

Original Article

Analysis of Agricultural Drought in Sone Command Area in Bihar, India using the Vegetation Condition Index

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Abstract - Agricultural drought poses a significant threat to crop productivity, rural livelihoods, and regional food security, particularly in irrigation-dependent regions where climatic variability and water management practices interact. Although canal irrigation systems are designed to buffer rainfall deficits, spatial and seasonal variability in vegetation stress often persists. This study assesses agricultural drought in the Sone Command Area, Bihar, India, using the Vegetation Condition Index (VCI) derived from Landsat-based Normalized Difference Vegetation Index (NDVI) for the years 2000, 2010, and 2020. Seasonal analysis was conducted for pre-monsoon and post-monsoon periods to evaluate intra-annual drought dynamics and long-term variability over two decades. NDVI was computed using red and near-infrared bands of Landsat imagery, and VCI was derived by normalizing NDVI values against historical minimum and maximum conditions to quantify relative vegetation stress. The results reveal pronounced seasonal contrasts, with pre-monsoon periods exhibiting significantly higher drought severity compared to post-monsoon seasons. The percentage of drought-affected area during pre-monsoon was estimated at 75.23% in 2000, 93.78% in 2010, and 19.75% in 2020, indicating extreme vegetation stress in 2000 and 2010, followed by notable improvement in 2020. In contrast, post-monsoon drought-affected areas were 47.52%, 44.98%, and 29.36% for the respective years, demonstrating relatively reduced stress conditions after monsoon rainfall. The analysis highlights pronounced seasonal contrasts and spatial heterogeneity in vegetation stress within the irrigation command. The findings demonstrate that Landsat-derived VCI provides a reliable, high-resolution tool for monitoring agricultural drought in irrigation-supported regions and offers valuable insights for drought mitigation planning and water resource management.

Keywords - Agricultural drought, NDVI, Vegetation Condition Index, Landsat, Sone Command Area, Seasonal drought analysis.

1. Introduction

Agricultural drought is a crucial factor in the economy of agricultural countries such as India, where agriculture employs more than 68 percent of the population [1]. Drought affects around 16 percent of India's total land area, and over 50 lakh people are impacted each year. Drought-prone regions of India are mostly limited to western and peninsular India, primarily desert, semi-arid, and sub-humid regions [2]. In terms of size, interval, variation, and length, India had one of the most severe and most unusual droughts in history from 2002 to 2003 [3, 4]. Drought is a significant occurrence that ranked first among all-natural disasters in terms of the number of people impacted worldwide [5]. Drought threats grow slowly, typically over a long period, and might last for years after the drought has ended [6]. It has been identified as one of the most serious environmental crises, harming natural ecosystems, agriculture, and water systems [7]. Drought intensity is difficult to evaluate since the beginning and end of the drought are hard to predict. Droughts begin as a period of

below-average rainfall and progress into an intense climactic event with significant environmental consequences [8].

For drought assessment, remote sensing is an efficient and helpful tool. Therefore, in context, drought monitoring using satellite-based data has gained popularity in recent years because of its low cost, graphical perspective, data collection repetition, and dependability. Furthermore, the Vegetation Condition Index (VCI) and the Normalized Difference Vegetation Index (NDVI) have been widely used for detecting agricultural dryness in various locations with varied ecological circumstances. Despite meteorologically based drought forecasting, VCI gives near-real-time satellite data with a high spatial resolution [9-11]. It can determine the state of vegetation based on the best and worst vegetative vigour over a period of time in different years, providing more accurate results than NDVI when assessing drought on a regional scale [12, 13]. The satellite-based VCI has gained widespread acceptance for its capacity to assess numerous



drought-related indicators, including drought onset, duration, intensity, and severity [14, 15]. The main objective of this study is an assessment of agricultural drought with a satellite-based vegetation condition index in the Sone command area in Bihar, India.

In this study, three years, i.e., 2000, 2010, and 2020, satellite-based data acquired from USGS Earth Explorer, Landsat-8 very high-resolution images are used for VCI calculations. The main objective of the study is the assessment of agricultural drought using drought indices and satellite-based VCI index in the Sone irrigation scheme in Bihar, India, for the past two decades. In order to record long-term variations in agricultural drought conditions within the Sone Command Area, the years 2000, 2010, and 2020 were taken for a structured decadal comparison over a 20-year period. These years enable the evaluation of temporal changes in vegetation stress under shifting irrigation and rainfall patterns because they represent early, intermediate, and recent climatic stages.

2. The Study Area

The southernmost region of Bihar, India, is taken as the study area for this research. The Sone River, a significant tributary of the Ganga, is 881 kilometres long, originating in Madhya Pradesh, close to Amarkantak. The Indrapuri barrage, located near Dehri on Sone, is also included in the study area. The river's whole catchment area is 7 lakh hectares. Eight districts in Bihar are under the jurisdiction of the Sone command, i.e., Patna, Aurangabad, Jahanabad, Gaya, Bhojpur, Baxur, Rohtas, and Bhabhua. The average annual rainfall is 1398 mm. There are 37,07,904 hectares in the Sone command area overall. The study location often has clay loam soil. The research area's primary land use patterns include urban, rock, water, vegetation, and bare land.

2.1. Sone Irrigation Scheme

In the south Bihar plains, the Sone Canal is a diversion irrigation system that dates back 120 years. In 1871, the Sone irrigation program was first established. However, in 1879, it was systematically employed for irrigation. Consequently, the 1410-meter barrier was constructed near Indrapuri in 1968. Each branch canal in the Sone Canal System has multiple major and minor sub-distributaries, in addition to the main canals. The water supply enhancement will be funded by the Sone Irrigation Project in India. The construction of a new barrage across the Sone River to replace the current diversion weir, headworks, and navigation streams at the new barrage would be connected to the current canal system by link canals, as well as remodelling and expanding the current irrigation system, all of which are included in this project. The new structures will allow for improved control of the river head and flow for water delivery. The sone irrigation scheme will enhance the 3 lakh hectares of crops that are already irrigated annually and would enable the irrigation of another 1.2 lakh hectares of crops.

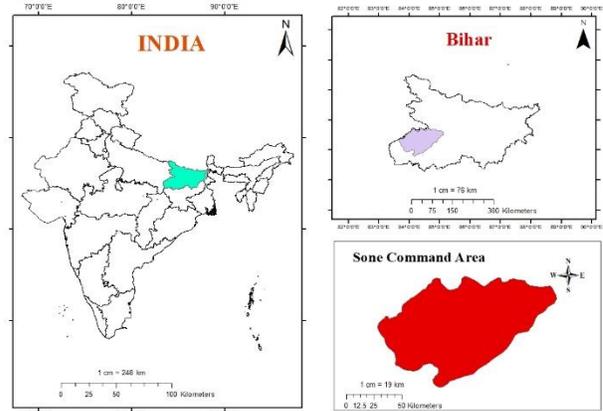


Fig. 1 The Sone Command area

3. Materials and Methods

In the present study, the three years (2000, 2010, and 2020) of pre-monsoon, post-monsoon, and winter seasons of satellite data have been analysed for drought analysis.

3.1. Normalized Difference Vegetation Index (NDVI)

Spectral reflectance in the red and Near-Infrared (NIR) waveband region can be measured to determine the NDVI. In crop modelling, yield estimation, soil erosion, and drought evaluations, the satellite-based NDVI is used [16, 17]. The NDVI method is based on the observation that while leaf chlorophyll and other pigments absorb a significant portion of the red visible (R) radiation, the internal mesophyll structure of healthy green leaves emits Near-Infrared (NIR) light as shown in Equation 1.

$$NDVI = \frac{NIR - R}{NIR + R} \quad (1)$$

Where, NIR= Near Infrared (Band-5), R= Red band (Band-4). The NDVI range is +1 to -1. The location having an NDVI value below 0.1 indicates the locations with barren rock, sand, and snow cover, whereas in temperate and tropical rainforests, it can range from 0.6 to 0.8. The NDVI has become a popular gauge for tracking agricultural drought, calculating soil moisture, and assessing vegetation health [18]. Moreover, various sources of errors, such as air noise and other factors, such as satellite orbital drift, satellite change, and sensor breakdowns, may limit the utility of NDVI for investigating vegetation and related concerns. Because weather-related NDVI changes are hard to know, the biological component must be segregated from the weather's impact when determining the true state of vegetation health.

3.2. Vegetation Condition Index (VCI)

The VCI data have been obtained from the NDVI data calculated from USGS Earth Explorer, which were taken from Landsat-8 and span the years 2000, 2005, 2010, 2015, and 2020. The VCI obtained from NDVI data, a worldwide drought monitoring system, was constructed using the VCI-

based drought metric equation [18]. Equation 2 is used for calculating VCI from the final NDVI data.

$$VCI = \frac{NDVI_k - NDVI_{min}}{NDVI_{max} - NDVI_{min}} \times 100 \quad (2)$$

WHERE, $NDVI_k$ = NDVI value for specific year/season, $NDVI_{min}$ = Minimum NDVI over historical period, $NDVI_{max}$ = Maximum NDVI over historical period. VCI offers a uniform assessment of vegetation vitality in relation to the historical NDVI spectrum for every pixel, facilitating comparisons across different years. Time-series NDVI metrics were derived for each pixel based on the Landsat images previously specified.

Table 1. VCI index classification

Sl. No.	VCI Range	VCI Index	Dryness Level
1.	0 – 20	1	Extreme
2.	20 – 40	2	Severe
3.	40 – 60	3	Moderate
4.	60 - 80	4	Light
5.	80 - 100	5	Very light

4. Results and Discussion

The VCI was computed for the years 2000, 2010, and 2020 using NDVI data derived from Landsat imagery for the Sone Command Area and is shown in Figures 2 to 6. Seasonal analyses were carried out for the pre-monsoon and post-monsoon periods to evaluate the spatial extent and severity of agricultural drought.

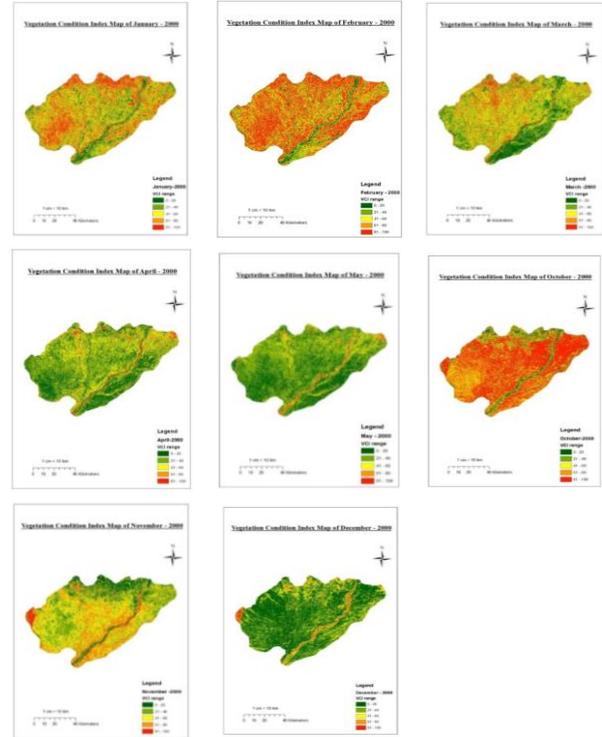


Fig. 3 Pre-monsoon and post-monsoon VCI Maps of 2000

The analysis generated twenty-four NDVI maps and corresponding VCI maps, which highlighted the temporal and spatial variability of drought in the region.

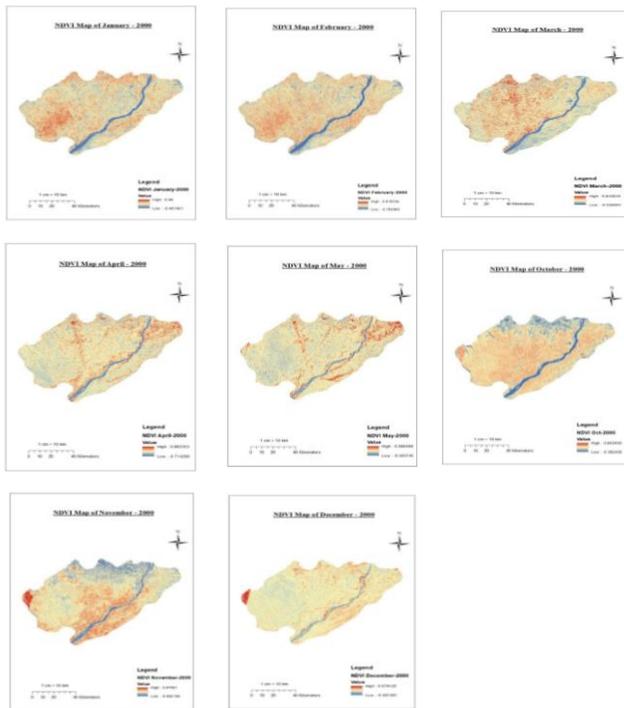


Fig. 2 Pre-monsoon and post-monsoon NDVI Maps of 2000

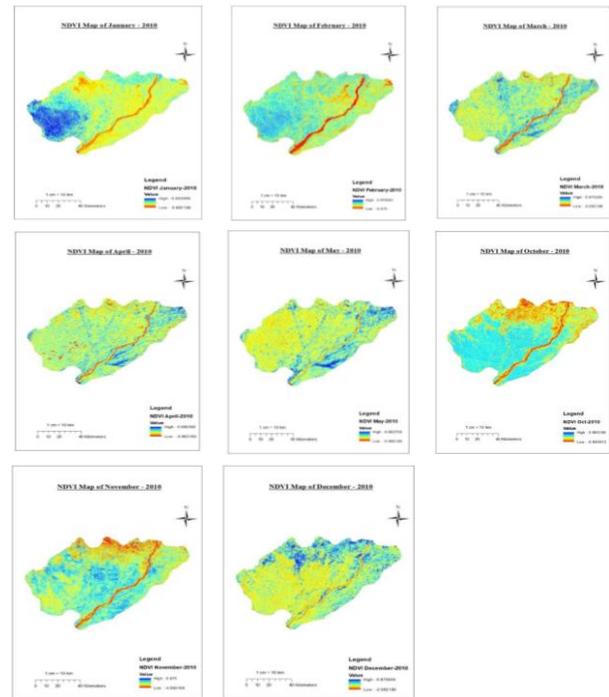


Fig. 4 Pre-monsoon and post-monsoon NDVI Maps of 2010

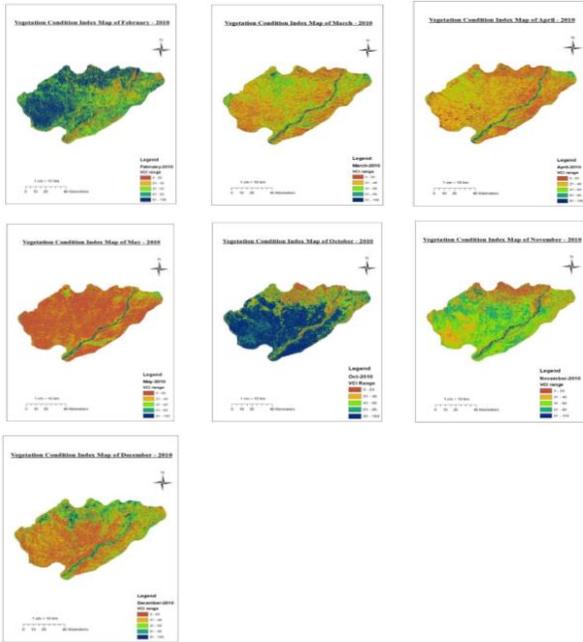


Fig. 5 Pre-monsoon and post-monsoon VCI Maps of 2010

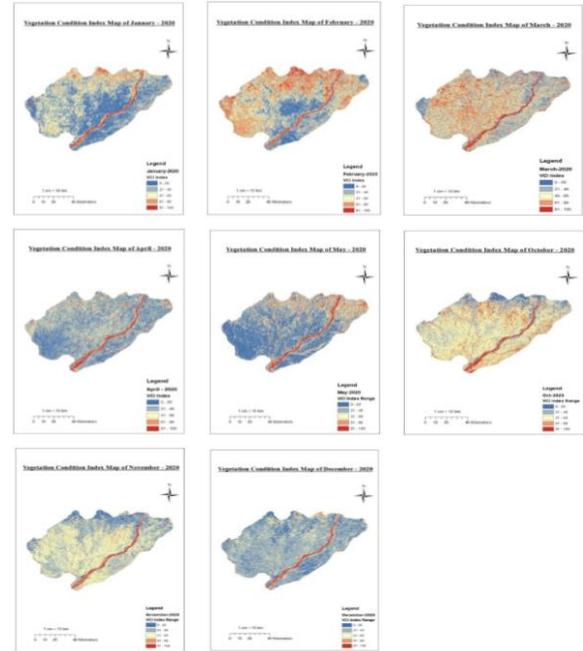


Fig. 6 Pre-monsoon and post-monsoon VCI Maps of 2020

During the pre-monsoon season, the percentage of area affected by drought was found to be 75.23% in 2000, 93.78% in 2010, and 19.75% in 2020, indicating extreme drought conditions, particularly in 2010, followed by 2000, while 2020 showed a significant reduction in drought severity. In the post-monsoon season, the drought-affected area was estimated at 47.52% in 2000, 44.98% in 2010, and 29.36% in 2020, again reflecting a decreasing trend in drought severity over the two decades.

These results suggest that the pre-monsoon season is more prone to severe drought compared to the post-monsoon season, as shown in Figures 7 to 9. The extreme drought events of 2000 and 2010 may be attributed to lower precipitation and higher evapotranspiration during these years, which is consistent with meteorological records. The reduction of drought severity in 2020 could indicate improved rainfall distribution or better water management practices in the region.

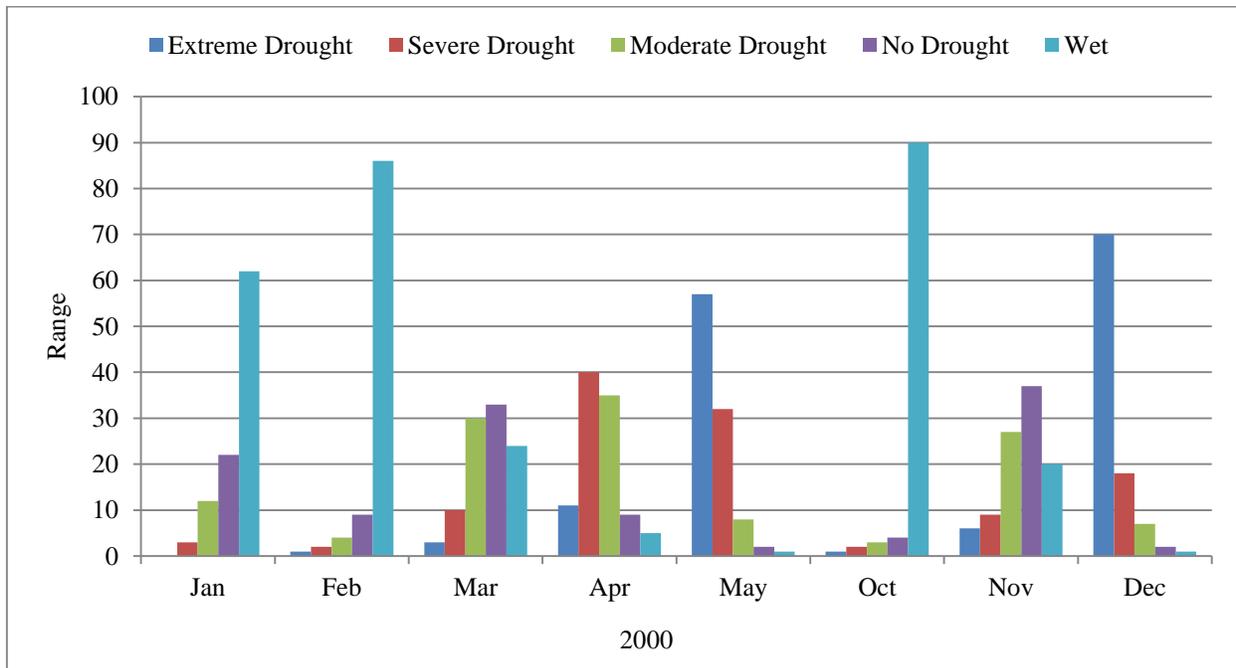


Fig. 7 The percentage of the area that experienced the drought in 2000

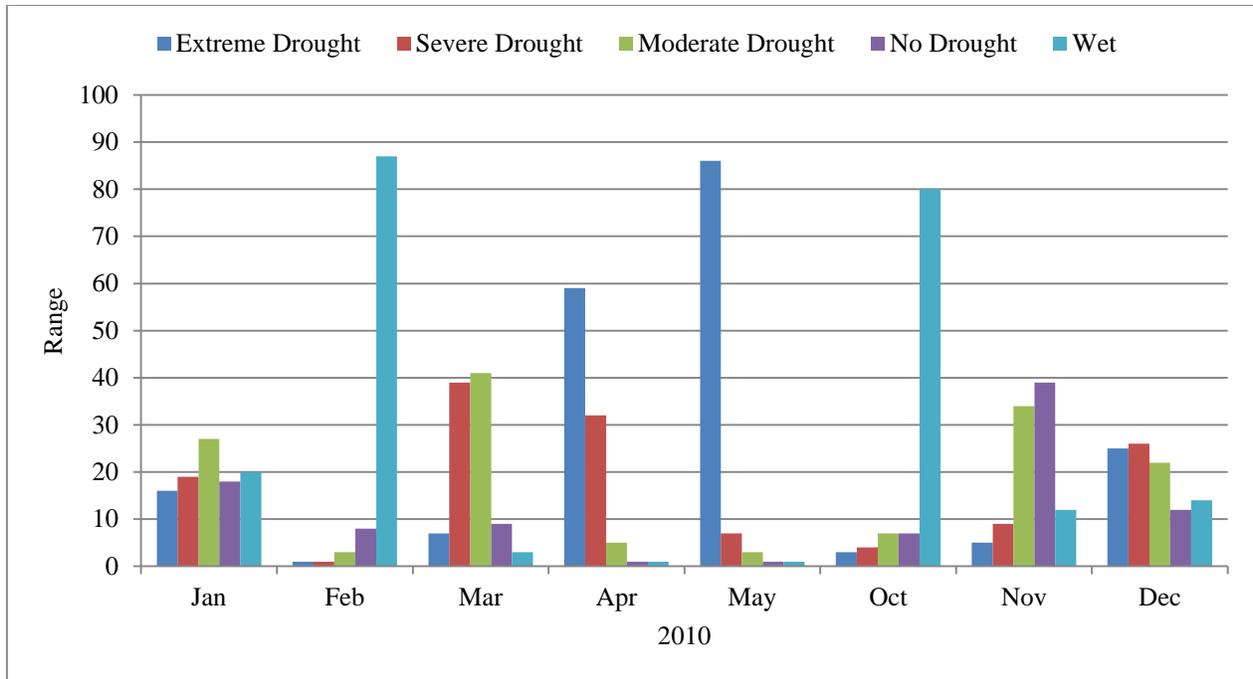


Fig. 8 The percentage of the area that experienced the drought in 2010

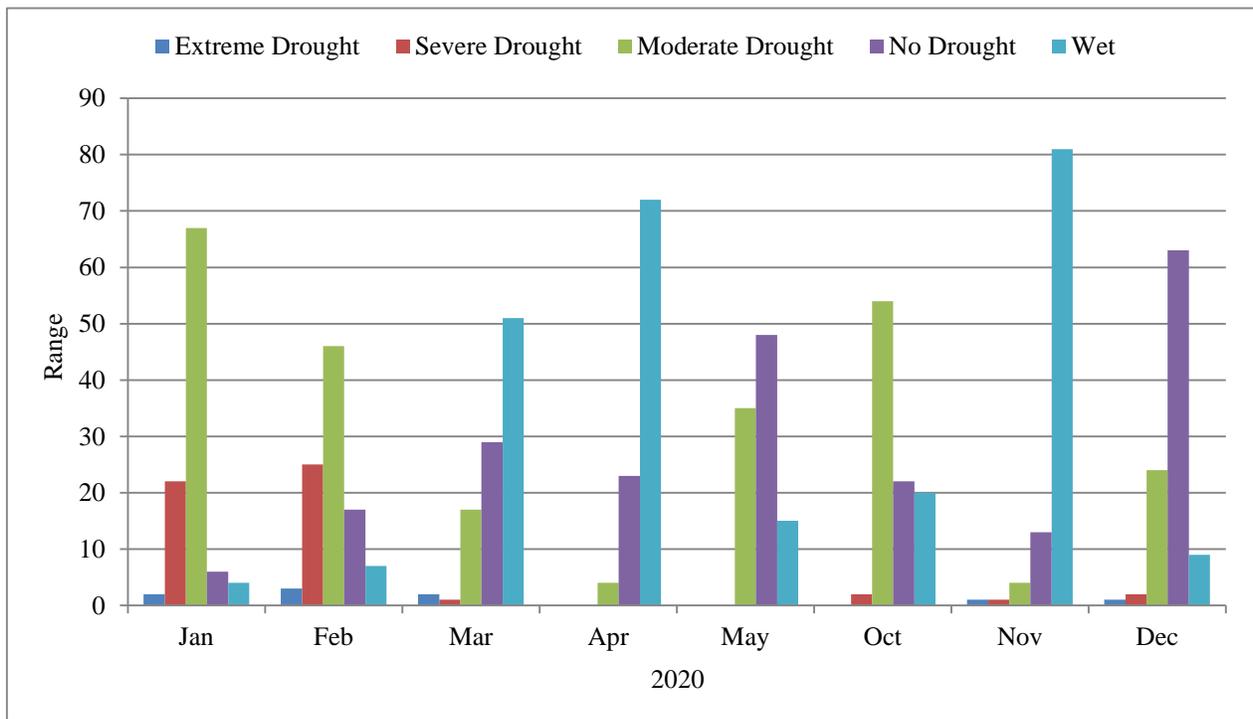


Fig. 9 The percentage of the area that experienced the drought in 2020

The study also underscores the effectiveness of VCI derived from satellite imagery as a reliable tool for monitoring agricultural drought, especially in regions where ground-based meteorological data are scarce or incomplete. The spatial patterns observed in the VCI maps provide useful insights into localized drought conditions that may not be

evident from point-based meteorological observations alone. The findings of this study provide important implications for agricultural and water resource management within the Sone Command Area. The clear identification of severe pre-monsoon vegetation stress highlights the need for improved irrigation scheduling, particularly during critical crop growth

stages when soil moisture deficits are highest. By mapping spatial variability in drought intensity, the results support crop diversification planning in highly vulnerable zones, encouraging the adoption of less water-intensive or drought-tolerant crops in repeatedly stressed areas.

5. Conclusion

The study successfully assessed agricultural drought in the Sone Command Area using the Vegetation Condition Index derived from NDVI data. The findings reveal that extreme drought conditions were observed in the pre-monsoon seasons of 2000 and 2010, while no extreme drought was detected in 2020. The observed decrease in drought severity over time highlights the potential influence of climatic

variability and possibly improved irrigation management in the study area. The results demonstrate that VCI is a robust and practical indicator for assessing and monitoring drought at a regional scale, providing critical information for agricultural planning and drought mitigation strategies. Importantly, VCI can be used effectively even in the absence of reliable meteorological data, making it a valuable tool for drought assessment in data-sparse regions.

Future work could include integrating meteorological indices with VCI to develop a more comprehensive drought monitoring framework and to explore the socio-economic impacts of drought on agricultural productivity in the region.

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