Drought Analysis in Right Bank Main Canal Command Area of Dharoi Reservoir using Meteorological and Remote Sensing Indices

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Abstract: Drought is characterized by a prolonged and abnormal lack of moisture, often stemming from insufficient or uneven distribution of precipitation, resulting in water shortages in streams or reservoirs, with detrimental impacts on both natural and socioeconomic systems. The paper focuses on the climatic drought patterns within the Right Bank Main Canal Command Area of Gujarat's Dharoi Reservoir. To evaluate drought conditions, the study employs several indices including the Standardized Precipitation Index (SPI)and Normalized Difference Vegetation Index (NDVI). Daily rainfall data, obtained from IMD gridded data and extracted using ArcGIS software, is utilized to calculate SPI values at a three-month time scale. NDVI is determined using Landsat-8 OLI data spanning from 2013 to 2022 to analyze changes in agricultural vegetation. Comparisons among NDVI and SPI reveal that the year 2018 experienced significant rainfall deficits across the region, leading to severe water scarcity. This shortage impacted agricultural practices, evident in reduced crop cultivation areas as indicated by NDVI results and validated using the crop yield data for the time series. Specifically, the NDVI analysis highlights that 33.5% of the RBMC command area exhibited signs of dryness, with an additional 64.5% showing moderate dryness. The study endeavors to pinpoint drought-affected regions utilizing precipitation data, reservoir storage information, and remote sensing methodologies.

Keywords: Drought, Rainfall, Meteorological Drought, Agricultural Drought, Standard Precipitation Index, Reservoir Storage Index, Normalized Difference Vegetation Index.

I. INTRODUCTION

Drought is a recurring, yet periodic aspect of climate that occurs throughout all climatic regimes and is typically characterized by fluctuation in terms of regional extent, intensity, and duration. Drought conditions emerge primarily as a result of significant rainfall variation from the normal and/or skewed character of the geographical / temporal distribution to such an extent that it has a detrimental influence on crops across an agricultural season or successive seasons.

Wilhite and Glantz [6] classified droughts into four categories: meteorological, hydrological, agricultural, and socioeconomic. Meteorological drought, also known as climatological drought, is defined as a deviation in precipitation from the usual average for a specific time period and region. It is often described by the degree of dryness and the length of the dry spell. Hydrological drought is defined as a lack of water on the surface or beneath the ground caused by a decrease in precipitation. Deficits in precipitation take longer to show up in hydrological system components like stream flow, groundwater and reservoir levels.

Agricultural drought connects numerous meteorological and hydrological drought characteristics to agricultural impacts, with a focus on precipitation shortages, disparities between actual potential evapotranspiration, soil water deficits, and reduced groundwater or reservoir levels. Socioeconomic definitions of drought link the supply and demand for a particular economic good to features of meteorological, hydrological, and agricultural drought. It differs from the other types of droughts stated above because its occurrence is dependent on the time and space processes of supply and demand to define or classify droughts.

II. STUDY AREA

The study area is the Dharoi Right Bank Main Canal Command. Dharoi Reservoir Project is located across river Sabarmati near village Dharoi in Satalasana taluka of Mehsana district, Gujarat state. Command area of project is on both sides of Sabarmati River, through two main canals namely, L.B.M.C. (Left Bank Main Canal) and R.B.M.C. (Right Bank Main Canal). The project is planned for irrigation facilities to 127 villages of Kheralu, Visnagar, Mehsana, Sidhpur and Vijapur talukas of

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Mehsana district through R.B.M.C. and 49 villages of Idar and Himmatnagar talukas of Sabarkantha district through L.B.M.C. [13]

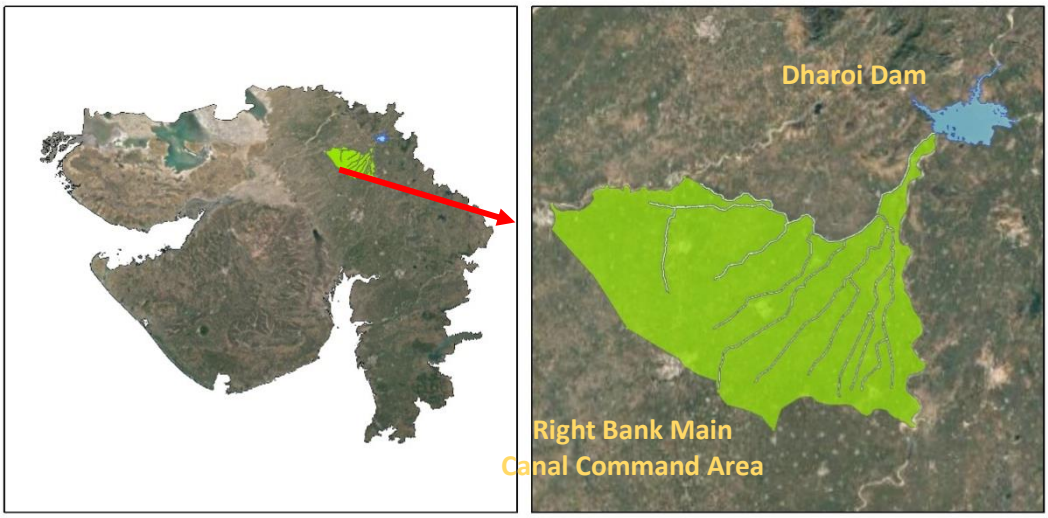

Fig 1. Location Map of Project

The Right Bank Main Canal Command (SRBMC) area spreads over 817.54 sq.km (81,754 ha) including 4298 ha of lift irrigation. The canal network in RBMC area has total length is about 969.5 km where main canal has total length of about 63.5 km.

A. Climate

The climate of study area is characterized by a hot summer and general dryness for the major part of the year. There are four seasons in a year. December through February is considered the cold season. The southwest monsoon season lasts till the end of September after the hot season, which lasts from March to the middle of June. The post-monsoon or transitional phase is between October and November.

The region receives 752.6 mm of rain on average annually. During the southwest monsoon, or from June through August, the area receives about 97% of its annual rainfall. the rainiest month being July. The variation in the rainfall from year to year is large. Based upon the annual average rainfall of last 30 years, it was consequent that year 2018 was a year with a rainfall deviation of around 60%. The year 2018 received only 40 % of the average annual rainfall for whole year, making year 2018 as a water scarce year. The situation was almost similar in the entire north west region.

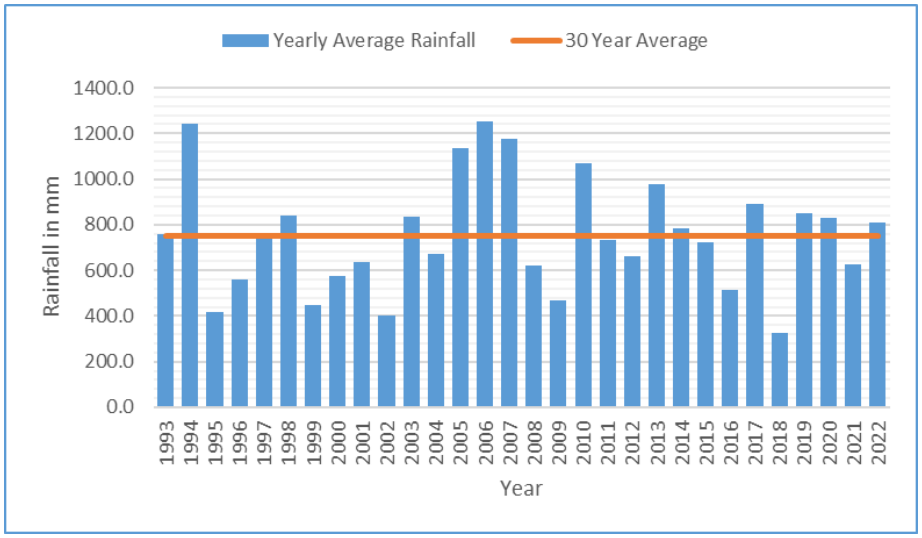

Fig-2. Annual Average Rainfall for Study Area

III. MATERIAL AND METHODS

A. Standard Precipitation Index (SPI)

Standardized Precipitation Index (SPI) is calculated using SPI Program developed by National Drought Mitigation Center [12]. The SPI is a is a useful index that was created in previous research and is beneficial for any drought occurrence (from meteorological to hydrological because of its calculation at varied timescales) based on historical precipitation data.

The Standardized Precipitation Index (SPI) is a statistical measure that compares the total amount of precipitation that happened at a specific location over n months with the long-term rainfall distribution for that location over the same time period. SPI is computed on a monthly basis for a moving window of n months, where n denotes the duration of rainfall accumulation, which is commonly 1, 3, 6, 9, 12, 24 or 48 months. SPI-1, SPI-3, SPI-6, etc. are the corresponding SPIs. SPI is based on a transformation of the collected precipitation into a standard normal variable with zero mean and variance equal to one, allowing for the statistical comparison of wetter and drier regions. Results from the SPI are expressed as standard deviations from the standardized distribution's long-term mean.

The long-term rainfall record for a specific period is fit with a probability distribution, which is further converted to a normal distribution. Gamma distribution is a good fit with the long-term time series. Periodical sums of precipitation usually follow the gamma distribution. In order to normalize the precipitation sequence, the transformation function f (P) is provided below. As a result, the SPI can be written as follows.:

$$f(P) = X = \sqrt[3]{P} \quad (1)$$

$$SPI = \frac{X - X_m}{\sigma} \quad (2)$$

Where 'P' stands for the element of the precipitation sequence., 'X' shows the Precipitation noted at the given station in mm, Precipitation reported at the specified station is displayed in mm under "X" and 'σ' represents Standard deviation measured in mm. Positive and negative readings of the SPI, respectively, show whether the precipitation is above or below the long-term mean. As the SPI is normalized, it can be compared across different locations, irrespective of the absolute values of precipitation [3]. It uses standard deviation to express deviation from the long-term mean. The classification of drought conditions is given in Table 2.

TABLE I
CLASSIFICATION OF DROUGHT BASED ON SPI VALUES

SPI Range	Category Level
≥ 2.0	Extremely Wet
1.5 to 1.99	Very Wet
1.0 to 1.49	Moderately Wet
-0.99 to 0.99	Near Normal
-1.0 to -1.49	Moderate Drought
-1.5 to -1.99	Severe Drought
≤ -2.0	Extreme Drought

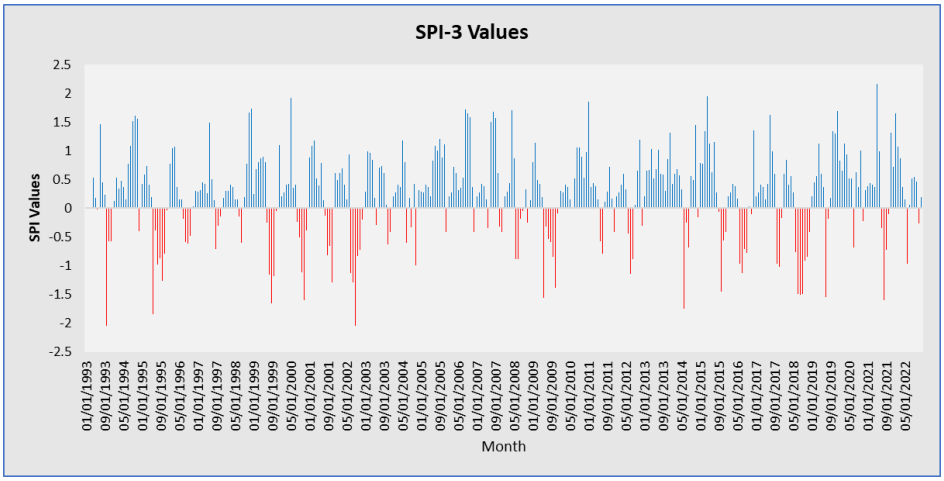

Fig3. Month wise SPI-3 Values for 30 years

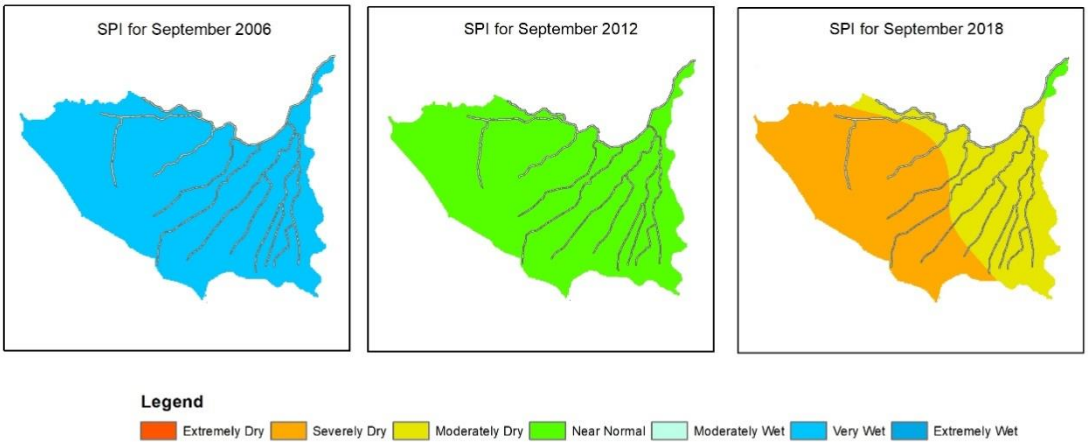

Fig 4. Spatial Distribution of SPI-3 for the month of September for year 2006, 2012 and 2018

The trend shows that there was moderate to severe drought like situation in 1995, 1999, 2002, 2009 and 2018 throughout the region, 2018 being one of the extreme events.

B. Normalized Difference Vegetation Index

According to Kamble et. al. [8], Normalized Difference Vegetation Index (NDVI) is based on the notion that vegetation vigor is an indicator of water availability or lack thereof. It establishes the effects of climate on vegetation in terms of its absorptive capacity in visible light but little in the near-infrared spectrum. The difference of visible and near-infrared reflectance represents photosynthetically active vegetation; this information is used to construct a vegetation index. The lowering of the vegetation index indicates moisture stress in vegetation, resulting from prolonged rainfall deficiency. High NDVI values might reflect ideal growing conditions if vegetation greenness is higher than that encountered in other years. The calculation of NDVI is given as

$$NDVI = \frac{NIR - R}{NIR + R}$$

where, Near Infrared (NIR) and Red light (RED) are the reflectance in the near-infrared and red bands, respectively. The values of NDVI range between −1 and +1. High NDVI value represents healthy green vegetation.

TABLE-II
CATEGORIZATION OF NORMALIZED DIFFERENCE VEGETATION INDEX

Percent of NDVI Anomalies	**Class**
0.6 to 1.0	Extremely Wet
0.4 to 0.6	Wet
0.2 to 0.4	Moderate
0.0 to 0.2	Severe Drought
-0.4 to 0.0	Very Severe Drought
-1.0 to -0.4	Barren Land

Landsat-8 OLI data of January 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020, 2021 and 2022 covering the command area of the Dharoi Reservoir was used to measure the temporal NDVI anomalies. The classified NDVI are presented in Fig.8

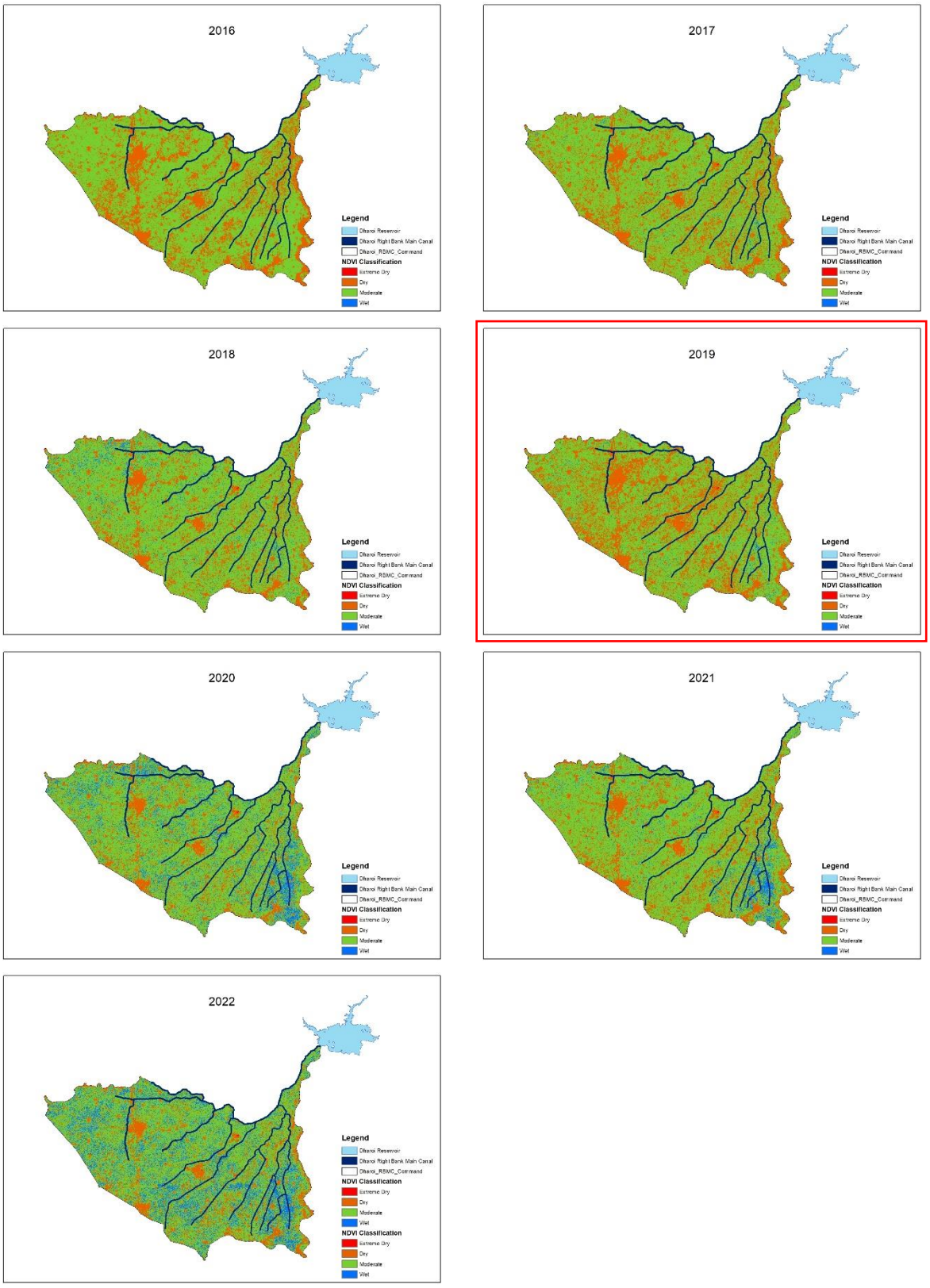

Fig 5. NDVI Classified Images from 2016 -2022

The percentage area for the different NDVI classes were extracted using Raster images processing in ArcGIS. The classification is presented in Table-3.

TABLE-III
PERCENTAGE OF COMMAND AREA UNDER EACH NDVI CLASS

NDVI Class	2016	2017	2018	2019	2020	2021	2022
	Percentage of Dharoi Command Area						
Extreme Dry	0.01	0.12	0.14	0.04	0.15	0.12	0.13
Dry	29.07	28.19	20.95	33.54	16.44	21.53	16.55
Moderate	70.86	70.29	74.13	64.57	70.61	72.46	65.24
Wet	0.07	1.40	4.78	1.85	12.79	5.89	18.08

The results indicate that, in the middle of the Rabi Crop seasoned November to March, succeeding the monsoon of 2018, ofthe total command area of RBMC, 33.5 % area was having a NDVI value showing dry area and 64.5 % area moderately dry. The percentage of dry area is on a higher side when compared with the time series data of other years.

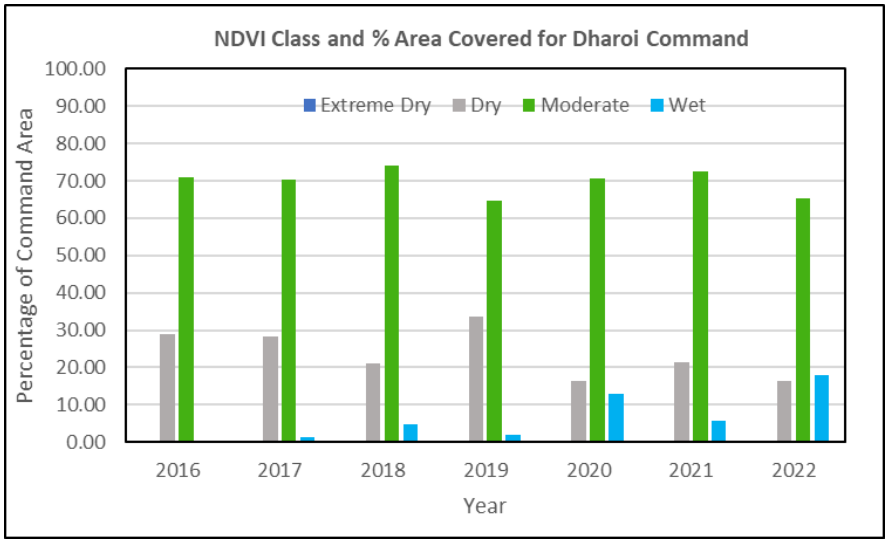

Fig 6.Year Wise Plot of Percentage of Command Area under each NDVI Class

C. Validation

To assess the impact on agriculture, district-wise data on area, production, and yield spanning from 2016 to 2022 from Directorate of Agriculture's was utilized [5].Analysis of the agriculture data focusing on three crop seasons: kharif, rabi, and summer crops was undertaken.

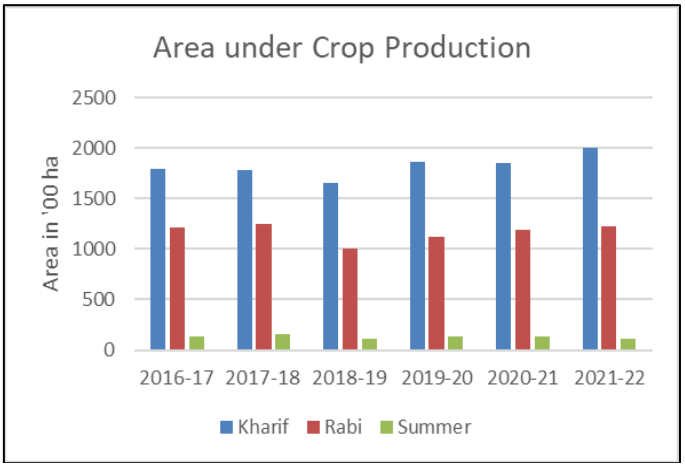

Fig 7. Year Wise Area Under Crop Production in Hectares

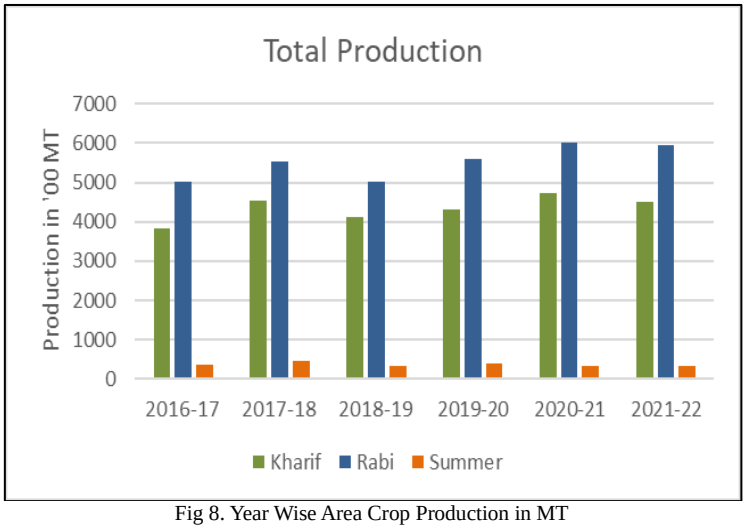

Fig 8. Year Wise Area Crop Production in MT

The analysis of data for total area under production, total production each year, area under production for major crops and total food grain productions was caried out. It is found that the in the total area under production from 2016 to 2022, the was the lowest in 2018-19, i.e 10 % less than the average of last 6 years.

The area under production decreased in both kharif and rabi seasons i.e 9 % and 14 % respectively, while the area for summer crops remained relatively consistent every year.

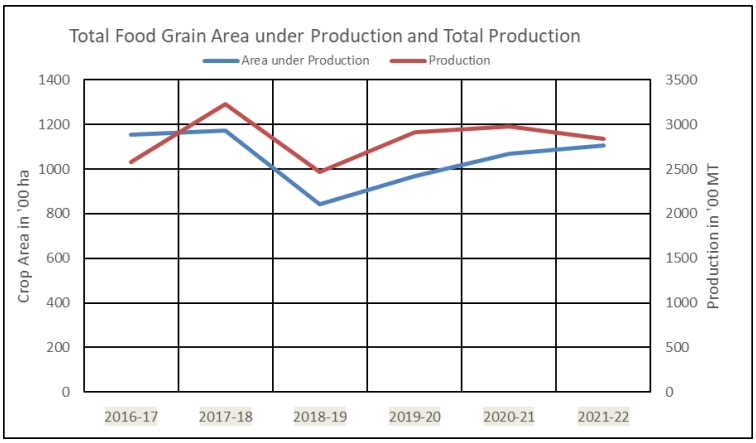

Fig 9. Year Wise Food Grain Area under Sowing and Production in MT

In term of total production, it is found that in the total production from 2016 to 2022, the was the lowest in 2018-19, i.e 7.5 % less than the average of last 6 years. Also, the production decreased in all the three season kharif, rabi and summer seasons by 5.2, 9.2 and 8.7 % respectively.

The analysis of agriculture data validate that area under production in 2018-19 was more or less same as average for last 6 years, but the yield and production was less compared to average of last 6 years, the reason can be attributed to meteorologicaldrought situation in the area leading to agricultural drought in the region.

IV. RESULT AND DISCUSSION

The time series of the NDVI is plotted and compared with the Plot of Annual Average rainfall and SPI. The comparison establishes the fact that 2018 was one of the years with the least annual average rainfall in last 30 year.

The NDVI comparison shows that although the rainfall was scanty in other years during 2016 to 2022 except 2018. The percentage area under each NDVI class remains more or less same, this could be attribute to availability of irrigation water from Dharoi Dam. However due to rainfall deficit in the catchment area of Dharoi Dam irrigation water was not available from Dharoi Dam in year 2018-19, leading to agricultural drought in the command area.

The SPI Valueand NDVI when used in conjunction helps to characterize drought propagation from meteorological to agricultural droughts, which could be validated using the agriculture data for a better understanding of the drought impact.

This across-scale drought characterization and assessment can help to formulate measures to mitigate drought impacts in a better way.

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