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Temporal and Spatial Analysis of Rainfall and Associated Normalized Difference Vegetation Index (NDVI) over the Pune District, India

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Abstract

Introduction: With increasing population, demands for agricultural products are increasing in tropical
countries like India. However, vegetation cover is decreasing to meet the human requirements. Rainfall through hydrological cycle plays an important role in the vegetation growing cycle. It acts as a determining factor for agriculture and food security. Since agricultural products are monsoon rainfall dependent, it is essential to know the changes in the vegetation cover and trends and its relationship with the climate change. This will be helpful in accurate prediction of vegetation cover and therefore in management of loss and damages to the economy of the country. Therefore, a detailed understanding of the relationship between rainfall variability and vegetation cover is very important.

Method: An attempt has been made in this paper to study the distribution of rainfall over the Pune district (Maharashtra state, India) and its impact on NDVI during 1971-2012. Analysis of data was carried out by programming, ERDAS & GIS technique using Landsat MSS and Resourcesat data and Microsoft Excel functions.

Results: The results indicated that the NDVI values changed in relation to different amount of precipitation showing that about 54% and 13% of area remained barren during 1972 and 2009 drought years respectively.

Conclusion: The NDVI has been used to monitor the response of vegetation cover to rainfall and this showed that vegetation cover has drastically reduced during drought years of1972 and 2009, whereas there is increase in vegetation cover during good rainfall years of 1975 and 2010. The comparative study of rainfall pattern and NDVI will be useful to farmers (agricultural section), engineers (irrigation sector) and water resources management point of view.

INTRODUCTION

In recent years, intensity and frequency of natural disasters, including droughts and floods are increasing significantly because of extreme weather conditions and possible climate changes that have been observed. These phenomena cause significant economic damages and losses. Therefore efforts in understanding the climate impacts on ecosystems are increasing and programs are outlined by different global scientific communities to overcome it. Among the climatic elements the rainfall is the first index, ever thought of by farmers and climate analyzers as it is the most important single factor which determines the development and progress of the society. Climate is one of the most important factors affecting vegetation condition. Therefore, to evaluate the quantitative relationship between vegetation patterns and climate is an important object on regional and global scales. The basic knowledge of the vegetation response to the climatic factors serves as the major inputs in recognition and understanding the areas vulnerable to risk events as well as for effective forecasting and assessment of such risk events. In nature, vegetation cover is more sensitive to any change in the climatic factors viz. encogenic or exogenic, natural or anthropogenic. In addition factors such as geology, soil characteristics, underground water regime, land use etc. of the region also act as the regulatory factors for the vegetation cover. Therefore, the combined effect of these factors explains the vegetation cover and its dynamics of a region particularly in arid/ semi-arid regions. However, the strength of vegetation response to climate factors will also be significantly altered by external forces such as human impact. If the response of vegetation to precipitation remains constant, increase/decrease of vegetation activity will exactly reflect changes in precipitation [1] which is the rule for undisturbed vegetation cover. It means that weaker the response of vegetation to climate more is the degradation of vegetation cover caused by non-climatic factors (e.g. human impact), while a stronger response may indicate an improvement of vegetation conditions. The vegetation data sets of National Oceanic and Atmospheric Administration (NOAA)-Advanced Very High Resolution Radiometer (AVHRR), popularly known as Normalized Difference Vegetation Index (NDVI) are of useful in studying the ground vegetation cover. It serves as an important object in investigation of relation between the vegetation cover and its associated climate factors at regional and global scales [2-4]. Therefore, NDVI can act as a good measure of landscape patterns of primary productivity and can be used as a general substitute for many forms of vegetation cover such as over-ground biomass, leaf area index (LAI), fraction of photosynthetically active radiation (fPAR) etc. [3, 5, 6]. Precipitation, especially in dry areas is one of the major driving forces for vegetation growth and is therefore in general highly correlated with vegetation. To achieve a better understanding of the relationships between precipitation pattern and vegetation dynamics, several studies analysed time series of precipitation data and vegetation indices like NDVI [7-13]. Several studies estimated trends in vegetation cover or monitor land performance and land degradation respectively by analysing relationship between rainfall and vegetation dynamics [10]. Many studies focused different applications of NDVI in studying crop growing periods [14] and drought assessment [15, 16]. In view of the above and considering the close relationship between rainfall and vegetal cover, an attempt has been made in this paper to analyse the relationship between rainfall and NDVI over the Pune district which falls in the semi-arid region of the Maharashtra state, India and having most of the drought prone talukas during 1971-2012.

Study Area

Among the 35 districts of Maharashtra state, Pune is the second largest district in respect of its geographical area 15,642 sq.km, which is about 5% of the total area of the State. It is situated in the western part of the State and lies to the leeward side of the Sahyadri mountain range (viz. Western Ghat), which forms a barrier across the Arabian Sea (Fig. 1).

On the basis of climate variability and varied topographical features (Fig. 2), the entire Maharashtra state has been divided into four meteorological subdivisions and Pune district falls in the Madhya Maharashtra subdivision (Fig. 1). Bhima and Nira are the two main rivers in the district with several major tributaries to their north and south. Topographical and rainfall features, divide the entire district into three distinct rainfall regimes:

Western Zone: 15-30 km strip of Sahyadri mountain area (Western Ghat) (500-1500m a.s.l.) on the west having Lonavala and Khandala, hill stations with thick forest cover, receiving more than 90% of annual rainfall.

Transition Zone: To the east of Western Ghat, another 15-30 km belt of hilly and undulating area (100-500 m a.s.l.) known as "Maval" with moderate forest, receiving 80-90% of annual rainfall.

Eastern Zone: To the east of 'Maval' is the remaining belt of plain region known as Eastern Plateau or 'Desh', receiving 70-80% of annual rainfall.

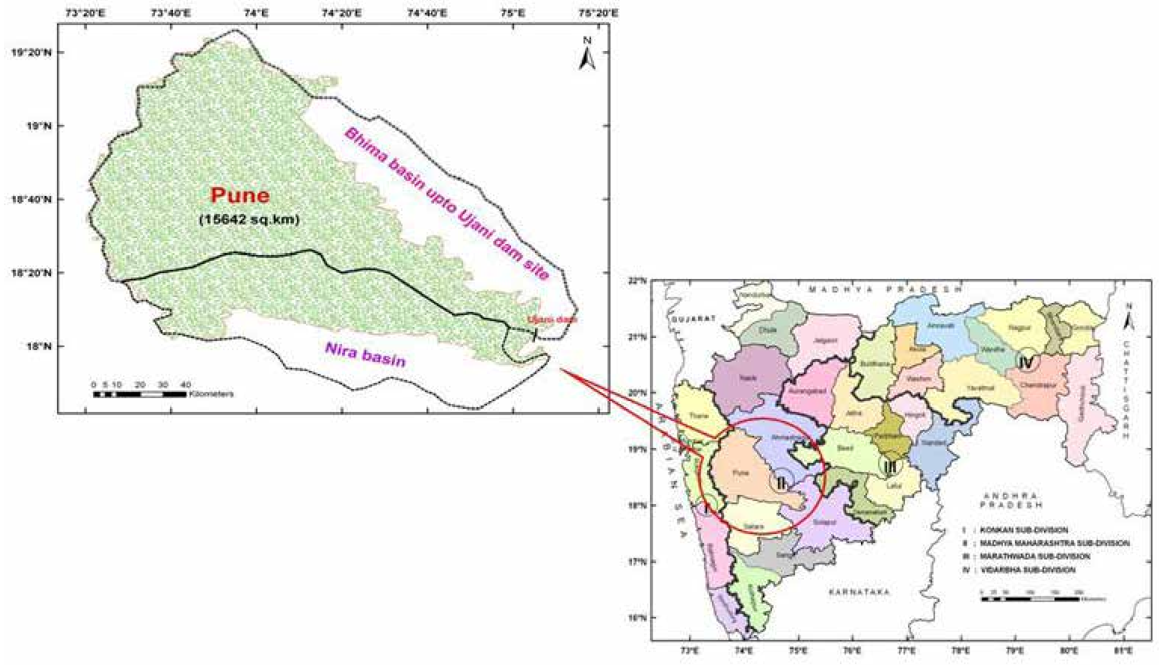

Figure 1: Location Map of Pune district

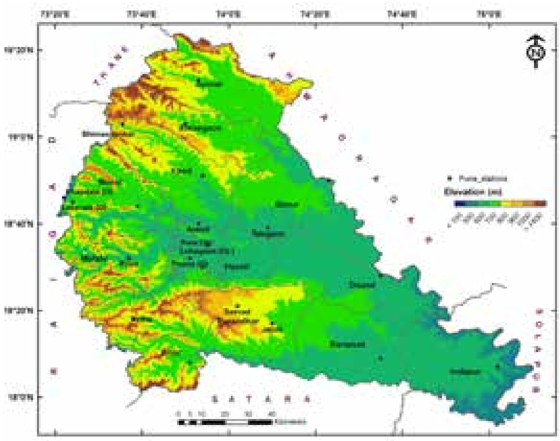

Figure 2: Topography Map of the Pune District with Rainfall Stations

Considering its geographical location, the climate of the district is broadly described as tropical monsoon type. Monsoon sets in over the district by about 10 June and withdraws by about 1st October comprising 113 to 115 days. There is great influence of topography on rainfall distribution reflecting the more rainfall in the wind ward side of the Western Ghat than the leeward side. The southwest or the summer monsoon (Jun-Sept) is the main source of rainfall, providing 80% of the annual rainfall. The average rainfall recorded varies from 500-700 mm (to east) to > 3000 mm (to west). Generally, rainfall decreases from west to east. The temperature over the district ranges between 12°C to 37°C.

Data Used

Daily rainfall data of all the stations (see Fig. 2) inside the district have been procured for 1971 to 2004 from the National Data Centre (NDC), India Meteorological Department (IMD), Pune and from Department of Agriculture, Govt. of Maharashtra for 1998 to 2012. A series of Remote Sense (RS) data was prepared from the available data for the period 1971 to 2012. It was observed that no continuous RS data was available for one computational year. Therefore post monsoon RS data for the years 1972, 1975, 2009 & 2010 were used to make a case study of rainfall and associated vegetation cover in the study region (see Table 1). These selected years were relatively bad and good rainfall years which greatly influenced the rainfall characteristics in the region.

METHODS

Rainfall Analysis

On the basis of all the available daily rainfall data, a homogeneous set of rainfall data was prepared excluding all the outliers. Using this data, mean monthly, seasonal and annual rainfall was calculated for the entire district along with the standard deviation and coefficient of variability for 1971 to 2012.

NDVI Analysis

In the present study geo-referenced Landsat MSS and Resourcesat data were used. Various techniques like staking of different bands, mosaic of different staked MSS & AWiFS images and NDVI process was done using ERDAS image processing software. ARC GIS has been used for digitization, editing and topology creation and Spatial Analysis tool for Integration of thematic layers. A typical spectral image when converted in a typical false colour composite (FCC) image using NIR, the features become very distinct as shown in Fig. 3. In FCC, the vegetation thus appears invariably red (due to high reflection in NIR from green leaves). After processing the multispectral images in ERDAS and GIS, the Final NDVI Image with single banded gray shade was obtained for the Pune district, in which dark toned colour bands (nearly positive DN values) represented vegetation (see Fig. 3). These NDVI images were also compared with the FCC images keeping FCC images below the NDVI images in Arc GIS using the help of null colour property. Calculation of NDVI was done using the following equation (1):

NDVI=(NIR-R)/(NIR+R).........(1)

Where NIR stand for the spectral reflectance measurements acquired in the near-infrared regions (NIR) and visible (red), respectively

Calculations of NDVI for a given pixel always result in a number that ranges from -1 to +1. No green leaves give a value close to zero (i.e. zero vegetation). Close to +1 (~ 0.8 to 0.9) indicates the highest possible density of green leaves (Fig. 4).

Table 1: Data used for NDVI Analysis

	MSS	AWiFS
Bands	4	4
	Selected Years	
Bad RF years	1972	2009
Good RF years	1975	2010
Resolution	30 m	56 m
Projection –	UTM Zone 43	WGS 84
	Path & Row/Toposheet No.	
	158/047	E43B, E43C
	157/047	E43H, E43I,
	157/048	E43J, E43O & E43P
Type of Data	Landsat MSS & Resourcesat AWiFS Imagery of Pune District	
Source	a) United States Geological Survey (USGS) earthexplorer.usgs.govb) NRSC Open EO Data Archives bhuvan-noeda.nrsc.gov.in/	

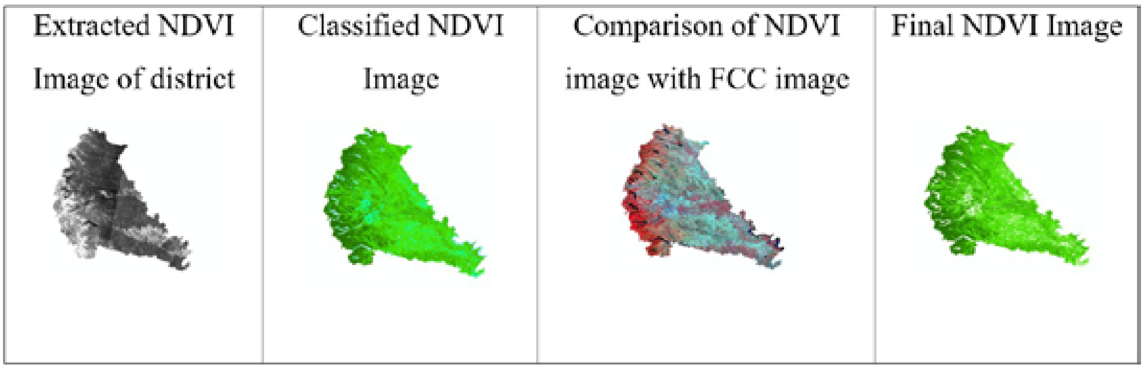

Figure 3: Landsat MSS Map Features for NDVI Analysis

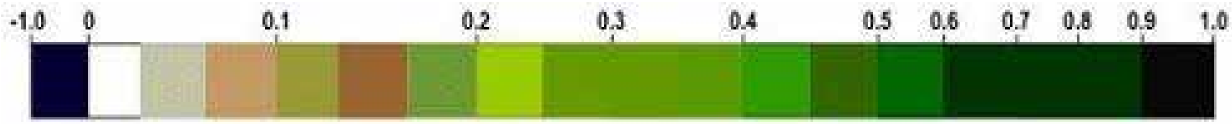

Figure 4: Index Calculation for NDVI Map (Source: http://www.scanex.ru/en/monitoring/default.asp?submenu=farming&id=ndvi)

Table 2: Talukawise Distribution of Average Rainfall and Rainy Days

Talukas	Average Rainfall (mm)		% of Jun-Sept Rainfall with respect to annual	Average Rainy Days		% of Jun-Sept Rainy Days with respect to annual
	Annual	Jun-Sept		Annual	Jun-Sept	
Velhe	2498.0	2362.5	95	96	88	91
Mulshi	1712.6	1573.5	92	90	81	90
Maval	2923.0	2797.9	96	89	82	92
Bhor	1137.9	995.8	88	80	71	89
Junnar	587.6	492.1	84	59	51	87
Ambegaon	824.5	692.3	84	62	55	88
Khed	688.8	552.5	80	76	65	86
Haveli	735.9	603.0	82	83	69	83
Purandar	552.0	431.8	78	44	36	83
Shirur	509.7	392.5	77	39	32	82
Daund	510.9	365.5	72	40	31	78
Baramati	524.3	371.5	71	48	36	75
Indapur	570.4	433.2	76	43	34	79

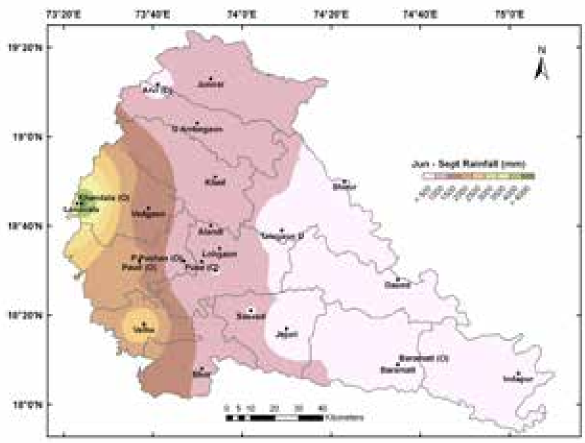

Figure 5: Spatial Distribution of Average Jun-Sept Rainfall (mm) over the Pune District

In the present situation, the images were reclassified into two classes i.e. 0 and 1, where 1 value represents the DN values with vegetation area whereas 0 represents the DN values with non-vegetation area. If an NDVI value varies from 0 to 0.2, it is considered as low vegetation. If the value lies in between 0.2 to 0.4, then the vegetation status is taken as medium and if NDVI is more than 0.4, it can be treated as high vegetation. Negative values of NDVI impart the non-vegetated areas like snow, ice, water, rock etc. (Source: http://metart.fao.org). It is important to note that NDVI images do not distinguish neither between different vegetation types nor between cultivated and natural vegetation. NDVI images help to identify vulnerable areas. In addition, knowledge of the crop calendar and location of growing areas for the different crop types can help to analyze the images and trace vegetation that might be affected by a loss of vegetation potency. However, it is essential to verify findings from the images by field observations or local expert knowledge to assess the intensity of vegetation loss on cultivated land.

RESULTS

Rainfall Variation over the Pune District

The long term mean annual rainfall based on 42 years data (1971-2012) varied from 524 mm over Baramati (O) to 2498 mm over Velhe station so far as plain area is concerned. The two hill stations, Khandala and Lonavala recorded mean annual rainfall of the order of 3736 mm and 4542 mm respectively. The same ratio was observed during monsoon rainfall. Table 2 gives the talukawise distribution of rainfall and rainy days during monsoon months and annual. It is seen from the spatial distribution of average annual and seasonal rainfall (Fig. 5) over the district goes on decreasing from west to east with higher CV during monsoon season than annual rainfall.

Precipitation Ratio

The abnormalities of rainfall at any location may be brought by a simple ratio of precipitation. It is the difference between maximum and minimum rainfall of the annual rainfall series expressed in terms of mean.

$P_R=((P_{Max}-P_{Min})/P_{MAR})*100$ (2)

Where, P_R = Precipitation Ratio

P_{Max} = Maximum mean annual rainfall

P_{Min} = Minimum mean annual rainfall

P_{MAR} = Mean annual rainfall

This ratio may give the stability of rainfall with special relationship. Higher the ratio, higher is the abnormality in rainfall and vice versa [17]. The minimum and maximum precipitation ratios worked out for different decades showed that the maximum abnormality (i.e. 80% to 178%) in annual rainfall was recorded during 2001-2010 decade during which the district as a whole recorded less annual rainfall due to two severe drought years, 2002 and 2009. Even overall rainfall during this decade was comparatively lesser than the other decades. During the monsoon season also 2001-2010 decade recorded high abnormality followed by 1971-1980 decade due to severe 1972 drought year. This clearly shows that during the recent past there is reduction in rainfall over the district which is mostly related with the change in climate which is associated with reduction in rain bearing low pressure systems like depressions, cyclonic storms, etc during this period.

Normalized Difference Vegetation Index (NDVI) Analysis

The most essential element for vegetation growth on the earth is water which is available through rain. There is perfect synchronization between plant growth and the rainy season in many ecosystems, particularly grasslands and cropland. Therefore, rainfall is a most determining factor for agriculture and food security. In these ecosystems, there are poor or no vegetation growth during droughts and more vegetation during normal or excess rain. The ecosystems depending on groundwater, respond very slowly to changes in rainfall. Therefore, a detailed understanding of the relationship between rainfall variability and vegetation cover is essential. As mentioned earlier, NDVI is a standard algorithm designed to estimate the amount of green vegetation cover above the ground from measurements of red and near-infrared reflectance. NDVI can also describe the vegetation density, allowing the farmers to evaluate plant germination, growth and productivity. The principle behind the NDVI is that 'green' leaves absorb radiation at red wavelengths (640-670 nm) due to the presence of chlorophyll pigments whilst scattering radiance at very near infrared wavelengths (700-1100 nm) due to the internal structure of the leaf. In contrast a bare soil surface has higher reflectance at red wavelengths and lower reflectance at near-infrared wavelengths. The NDVI is more widely used because it ranges between -1 (for snow and ice) and +1 (for complete vegetation cover) and may have a more linear relationship with vegetation properties such as biomass or leaf area index (LAI). Thus, NDVI is an effective indicator of the amount of green vegetation present in an area of interest. Values of NDVI vary with absorption of red light by plant chlorophyll and the reflection of infrared radiation by water-filled leaf cells. By calculating index for each space image pixel in red and near-infrared spectrum a derived image – the NDVI map can be obtained (see Fig. 6 & 8). For the green vegetation the red spectrum reflection is always lower than in the near-infrared due to light absorption by chlorophyll. Therefore NDVI values for the vegetation cannot be lower than 0. Periodical droughts can produce serious agricultural, ecological or hydrological imbalance. For the last 2 to 3 successive years the Pune district in Maharashtra experiencing drought conditions which has drastically reduced the agricultural production and affected economic condition. The relationship between vegetation cover and rainfall variability is pronounced in Pune district and therefore, it was investigated by examining differences of correlation between rainfall and NDVI during drought and good monsoon years. From the analysis of rainfall data, and available Landsat MSS & Resourcesat AWiFS Imagery of Pune District the following good and bad rainfall years were selected for NDVI analysis (Refer to Section 4.2) of the Pune district as a case study i.e. a) 1972 (drought year) and 1975 (good year) b) 2009 (severe drought year) and 2010 (good rainfall).

The calculated vegetation and non-vegetation area along with the average rainfall over the area during the two cases are given in Table 3. Actual vegetation and non- vegetation cover has been shown in Fig. 6 (a & b) and Figs.8 (a & b) with rainfall distribution (Fig. 7 (a & b) & 9 (a & b)) for 1972 and 1975 and for 2009 and 2010 respectively by way of comparison. It is seen from these figures that vegetation has drastically reduced during drought years of 1972 and 2009, whereas there is increase in vegetation during good rainfall years of 1975 and 2010.

Table 4: Vegetation and Non-Vegetation Area during a) 1972 & 1975, b) 2009 & 2010

Selected Years	Total Area (Sq. Km)	Average Rainfall (mm)	Area under Vegetation (Sq. Km)	Remaining Land Use (Sq. Km)
1972	15591.83	702.6	7217.14 (46.3%)	8374.68 (53.7%)
1975	15591.83	1189.5	13959.51 (89.5%)	1632.19 (10.5%)
2009	15592.20	707.6	5375.93 (34.5%)	10216.07 (65.5%)
2010	15592.20	849.8	11088.76 (71.1%)	4503.32 (28.9%)

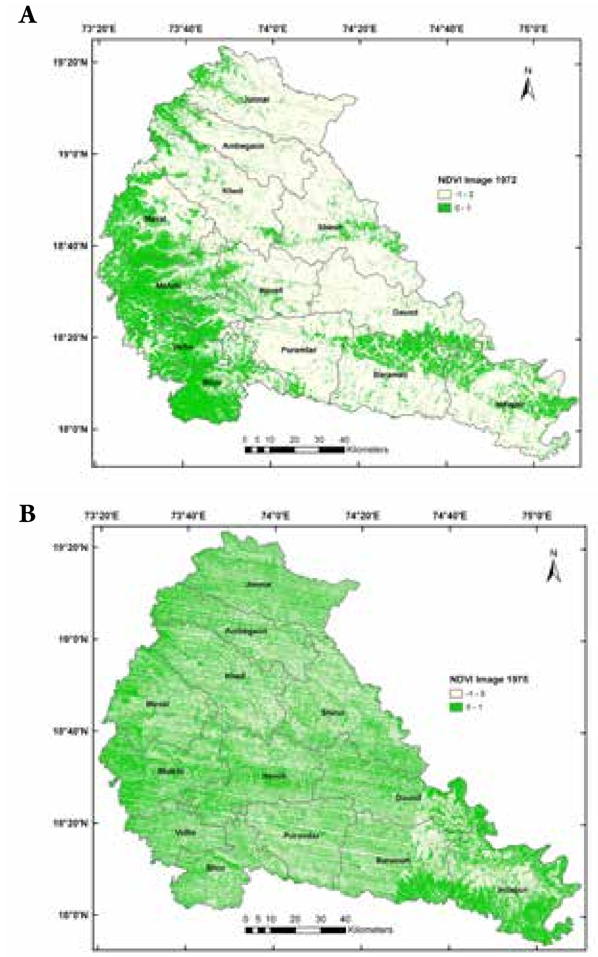

Figure 6: a) NDVI Image for Drought Year of 1972, b) NDVI Image for Good Rainfall Year of 1975

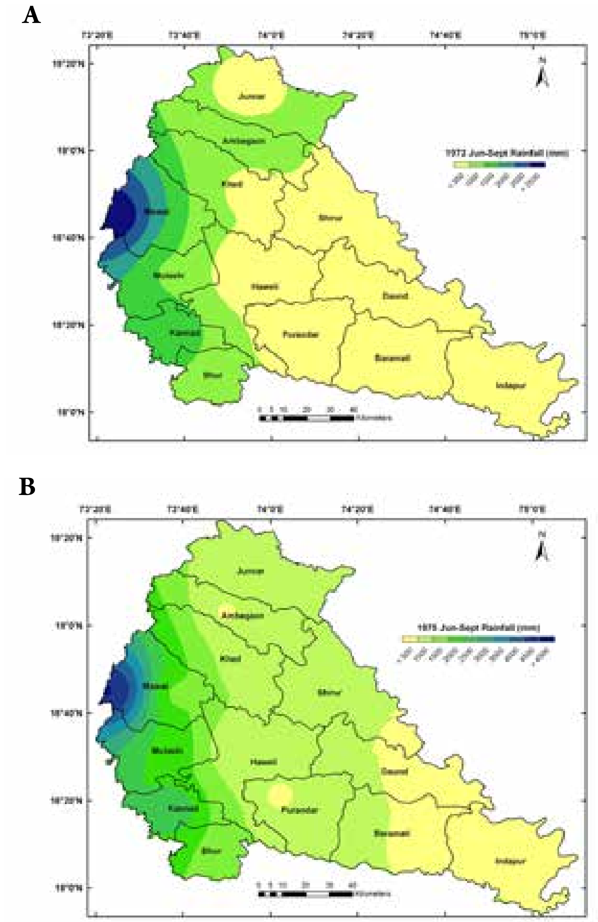

Figure 7: a) Jun-Sept Rainfall (mm) Distribution for Drought Year of 1972, b) Jun-Sept Rainfall (mm) Distribution for Good Rainfall Year of 1975

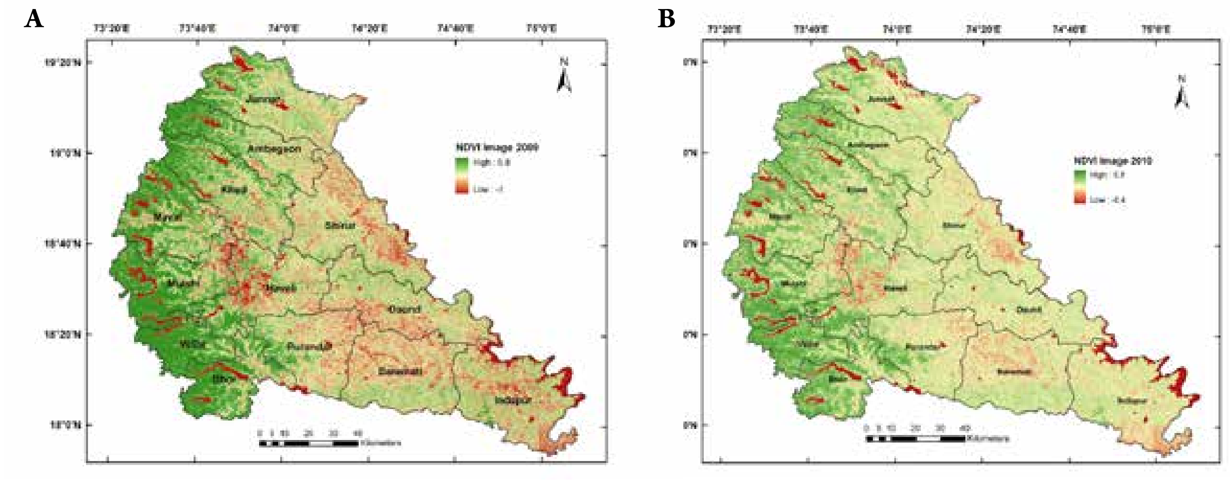

Figure 8: a): NDVI Image for Drought Year of 2009, b): NDVI Image for Drought Year of 2010

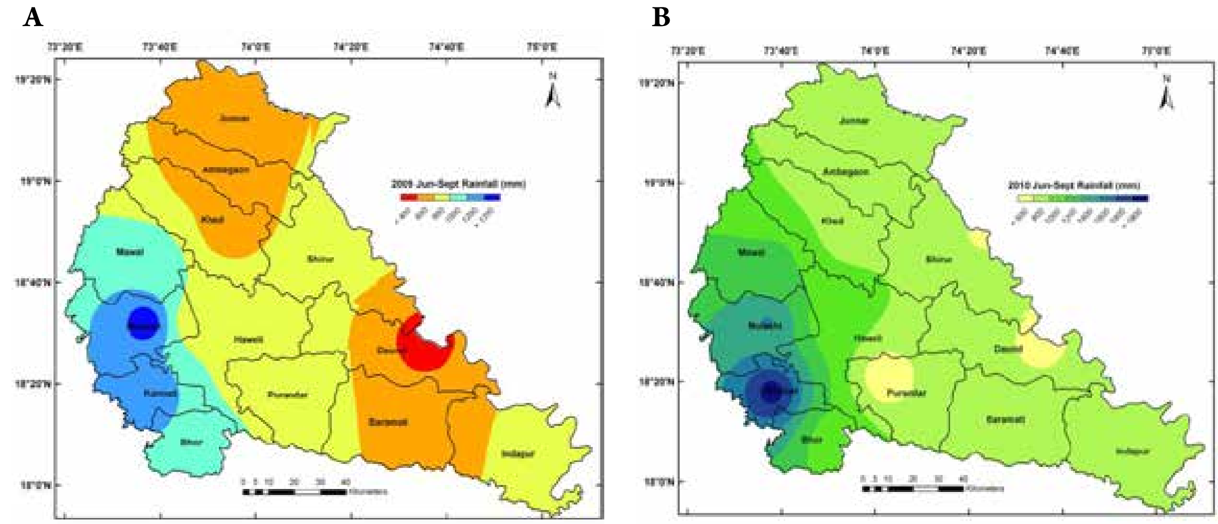

Figure 9: a): Jun-Sept Rainfall (mm) distribution for drought year of 2009 b): Jun-Sept Rainfall (mm) distribution for good rainfall year of 2010

DISCUSSION

Many studies have used NDVI to monitor the response of vegetation to climatic fluctuations. Several global and regional studies have previously investigated the relationship between NDVI and rainfall in different parts of the world. Generally, the results indicate a relationship between the two aforementioned variables [18, 19]. Temporal variations of NDVI are closely related to precipitation and there is a strong linear [20] or log-linear [21] relationship between NDVI and precipitation in cases where monthly or annual precipitation is within a certain range (500-1,000 mm/year). The relationship between NDVI and rainfall regionally varies due to variation in properties such as vegetation type and soil background [22, 23]. Spatial correlations between NDVI and climatic factors are investigated in many research works particularly in the arid regions [7, 8, 23-26]. However, [27] showed that there are many cases indicated non-stability of this relationship in space. 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 Studies on the inter-annual variability of All India NDVI (AINDVI) and its relationship with rainfall, temperature, soil moisture adequacy, Southern Oscillation Index (SOI) and Nino 3 Sea Surface Temperature (Nino 3 SST) were carried out to understand the influence of these variables on vegetal cover [17, 28]. Their results showed that the NDVI is high during the south-west (June to September) monsoon and retreat (October and November) seasons wherein major crop seasons Kharif and Rabbi take place over India. The results obtained from the above studies are also supported by the rainfall-NDVI analysis over the Pune district of Maharashtra state in India. The district experienced three severe drought years viz. 2002, 2009, and 2012 during 2001 to 2012 period. The arid to semi-arid regions of the district especially Junnar, Ambegaon, Khed, Daund, Baramati talukas highly showed close relationship between the quantity of rainfall received and vegetation cover. A linear regression analysis was carried out and Pearson Correlation applied to Jun-Sept rainfall and NDVI also showed a poor relationship between rainfall received during the monsoon months and NDVI. The results also show how much land area got affected due to drought condition. There is consistent variation in the NDVI values and the rainfall received during the monsoon months. This is mostly because of frequent drought conditions, high irrigation extraction from the ground leading to severe water scarcity for drinking and agricultural production also.

CONCLUSIONS

Many semi-arid and semi humid areas are characterised by high rainfall variability. To achieve a better understanding of the relationships between precipitation pattern and vegetation dynamics, several studies analysed time series of precipitation data and vegetation indices like Normalized Difference Vegetation Index (NDVI). In the present study of rainfall pattern over the Pune district showed that there is decrease in rainfall during the past 12 years resulting into sequential droughts in many villages of the district. The scarcity of water has caused death of human and cattle lives, reduced agricultural production which in turn affected economic status of the district. The NDVI has been used to monitor the response of vegetation cover to rainfall and this showed that vegetation cover has drastically reduced during drought years of 1972 and 2009, whereas there is increase in vegetation cover during good rainfall years of 1975 and 2010. The comparative study of rainfall pattern and NDVI will be useful to farmers (agricultural sector), engineers (irrigation sector) and water resources management point of view.

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AUTHORS' CONTRIBUTION

The concept of the study, literature review, accumulation of rainfall and RS data, analysis and interpretation of results, drafting of the manuscript and its critical revision was performed by the authors.

CONFLICTS OF INTEREST

There is no conflict of interest.

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