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Spatial Monitoring of Agricultural Drought Using Multiple Drought Indices Using GIS Approach in Sabarkantha district of North Gujarat Region

Mistry P.B.* [1] and Suryanarayana T.M.V. [2]

Water Resources Engineering and Management Institute, Faculty of Technology and Engineering, The Maharaja Sayajirao University of Baroda, Samiala - 391 410, India
*Email : pranav.mistry-wremi@msubaroda.ac.in

ABSTRACT

Drought is a meteorological anomaly that is defined by an acute shortage of moisture. Low rainfall, which affects agricultural production, is the main reason for agricultural drought. The use of RS and GIS has recently made significant contributions to the assessment of numerous natural and artificial hazards. In the present study, different agricultural drought indices have been used to measure the severity of drought and identify the amount of areas that have been severely affected by droughtin Sabarkantha district using Landsat 8 data from 2013to 2019.According to the data obtained, the results showed that NDVI and NDWI both decreased by 4% to 6%, while LST significantly increased by 0.35°C to 2.5°C. The results of the NDVI indices shows that 2518.10 sq.km area and 59.03 sq.km area falls under severe dry and moderate wet conditions in 2013, which is 60.12% and 1.40%, respectively in Sabarkantha district.The result of the VCI thematic map for the year 2018 shows 28.8 sq.km area as extreme dry and 112.29 sq.km km as severe drought. Moderate drought covered an area of 2397.88 sq.km which is about 57.25% of the study area. Similarly, in 2019, 46.93% of the area falls under moderate dry and 38.38% of the area fell under normal dry. This relationship revealed that when rainfall increases, NDVI and VCI also tend to decrease. Also, there is an increase in NDBI. As a result, the occurrence of agricultural droughts increased. According to the VCI analysis, the study region contains areas of extreme, high, and moderate drought, respectively.

Keywords : Agricultural drought, Remote sensing and GIS, Rainfall, NDVI, NDWI, NDBI, LST and VCI.

INTRODUCTION

Drought is a frequent or erratic natural occurrence in almost every kind of climate in the world. Usually, it occurs when precipitation gradually decreases naturally (Badaq Jamali *et al.*, 2005). The major rainy season in India accounts for around 95% of the country's crop production, hence rainfall during this period is essential for agricultural activity. Contritely, the drought state has drawn less attention and has been the subject of less scientific investigation than natural catastrophes like floods or hurricanes. When it comes to damage and loss, drought can be far more destructive than flood, hurricane, and storm surge combined (Alam et al., 2012).In many countries across the world, drought has become a regular occurrence due to climate change and fluctuation. It shows up as an erratic and unpredictable distribution of rainfall in farming areas that rely on it, especially in dry and semi-arid ecosystems.

Frequent and severe drought is one of the most important natural disasters in sub-saharan Africa (Tadesse *et al.*, 2008). Droughts are often followed by severe economic, social, and environmental crises, which are typified by the emergence of unstable agricultural sectors (Kandji and Verchot 2006).

Agriculture is the main economic sector which is affected by agricultural drought. Since agriculture is the largest user of water and hence most susceptible to agricultural drought, it is particularly affected negatively by short-term droughts during important growth phases. Remotely sensed data and GIS tools have been used to track changes in the environment and urban features during the years. According to Surya et al. (2020), the research of regional eco-environment should concentrate on ecosystem conservation and economic development. As such, it has saved in creasing attention from global researchers. Soil moisture shortage is a characteristic of agricultural droughts (Dracup *et al.*, 1980). The science of remote sensing gathers data on a location or thing on Earth's surface without physically studying the subject of the data (Aggarwal 2003).

Because of its high geographical and temporal resolutions, consistent, wide coverage, and ability to assess and track aspects of terrestrial ecosystems at several scales, RS has become a valuable instrument (Gu and Wylie 2015).The assessment and ongoing monitoring of surface water resources depend heavily on satellite remote sensing. Using a variety of sensors and resolutions, satellite remote sensing is used to gather data regarding surface water resources (Chawla et al., 2020).

The NDVI, a measure of vegetative health, is one of the most widely used techniques for monitoring drought occurrences amongst those indices (GU *et al.*, 2007). The various vegetation indices were applied based on the findings of this study (Acharya *et al.*, 2019). LST is crucial for agricultural studies, urban heat island effects, and environmental monitoring research (Lu and Weng 2006). Remote multispectral and hyperspectral observations have proven to be an essential source of data for assessing drought and vegetation changes (Yang *et al*., 2012).

It has been shown by Xu (2006) that MNDWI is especially effective in locating open water. Typically, the MNDWI has a negative value for soil and vegetation and a positive value for water bodies. In LST-related investigations (Julien *et al.*, 2006), the NDVI is widely utilised to measure plant abundance. Water is shown by negative NDVI values, while built-up regions and bare land are shown by positive NDVI values up to 0.2. Higher NDVI values imply healthy vegetation, and more than 0.2 NDVI values indicate the presence of vegetation (Guha *et al.*, 2018).The ±1 value of the NDVI is variable. Here, the NDVI value of +1 indicates the dense vegetation; water usually has an NDVI value of less than zero (Taloor *et al.*, 2021).

Among various indices, one of the most often used methods for monitoring drought episodes is the NDVI, which serves as a probe for vegetative health (Rhee *et al.*, 2010). It has been suggested that combining temperature and vegetation index will improve the method. Different studies shows that remote sensing are drawn to the interesting link between LST

and NDVI from a variety of angles (Govil et al., 2019). Time and space play a major role in this relationship's form and intensity. The LST-NDVI association is typically negative in tropical environments (Gorgani *et al.*, 2013). As an early warning system, the combination of LST and NDVI offers a good connection and useful information for identifying agricultural drought (Sruthi *et al.*, 2015).This information is essential for early warning, risk assessment, resource management, and decision-making in agriculture, water resource management, disaster preparedness, and environmental conservation in drought-prone regions.

Geospatial approaches can help with the identification and mapping of agriculturally drought-prone areas as well as the proper site monitoring for specific mitigation initiatives. A map of the agricultural drought risk zones will be created by this research, which will help policymakers decide what steps to take in light of the risk. On the other hand, data that illustrates how to maintain soil moisture and manage crops in drought-prone areas is beneficial to scholars. It might also be beneficial for governmental and non-governmental organisations (NGOs) in managing drought.

The scope of agricultural drought analysis using RS and GIS tools is extensive and valuable for monitoring, assessing, and managing drought impacts on agriculture. These can be used to monitor and track drought conditions in real-time or over extended periods. Satellite imagery and remote sensing data help in assessing various drought indicators like precipitation, soil moisture, and vegetation health, which are critical for agricultural planning. Also, it can provide quantitative measures of drought severity, helping to categorize drought events as mild, moderate, or severe. This information is crucial for resource allocation and drought impact assessment.

The main objective of the present study is to evaluating multiple drought indices viz., NDVI, NDWI, LST, NDBI, and VCI for assessment of drought in Sabarkantha district using Lands at 8 from 2013 to 2019.Also, to assess the impact of on drought patterns and trends to study the shifts in vegetation, water availability, and temperature, which are essential for adaptation and mitigation strategies. Also, estimate the area falls under each categorize of drought such as mild, moderate, severe, or extreme drought, based on index values.

The Sabarkantha district, which is a part of North Gujarat, is located between latitudes 23°03' and 24°30' N and longitudes 72°43' and 73°39' E which is shown in Figure 1. The annual average rainfall of the district is 825 mm, and the maximum temperature is

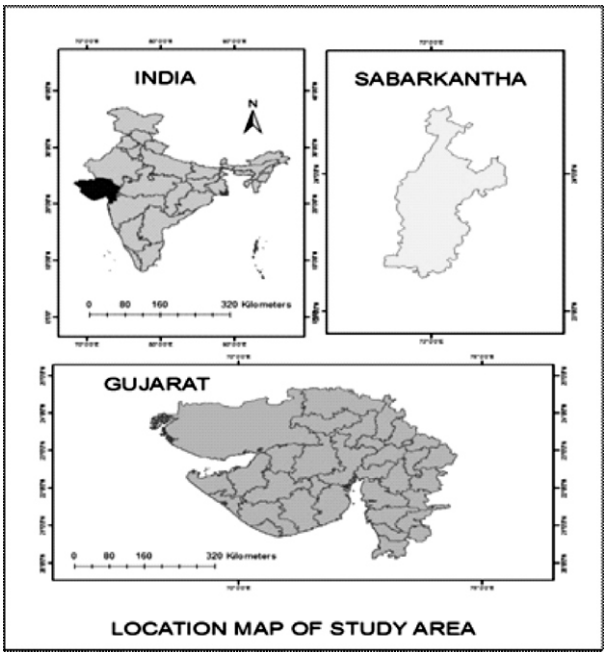


Figure 1: Study Area Map

40.5o C and the minimum is 9.04o C. For estimation of drought indices the Lands at data has been downloaded from the Earth Explorer (https://earthexplorer.usgs.gov/) and the images taken from Lands at 8 satellite with a spatial resolution of 30 m were used. The study will enable us to make a proper plan for irrigation practice in drought-vulnerable areas and will provide prior knowledge of challenges during cultivation in this region.

MATERIALS AND METHODS

The Lands at 8 band characteristics are shown in Table 1 below. A band is the name given to each range, and Lands at 8 contains 11 bands. Red, green, and blue sensors on Lands at are numbered 4, 3, and 2 respectively. Different bands were employed in the current location to estimate the drought indices, the section below explains the methodology for the current investigation.

Table 1: Lands at 8 Band Characteristics

Band No.	Description	Wavelength (mm)	Band No.	Description	Wavelength (mm)
1	Coastal Aerosol	0.430 - 0.450	6	SWIR 1	1.570 - 1.650
2	Blue	0.450 - 0.510	7	SWIR 2	2.110 - 2.290
3	Green	0.530 - 0.590	8	Panchromatic	0.500 - 0.680
4	Red	0.640 - 0.670	9	Cirrus	1.360 - 1.380
5	Near Infrared	0.850 - 0.880	10	TIRS 1	10.60 - 11.19
			11	TIRS 2	11.50 - 12.51

NDVI (Normalized Difference Vegetation Index), NDWI (Normalized Difference Water Index), LST (Land Surface Temperature), NDBI (Normalized Difference Built-Up Index), and VCI (Vegetation Condition Index) are widely used remote sensing and satellite-based indices in drought assessment. These indices can be used to assess the impact of climate change on drought patterns and trends. Long-term data series from 2013 to 2019 used to study the shifts in vegetation phenology, water availability, and temperature, which are essential for adaptation and mitigation strategies.

Normalised Difference Vegetation Index (NDVI)

A popular slope-based vegetation index that uses the red and near infrared bands is called NDVI. Additionally, the measurement scale has the advantageous virtue of having a range from -1 to 1, where -1 corresponds to non-vegetated surfaces and 0 roughly corresponds to no vegetation. High NDVI values indicate healthy vegetation, while low values suggest stressed or sparse vegetation. Here, the NDVI is calculated to depict the drought's susceptibility.In drought assessment, decreasing NDVI values can indicate reduced plant growth and water stress in crops and natural vegetation.The calculation was made using the following equation:

$$\mathrm{NDVI} = \frac{(\mathrm{NIR} - \mathrm{RED})}{(\mathrm{NIR} + \mathrm{RED})}$$

Normalised Difference Water Index (NDWI)

McfeetersS.K. (1996) backed the use of NDWI to emphasise water bodies which is based on the observation that vegetation has the highest near-infrared reflection and water has the highest near-infrared absorption. NDWI quantifies the presence of water in the environment, including surface water, soil moisture, and vegetation canopy water content. Decreasing NDWI values can indicate reduced water availability, such as drying rivers, lakes, or soil moisture deficits.The calculation was made using the equation:

$$\mathrm{NDWI} = \frac{(\mathrm{NIR} - \mathrm{SWIR})}{(\mathrm{NIR} + \mathrm{SWIR})}$$

Normalized Difference Built-up Index (NDBI)

The NDBI measures how much more reflective built-up regions.NDBI is used to detect the presence of built-up or impervious surfaces in urban areas.The below equation has been used for computing NDBI, which is very useful for mapping urban built-up areas:

$$\mathrm{NDBI} = \frac{(\mathrm{SWIR} - \mathrm{NIR})}{(\mathrm{SWIR} + \mathrm{NIR})}$$

Vegetation Condition Index (VCI)

Based on NDVImin and NDVImax values, VCI is a popular algorithm for evaluating vegetation state. The VCI, which is given as a percentage (%), provides a sense of where the observed value falls in relation to the extreme values (minimum and maximum) from prior years. VCI assesses the health and vigor of vegetation by comparing current NDVI values with long-term averages. Decreased VCI values indicate vegetation stress, which can be attributed to drought conditions. VCI is particularly valuable for monitoring the impact of drought on agricultural crops.

These indices are often used in combination and integrated with Geographic Information Systems (GIS) for a more comprehensive assessment of drought conditions.

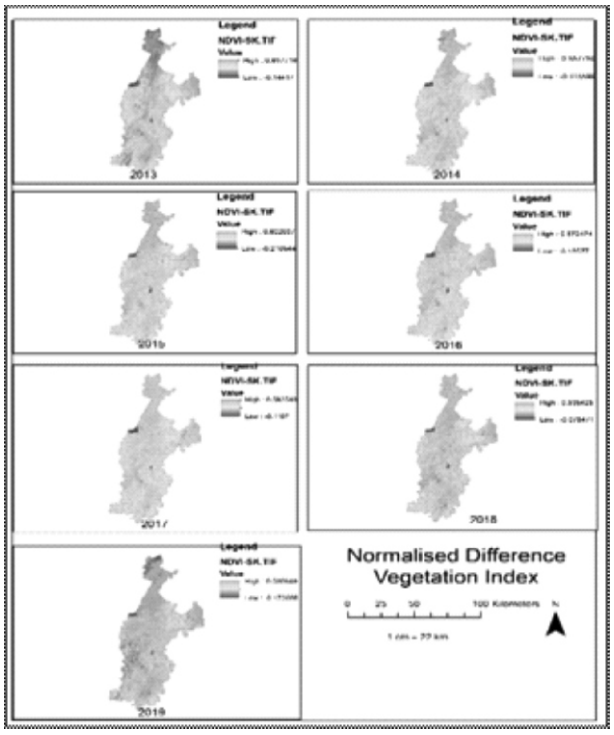
The VCI was computed using the equation shown below:

$$\mathrm{VCI}_{ij} = \frac{\mathrm{NDVI}_j - \mathrm{NDVI}_{min}}{\mathrm{NDVI}_{max} + \mathrm{NDVI}_{min}} * 100$$

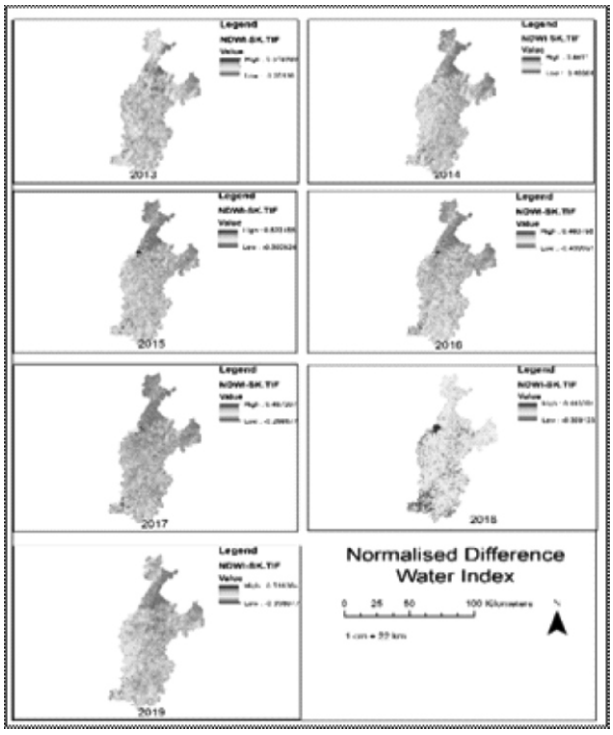
RESULTS AND DISCUSSION

In the present study, RS images that are multi-temporal and multi-resolution can give the fundamental information needed to analyse spatial data using a long-term series of Landsat 8 data from 2013 to 2019 to determine the severity of drought using several agricultural drought indices and understand how they relate to NDVI, NDWI, MNDWI, NDBI, LST, and VCI in Sabarkantha district.

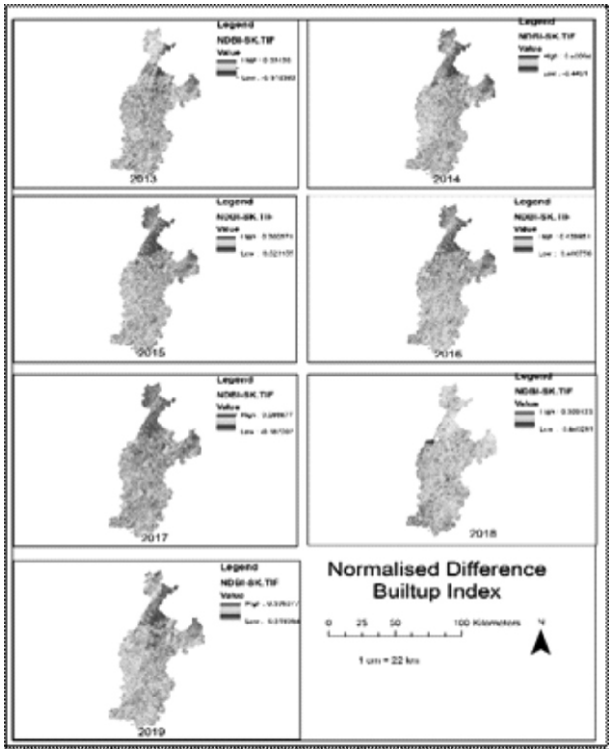
The NDVI is a vegetation indicator generated from Lands at that takes into account the vegetation's reflectance in the near-infrared (NIR) and red bands of electromagnetic radiation. The high NDVI values indicate healthy, thick vegetation, and it has become the primary tool for describing the phenology of vegetation. Because of monthly variations in vegetation responses, the obtained NDVI data was analysed for each year. NDVI values were often highest during wet seasons and lowest during dry seasons. The NDVI threshold value is between -1 and +1. The NDVI value decreases with increasing temperature, indicating a reduction in vegetation density. A severe agricultural drought is brought on by a reduction in soil



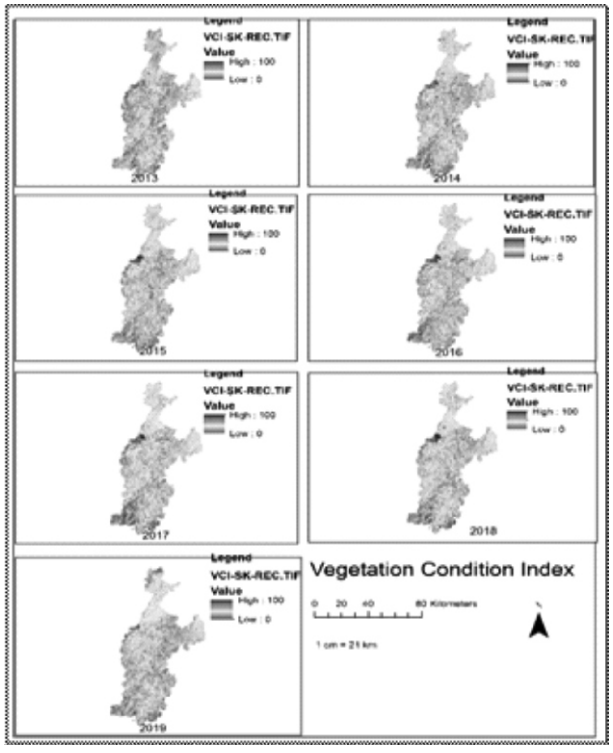
(a) Normalised Difference Vegetation Index



(b) Normalised Difference Water Index



(c) Normalised Difference Builtup Index



(d) Vegetation Condition Index

Figure 2: Maps of Agriculture Drought Indices

In the present study area, NDVI values range from -0.1107 to 0.1965, and an average NDVI of 0.2061 was observed. The results of 2013 show the minimum NDVI value as -0.1447 and the maximum value as 0.1965. Similarly, for the remaining year, the statistical data obtained for NDVI images is shown in Table 2. The NDVI maximum value declined from 2013 to 2019, while the minimum NDVI value was raised significantly, according to the image statistics and NDVI data obtained. However, from 2013 to 2019, the mean NDVI value decreased. As a result, it indicates that during the study period, the vegetation's decline.

Table 2: Obtain Values for LST and NDVI

	2013	2014	2015	2016	2017	2018	2019
LSTmin	22.81	11.75	13.62	24.59	27.03	25.36	13.78
LSTmax	44.08	43.04	47.50	47.56	48.05	43.07	42.62
NDVImin	-0.1447	-0.1155	-0.2105	-0.1257	-0.1107	-0.0784	-0.1736
NDVImax	0.6337	0.5577	0.6020	0.5724	0.5925	0.5954	0.5809
NDVIAvg	0.1965	0.2070	0.2093	0.1962	0.2010	0.2061	0.1869

The results of the NDVI indices show that 2518.10 sq.km area and 59.03 sq.km area falls under severe dry and moderate wet conditions in 2013, which is 60.12% and 1.40%, respectively, in Sabarkantha district. Owing to the low annual average rainfall in the Sabarkantha district in 2018 (427.15 mm), the dryness in the study region has dramatically increased, with 2486.70 sq.km as severe dry and 1545 sq.km as moderate dry, which is the highest amongst the study periods considered. Similar results were observed and analysed for the remaining years of the study period. Also, from the results of the NDVI, it was observed that the minimum percentage of dry areas in the year 2019 during this year was 875.39 mm in the study region, and the temperature derived from LST maps also shows that the minimum temperature was 13.78°C and the maximum temperature was 42.62°C. The developed images for NDVI from 2013 to 2019 are shown in Figure 2(a).

The NDWI unit is a numeric value that depends on the presence of surface water and varies from -1 to +1. A high water content in the plant is indicated by a higher NDWI measurement. Low NDWI values imply low vegetation water content; therefore, when there is a shortage of water, the NDWI rate falls. The NDWI value rises as precipitation increases. In the provided area, the average NDWI value for the water content of vegetation drops numerically from 2013 to 2019: 0.41, 0.39, 0.43, 0.42, and 0.41. The developed images for NDWI from 2013 to 2019 are shown in Figure 2(b).

The results of the NDBI indices show that it was feasible to observe changes in land use dynamics by comparing the fraction of the year's total area occupied by each feature to the features of the land feature. The built-up area increased by almost 4% over the last seven years (from 85% to 89%). The developed images for NDBI from 2013 to 2019 are shown in Figure 2(C).

The LST maps were prepared from satellite data analysis and represent the spatial distribution of surface temperature in the Sabarkantha district. LST analysis has shown a higher surface temperature on built-up and bare surfaces and a lower

temperature in healthy vegetated areas. Dry soil is usually visualised by a high LST. The minimum LST for the Sabarkantha region from 2013 to 2019 was 22.81°C, 11.75°C, 13.62°C, 24.59°C, 27.03°C, 25.36°C, and 13.78°C and the maximum temperature was 44.08°C, 43.04°C, 47.50°C, 47.56°C, 48.05°C, 43.07°C, 42.62°C respectively, which is shown in Table 2. The results also indicate that LST increased significantly from 2013 to 2019, but decreased slightly in 2014 and 2015. It was observed that dry conditions had high LST and low NDVI during the study period.

The stress of decreased water availability and rising temperatures on vegetation during the dry season is calculated by the VCI index values, which range from 0 to 100. The smaller the values, the higher the stress on the health of the vegetation. From no drought to intense, the VCI maps were easily divided into seven stages of drought severity, which are displayed in the below tables. Table 3 shows the severity of the classification of drought, ranging from extreme drought to extreme wet conditions for different years.

Table 3: Results of Vegetation Condition Index for Sabarkantha district

	2013	2014	2015	2016	2017	2018	2019
1 ED	21.09	24.80	23.32	23.34	27.82	28.80	16.86
2 SD	341.19	51.62	29.79	19.99	35.57	112.29	151.51
3 MD	2269.07	1998.75	1443.87	1145.29	1989.08	2397.88	1965.74
4 NN	1106.36	1446.96	1959.50	2281.74	1467.29	1022.97	1607.37
5 MW	343.94	422.22	474.89	495.73	371.69	349.77	295.90
6 SW	98.16	181.73	189.89	155.35	194.03	189.28	110.89
7 EW	8.69	62.44	67.25	67.09	103.03	87.53	40.25
Sq.km Area	4188.48	4188.48	4188.48	4188.48	4188.48	4188.48	4188.48

Table 4: Percentage Area of Vegetation Condition Index

Classification	2013	2014	2015	2016	2017	2018	2019
1 ED	0.504	0.592	0.557	0.557	0.664	0.687	0.402
2 SD	8.147	1.233	0.711	0.477	0.849	2.681	3.618
3 MD	54.18	47.72	34.47	27.34	47.49	57.25	46.93
4 NN	26.41	34.55	46.78	54.48	35.03	24.42	38.38
5 MW	8.21	10.08	11.33	11.83	8.87	8.35	7.06
6 SW	2.34	4.33	4.53	3.70	4.63	4.52	2.64
7 EW	0.206	1.483	1.599	1.599	2.455	2.083	0.955
	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Similarly, Table 4 shows the percentage area under each class for the same The result of the VCI thematic map for the year 2018 shows almost 28.8 sq.km area as extreme drought, 112.29 sq.km as severe drought, and moderate drought covered an area of 2397.88 sq. km, which is about 57.25% of the study area. The average rainfall is only 427.15 mm in the study region, due to which vegetation in the study area has decreased drastically compared with the previous years. Also, the land surface temperature in 2018 was the lowest compared to other years. Similarly, in 2019,

46.93% of the area falls under moderate dry and 38.38 of the area as normal dry. From the above table and figure, it is implied that the drought extent in the research area has been significant throughout, from mild drought to severe drought. By comparing VCI with individual LST and NDVI values, the severity was mainly due to the rise of LST. The developed images for VCI from 2013 to 2019 are shown in Figure 2(d).

CONCLUSIONS

The southwest monsoon typically starts from July to September, which is the main time period for agriculture, so the results of the data analysis here are concentrated on the months of April and May. If the region encounters drought towards the end of the season, it indicates that the whole region will be affected by dry conditions. According to the results obtained, the research area's NDVI and NDWI both fall by 4% to 6%, while LST significantly increased by 0.35°C to 2.8°C.The results of the NDVI indices show that 2518.10 sq.km area and 59.03 sq.km area falls under severe dry and moderate wet conditions in 2013, which is 60.12% and 1.40% respectively of Sabarkantha district. The built-up area over the past seven years has expanded by around 4% (from 85% to 89%). The significant positive association between LST and NDBI indicates that surface temperatures are higher in more populated areas. The result of the VCI thematic map for the year 2018 shows almost 28.8 sq. km of area as extreme and 112.29 sq. km as severe drought, and moderate drought covered an area of 2397.88 sq. km, which is about 57.25% of the total study area.The results of multiple agricultural drought indices were analysed for Sabarkantha district during 2013 to 2019, and it was found that more than 60% of the land was dry. The results of this study will help smallholder farmers mitigate the effects of drought by participating in a variety of on- and off-farm activities, and it could aid in enhancing the current agricultural drought monitoring systems used in Sabarkantha and North Gujarat in general.

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