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Studies on spatial pattern of NDVI over India and its relationship with rainfall, air temperature, soil moisture adequacy and ENSO

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The changes in spatial distribution of Advanced Very High Resolution Radiometer (AVHRR) Normalized Difference Vegetation Index (NDVI) are studied for different seasons in India for the period 1982 to 2000. The inter-annual variability of All India NDVI (AINDVI) has been studied and related to rainfall, air temperature, soil moisture adequacy, Southern Oscillation Index (SOI) and Nino 3 Sea Surface Temperature (Nino 3 SST) to understand the influence of these variables on vegetal cover. The results show that the NDVI is high during the south-west (June to September) monsoon and retreat (October and November) seasons where in major crop seasons *Kharif* and *Rabi* take place over India. The trend of AINDVI is increasing and displayed higher values during La Niña and lower in El Niño episodes. The correlation between rainfall and NDVI of All India is not significant on monthly basis (+0.13) but it is more prominent when the cumulative annual amounts of rainfall are involved (+0.61). NDVI responded very well to the variations of soil moisture adequacy (S_{AD}) which enumerates the strongest correlation (+0.73) of crop performance with NDVI. This significant strong correlation inferred that S_{AD} can be taken as the indicator for the NDVI variations rather rainfall. The linear regression analysis of AINDVI and the ENSO indices revealed the strong impact of sea surface temperatures than SOI on vegetation pattern over India.

Keywords: NDVI, inter-annual variability, rainfall, air temperature, soil moisture adequacy and ENSO

1. Introduction

The demand in understanding the climate impacts on eco systems is increasing due to the level of human activity and is outlined the attention towards the global scientific community. The fundamental knowledge of the vegetation response to the climatic factors serves as the potential for discrimination of threatened areas, for effective forecasting and assessment of risk events. The vegetation data sets of National Oceanic and Atmospheric Administration (NOAA) AVHRR, popularly known as Normalized Difference Vegetation Index (NDVI) are of useful in studying the ground vegetal cover. It is reported that NDVI is commonly used to monitor the seasonal and annual vegetation (Jackson et al., 1983; Tucker et al., 1991). Many studies focused different applications of NDVI in studying the climate feedback mechanism (Lu et al., 2001; Mabuchi and Sato, 2005), crop growing periods (Sarma and Kumar, 2006) and drought assessment (Savin and Flueraru, 2006; Sarma and Kumar, 2007). Shilong et al. (2004) studied the vegetation index in relation to climate in China and found the heterogeneous trends of NDVI are due to changes in climate, land use and vegetation structure and these variations are closely related to temperature and rainfall. NDVI can also be used to identify the dynamics of the terrestrial biosphere (Fung et al., 1987). Propastin et al. (2007) employed the NDVI data to study the inter-annual dynamics of vegetation for different types of vegetation and observed the substantial correspondence between NDVI and climate factors. It is also believed that the vegetation is influenced by the global teleconnections associated with El Niño and La Niña and significant correlations were found with NDVI (Sarkar and Kafatos, 2004). Sarma et al. (2007) reported the variability of Integrated NDVI (INDVI) with reference to rice yield of Andhra Pradesh and concluded a strong agreement of positive phase between them. Many studies have been done on the impact of ENSO on rainfall patterns over India (Kripalani and Kulkarni, 1997; Kumar et al., 2010). Kumar et al. (2010) reported the sensitivity of Indian monsoon rainfall distribution and its annual cycle to the El Niño and found that the notable deficiency of rainfall is observed during June, July, August and September, i.e south-west monsoon rainfall. Since, ENSO has considerable impact on south-west monsoon rainfall, it is believed that the crops in this season suffer with inadequate water amounts which are required for the crop growth in India. Sarkar and Kafatos (2004) reported the monsoonal precipitation patterns associated with the ENSO indices, SOI and Niño 3 SST and concluded El Niño captures the effect over Indian subcontinent. Rao et al. (2012) also studied the AVHRR NDVI pattern over different homogeneous monsoon regions of India and reported the notorious impact of El Niño on vegetation pattern.

So, in view of above studies, main aim in the present paper is to study the spatial distributions of AVHRR NDVI over India (Fig. 1) for different seasons. Also, the inter-annual variability of All India NDVI (AINDVI) is dealt in detail. The present study also focuses to understand the impact of meteorological (rainfall and air temperature) / agrometeorological (soil moisture adequacy) / ENSO (SOI and Nino 3 SST) parameters on the vegetation pattern over India.

2. Materials and methods

The NOAA AVHRR Normalized Difference Vegetation Index (NDVI) data is downloaded from the website http://www.jisao.washington.edu on global scale and

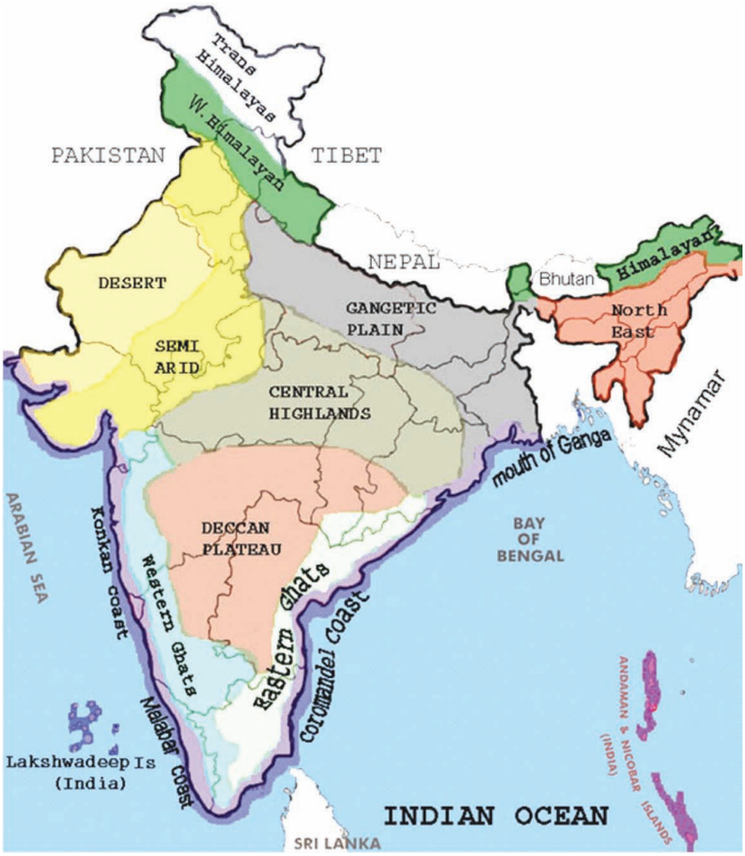

Figure 1. Geographical regions of India.

are retrieved for India for the period 1982–2000 with the grid resolution of 1° × 1°. The data is basically with 8 km resolution and are put up in the website with 1° × 1° grid resolution and in entire data set, the NDVI values for November 1993 and September to December 1994 are missing and accordingly, the study is made.

CMAP (Centre Merged Analysis of Precipitation) precipitation data on monthly scale from 1979 to 2004 with 2.5° × 2.5° grid resolution which are obtained from five kinds of satellite estimates (GPI, OPI, SSM/I scattering, SSM/I emission and MSU) are used for the present study. The mean monthly air temperature data of 2.5° × 2.5° grid resolution is also downloaded from the website http://www.cdc.noaa.gov and used for the period from 1982 to 2000. The data of ENSO indices, Southern Oscillation Index (SOI) and sea surface temperatures in the Niño 3 region (Niño 3 SST) are downloaded from the website www.cdc.noaa.gov.

The NDVI value of gridded data sets varies from –1 to +1. If NDVI varies from 0 to 0.2, it is considered as low vegetation. If the value lies in between 0.2

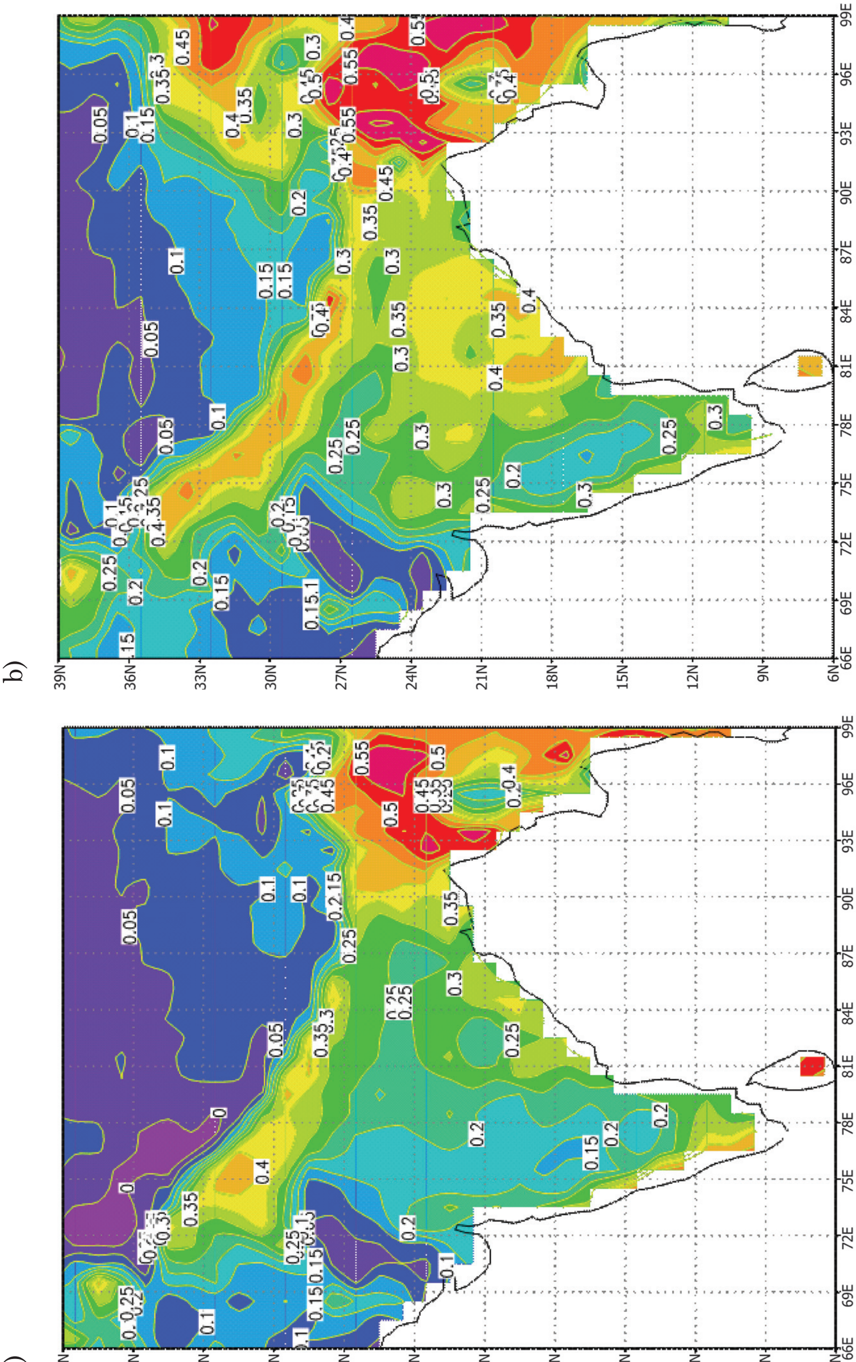

Figure 2. Spatial distributions of Normalized Difference Vegetation Index (NDVI) over India in the period 1982–2000 for: a) hot weather, b) south-west monsoon seasons, c) retreat and d) winter seasons.

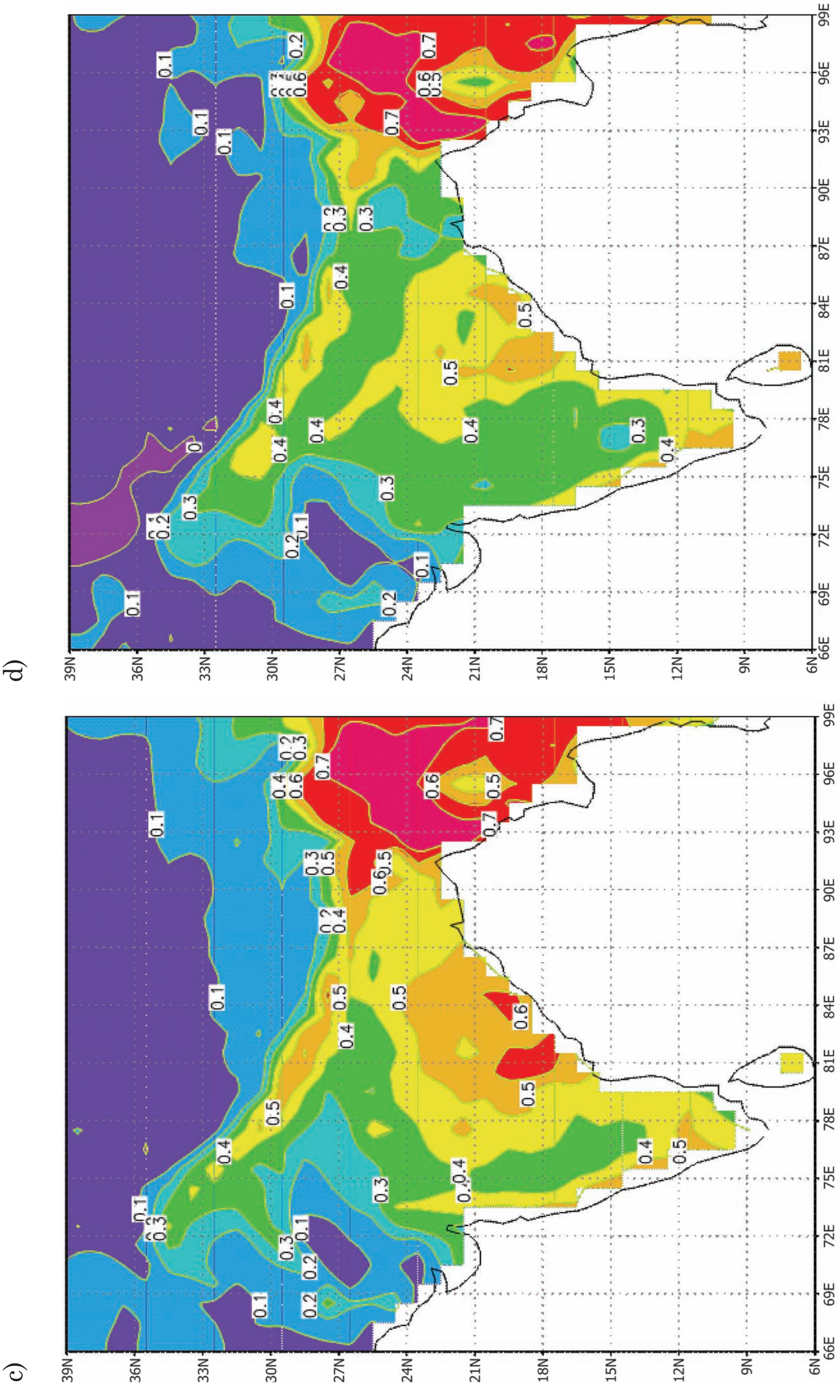

Figure 2. Continued.

to 0.4, then the vegetation status is taken as medium and if NDVI is more then 0.4, it can be treated that the vegetation reached to matured status (high vegetation). Negative values of NDVI impart the non vegetated areas like snow, ice, water, rock etc (http://metart.fao.org). The seasonal anomalies for the respective south-west monsoon of a year over India were calculated from the long term averaged values (1982–2000) and the inter-annual variability of AINDVI is examined. Then, the variations of AINDVI has been discussed in the context of the two phases of the global phenomenon (ENSO), viz-a-viz El Niño and La Niña events which are characterised by unusual warm and cold temperatures over equatorial Pacific region.

The All India soil moisture adequacy (S_{AD}) in the present investigation is derived from the revised water balance model of Thornthwaite and Mather (1955) which works with the inputs of rainfall and potential evapotranspiration (PE). The S_{AD} in percentage can be obtained from the following expression

$$S_{AD} = (AE/PE) \times 100 \tag{1}$$

where AE is the actual evapotranspiration.

Pearson correlation statistic has been applied to understand the mode of relation between AINDVI and rainfall, moisture adequacy, air temperature of All India, Niño 3 SST and SOI respectively. With the help of student t-test, the significances of these correlations are verified and the linear fit approximations are suggested for further use.

3. Results and Discussion

3.1. Spatial distribution of NDVI in different seasons

Fig. 1 depicts the bio-geographical regions of India on which the present study has been carried out. Fig. 2a-d represents the mean seasonal patterns for summer (from March to May; Fig. 2a), south-west monsoon (Fig. 2b), retreat of south-west monsoon (Fig. 2c) and winter seasons (from December to February; Fig. 2d) respectively for the period 1982–2000. The NDVI chart for summer season (Fig. 2a) maintained a vegetation index lesser than 0.3 in most of the places and the north-east part displayed more than 0.3. The north-west part and Western Ghats are the regions maintained low vegetation values, i.e. around 0.15 compared to other regions in the country.

The NDVI chart for south-west monsoon revealed a recovery of vegetal cover over many parts of the country (Fig. 2b) and is varying from 0.15 (north-west part) to a maximum of 0.55 (north-east part). The development in vegetation pattern is observed from hot weather to south-west monsoon season and is a replica for the crop performance during *Kharif* season. Eastern Ghats and eastern part of Deccan Plateau showed NDVI values of 0.4 which might be because of the south-west monsoonish current originates from Arabian sea and the Bay of Bengal that sweep the respective western part of India and north of Bay of Bengal (Assam) and finally these two branches merge in the monsoon trough region for more rains over India that result not only induce but also fairly wide spread of more vegetation that pave way for better crop yields.

The withdrawal of the monsoon is a far more gradual process than its onset. It usually withdraws from north-west India by the beginning of October and from the remaining parts of the country by the end of November. During this period, the north-east winds contribute to the formation of the north-east monsoon activity over the southern half of Peninsula by October. It is known that the retreating monsoon follows in the wake of the withdrawal of south-west monsoon. Hence, the impact of retreat season over vegetal cover can be observed in the parts of Western Ghats as the NDVI value raised more than 0.4 where as it is below 0.4 at the time of south-west monsoon (Fig. 2c). This is because of Tamil Nadu and Kerala, parts of Western Ghats receive rain during this season that lead to fair vegetation. The country over all showed an improvement in NDVI status. The north-eastern part of India i.e. Assam and its surroundings are always extremely wet and humid and this is why there is always highest vegetation index ($NDVI > 0.6$).

By approaching the winter season, the NDVI gradually decreased in parts of India (Fig. 2d). Parts of Western Ghats and Gangetic plains are witnessed the reduced vegetation patterns ($NDVI < 0.3$). North-west part that is covered by desert and semi arid regions displayed a vegetation of less than 0.2. Parts of Gangetic plains showed low vegetation ($NDVI < 0.3$) and north-east part recorded highest NDVI over the country and it is more than 0.6.

3.2. Inter-annual variability of AINDVI

Fig. 3 depicts the anomalies of AINDVI from the long term for the period 1982 to 2000. All India anomalies varied from a minimum of 12.7% below the normal in the year 1982 to a maximum of 12.6% in the year 1998. The standard deviation of NDVI for the period is 0.26 and the trend of anomalies is increasing with a slope of 0.76. Fig. 3 shows that the period from 1982 to 1989 was associated with prevailing negative anomalies, while during the 1990–2000 period positive anomalies were predominant. The pronounced variation of NDVI during the year 1998 might be attributed to the cold episode of ENSO phase during the year 1998 when in the country received 8% above the normal rainfall. A similar negative phenomena is observed in the year 2000 when the AINDVI fell nearly 8% to the normal and the same is reflected with rainfall figures of 7.5% below the normal in that year. The impact of warm and cold phases of ENSO (El Niño and La Niña) can be distinguished on the vegetation patterns over India if the consequent years of warm and cold phases are considered. The year 1987 (El Niño; warm phase) and 1988 (La Niña; cold phase) are associated with a rise in vegetation status of –5.9% to –1.2% from the normal and in the same way, the 1997 (5.5%) and 1998 when in the vegetation has increased considerably from 1997 (Fig. 3).

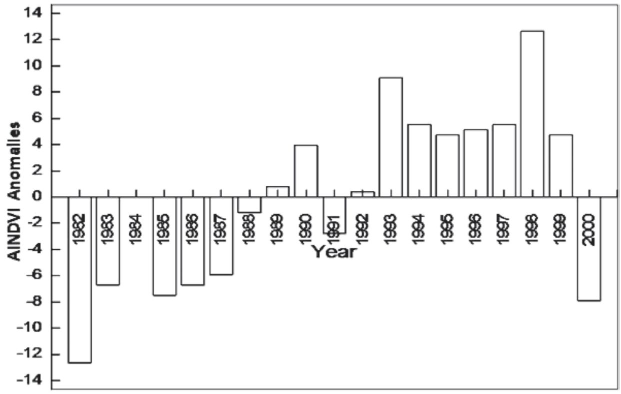

Figure 3. Inter-annual variability of annual Normalized Difference Vegetation Index of All India (AINDVI) in the period 1982–2000.

3.3. Annual cycle of NDVI

The Fig. 4 illustrates the mean annual cycle of NDVI for the long term along with the composites of El Niño (warm phase) (1983, 1987 and 1997) and La Niña (cold phase) (1988 and 1998) years. Fig. 4 shows that NDVI achieved very low values in the period from April to June. From June, the vegetation began its growth and reached maximum in October. It can be reported that during the south-west monsoon period of El Niño years, the NDVI showed values below the 1982–2000 normal by –3%, –4% and –2% in June, July and August. Later the

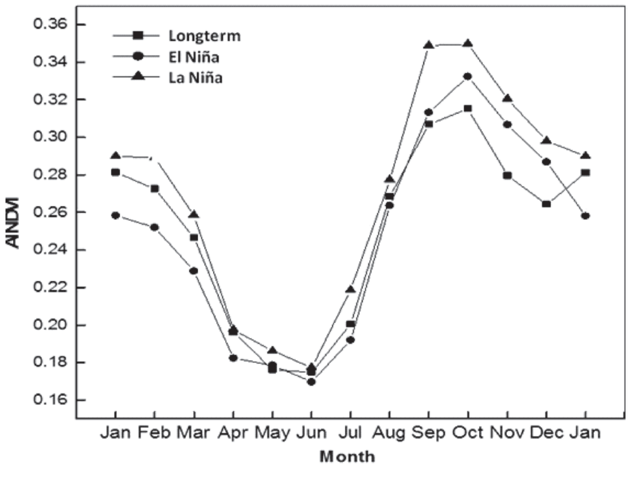

Figure 4. Annual cycle of Normalized Difference Vegetation Index of All India (AINDVI) in the period 1982–2000, in El Niño years (1983, 1987 and 1997) and in La Niña years (1988 and 1998).

Table 1. Linear fit regression expressions of Normalized Difference Vegetation Index of All India (AINDVI) with Southern Oscillation Index (SOI) and Niño 3 Sea Surface Temperature (Niño 3 SST) in the period 1982–2000 and in El Niño and La Niña years.

Period/Years	Linear regression	
	SOI	Niño 3 SST
1982–2000	AINDVI = 0.255 + 7.02694 $\cdot 10^{-4}$ (SOI)	AINDVI = 0.904 – 0.025 (SST)
1983, 1987 and 1997	AINDVI = 0.271 + 0.002 (SOI)	AINDVI = 1.05 – 0.03 (SST)
1988 and 1998	AINDVI = 0.223 + 0.005 (SOI)	AINDVI = 0.75 – 0.2 (SST)

NDVI increased the normal values by registering +2%, +5%, +9% and +8% for the all months from September and December as the north-east monsoon activity progresses. The La Nina events favour for the good monsoonish weather pattern, accompanied by good vegetation for the south-west and north-east monsoon months by registering the departures 1%, 9%, 3%, and 14%; 11%, 14% and 12% above the normal, respectively. The annual cycle of NDVI infers temporally that the period from June to October is the most important for Indian agriculture since June and October are the starting and ending seasons of *Kharif* crops. This type of changes in NDVI time series and reduced plant activity were also observed during El Niño over Africa (Eastman and Fulk, 1993; Poveda et al., 2001). It is also reported that the carbon uptake during El Niño become less prominent compared to other normal years on global scale (Turner and Brittain, 1962; Hashimoto et al., 2004). This reduced carbon uptake hinder the photosynthetic activity of the leaves which leads to lesser values of vegetation over El Niño years.

3.4 All India NDVI in relation to climate indices

a) Rainfall

With the aim of extracting a relationship between rainfall and NDVI, a linear regression analysis has been carried out. The regression equation allows the calculation of rainfall for each month from the NDVI values. Pearson correlation is applied for All India rainfall and NDVI and the study revealed a poor correlation (+0.13) which is of insignificant level. This poor positive correlation could be explained with the help of irrigation statistics that India has undergone since 1950. The irrigated area in India has been increased from 22.6 M ha (1950/51) to a value of 140 M ha (2000/01) respectively. In this, more than 45% of the irrigation is extracted from the ground water resources (Kumar et al., 2005). It is to worth mention that 56% of the crop yields in India are dependent on irrigation (Thakkar, 1999). It is also reported that the coupling of interplay between land cover and microclimate is the deciding factor in explaining the relationship of rainfall and NDVI (Sarma and Kumar, 2006). So, it is attempted to elevate the relation between rainfall and NDVI by obtaining the correlations with one and two months lag intervals as suggested by Davenport and Nicholson (1993) which are again resulted in poor correlation. So, an attempt is made to quantify the prominent relation by taking cumulative amounts of rainfall as reported by Al-Bakri and Suleiman (2004).

The linear regression is given for the calculation of annual rainfall in mm with the help of NDVI for All India:

$$P = 333.3 + 2928.9 \times (AINDVI) \quad (2)$$

A high sensitivity of AINDVI to the annual rainfall is observed over India i.e strong positive correlation of +0.61 at the 0.01 significant level (Fig. 5). From this correlation study, it can be known that the AINDVI is consistently varied with the annual fluctuations of rainfall. Based on this criterion, the NDVI can be used as an indicator for rainfall deficiencies which in turn portray the nature of climate stress.

b) Air temperature

All India NDVI values are correlated with All India mean air temperature on a monthly basis to understand the degree of relation between them. The linear regression equation for the calculation of mean monthly air temperature (in °C) from AINDVI is given below

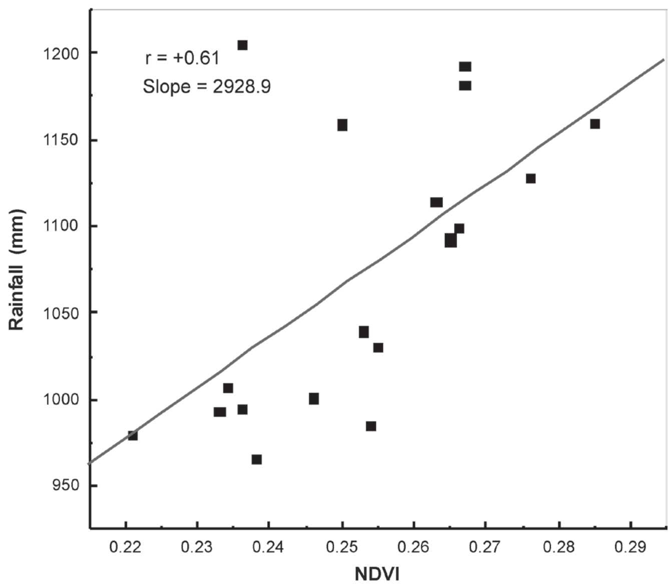

Figure 5. Linear fit of annual rainfall and Normalized Difference Vegetation Index of All India (AINDVI) in the period 1982–2000.

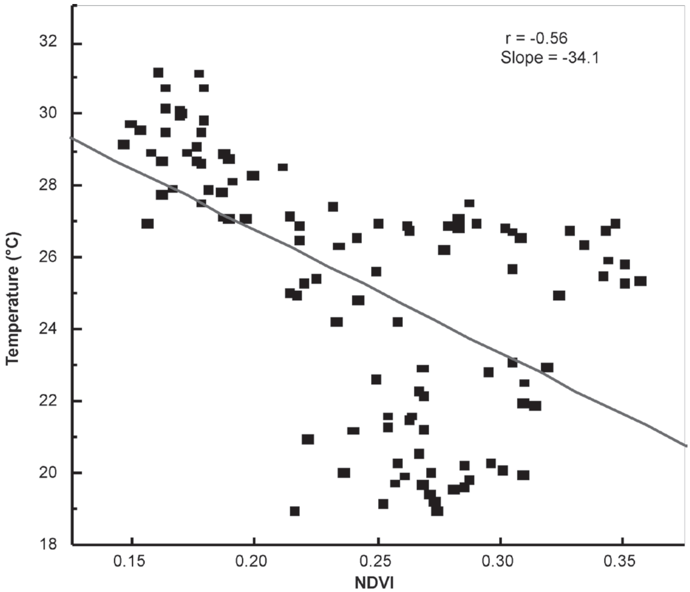

Figure 6. Linear fit of monthly air temperature and Normalized Difference Vegetation Index of All India (AINDVI) in the period 1982–2000.

$$T = 33.8 - 37.3 \times (AINDVI) \quad (3)$$

and the significance in this case is at 0.01 level. The Pearson correlation in this case is –0.56 which infers the negative impact on vegetation as the air temperature increases (Fig. 6). It is reported that the higher air temperatures increase the plant respiration, especially rice and reduce the net photosynthesis hence ultimately reducing the crop yield (Idso et al.*,* 1979).

c) Soil moisture adequacy

Soil moisture adequacy which is the key parameter in deciding the crop performance is made related to All India NDVI to understand the extent of relation on All India scale (Fig. 7). The linear regression expression of NDVI with soil moisture adequacy (in %) is as follows

$$S_{AD} = -44.2 + 391.9 \times (NDVI) \quad (4)$$

The monthly values of NDVI and soil moisture adequacy are subjected to Pearson correlation and this relation unfolded the strong positive value of +0.73 with 0.01 level of significance. It can be interpreted from this that there is a strong dependence of vegetal cover on soil moisture adequacy. The relation explores the information that the soil moisture adequacy is a more robust parameter since it signifies the extent of meeting or satisfying the water requirement of the place and on which the crop performance has a bearing. Therefore, the correlation is high compared to the rainfall and air temperature with NDVI.

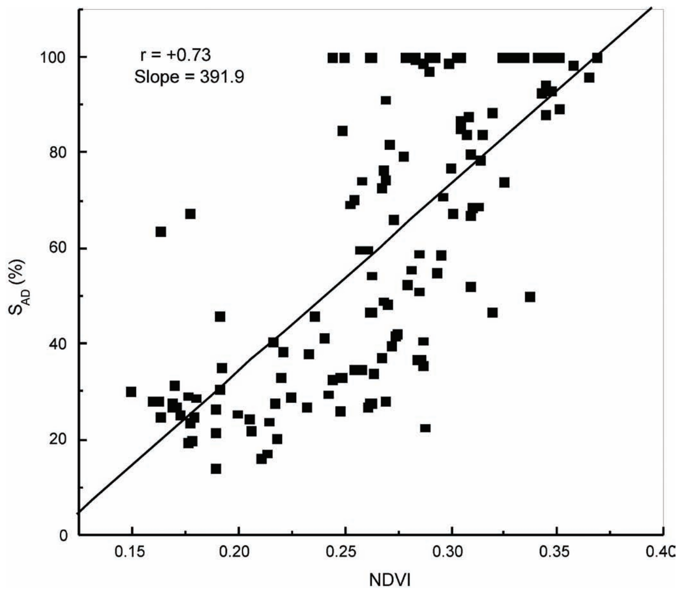

Figure 7. Same as Fig. 6 except for monthly soil moisture adequacy.

3.5. All India NDVI in relation to ENSO indices

The values of AINDVI along with the ENSO indices, SOI and Niño 3 SST unravelled the impact of these short term climate signals on Indian vegetal cover. Especially, 1982/83 and 1986/87 witnessed a low-key in NDVI value followed by a deficit of 14.5% and 19.4 % annual rainfall respectively. It was also reported that during these years, India suffered 29.1% and 47.7% of its area under drought (Sivasami, 2000) where the values of Niño 3 SST were raised by 4.1% and 4.5% of its normal. The same thing is explicable from the point of crop yields that had received during those years and as a fool proof, the rice yields of India reduced by 8% and 3% as compared to the yields of previous years (Sarma et al., 2008). Hence, a statistical study has been carried out to delineate the mode of impact of these parameters on Indian NDVI pattern.

The monthly values of AINDVI are correlated with SOI and Niño 3 SST. Figs. 8–10 represent the linear fits that are drawn between AINDVI and the analyzed ocean indices and the regression expressions are given in Tab. 1. NDVI maintained a poor correlation with the SOI (+0.14, significant at 0.05 level) compared to Niño 3 SST (–0.61, significant at 0.01 level). It implies strong impact of Pacific sea surface temperatures. The study is then partitioned and focused on to the El Niño and La Niña years separately. The years (1983, 1987 and 1997) registered +0.42 correlation with the SOI which is of 0.05 level of significance while the Niño 3 SST showed a dominated impact on vegetation witnessed by –0.80 correlation with the 0.01 level of significance. The La Niña years (1988 and

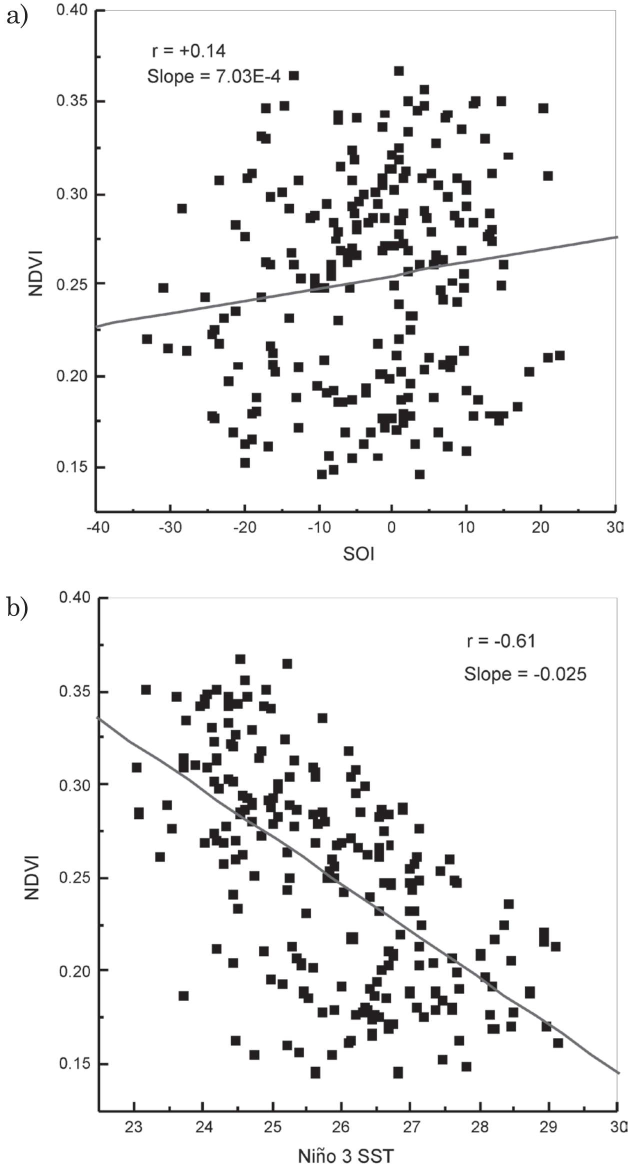

Figure 8. Linear fits of (a) Southern Oscillation Index (SOI) and (b) Niño 3 Sea Surface Temperature (Niño 3 SST) with Normalized Difference Vegetation Index of All India (AINDVI) in the period 1982–2000.

1998) yielded to +0.53 and –0.52 correlations at the 0.05 significant level with the SOI and Nino 3 SST respectively. Similar type of negative correlation was found by Anyamba et al. (2002) between NDVI and Niño 3 SST over east and

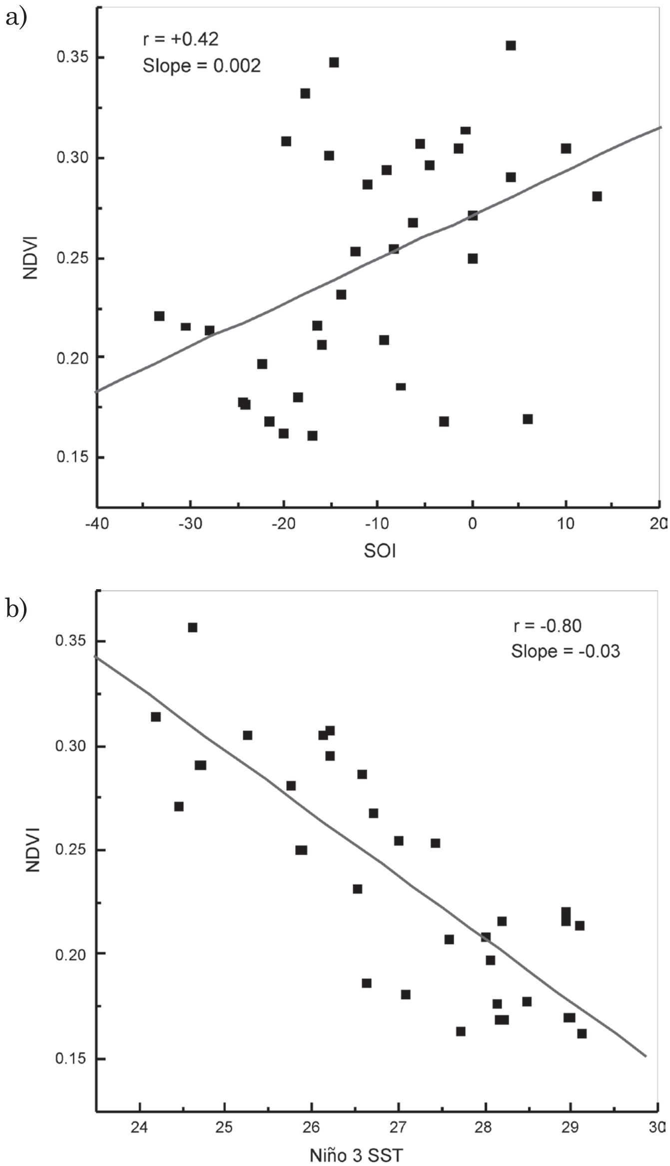

Figure 9. Same as Fig. 8 except in El Niño years (1983, 1987 and 1997).

southern Africa. This could be because of the variations in SST, influence the regional scale circulation which shows impact ENSO relationship on vegetation patterns. Kumar and Barbosa (2012) also reported the diminishing trend of rice yields over India during the El Niño years when compared with the neutral

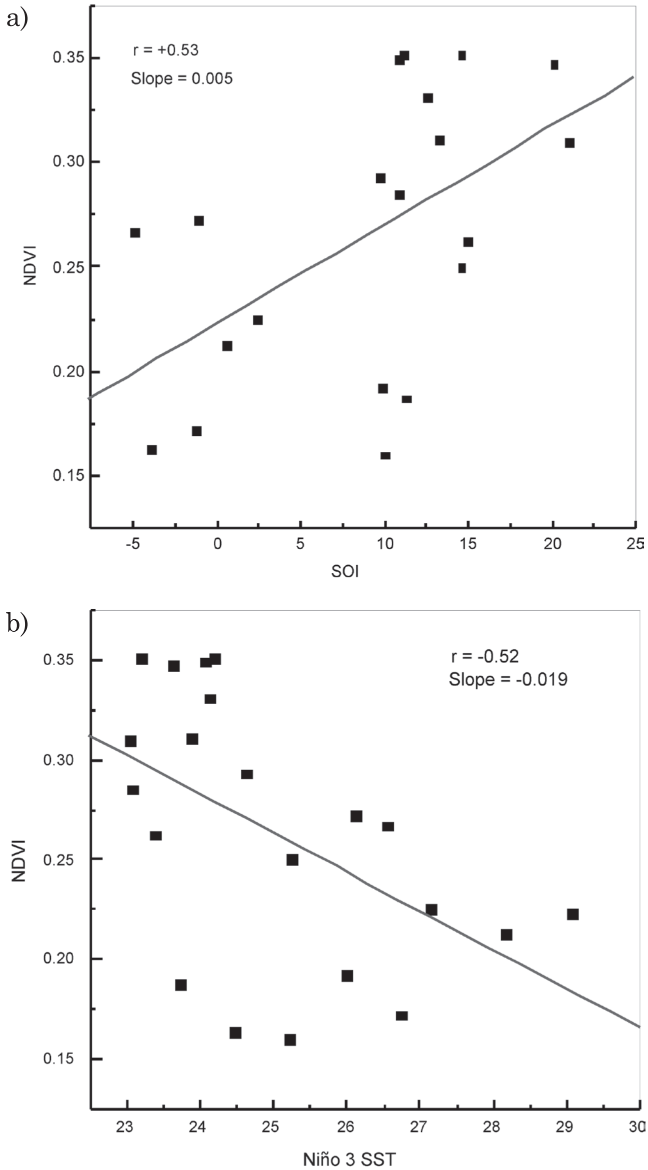

Figure 10. Same as Fig. 8 except in La Niña years (1988 and 1998).

years. This overall correlation analysis of the present study inferred that the vegetation has stronger correlation with Niño 3 SST than SOI. This is also to be noted here that the correlation of SOI and Niño 3 SST was found as –0.88 with 0.01 level of significance for the period 1982 to 2000. Power et al 2006 reported that the association of SOI and the climate variables is not satisfactory over Australia during twentieth century. It is worth to note the work of Weiss and Weiss (1999) on the „Quantifying persistence in ENSO", where they observed the weaker SOI barrier with less statistical significance than that of Niño 3 SST time series. This may be due to highly varying nature of atmospheric component (SOI) compared to ocean component (Niño 3 SST). It is also to be noted that vegetation over a region does not change rapidly. Hence, the linear relationship of NDVI–SOI may not be stronger as relationship of NDVI–Niño 3 SST.

4. Conclusions

The seasonal variability of NDVI is a replica of the vegetation status and in turn the crop performance and thus it can be used to monitor the vegetal cover over India. The vegetation is high during the south-west monsoon and retreat seasons compared to the remaining two seasons. It is believed that the increased status of NDVI over these seasons is due to the manifestation of *Kharif* and *Rabi* seasons which are the major crop seasons for the country. For example *Kharif* crops are rice, millet, sorghum, maize, sunflower, soybean etc. and *Rabi* crops are wheat, barley, pea etc.

The trend of AINDVI is increasing and displayed higher status in the La Niña whereas it is low during the El Niño events. The relation between rainfall and AINDVI is not strong on monthly basis but it is more prominent when the cumulative annual amounts of rainfall are involved. NDVI responded very well to the variations of soil moisture adequacy which enumerates the strongest relation of crop performance with AINDVI. The correlation analysis of AINDVI and the ENSO indices revealed stronger correlation between vegetation over India and Niño 3 SST than that between vegetation and SOI due to the noisy nature of SOI.

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SAŽETAK

O prostornoj razdiobi normiranog diferencijalnog vegetacijskog indeksa nad Indijom i njegova veza s oborinom, temperaturom zraka, dostatnošću vlažnosti tla i ENSO pojavom

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Promjene prostorne raspodjele normiranog diferencijalnog vegetacijskog indeksa (NDVI) dobivenog na temelju mjerenja radiometrom vrlo visoke rezolucije (AVHRR) proučavane su za različite sezone na području Indije tijekom razdoblja od 1982. do 2000. godine. Promatrana je međugodišnja promjenjivost NDVI-a izračunatog za cijelo područje Indije (AINDVI) te njegova povezanost s oborinom, temperaturom zraka, dostatnošću vlažnosti tla, indeksom Južne oscilacije (SOI) te Niño 3 površinskom temperaturom mora (Niño 3 SST) kako bi se utvrdila povezanost tih varijabli i vegetacijskog pokrova. Rezultati pokazuju da NDVI poprima visoke vrijednosti tijekom sezone jugozapadnih monsuna (od lipnja do rujna) te tijekom prijelazne sezone povlačenja monsuna (listopad i studeni) što se uglavnom podudara sa žetvenim sezonama *Kharif* i *Rabi*. NDVI ima pozitivan trend te poprima više vrijednosti tijekom La Niña, a niže vrijednosti tijekom El Niño događaja. Iako korelacija između mjesečnih vrijednosti oborine i NDVI-a za cijelo područje Indije nije signifikantna (+0,13), ona je značajno veća ukoliko se promatraju kumulativne godišnje vrijednosti oborine (+0,61). Varijabilnost NDVI-a je u skladu s promjenama dostatnosti vlažnosti tla (S_{AD}) što rezultira značajnim koeficijentom korelacije između indeksa NDVI i prinosa usjeva (+0,73). Ova signifikantna i jaka povezanost ukazuje da se S_{AD} može koristiti kao uspješniji pokazatelj promjenjivosti NDVI-a nego sama oborina. Linearna regresija između AINDVI i ENSO indeksa pokazala je da su površinske temperature mora (Niño 3 SST) bolje korelirane s vegetacijskim pokrovom Indije nego indeks SOI.

Ključne riječi: NDVI, međugodišnja varijabilnost, oborina, temperatura zraka, dostatnost vlažnosti tla i ENSO

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