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AGRICULTURAL DROUGHT MONITORING USING GEO-INFORMATICS TECHNOLOGY: A CASE STUDY OF SURENDRANAGAR DISTRICT, GUJARAT

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ABSTRACT

Drought is the most complex but least understood of all natural hazards. It is broadly defined as “sever water shortage”. In recent years, Geographic Information System (GIS) and Remote Sensing (RS) have played a key role in studying different types if hazards either natural or man-made. This study stresses upon the use of RS and GIS in the field of Drought Risk assessment. Various drought indices were computed using Landsat 7 data of February 2000, Landsat 4-5 TM data of February 2009 and Landsat-8 OLI & TIRS data of February 2018 as well as meteorological data for drought severity assessment and to derive spatiao-temporal drought risk areas facing agriculture in Surendranagar district, Gujarat State. The indices generated included Normalize Difference Vegetation Index (NDVI) for 2000, 2009 and 2018 and meteorological data based Standardized Precipitation Index (SPI) and Aridity Index. 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. 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 Surendranagar district were identified by using Remote Sensing and GIS technology and drought risk areas were to delineate by integration of satellite images, and meteorological Information in GIS environment.

Key Words: *Normalized Deference Vegetation Index (NDVI), Soil Adjusted Vegetation Index (SAVI), Land Use & Land Cover, Standardized Precipitation Index (SPI), Aridity Index (AI), Agricultural Drought Index*.

I. INTRODUCTION

Drought is a natural disaster which affects a wide range of ecological factors and activities related to agricultural, vegetation, human and wild life and local economies. Drought is an extensive period when a region receives a deficiency in its water supply, weather atmospheric, surface or ground water. A drought can last for months or years, or may be declared after as 15 days. Generally this occurs when a region receives consistently below average precipitation. It can have a significant impact on the ecosystem and agriculture of the affected region. Although droughts can persist for several years even a short, intense 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, socio-economic drought. The major parameters which are used to analyze drought condition are vegetation health, rainfall, evaporation, stream flow, and temperature and soil moisture. Drought indices are commonly used to assess the drought condition around the world because it is more functional than row data for decision making. The present study mainly concentrated on drought assessment of Surendranagar district in Gujarat. Surendranagar district as categorized under drought area of Gujarat. It happened due to meteorological and hydrological drought, agricultural drought inter-related with hydrology, it highly influence in primary economic activities such as agriculture and cropping pattern. The major objective was to monitor the drought using specific Remote Sensing based drought indices with the help of geospatial technology. 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 effective decision making process in reducing the impacts of drought.

II. MATERIALS AND METHODS

2.1 Study Area

Surendranagar District is one among 25 Districts of Gujarat State, India. Surendranagar District Administrative head quarter is Surendranagar. It is Located at 22.00^0 To 23.45^0 North, 69.45^0 To 72.15^0 East Longitude. It is Located 139 KM East towards State capital Gandhinagar. Surendranagar District population is 1755873. It is 16^{th} largest District in the State by population. Surendranagar District is sharing border with Ahmadabad District to the East, Rajkot District to the west. Surendranagar District occupies an area of approximately 10489 square kilometers. It's in the 67 meters to 108 meters elevation range. This District belongs to Western India.

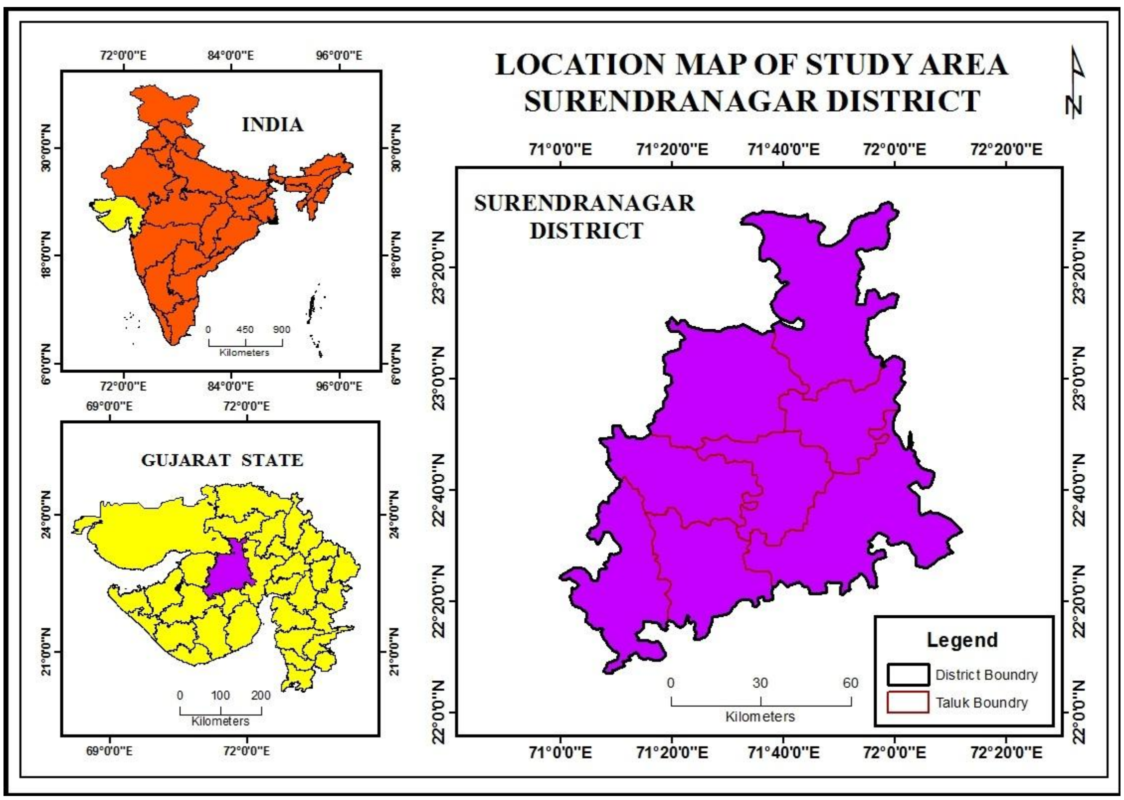


Figure- 1: Location Map of Study Area

2.2 Meteorological Data

Monthly & year-wise rainfall and temperature datasets were acquired from Gujarat Water Data Centre, Gandhinagar from 1999 to 2017. The Gujarat Water Data Centre, Gandhinagar have setup a rainfall monitoring station for each taluka.

2.3 Satellite Data

Landsat-7 ETM+ data of February 2000, Landsat 4-5 TM data of February 2009 and Landsat- 8 OLI & TIRS 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	Source	Resolution
1	Landsat 4-5 TM (Thematic Mapper)	USGS Earth Explorer	30m
2	Landsat-7 ETM + Enhanced Thematic Mapper	USGS Earth Explorer	30 m
3	Landsat-8 (OLI/TIRS)Operational Land Imager/ Thermal Infrared Sensor	USGS Earth Explorer	30m

2.4 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: i) Normalized Difference Vegetation Index (NDVI), ii) Soil Adjusted Vegetation Index (SAVI) iii) Standardized Precipitation Index (SPI) and iv) Aridity Index (AI).

2.4.1 Standardized Precipitation Index (SPI):

SPI was developed in Colorado by McKee et al., (1993) and is based just on precipitation and, therefore, requires less input data and calculation effort than PDSI. A long-term precipitation record at the desired station is fitted to a probability distribution, which is then transformed into a normal distribution so that the mean SPI is zero (Edwards and McKee 1997). SPI may be computed with different time scales (e.g., 1 year, 3 year..., 12 year). Positive SPI values indicate greater than mean precipitation and negative values indicate less than mean precipitation.

Rainfall deviation = (Actual rainfall − Normal rainfall) / Normal rainfall × 100

The positive sum of the SPI for all the months within a drought event is referred to as 'drought magnitude'. To date, SPI is finding more applications in southwest Asia than other drought indices due to its limited input data requirements, flexibility and simplicity of calculations.

2.4.2 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)** is the annual precipitation and ***T*** **(°C)** the annual mean temperature.

2.4.3 Normalized Difference Vegetation Index (NDVI):

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

NDVI = (λNIR - λRED) / (λNIR + λRED)

Where, λNIR and λRED are the reflectance in the NIR and Red bands, respectively. NDVI reflects vegetation vigor, percent green cover, Leaf Area Index (LAI) and biomass. The 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, and 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.

2.4.4 Soil Adjusted Vegetation Index (SAVI):

The SAVI is structured similar to the NDVI but with the addition of a "soil brightness correction factor,"

$$SAVI = \frac{NIR - RED}{(NIR + RED + L)} * (1 + L)$$

Where NIR is the reflectance value of the near infrared band, RED is reflectance of the red band, and L is the soil brightness correction factor. The value of L varies by the amount or cover of green vegetation: in very high vegetation regions, L=0; and in areas with no green vegetation, L=1. Generally, an L=0.5 works well in most situations and is the default value used. When L=0, then SAVI = NDVI.

2.5 Land Use and Land Cover (LU/LC):

Land cover is the physical material at the surface of the earth. Land covers include grass, asphalt, trees, bare ground, water, etc. Earth cover is the expression used by ecologist Frederick Edward Clements that has its closest modern equivalent being vegetation. The expression continues to be used by the Bureau of Land Management. Land use land cover data documents how much of a region is covered by forests, wetlands, Fallow land impervious surfaces, agriculture, and other land and water types. Water types include wetlands or open water. Land use shows how people use the landscape – whether for development, conservation, or mixed uses. The different types of land cover can be managed or used quite differently.

III. RESULT AND DISCUSSION

3.1 NDVI Based Drought Condition Assessment

Among the various 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 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 near infrared bands of a sensor system and is a function of green leaf area and biomass. Computation of NDVI is given by:

NDVI = (NIR reflectance – Red reflectance) / (NIR reflectance + Red reflectance)

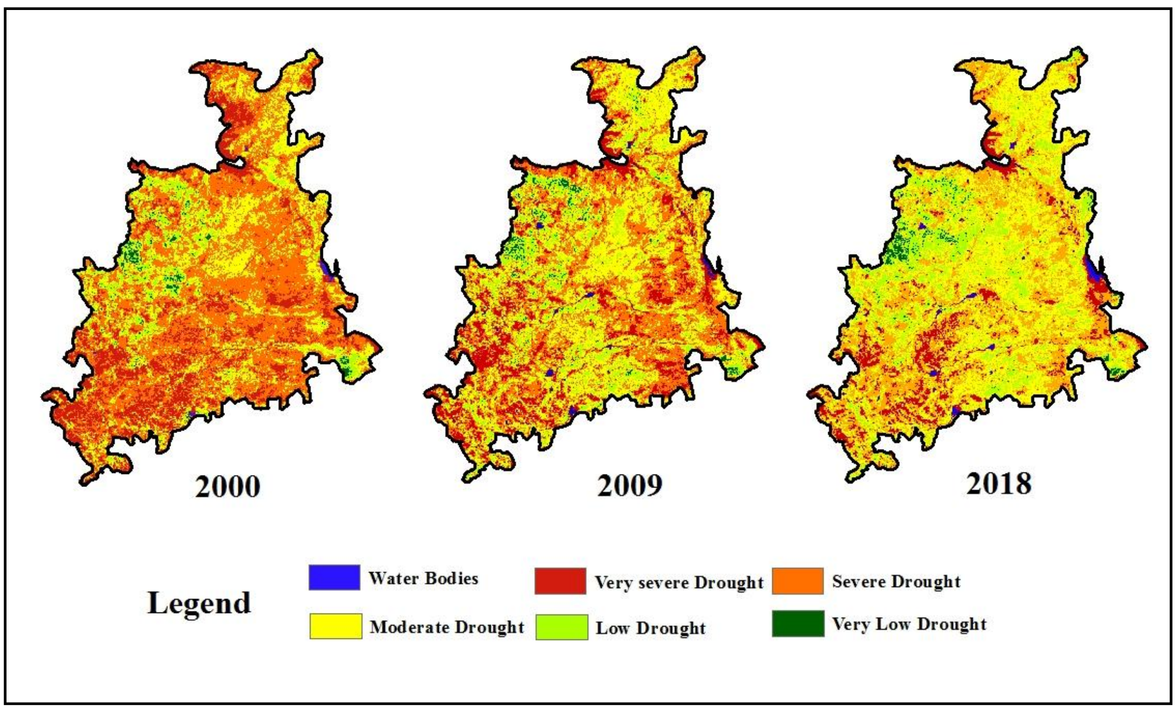


Figure 2: NDVI Based Drought Condition of Surendranagar District (Gujarat)

3.2 SAVI Based Drought Condition

The SAVI is structured similar to the NDVI but with the addition of a "soil brightness correction factor," where NIR is the reflectance value of the near infrared band, RED is reflectance of the red band, and L is the soil brightness correction factor. The value of L varies by the amount or cover of green vegetation: in very high vegetation regions, L=0; and in areas with no green vegetation, L=1. Generally, an L=0.5 works well in most situations and is the default value used. When L=0, then SAVI = NDVI.

SAVI = (NIR reflectance – Red reflectance) / (NIR reflectance + Red reflectance)*(1+L)

In this study, a functional L factor was developed, requiring no prior knowledge of vegetation amounts, to replace the constant L=0.5, in the SAVI equation. The purpose of this SAVI is to find a self-adjustable L so as to increase the SAVI vegetation sensitivity by increasing the dynamic range and further reducing the soil background effect.

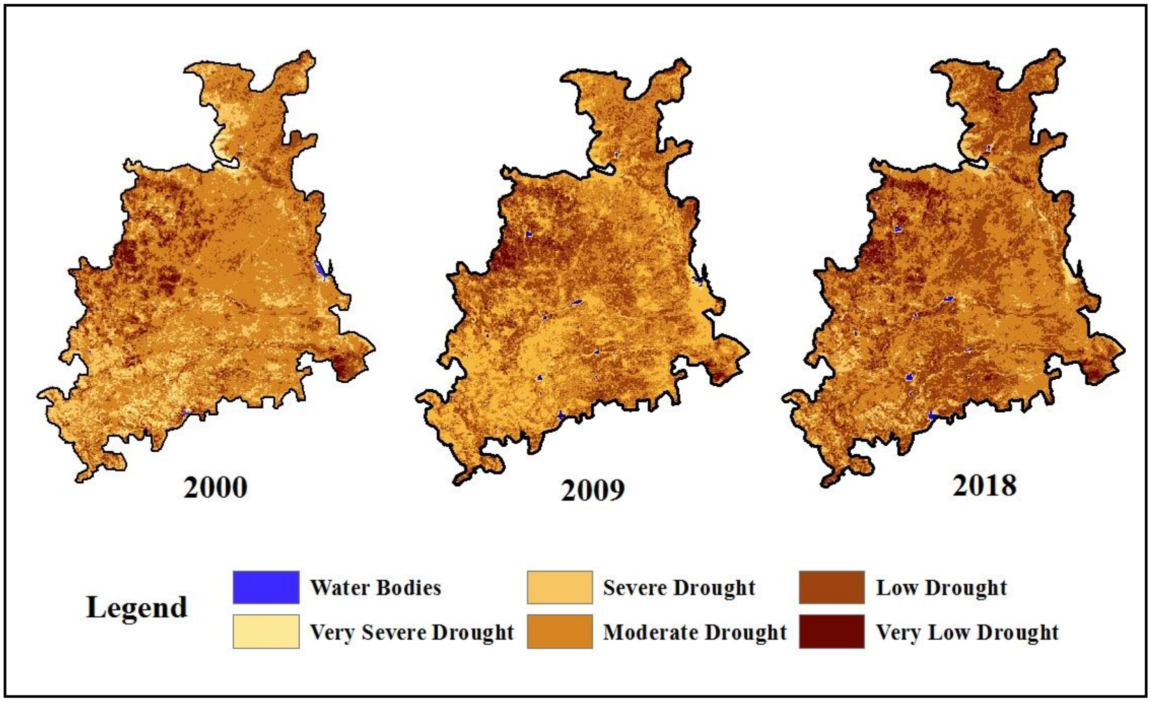


Figure-3: SAVI Based Drought Condition of Surendranagar District (Gujarat)

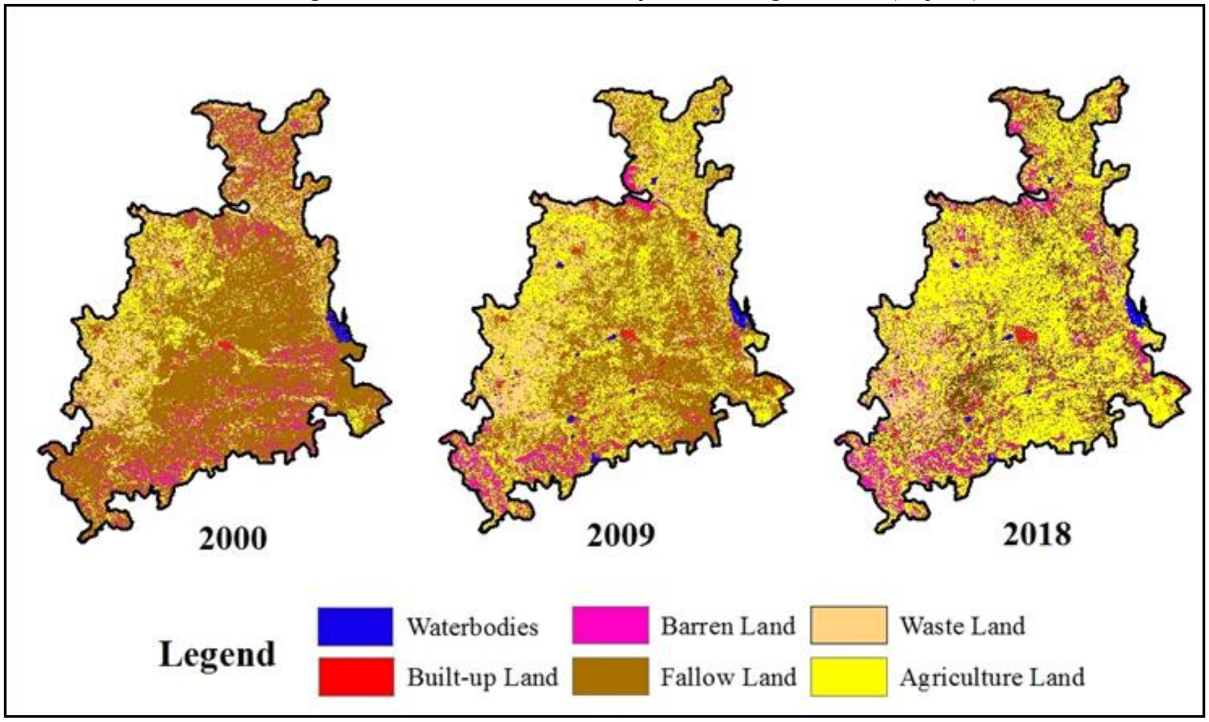
3.3 Land Use and Land Cover Classification

Land use refers to man's activities and various uses, which are carried on land. Land cover refers to natural vegetation, water bodies, rock/soil, artificial cover and others resulting due to land transformation. Although land use is generally inferred based on the cover, yet both the terms land use and land cover are closely related and interchangeable. Thematic land classes can be derived digitally by grouping pixels that have similar spectral signatures from the measurements of individual bands throughout the spectrum. Usually this classification is made with visible, near-infrared, and middle infrared part of the spectrum. The Land Use/Land Cover is classified by supervised classification using QGIS software.

Table-2: Land Use and Land Cover Statistics for 2000, 2009 & 2018

Sr. No.	Categories	2000		2009		2018	
		Area in Sq. Km	Area in %	Area in Sq. Km	Area in %	Area in Sq. Km	Area in %
1	**Water Bodies**	36.6	0.4	113.5	1.2	132.4	1.4
2	**Built-up Land**	180.4	2.0	199.4	2.2	235.8	2.6
3	**Fallow Land**	5670.7	61.5	3944.5	42.8	1871.1	20.3
4	**Waste Land**	1300.6	14.1	1568.9	17.0	823.5	8.9
5	**Agriculture Land**	898.3	9.7	2862.2	31.0	4984.5	54.0
6	**Barren Land**	1136.7	12.3	534.8	5.8	1176.0	12.8
	Total	9223.3	100	9223.3	100	9223.3	100.0

Figure-4: Land Use / Land Cover of Surendranagar District (Gujarat)



3.4 Standardized Precipitation Index (SPI)

Drought risk has been identified using in Surendranagar district (Gujarat) by interpolating SPI values over 20 years. SPI values for the years 1999, 2008 and 2017 for Surendranagar district were computed.

Table-3: Computed SPI Values during 1999, 2008 & 2017

Sr. No	Tahsil	1999	2008	2017
0	Chotila	3.10	-0.05	1.73
2	Chuda	0.17	-0.34	1.01
1	Dasada	-1.94	0.64	1.65
7	Dhrangadhra	4.06	1.56	3.90

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9	Lakhtar	-1.47	0.49	1.24
8	Limbdi	2.96	0.50	1.74
6	Muli	-2.35	0.19	-0.37
5	Sayla	-1.06	3.54	-0.40
4	Thangadh	-3.97	-3.19	-1.26
3	Wadhvan	-1.12	-0.64	5.93

The SPI values and different classes of wetness and dryness conditions are given in Table-4. SPI is computed with help of 10 station daily rainfall data. The drought that happened in year of 2000 and 2009 was very severe rather than 2018 as explained by the SPI values that range from -1.98 to 2.00 and -1.71 to 2.00 respectively. The result indicates that during 1999, 2008 and 2017 years, there was rainfall deficit in the growing season and it, therefore, was the worst dry seasons. On the other side, the SPI values in 2017 was ranged between 1.5 and 1.99 & Above 2.0 which indicates during this year there was relatively high precipitation as compare to 2008 & 1999. According to Standard Precipitation Index in 1999 North, west & central part of the area suffering High rainfall deficit, but in 2008 and 2017 it extends to southern region of the area and 2017 it converted as moderate to extremely wet rainfall condition, but South eastern part is always moderately rainfall deficit. The result of Standard Precipitation Index south eastern and northwestern part of the region have moderate climatic condition and few amount of area come under extreme wet or good rainfall condition.

Table-4: 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

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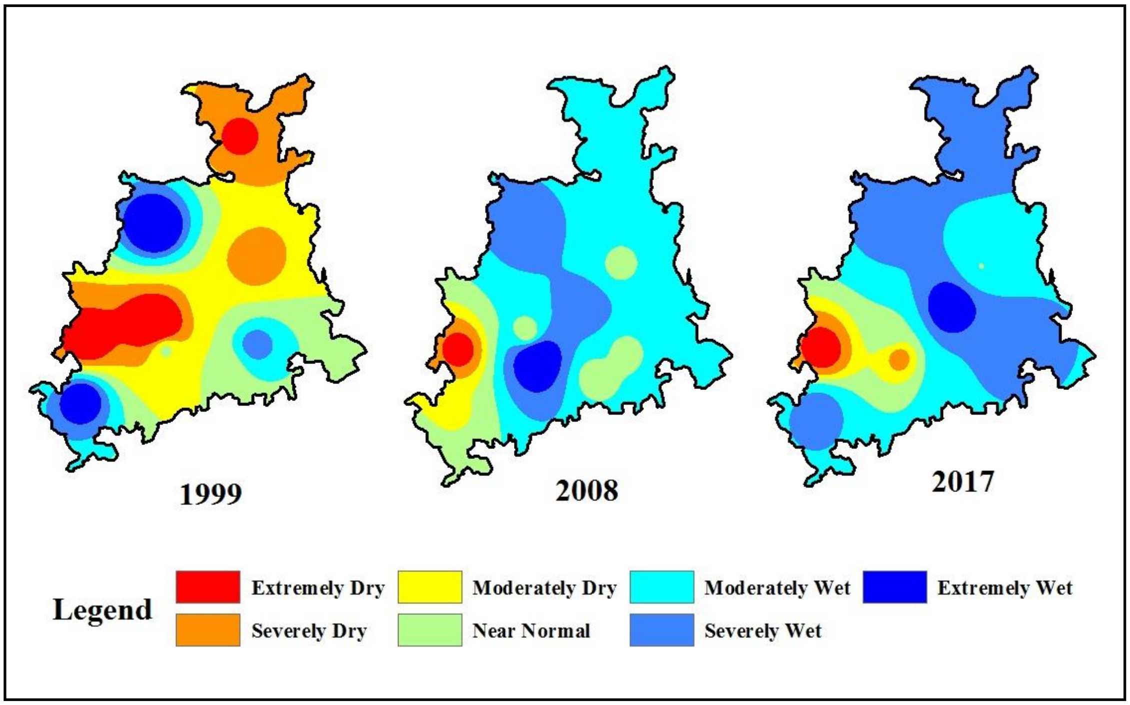

Figure-5: Standardized Precipitation Index of Surendranagar District (Gujarat)

3.5 Aridity Index

De Mortonne (1926) put forward the De Mortonne's index by modifying the Lang's rain factor in which he suggested to divide the annual precipitation in mm by the mean annual temperature in °C + 10 (http://www.droughtmanagement.info/aridity-index-ai/).

$$I = P/T + 10$$

Where,

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

Table-5: Aridity Index (AI) Classes

Classification	**Aridity Index**
Hyperarid	AI < 0.05
Arid	0.05 < AI < 0.20
Semi-arid	0.20 < AI < 0.50
Dry subhumid	0.50 < AI < 0.65

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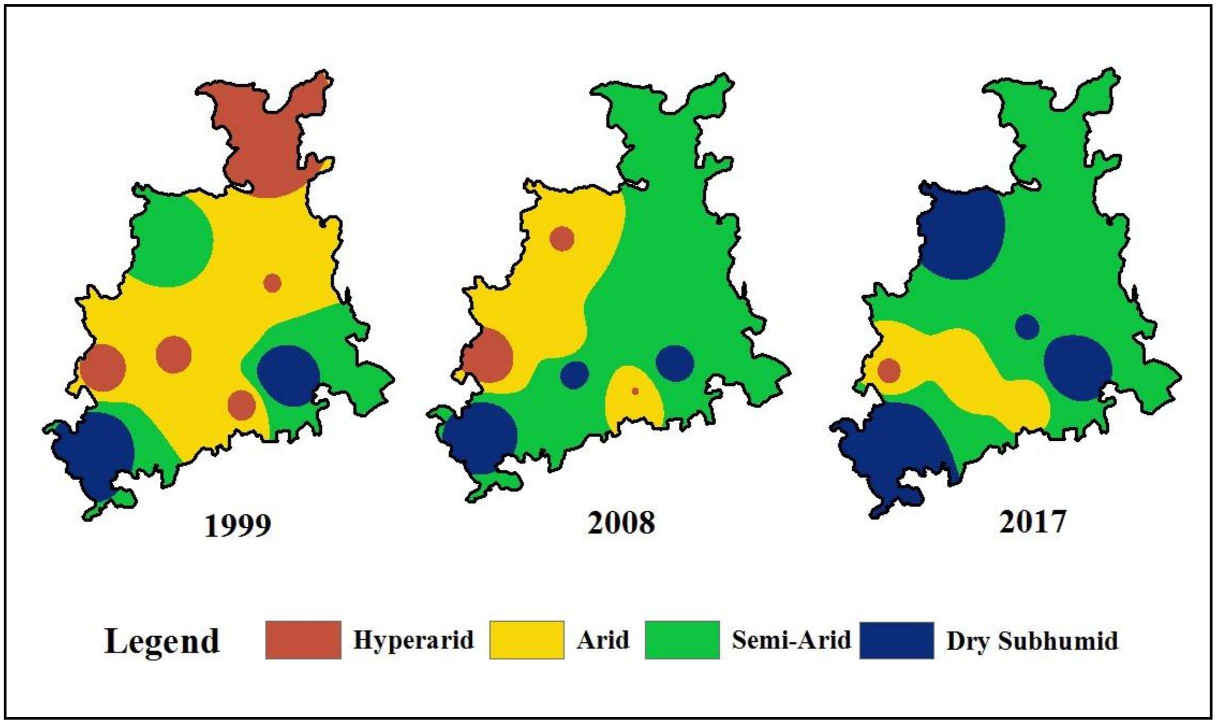

Figure-6: Aridity Index of Surendranagar District (Gujarat)

3.6 Agricultural Drought Risk Assesment

The agricultural drought risk maps for each three years has been prepared by integrating all the drought frequency layers generated from the three drought indices, NDVI, SAVI, LULC for each year. The Three layers representing drought indices were prioritized according to their degree of influence using pair-wise comparison and the drought condition maps were obtained by overlaying all the three indices in terms of weighted overlay methods using the QGIS. During the weighted overlay analysis, the ranking has been given for each individual parameter of each indices and the weights were assigned according to the influence of the different parameters. Based to the result derived from the combining of all these parameters.

Surendranagar district is classified into five agricultural drought severity classes, very severe, severe, moderate, low, and very low. From the obtained result of drought condition map of 2000 it has been observed that, maximum very Severe drought is covered in Central, North Eastern western part of the Surendranagar district. According to 2009 image 63 percent of the total geographical area of Surendranagar District affect very severe drought condition. Drought condition Surendranagar district condition map of 2009 is showing 52 percent of area is covered by Severe and Very Severe drought within the entire study area. Similarly, drought condition map of 2018 shows minimum drought from 2000 and 2009.

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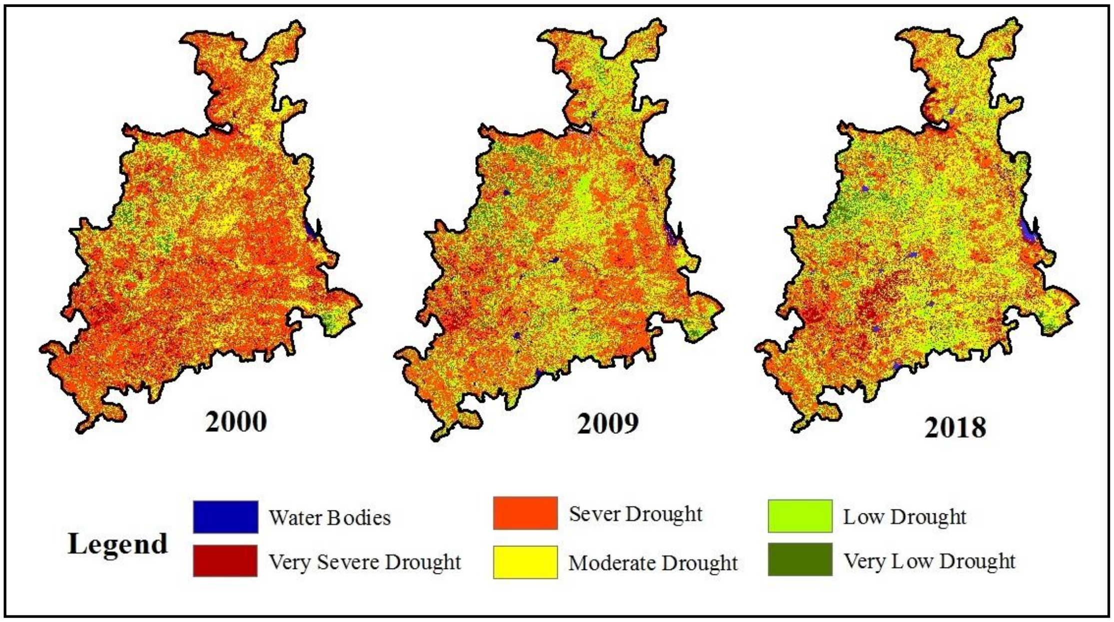

Figure-7: Agricultural Drought Index of Surendranagar District (Gujarat)

Table-6: Agricultural Drought (1999, 2008 & 2017)

Sr. No	Categories	1999		2008		2017	
		Area in Sq. Km	Area in %	Area in Sq. Km	Area in %	Area in Sq. Km	Area in %
1	**Water Bodies**	35.6	0.4	112.6	1.2	126.2	1.4
2	**Very Severe Drought**	1086.0	11.8	669.4	7.3	563.4	6.1
3	**Severe Drought**	4745.1	51.4	4256.8	46.2	2365.4	25.6
4	**Moderate Drought**	2343.0	25.4	1287.0	14.0	2506.7	27.2
5	**Low Drought**	577.2	6.3	2259.3	24.5	2507.1	27.2
6	**Very Low Drought**	436.3	4.7	638.3	6.9	1154.4	12.5
	Total	**9223.3**	**100**	**9223.3**	**100**	**9223.3**	**100**

IV. 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 Surendranagar district were identified by using Remote Sensing and GIS technology and agricultural drought risk areas were delineated by integration of satellite images, meteorological information.

The results of SPI analysis indicated that SPI is an excellent means that gives indication of the drought characteristics like onset, severity, and spatial extent. According to the result derived from the integration of SPI south western part and middle part of the Surendranagar district have rainfall deficit or meteorological drought.

The drought assessment demonstrated that the area under Very severe agricultural drought is maximum in 2009 and minimum in 2018. Meteorological drought mainly happened in 1999 and 2008, whereas it was minimum in 2017, but in 2009 moderate drought condition distributed in all over the district. According to Agricultural drought index map 2000 showing drought year but Agricultural drought index map 2018 showing normal and wet year in Surendranagar district.

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