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Reaserch Article

Monitoring Drought and Its Impact on Agriculture Using Drought Indices and Geo-informatics Technology in Patan District, Gujarat

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Abstract

Remote sensing (RS) and Geographic Information System (GIS) has played a major role in the study of different types of drought i.e. agricultural or hydrological drought. The present study on agricultural Drought assessment was carried out in the Patan District of North Gujarat, India. This study focuses on the assessment of climate change and its impact on Agriculture using Remote Sensing (RS) and GIS technology. The Landsat-7 TM and Landsat-8 OLI data of February-2002 and February-2018 covering Patan District was analysed for Land use/Land Cover mapping and monitoring changes in agricultural area over the period of 16-years. The Spectral vegetation index namely Normalized Difference Vegetation Index (NDVI) was computed using Landsat-7 TM and Landsat-8 OLI digital data for assessment of changes in agricultural vegetation during the drought and normal monsoon periods. Meteorological data like Minimum & maximum Temperatures and rainfall was collected from State Data Centre. Various Drought indices like Standardized Precipitation Index (SPI), Potential Evapo-Transpiration (PET) and Aridity Index (AI) were computed using meteorological data of past 16-years.

The results indicate that total agricultural vegetation during drought season was only 21.9 per cent (2002) which has increased to 58.7 per cent during the normal monsoon season of 2018. The rainfall deviations were computed for various years and it was observed that high negative rainfall deviations (-40 to -70%) having low rainfall occurrence were associated with negative SPI values ranging from -0.5 to -1.1 in Patan district. These positive rainfall deviations were associated with positive SPI values of 1.08, 0.57 and 0.62 of respective years indicating moderately wet and mildly wet conditions. During drought year of 2002 total precipitation was very less resulting in Aridity Index of 0.09 which is classified as hyper arid for the Patan District.

Keywords: Agricultural Drought, Meteorological Drought indices, Aridity Index, Standardized Precipitation Index (SPI), Potential Evapo-Transpiration (PET), Remote Sensing and GIS.

Introduction

Drought is usually defined in a different way by many of the people. Drought is a natural disaster which affects a wide range of ecological factors and activities related to agricultural vegetation, human and wildlife and economies. The impact of drought climate events is mostly widespread, because drought is a natural and recurring feature of climate and occurs in almost all climatic regimes (Min, et al., 2011; Perkins, et al., 2018).Drought is a complex and recurring natural disaster that occurs throughout the world and often has negative impacts on many sectors of society. Drought monitoring is challenging given the complex spatio-temporal dimensions of drought and its severity. Traditionally, drought monitoring has relied mainly upon climate-based indicators and indices. Drought is an extended period when an area receives a deficiency in its water supply, whether atmospheric, surface or groundwater. A drought can last for months or years or may be declared after as 15 days. Generally, this happens once when a region receives consistently below average precipitation. It will have a major impact on the system and agriculture of the affected region. Although droughts might persist for many years even a short, intense drought can cause significant damage and harm to the local economy (Ülker et al., 2018; Esetlili et al., 2018; Goumehei et al., 2016). Usually, drought is Classifies in four major categories namely meteorological drought, Hydrological drought, Agricultural drought, Socio-economic drought.

Remote sensing has provided relatively high spatial resolution and high temporal resolution observations of the Earth. Remotely sensed imagery provides spatial continuous spectral measures across large areas that reflect both atmospheric and land surface characteristics. As a result, remote sensing data has been increasingly used for large-area drought monitoring (Elhag and Zhang, 2018).

Normalized Difference Vegetation Index (NDVI) based Drought Assessment

NDVI is a nonlinear function that varies between -1 and +1 and values of NDVI for vegetated land generally range from about 0.1 to 0.7, with values greater than 0.5

indicating dense vegetation. The study was carried out for the development of the near-real-time drought-monitoring and reporting system for the South West Asia, which includes Afghanistan, Pakistan and western parts of India. The drought-related indices, derived from remote-sensing data include a deviation from the Normalized Difference Vegetation Index (NDVI) from its long-term mean and a vegetation condition index (VCI) (Thenkabail et al., 2004; İmamoğlu and Sertel, 2018; Gorji, et al., 2019). Furthermore, NDVI can be used not only for accurate description of vegetation vigour, vegetation classification and continental land cover but is also effective for monitoring rainfall and drought, estimating net primary production of vegetation, crop growth conditions and crop yields, detecting weather impacts and other events important for agriculture, ecology and economics (Ramesh et al., 2003).

Drought Assessment using Meteorological Indices

Monthly rainfall data from June to October for 39 years were analysed to compute Standardized Precipitation Index (SPI) values based on two parameter gamma distribution for a low rainfall and a high rainfall districts of Andhra Pradesh state, India. In this study, the SPI values of different years were analyzed with actual rainfall as well as rainfall deviation from normal in a low rainfall and a high rainfall districts. The results indicated that of rainfall deviations vs. SPI indicated less sensitivity of SPI to low rainfall events (Naresh Kumar et al., 2009). Monthly precipitation data from three meteorological stations in Patan district from 1980 to 2012 (30-years) have been for assessment of drought using SPI and rainfall deciles (Gandhi and Parekh, 2017). According to SPI value the drought severity years have been classified into three categories namely, moderate, severe and extreme drought and severe drought years were 1985, 1986, 2011 and 2012. Agricultural drought monitoring in Surendranagar district, Gujarat state was carried out using various drought indices. Landsat data of 2000, 2009 and 2018 was analysed for spatio-temporal assessment of agricultural drought (Sakthivel et al., 2018).

Meteorological data of previous 20-years was analysed and drought indices like Standardized Precipitation Index (SPI) and Aridity Index were computed to assess the severity of drought. Correlation analysis was performed between NDVI, SPI and Aridity index. SPI and Aridity Index values were interpolated to get the spatial pattern of meteorological based drought. NDVI, SAVI, LULC threshold were identified to get the agriculture drought risk. The NDVI, SPI, Rainfall anomaly and food grain anomaly in Gujarat State was studied and it was observed that there is high correlation between SPI and crop yield. The rainfall anomaly and NDVI were also correlated and from the threshold defined by IMD for meteorological drought the drought risk in North and Central part of Gujarat State was defined (Chopra, 2006). The present study mainly concentrated on drought assessment of Patan district in Gujarat. Patan district as categorized under drought area of Gujarat. The major objective was to monitor the drought using specific Remote Sensing based drought indices with the help of geospatial technology. A geospatial technique like remote sensing and GIS played a key role in assessing hydrological drought. Timely determination of the level of drought will help in the effective decision-making process in reducing the impacts of drought (Patan District handbook, 2011).

Materials and Methods

Study area

This research was conducted in Patan District of Gujarat, India. Patan District with geographical region of 5600 sq.akilometer is found between 20° 41' to 23° 55' north latitude and east longitude of 71° 31' to 72° 20'. Patan District shares boundaries with Runn (desert) of tannic acid, Palanpur, Banaskantha, Surendranagar and Mehsana District of Gujarat state. The study area map is shown in Figure one. The study area covers around eight taluks and 517 villages. The average rainfall during 1982–2011 years was 539 mm (Patan District Panchayat, 2013). The study area has a semi-arid climate. High temperatures, inconsistent precipitation, and high evaporation rate are the major characteristics of this type of climate. The major factors that have affected agricultural productivity within the Patan District are depletion of groundwater level, deterioration of soil and water properties due to salinity ingress, irregularity of rainfall and recurrent droughts scarcity. This study aims to study the impact of climate change and drought on Agriculture using Geo-informatics Technology. The location map of the study area is given in Figure-1.

The land suitability assessment for wheat crop has been conducted in Patan District, Gujarat State, to help the decision makers, farmers as well as agricultural development planners (Dadhich et al., 2017). The results indicate that distribution of wheat acreage under various suitability classes was highly suitable: 34.09%, moderately suitable: 47.37%, marginally suitable: 11.76% and unsuitable: 6.76%.

Meteorological Data:

Monthly & year-wise rainfall and minimum and maximum temperature datasets were acquired from Gujarat Water Data Centre, Gandhinagar from 2000 to 2017. The Gujarat Water Data Centre, Gandhinagar have set up a rainfall monitoring station for each taluka.

Satellite data:

Landsat-7 ETM+ data of February 2002 and Landsat-8 OLI & TIRS data of February 2018 was downloaded from the website https://earthexplorer.usgs.gov/. The details of satellite data used are given in Table-1. Landsat-8 digital mosaic with Patan district boundary and extracted image covering Patan District is given in Figure-2.

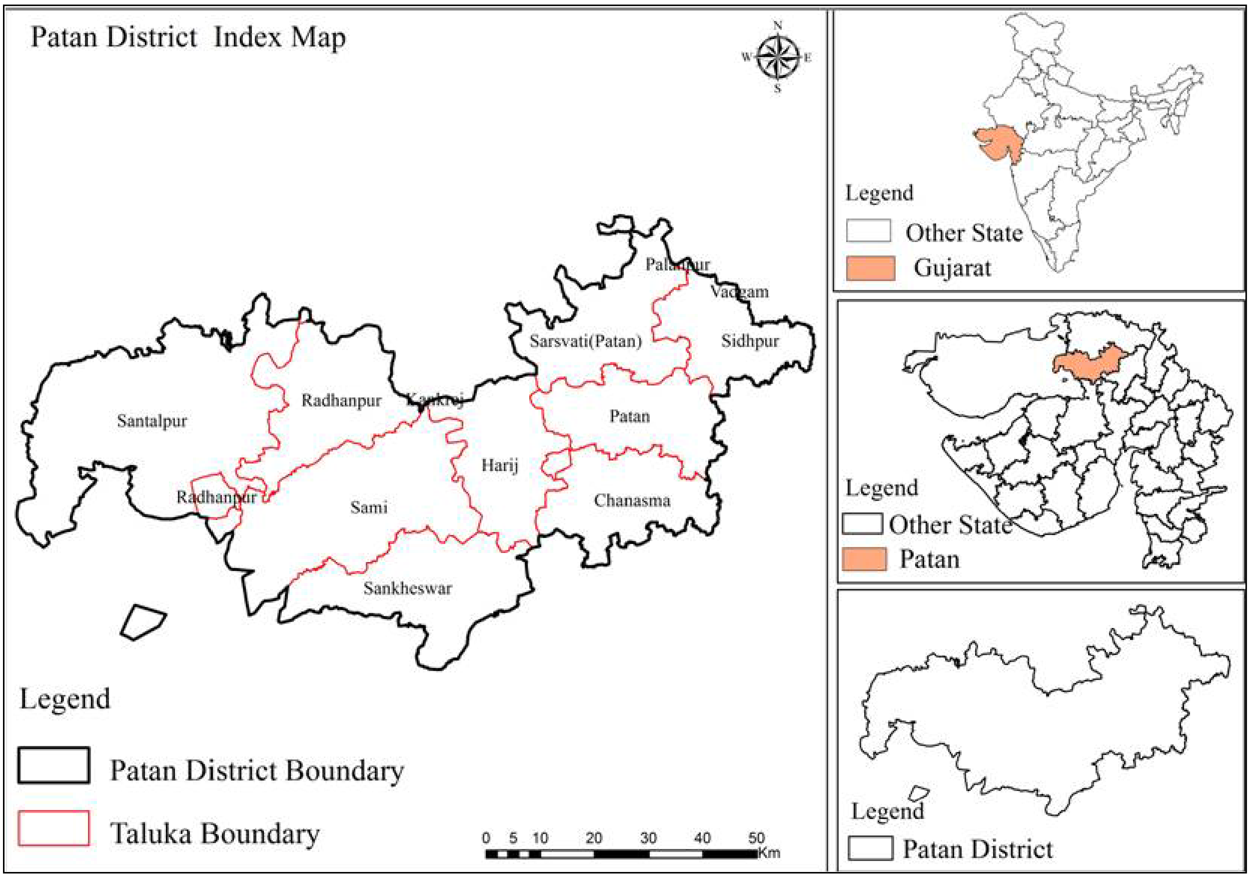


Figure-1: Location Map Patan District in Gujarat State

Table-1: Details of satellite data used

Satellite/Sensor	Path	Row	Date of Pass
Landsat-7 /TM	149	43	21.02.02
	149	44	21.02.02
Landsat-8 /OLI	149	43	09.02.18
	149	44	09.02.18

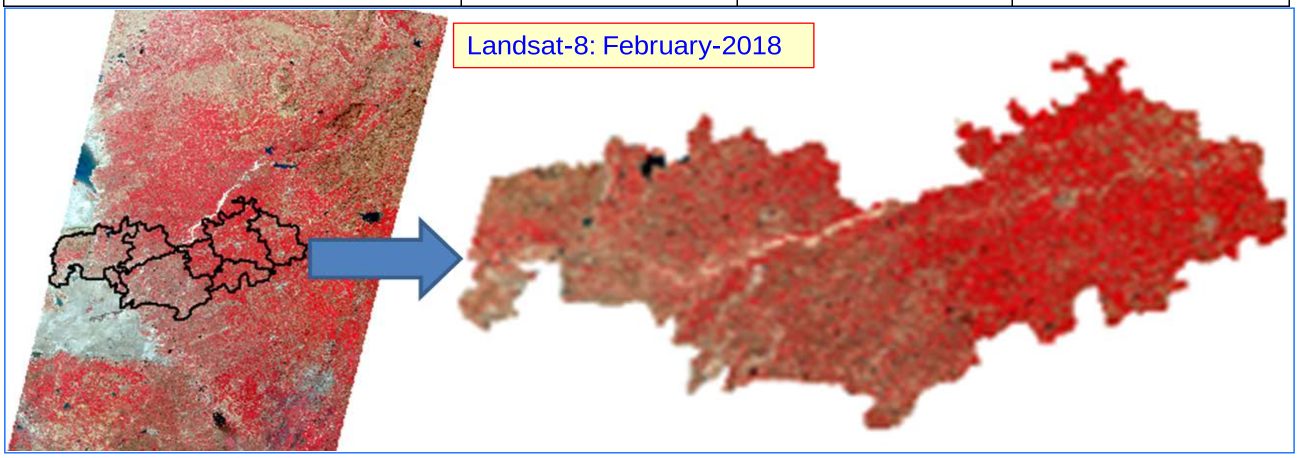


Figure-2: Landsat-8 with Patan district boundary and extracted image covering Patan District

Generation of NDVI

Vegetation indices derived from satellite imagery provide an estimate of the health and vigor of agricultural crops. One of the most widely used vegetation indices is the Normalized Difference Vegetation Index (NDVI) defined by Rouse et al. (1974). The Normalized Difference Vegetation Index (NDVI) images of Feb 2002 and Feb 2018 Landsat data covering Patan district were generated. This index is based on the difference between the maximum absorption of radiation in the red due to the chlorophyll pigments and the maximum reflection of radiation in the NIR due to the leaf cellular structure. NDVI provides a measure of vegetation health and vigour. The NDVI values range between -1 and +1. The NDVI images were generated using the following formula: NDVI = (NIR - R) / (NIR + R). The NDVI images generated for Feb. 2002 and Feb. 2018 along with corresponding FCC images are given in Figure-3.

Generation of Drought Indices

In this study different types of indices were carried out for calculating drought and the change in the Climate during that time. The various types of drought generated are Normalized Difference Vegetation Index (NDVI), the Standardized Precipitation Index (SPI) and Aridity Index (AI).

Standardized Precipitation Index (SPI)

Tom Mckee, Nolan Doesken and John Kleist of the Colorado Climate Centre formulated the SPI in 1993. The SPI was designed to quantify the precipitation deficit for multiple time scales. These time scales reflect the impact of drought on the availability of the various water resources. Thus, McKee et al. (1993) originally calculated the SPI for 3–, 6–, 12–, 24– and 48– month time scales. Standardized Precipitation Index (SPI) expresses the actual rainfall as standardized departure from rainfall probability distribution function and, hence, this index has gained importance in recent years as a potential drought indicator. The values of SPI are expressed in standard deviations with positive SPI values indicating greater than median precipitation and negative values indicating less than median precipitation (Edwards and McKee, 1997).

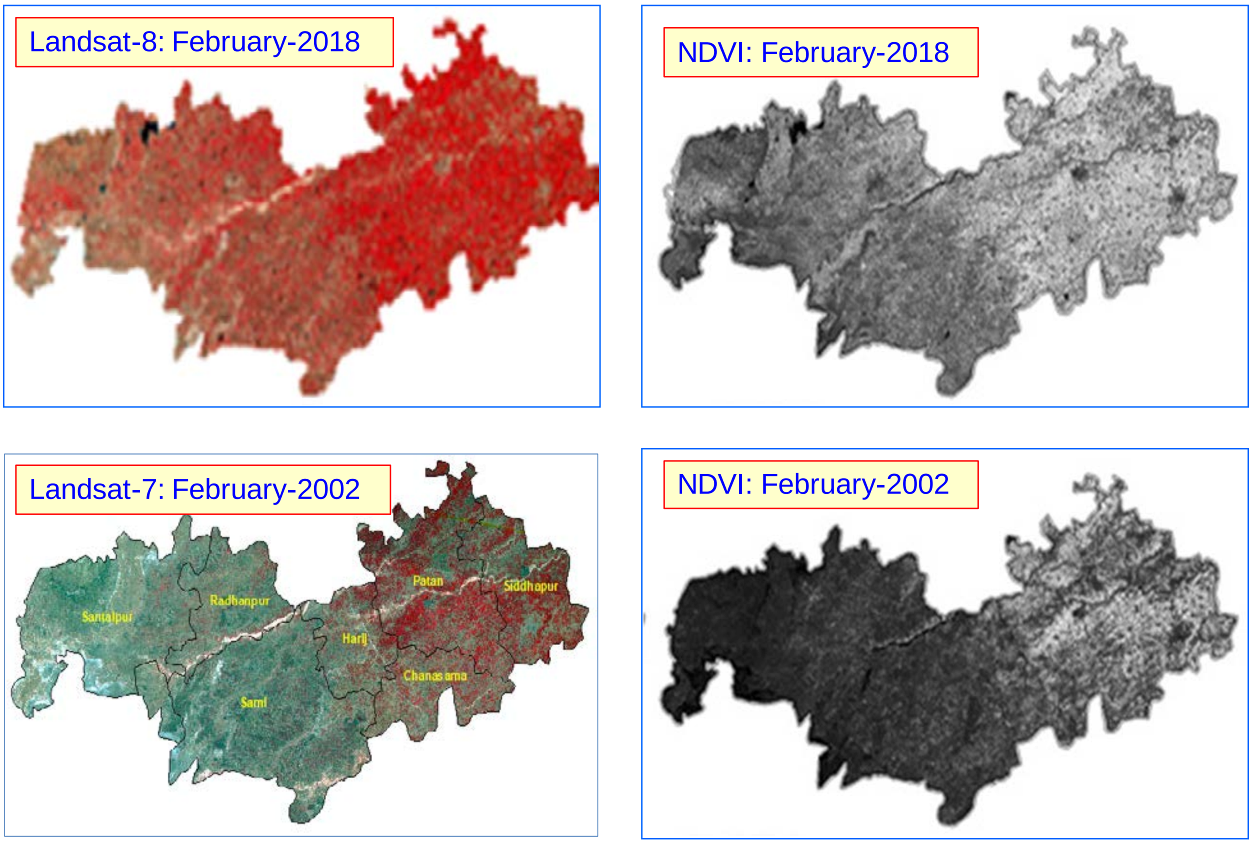


Figure-3: NDVI images along with corresponding FCC images covering Patan District

In the present study SPI was calculated using Drought Indices Calculator (DrinC) software, which was downloaded from the website: URL 1This software provides a user-friendly tool for the calculation of several drought indices such as Reconnaissance Drought Index (RDI) and the Stream-flow Drought Index (SDI). Also, the widely used Standardized Precipitation Index (SPI) and rainfall Deciles can be computed using DrinC Software. While calculating SPI, the Potential Evapo-Transpiration (PET) is computed by using Maximum and Minimum monthly average temperature. DrinC provides a module for the calculation of Potential Evapo-Transpiration (PET) with temperature based on three methods: i) Hargreaves (Tmin, Tmax), ii) Thornthwaite (Tmean) and Blaney – Criddle (Tmean). In this study, PET is computed using the Hargreaves method. Hargreaves (1975) developed an equation for estimating ET that doesn't need wind speed information. The ET is computed as ET = 0.0023 (Tm + 17.8) (T max – T min) 1/2.Ra, where: Tm: daily mean temperature, Ra – extra-terrestrial radiation [MJ m2 day1]. This needs a comparatively small range of data for the calculation and therefore the results are simply interpreted and employed in strategic planning and operational applications. DrinC has full graphical user interface functionality (GUI) and runs on MS Windows operating systems. Standardized Precipitation Index (SPI) values were computed using monthly rainfall data from July to October for 18 years. The present study analyses the response of seasonal SPI values to drought situation and its comparison with actual rainfall data.

Aridity Index (AI)

Aridity is measured by comparing long-term average water supply (precipitation) to long-term average water demand (evapo-transpiration). If demand is greater than supply, on average, then the climate is arid. Drought refers to the moisture balance that happens on a month-to-month (or more frequent) basis. If the water supply is less than water demand for a given month, then that month is abnormally dry Aridity is permanent, while drought is temporary (NOAA's National Centers for Environmental Information (NCEI). Thornthwaite's (1948) water balance technique is generally used to compute the aridity anomaly index. This methodology is widely used to represent crop moisture stress. Aridity index (AI) is computed as given below:

$$AI = \text{Water deficit/ Water need} = (PE - ET)/PE \quad (1)$$

Where: ET is the actual evapotranspiration computed from the water balance technique and PE the potential evapotranspiration, which is supposed to represent the water need of the plant. The simplest aridity index is based solely on precipitation. A commonly used rainfall-based definition is that an arid region receives less than 250 mm of precipitation per year. This criterion for aridity was used by the Intergovernmental Panel on Climate Change (IPCC 2007). Semiarid regions are commonly defined by annual rainfalls between 250 and 500 mm. The United Nations Environment Programme (UNEP), 1992 has adopted another index of aridity, defined as: AI = P/PET, where: PET is Potential Evapo-Transpiration and P is the average annual precipitation (UNEP, 1992). PET and P should be expressed within the same units, e.g., in millimeters.

Result and Discussion

Land Use/Land Cover classification

The Landsat digital data of Feb. 2002 (drought year) and Feb 2018 (normal monsoon season) covering Patan district was classified using Maximum Likelihood 9MXL) supervised classification technique. The agricultural vegetation was classified into sparse and dense vegetation and other land use classes like waste land, sandy areas, built-up land etc were also classified. The area under sparse and dense agriculture classes as well other land use classes was computed. As we can see the images of 2002 and 2018 that shows a major difference in the vegetation and severity during drought and normal monsoon years. The total agricultural vegetation during drought season was only 21.9 per cent (drought year 2002) which has increased to 58.7 per cent during the normal monsoon season of 2018. This increase is mainly due to converting waste lands into agriculture cultivation because of favourable monsoon conditions for good growth of agricultural crops.

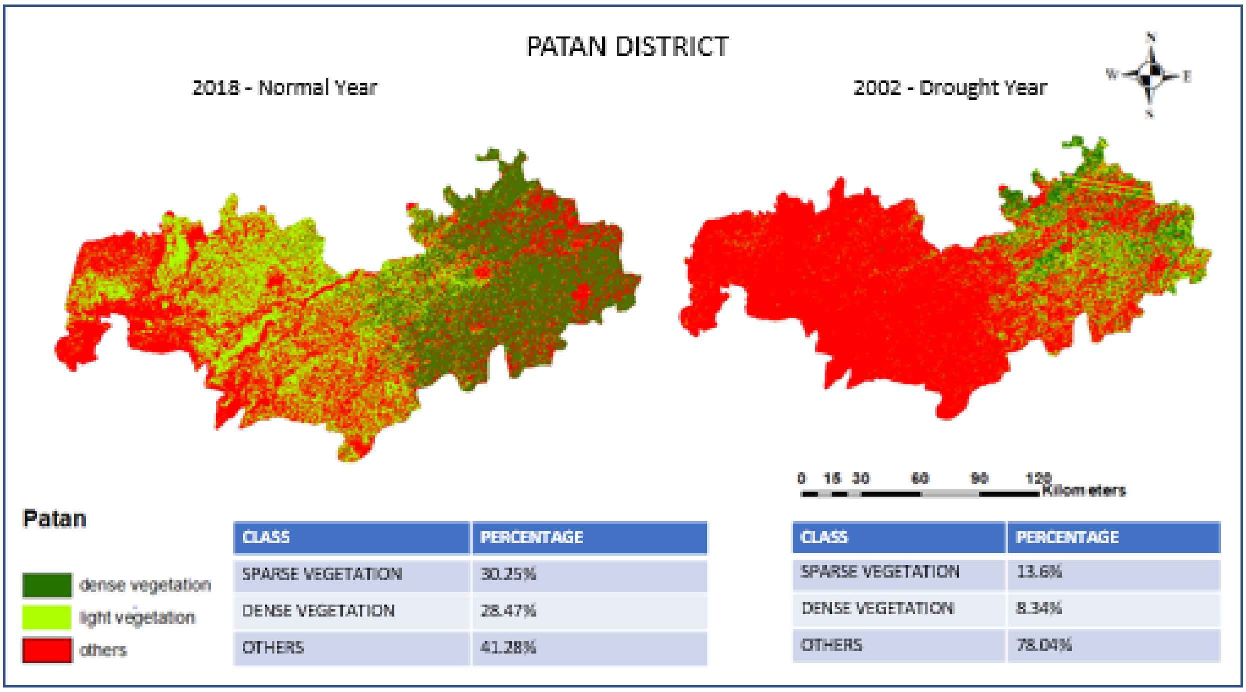


Figure 4: Land use Classification using Landsat data of Feb 2002 and Feb. 2018

NDVI Based Drought Condition Assessment

Among the assorted vegetation indices, Normalized Difference Vegetation Index (NDVI) is widely used for operational drought assessment because of its simplicity in calculation, easy to interpret and its ability to partially compensate for the effects of the atmosphere. NDVI is a transformation of reflected radiation within the visible and close to infrared bands of a sensor system and is a function of green leaf area and biomass.

NDVI Image Thresholding

The histograms of NDVI images were generated and agricultural vegetation (dense and sparse) as well as other land use classes were identified on the Landsat digital data of Feb 2002 and Feb 2018 and NDVI images. The agricultural vegetation was divided in to two density classes and the range of NDVI values for each class were decided for 2002 and 2018 images separately. The false colour composites images from NDVI threshold values were generated separately for drought year2002 and normal monsoon season of 2018. The classified images based on NDVI thresholding of 2002 and 2018 covering Patan district are given in Figure-5. The NDVI thresholding range values for dense agriculture, sparse agriculture and other land use classes were generated. NDVI Thresholding is dividing the number of classes in a particular range where we can identify different classes.

Standardized Precipitation Index (SPI) of Normal and Drought Years

Standardized Precipitation Index (SPI) values were computed using monthly rainfall data from July to October for 18 years using DrinC software. Firstly, the DrinC software computes PET and then this PET is used to calculate SPI. The quantitative assessment of meteorological drought in the Patan District was carried out using the SPI ranges as suggested by McKee *et al*. (1993) corresponding to different severity levels of drought. The SPI values and different classes of water and dryness condition are given in Table-2. The SPI values computed for different years in Patan district are given in Table -3 and classified into various drought severity levels during different monsoon seasons. The Drought that occurred during 2002-03 was moderately drought condition as per SPI values however, during 2000-01, 2009-10, 2012-13, 2014-15, 2015-16 and 2016-17 it was mild drought condition and SPI values ranged between 0 to -0.99 as per McKee *et al*. (1993) classification.

Rainfall Deviations and SPI Values

The SPI calculation for any location is based on the long-term precipitation record that is fitted to a probability distribution, which is then transformed into a normal distribution so that the mean SPI for the location and desired period is zero (Edwards and McKee, 1997). A drought event occurs any time the SPI is continuously negative and reaches intensity of -1.0 or less. The event ends when the SPI becomes positive. Each drought event, therefore, has a duration defined by its beginning and end, and intensity for each month that the event continues. The positive sum of the SPI for all the months within a drought event can be termed the drought's "magnitude". The rainfall deviations from the normal and SPI values were compared to evaluate the rainfall occurrence with SPI values in Patan District. The rainfall deviations from the long term normal rainfall were computed as follows:

$$\text{Rainfall Deviation (\%)} = (\text{Actual Annual rainfall} - \text{Normal Rainfall}) / \text{Normal Rainfall} * 100 \qquad (2)$$

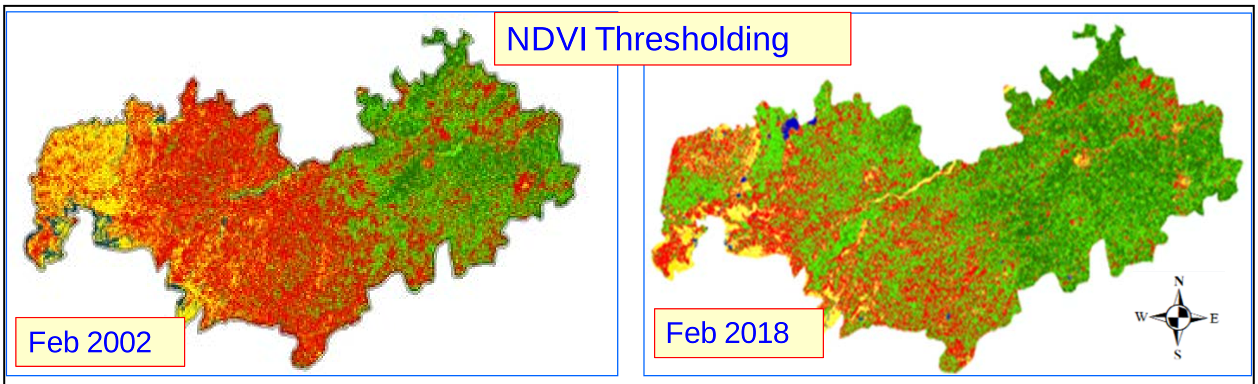
If the occurrence of rainfall is zero then rainfall deviation can be -100%. The scatter plot of annual rainfall deviations and SPI is given in Figure-5. The rainfall deviations are positive if the actual rainfall is greater than normal rainfall and negative if the actual rainfall is less than normal rainfall. Figure-5 indicates that high negative rainfall deviations (-40 to -70%) having low rainfall occurrence were associated with negative SPI values ranging from -0.5 to -1.1. These SPI values represent the mild to moderate drought conditions during these years. The positive rainfall deviations were observed during 7-years out of 18 years considered in this study. The rainfall occurrence during 2006, 2007 and 2010 had highest positive rainfall deviations of 99%, 77% and 43%, respectively. It was observed that these positive rainfall deviations were associated with positive SPI values of 1.08, 0.57 and 0.62 of respective years indicating moderately wet and mildly wet conditions.

Aridity Index and Drought Assessment

An Aridity index (AI) is a numerical indicator of the degree of dryness of the climate at a given location. These indicators serve to identify, locate or delimit regions that suffer from a deficit of available water, a condition that can severely affect the effective use of the land for agriculture. The Aridity Index in this study is computed using the UNEP (United Nations Environment Programme, 1992), defined as: AI=P/PET. The PET is computed using the DrinC software. The computed PET and Aridity Index values for various years from 2000 to 2017 are given in Table-4. UNESCO (1979) proposed a classification of climate zones based on AI index, in which arid regions are defined by an index of less than 0.20 (Table-5). Alternative versions of the classification use an AI value for 0.05 for the boundary between hyper-arid and arid regions.

Table-4 indicates that during 2002 total precipitation was very less resulting in Aridity Index of 0.09 which is classified as hyper arid for the Patan District. The Drought that occurred during 2002-03 was moderately drought condition as per SPI values however, during 2000-01, 2009-10, 2012-13, 2014-15, 2015-16 and 2016-17 it was mild drought condition and SPI values ranged between 0 to -0.99 as per McKee et al. (1993) classification.

The monsoon seasons having high negative rainfall deviations (-40 to -70%) with low rainfall occurrences, as per aridity index values for these years they have been classified as arid and semi-arid conditions which correspond to mild to moderate drought conditions during these years.



LEGEND	2002	2018
Water	-0.512 to -0.1376	-0.2681 to 0.0385
Waste Land	-0.137 to -0.0726	0.0385 to 0.1036
Barren Land	-0.078 to 0.0269	0.1036 to 0.1687
Sparse Vegetation	0.020 to 0.2963	0.1687 to 0.3041
Dense Vegetation	0.2963 to 0.930	0.3041 to 0.5695

Figure 4: Land use classification based on NDVI Thresholding for 2002 and 2018 images

Table-2: SPI values & Drought Categories

SPI	Classification
2.00 >	Extremely wet
1.50 to 1.99	Very wet
1.00 to 1.49	Moderately wet
0 to 0.99	Mildly wet
0 to -0.99	Mild drought
-1 to -1.49	Moderate drought
-1.50 to -1.99	Severe drought
-2.00 <	Extreme drought

Table-3: SPI values and drought severity

SPI INDEX		
Year	SPI	
2000 - 2001	-0.69	Mild Drought
2001 - 2002	0.53	Mildly wet
2002 - 2003	-1.08	Moderately drought
2003 - 2004	0.07	Mildly wet
2004 - 2005	0.16	Mildly wet
2005 - 2006	0.58	Mildly wet
2006 - 2007	1.08	Moderately wet
2007 - 2008	0.57	Mildly wet
2008 - 2009	0.31	Mildly wet
2009 - 2010	-0.58	Mild Drought
2010 - 2011	0.62	Mildly wet
2011 - 2012	0.62	Mildly wet
2012 - 2013	-0.55	Mild Drought
2013 - 2014	0.36	Mildly wet
2014 - 2015	-0.13	Mild Drought
2015 - 2016	-0.11	Mild Drought
2016 - 2017	-0.20	Mild Drought

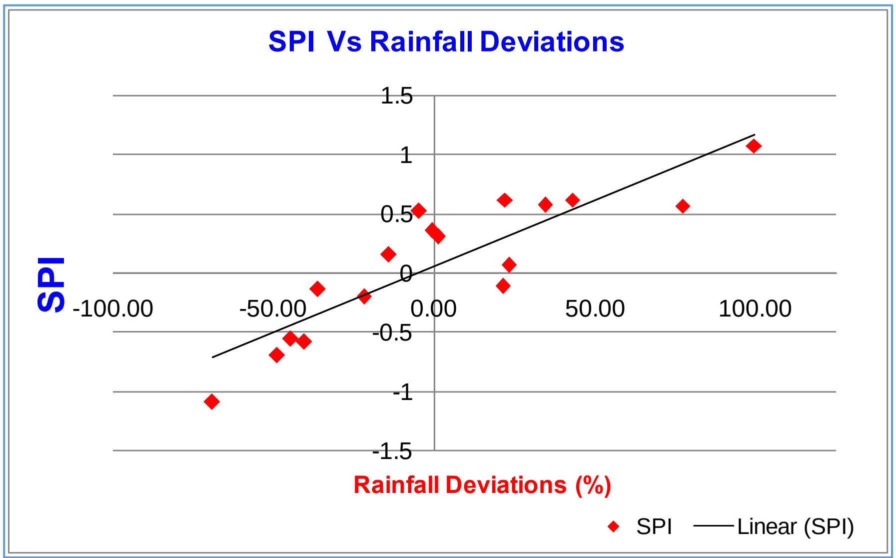


Figure-5: Annual rainfall Deviations and SPI values in Patan District

Table-4: Computed PET and Aridity Index values using DrinC Software

ARIDITY INDEX				
	AVERAGE PRECIPITATION(mm)	PET	ARIDITY INDEX	CLASSIFICATION
2000	285.56	1405.873604	0.2	Arid
2001	533.53	1538.256256	0.34	Semi-arid
2002	173.09	1796.276779	0.09	Hyperarid
2003	689.04	1764.789581	0.39	Semi-arid
2004	479.82	1763.853157	0.27	Semi-arid
2005	752	1674.487625	0.44	Semi-arid
2006	1116.79	1562.671291	0.71	Dry Subhumid
2007	991.16	1730.846542	0.57	Dry Subhumid
2008	565.54	1806.761047	0.31	Semi-arid
2009	332.04	1857.899048	0.17	Arid
2010	799.875	1849.391136	0.43	Semi-arid
2011	682.875	2011.276039	0.33	Semi-arid
2012	309.75	1898.535347	0.16	Arid
2013	554.875	1998.572113	0.27	Semi-arid
2014	357.25	2022.193466	0.17	Arid
2015	678.33	1925.37133	0.35	Semi-arid
2016	436.83	2025.653694	0.21	Semi-arid
2017	1156.33	1801.924003	0.64	Dry Subhumid
2018				

Table-5: Classification based on Aridity Index

Calssification	Aridity Index
Hyperarid	AI<0.05
Arid	0.05<AI<0.20
Semi-Arid	0.20<AI<0.65
Dry subhumid	0.50<AI<0.65

The computed annual PET values from 2000 to 2017 using DrinC software are given in Figure-6. As per 2017 and 2018 were normal monsoon years as per SPI values come under Near Normal and as per Aridity index values comes under Dry sub-humid. Because of these conditions, total Agriculture vegetation in Patan taluka was very high as compared to 2002. As per SPI values, 2006-2007 was in the category of Moderately wet and Aridity Index 2000, 2009, 2012, 2014 are the years with drought conditions.

Conclusions

The study was carried out for monitoring Climate change and drought assessment over Patan District using Landsat7 and Landsat 8 digital data of the drought (2002) and normal monsoon year (2018). Meteorological Data of Last 18 Years from 2000 to 2018 was collected from State Water Department to carry out various Indices. Visual interpretation, as well as digital classification techniques, was used to carry out the change in the climate of Patan city using Landsat-7 and Landsat-8 digital data. The major conclusions of this study were as followed:

- Supervised Classification was carried out on Landsat-7 and Landsat-8 images of the drought and normal monsoon periods to study the changes in agricultural vegetation.
- The results indicate that total agricultural vegetation during drought season was only 21.9 per cent (2002) which has increased to 58.7 per cent during the normal monsoon season of 2018.
- Meteorological Drought indices like Aridity index (AI) and standard Precipitation Index (SPI) were calculated from the meteorological data of past 16-years using DrinC software.
- The rainfall deviations are positive if the actual rainfall is greater than normal rainfall and negative if the actual rainfall is less than normal rainfall. The high negative rainfall deviations (-40 to -70%) having low rainfall occurrence were associated with negative SPI values ranging from -0.5 to -1.1 in Patan district.
- It was observed that these positive rainfall deviations were associated with positive SPI values of 1.08, 0.57 and 0.62 of respective years indicating moderately wet and mildly wet conditions.

During drought year of 2002 total precipitation was very less resulting in Aridity Index of 0.09 which is classified as hyper arid for the Patan District.

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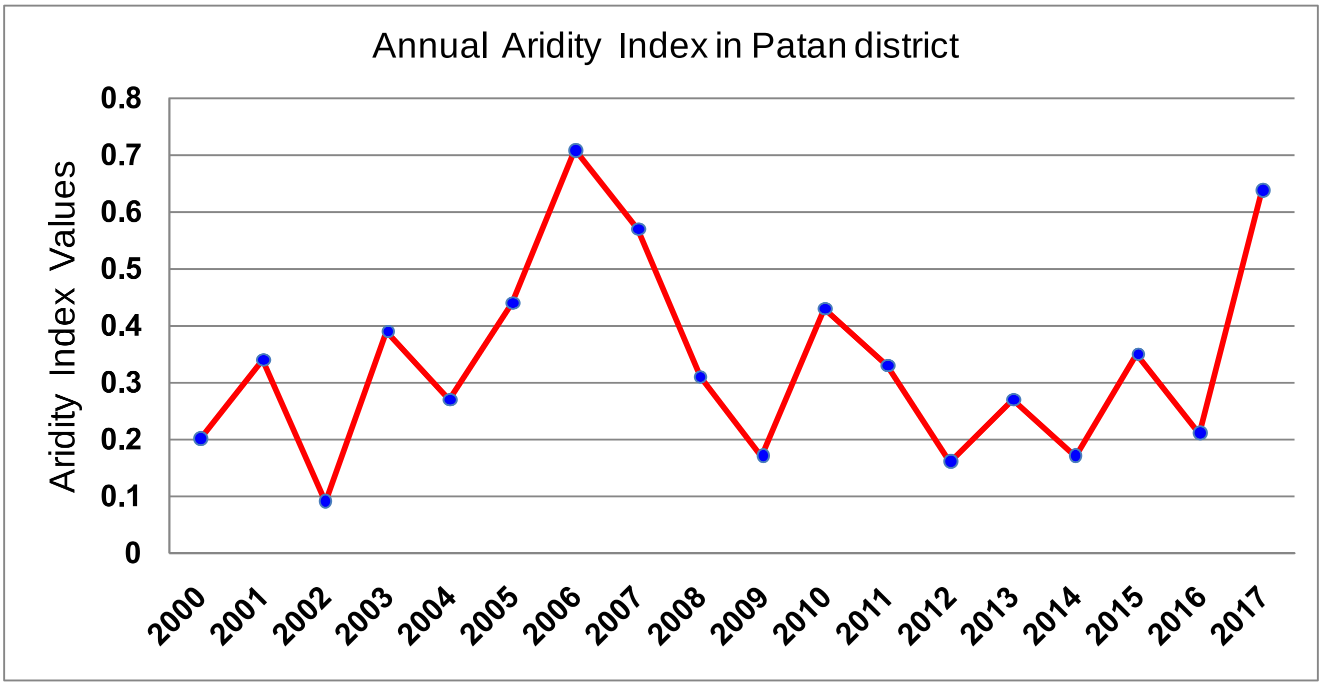

Figure-7: Annual Aridity Index values in Patan District

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