Assessing Agricultural Vulnerability to Climate Change and Drought in Sabarkantha Using Geospatial Techniques

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ABSTRACT

Drought is a long duration dry period in natural Climate Cycle.it is defined as "Severe water shortage". In recent years, Geographic Information System (GIS) and Remote Sensing (RS) have played a key role in studying different types of hazards either man-made or natural. This Study stresses upon the use of GIS and RS in the field of climate change and drought impact on agriculture. Different indices were computed using Landsat-7 data of January 2002 and Landsat-8 data of February 2018 as well as meteorological data for drought severity assessment in Sabarkanta district, Gujrat State. The indices generated include Normalize Difference Vegetation Index (NDVI) for 2002 and 2018 and meteorological data based Standardized Precipitation Index (SPI), and Aridity Index (AI). Correlation analysis was performed between NDVI, SPI and AI. SPI and AI values were incorporated to get the spatial pattern of meteorological based drought. NDVI threshold were Identified to get the Agricultural Drought risk. Large historical datasets are required to study drought condition of the study area, to study complex interrelationship between spatial data and meteorological data. In this study, the drought prone areas in the Sabarkantha district were identified by using RS and GIS technology and drought risk areas were delineate by integration of satellite images and meteorological information in GIS environment.

Keywords: *Normalized Deference Vegetation Index (NDVI), Standardized Precipitation Index (SPI), Aridity Index (AI).*

I. INTRODUCTION

Drought is a period of time with below normal rainfall. Droughts are natural events. It also describes as deficiency of precipitation over an extended period of time. A Drought can last for months or years. may be declared after as 15 days. Generally, this occurs when a region receives consistently below mean (average) precipitation. It can have significant impact on the ecosystem and agriculture of the affected region. Although droughts can continue for several years. even a short, severe drought can cause significant damage and harm to the local economy. Precipitation deficiency, dry season, El Nino, Erosion and Human activities, climate change are the major causes of drought. Drought can be classified in to four categories such as meteorological drought, agricultural drought, hydrological drought, and socio-economic drought. The major parameters which are used to analyse drought condition are vegetation health, rainfall, evaporation, stream flow, temperature and soil moisture.

There are four basic approaches to measuring drought: meteorological drought, Hydrological drought, agricultural drought, and socioeconomical drought. The first three deal with ways to measure drought as physical phenomenon. The last deals with way to measure drought in terms of supply and demand, tracking the effects of water shortfall as it ripples through socioeconomic system.

Type of Droughts:

- **Meteorological Drought:**

It is defined usually on the basis of the duration of the dry period and degree of dryness (in comparison to normal or average amount). It is also defined by comparing the rainfall in a particular place and at a particular time with normal mean rainfall for that place. That's why this drought have definition for specific to a particular location. This type of drought leads to an exhaustion of soil moisture and this almost always has an impact on crop production.

- **Agricultural Drought:**

This type of drought links various aspects of hydrological or meteorological drought to agricultural impacts, differences between actual and potential evotranspiration, soil water deficits, focusing on precipitation shortage, reduced ground water or reservoir levels and so on. Plant water demands depends on biological characteristics of the specific plants, its growth stage, prevailing weather conditions, and the physical and biological properties of the soil.

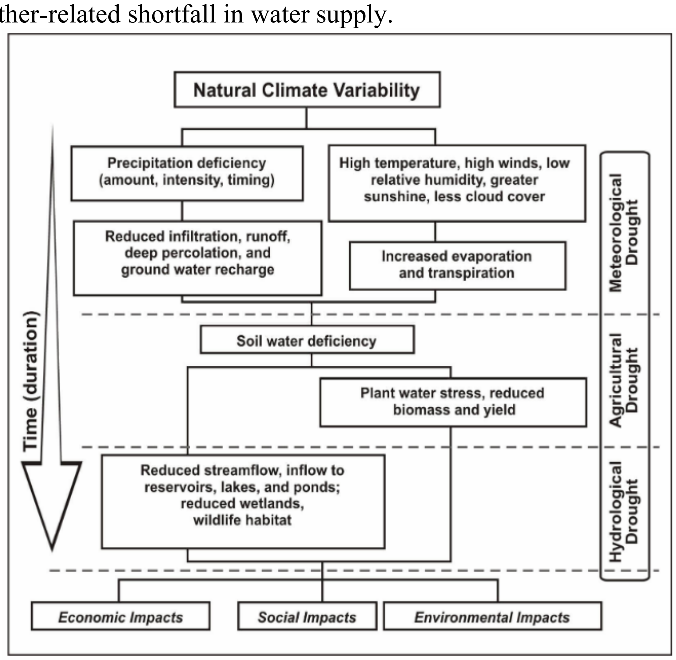
This drought is also referring to circumstances when soil moisture is insufficient and results in the lack of crop growth and production. It concerns itself with short time drought situations. Agriculture can rebound within a very short period of time depending upon strength of drought conditions or precipitation event. A nice definition of agricultural drought should be able to report for the variable vulnerability of crops during different stages of crop development, from emergence to maturity. Deficient topsoil moisture at planting may leading to low plant populations per hectare, hinder germination and reduction of final yield. However, if top soil moisture is sufficient for early growth demands, shortage in subsoil at early stage may not affect the final yield. If subsoil moisture is restored as the growing season progresses or if rainfall meets plant water needs.

- **Hydrological Drought:**

Hydrological drought is related with the effect of periods of precipitation, streamflow, reservoir and lake levels, groundwater. The frequentness and severity of this drought is often defined on a river basin scale or watershed. Although drought emerge with a deficiency of precipitation, hydrologist are more bothered with how this deficiency plays out through the hydrologic system. Hydrological drought is usually out of phase with or lag the occurrence of agricultural and meteorological droughts. It takes longer for precipitation deficiencies to show up in elements of the hydrological system such as streamflow, soil moisture, and groundwater and reservoir levels. As a result, these impressions are out of phase with impacts in other economic sectors.

- **Socioeconomic Drought:**

Socioeconomic drought definition associate with the supply and demand of some economic good with elements of meteorological, agricultural, and hydrological drought. It vary from the aforesaid types of drought because its incidents depends on the time and space processes of supply and demand to classify or identify droughts. The supply of many economic goods, such as food grains, water, fish and hydroelectric power, depends on weather. Because of the natural variableness of climate, water supply in sufficient in some years but unable to meet human and environmental need in other years. Socioeconomic drought occur when demands for and economical goods exceeds supply as a result of a weather-related shortfall in water supply.



Series of drought occurrence and impacts for commonly accepted drought types. All droughts derived from a deficiency of precipitation or meteorological drought but other types of drought and impacts cascade from this deficiency. (Source: NDMC)

II. OBJECTIVES

- To Study the Impact of Drought on Agriculture in Sabarkantha district using multi-date Landsat Satellite data

- To Analyze the Meteorological data and Compute Meteorological Indices related to Drought and study its Variability over the period of 15 years.
- Relate the Meteorological Indices with Agriculture Drought Condition in Sabarkantha District.

III. MATERIALS AND METHODS

Study Area
Sabarkantha District is situated in North Eastern part of Gujarat State. Himmatnagar is the administrative headquater of Sabarkantha District, about 80 km from Ahmedabad.

Sabarkantha District is surrounded by Rajasthan state to the north-east, Banaskantha and Mehsana districts to the west, Gandhinagar to the south and Aravalli District to the South- East. This District belongs to Western India.

The district is situated between 23.03 N latitude and 24.30 N latitude & 74.43 E longitudes to 73.39 E longitudes. The "Tropic of Cancer" passes through Sabarkantha district.

The total area of the district is 5390 Sq.km. North – Eastern part of the district is covered by the rows of "Aravalli" hills.

Average rainfall of Sabarkantha District is 825 mm.

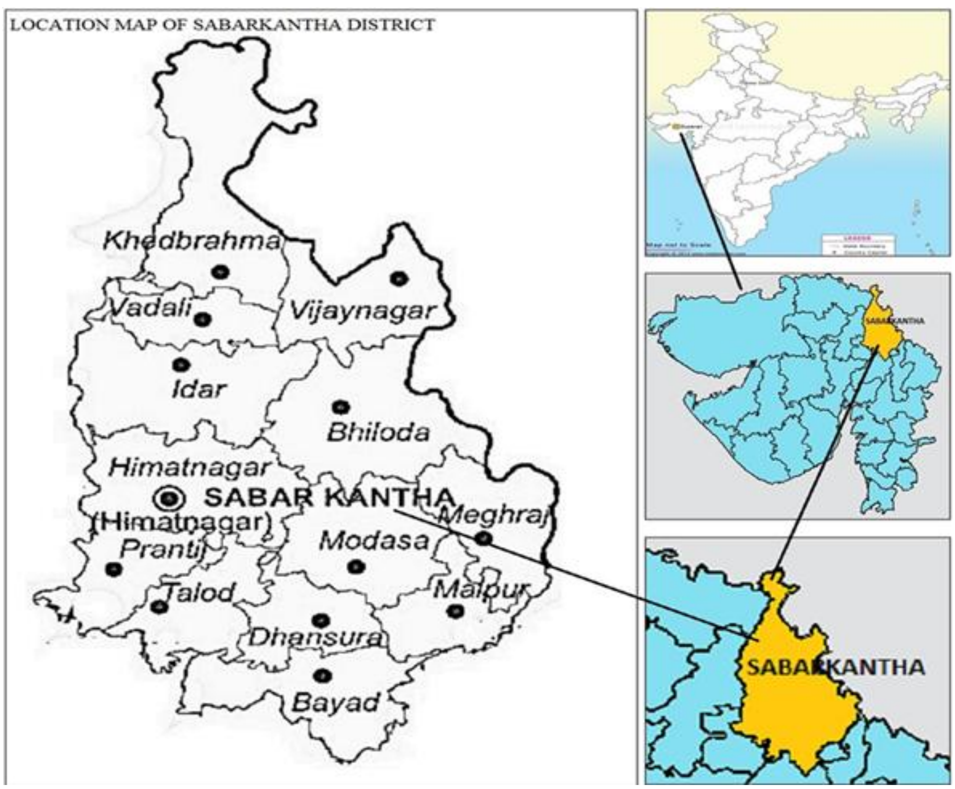


Figure-1: Location Map of Study Area

Meteorological Data
Monthly & year-wise rainfall and temperature datasets were acquired from Gujarat Water Data Centre, Gandhinagar from 2000 to 2017. The Gujarat Water Data Centre, Gandhinagar have setup a rainfall monitoring station for selected taluka.

Satellite Data
Landsat-7 ETM+ data of January 2002, and Landsat-8 OLI&TRIS data of February 2018 was downloaded from the earth explorer site: https://earthexplorer.usgs.gov/. the details of Satellite Data used are given in Table-1.

Table-1: Satellite data used for the study

Sr.No	Data	Date	Resolution
1	Landsat-7 ETM + Enhanced Thematic Mapper	January 2002	30m
2	Landsat-8 (OLI/TIRS)Operational Land Imager/ Thermal Infrared Sensor	February 2018	30m

Generation of Drought Indices

In this study different types of indices derived from satellite images and rainfall data were used for drought assessment.

The various drought indices generated are:
1. Normalized Difference Vegetation Index (NDVI),
2. Standardized Precipitation Index (SPI),
3. Aridity Index (AI).

Standardized Precipitation Index (SPI)

The Standardized Precipitation Index (SPI) is a broadly used index to characterize meteorological drought on a range of timescales.

On short timescales, the SPI is closely related to soil moisture, while at longer timescales, the SPI can be related to groundwater and reservoir storage.

Standardized Precipitation Index (SPI) is an index that was developed to evaluate precipitation deficit at different time scales and can also help assess drought severity (Das S, Choudhury MR, Nanda S., 2013).

$$\mathrm{SPI} = \{(Xij - Xim)/\sigma\}$$

Where, Xij= seasonal precipitation
Xim= long-term seasonal mean
σis= standard deviation.

The value of drought generally varies from -2 to +2. If the value is below 0 i.e. between -1 to -2 then the probability of drought is more, and it has unfavourable effect on crop productivity.
If it remains below than obviously the productiveness and health will be less. If the value is 0 than there would be no vegetation, and if the value is above 0 than vegetation will be high.

Aridity Index (AI)

A measure of the precipitation effectiveness or aridity of a region, proposed by De Martonne (1925), given by the following relationship:

$$\text{index of aridity} = \frac{P}{T + 10},$$

Where, **P (cm)=** annual precipitation and,
T (°C) = Annual mean temperature.

Normalized Difference Vegetation Index (NDVI)

NDVI was first suggested by Tucker in 1979 as an index of vegetation health and density.

$$\mathbf{NDVI = (NIR\ reflectance - Red\ reflectance) / (NIR\ reflectance + Red\ reflectance)}$$

Where, λNIR and λRED are the reflectance in the Near Infrared and Red bands, respectively. NDVI reflects vegetation vigor, percent green cover and biomass.

NDVI is the most commonly used vegetation index, it varies in a range of -1 to + 1.
However, NDVI a) uses only two bands and is not very sensitive to influences of soil background reflectance at low vegetation cover, b) has a lagged response to drought because of a lagged vegetation response to developing rainfall deficits due to residual moisture stored in the soil.

Table-2: NDVI range

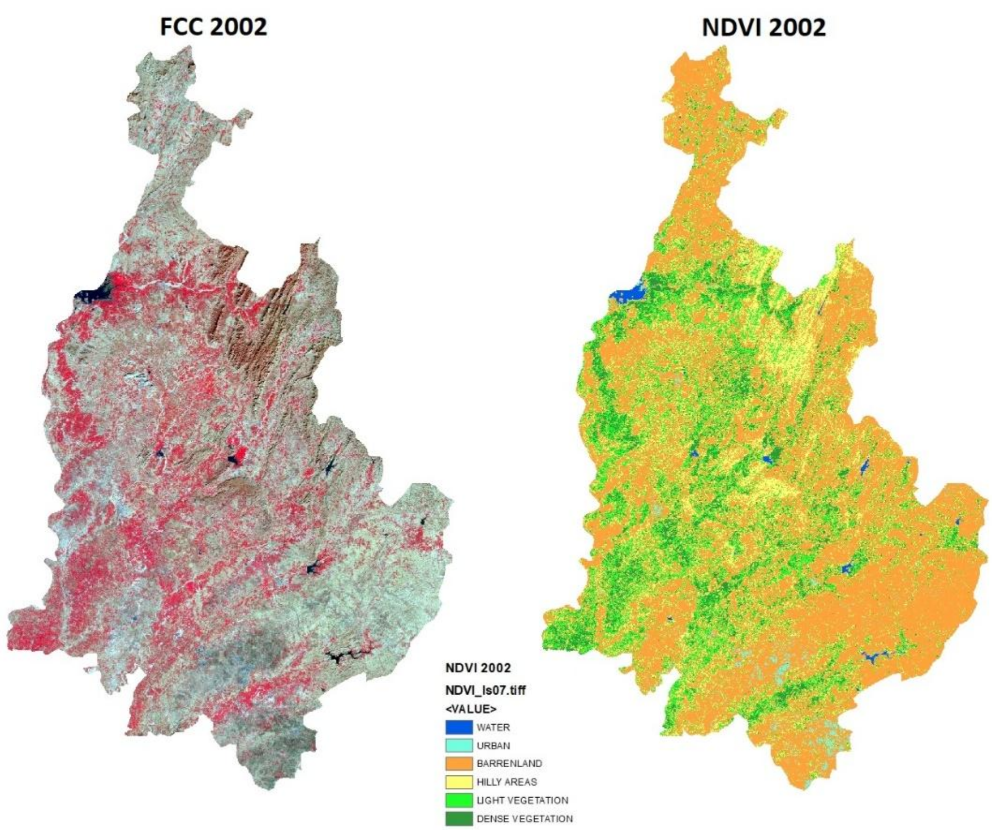
NDVI Range	Type of cover
-1.0 - 0,0	Barren areas
0.0 – 0.5	Vegetation cover
0.5 - 0.7	Dense vegetation
0.7 - 1.0	Very dense vegetation

IV. RESULT AND DISCUSSION

Normalized Difference Vegetation Index (NDVI)

Normalized Difference Vegetation Index (NDVI) is broadly used for operational drought assessment because of its simplicity in calculation, easy to interpret and its ability to partially compensate for the effects of atmosphere, illumination geometry etc. (Malingreau, 1986; Tucker and Chowdhary, 1987; Johnson *et al*., 1993; Kogan, 2001). NDVI is a transformation of reflected radiation in the visible and NIR (Near Infrared) of a sensor system and is a function of green leaf area and biomass. Computation of NDVI is given by:

$$\text{NDVI} = (\text{NIR reflectance} - \text{Red reflectance}) / (\text{NIR reflectance} + \text{Red reflectance})$$



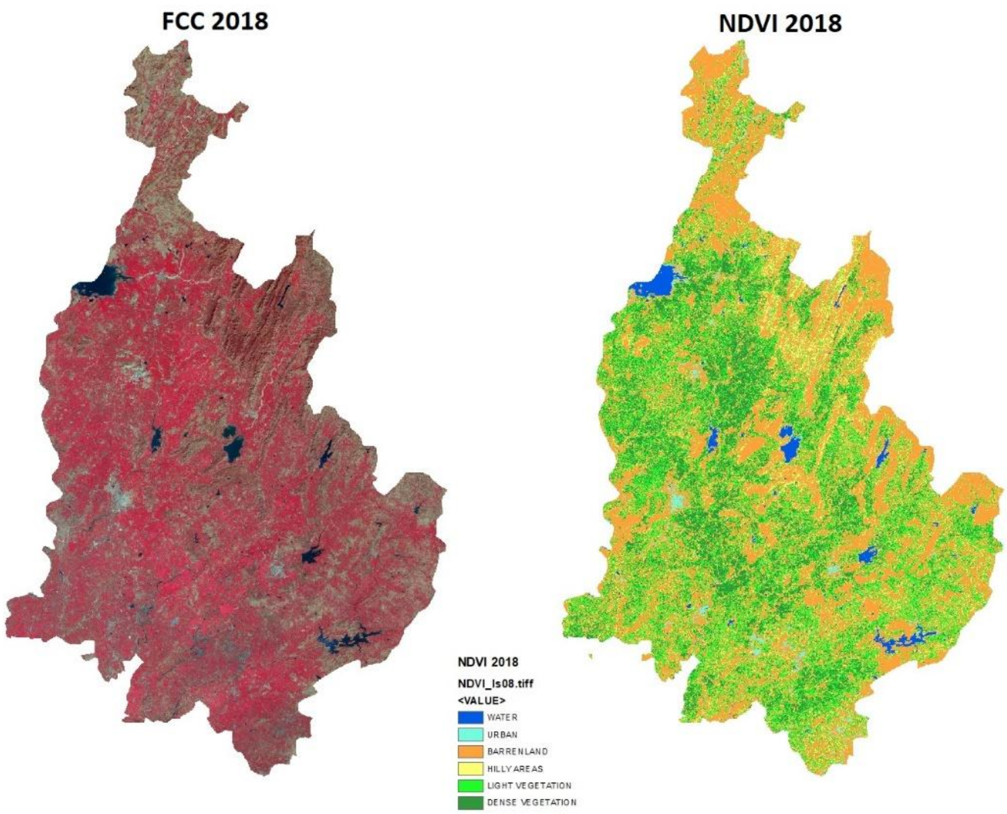


Figure 2: NDVI Based Drought Condition of Sabarkantha District (Gujarat)

Standardized Precipitation Index (SPI)

Drought risk has been identified using in Sabarkantha District (Gujarat) by interpolation SPI values of 15 years. SPI values from 2002 to 2017 for Sabarkantha District were computed.

$$SPI = \{(Xij - Xim) / \sigma\}$$

Where, Xij= is the seasonal precipitation

Xim is its long-term seasonal mean, σis its standard deviation.

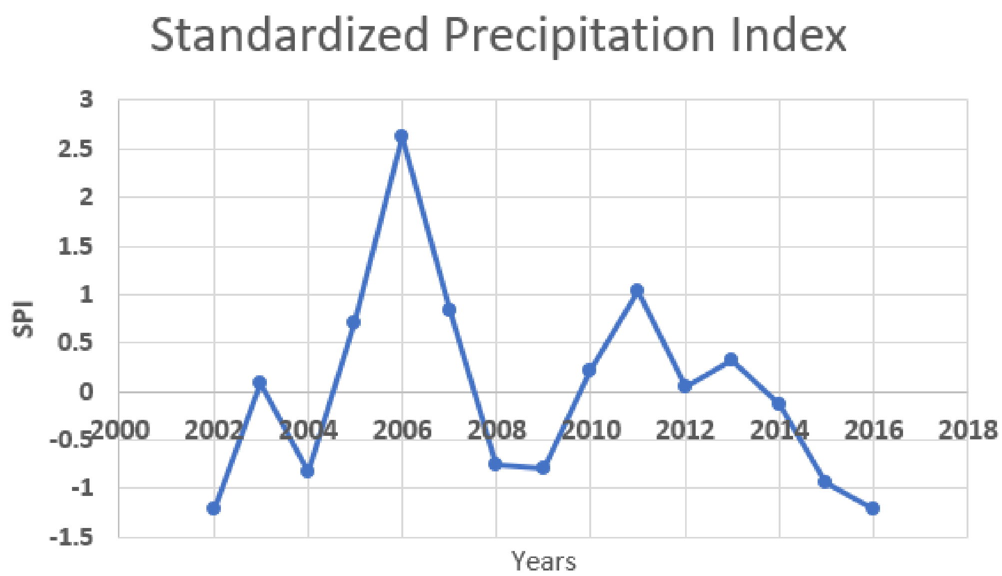
Table-3: SPI Classes

SPI Values	
2.0+	Extremely Wet
1.5 to 1.99	Very Wet
1.0 to 1.49	Moderately Wet
-.99 to .99	Near Normal
-1.0 to -1.49	Moderately Dry
-1.5 to -1.99	Severely Dry
-2 and Less	Extremely Dry

Table-4: Computed SPI values from 2002 to 2018

Years	SPI Values	Climate Type
2002-2003	-1.21	Moderately Dry
2003-2004	0.08	Near Normal
2004-2005	-0.82	Near Normal
2005-2006	0.71	Near Normal
2006-2007	2.61	Extremely Wet
2007-2008	0.83	Near Normal
2008-2009	-0.75	Near Normal
2009-2010	-0.79	Near Normal
2010-2011	0.2	Near Normal
2011-2012	1.04	Moderately Wet
2012-2013	0.04	Near Normal
2013-2014	0.32	Near Normal
2014-2015	-0.13	Near Normal
2015-2016	-0.93	Near Normal
2016-2017	-1.2	Moderately Dry

Table-5: SPI Graph



The SPI values and different classes of wetness and dryness conditions are given in Table-4. SPI is computed with help of stations yearly Rainfall data. The Drought that happened in 2002 and 2016 was very severe rather than 2006 which is very wet. Which is explained by the SPI values that range from -1.21 to 2.61. that result indicates that during 2002 and 2016 there is low rainfall and because of that it is known as worst dry seasons. On the other side, the SPI values in 2006 was above 2.0 which indicates during this year was relatively high precipitation as compare to 2002 and 2016.

Aridity Index (AI)

There is de Martonne classification for compute Aridity Index, where Aridity Index I has a direct ratio with rainfall and has an inverse ratio with the average annual temperature. So, increased I shows the high humidity and decreased I shows the aridity (dryness) of the region.

This classification is based on the average annual temperature. De-Martonne aridity index is calculated by the next calculation.

$$\text{index of aridity} = \frac{P}{T + 10},$$

Where,

I= Index of Aridity, P= Annual Precipitation, & T= Mean Annual Temperature

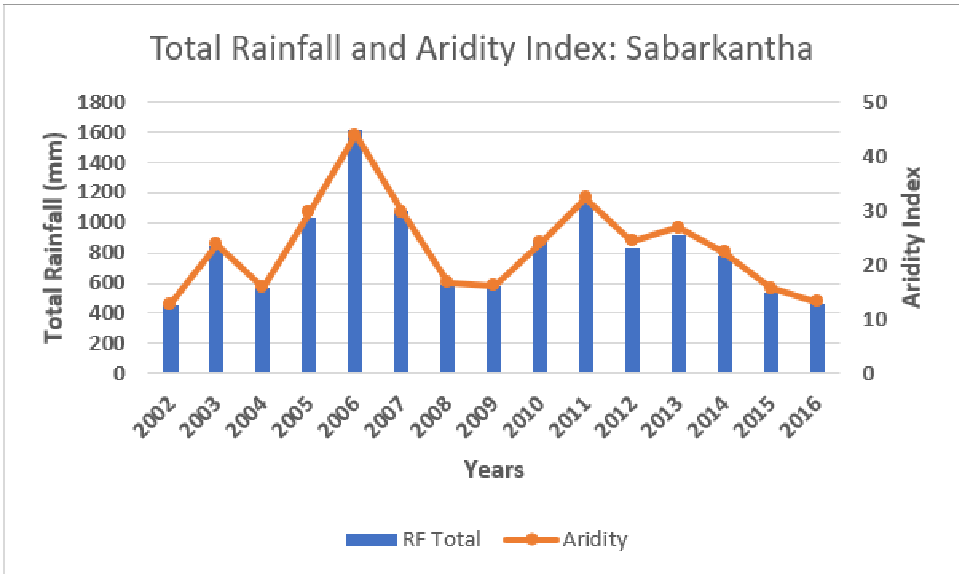
Table-6: Aridity Index (AI) Classes

Climate Type	Aridity Index
Arid	0-10
Semi-arid	10-20
Mediterranean	20-24
Semi-humid	24-28
Humid	28-35
Very Humid	35-55
Extremely Humid	>55

Table-7: Aridity Index (AI)

Years	Aridity Index	Climate Type
2002-2003	12.73	Semi-Arid
2003-2004	23.88	Mediterranean
2004-2005	15.88	Semi-Arid
2005-2006	29.72	Humid
2006-2007	43.98	Very-Humid
2007-2008	29.88	Humid
2008-2009	16.78	Semi-Arid
2009-2010	16.21	Semi-Arid
2010-2011	24.15	Semi-Humid
2011-2012	32.2	Humid
2012-2013	24.38	Semi-Humid
2013-2014	26.9	Semi-Humid
2014-2015	22.4	Mediterranean
2015-2016	15.8	Semi-Arid
2016-2017	13.19	Semi-Arid

Table-8: Aridity Index Graph



V. CONCLUSION

Agriculture remains by far the most vulnerable and sensitive sector that is seriously affected by the impacts of climate variability and climate change, which is usually manifested through rainfall variability and drought. In this study, the drought prone areas in the Sabarkantha district were identified by using Remote Sensing and GIS technology and agricultural drought risk areas were delineated by integration of satellite images, meteorological information.

This study was conducted to understand the impact of Drought on Agriculture in Sabarkantha district.

Landsat digital of 2002 and 2018 covering Sabarkantha district was analysed using open source QGIS Software and ArcMap Software.

The Meteorological Data like Monthly Total Rainfall, Minimum-MaximumTemperature, from 2002 to 2016 was analysed to derived Aridity Index and Standardized Precipitation Index. Which are the some of the best Indicators of Drought conditions.

2002 was a Drought year in Gujarat state. And 2006 was a good rainy season so as per the Aridity Index it was Very Humid condition in this district.

During 2016-1017 rainfall was not normal and it was below normal there for during this year as per the Aridity index it was semi-arid condition in this district.

The Aridity Index also indicated that the High Rainfall conditions Aridity Index was High and during Low Rainfall conditions Aridity was Low.

The Standardized Precipitation Index also showed that it was Positive values when Rainfall was Very High and had Negative values during the below Average Rainfall Conditions.

The Remote Sensing data along with Drought indices like Aridity Index and Standardized Precipitation Index were very useful to understand the Drought conditions, as well as the below normal Rainfall conditions.

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