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Assessment of agricultural and meteorological drought indices using remote sensing and GIS technology

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Abstract
The agricultural productivity of India is greatly dependent on rainfall since it is an agrarian nation. As a result of the lack of rainfall, the national economy is adversely affected. Planning and management of drought require constant monitoring to better understand its intricate nature. Droughts occur in different parts of the world and vary in severity. Long-term vegetation analysis is required for monitoring agricultural drought on a regional scale. The present study attempts to study and monitor the spatial and temporal variation of agriculture and meteorological drought in Gujarat, India. This is, a state prone to drought, especially when monsoons fail or when they change. The long-term Normalized Difference Vegetation Index (NDVI) of NOAA-AVHRR NDVI data was used to assess agricultural drought through the NDVI-based Vegetation Condition Index (VCI), the most popular index to describe vegetation health for the period 1986-to-20015. The variation of VCI during the major crop-growing period of the Kharif season (June to September) was used to determine the spatial-temporal drought conditions of Gujarat. The results indicate that there is a wide variation in drought intensity among the districts within the state. The keen observation of yearly variation of long-term agricultural drought helps find the onset, period, and spatial extent of drought in various districts of the state. The districts that were most often prone to moderate to severe drought conditions during the analysis period were analyzed to develop various strategies to improve agricultural productivity in that region. The VCI values of normal and drought years were compared to the SPI, Rainfall Anomaly Index, and Yield Anomaly Index derived from meteorological data, and a good agreement was found between them. In addition, the correlation coefficient between maximum NDVI and mean seasonal rainfall ($r > 0.52$) confirms the usefulness of assessing agricultural drought. The persistent drought in the state necessitates that the government takes appropriate preventive measures to prevent drought in the future identifying the high-risk zones based on agricultural drought intensity maps, you can prioritize action plans based on the severity of the drought.

Keywords: Standardized precipitation index (SPI), vegetation condition index (VCI), normalized difference vegetation index (NDVI), agricultural drought, meteorological drought, drought risk, crop anomaly

Introduction
Drought is widely observed as the most complex but least understood disaster, impacting more people than any other. However, there is still a lot of uncertainty about its characteristics in the scientific and policy communities. This confusion, to some extent, explains the lack of progress in drought planning in most parts of the globe. Drought is a slow-onset, creeping natural hazard that is a normal part of the world's climate; it has serious economic, social, and environmental consequences. Drought onset and end are often difficult to control, as is its severity. Drought risk arises as a result of a region's vulnerability to natural disasters and its risk of extended periods of water scarcity (Wilhite, 2000). Nations and regions must improve their understanding of the hazard and the factors that influence vulnerability if they are to make progress in reducing the serious consequences of drought. Drought-prone areas must better understand their drought climatology (the likelihood of drought at various levels of intensity and duration) and establish a comprehensive and integrated drought information system that includes climate, soil, and water supply factors such as precipitation, temperature, soil moisture, snowpack, reservoir and lake levels, groundwater levels, and stream flow. All drought-prone countries should develop national drought policies and preparedness plans that emphasize risk management rather than the traditional crisis management approach, which focuses on reactive, emergency response measures. Drought is broadly characterized as being meteorological, hydrological, agricultural, or socioeconomic (Boken *et al.*, 2005; Lloyd-Hughes and Saunders, 2002) [5, 16]. Agricultural droughts in India are also classified according to the timing of rainfall deficiency during a crop season: early, mid, and late-season droughts

(Kumar *et al.,* 2009) [13]. Early season droughts are associated with delay in commencement of the monsoon resulting in no or delayed sowing of crops. Mid-season droughts are associated with breaks in southwest monsoon and coincide with the vegetative growth stage of crops. Late season droughts coincide with the reproductive stage of the crops leading to forced maturity. The relationships between different types of droughts are complex and their understanding is important for the prognosis of impacts.

Several drought indices have been developed over the last century and new indices are being developed based on new technological advances for quantifying drought impacts, with each index having its advantages and limitations (Lloyd-Hughes and Saunders, 2002; Morid *et al.,* 2006; Dhakar *et al*., 2013; Vaani and Porchelvan, 2017) [16, 17, 9, 27]. A drought index value is typically a single number that aids in making decisions about drought mitigation based on drought severity values (http://drought.unl.edu/Planning/Monitoring/Comparison of DroughtIndices.aspx). Accessed on 25/06/2020. Drought indices make use of a variety of independent or collective hydro-meteorological data, including rainfall, stream flow, reservoir storage, soil moisture, groundwater, and water supply indicators (WMO, 1975). Based on these physical datasets, the drought indicators are divided into three categories: meteorological drought indicators, agricultural drought indicators, and hydrological drought indicators. The popular meteorological drought indicators are the Standardized Precipitation Index (SPI), Standardized Precipitation Evapotranspiration Index (SPEI), and Reconnaissance Drought Index (RDI). Then, Vicente-Serrano *et al*. (2010) [29] compared the performances of SPI, SPEI, and PDSI concerning global drought monitoring and found that SPI and SPEI were better than PDSI for hydrological and agricultural drought monitoring and that SPEI In the past few decades, several indices have also been developed using remote sensing data such as Normalized Difference Vegetation Index (NDVI), Vegetation Condition Index (VCI), Enhanced Vegetation Index (EVI), and Temperature Condition Index (TCI), are some of the widely used indices based on drought indices (Quiring and Ganesh, 2010; Dutta *et al*., 2013; Kumar and Purushothaman, 2016; Bento *et al*., 2018; Yulistya *et al*., 2019) [22, 10, 14, 4, 30]. Lots of vegetation indexes based on remote sensing data have been used to monitor vegetation with the most extensively adopted NDVI (Zhou *et al*., 2009) [31]. Currently, NDVI data play a significant role in monitoring the vegetation drought (Sona *et al*., 2012; Dutta *et al*., 2013; Aswathi *et al*., 2018; Venkadesh *et al*., 2019; Jimenez-Donaire *et al*., 2020) [26, 10, 2, 28, 12]. These indices can be integrated with the meteorological indices and can provide valuable information if the ground data are not available. However, the frequent cloud cover during monsoon seasons creates difficulty in interpreting vegetation cover from remote sensing images.

Geography and Area of Extent

The Gujarat state of India is located on the west coast of India between latitude 20°06'N and 24°42'N and longitude 68°100'E and 74°28'E, covering an area of 196,000 km^2 (Figure 1). Gujarat has the longest coastline (1600 km) among the mainland states of India. However, despite its location bordering the Arabian Sea, major parts of Gujarat possess an arid to semiarid climate owing to its proximity to Thar-the Great Indian Desert to its north. The overall environment of Gujarat is a result of the combined influence of topography, soil, vegetation, and climate. The topography is characterized by vast plains with occasional small hilly tracts. The climate of the state is characterized by a large spatiotemporal variation in monsoon rainfall. Rainfall in Gujarat is governed by the southwest monsoon and occurs mainly from late June to the end of September, which accounts for more than 90% of annual rainfall. The state is also associated with significant variation in seasonal temperature except in the coastal regions. Although the mean annual temperature of the state varies between 28°C and 33 °C, the mean summer (April-June) temperature is 40 °C, and the maximum temperature at many places rises to 48 °C, particularly during heat-wave events.

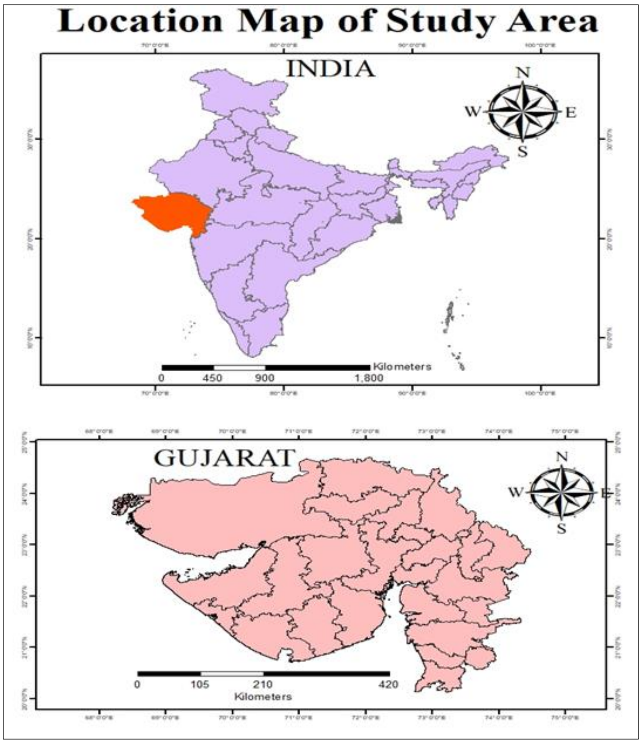


Fig 1: Location map of study area Gujarat (India)

Normalized Difference Vegetation Index (NDVI)

Numerous researchers have successfully used NDVI in studies involving the phenology of vegetation, classification of vegetation, and mapping of land cover on the continent (Tucker *et al*., 1985) [1]. NDVI can be used for drought monitoring, estimating crop growth conditions, and estimating crop yields (Kogan, 1987). The NDVI is based on the fact that the internal structure of healthy leaves reflects Near-Infrared (Ch2) radiation, while the chlorophyll and other pigments absorb a large proportion of the red visible (Ch1) radiation. In unhealthy water-stressed vegetation, this function of the leaf structure is reversed.

$$NDVI = (Ch2-Ch1) / (Ch2+Ch1) \qquad (1)$$

Near-infrared (Ch2) and visible red (Ch1) bands of the electromagnetic spectrum. NDVI values range from -1 to +1. The level is below 0.1 in areas with rock, sand, and snow cover, while it may range from 0.6 to 0.8 in tropical and temperate rainforests. NDVI is a popular index for monitoring agricultural drought, estimating soil moisture, and evaluating vegetation conditions. The utility of NDVI for studying vegetation and related issues may be limited by various sources of error, such as atmospheric noise, satellite orbital drift, and sensor degradations (Kogan, 1995).

Vegetation Condition Index (VCI)
The following VCI equation was applied to the final NDVI database:
Vegetation Condition Index (VCI)

$$VCI = (NDVI_i - NDVI_{min}) / (NDVI_{max} - NDVI_{min}) * 100 \quad (2)$$

Here, $NDVI_{max}$ and $NDVI_{min}$ represent the maximum and minimum NDVI of each pixel calculated for each month and j represents the index of the current month. The VCI value is expressed as a percentage ranging from 1 to 100. A value between 50% and 100% indicates that the vegetation is in good condition, whereas a value between 50% and 35% indicates that the vegetation is in drought, and a value less than 35% indicates that the vegetation is in severe drought. This index normalizes NDVI and distinguishes the long-term ecological signal from the short-term climate signal, making it a better indicator for monitoring water stress conditions than NDVI.

NDVI Anomaly Index
The severity of drought (or, on the other end of the spectrum, the extent of wetness) can be defined as the deviation of NDVI values from the long-term mean of NDVI values (Bandyopadhyay & Saha 2016) [3]. The calculation formula is as follows:

$$NAI = NDVI_i - NDVI_{mean,\, m} \quad (3)$$

Where NDVIi is the NDVI value for a month I and $NDVI_{mean}$, m is the average of mean monthly NDVI values of 30 years from 1986 to 2015 for (June to October) month of a particular year. When the NDVI Anomaly is negative, it indicates below-normal vegetation condition/health and, as a result, indicates a drought situation. The magnitude of the drought is proportional to the magnitude of the negative departure. In general, NDVI deviation from the long-term mean is more than just a drought indicator, because the long-term NDVI value reflects the conditions of healthy vegetation under normal conditions. Its limitations include the fact that the deviation from the mean does not account for the standard deviation, and thus can be misinterpreted when the variability in vegetation condition in a region is very high in any given year. The values range from -100 to + 100% departure from normal.

Yield Anomaly Index (YAI)
To quantify the impact of drought on the production of major Kharif crops (June- October) in Gujarat from 1986 to 2015, the correlation between SPI district level crop yields has been examined. Crop yield has been correlated to NDVI and VCI because they take advantage of the reflective and absorptive characteristics of plants in the red and near-infrared portions of the electromagnetic spectrum and have been used in research on vegetation yield and productivity. The yield trend has been calculated to examine the yield trend over the last 30 years (1986-2015). Yield trends have been computed on a district-by-district basis. The trend computation is followed by the formulas for calculating trend and yield anomaly. To determine crop production anomalies in years where the trend was missing, an average of the yield in that particular year has been computed. The yield anomaly has been calculated in the same way as the NDVI anomaly.
Yield anomalies of these crops were calculated using the following formula:

$$YAI = (Y - \mu)/\sigma \quad (4)$$

Where, YAI = Yield Anomaly Index
Y= Crop Yield
l = Long term average yield
r = Standard Deviation.

Rainfall Anomaly
Rainfall anomaly has to compute from (1986-to 2015 years) for the growing season June-October to indicate meteorological drought. Rainfall anomaly has been computed as:

$$RFA_i = [(RF_i - RF_\mu)]/(RF_\mu)*100 \quad (5)$$

Where
I is rainfall anomaly for an ith year;
RF i is seasonal rainfall for the ith year and
RFμ is the mean seasonal rainfall.

Meteorological drought, as defined by the Indian Meteorological Department (IMD), occurs when seasonal rainfall received over an area is less than 75% of its long-term average value. The meteorological is further classified as mild drought when rainfall is 25% less than normal, moderate drought when rainfall is 50% less than normal, and severe drought when rainfall is 75% less than normal. The meteorological drought was classified using the same criterion as defined by IMD.

Results and Discussion
Evaluation of Relationship of Maximum NDVI with Seasonal Rainfall
The relationship between maximum NDVI and seasonal rainfall shows that there is a consistent increase in NDVI as a result of rainfall. Maximum values of NDVI have been taken because these maximum values are assumed to represent the maximum greenness during the period. Also (Senamaw *et al.*, 2021) [25] according to their study NDVI is a measure of the magnitude of greenness available through time and therefore quantitatively reflects the capacity of the land to support photosynthesis and primary production. From the figure (Fig. 1) it can be analyzed that NDVI linearly increased from 0.1 to 0.5 with an increase in seasonal rainfall from 300mm to 1000mm. but NDVI get saturates once seasonal rainfall exceeds the 1000 mm threshold, after this point there is no significant increase in NDVI even when there is an increasing event of rainfall. As discussed above that the average NDVI and seasonal rainfall represent the growing season fairly, but what really can be analyzed from figure 1 and NDVI attains a higher value in the maximum but low in average NDVI however correlation is higher on average than the maximum NDVI. This increase in R^2 due to data averaging might be attributed to the considerable decrease in observation rather than the removal of outliers. Thus, it can be said averaging the NDVI values to remove inter-annual variations reduce the NDVI that may not truly represent the vegetation condition prevailing during the growing season.

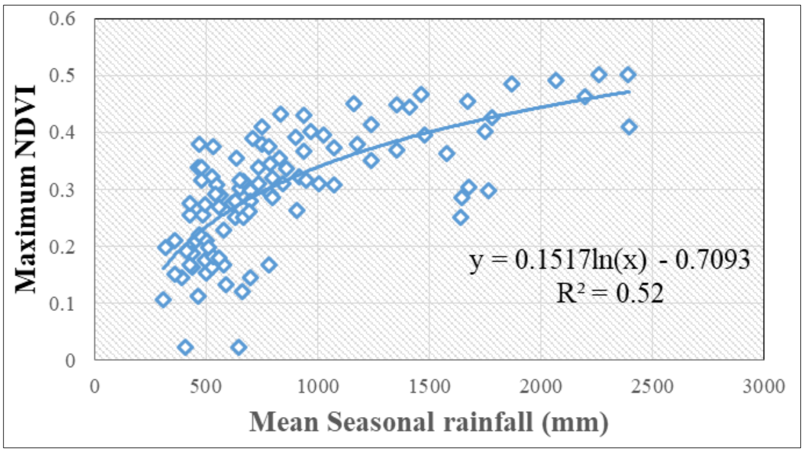


Fig 1: Relationship between mean seasonal rainfall and maximum NDVI

The seasonal pattern of rainfall and NDVI can also be analyzed (Fig. 2), which shows that the western part of Gujarat is a low rainfall area with 300 mm of rainfall for the entire season and low NDVI values (-0.3). Whereas in central and southern Gujarat, comparatively high rainfall areas can be identified, with rainfall reaching 2500 mm and above, resulting in high NDVI values (Chopra, 2006, Shukla *et al.*, 2007, Murad & Islam, 2011, Kundu & Dutta, 2011) [6, 25, 18, 10]. Rainfall is one of the most important components of plant growth. Seasonal plant growth occurs in many ecosystems, particularly grasslands and cropland, in perfect synchronization with the rainy season. During droughts, the vegetation in these ecosystems grows slowly, if at all. An abundance of rain results in a burst of green. The rainfall graph shows the total yearly rainfall in millimeters. Vegetation is represented as a scale or index of greenness on this graph. Greenness is determined by a variety of factors, including the number and type of plants, their leafiness, and overall health. The index is high, represented in dark green, in areas with dense foliage and rapid plant growth (Davenport & Nicholson, 1993, Islam & Mamun, 2015) [7, 11]. Figure 3 shows from 1986 to 2015, the temporal pattern of NDVI and rainfall The graph clearly shows that during low rainfall years, NDVI values were also low, and two major dips in 1986 and 1987 show low rainfall and NDVI, indicating that these were drought years (Rimkus *et al*., 2017, Pei *et al.*, 2019) [23, 21].

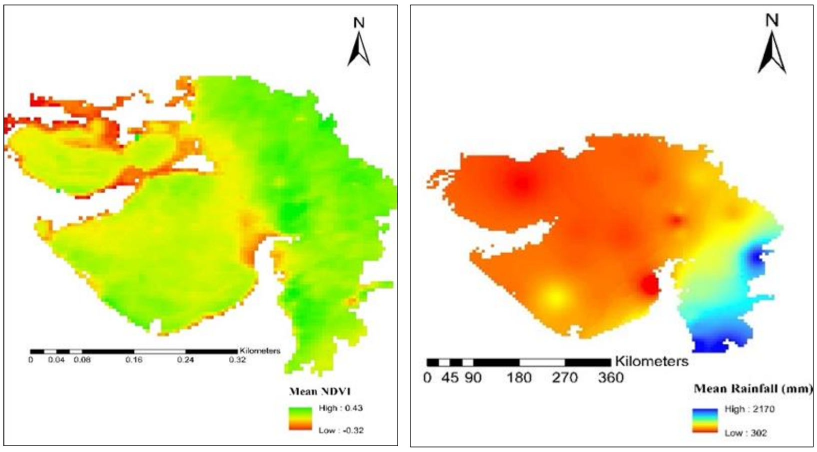


Fig 2: Average rainfall and Average NDVI (1986-2015)

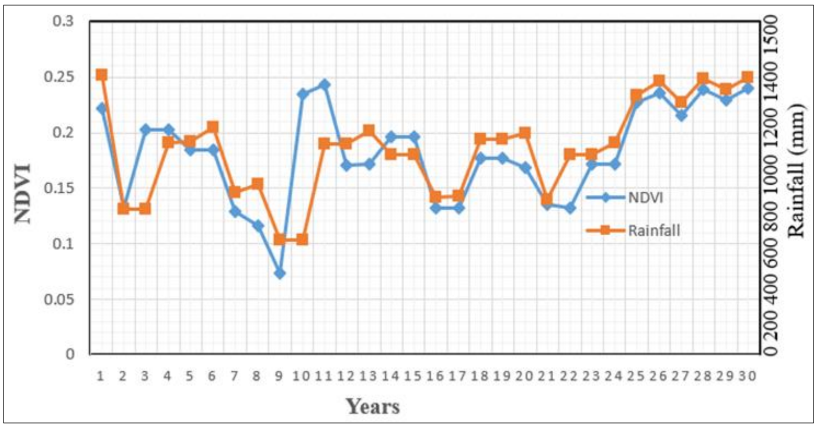


Fig 3: Temporal trends of NDVI and Rainfall (1986-2015)

Spatial Pattern of NDVI Anomaly and Rainfall Anomaly

Figure 4 depicts the spatial pattern of NDVI and rainfall anomaly during the 1987 drought and 1997 wet year. It can be seen that the entire state of Gujarat had negative NDVI anomalies and corresponding negative rainfall anomalies in 1987, whereas rainfall and NDVI anomalies were positive in 1997, a wet year (Chopra, 2006 & Nanzad *et al*., 2019) [6, 19]. This demonstrates that rainfall has a significant impact on the condition of the vegetation. When there is a lot of rain, the vegetation responds well, and the NDVI values are higher than when there's not a lot of rain.

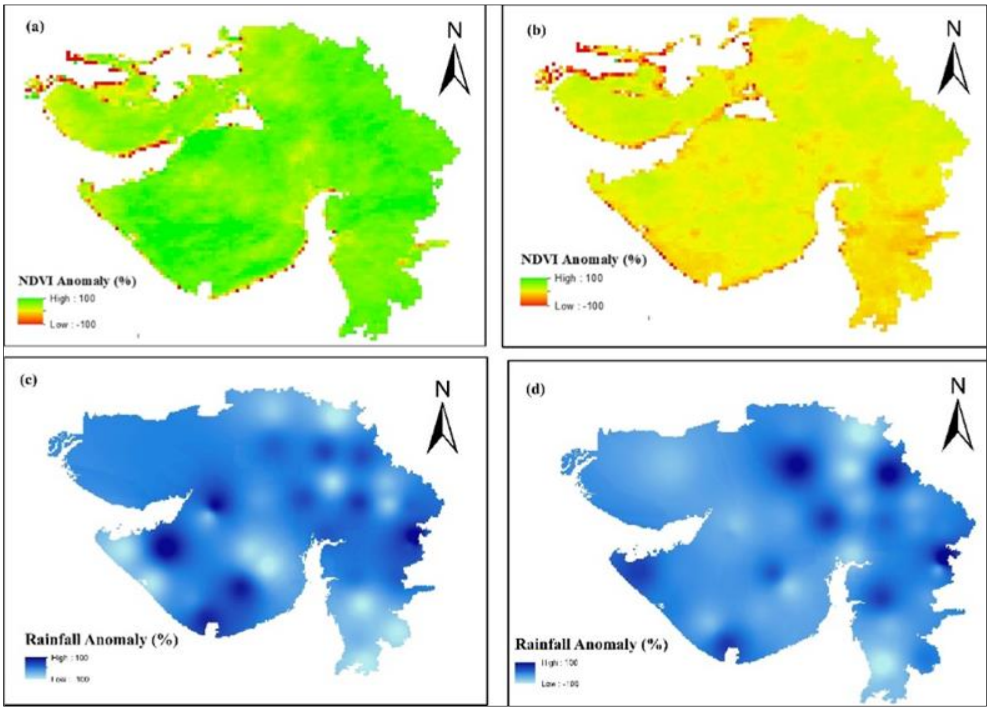
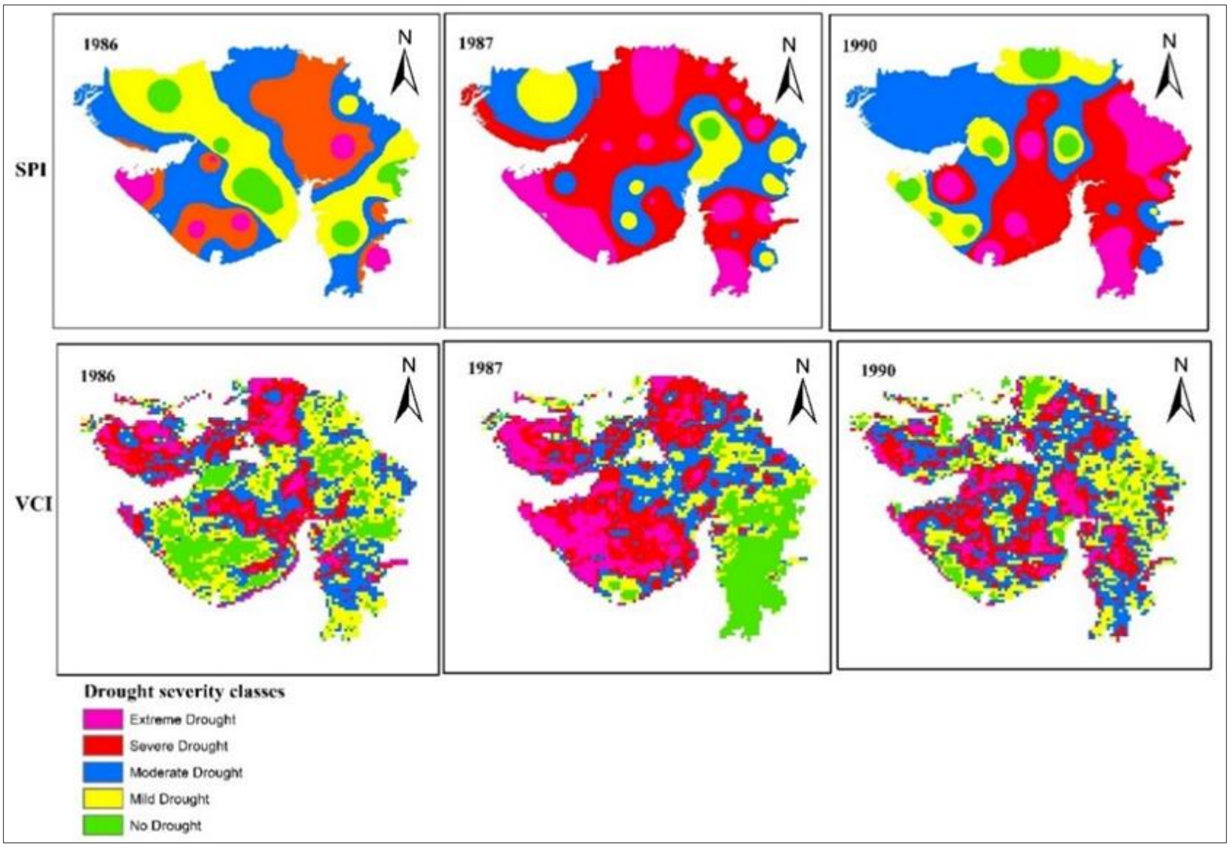
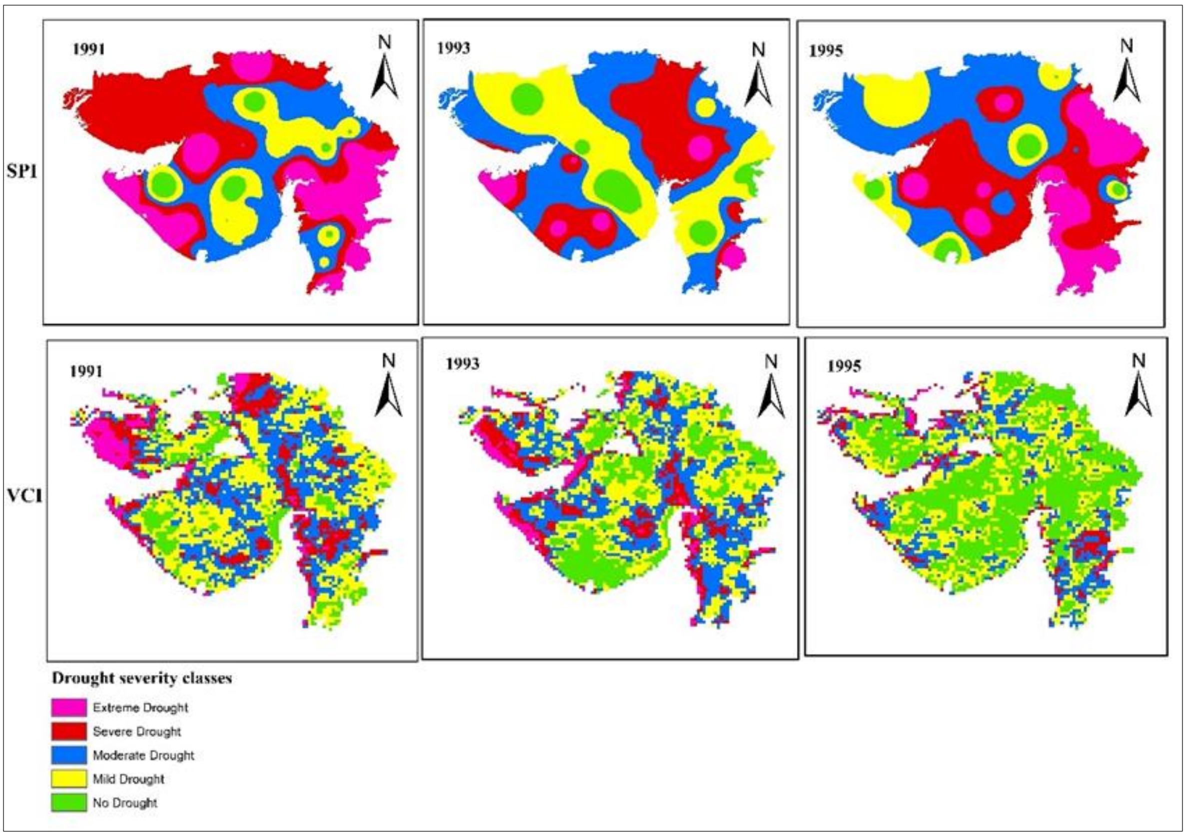
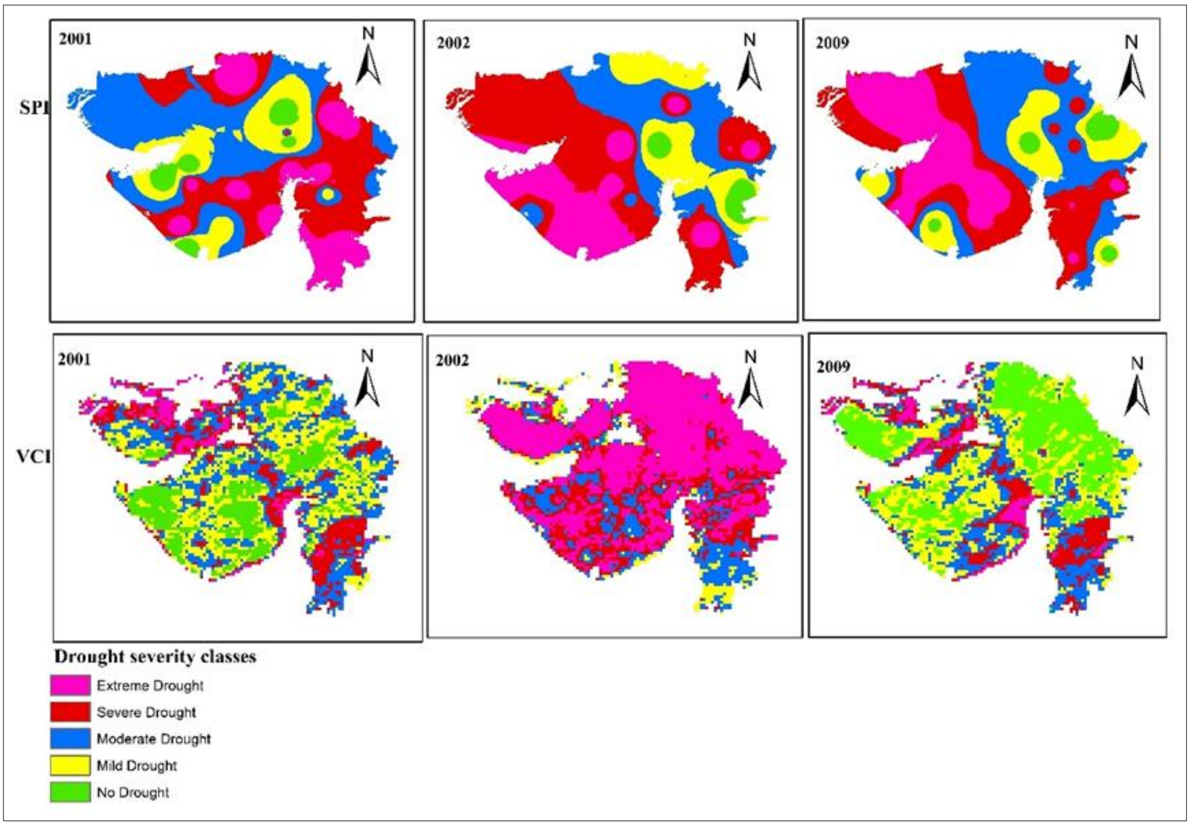


Fig 4: Spatial pattern of NDVI anomaly and rainfall anomaly (a) & (c) 1987 and (b) & (d) 1997

Spatial Pattern of Drought Years of SPI and VCI




1991
1993
1995
SPI
VCI
N
Drought severity classes
Extreme Drought
Severe Drought
Moderate Drought
Mild Drought
No Drought


2001
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Drought severity classes
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Severe Drought
Moderate Drought
Mild Drought
No Drought

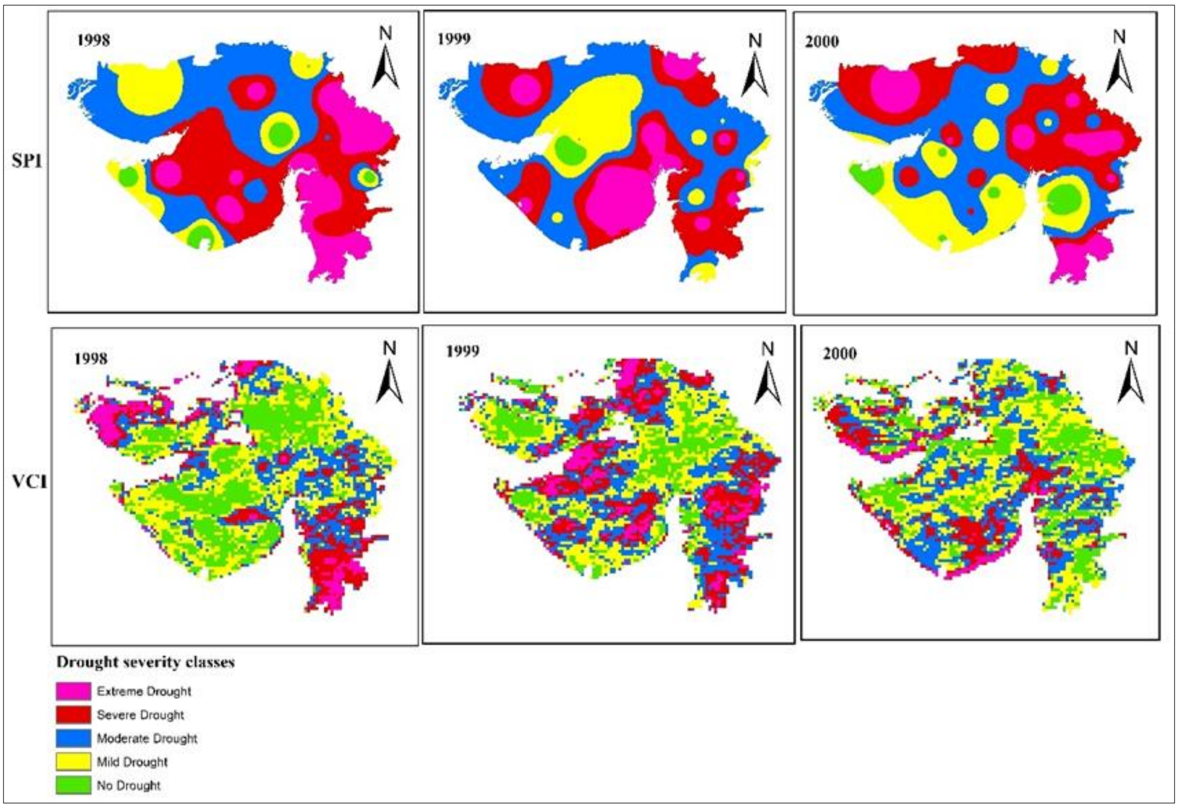
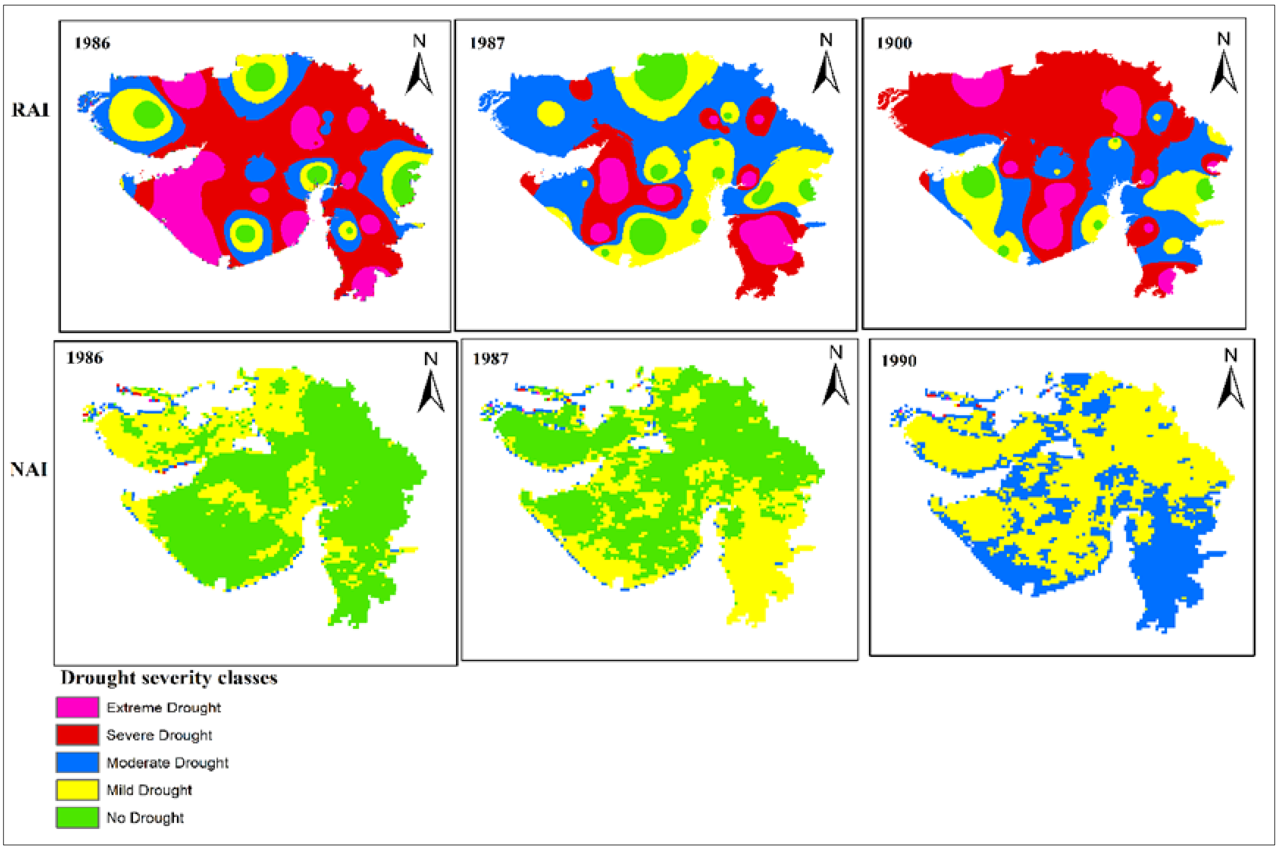


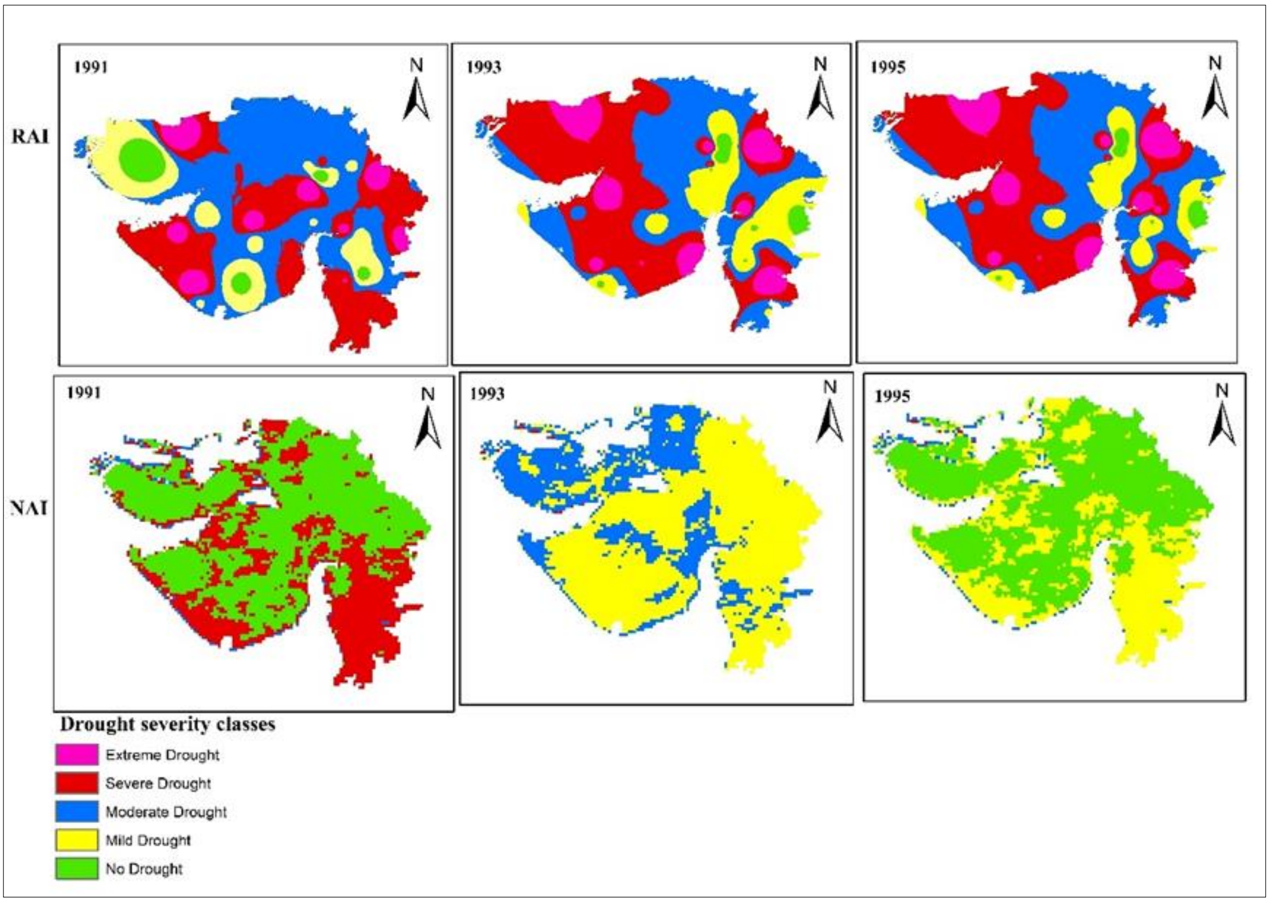
Fig 5: Important drought years from 1986 to 2015 are represented by two indices

The SPI and VCI-based Meteorological and agricultural drought intensity maps from 1986 to 2015 years are shown in Figure 5. As reported by (Bandyopadhyay & Saha, 2016) [3] the last decades of the 30th century faced the worst droughts in Gujarat. It was mentioned during the years 1986, 1987, 1990, 1991, 1993, 1995, 1998, 1999, 2000, 2001, 2002, and 2009. As the drought analysis period of the present study in the state starts from 1986 onwards, the check on the severity of the drought during the drought-affected years of 1987, 1999, and 2001 was not made possible. Nevertheless, the drought during the year 1986 could be observed in Figure 5 as the whole state faced a severe drought situation with many districts shown in red color. Similar conditions were observed in 1990, 1998, 2000, 2001, 2002, and 2009 also as many districts come under the extreme to severe drought category as seen in Figure 5.

During the monsoon period in Gujarat, the drought severity levels are not during all the months as it could be well perceived through the drought maps of 12 major drought years. It could be conceived that there are definite changes in the onset of monsoon during the analysis period as the vegetation status of the state as a whole was not uniform every year. During the year 1997, the whole state was under normal conditions except for a few districts facing problems with drought. But in July, August, and September, it went to moderate to severe condition. This shows that the early onset of monsoon which leads to the failure of crops with the wrong anticipation.

Spatial Pattern of Drought Years of RAI and NAI





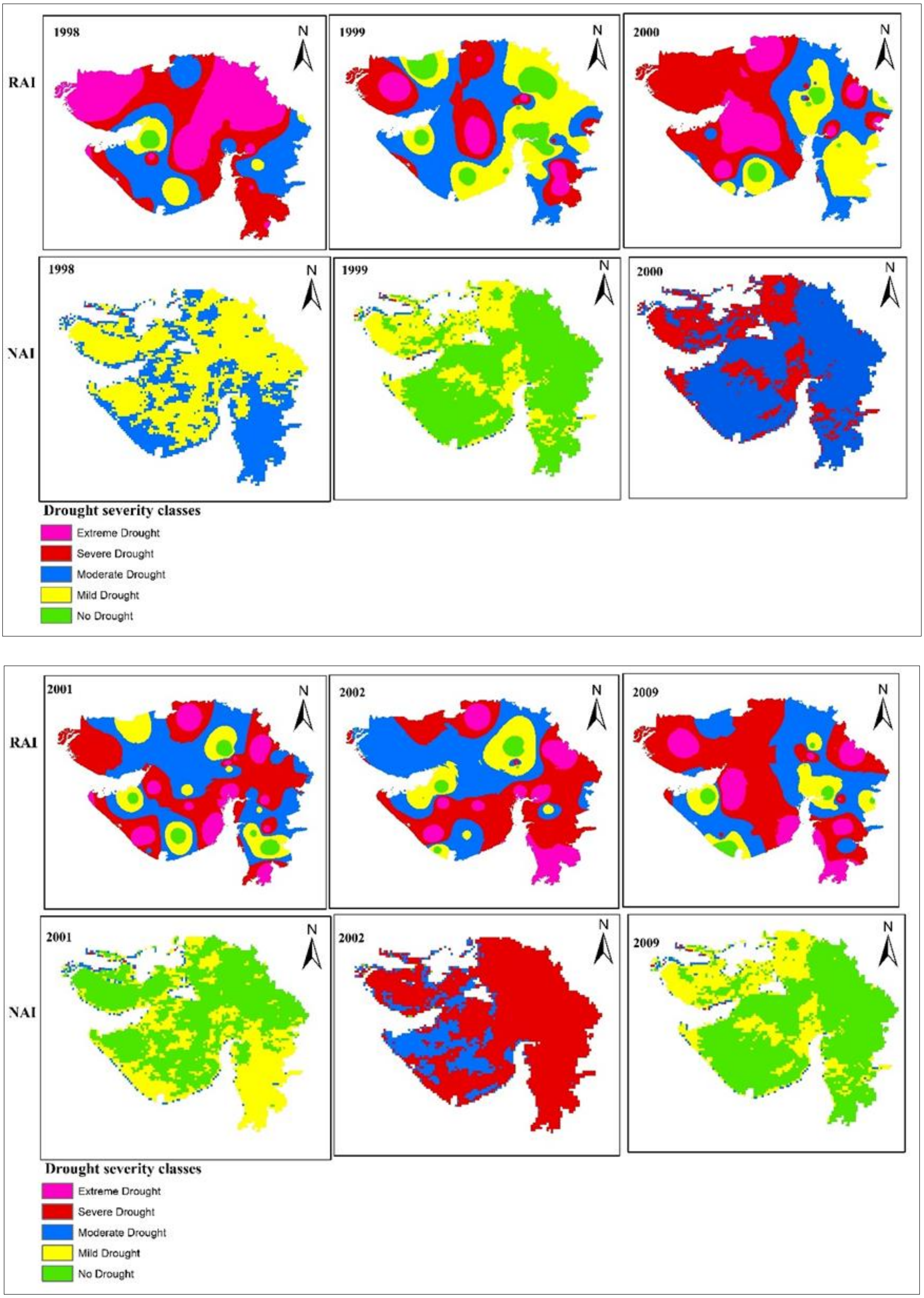


Fig 6: Important drought years from 1986 to 2015 are represented by two indices

Van Rooy's (1965) RAI is another useful index for identifying positive and negative rainfall departures. Several studies have shown that an area's vegetation growth is influenced by the amount of rainfall it receives. Long-term RAI was used from 1986 to 2015 to analyze the spatial and temporal pattern of rainfall, and years with abnormally low rainfall were identified. According to the study, RAI values were significantly lower in 1986, 1987, 1990, 1991, 1993, 1995, 1998, 1999, 2000, 2001, 2002, and 2009, indicating acute rainfall deficit and meteorological drought stress in most of

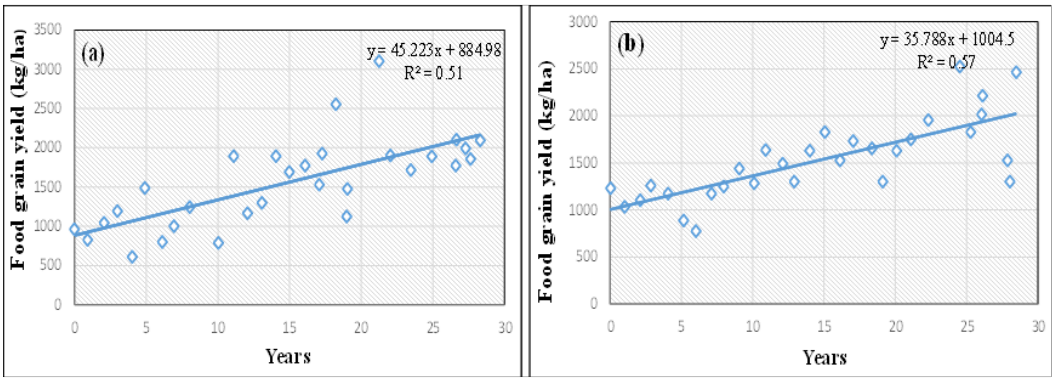
the areas (Fig. 6). In those years, RAI values were estimated to be less than <-3 has Extreme drought whereas they were positive >3 has Extreme wet conditions in 1988, 1993, 1997, 2003, 2011, and 2013. It was found that the RAI results were nearly identical to the SPI results in terms of the incidence of severe drought and normal conditions in 2003 and 2013, respectively. It is worthy to mention that previous research on droughts in Gujarat also agreed with the occurrences of severe drought conditions (Patel and Yadav, 2015, Bandyopadhyay & Saha, 2016, Thomas *et al.* 2016, Nanzad *et al.*, 2019) [3, 19].
Similarly, NAI was developed by Anyamba and Tucker, (2005) [1] the variation of the NAI with a positive value of +100 indicates normal drought conditions while a negative value of -100 indicates severe drought conditions (Nightingale & Phinn, 2003, Dubey *et al.*, 2012, Bandyopadhyay & Saha, 2016], Vaani and Porchelvan, 2017, Nanzad *et al.*, 2019) [20, 8, 3, 27, 19]. According to the study, NAI values were significantly lower in 1986, 1987, 1990, 1991, 1993, 1995, 1998, 1999, 2000, 2001, 2002, and 2009, indicating acute rainfall deficit and Agricultural drought stress in most of the areas (Fig. 6). In those years, NAI values were estimated to be less than -100 has Extreme drought whereas they were positive +100 has Extreme wet conditions in 1988, 1993, 1997, 2003, 2011, and 2013. It was found that the NAI results were nearly identical to the NDVI results in terms of the incidence of severe drought and normal conditions in 2003 and 2013, respectively.

Crop Yield Anomaly for Food Grain and Oilseeds Crops

Table 1: Yield trend for (A) Oilseeds and (B) Food grains

DISTRICTS	Oilseeds (R^2)	Food grain(R^2)
Ahmedabad	0.43	0.162
Anand	0.14	0.116
Banaskantha	0.549	0.134
Bharuch	0.148	0.102
Dahod	0.16	0.108
Dang	0.112	0.132
Gandhinagar	0.689	0.531
Kheda	0.253	0.152
Mehsana	0.406	0.114
Narmada	0.109	0.129
Navsari	0.116	0.134
Panchmahal	0.369	0.144
Patan	0.105	0.103
Sabarkantha	0.613	0.296
Surat	0.321	0.527
Tapi	0.134	0.102
Vadodara	0.53	0.109

Yield trends were computed (Table 1), and it was found that the highest correlation in the case of food grain was found in Gandhinagar, Surat, and Surendranagar over the last 30 years. The trend is visible in figure 7, which shows that crop yield for food grains has increased with the increase in the number of years. It can be analyzed that in Gandhinagar approximately till 1994 the food grain yield was constant between 1000-1200 kg/ha but in the year 1997 it rises to 1500 stating that due to good rainfall in the year 1997 food grain production showed a hike. However, it is also noticed that during the years 1986, 1987 and 1990 food grain production fell to considerable levels between 500-700 kg/ha approximately because of the failure of the monsoon rainfall. Similar is the case with Surat and Surendranagar where food grain production showed an increase in yield during normal rainfall years, while during the drought years of 1986, 1987, and 1990 Surendranagar yield was reduced drastically between 300-400 kg/ha (Dutta *et al.*, 2013, Dutta *et al.*, 2015, Zhang *et al.*, 2017, Senamaw *et al.*, 2021) [11, 24].
In the case of oilseeds in figure 8, only two districts showed a good correlation, which states that in comparison to other districts Gandhinagar and Sabarknatha have depicted a good increase in oilseeds production throughout the years (1986-2015).



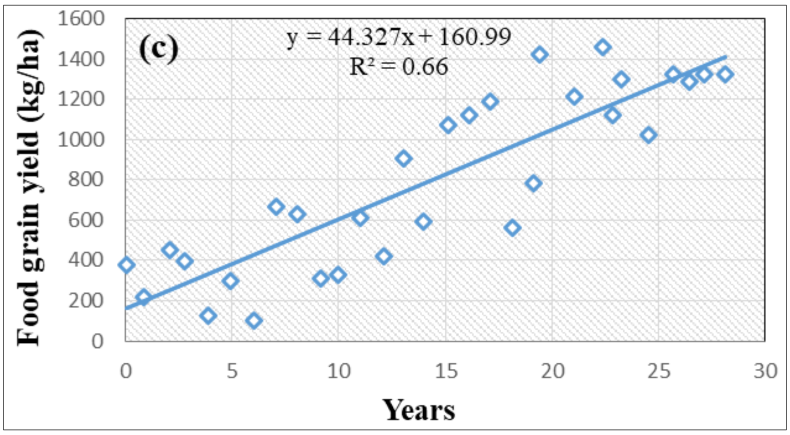


Fig 7: Food grain yield trend from 1986-2015 (a) Gandhinagar (b) Surat and (c) Surendranagar

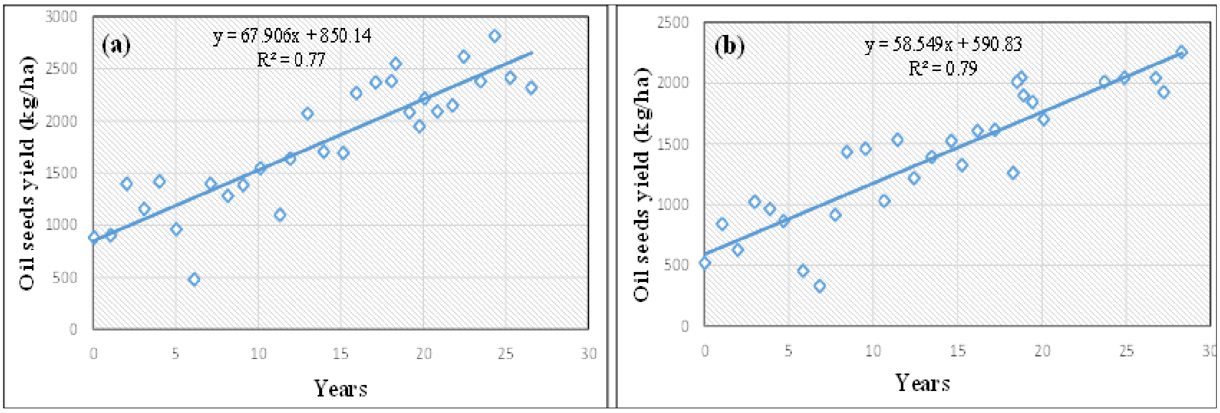


Fig 8: Oil seeds yield trend from 1986-2015 (a) Gandhinagar (b) Sabarkantha

Conclusion

Agriculture in India is entirely dependent on rainfall, which is one of the main reasons why even minor variations in rainfall can result in drought. The effects of climate change will ultimately affect agricultural production. According to recent statistics, many farmers commit suicide due to crop failure. A nation's social and economic well-being depends on its ability to handle crises without compromising its development. This is the main reason why developing nations have been in the same state for so long. It is of the utmost importance for developing countries like India, whose economy and social status rely heavily on the agricultural sector. This is because they need to improve agricultural productivity in the event of a monsoon failure. Several indexes were used in this study to study and monitor the drought level in Gujarat: NDVI, VCI, RAI, YAI, and NAI. We prepared drought intensity maps for Gujarat for 30 years using NDVI-based VCI and a very efficient spatial data management tool, the Geographical Information System (GIS). During the analysis period of 30 years, normal, moderate to severe drought conditions were obese additionally, this variation of drought should prompt the government to take preventive measures to avoid droughts in the future. For better management of drought, soil and water conservation measures like the construction of contour bunds, check dams, percolation ponds, etc. Should also be considered by the government.

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