



# Effect of Temperature and Precipitation on the Vegetation Dynamics of High and Moderate Altitude Natural Forests in India

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## Abstract

In the present study, the high-altitude vegetation dynamics of natural forest cover were analyzed to find the effect of local hydrology for about 10 years. Vegetation dynamics in four different topographical and climatic conditions in India were studied using normalized difference vegetation index (NDVI) data from vegetation sensor of SPOT satellite, and daily temperature and precipitation data from Asian Precipitation–Highly Resolved Observational Data Integration Towards Evaluation project. The main objective was to understand how and to what extent the natural vegetation reciprocates in various climatic conditions. First, the vegetation data was denoised by using empirical mode decomposition technique. The relation between the vegetation growth and hydrological parameters was studied to find the anomalies. Then, the wavelet analysis of the hydrological data was carried out to find the frequency and extent of the anomalies. Finally, nonparametric Mann–Kendall trend analysis and Sen’s slope analysis were applied to find the trend of the vegetation, temperature, and precipitation dynamics. Results indicate that the growth of the vegetation starts when the average temperature is 10 °C or higher. Beyond that the increase in temperature may have a negligible effect on growth of vegetation. The vegetation also shows positive change in monthly NDVI with the increase in precipitation depending forest type and local climate. However, with excessive rainfall, a declining trend in vegetation growth was observed. The NDVI data show positive trend in all four sites. In northern region, the temperature showed positive trend, while precipitation had negative trend. In eastern and western regions, the temperature had negative trend and precipitation had positive trend.

**Keywords** Natural vegetation dynamics · Forest cover · Wavelet analysis · Trend analysis

## Introduction

Assessment of the impact of temperature and precipitation on the vegetation growth is important especially for the natural forest or vegetation at remote locations. The inter-annual variation of the climatic factors and the effect of climate change modify the phenology of the vegetation, and its growth pattern. Studies on all continents revealed that the phenological variability is directly linked with the climate change (Fuller and Prince 1996; Chmielewski and Rotzer 2001; Cramer et al. 2001; Wolfe et al. 2005). This natural vegetation cover controls the local hydrology, as the evapotranspiration and soil moisture are the two, out of

many other controlling factors for local hydrology. In turn, evapotranspiration and soil moisture are controlled by local temperature and precipitation. Hence, out of many climatic factors, precipitation and temperature are the two most important controlling factors for growth of plant and vegetation coverage (Chang et al. 2011).

A good number of studies addressed this issue to study the impact of temperature (e.g., Braswell et al. 1997), precipitation (e.g., Davenport and Nicholson 1993) or both (e.g., Chang et al. 2011) on the vegetation dynamics for various types of vegetation coverage such as conifer, hard wood and grassland (e.g., Chang et al. 2011). The vegetation coverage and its dynamics is geospatial information, which can be studied efficiently using remote sensing data. Several vegetation indices are available to monitor the vegetation dynamics. Among them, NDVI and enhanced vegetation index (EVI) are widely used for the vegetation study. Although in some cases EVI provided more reliable

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vegetation information (Chang et al. 2014), studies show that NDVI also provides reliable estimation of chlorophyll presence with higher value indicating dense vegetation (e.g., Li et al. 2010; Verma and Dutta 2013). Previous studies also established relationship between EVI and NDVI. Chang et al. (2014) found linear relationship between EVI and NDVI for various vegetation types, which are statistically significant. Hence, NDVI can be used to get reliable information as EVI studies.

Green leaves (actually chlorophyll pigments) absorb near red band (0.6–0.7  $\mu\text{m}$ ) of the incident solar radiation efficiently and scatter the near-infrared (NIR) band (0.7–1.1  $\mu\text{m}$ ) through the spongy mesophyll layers. The NDVI of any vegetation cover can be calculated using the following equation:

$$\text{NDVI} = \frac{\text{NIR} - \text{RED}}{\text{NIR} + \text{RED}} \quad (1)$$

where NIR are reflectance data from near-infrared band and RED are data from the visible red band of the electromagnetic spectrum. Although NDVI ranges from  $-1$  to  $+1$ , the data ranges are available from  $-1$  to  $+0.7$  (Verma and Dutta 2013) and some cases  $+0.9$  also can be found. Negative NDVI indicates clouds, water, snow and other non-vegetation cover. NDVI from  $+0.1$  or more indicates vegetation classes. NDVI, up to  $0.1$ , indicates a poor vegetation cover which may be due to unfavorable weather conditions (Bellone et al. 2009a, b), whereas high NDVI indicates dense vegetation conditions.

Méndez-Barroso et al. (2009) studied the impact of precipitation and surface soil moisture on vegetation greenness. They reported that the correlation of greenness and accumulated monthly precipitation is positive. Their study indicates that the plant water use is related to hydrologic variations and strongly controlled by elevation. Chang et al. (2011) showed that the temperature is more strongly correlated with NDVI than precipitation in various land use types in Taiwan. Similar finding were also reported by Guo et al. (2008). Recently, Chang et al. (2014) related the vegetation dynamics to temperature and precipitation at monthly and annual timescales in Taiwan where diverse topographical variations are present. They found that vegetation greenness responded positively with temperature and precipitation in monthly timescale level, while examining data of 13 years.

Deng et al. (2007) reported that the vegetation growth depends on energy received. As the energy available to vegetation is controlled by temperature, NDVI is more strongly related to temperature than precipitation. However, the need of precipitation for the vegetation is also essential. The previous studies are limited to identify the

direct relation between greenness and precipitation with various forest type and climatic conditions. This paper aims to study: (i) the effect of temperature and precipitation dataset monitored by APHRODITE water resources system (Japan) to relate the vegetation dynamics of natural evergreen forest with diversified climatic conditions and greenness and (ii) the extent and how the vegetation reciprocates with the climatic conditions.

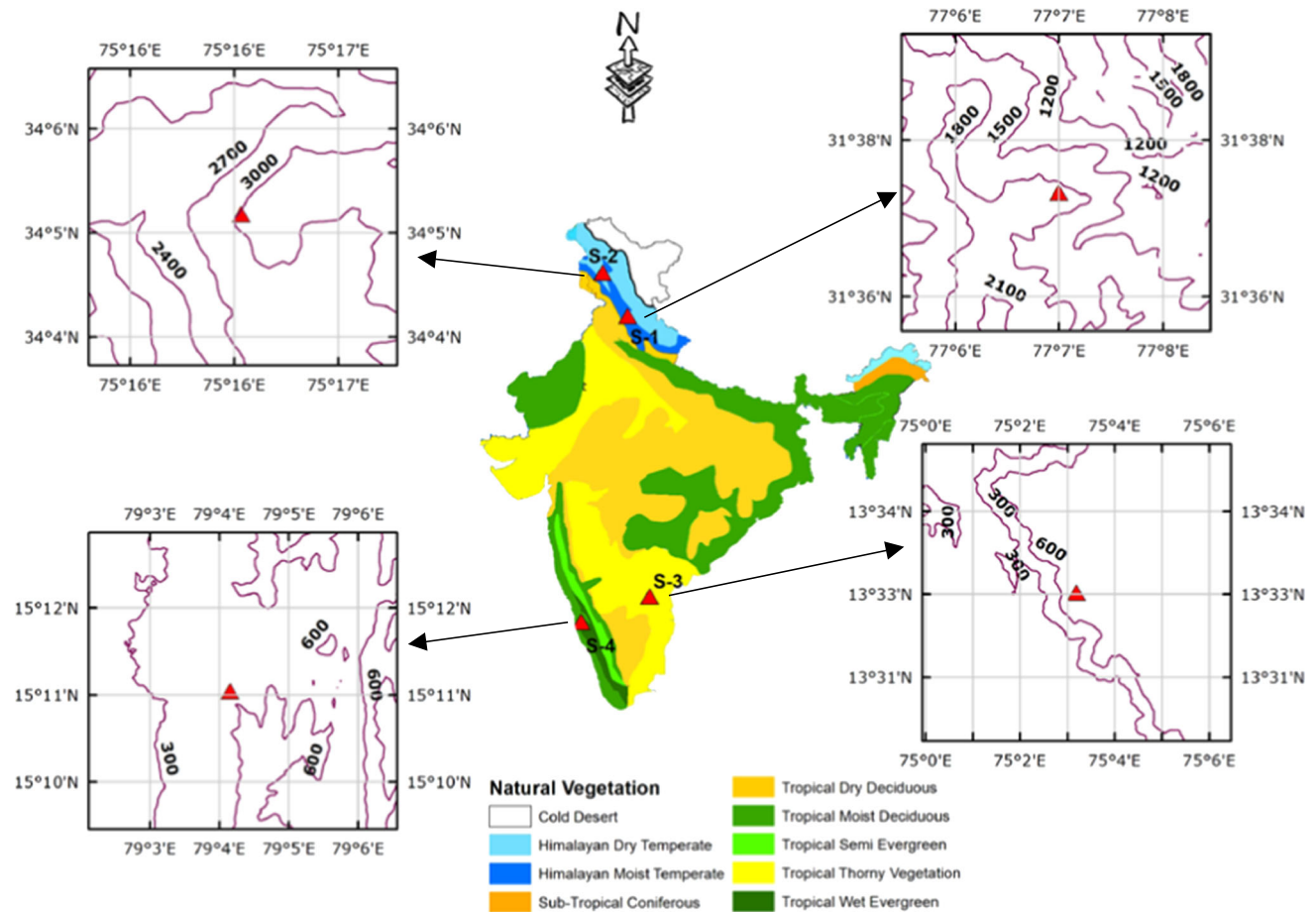
## Study Area

The present study was carried out in four natural forest locations in India (Fig. 1). These sites (S-1, S-2, S-3 and S-4) (Table 1) were chosen by observing satellite data at different time scale, so that they cover only natural forests. Each site has different tree cover, where Tendu, palas, amaltas, bel, khair and axlewood are the common trees cover at S-1. Deodar, chinara and the walnut trees at S-2, and babool, ber, wild date palm, khair, neem, khejri and palas at S-3, while, rosewood, mahogany, aini, ebony at S-4 (NCERT 2006). There are many places in the mountainous regions where contour farming is common. Since, the study is aiming to the natural evergreen vegetation dynamics only, the site chosen from satellite images were verified using multi-date images. The elevation of these sites varied from 600 m to 3000 m above mean sea level. The temperature ranges from  $-4.5$   $^{\circ}\text{C}$  to  $+28$   $^{\circ}\text{C}$  with mean of  $10$   $^{\circ}\text{C}$  in the northern parts. Average temperature remains sub-zero from December to February in this region. In the southern sites, the average temperature varies from  $25$   $^{\circ}\text{C}$  to  $35$   $^{\circ}\text{C}$ . Annual precipitation varies significantly from 500 mm in Eastern Ghats and Himalayan mountainous region to 4235 mm in the Western Ghats region with monsoon period from June to September.

## Data Used

### Vegetation Data

We used NDVI data of VGT S-10 freely available between 1998 till 2007 from <http://www.vito-eodata.be/> for the study location. These data are acquired from the VEGETATION sensor of the SPOT satellite. The VGT S-10 data are the 10-day maximum value composited (MVC) in order to minimize the effect due to cloud contamination (Holben 1986a, b). These data have a spatial resolution of  $1 \text{ km} \times 1 \text{ km}$  with 2250 km swath. These data are obtained in HDF file format and extracted for the area of interest using MATLAB program.



**Fig. 1** Locations of study area (the forest cover image was taken from Wikimedia and verified with [http://agritech.tnau.ac.in/forestry/forest\\_india\\_types.html](http://agritech.tnau.ac.in/forestry/forest_india_types.html))

**Table 1** Details of study sites

Site	Lat. (N)	Long. (E)	Elev. (m)	Temp. (°C)	Prec. (mm)
Site-1	31° 37'	77°07'	1874	− 4.5–21	0–56
Site-2	34° 05'	75°16'	3124	2.9–28.1	0–77
Site-3	15° 11'	79° 04'	623	22.5–36.7	0–60
Site-4	13° 32'	75° 03'	707	24.1–31.1	0–264

**Temperature and Precipitation Data**

Daily temperature and precipitation data from 1998 to 2007 were collected from online APHRODITE project (<http://www.chikyu.ac.jp/>) with 0.25° spatial resolution. The data of the study location were extracted from the large spatial data using MATLAB program.

The period of 1998 to 2007 was chosen in this study as this is the common period of availability of both the data at the study locations. As the temperature is highly related with elevation, it is necessary to downscale the temperature data to a resolution of 1 km. The ordinary kriging (OK)

was applied on monthly temperature to reduce the spatial resolution from 25 km to 1 km. Also the multi-linear regression (MR) model was applied between elevation and spatial location on temperature (Chiu et al. 2009; Chang et al. 2014).

**Methodology**

**NDVI Denoising**

The NDVI was used in this study instead of using EVI data due to lack of EVI data availability for the study area. In spite of 10-day maximum value composite data are used to generate NDVI dataset, there are several points which show abrupt changes in the NDVI values, and due to this, the denoising of the data is essential. Studies show various methods are available for denoising the NDVI data, for example, fast Fourier transformation and discrete Fourier transformation. Out of these, empirical mode decomposition (EMD) is the method as proposed by Huang et al. (1998). This method can be used for nonlinear and non-

stationary time series. The raw signal is decomposed into mono-component signals or intrinsic mode functions (IMF). The details of this method is discussed by Verma and Dutta (2013) and hence not discussed here. The reconstructed signals after passing through low-pass filter (ignoring high frequency components) are expressed as given in Eq. (2).

$$NDVI(t) = \sum_{i=k}^n c_i + r_n \tag{2}$$

where  $t$  is the time,  $c_i$  is the IMF components,  $r_n$  is the residuals after  $n$  empirical modes.

Verma and Dutta (2013) reported that the reconstructed signals after ignoring first two high frequency IMFs can give acceptable NDVI time series. However, in this case, we found that ignoring, the first three-high frequency components, gave better reconstruction of the denoised NDVI data and followed for further study. Typical raw and denoised data are shown in Fig. 2.

### Statistical Characteristics of Daily and Total Monthly Data

In the study sites, basic statistical analysis was carried out on 10-year (1998–2007) time series data for NDVI, temperature, and precipitation.

### Mann–Kendall Trend Analysis

Mann–Kendall trend is one of the nonparametric trend analyses which is used to evaluate the time series data in order to find the increasing, decreasing or no trend. The test utilizes the null hypothesis ( $H_0$ ) to describe no trend in time series data, and the alternative hypothesis ( $H_1$ ) refers to the rejection of null hypothesis and tells about the increasing or decreasing trend in time series. Each value in the series is then compared with all subsequent data values in the series. The  $S$  statistic in Mann–Kendall trend can be found using formula (Meshram et al. 2017):

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^n \text{sgn}(x_j - x_i) \tag{3}$$

where

$$\text{sgn}(x_j - x_i) = \begin{cases} +1, & (x_j > x_i) \\ 0, & (x_j = x_i) \\ -1, & (x_j < x_i) \end{cases} \tag{4}$$

Variance of  $S$  is given with Eq. (5):

$$\text{Var}(S) = \frac{n(n-1)(2n+5) - \sum_{p=1}^q t_p(t_p-1)(2t_p+5)}{18} \tag{5}$$

For one-tailed test, the standardized statistic ( $Z$ ) of  $S$  which tells whether the trend increases or decreases is given with Eq. (6):

$$Z = \begin{cases} \frac{S-1}{\sqrt{\text{Var}(S)}}, & (x_j - x_i) > 0 \\ 0, & (x_j - x_i) = 0 \\ \frac{S+1}{\sqrt{\text{Var}(S)}}, & (x_j - x_i) < 0 \end{cases} \tag{6}$$

### Sen’s Slope Estimator Test

However, the Mann–Kendall test does not provide the magnitude of the trend. This can be predicted by the Sen’s slope method as it is increasing, decreasing or constant. Then, the slope ( $T_i$ ) of all data pairs is computed as (Sen 1968) following Eq. (7):

$$T_i = \frac{x_j - x_k}{j - k} \tag{7}$$

For  $i = 1, 2 \dots N$ , where  $x_j$  and  $x_k$  are considered as data values at time  $j$  and  $k$  ( $j > k$ ). The median ( $Q$ ) of these  $N$  values of  $T_i$  are represented as Sen’s estimator of slope which is estimated with Eq. (8):

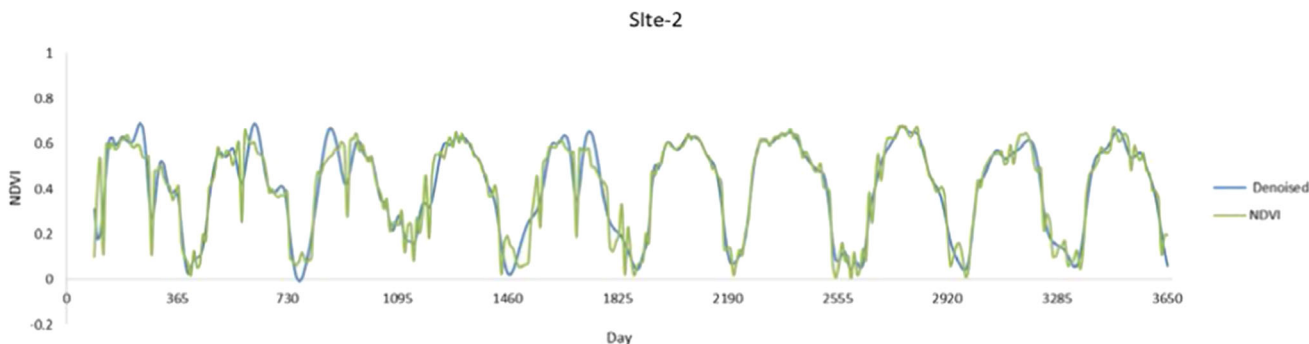


Fig. 2 Typical original and denoised NDVI time series

$$Q = \begin{cases} T \frac{N+1}{2}, & N \text{ is odd} \\ \frac{1}{2} \left( T \frac{N}{2} + T \frac{(N+2)}{2} \right) & N \text{ is even} \end{cases} \quad (8)$$

The results of  $Q$  can be positive or negative depending on the increasing or decreasing trends, respectively.

### Wavelet Analysis of Parameters

Continuous wavelet transformation (CWT) provides dynamics of the waves in different temporal scales. The temporal series is transformed into two-dimensional time–frequency relations using CWT (Karmaker et al. 2017). CWT is expressed by  $W(s, \sigma)$  with the basis function  $\Psi_{x,\sigma}$ .

$$W(s, \sigma) = \int_{-\infty}^{\infty} y(x) \psi_{x,\sigma}(x) dx \quad (9)$$

where  $\Psi_{x,\sigma} = \frac{1}{\sqrt{s}} \Psi\left(\frac{x-\sigma}{s}\right)$ ,  $s$  is the scale of wavelet function and  $\sigma$  is the degree of distance translation along the time series. The details are given in the work by Torrence and Compo (1998). The Morlet function as a basis function with order 3 can clearly resolve different time series (Torrence and Compo 1998 and Karmaker et al., 2017), and hence used in analyzing hydrological data (temperature and precipitation) and NDVI data.

## Results

### NDVI and Its Relation with Hydrologic Parameters

The NDVI analysis shows drastic variations among the four sites considered in this study. The average monthly trend of the NDVI from 1998 to 2007 is shown in Fig. 3a for four sites. In site-1 and site-2 (Himalayan part), the trend is nearly similar. Till the month of April, there is negligible change in NDVI. From May onward, it increases till a peak NDVI is reached in September; after that, it decreases and reaches to a minimum value in January/February. In site-3 (Eastern Ghats site), minimum NDVI (median =  $\sim 0.18$ ) was observed in July and it increases gradually till November and remains almost constant (median =  $\sim 0.80$ ) up to February and after that it starts decreasing. In site-4, minimum NDVI (median =  $\sim 0.30$ ) was observed in March and the maximum in November (median =  $\sim 0.70$ ). The average monthly temperature (Fig. 3b) of these locations reveals that in winter, the temperature of site-1 and site-2 goes below freezing temperature, and once it crosses beyond 10 °C, the growth of

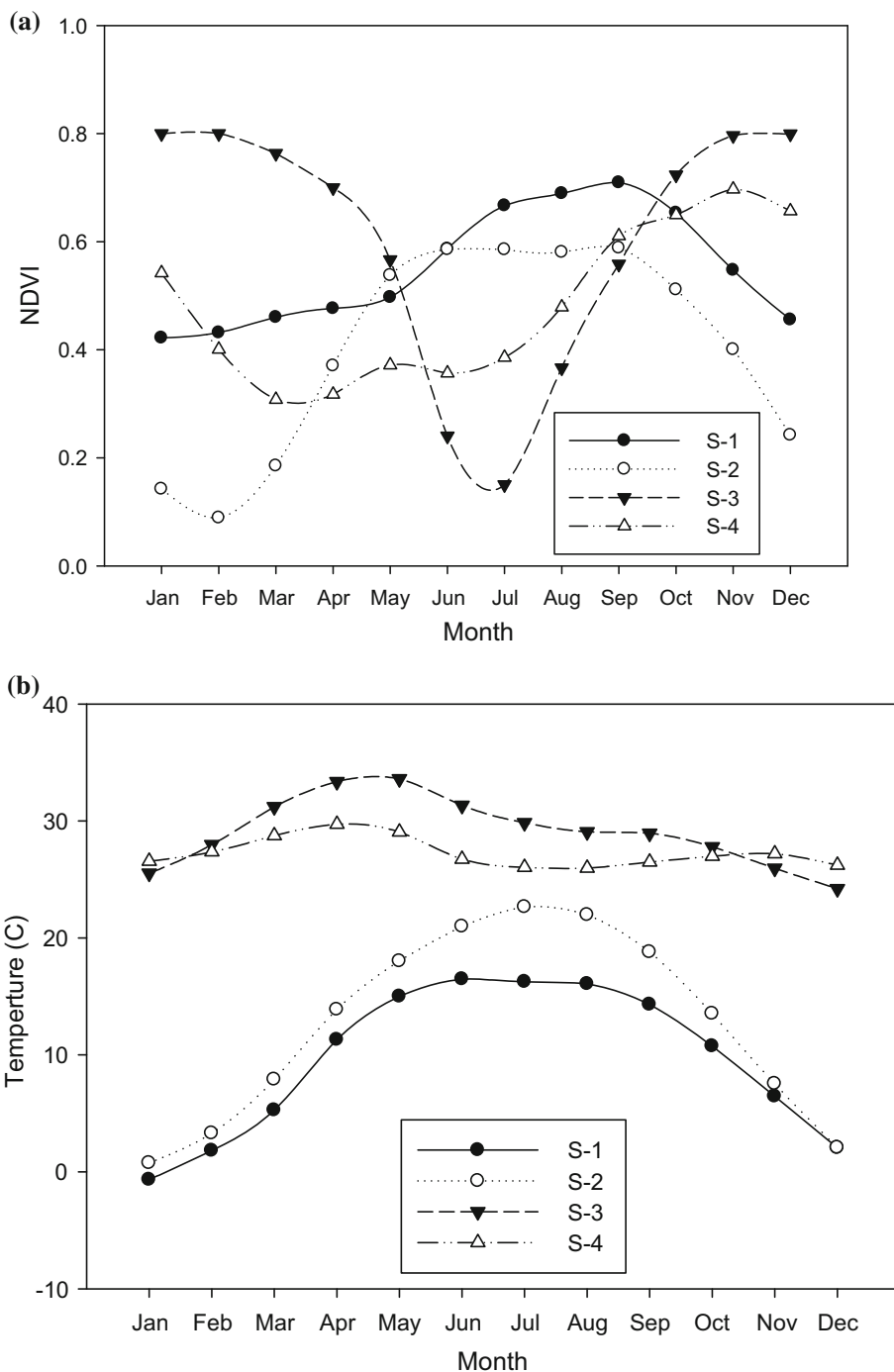
vegetation starts. In site-3 and site-4, the temperature is always well above the minimum value.

In the four sites, different types of forest cover can be noticed from the NDVI pattern. In site-1, Himalayan moist temperate forest; in site-2, Himalayan dry temperate forest; in site-3, Tropical thorny vegetation; and in site-4, tropical moist deciduous types of forests are present. The peak NDVI in the site-1 and site-2 is nearly 0.60, while in site-3, it is 0.80 and site-4, it is 0.70. Naturally, these vegetations respond differently with the precipitations. Figure 4 shows the relation of average monthly NDVI with the monthly precipitation. It can be noted that in this study, the monthly precipitation is used to consider the time required to respond the vegetation with precipitation. Figure 4a shows that at site-1, with the increase in precipitation, NDVI is increasing. In site-2 (Fig. 4b), the monthly average NDVI was initially increasing up to 40 mm of precipitation and then decreasing marginally. At site-3 (Fig. 4c), NDVI was increasing with the precipitation. All these three sites, the monthly precipitation is within 250 mm. Site-4 (Fig. 4d) shows a decreasing trend in NDVI with the increase in precipitation. It can be noticed that the precipitation here is very high compared to other three sites (up to  $\sim 1600$  mm). It could be explained that excessive rainfall decreases air voids from soil that are essential components for growth and so the declining trend is found. Further analysis of the NDVI data shows that there exist a relation between monthly precipitation and the increase in monthly NDVI (average) in all these sites (Fig. 5a–d). In site-1, it can be seen from the trend line ( $p$  value  $< 0.001$ ) that when the monthly precipitation is more than 50 mm, there is a positive change in NDVI. Similar study at other locations revealed that a minimum monthly precipitation of 50 mm for site-2 ( $p$  value  $< 0.001$ ), 30 mm for site-3 ( $p$  value  $< 0.001$ ) and 10 mm for site-4 ( $p$  value  $< 0.001$ ) is required for positive change in NDVI values.

Direct comparison of temperature or precipitation with the vegetation growth is not possible as it requires some time to respond. In addition, there is likely a time lag between temperature change and plant growth response, which may be from a week to few months. So, the analysis of cumulative temperature (Temp-day) or rainfall effect on integrated vegetation growth (INDVI) was carried out in this study (Méndez-Barroso et al. 2009). We explore the relation between cumulative temperature and INDVI for all the four study sites (Fig. 6a–d). In most of the cases, it follows an exponential relation. Similarly, we found the relations between cumulative rainfall and INDVI for the four sites (Fig. 7a–d). Similar to earlier sites, it also follows an exponential relation in most of the cases with  $R^2$  of more than 0.9. In a similar study, Méndez-Barroso et al. (2009) reported a linear relation between integrated vegetation index with the precipitation. But we found the fitting better



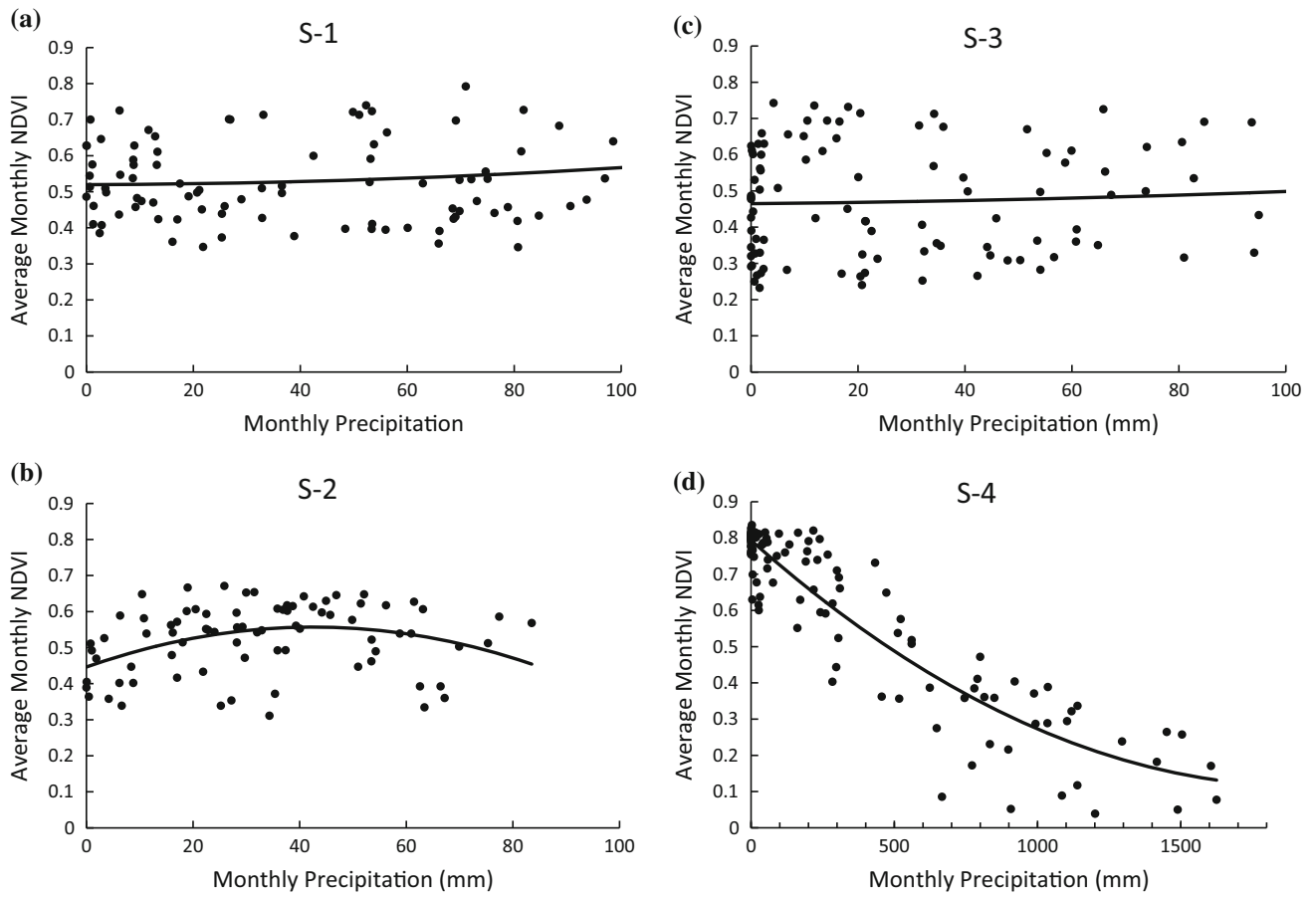
**Fig. 3** Ten-year monthly NDVI and temperature of the study sites



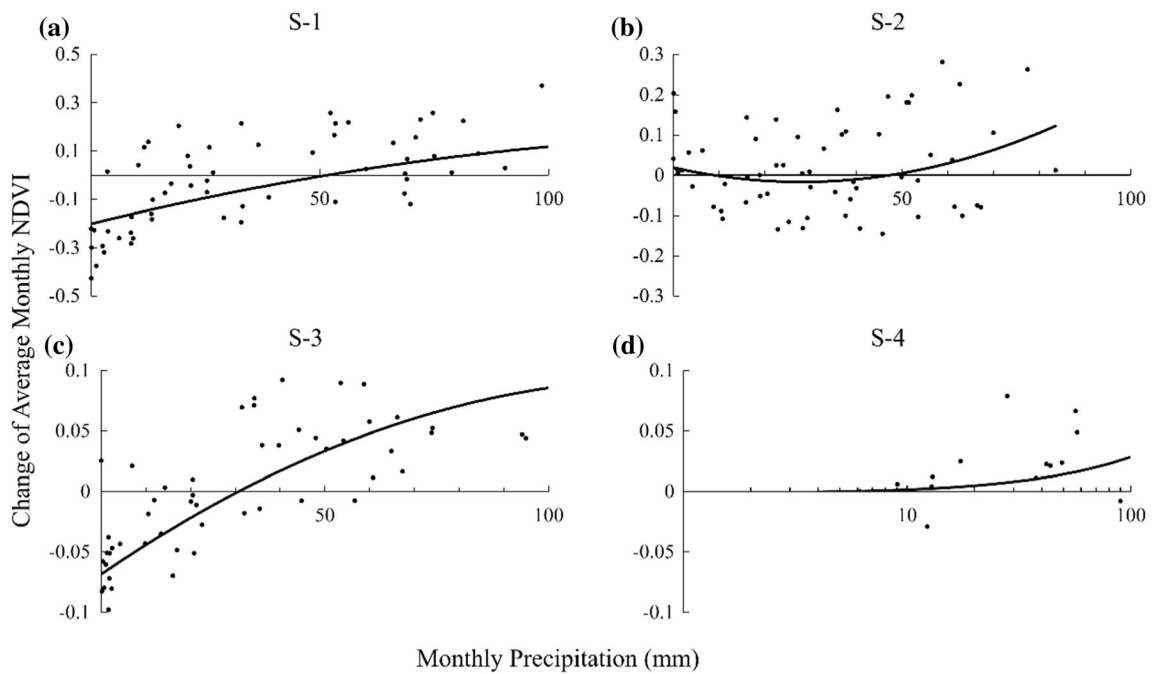
with exponential relation. Nevertheless, some anomalies can be noticed where correlation coefficient was very low (e.g., year 2004, Site-1). In order to find the reason, we carried out wavelet analysis of the hydrological parameters (Figs. 8, 9, and 10). It can be noticed from the wavelet analysis of temperature (Fig. 8) that there is not much variations and no significant zones are found. However, analysis of precipitation showed a wave period of 2 years or less and significant zone extended from early period in

2003–2004. It can be concluded that as the temperature is almost similar, the precipitation variations triggered the anomaly in dynamics of NDVI.

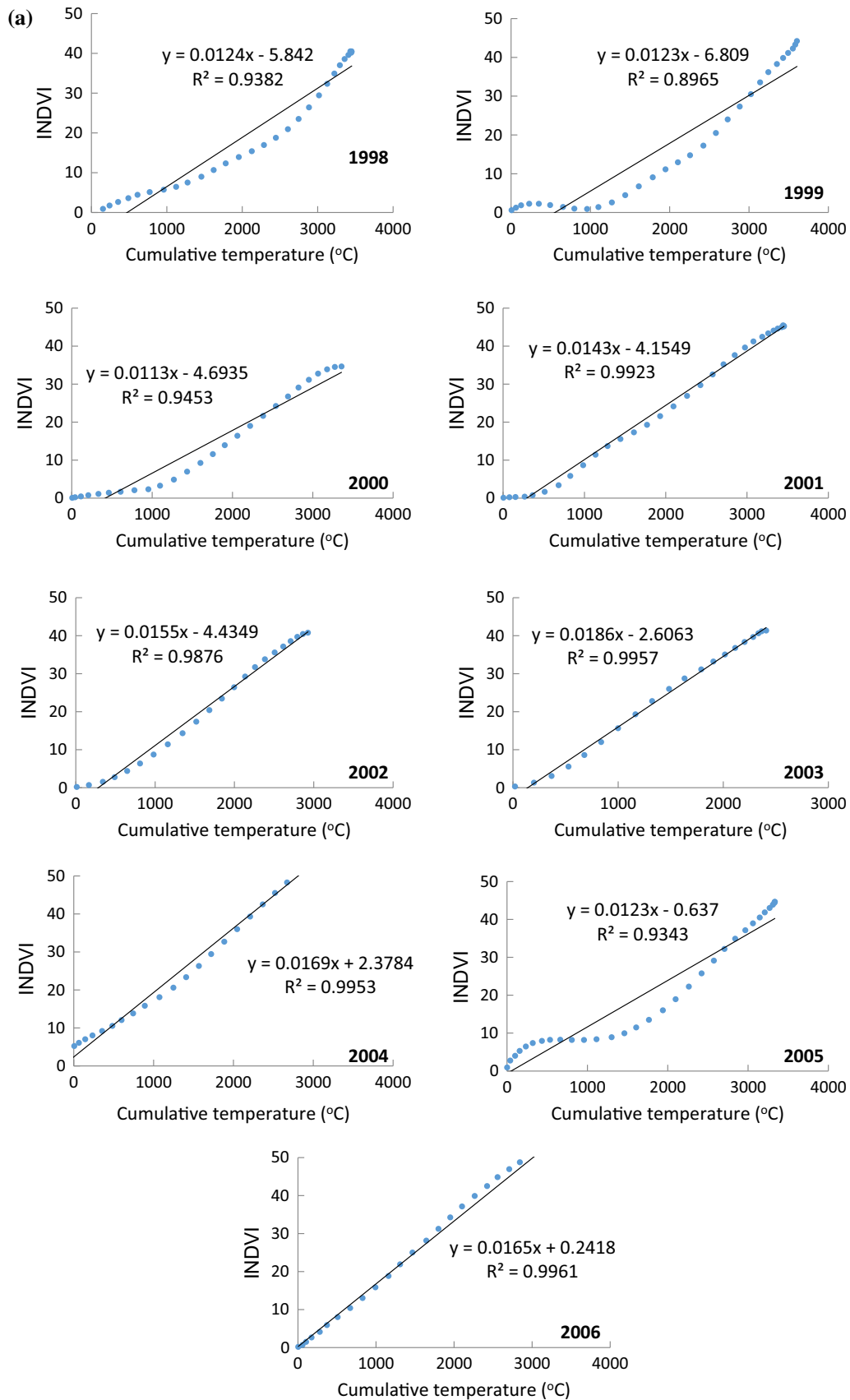
The analysis was also carried out using high-resolution temperature data (1 km) to find out the effect of topography and location on the data quality. Two locations were chosen for this test. One at the moderate altitude site (S-3) and another at the high-altitude site (S-2). Figure 9 a, b shows the variation of INDVI with cumulative temperature



**Fig. 4** Response of monthly NDVI with monthly precipitation at **a** S-1, **b** S-2, **c** S-3 and **d** S-4



**Fig. 5** Response of increase in monthly average NDVI with monthly precipitation at **a** S-1, **b** S-2, **c** S-3 and **d** S-4



**Fig. 6** Relation between INDVI and cumulative temperature at **a** S-1, **b** S-2, **c** S-3 and **d** S-4



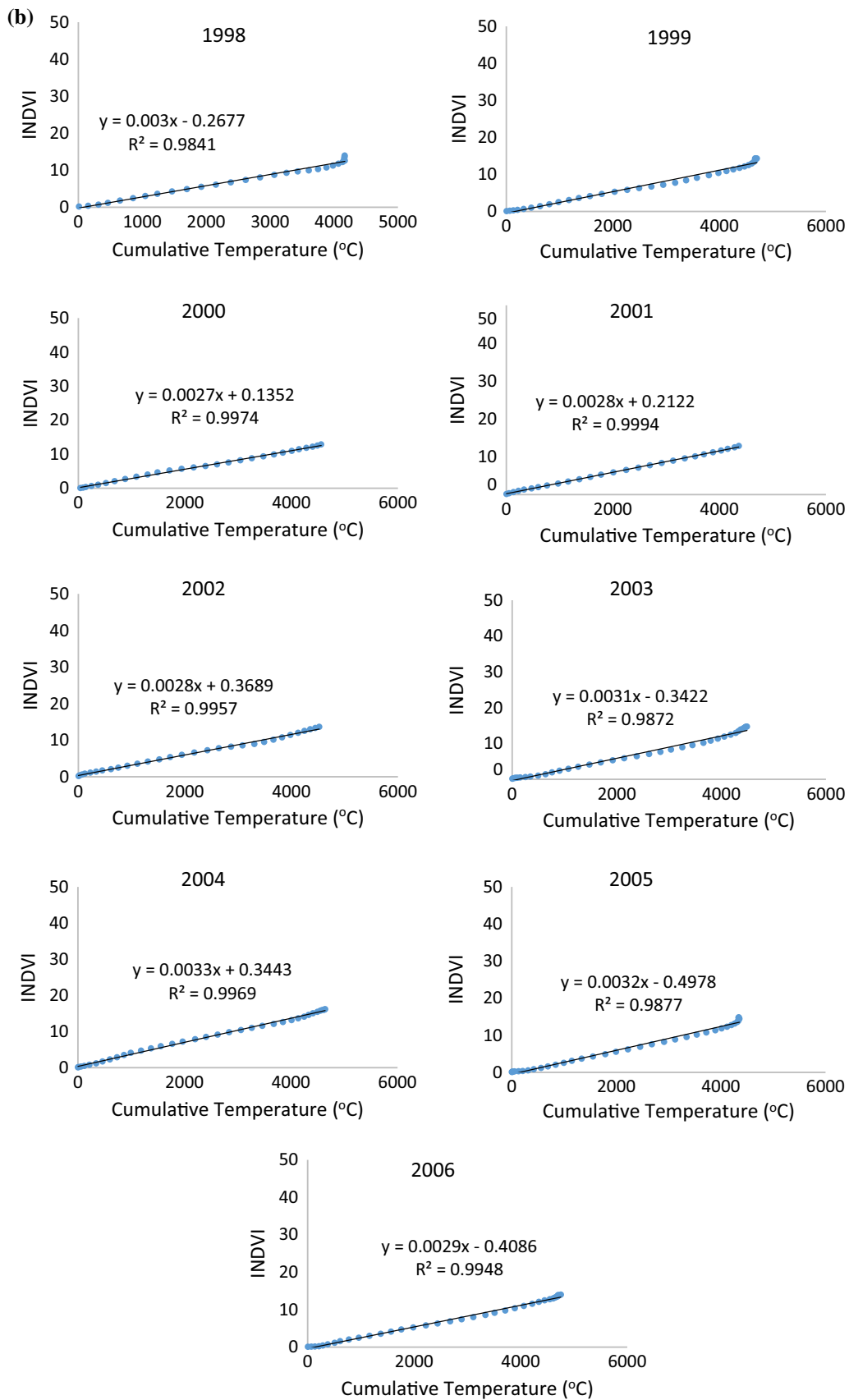


Fig. 6 continued

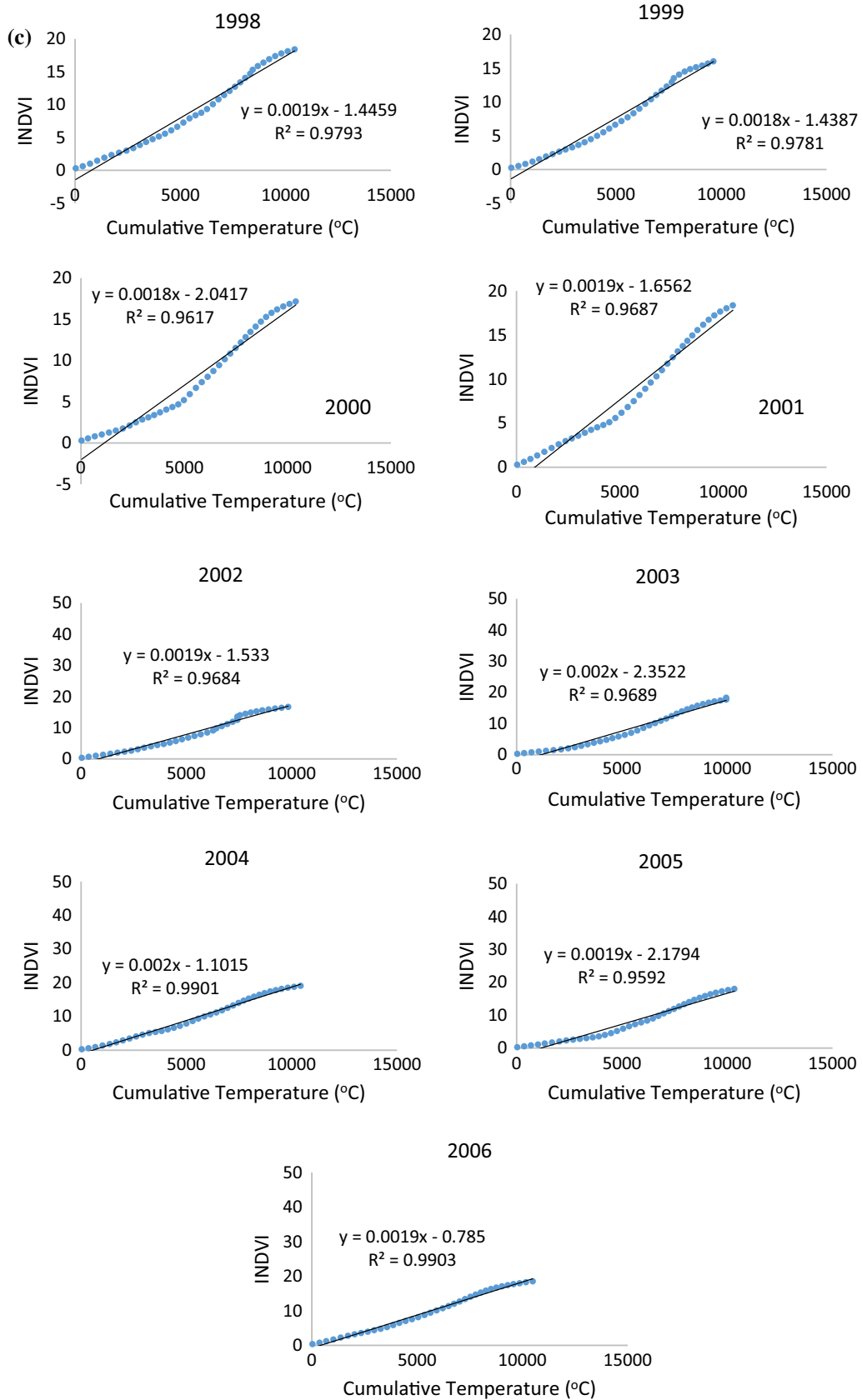


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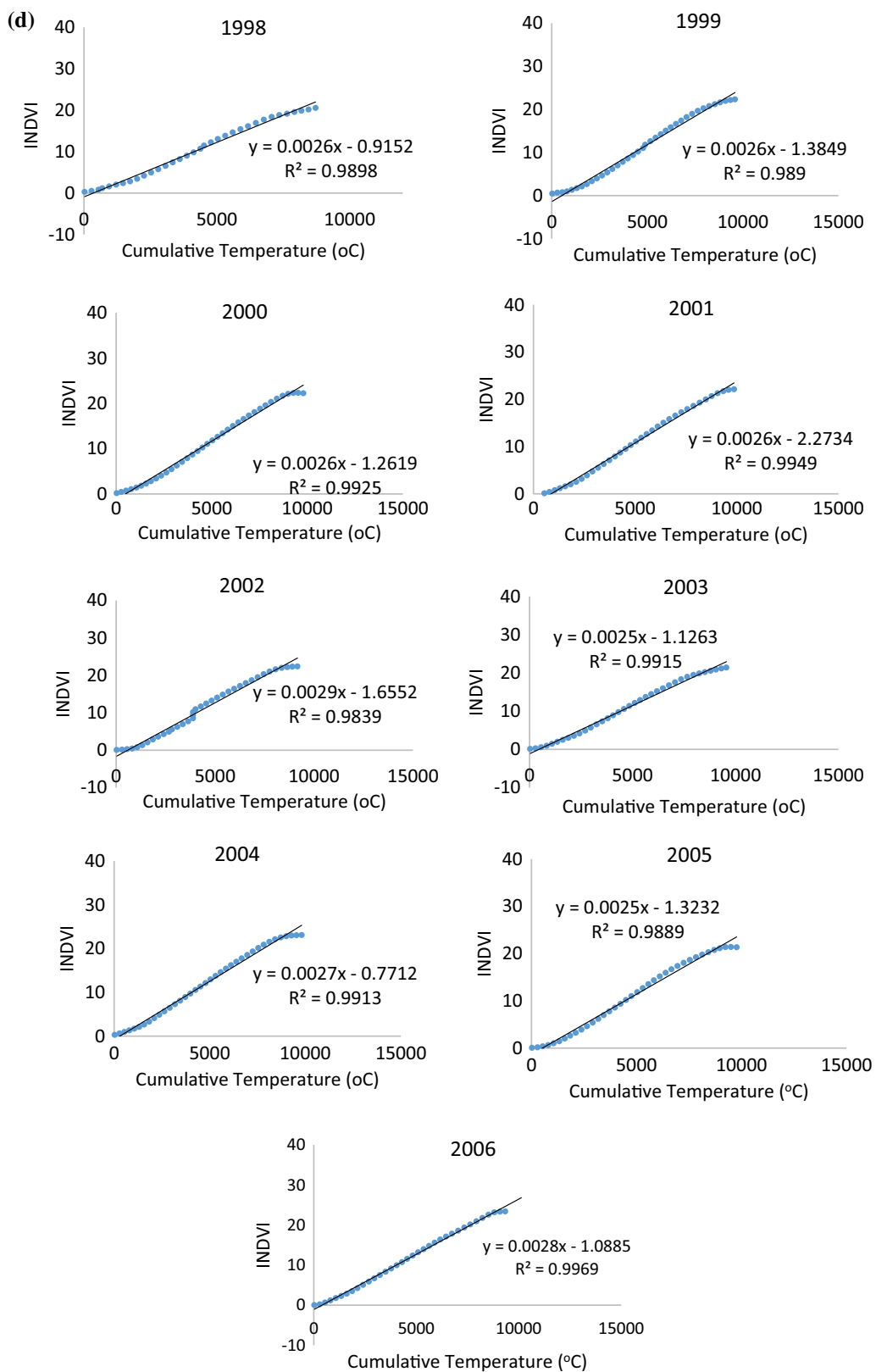


Fig. 6 continued

**Fig. 7** Relation between INDVI and cumulative precipitation at **a** S-1, **b** S-2, **c** S-3 and **d** S-4

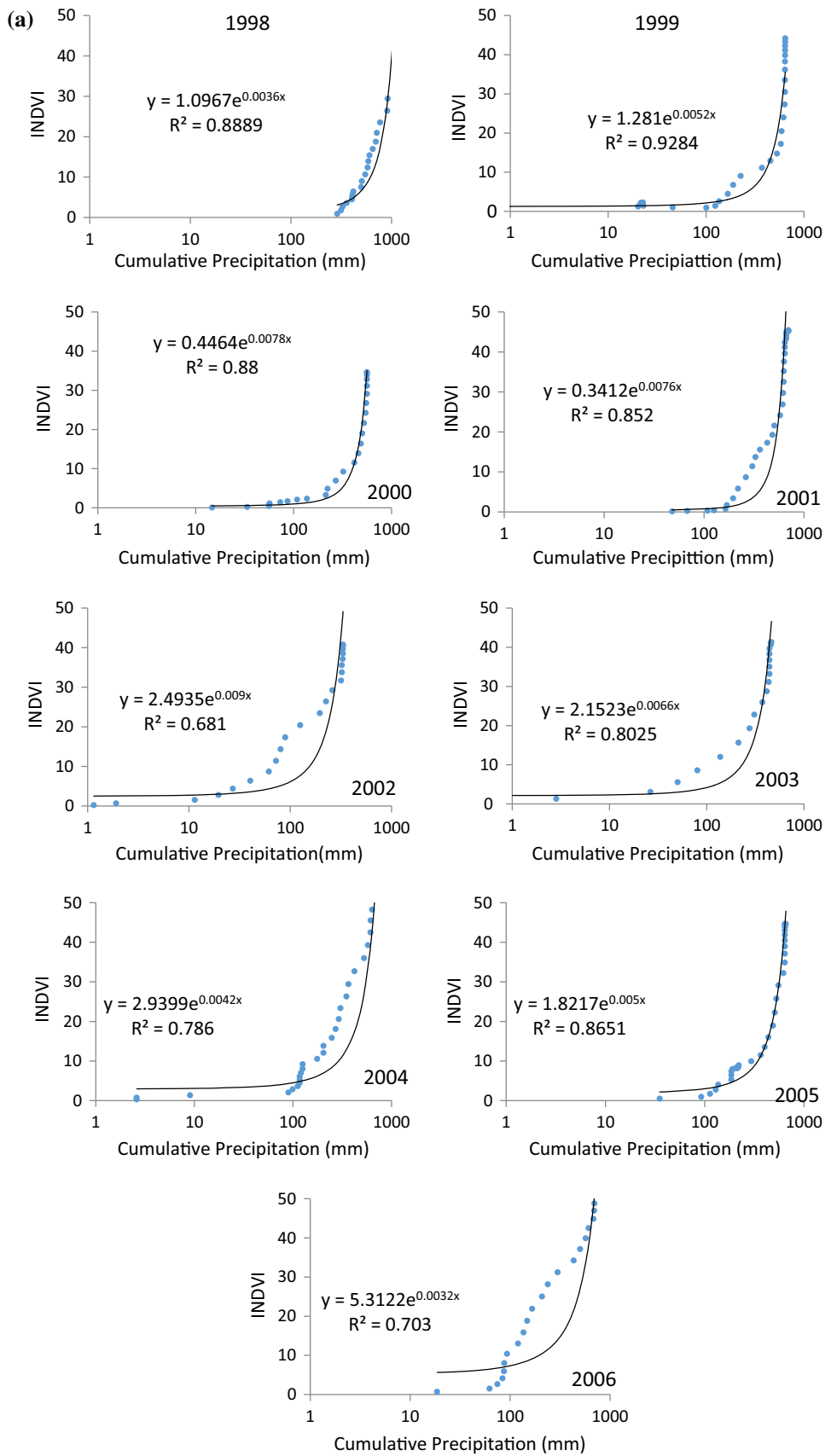
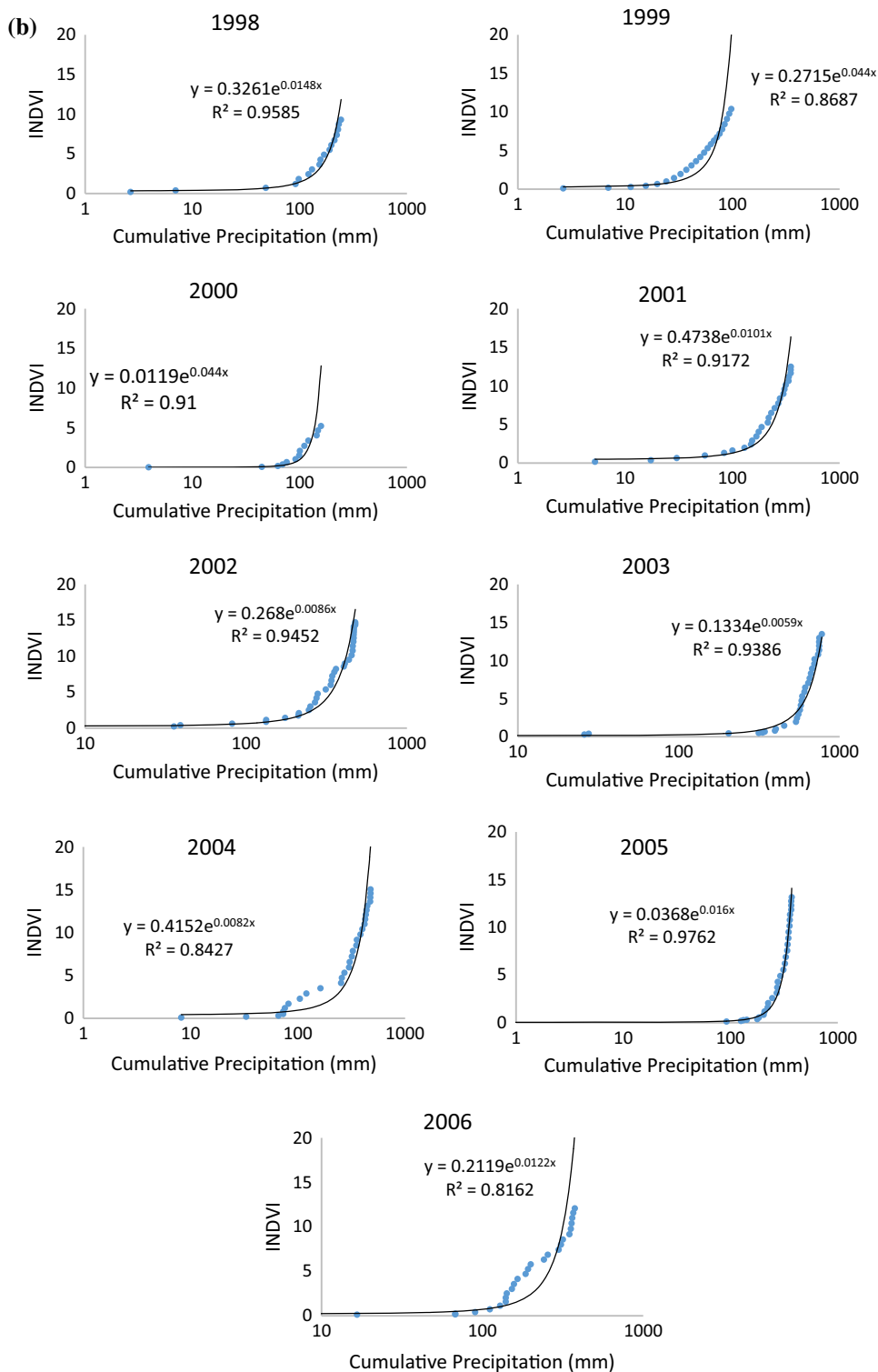


Fig. 7 continued

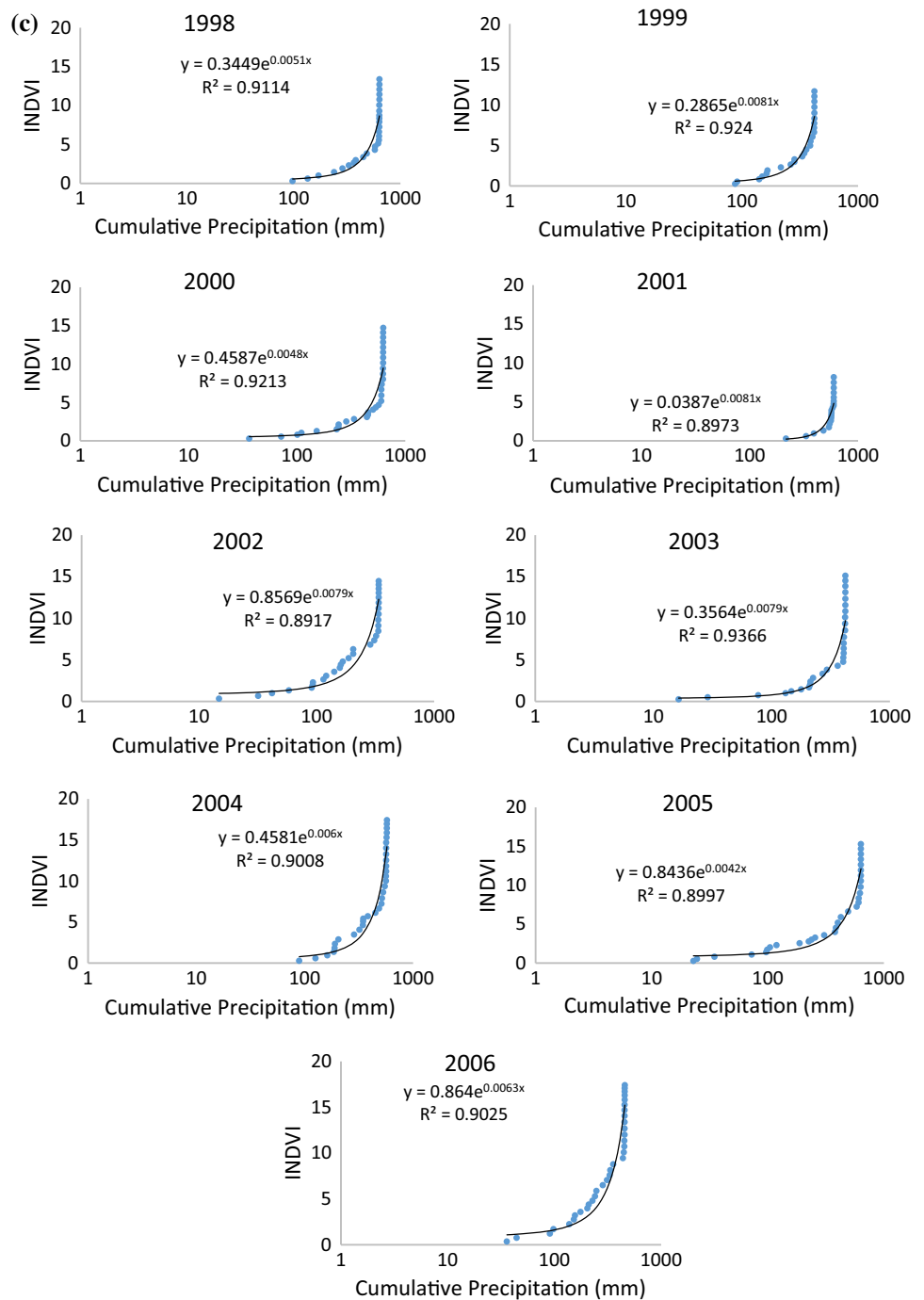


using OK and MR at these two sites. It can be found that for moderate altitude, the trend is almost matching with that of low spatial resolution result (Fig. 9a). However, for high altitude, there is deviation in various methods with the low-resolution data, although the trend is matching (Fig. 9b).

### Wavelet Analysis of NDVI and Hydrological Variables

Wavelet analysis was carried out for NDVI, precipitation and temperature at each location during 1998–2007. A wave period of one year was found at all the sites.

Fig. 7 continued



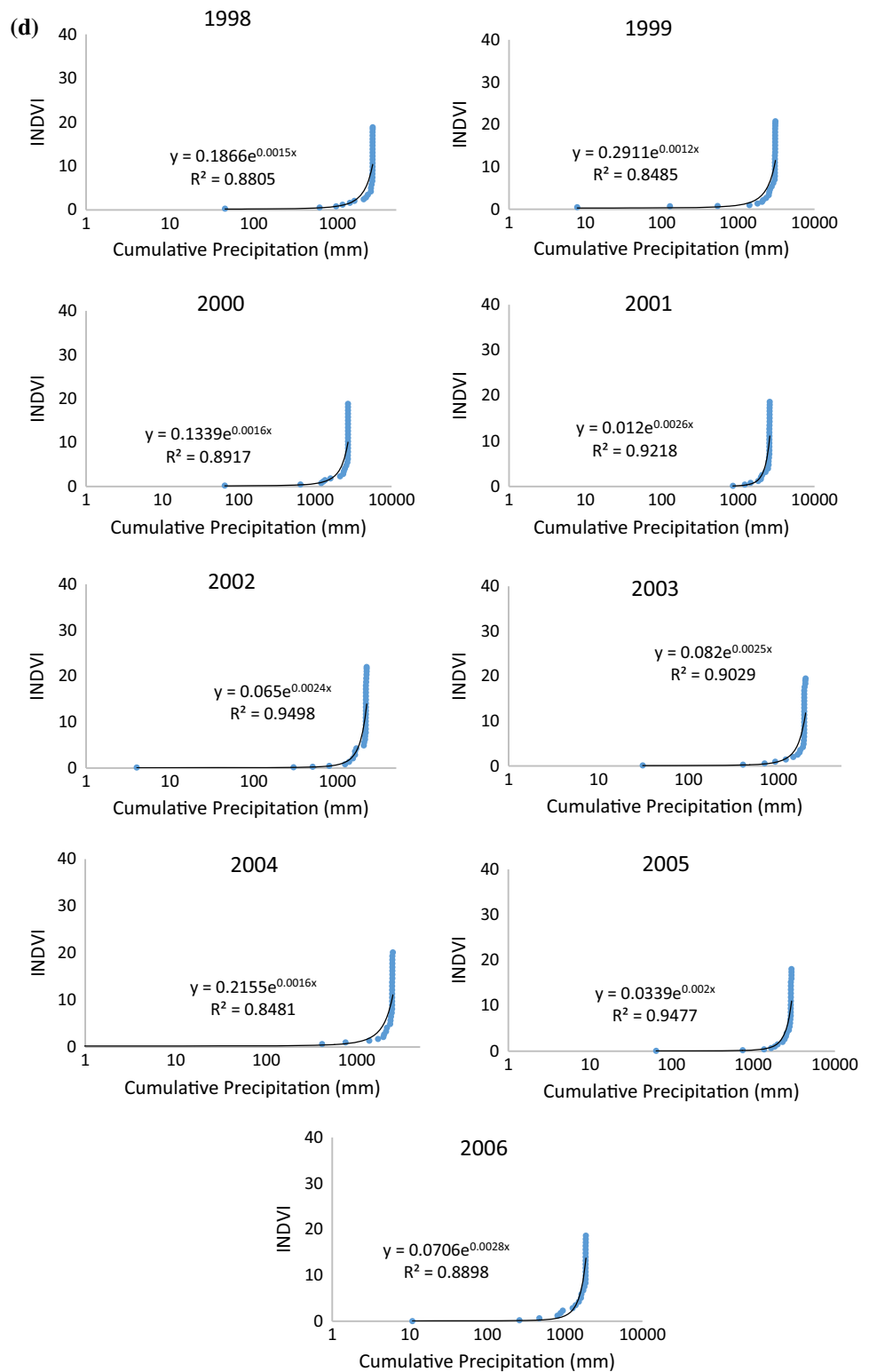
However, locally significant zones in NDVI were found at site-1 in 2000 and 2004 with a wave period of 0.5 year (Fig. 10a). At site-2, local significant zones are found in 2003–2004 and 2005–2006 with a wave period of 0.5 year (Fig. 10b). At site-3, it has shorter significant zones with wave period 0.5 year during 2004 (January–March)

(Fig. 10c). Finally, at site-4, it has one longer stretches start from 2000 (December) to 2003 (May) and shorter stretches during 2004 (December) till 2005 (August) and 2006 (April–December) (Fig. 10d).

Wavelet analysis of the precipitation data indicates a longer significant zone during 1999–2001 and 2003–2007



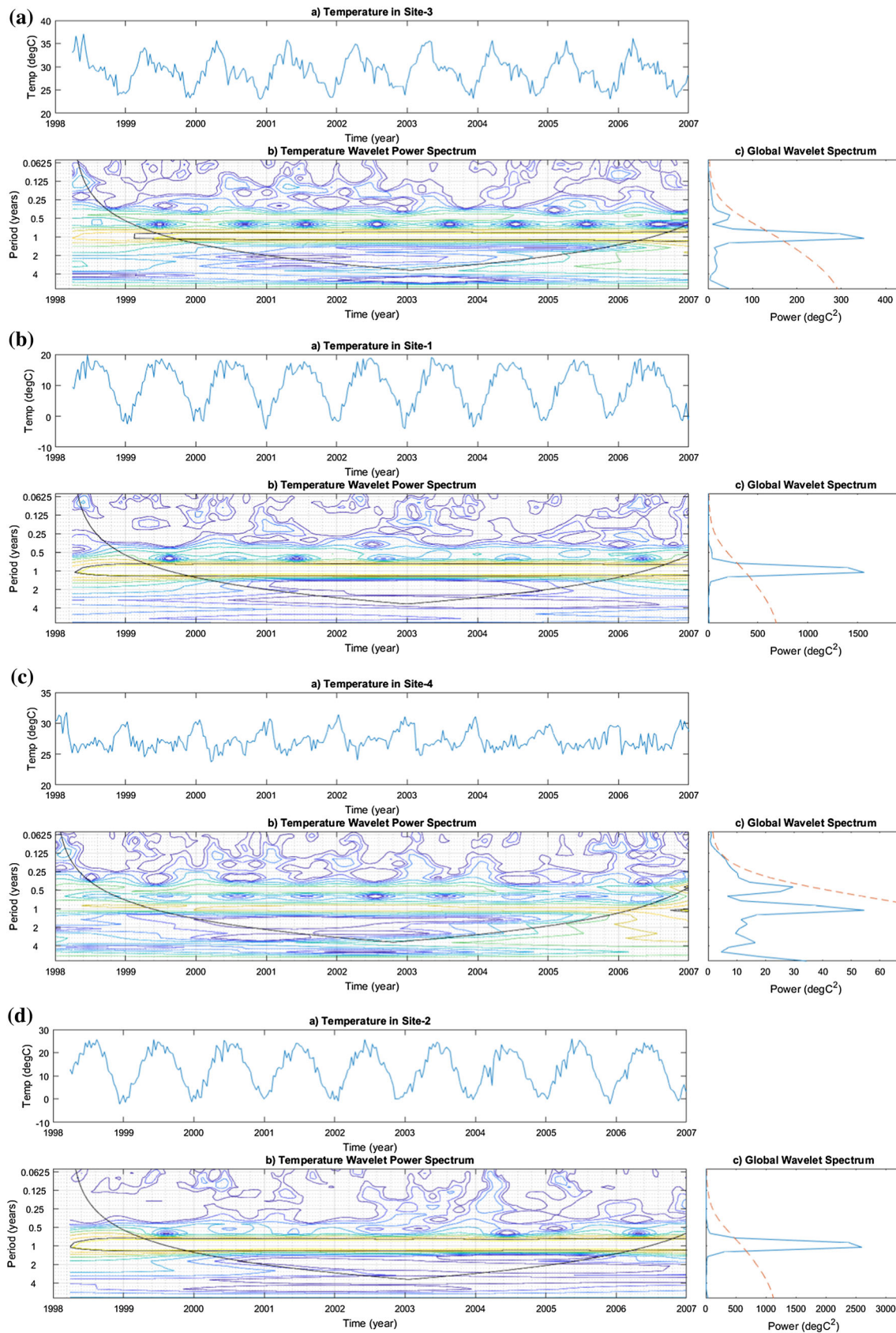
Fig. 7 continued



with a wave period of 1 year at site-1. In other years, a wave period of 0.5 years or less was resolved (Fig. 11a). At site-2, a wave period of 1 year was found from 2003 to 2005 (Fig. 11b). In other years, no significant zones were

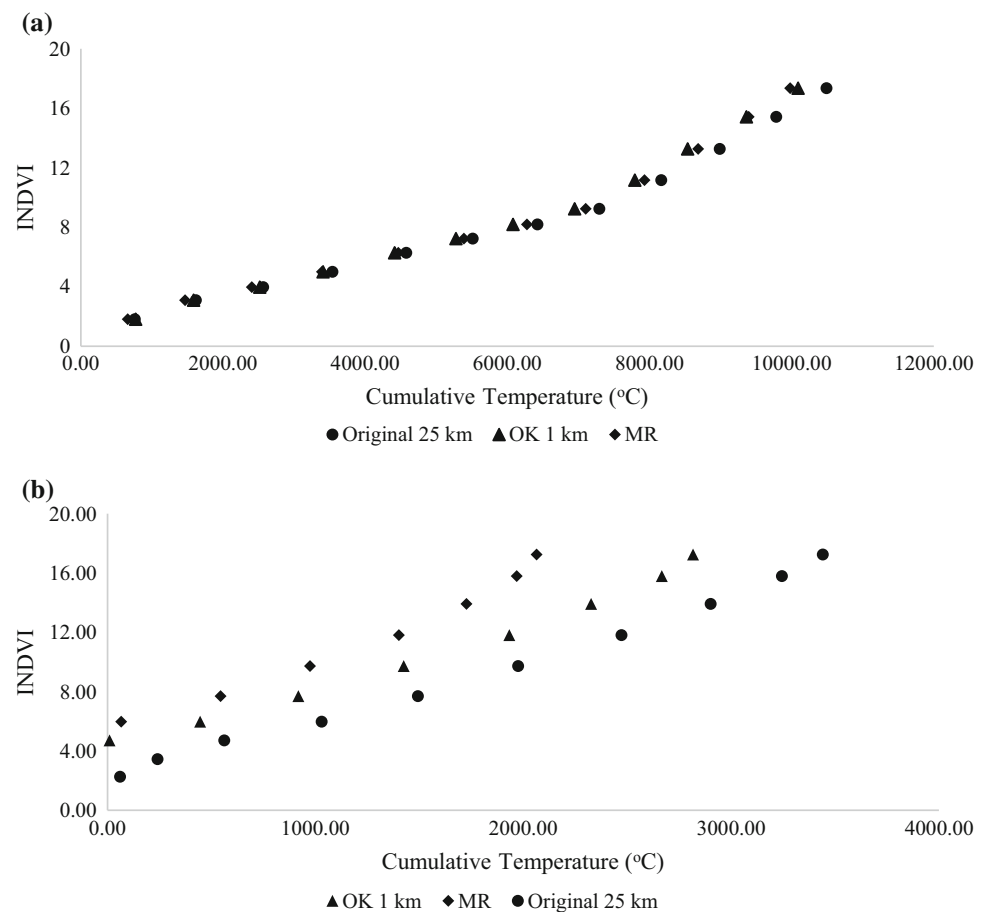
found, whereas at sites-3 and site-4, a wave period of one year was resolved during 1998–2007 (Fig. 11c, d).

Wavelet analysis resolved a wave period of one year at all the sites. The analysis clearly shows that during the



**Fig. 8** Wavelet analysis of temperature in **a** S-1, **b** S-2, **c** S-3 and **d** S-4

**Fig. 9** Relation between INDVI and cumulative temperature at **a** S-3 and **b** S-2



period 1998–2007, the precipitation was more related to the change of NDVI, rather than temperature.

## Trend Analysis

### Mann–Kendall Test

In annual scale, among NDVI, temperature and precipitation, we have found trend in more than 75% of  $Z$  values ( $p < 0.05$ ) in all the four locations. Table 2 shows the  $Z$  statistic of NDVI, precipitation and temperature based on daily data. It can be concluded that in site-1 and site-2, NDVI and temperature have a positive trend, while the precipitation has a negative trend. But in sites-3 and 4, precipitation has positive trend, while temperature has a negative trend. Interestingly, in site-3, NDVI has positive trend, while in site-4 no positive or negative trend was observed except in 1998.

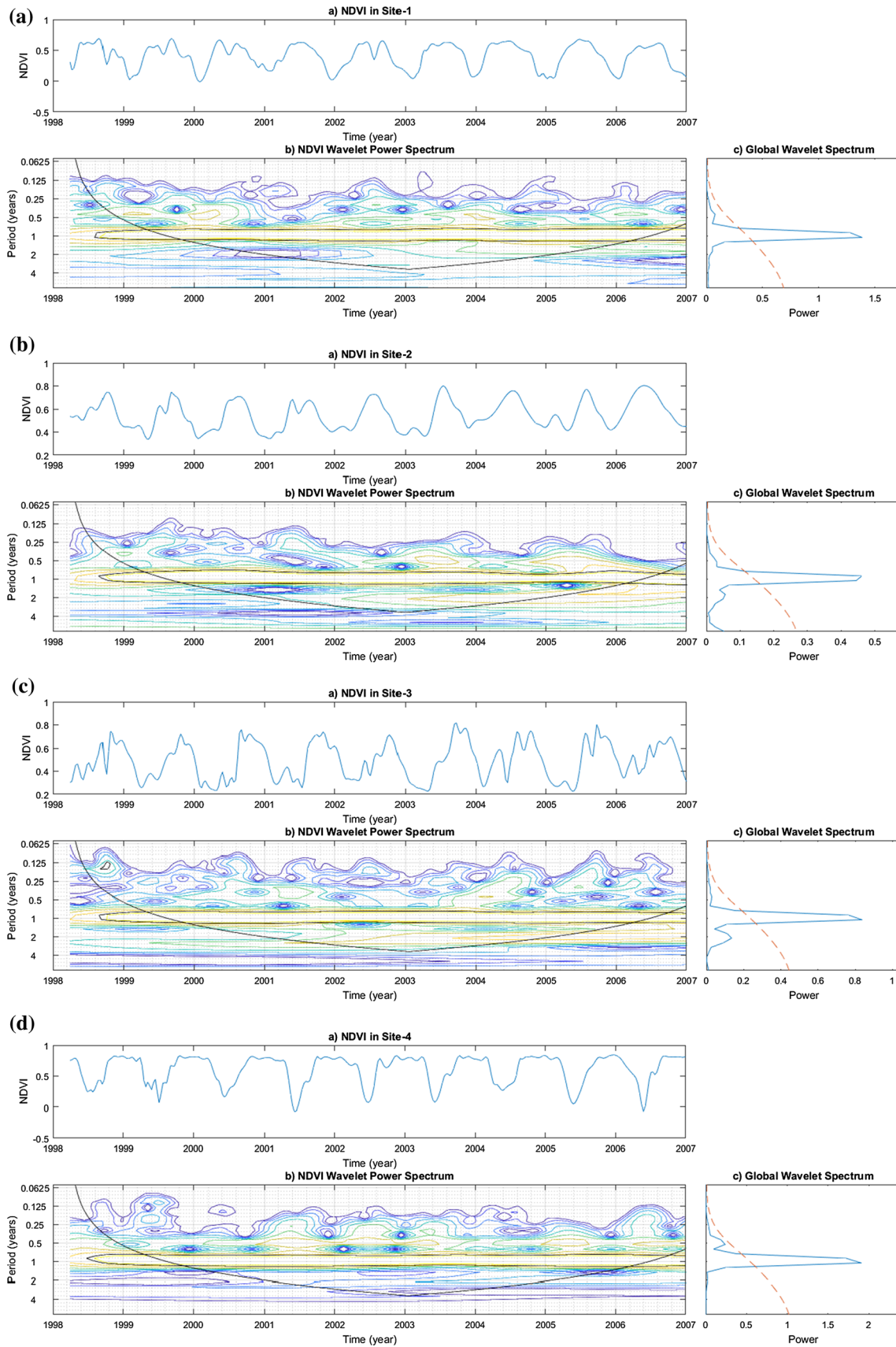
### Sen's Slope Estimator

The Sen's slope of daily data (10 daily data of NDVI) for each year was estimated for the parameters to find the magnitude of the trend. These are listed in Table 3, which

shows the  $Q$  statistics. Positive slope (0.004–0.010) was found in NDVI in site-1, while site-2 shows a positive slope from  $-0.001$  to  $0.012$ . In site-3, an increasing trend in NDVI (0.011–0.014) was estimated, while at site-4, the NDVI slope is almost zero. The temperature slope of site-1 varies from  $0.006$  to  $0.017$ , and site-2 varies from  $0.012$  to  $0.026$ . However, the temperature slope of site-3 varies from  $-0.014$  to  $-0.021$ , and in site-4, it varies from  $-0.006$  to  $-0.002$ . Precipitation analysis during the monsoon period shows a negative slope in all the sites. Nevertheless, these results can be expected due to drastic difference in environment and climate conditions in southern and northern India.

## Discussions

Results from the analysis of precipitation indicate that monthly NDVI has stronger relation with monthly precipitation than temperature. However, the Himalayan temperate forests required a minimum temperature of  $\sim 10$  °C to greenup. After that, there is negligible effect of temperature on the change of NDVI. Further, precipitation analysis also shows a minimum requirement of



**Fig. 10** Wavelet analysis of NDVI in **a** S-1, **b** S-2, **c** S-3 and **d** S-4



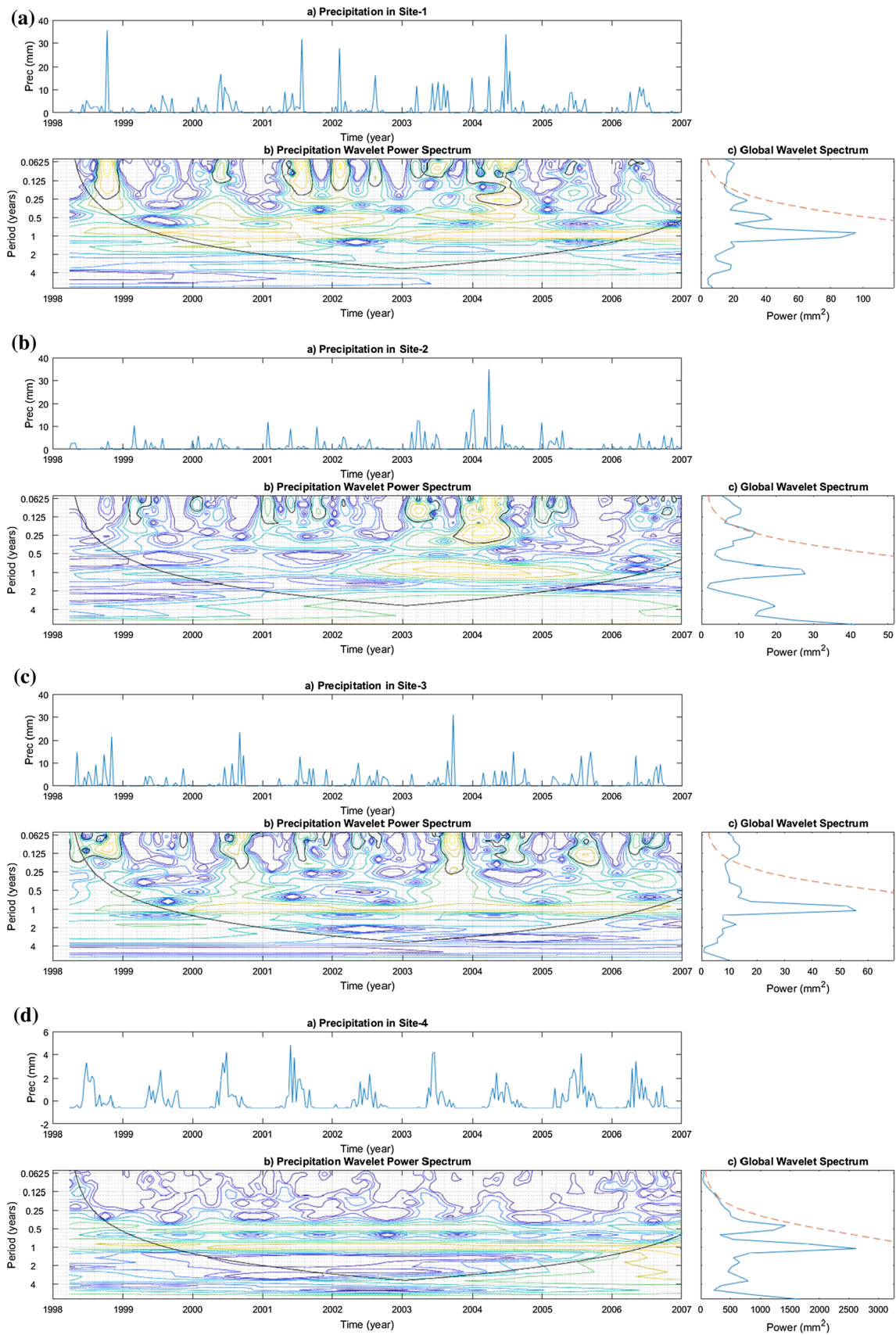


Fig. 11 Wavelet analysis of precipitation at a S-1, b S-2, c S-3 and d S-4

**Table 2** Z statistics of NDVI, temperature, precipitation (total) and precipitation (monsoon) based on daily data

	Site-1			Site-2			Site-3			Site-4						
	NDVI	Temp.	Prec.	monsoon	NDVI	Temp.	Prec.	monsoon	NDVI	Temp.	Prec.	monsoon				
1998	1.956	<b>2.643</b>	- 2.180	- 0.556	- 0.099	<b>4.125</b>	- 6.329	- 3.346	<b>4.722</b>	- 10.099	<b>7.732</b>	<b>3.397</b>	<b>1.995</b>	- 8.055	<b>7.164</b>	- 5.245
1999	<b>3.146</b>	<b>2.493</b>	- 1.777	- 6.925	<b>2.847</b>	<b>3.764</b>	- 5.783	- 3.869	<b>3.174</b>	- 8.019	<b>5.621</b>	1.693	- 0.014	- 3.550	<b>4.404</b>	- 4.977
2000	<b>3.178</b>	<b>3.190</b>	- 3.832	- 7.720	1.112	<b>3.953</b>	- 3.579	- 6.138	<b>3.126</b>	- 8.426	<b>4.911</b>	0.175	- 0.693	- 4.572	<b>3.414</b>	- 7.390
2001	<b>3.021</b>	<b>3.405</b>	- 1.439	- 7.853	0.824	<b>3.192</b>	- 0.616	- 4.668	<b>2.812</b>	- 9.091	<b>7.456</b>	<b>4.075</b>	0.144	- 3.506	<b>3.593</b>	- 8.066
2002	<b>2.329</b>	<b>2.020</b>	- 3.619	- 2.111	<b>2.629</b>	<b>2.611</b>	- 2.578	- 2.991	<b>2.629</b>	- 7.945	<b>3.853</b>	0.934	- 0.885	- 3.462	<b>3.577</b>	- 5.109
2003	<b>2.995</b>	<b>3.502</b>	0.250	- 3.934	<b>2.629</b>	<b>4.205</b>	- 1.142	- 2.403	<b>4.617</b>	- 8.563	<b>6.713</b>	- 0.171	0.353	- 5.750	<b>3.774</b>	- 6.714
2004	<b>2.547</b>	<b>3.502</b>	0.478	- 3.114	0.558	<b>3.455</b>	- 0.978	- 2.316	<b>3.909</b>	- 8.533	<b>4.091</b>	1.610	1.212	- 4.505	<b>3.305</b>	- 7.481
2005	<b>2.080</b>	<b>4.109</b>	- 2.198	- 3.917	<b>2.786</b>	<b>4.734</b>	- 6.619	- 4.477	<b>3.126</b>	- 10.299	<b>7.876</b>	<b>5.037</b>	- 0.745	- 6.727	<b>5.205</b>	- 5.028
2006	1.240	1.349	0.698	- 4.601	<b>2.983</b>	<b>3.178</b>	1.550	- 2.951	<b>3.637</b>	- 6.862	<b>6.116</b>	0.557	- 0.940	- 3.922	<b>5.139</b>	- 5.686
2007	<b>5.532</b>	<b>2.384</b>	- 0.896	- 4.655	1.216	<b>2.203</b>	- 3.223	- 5.514	<b>4.617</b>	- 8.719	<b>6.430</b>	- 0.373	- 0.850	- 4.701	<b>4.914</b>	- 5.175

Numbers in bold indicate the *p* value less than 5% confidence level



**Table 3** Sen's slope values of NDVI, temperature, precipitation (total) and precipitation (monsoon) based on daily data

	Site-1			Site-2			Site-3			Site-4			
	NDVI	Temp.	Prec. (June–October)	NDVI	Temp.	Prec. (June–October)	NDVI	Temp.	Prec. (June–October)	NDVI	Temp.	Prec. (June–October)	
1998	0.006	0.011	0.000	0.000	0.024	0.000	0.014	– 0.021	0.000	0.004	0.007	– 0.006	0.001
1999	0.007	0.009	0.000	0.011	0.020	0.000	0.009	– 0.017	0.000	0.001	0.000	– 0.003	0.000
2000	0.007	0.012	0.000	0.005	0.018	0.000	0.010	– 0.015	0.000	0.000	– 0.001	– 0.003	0.000
2001	0.006	0.014	0.000	0.004	0.016	0.000	0.008	– 0.019	0.000	0.006	0.000	– 0.002	0.000
2002	0.005	0.009	0.000	0.010	0.015	0.000	0.007	– 0.021	0.000	0.000	– 0.002	– 0.003	0.000
2003	0.006	0.014	0.000	0.010	0.019	0.000	0.016	– 0.017	0.000	0.000	0.000	– 0.005	0.000
2004	0.005	0.014	0.000	0.002	0.016	0.000	0.009	– 0.016	0.000	0.001	0.001	– 0.003	0.000
2005	0.004	0.017	0.000	0.012	0.026	0.000	0.011	– 0.021	0.001	0.019	– 0.001	– 0.004	0.001
2006	0.003	0.006	0.000	0.009	0.016	0.000	0.007	– 0.014	0.000	0.001	– 0.001	– 0.003	0.000
2007	0.010	0.008	0.000	0.005	0.012	0.000	0.013	– 0.021	0.000	0.000	– 0.001	– 0.004	0.000

**Table 4** Median of phenological metrics during 1998–2007

Forest cover	Year	Onset	End	Duration	Onset value	End value	Peak value	Date of peak
Himalayan moist temperate (Site-1)	1998	6/1/1998	12/21/1998	203	0.52	0.45	0.76	8/21/1998
	1999	5/21/1999	12/21/1999	214	0.33	0.48	0.75	9/1/1999
	2000	5/11/2000	12/21/2000	224	0.39	0.37	0.73	9/21/2000
	2001	5/1/2001	12/21/2001	234	0.38	0.43	0.75	8/1/2001
	2002	5/11/2002	12/21/2002	224	0.40	0.41	0.73	8/11/2002
	2003	5/21/2003	12/21/2003	214	0.35	0.45	0.73	7/1/2003
	2004	3/11/2004	12/21/2004	285	0.43	0.46	0.76	9/21/2004
	2005	7/3/2005	2/8/2006	220	0.50	0.45	0.75	9/1/2005
Himalayan dry temperate (Site-2)	1998	4/11/1998	2/15/1999	310	0.18	0.05	0.69	8/29/1998
	1999	2/25/1999	2/10/2000	350	0.09	– 0.01	0.69	9/13/1999
	2000	2/20/2000	2/14/2001	360	0.01	0.17	0.67	5/20/2000
	2001	2/24/2001	1/20/2002	330	0.16	0.04	0.63	7/14/2001
	2002	1/30/2002	1/15/2003	350	0.08	0.18	0.65	9/27/2002
	2003	1/25/2003	1/20/2004	360	0.15	0.07	0.63	8/23/2003
	2004	1/30/2004	1/24/2005	360	0.08	0.12	0.65	7/28/2004
	2005	2/3/2005	1/29/2006	360	0.07	0.09	0.68	8/2/2005
Tropical thorny vegetation (Site-3)	1998	4/1/1998	3/27/1999	360	0.30	0.28	0.74	28/10/1998
	1999	4/9/1999	3/11/2000	337	0.26	0.32	0.72	2/11/1999
	2000	3/21/2000	3/16/2001	360	0.29	0.29	0.76	17/9/2000
	2001	3/26/2001	3/21/2002	360	0.29	0.33	0.74	21/11/2001
	2002	3/31/2002	3/26/2003	360	0.34	0.26	0.71	6/11/2002
	2003	4/15/2003	3/10/2004	330	0.25	0.27	0.82	22/10/2003
	2004	3/20/2004	3/15/2005	360	0.27	0.28	0.75	15/11/2004
	2005	3/25/2005	3/20/2006	360	0.27	0.34	0.80	31/10/2005
Tropical moist deciduous (Site-4)	1998	7/20/1998	6/15/1999	330	0.28	0.39	0.82	27/11/1998
	1999	6/25/1999	6/19/2000	360	0.45	0.16	0.83	2/11/1999
	2000	6/29/2000	6/24/2001	360	0.19	– 0.07	0.82	16/11/2000
	2001	7/4/2001	6/29/2002	360	– 0.06	0.15	0.82	22/10/2001
	2002	7/9/2002	7/4/2003	360	0.08	0.08	0.83	16/12/2002
	2003	7/14/2003	6/28/2004	350	0.10	0.27	0.83	11/11/2003
	2004	7/8/2004	7/3/2005	360	0.29	0.05	0.83	3/2/2005
	2005	7/13/2005	7/8/2006	360	0.06	– 0.06	0.84	29/1/2006
	2006	7/18/2006	6/23/2007	340	0.01	0.03	0.85	14/3/2007

precipitation to have a positive change in NDVI. The type of forest depends on the amount of precipitation. For example, results show that Himalayan moist and dry temperate forests show a minimum of 50 mm of monthly rainfall to have a positive change in NDVI. Similarly, tropical thorny vegetation type of forest show a minimum of 30 mm and tropical moist deciduous show a minimum of 10 mm of monthly rainfall to increase the monthly average NDVI value. The results are consistent with other

study for monitoring the NDVI in tropical regions of India (Prasad et al. 2005).

Further, the cumulative precipitation relation with INDVI indicates a good way to analyze the anomaly in the greenup pattern of the forest. The anomaly in 2004 and 2006, in the relation between these two at site-1 indicated an early rainfall could accelerate the greenup. From the wavelet analysis, significant zones in the precipitation time series data are identified which exhibits a fast greenup. Table 4 shows the phenological characteristics of the

forests in different years. For Himalayan moist temperate vegetation, the early rainfall indicates a high onset NDVI value than the other years. In other forests covers, similar anomaly were not visible suggesting that the forest type is fairly resilient to local hydrological changes. The precipitation was found to follow an exponential relation ( $R^2 > 0.9$ ) with INDVI, although Méndez-Barroso et al. (2009) found a linear relation with IEVI ( $R^2 = 0.763$ ). However, these relations are consistent with Li et al. 2010, where they found linear relation between precipitation and NDVI. Both the studies reported a higher vegetation production with increase in precipitation.

## Conclusion

The high-altitude natural vegetation dynamics were studied in four different topographical and climatic sites from 1998 to 2007. Maximum value composite of 10-day NDVI data with spatial resolution of 1 km × 1 km from the SPOT vegetation sensor, daily precipitation and temperature data from APHRODITE project with spatial resolution of 0.25° were considered in this study. Two of the sites are located in northern Himalayan part, and other two sites are located in Eastern Ghats and Western Ghats hilly regions in India. Empirical mode decomposition method was applied to remove the noises from the NDVI data. The Mann–Kendall trend analysis and Sen's slope estimator were used to find the trend of the time series, and the wavelet analysis was carried out to find the extent of the anomalies in data. Analysis shows that for vegetation growth, a minimum temperature (10 °C) is required. Up to a precipitation of 50 mm, the precipitation has no effect on the vegetation dynamics. This minimum precipitation is commonly lost due to evaporation. Analysis also shows that for various species of vegetation, optimum precipitation may vary, but excessive precipitation declines the vegetation growth.

The wavelet analysis indicates that the anomalies in vegetation dynamics in a particular site are directly related to the precipitation of the monsoon season. The NDVI has a stronger relation with precipitation than temperature. The vegetation dynamics in all the sites shows a positive trend indicating an increase in the net biomass production. The temperature and precipitation trend behaved differently in northern region and other parts. In the northern region, temperature trend was positive, while precipitation was negative (Table 2). In the Eastern and Western Ghats regions, the temperature has negative trend, while the precipitation has positive. However, the Sen's slope shows that magnitude was very small (within 0.03) except in western region during the monsoon, where the magnitude was  $-0.310$  to  $+0.134$  for precipitation. In summary, the

study shows that the local hydrology controls the vegetation dynamics within a very short period about few months.

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## References

- Bellone, T., Boccardo, P., & Perez, F. (2009a). Investigation of vegetation dynamics using long-term normalized difference vegetation index time-series. *American Journal of Environmental Sciences*, 5(4), 461. <https://doi.org/10.3844/ajessp.2009.461.467>.
- Bellone, G., Novarino, A., Vizio, B., & Ciuffreda, L. (2009b). Impact of surgery and chemotherapy on cellular immunity in pancreatic carcinoma patients in view of an integration of standard cancer treatment with immunotherapy. *International Journal of Oncology*, 34(6), 1701–1715.
- Braswell, B. H., Schimel, D. S., Linder, E., & Moore, B., III. (1997). The response of global terrestrial ecosystems to inter-annual temperature variability. *Science*, 278, 870–873.
- Chang, C. T., Lin, T. C., Wang, S. F., & Vadeboncoeur, M. A. (2011). Assessing growing season beginning and end dates and their relation to climate in taiwan using satellite data. *International Journal of Remote Sensing*, 32(18), 5035–5058.
- Chang, C. T., Wang, S. F., Vadeboncoeur, M. A., & Lin, T. C. (2014). Relating vegetation dynamics to temperature and precipitation at monthly and annual timescales in Taiwan using MODIS vegetation indices. *International Journal of Remote Sensing*, 35(2), 598–620.
- Chiu, C. A., Lin, P. H., & Lu, K. C. (2009). GIS-based tests for quality control of meteorological data and spatial interpolation of climate data. *Mountain Research and Development*, 29(4), 339–349.
- Chmielewski, F. M., & Rotzer, T. (2001). Response of tree phenology to climate change across Europe. *Agricultural and Forest Meteorology*, 108(2), 101–112.
- Cramer, W., Bondeau, A., Woodward, I., & Young-Molling, C. (2001). Global response of terrestrial ecosystem structure and function to CO<sub>2</sub> and climate change: results from six dynamic global vegetation models. *Global Change Biology*, 7(4), 357–373.
- Davenport, M. L., & Nicholson, S. (1993). On the relation between rainfall and the Normalized Difference Vegetation Index for diverse vegetation types in East Africa. *International Journal of Remote Sensing*, 14(12), 2369–2389.
- Deng, Y., Chen, X., Chuvieco, E., Warner, T., & Wilson, J. P. (2007). Multi-scale linkages between topographic attributes and vegetation indices in a mountainous landscape. *Remote Sensing of Environment*, 111, 122–134.
- Fuller, D. O., & Prince, S. D. (1996). Rainfall and foliar dynamics in tropical Southern Africa: potential impacts of global climatic change on savanna vegetation. *Climatic Change*, 33, 69–96.
- Guo, N., Zhu, Y. J., Wang, J. M., & Deng, C. P. (2008). The relationship between NDVI and climate elements for 22 years in different vegetation areas of Northeast China. *Chinese Journal of Plant Ecology*, 32(2), 319–327. (in Chinese).
- Holben, B. (1986a). Characteristics of maximum-value composite images from temporal AVHRR data. *International Journal of Remote Sensing*, 7(11), 1417–1434.

- Holben, B. N. (1986b). Characteristics of maximum-value composite images from temporal AVHRR data. *International Journal of Remote Sensing*, 7, 1417–1434.
- Huang, N. E., Shen, Z., Long, S. R., et al. (1998). The empirical mode decomposition and the Hilbert spectrum for nonlinear and non-stationary time series analysis. *Proceedings of the Royal Society of London Series A*, 454, 903–995.
- Karmaker, T., Medhi, H., & Dutta, S. (2017). Study of channel instability in the braided Brahmaputra river using satellite imagery. *Current Science*, 112(7), 1533–1543.
- Li, X., Zhu, J., Xiao, Y., & Wang, R. (2010). A model-based observation-thinning scheme for the assimilation of high-resolution SST in the shelf and coastal seas around China. *Journal of Atmospheric and Oceanic Technology*, 27, 1044–1058.
- Méndez-Barroso, L. A., Vivoni, E. R., Watts, C. J., & Rodriguez, J. C. (2009). Seasonal and interannual relations between precipitation, surface soil moisture and vegetation dynamics in the North American monsoon region. *Journal of Hydrology*, 377, 59–70.
- Meshram, S. G., Singh, V. P., & Meshram, C. (2017). Long-term trend and variability of precipitation in Chhattisgarh State, India. *Theoretical and Applied Climatology*, 129(3–4), 729–744.
- National Council of Education Research and Training (NCERT). (2006). *India physical environment*. NCERT Campus, Sri Aurobindo Marg, New Delhi. ISBN 81-7450-538-5.
- Prasad, V. K., Anuradha, E., & Badarinath, K. V. S. (2005). Climatic controls of vegetation vigor in four contrasting forest types of India—evaluation from National Oceanic and Atmospheric Administration’s Advanced Very High Resolution Radiometer-datasets (1990–2000). *International Journal of Biometeorology*, 50, 6–16.
- Sen, P. K. (1968). Estimates of the regression coefficient based on Kendall’s tau. *Journal of the American Statistical Association*, 63(324), 1379–1389.
- Torrence, C., & Compo, G. P. (1998). A practical guide to wavelet analysis. *Bulletin of the American Meteorological Society*, 79(1), 61–78.
- Verma, R., & Dutta, S. (2013). Vegetation dynamics from denoised NDVI using empirical mode decomposition. *Journal of the Indian Society of Remote Sensing*, 41, 555–566.
- Wolfe, J. M., Horowitz, T. S., & Kenner, N. M. (2005). Rare items often missed in visual searches. *Nature*, 435, 439–440.

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