

On the relation of vegetation and southwest monsoon rainfall over Western Ghats, India

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Abstract This article presents the tendency of the normalized difference vegetation index (NDVI) and the dependence of vegetation on the rainfall and number of rainy and non-rainy days over Western Ghats. The study makes use of MODIS Terra NDVI data with 8-day intervals and 250-m resolution from 2000 to 2010 during the southwest monsoon (June to September) season. The results show an increasing tendency of the NDVI over different test sites in Western Ghats. The relation of the NDVI with the Antecedent Precipitation Index obtained from rainfall showed good agreement, and the relation of rainfall and the NDVI was mainly dependent on the available soil moisture levels and elevations of the test sites. Correlations were significant and positive with the number of rainy days and negative with the number of non-rainy days with a nearly 2-month lag.

Keywords NDVI · API · Monsoon · Western Ghats · MODIS TERRA

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1 Introduction

In mountain regions where the majority of the population depends on agricultural production, understanding the relation among vegetation, rainfall and productivity is essential. The Normalized Difference Vegetation Index (NDVI) derived from the Moderate Resolution Imaging Spectroradiometer (MODIS) TERRA is most useful in studying the aforementioned aspects by relating them with the rainy seasons, crop yields and production (Funk and Michael 2009; Gunnula et al. 2011). Since the data of the MODIS NDVI are available at finer spatial resolution levels (e.g., 250 m), the studies on vegetation dynamics over mountains will be more reliable. Since the meteorological factors, such as rainfall, temperature, wind speed and so on, vary significantly from land to mountains, which results changes in crop productivity, study of the impact of meteorology on vegetation over mountains attains great importance. Also, vegetation over mountains varies with altitude and land heterogeneity, and the studies on vegetation dynamics are complex. Song and Ma (2008) studied the vegetation variations over mountain areas of Shandong Province in China and reported the precipitation and atmospheric temperature affect the vegetation. Fu et al. (2013) studied the vegetation cover variation over the Qilian Mountains, China, in response to climate change and reported the positive and negative trends of vegetation. They suggested that the changes in vegetation are also controlled by the topography and local hydrology. Shary and Sharaya (2014) examined the changes in the NDVI over the mountain basins of the Northern Caucasus as a function of topography and revealed a nonlinear association between the NDVI and summer temperatures.

Western Ghats, one of the mountainous regions in India, attains great significance because of its biodiversity and evergreen forests. It is located along the west coast of India and experiences most of the annual rainfall during the southwest monsoon season, with an average over some parts exceeding 2500 mm (Rao 1976; Soman and Krishna Kumar 1990; Francis and Gadgil 2006). This heavy rainfall pattern is due to dynamic controls as well as the localized factors that interact during the course of the monsoon. During the SW Monsoon season, persistent equatorial Westerlies approach Western Ghats, which forms a barrier to these winds because of the height of the ghats (1500 km wide and 1000–2500 m

Table 1 Details of the crops in Western Ghats

Crop	Area ('000 ha)	Production ('000 ha)	Productivity (kg/ha)
Rice	2685	6530	2387
Sorghum	2944	1751	863
Maize	784	1778	2046
Groundnuts	910	1008	1207
Areca nut	232	285	1196
Cardamom	66	10	74
Tea	108	210	1325
Coffee	259	225	752
Cashew	176	76	384
Rubber	244	302	962
Black pepper	229	91	952
Tapioca	164	4566	25,243

high). The orographic lifting of the moisture-laden SW monsoon current is reinforced locally by convergence because of the channeling effect of the concave-shaped terrain along the crestline of Western Ghats, thus producing exceptional quantities of rainfall (Von Lengerke 1980). Recent studies by Krishnan et al. (2012) and Rajendran et al. (2012) suggested that the summer monsoon rainfall and vertical velocities over Western Ghats have weakened as compared to the past. They also reported that while the windward side of Western Ghats has a decreasing seasonal rainfall trend, the leeward side has shown an increasing trend. A decreasing trend in the frequency of moderate to heavy rainfall (20–100 mm per day) and an increasing trend in light rainfall events were also observed.

The traditional land use in Western Ghats is paddy cultivation along with valley and hill slope cultivation (Report of Gadgil 2011). In terms of area covered, the major crop in Western Ghats is sorghum, followed by rice, groundnuts and so on. Coconut is also a major crop in the Western Ghats region of the Kerala state, but not in Karnataka. Table 1 gives an idea of the different crops covering Western Ghats in parts of Karnataka state as reported by Naresh et al. (2011). The test sites covering Western Ghats are shown in Fig. 1.

Krishna Prasad et al. (2008) studied the effects of precipitation, temperature and topographic parameters on the vegetation over Western Ghats. They reported that the combination of precipitation and temperature has a significant impact on vegetation in Western Ghats. While studying the spatiotemporal patterns of the NDVI over India, Lakshmi Kumar et al. (2013) inferred that the vegetation characterized by the NDVI showed the highest value in Western Ghats compared to other regions of the country due to the availability of plenty of soil moisture, which is used for the growth of vegetation.

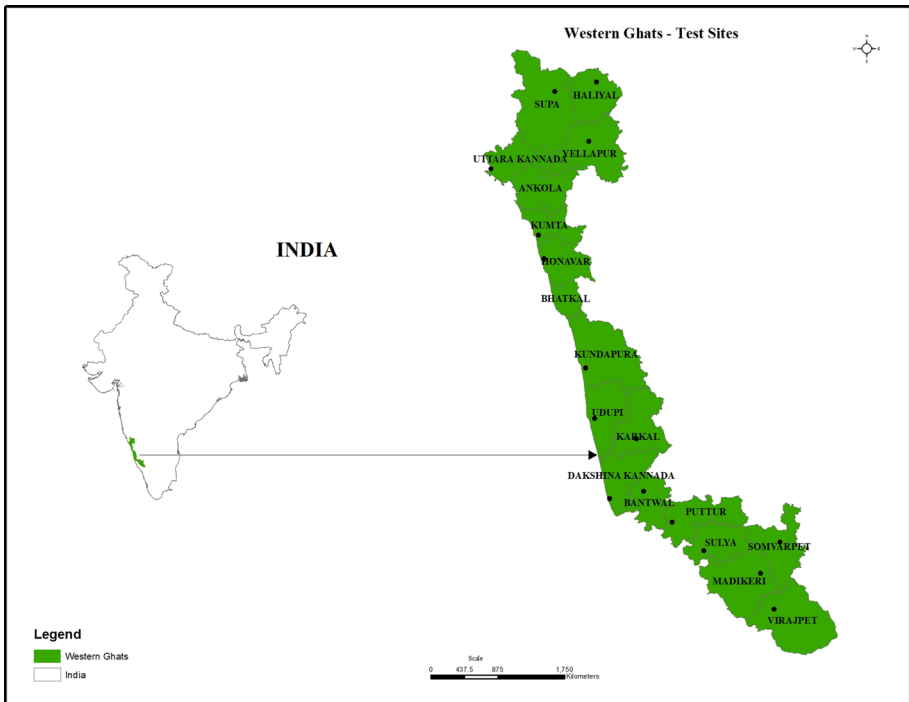


Fig. 1 Location map of the study area

Similarly, Revadekar et al. (2012) studied the spatial variations of the NDVI over India for the 1981–2010 period using the data from two different sources (AVHRR and MODIS) and reported higher NDVI values in Western Ghats due to higher rainfall amounts. Sarma (2006) also reported that Western Ghats is an all-time humid region where the moisture index (derived from the Thornthwaite Climatic Approach) is always above 80 %, which indicates the perhumid climate. Studies of the NDVI over humid regions are limited because of the prevailing high soil moisture (Lakshmi Kumar et al. 2016). Rhee et al. (2010) studied the vegetation characteristics over arid and humid regions and suggested that the NDVI values were better correlated with in situ variables in arid than in humid parts. Thus, relating the NDVI with the rainfall over humid regions is a crucial task. In the present work, we carried out studies in Western Ghats region to identify short-term vegetation trends (tendency) and their variability during the stage “rate of green-up” in the crop-growing periods. As Western Ghats features traditional valley and hill slope cultivation, the relation of both rainfall and the rain events is of importance when discussing vegetation trends. So, our analysis includes the NDVI variations with the number of rainy and non-rainy days during the southwest monsoon season over Western Ghats.

2 Data and methodology

The 8-day products of the MODIS NDVI supplied by NASA were collected from the www.lpdaac.usgs.gov website and processed to derive the NDVI values for the test sites. The Moderate Resolution Imaging Spectroradiometer onboard NASA’s Terra satellite (Zhang et al. 2003) provides seven spectral bands for land applications with spatial resolutions from 250 m to 1 km (Justice et al. 1997). The data from this satellite are available after carrying out atmospheric corrections and are reliable for land studies (Vermote et al. 2002). The wavelengths used by MODIS TERRA for the NDVI are 645 nm in visible light and 857 nm in near infrared light (Gu et al. 2008). ERDAS software was used to extract the NDVI for the 2000–2010 period during the southwest monsoon season. In total, 176 images were processed. The procedure and basic steps for deriving the NDVI from ERDAS Imagine were given in Lakshmi Kumar et al. (2016). In the present study, the authors considered the test sites of Western Ghats covering Karnataka State. Lakshmi Kumar et al. (2016) have studied the NDVI variations over these test sites and reported the relation of the NDVI with light, moderate and heavy rain days along with the monsoon distribution and monsoon activity. In their study, Lakshmi Kumar et al. (2016) reported the results of the overall analysis of Western Ghats.

Based on the spectral properties of vegetation, the NDVI can be calculated from the reflectance of visible and infrared light from the incoming solar radiation. Using this concept, the NDVI is defined as the ratio of the difference of near infrared and red light from its sum, and the value varies from -1 to $+1$. The general classification of the NDVI is given by the Food and Agriculture Organization (FAO) as follows.

- NDVI < 0.2—less vegetation
- 0.2 < NDVI < 0.4—medium vegetation
- NDVI > 0.4—high vegetation

Daily rainfall data for the test sites were collected from Karnataka State Natural Disaster Monitoring Centre (KSNDMC), Bangalore, Karnataka, India, for the 2000–2010 period. To assess the relation between the NDVI and rainfall, using daily rainfall, we

calculated the Antecedent Precipitation Index (API) for the test sites, based on Rosenthal et al. (1982):

$$API(j) = API(j - 1) \times C^t + P_t$$

where j is the current week; $(j - 1)$ is the previous week; $C^t = (P_t/P_o)$, where P_t is the t th week rainfall, and P_o is the rainfall of the starting week.

The Pearson correlation technique was used to relate the NDVI to the API over the test sites of this study.

3 Results and discussion

3.1 Tendency of the NDVI during the SW Monsoon season—Western Ghats

Figure 2a–p of the present study shows the short-term trends of the SW monsoon NDVI at the optimum state of the crops for an 11-year period starting in 2000 for the individual test sites. The linear fits (direction and rate of change together) shows an increasing tendency right from the year 2000, although there are distinguished yearly fluctuations in the NDVI. The average NDVI at the optimum stage varied spatially from 0.469 (Bantwal) to 0.579 (Sulya) during the study period. The studies of Piao et al. (2005) showed that the semi-arid and semi-humid areas (categorized based on the value of the moisture index derived from the Thornthwaite Climatic Approach) in China have NDVI values of around 0.219 and 0.323, respectively. The present study area falls under humid/perhumid conditions

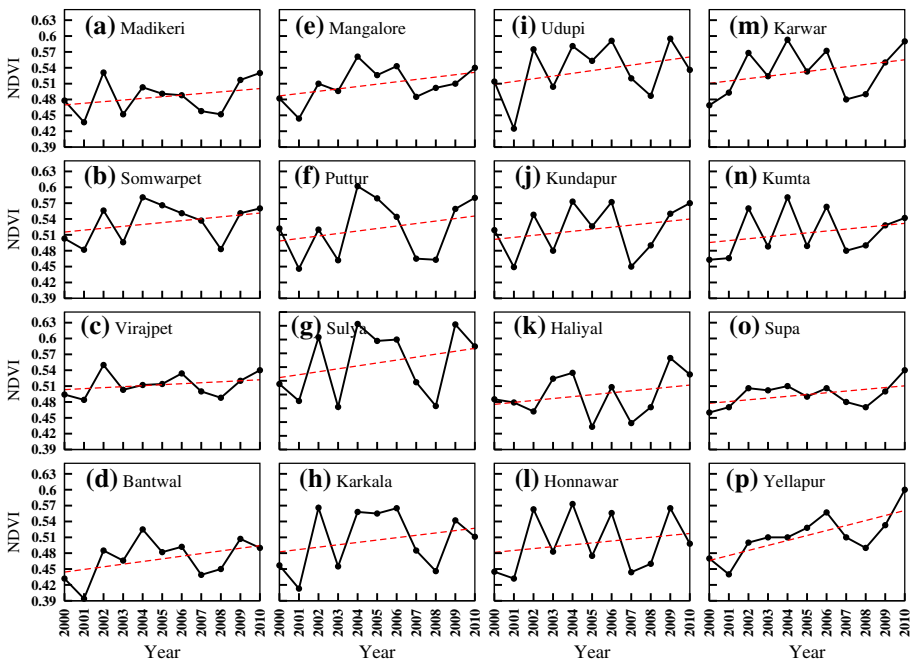


Fig. 2 Short-term trends of the NDVI at the optimum stage over different test sites

(moisture index above 80 %), and NDVI values above 0.469 are observed over Western Ghats (Fig. 3).

It is reported that the interannual variability of vegetation is high (low) in arid (humid) regions characterized by low (high) vegetation activity (Vicente Serrano 2006). Shi et al. (2003) also found that warm arid areas had a strong transformation signal of the warm wet type indicated by enhancement on the rainfall/moisture index; as a consequence, the NDVI values showed higher values. Theoretically, higher NDVI values result from an increasing difference between near infrared and red reflectance, caused by the higher absorption of the red wavelength of light by green plants. The overall NDVI value over Western Ghats, calculated as the average of all 16 test sites during the study period, was 0.506 with a standard deviation of 0.038. The increasing tendency of the NDVI over individual test sites varied with respect to the slopes of the linear fits, showing a high rate of NDVI increase at Yellapur (slope = 0.009) and a very low rate of NDVI increase at Virajpet (slope = 0.001). Similarly, an increasing tendency of the NDVI was observed in the humid regions for the MODIS data sets—16-day composites over the Mongolian region characterized by ecological transition zones and mountainous forests (Yin et al. 2012).

3.2 Relation of the NDVI with the API

The crop phenophases, such as the start of season, rate of green-up, optimum stage, rate of senescence and end of season, have their own responses to weather changes, including rainfall occurrence, temperature variation and so on. The response of the main phenological stage of the crops—rate of green-up—to the seasonal rainfall, which is

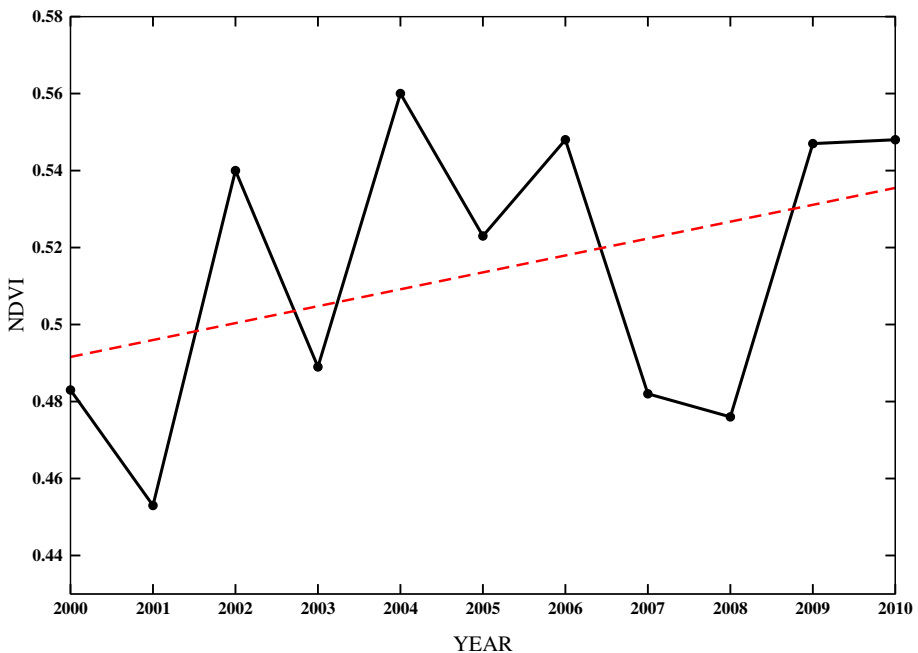


Fig. 3 Values of the NDVI at the optimum stage from 2000 to 2010 over Western Ghats

characterized by the antecedent precipitation index (API)—is depicted in Fig. 4. When trying to understand the relation between rainfall and the NDVI over this area, we could not find a direct relation of the NDVI with rainfall, and in some cases, a negative correlation was obtained. Jain et al. (2010) reported that the NDVI maintained the lowest correlation over Kota, a humid region, with the Standardized Precipitation Index (SPI), which was derived from rainfall data over Kota. They concluded that this poor correlation is because of adequate soil moisture provided by the Chambal River, which flows through Kota. Vicente Serrano (2007) also reported that the Vegetation Condition Index (VCI), which is derived from the time series NDVI, maintained a very high correlation with the SPI in the low vegetation areas of the middle Ebro valley. The relation of the NDVI and rainfall over humid areas has also been found to be dependent on previous levels of soil moisture achieved because of rainfall during the previous months/years. Although the SPI and VCI are different from the API and NDVI indices used in the present study, the variations in the SPI and VCI are analogous to those of the API and NDVI. The studies of Qiu et al. (2013) also confirmed that the climatic conditions of rainfall and temperature show less influence on vegetation distribution over hilly mountain regions.

With this understanding, the authors of the present investigation plotted the NDVI with the API over the test sites. All the sites in the present study showed significant correlations (Table 2) except three stations: Bantwal (0.10), Mangalore (0.21) and Supa (0.32). These poor correlations may be attributed to the increased urbanization, local weather dynamics and site-specific conditions such as the temporal distribution of rainfall, soil type, cropping regimes and so on. In addition, as can be seen in Table 2, the Somwerpet and Haliyal stations maintained the highest correlations with the API, viz. 0.96 and 0.92, and the highest values of the NDVI, viz. 10 and 13 %, from the normal values, respectively. One of the main causal factors for this high vegetation could be the elevation level. The studies by

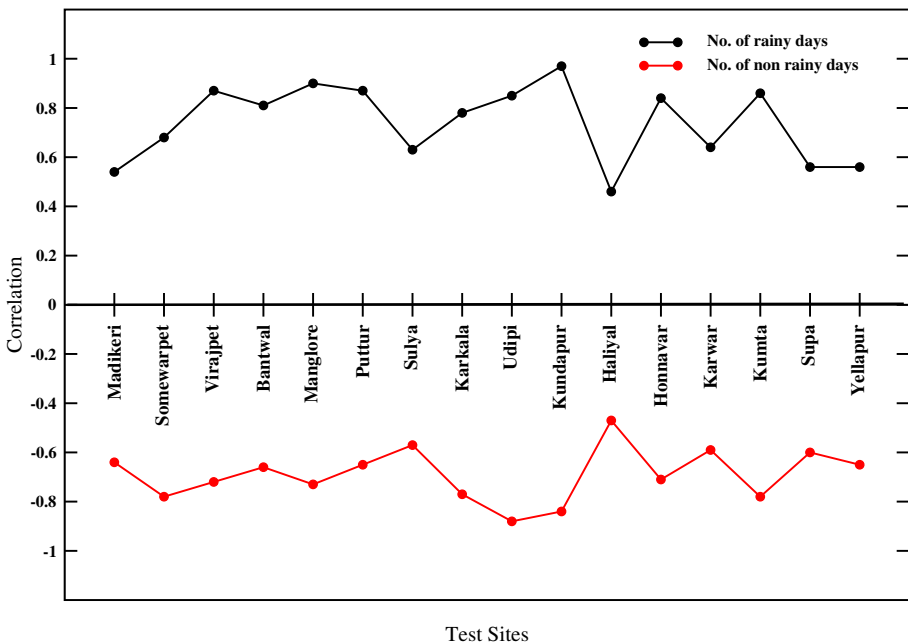


Fig. 4 Correlations of the NDVI with the number of rainy and non-rainy days

Table 2 NDVI anomaly and its correlation with the API

Sl. no.	Test site	NDVI anomaly	Correlation of the NDVI and API
1	Madikeri	−16	0.70
2	Somwerpet	10	0.96
3	Virajpet	0	0.43
4	Bantwal	−17	0.10
5	Mangalore	7	−0.21
6	Puttur	−2	0.74
7	Sulya	8	0.75
8	Karkala	−4	0.74
9	Udupi	9	0.84
10	Kundapur	13	0.90
11	Haliyal	13	0.92
12	Honnavar	7	0.63
13	Karwar	4	0.50
14	Kumta	3	0.53
15	Supa	−21	0.32
16	Yellapur	−5	0.59

Day and Monk (1974), Busing et al. (1992) and Titshall et al. (2000) stressed the importance of elevation in influencing the vegetation. The main reason for the enhancement of vegetation at elevated areas is the fall in temperature (the standard atmospheric lapse rate is 3.8° of foreign heat per 1000 feet); due to this, the crops/plants can show richer vegetation at considerable elevations. Also, it has been reported that high levels of oxygen prevail at the ground surface (oxygen is abundant in the earth's crust), which inhibits CO₂ uptake, thus reducing the efficiency of photosynthesis under optimal and natural conditions (Turner and Brittain 1962). At this stage, the phenomena of photo respiration dominate the fermentation. With the increase in elevation, as oxygen levels decrease, the CO₂ uptake leads to more photosynthetic activity and dominates the photorespiration by oxygen, thus leading to higher vegetation. However, with the enormous increase in elevation, the wind speed increases because of less friction as compared at the earth's surface and may cause damage to crops that are sensitive to wind. In the present study, the Somwerpet and Haliyal test sites were located at elevation levels of 1080 and 604 m above mean sea level, respectively, and experienced more orographic rainfall, thus yielding the highest correlations of the NDVI and API. It is also to be noted from Table 2 that the NDVI of Kundapur and Udupi also maintained strong correlations (0.90 and 0.84) with the API. These stations are located quite near to the coastline where sand-strand regimes are expected, which can obstruct agricultural activity. However, these two stations are situated 39 and 80 m above mean sea level, respectively. Olsson Seffer (1909) reported that the sand formations do not rise to great heights in sandy shore areas. For this reason, the Kundapur and Udupi stations showed good correlation values of the API with the NDVI, although they are coastal stations.

3.3 Impact of rainy days on vegetation over Western Ghats

As mentioned in the introduction, many studies have focused on the influence of rainfall on vegetation. In addition to the rainfall amount, the number of rainy days also influences vegetation, as reported by Theoharatos and Tselepidaki (1990). The number of rainy days can play a major role in calculating the dry/wet spells over a region, which signifies the agricultural activities of that region. Matzneller et al. (2010) reported that they observed changes in agricultural activities because of a decrease in the number of rainy days over the agro-meteorological station Bologna-Cadriano, Italy, from 1952 to 2007. In the present study, we analyzed the impact of rainy days on the NDVI during the period of green-up. At present, we did not focus on how the changes take place in the vegetation pattern because of changes in the rainy days. The criteria we followed were adapted from the India Meteorological Department (IMD), Government of India, in which a day can be called a rainy day if the rainfall exceeds 2.4 mm on that particular day. Also, we removed the number of heavy rainy days (rainfall above 35 mm), which are reported to create a hindrance to the crop growth in our analysis. Here we also obtained poor/negative correlations when we tried the analysis without any lag. Hence, we tried to look at the correlation aspects with lags of different periods. We found significant correlations with nearly 2-month lag. This means that the correlation of the NDVI during the green-up period was highly correlated with the number of rainy days during the beginning and preparatory periods of the crops, which is highly understandable in the context of excessive soil moisture levels in the soil (Fig. 5).

Jain et al. (2010) also reported that the correlation of the NDVI with the SPI is significant with a 1-month lag over Kota. Richard et al. (2008) studied the NDVI variations with respect to the number of rainy days in semi-arid South Africa. They found that the number of rainy days is one of the potential predictors of the vegetation. They reported that the NDVI showed a 7–10-month time lag with the number of rainy days for different types of vegetation in South Africa. Similarly, we found significant negative correlations with the number of non-rainy days with the same 2-month lag in Fig. 5. Table 3 shows that the

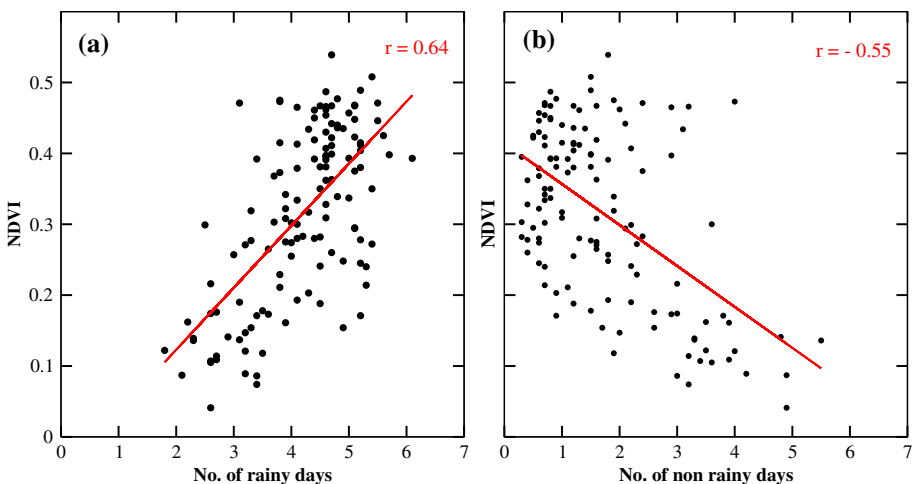


Fig. 5 Scatter plot of the NDVI with **a** the number of rainy days and **b** number of non-rainy days

Table 3 Number of rainy and non-rainy days in Western Ghats

Test site	Before the rate of green-up		During the rate of green-up	
	No. of rainy days	No. of non-rainy days	No. of rainy days	No. of non-rainy days
Madikeri	32	21	35	13
Somwarpet	29	29	35	20
Virajpet	32	29	36	19
Bantwal	31	25	33	10
Manglore	29	28	35	12
Puttur	29	25	32	11
Sulya	32	23	35	10
Karkala	28	23	27	11
Udipi	30	23	36	9
Kundapur	29	23	33	11
Haliyal	27	35	34	28
Honnavar	29	23	32	11
Karwar	28	27	33	13
Kumta	28	25	32	12
Supa	32	27	37	15
Yellapur	30	28	31	19

number of rainy days during the green-up period is slightly higher than during the earlier periods, whereas in the case of non-rainy days, the difference is quite large as compared to the number of rainy days. These distinguished correlations indicate the site-to-site vegetation responses to the rainfall activity. The correlation of the NDVI with the number of rainy days and number of non-rainy days when we pooled all the data yielded 0.64 and -0.55 , which is significant at the 0.05 level. The correlation of 0.64 shows the importance of antecedent moisture in the soil, which is utilized by the crops for their growth. It is also noted that some regression models were developed to estimate the vegetation using parameters such as the elevation, mean growing season (Calef et al. 2006), elevation and number of rainy days (Drake et al. 1996). However, these studies prefer that the models be developed when the type of vegetation is known. Although our present study touches on the NDVI variations with respect to the elevation and number of rainy days, we could not carry out any analysis based on the different types of vegetation. Therefore, the effort of developing a multiregression model to estimate the vegetation using inputs such as the number of rainy days and elevation alone may lead to an erroneous estimation. Despite the development of a model to estimate the NDVI, the results of the present work lead to a comprehensive understanding of how the NDVI varies over Western Ghats in relation to the elevation and number of rainy days.

4 Conclusions

The overall study was performed in the interest of understanding the vegetation tendency and its variability over Western Ghats. We conclude the following points based on our analysis of the NDVI and rainfall patterns from 2000 to 2010: the vegetation characterized

by the NDVI shows an increasing greening tendency. The minimum value of the NDVI during the optimum stage over this region during the study period was found to be 0.469 at Bantwal. The NDVI maintained good agreement with the Antecedent Precipitation Index (API) during the rate of green-up period; the possible reason for the increased vegetation and strong relation could be due to sufficient soil moisture levels and elevation. Finally, the NDVI during the rate of green-up period showed a high positive correlation with the number of rainy days and a significant negative correlation with the number of non-rainy days during the start of the season.

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