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ORIGINAL ARTICLE

Analyzing the extent of drought in the Rajasthan state of India using vegetation condition index and standardized precipitation index

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Abstract

Drought is the most complex but least understood of all natural hazards that impacts around 55 million people globally every year. A hydrological drought (drought here after) is when the lack of rainfall goes on long enough to empty rivers and lower water tables and causes severe water shortage. In recent years, Geographic Information System (GIS) and remote sensing (RS) have played a crucial role in studying different hazards either natural or man-made. This study stresses upon the use of RS technique for drought risk assessment in Rajasthan state of India for the year 2002 and 2019. In this study, an effort has been made to analyze the extent of drought using two drought indices, namely vegetation-based vegetation condition index (VCI) and meteorology-based standardized precipitation index (SPI). For VCI calculation, which indicates impact of soil moisture on vegetation, we used moderate resolution imaging spectroradiometer (MODIS), Normalized difference vegetation index (NDVI) data from year 2000 to 2019. Monthly SPI was calculated using rainfall data obtained from the Rajasthan water resource department. SPI values were interpolated to get the spatial pattern of meteorological drought. Whole area categorised into five drought classes including extreme drought, severe drought, moderate drought, mild drought and no drought, following the recommended value breaks. The results revealed that about 83.87% area was under drought in the year 2002 thus considered as drought year. It has also been calculated that only 15.62% area was showing drought condition in year 2019 especially in the western part of Rajasthan. Correlation analysis performed between VCI and SPI resulted in a coefficient of correlation of 0.92 and 0.79 in year 2002 and 2019, respectively. The high correlation endorses the reliability of RS data for drought-related analysis.

Keywords Drought · Vegetation condition index (VCI) · Standardize precipitation index (SPI) · Moderate resolution imaging spectroradiometer (MODIS) · Normalized difference vegetation index (NDVI)

Introduction

Drought can be described as significant shortage of water to meet the need of human activities, growth of vegetation and environment (Belal 2014; Matin et al. 2019). Drought is a natural hazard results from a deficiency of precipitation from expected precipitation or normal that extend over a season and a longer period of time. Precipitation is one of the important governing factors for drought including other factors like high land surface temperature, high evaporation and high evapotranspiration (Mala et al. 2014). Drought is a least understood insidious natural hazard having long-term impacts and wide spread (Hangman 1984). Due to insufficient rainfall or precipitation that causes decline in soil moisture available for crop growth and impacts productivity and finally creates drought-like condition. So, it is utmost important to assess and analyze drought as a time period study (Rathore 2009).

Broadly, drought can be categorized into four types: meteorological drought, agricultural drought, hydrological drought and socioeconomical drought (Rathore 2009). Meteorological drought is also known as climatological drought and depends on rainfall deficit from natural mean over a region for a certain period of time. Meteorological drought is recognized based on rainfall data, if precipitation under the threshold, it causes climatological deficiency results in meteorological drought (Panu and Sharma 2002). Agricultural

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drought is termed in relations with yield disaster and occurs when moisture is exhausted so that crop yield is condensed significantly (Wilhite 2000). Hydrological drought is a condition when the water level in natural sources of water falls below than average statistical level due deficiency of rainfall for a longer span. Socioeconomic explanations of drought subordinate the stream and request of some financial good with essentials of meteorological, hydrological, and agricultural drought (Linsley 1975). It varies from the other types of drought in that its existence rest on the progressions of supply and request.

Remote sensing is a promising technique to acquire and allocate information promptly over large extent through sensors attached on an aerial vehicle or satellite (Matin and Behera 2017). Various indices can be developed using different pixel values obtained from the satellite imagery. Immensity and duration of drought can be identified with the availability of consistent repetitive coverage of satellite data of a week temporal resolution (Thiruvengadachari and Gopalkrishna 1993). A recent successor to advance very high-resolution radiometer (AVHRR) is the moderate-resolution imaging spectrometer (MODIS); an advanced narrowband-width sensor, from which composited reflectance data are made available at no cost every 8 days by NASA and USGS, through the Earth Resources Observation Systems (EROS) data center (Justice and Townshend 2002). Meteorological details from ground locations always possess reliable accuracy, but the distribution of ground station is not sufficient for spatial details detection, though remote sensing and GIS act as a strong alternative (Brown et al. 2008). Indices like, normalized difference vegetation index (NDVI) and vegetation condition index (VCI), are adopted worldwide for determination of drought conditions in various regions (Seiler et al. 2000), and have global acceptability.

In this study, we attempted to map the extent of drought using two drought indices, namely vegetation-based vegetation condition index (VCI) and meteorology-based standardized precipitation index (SPI). Correlation between these two indices were also conducted.

Study area

The present study is conducted to check the extent drought condition using remote sensing data in Rajasthan state of India, lies between 23°30′ 30°11′ N latitude and 69°29′ 78°17′ E longitude (Fig. 1), having a total geographic area of 3, 42,239 Km^2 which is 10.4% of total land area of India. According to census 2011, population of Rajasthan is 68 million, 75% of which lives in rural area having dependency on rainfall for farming.

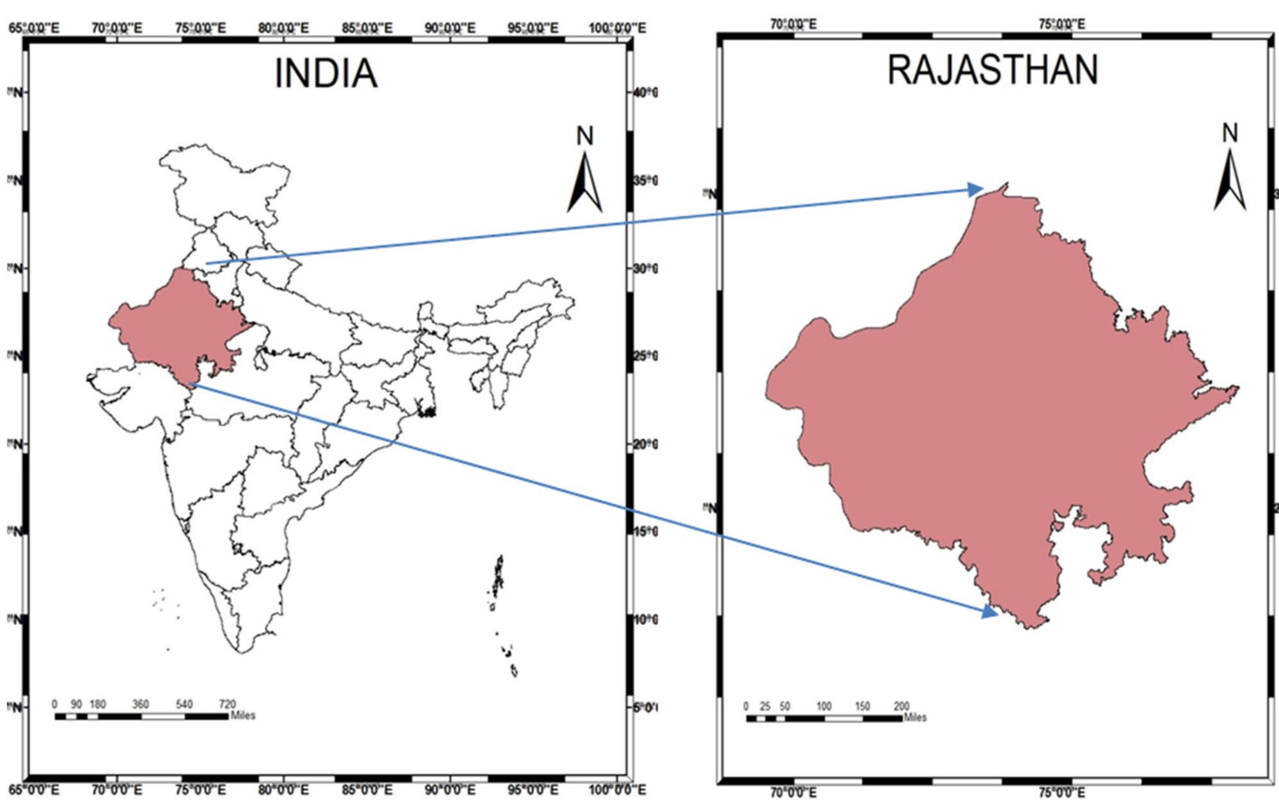


Fig. 1 Location map of Rajasthan, India

Geographically, Rajasthan is divided into four regions: (1) Western Rajasthan, which is covered with dessert and barren hills. (2) Northeastern Rajasthan is covered with rocky and sandy plains. (3) Central Rajasthan is majorly occupied by Aravalli hills which ranges from northeast to southwest and (4) Southeastern Rajasthan which is predominantly a plateau.

Rajasthan is the driest state of India as it has low and unpredictable precipitation, with inconsistence monsoon and rainfall causing frequent droughts. Climate of the state varies from arid in west and semiarid to sub-humid in southeast. Rajasthan receives total 574 mm average yearly rainfall. Distribution of rainfall is uneven in whole state and varies from 100 to 550 mm where Jaisalmer receives 100 mm rainfall and Ajmer receives 540 mm, Mount Abu receives 1638 mm rainfall which is the highest in whole state. Aravalli is among the oldest mountain ranges varies from southwest to northeast of the Rajasthan having total length of more than 550 km that highly effects the climatic and physiographic pattern of Rajasthan. Eastern Rajasthan gets optimum rainfall because Arabian branch of monsoon strikes directly the eastern slope of Aravalli and western Rajasthan is mostly dry. The northwestern Aravalli has desert or semi-desert conditions and southeastern area of Aravalli have fertile soil, humid climate and green vegetation. Northwest part of Rajasthan is covered by unique desert ecosystem which is known as Thar Desert which possesses a large variation in temperature during summer and winter season. Kharif and Rabi are two major crop seasons in the state that extends from June to October, whereas Rabi crops are sown in October and harvested in March–April. Among these, Kharif crops are majorly dependent on rainfall.

Method

Various vegetation indices were considered in this study to understand the basic terminology, scientific aspects and how the indcies are related to evaluate drought conditions.

Normalized difference vegetation index

Vegetation indices are one of the most common and widely studied remote sensing products which use transformation of electromagnetic spectrum reflected from the Earth's surface to the satellite sensors. Normalized difference vegetation index (NDVI) quantifies vegetation by measuring the difference between near infrared and red band (Tucker 1979). Red band is highly absorbed by vegetation, and near infrared is highly reflected by vegetation (https://gisgeography.com/ndvi-normalized-difference-vegetation-index/). NDVI is measured by the following equation, and ranges from − 1 to + 1.

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

(Source: Tucker 1979).

Where NIR shows reflectance in near infrared band RED shows reflectance in red band.

Vegetation condition index

Vegetation condition index (VCI) was developed by Kogan (1995) to study drought conditions. It shows the variation of present years NDVI index with minimum value of NDVI index which is obtained from historical data, as percentage change. It tells about the effect of drought on vegetation conditions, and it compares the effect of current year with the historic values. VCI indicates that how the NDVI of present months is near to the minimum value of NDVI which is obtained from previous years' data. The methodology of calculation of VCI is expressed by the following equation:

$$\text{VCI} = \frac{(\text{NDVI}i - \text{NDVImin})}{(\text{NDVImax} - \text{NDVImin})} \times 100 \tag{2}$$

(Source: Kogan 1995).

where NDVIi is NDVI of the year for which VCI is to be calculated.

NDVImin is the minimum NDVI obtained from historical data of few years.

NDVImax is the maximum NDVI obtained from historic data of few years.

On the basis of VCI values, the drought is classified into five different classes (Kogan 1995).

Low values of VCI indicate that current years NDVI is near to the minimum NDVI value obtained from long-term historical data. VCI value near to zero indicates that NDVI of current year is the minimum value of NDVI obtained from long-term historical values which indicate very dry condition or poor vegetation conditions. VCI is considered suitable for monitoring agricultural drought in different areas with changing ecological conditions. 100% VCI value shows that current years NDVI is the maximum value of NDVI obtained from long-term historical values. VCI values less than 50% shows dry conditions or we can say that area is subjected to some kind of drought, and VCI values near to 50% shows normal vegetation conditions, if values are very high that indicate the condition of vegetation is healthy and the area is wet (Kogan 1995). Thus, a low VCI value indicates drought conditions and as it increases the conditions are said to be improving as shown in Table 1.

Table 1 Relation between drought class and VCI (Source: Kogan 1995)

S.no	Drought class	Range of VCI
1	Extreme drought	0–10
2	Severe drought	10–20
3	Moderate drought	20–30
4	Mild drought	30–40
5	No drought	40–100

Table 2 Classification of drought classes according to SPI values (Source: http://drought.unl.edu/monitor/spi)

S. No	Drought classes	Range of SPI
1	Extreme drought	< − 2
2	Severe drought	− 1.99 to − 1.5
3	Moderate drought	− 1.49 to − 1.0
4	Mild drought	− 0.99 to 0.99
5	No drought	> 1

Standardize precipitation index

Standardize precipitation index (SPI) is a meteorological drought index used to study drought conditions. It is obtained by accumulated rainfall data of a long time-series and determines the number of standard deviation from the average climatological data. This index shows the effect of inadequate precipitation on spread of drought. SPI simply measures the precipitation deficit in non-monsoon and monsoon interval of the year. SPI is computed using the following equation.

$$\mathrm{SPI} = \frac{(Xij - Xim)}{\sigma} \tag{3}$$

where Xij is the rainfall of the year for which SPI is to calculate and Xim is the mean rainfall obtained from historical data of few years.

Negative values of SPI indicate drought condition, and positive values of SPI indicate normal, and higher values of SPI indicate wet condition. The drought is classified into different classes on the basis of the SPI value as shown in Table 2.

Data acquisition

MODIS NDVI (MOD13A) vegetation index product was used in the present study which is available at 16-day interval. MODIS vegetation index products are available at 250 m, 500 m and 1000 m spatial resolution. In this study, MODIS NDVI product for 20 years from 2000 to 2019 of Rajasthan state having 1 km spatial resolution was used. Rainfall data of Rajasthan from year 2000 to 2019 is used in the study acquired from Rajasthan water resource department. Daily, monthly, and annual rainfall data is available on the state water portal at www.water.rajasthangov.in.

Methodology

Parameters like vegetation stress, reduced precipitation, decline in soil moisture, and increasing land surface temperature can be analyzed by means of various indices using remote sensing data. With the advancement of remote sensing and GIS techniques, multi-date satellite images with specific resolution, and channels area available that can be used to derive the indices which indicate the conditions of the parameters related to drought. In this study, various indices like NDVI, VCI and SPI were used, and correlation was done to observe the reliability of satellite-based information to assess drought condition in the Rajasthan state of India.

For the analysis, 20 years MODIS 16-day averaged composite of NDVI data from 2000 to 2019 were used. NDVI product of MODIS (MOD13A) is available free of cost on United States Geological Survey (USGS) (www.lapdacappearsusgs.gov.in) website. NDVI product was processed in ArcGIS software to calculate final VCI. This VCI product was masked with the study area shapefile of the Rajasthan and classified into five drought classes (Table 1). All the drought classes were indicated using different color ramp for better spatial analysis. Classified VCI data were then exported in the form of VCI maps. Variation of VCI shows variation of vegetation condition of particular year in the form of NDVI of particular year with respect to minimum NDVI of all 20 years. To validate the results, ground data-based meteorological drought index, i.e., SPI was calculated. Monthly SPI of 32 ground station has been calculated from the data obtained from the Rajasthan water resource department. The methodology is explained by the flow diagram as shown in Fig. 2.

Results and discussion

VCI value is calculated in percentage varying from 1 to 100%. The resulted images of VCI were classified on the basis of drought severity classification proposed by Kogan (1995), (Table 2). In VCI map, extreme drought is marked

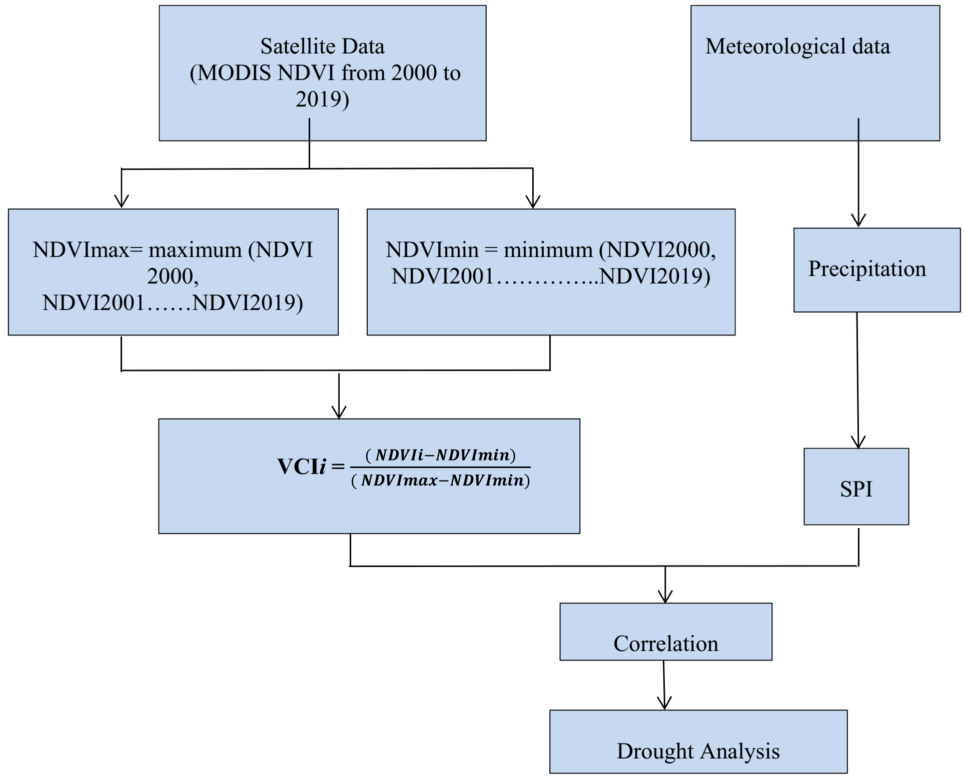


Fig. 2 Flow diagram of the methodology adopted

by red color, and no drought is marked by green color. Usually, monsoon period is studied for drought assessment and in India monsoon period ranges from month of June to September.

Analysis of VCI maps of year 2002

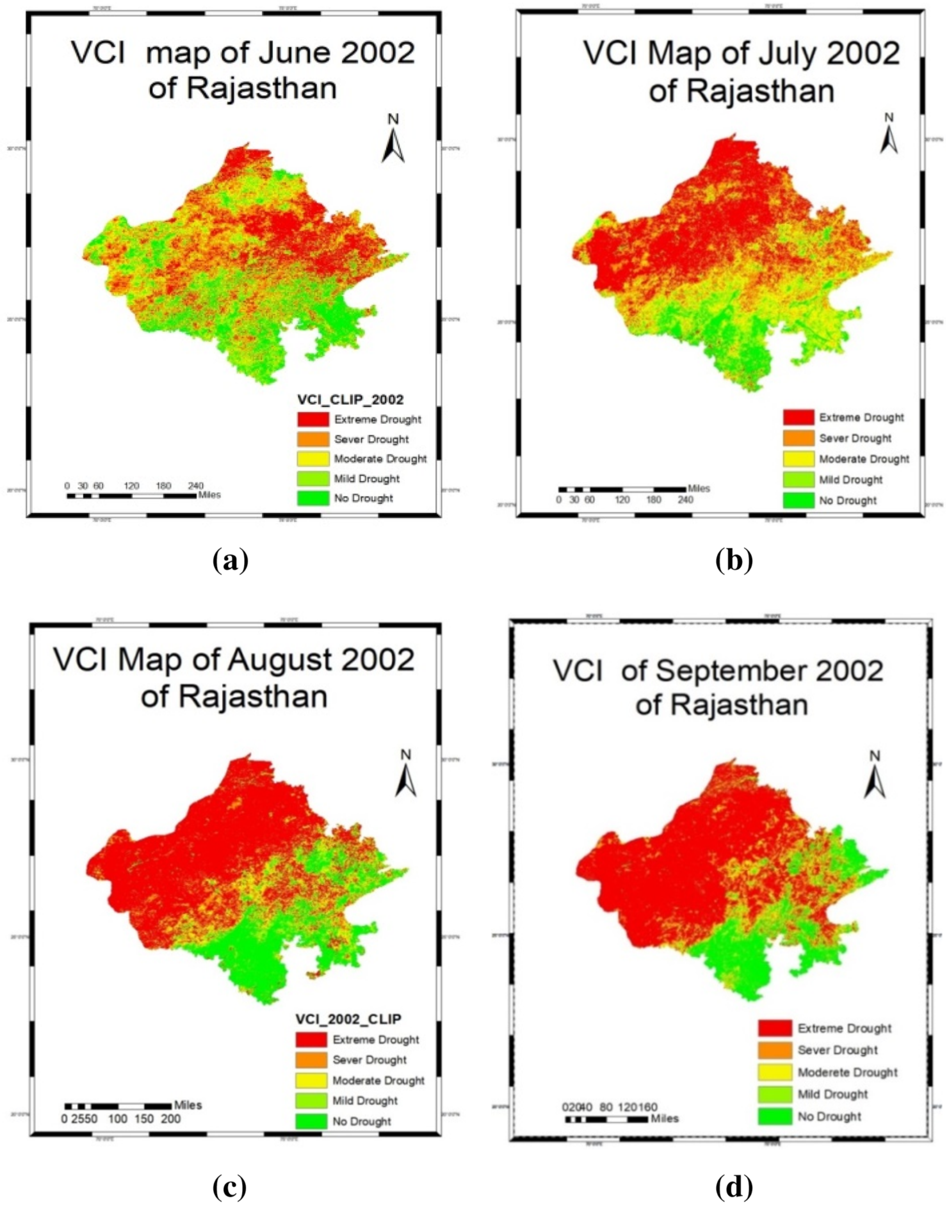
By studying VCI map of the year 2002 from month of June to September, it was observed that in June 2002 the north-east part of Rajasthan was under extreme drought as shown in Fig. 3a. It was observed that 84.14% of the total area was under drought, and 23.04% area was under extreme drought. In June 2002, 15.85% area was not showing any impact of drought in the central and south part of the state and marked green on the map. It has been calculated that 91.66% area was under drought in July 2002, and 36.7% area was under extreme drought condition (Fig. 3b). In July 2002, 8.33% area was found free from drought and marked green on map. Because of the rainfall in south part of the state in the month of August, overall drought area was reduced to 81.42% but area under extreme drought further increased to 54.55% (Fig. 3c). In September 2002, 83.87% area was found to be under drought, 59.31% area was found to be under extreme drought condition. In September 2002, only 16% area was not effected from any form of drought and that is south part of the state as shown in Fig. 3d.

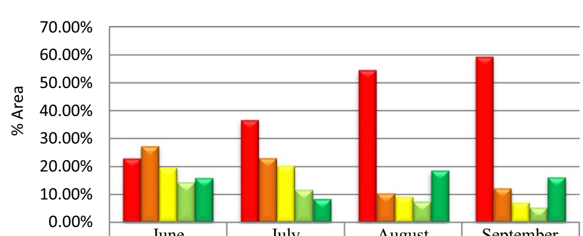
Statistical analysis of area under various drought classes in 2002 according to VCI maps is shown in Fig. 4. Overall analysis of VCI map shows that more than 80% area was found to be under drought in monsoon period, but the area under extreme drought condition having increased from 23.04 to 59.31% in successive months of June which means overall condition of vegetation declined in the region.

Analysis of VCI maps of year 2019

By studying VCI map of the year 2019 from the month of June to September, it has been observed that in June 2019, 56.15% area was under drought condition, and 6.18% area was found showing extreme drought which was marked red on the map, while 43.84% area was free from drought and marked green on the map (Fig. 5a). It was observed that for the month of July 2019, 58.20% area was under drought condition, whereas extreme drought class was increased to 18.33% which is marked red on the map, while 41.79% area was not showing any impact of drought (Fig. 5b). Because of the ample rainfall, 'No drought' class has been increased to 69.30% in August 2019, while area under drought has been decreased to 30.69%, and 8.08% area experiences extreme drought condition and marked red on the map (Fig. 5c). In September 2019, area under drought was reduced to half of previous month that is 15.62% and 4.28% area was under extreme drought condition and that was in western part of the state, while 84.37% area was under no drought condition as shown in Fig. 5d. The above discussed data is briefly showed in Fig. 6.

Fig. 3 VCI maps of year 2002 of **a** June **b** July **c** August **d** September





	June	July	August	September
extreme drought	23.04%	36.70%	54.55%	59.31%
severe drought	27.22%	23.07%	10.32%	12.17%
moderate drought	19.54%	20.23%	9.06%	7.13%
mild drought	14.32%	11.65%	7.48%	5.24%
no drought	15.85%	8.33%	18.57%	16.12%

Fig. 4 Bar chart showing percentage areas under various drought classes in 2002

Statistical analysis of area under various drought classes in 2019 according to VCI maps is shown in Fig. 6. Overall analysis of VCI map shows that the area under drought condition has reduced from 56.15 to 15.62% in the monsoon period of year 2019, and area under no drought condition has increased to 84.37% in the end of the monsoon period which shows an overall improvement in the vegetation condition in the region.

Relation between remote sensing VCI and ground data-based SPI

Relation between remote sensing and GIS-based drought index VCI and meteorological drought index SPI is analyzed. For a comparative analysis of drought indicated by

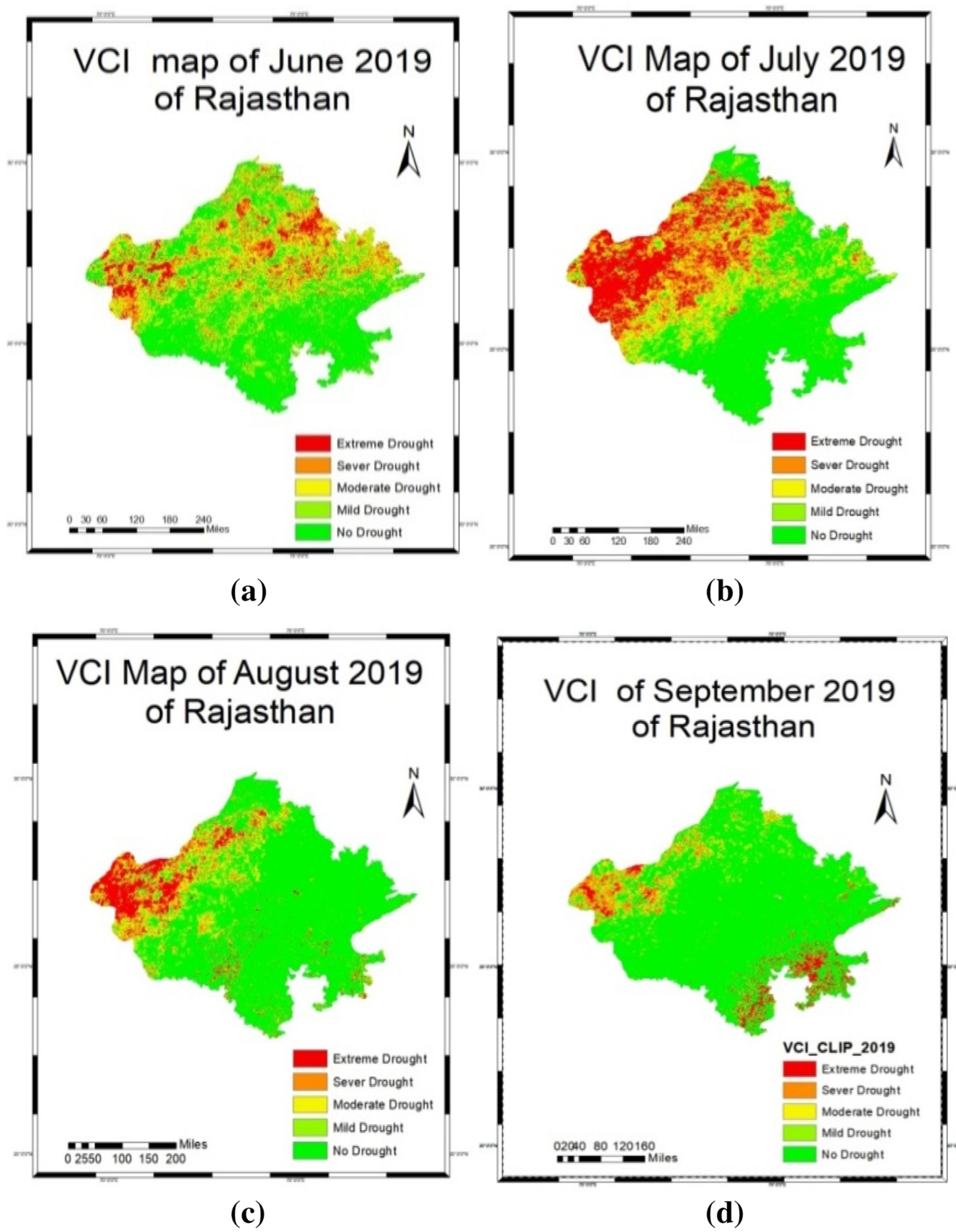


Fig. 5 VCI maps of year 2019 of **a** June **b** July **c** August **d** September

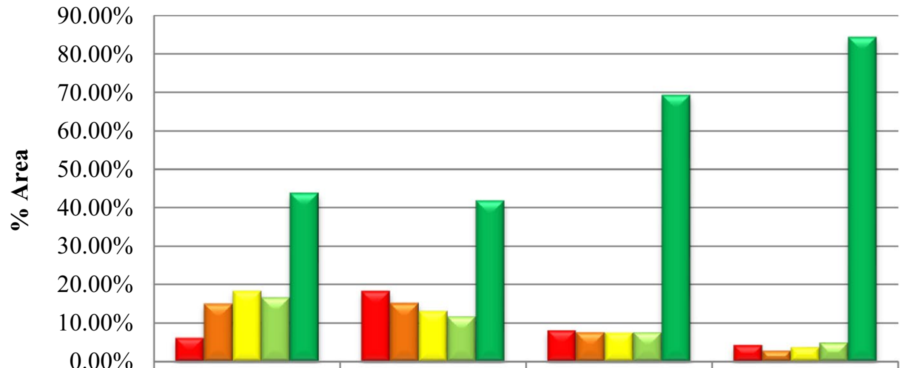
SPI and VCI, 32 ground stations were selected over the state, and values of SPI and VCI of month of September over these stations are shown in Table 3.

Values of SPI of September 2002 and VCI of September 2002 for 32 stations are shown in Table 3. These values are plotted on the graph, as shown in Fig. 7.

The VCI values were observed less than 40 for all the stations except Banswara and Udaipur which is in the southern part of the Rajasthan, which indicates the existence of drought condition in the region. The SPI values are negative for maximum stations which also shows extreme drought conditions over the area, and SPI values are positive for only Banswara and Udaipur which found free from drought. Results obtained from both SPI and VCI found following the similar trends which conforms that Rajasthan experienced extreme drought in the year 2002.

Graph of VCI and SPI reflects same pattern as shown in Fig. 7. Correlation coefficient between VCI and SPI was 0.92, which shows that results obtained by satellite imagery are reliable. VCI and SPI of September 2019 for 32 stations are shown in Table 3. These values were plotted on the graph (Fig. 8), showing the variation of SPI and VCI for the year 2019.

VCI values were found greater than 50 for 30 stations and most of them were greater than 60 which indicates wet condition over the area except some part of Jaisalmer and Bikaner district situated at western part of Rajasthan. VCI value was observed low for Jaisalmer and Bikaner



	june	july	august	september
extreme drought	6.18%	18.33%	8.08%	4.28%
severe drought	15.00%	15.17%	7.54%	2.76%
moderate drought	18.35%	13.05%	7.47%	3.71%
mild drought	16.60%	11.63%	7.59%	4.85%
no drought	43.84%	41.79%	69.30%	84.37%

Fig. 6 Bar chart showing percentage areas under various drought classes in 2019

Table 3 Values of SPI and VCI of year 2002 and 2019 over 32 stations of Rajasthan

Stations	District	SPI 2002	VCI 2002	SPI 2019	VCI 2019
1	AJMER	– 1.5	25.05	3.2	100
2	ALWAR	– 1.58	23	1.62	49.69
3	BANSWARA	0.95	60	1.6	34.43
4	BARAN	– 1.33	29.60	0.51	10
5	BARMER	– 2	10	0.15	70.99
6	BHARATPUR	– 1.37	28.9	0.67	9.96
7	BHILWARA	– 1.48	28	2.5	100
8	BIKANER	– 1.72	8.21	– 0.5	14.19
9	BUNDI	– 1.88	5	1.55	70.35
10	CHITTORGARH	– 1.81	5.5	1.49	71.53
11	CHURU	– 1.85	4	1.32	65.86
12	DAUSA	– 2.04	2.41	1.95	85.27
13	DHOLPUR	– 1.58	23	2.4	95.35
14	DUNGARPUR	– 1.5	24	2.5	100
15	GANGANAGAR	– 1.59	21.36	0.90	84.58
16	HANUMANGARH	– 1.92	2	0.75	53.67
17	JAIPUR	– 2.35	0.13	2	90.32
18	JAISALMER	– 2.18	2.33	– 0.67	25.56
19	JALORE	– 1.77	7.32	2.34	87.57
20	JHALAWAR	– 1.4	22.6	1.35	47.06
21	JHUNJHUNU	– 1.97	1.67	1.67	86.11
22	JODHPUR	– 1.65	20.83	1.2	62.22
23	KOTA	– 1.96	3.05	2.25	94.27
24	NAGAUR	– 1.48	13	2.45	94.14
25	PALI	– 1.49	12	2.1	85.90
26	RAJSAMAND	– 1.71	9	2.2	83.50
27	SAWAIMADHOPUR	– 1.95	1.56	2.45	100
28	SIKAR	– 1.61	19.17	1.34	68.60
29	SIROHI	– 1.9	0.75	1.67	95.55
30	TONK	– 1.85	4	2.34	84.50
31	KAROLI	– 1.59	21.53	2.24	86.63
32	UDAIPUR	1.55	70	1.85	62.98

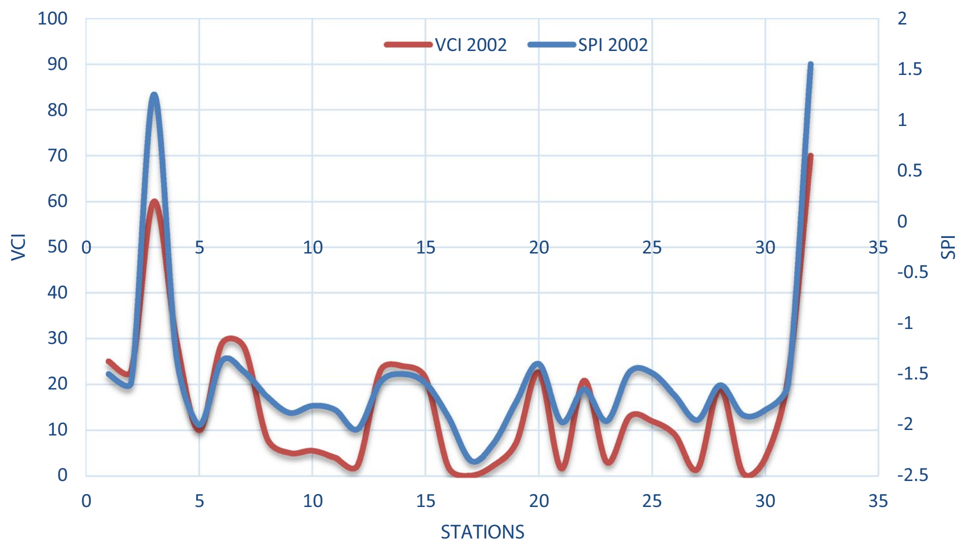


Fig. 7 Graph showing variations of VCI and SPI over 32 ground stations in 2002

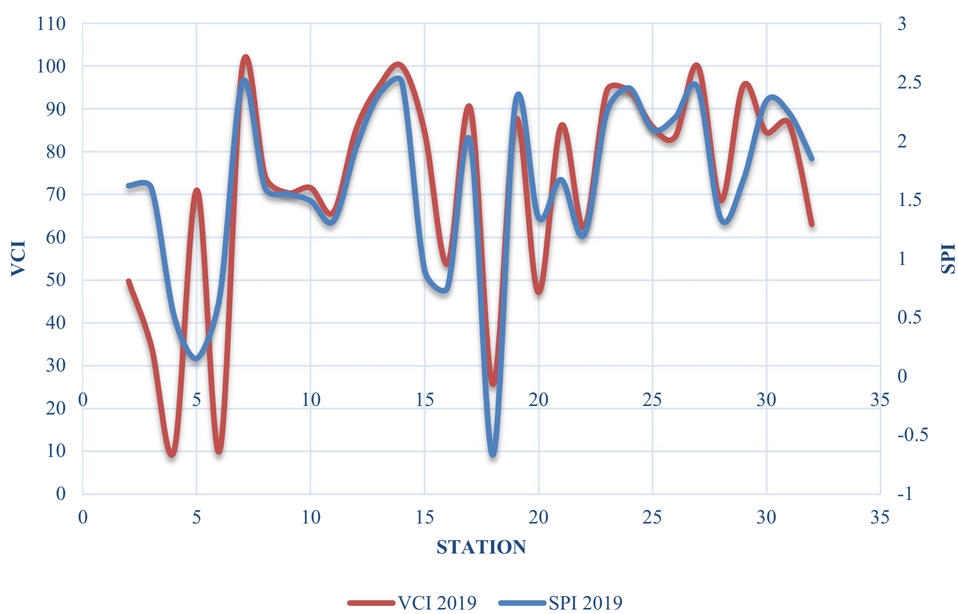


Fig. 8 Graph showing variations of VCI and SPI over 32 ground stations in the year 2019

which indicates drought condition in the region. The results obtained from both SPI and VCI thus exhibit that the Rajasthan state was not under drought condition except some part of western Rajasthan in year 2019.

Pattern of VCI and SPI are similar over whole area shows that remote sensing-based parameter VCI goes with the results of ground data-based SPI. Correlation coefficient between these two parameters is 0.79 which shows that results obtained by satellite imagery are reliable. Thus, the year 2002 was found to be a drought year according to the current study, and this result was also endorsed by the Central Arid Zone Research Institute (CAZRI), Jodhpur, in their annual report available for public read (www.cazri.res.in).

Conclusions

This study reconfirms that the use of RS technique for drought risk assessment is reliable based on the results obtained in this study. According to the VCI maps of year 2002, area under extreme drought condition increased from 23.04% in June 2002 to 59.31% in September 2002; thus, there is an increment of around 36.27% in areas under extreme drought condition from June to September which indicates poor vegetation condition, and 83.87% area is found under drought in the end of monsoon period. Spatial analysis of VCI maps shows that maximum part of the state was under drought except southern part of the state, and statistical analysis also shows that a large percentage of the area was facing drought. Thus, the year 2002 was found to be a drought year. According to VCI maps of year 2019, 56.15% area was under drought in June, and area under drought was reduced to 15.62% in September. Thus, there was a reduction (40.53%) in the area under drought from June to September which indicates there was an improvement in vegetation condition during monsoon period. Spatial analysis of the VCI maps of year 2019 shows that area under drought was decreased from June to September and in September only western part of Rajasthan was experiencing drought. Statistical analysis also indicates significant reduction in area under drought from June to September. Correlation coefficient between SPI and VCI for 2002 was calculated as 0.92, and correlation coefficient between SPI and VCI of year 2019 is calculated as 0.79; thus, we argue that the results obtained from satellite data based index analyses are reliable for drought-related analysis.

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