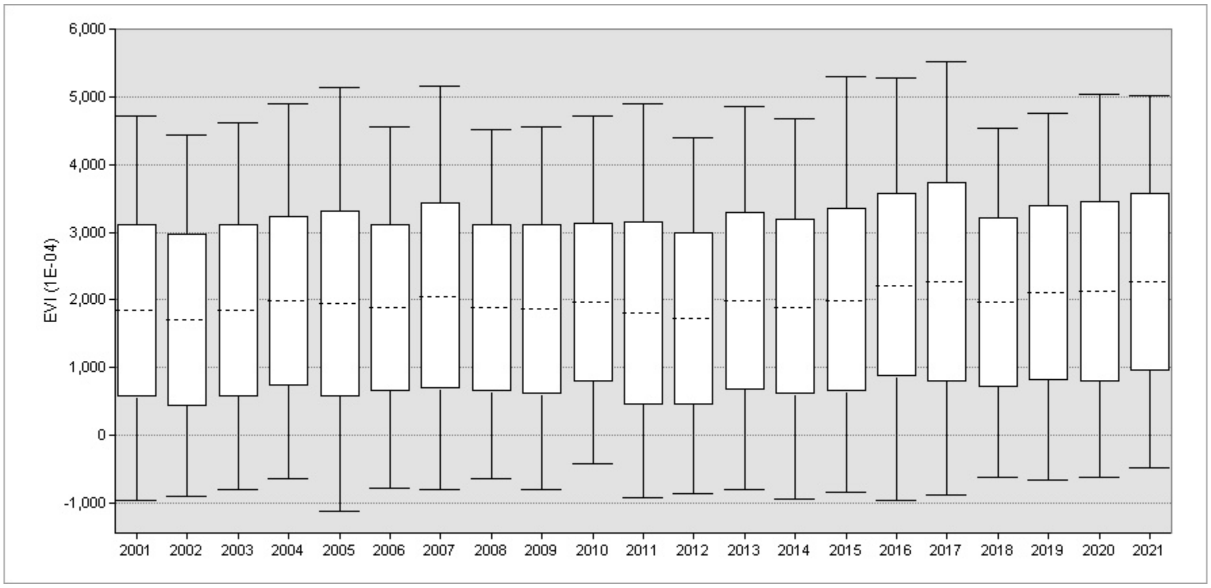

Fig. 1: Inter-annual variability of EVI during 2001–2021

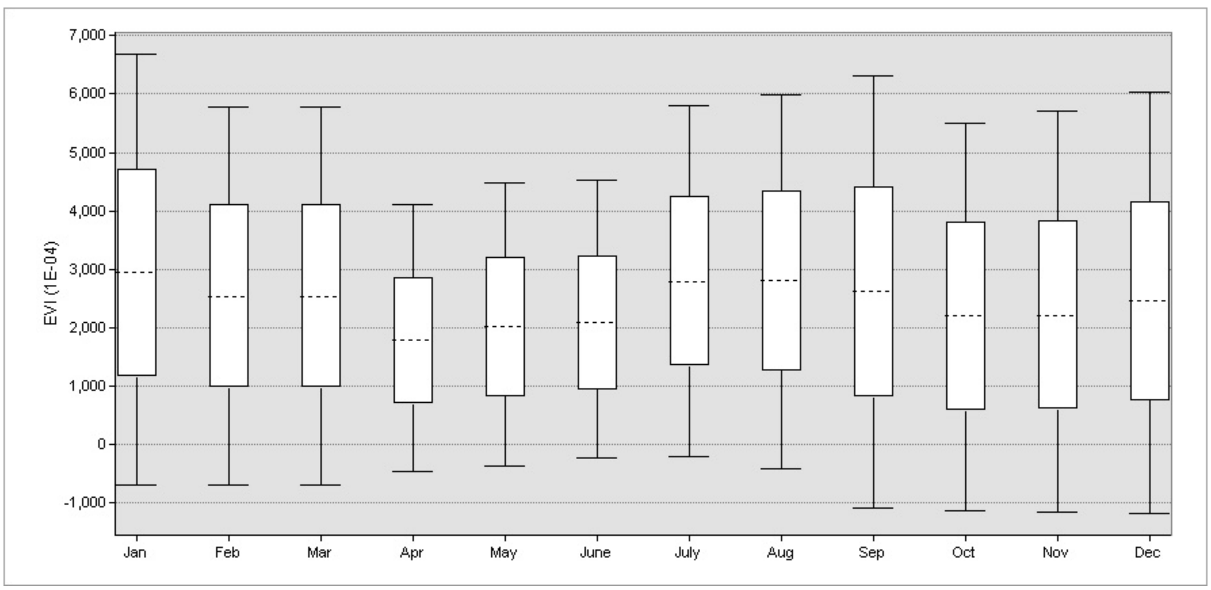

Fig. 2: Mean monthly variability of EVI during 2001–2021

spatial variability has occurred mainly due to uneven distribution of monsoonal rainfall which is significantly higher in southern and south-eastern part compared to western part of Rajasthan.

Agroclimatic zones such as Humid south eastern plain, Humid southern plains and Flood prone eastern plain and Sub-humid southern plains are having higher EVI due to high rainfall (800-1000 mm), which contribute in the cultivation of *kharif* crops, and residual moisture also helps in the growth of *rabi* crops. Central part of the Rajasthan (Transitional plain of inland drainage, Transitional plain of Luni basin and Semi-arid eastern plains) are having medium EVI due to availability of medium rainfall while, the western part has EVI values (< 0.15). The western part of Rajasthan has sandy Thar desert with typical arid climatic condition and very less rainfall resulting poor vegetation growth but recent irrigation management strategies have brought changes in this region (Sur *et al.*, 2018). It is clearly visible that vegetation condition was under stress during 2002 due to the severe drought phenomenon prevailed during *kharif* season of 2002 (Malik, 2014; Dutta *et al.*, 2015).

Trend analysis of EVI

Fig. 4 shows the trend of the mean EVI for Rajasthan over the period of 2001-2021. By averaging the mean EVI over all pixels for the entire Rajasthan, the linear regression model was developed. It is observed that there has been an overall temporal increasing trend in EVI values with a positive correlation of 0.77 over the years 2001–2021. The mean annual EVI values for Rajasthan vary from ~0.14 to 0.21. Fig. 5A & B represent a map of sen's slope

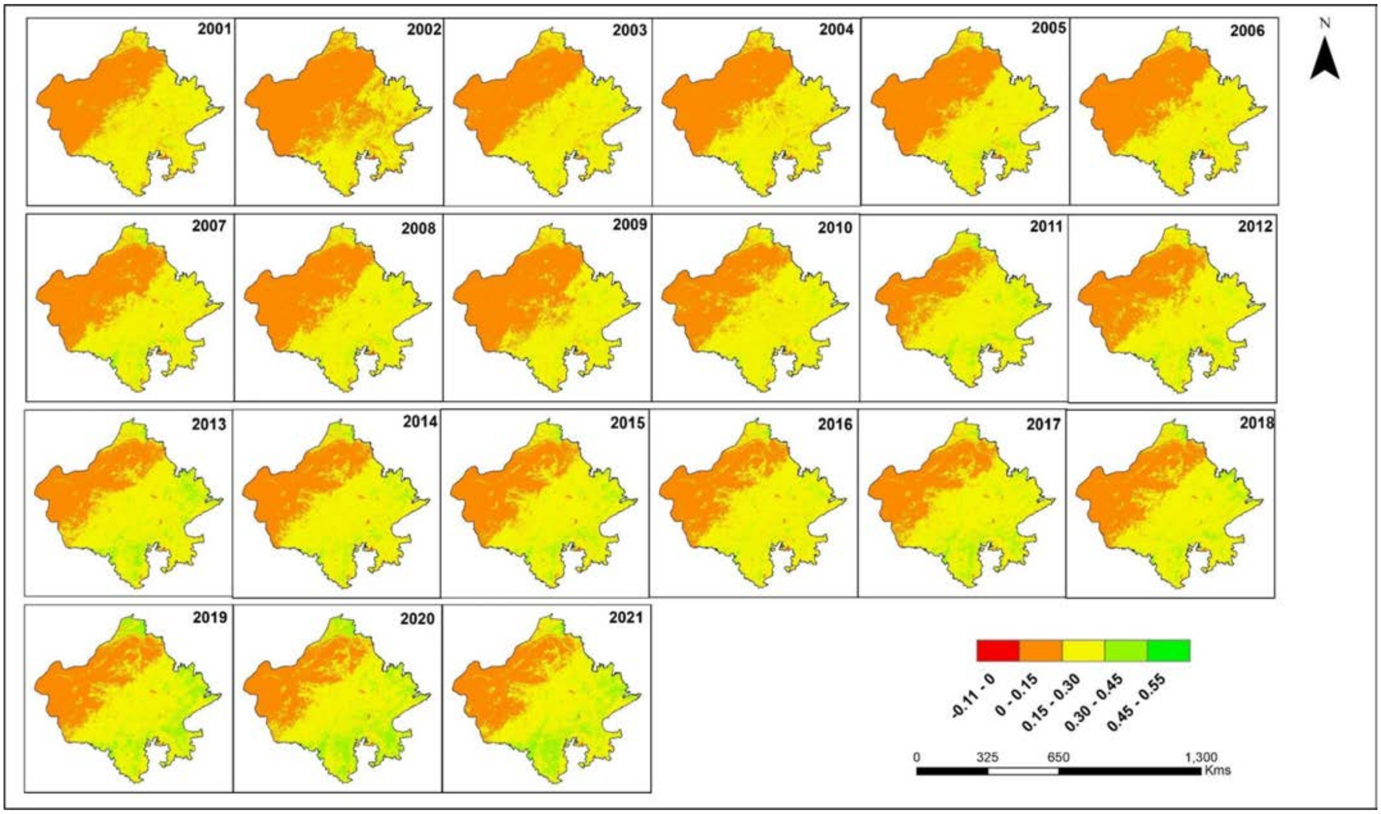

Fig. 3: Spatial variation of EVI during 2001–2021

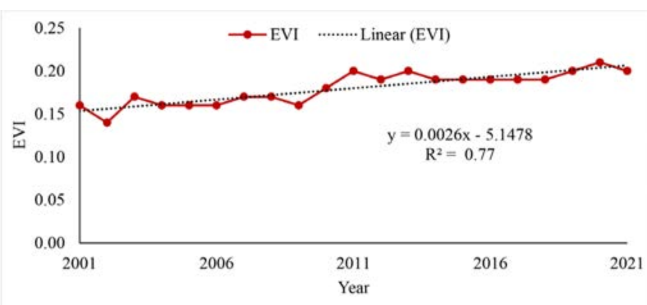

Fig. 4: Inter-annual variability of mean EVI for Rajasthan during 2001-2021

values for changes in EVI and Mann-Kendall test for statistically significant trends in mean annual EVI at the pixel level over the Rajasthan from 2001 to 2021. During the 2001 to 2021, there were more pixels exhibiting vegetation improvement than degradation. EVI increased in 93.3% of the study area (S>0) which were mainly located in southern and eastern parts while decreased in 6.6% of the total pixels (S<0). The significant changes ($p<0.05$) was seen in 76.6% of the total pixels. The EVI decreased in some parts of Jaipur and Jaisalmer but it increased significantly over the Indira Gandhi Canal command area. The EVI is showing increasing trend over Indira Gandhi Canal area and it is mainly due to better irrigation facility, changes in cropping pattern, restoration of degraded land, rain water harvesting structure and proper policy interventions. According to numerous research, the canal network may be a major factor in the increase in EVI (Moharana *et al.*, 2013; Goroshi *et al.*, 2017; Sur *et al.*, 2019). Particularly in the Jaipur district, some pixels (red pixels) exhibit a declining trend in EVI, which may be caused by industrialisation/urbanisation, ground water depletion, improper irrigation practises, changes in cropping patterns etc. This result is highly consistent with Guan *et al.*, (2019) and Lyu *et al.*, (2018) that extensive urbanization or industrialization has resulted in extensive losses of agriculture land.

CONCLUSION

In Rajasthan, monitoring of vegetation is a challenging task because of the complicated geography and significant climatic unpredictability. Therefore, remote sensing derived satellite products have immense potential for monitoring vegetation dynamics for any region. In the present study, EVI was used to characterize the spatiotemporal variation in vegetation greenness over Rajasthan during 2001-2021. For trend analysis, Mann-Kendall test was performed at 30 m pixel resolution after smoothing of data using Savitzky–Golay filtering technique. It was observed that 93.3% pixels have an increasing trend while 6.6 % pixels have a decreasing trend across the state. The current findings show conclusively that crop fields have increased significantly in Rajasthan particularly over the Indira Gandhi Canal area and degraded lands have significantly decreased over the time. The findings of this study may help in ecosystem protection, degraded land rehabilitation, and sustainable management of natural resources.

Conflict of Interest Statement: The author(s) declare(s) that there is no conflict of interest.

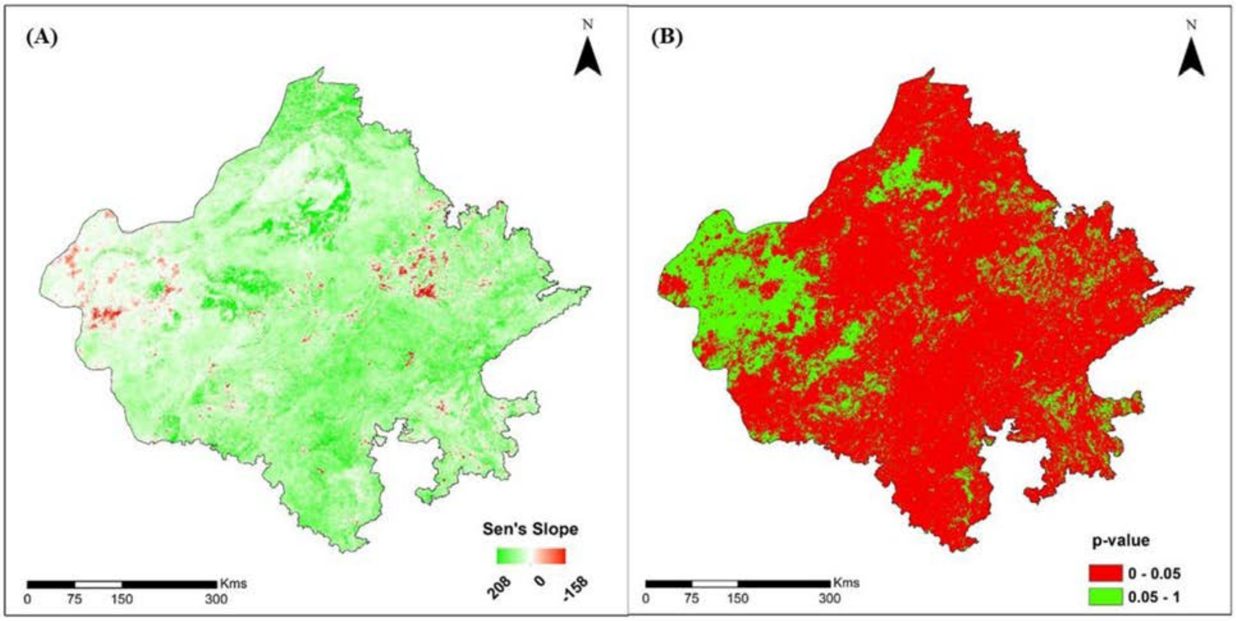

Fig. 5: (A) Sen's slope values for changes in EVI and (B) Mann-Kendall test for statistically significant trends in mean annual EVI at the pixel level

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