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Spatial and Temporal Assessment of Moisture Availability Index of Major Crops Grown in Anathapur District of Andhra Pradesh

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ABSTRACT

A comprehensive study was undertaken during, 2023 at CRIDA, Hyderabad, Telandana to quantify MAI for each crop and for each mandal to assess the sufficiency of rainfall for crop growth. The experiment was based on the data collected for the period of 45 years (1971 to 2015) for the sixty three (63) mandals of Ananthapur district, Andhra Pradesh, India. This research employed actual evapotranspiration (AET), potential evapotranspiration (PET) were used to quantify MAI. MAI for the major crops grown viz., groundnut, maize and sorghum during the crop growing season was used to indicate the crop wise number of very deficit, moderate deficit, and somewhat deficit periods specifically during crop growth stage (early, vegetative and reproductive growth stage). Sowing of crop was assumed to have taken place after receipt of 25 mm in 1 day or 40 mm in consecutive 3 days. MAI was computed for each week and assessment made to identify the periods of insufficient moisture. Compared to sorghum and maize groundnut crop was found to be most suitable to Ananthapur region provided few critical irrigation were planned. Atmakur, Rapthadu, Chenne Kothapalle, Roddam in the central part of the district and Gorantla, Puttaparthi in the southern parts and Bommanahal, Pamidi and Kudair mandals on the northern side showed a greater number of severe deficit, moderate deficit periods indicating a significant need for additional irrigation. This study highlights the necessity of supplementary irrigation to support crop growth in these areas, ensuring sustainable agricultural practices in the Ananthapur district.

KEYWORDS: Moisture availability index, crop planning, evapotranspiration

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Data Availability Statement: Legal restrictions are imposed on the public sharing of raw data. However, authors have full right to transfer or share the data in raw form upon request subject to either meeting the conditions of the original consents and the original research study. Further, access of data needs to meet whether the user complies with the ethical and legal obligations as data controllers to allow for secondary use of the data outside of the original study.

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1. INTRODUCTION

In arid and semiarid environments where yearly precipitation is only approximately 20–35% of potential evapotranspiration, a unique type of rainfed agriculture known as dryland farming is practiced to attain food security, enhanced nutrition and persuade sustainable agriculture (Ahmed et al., 2022, Allen et al., 2019, Eyhorn et al., 2019, Makwana et al., 2021). In Andhra Pradesh's, Ananthapur is one among four rayalseema district susceptible to drought since it is situated in a rain-shadow area (Rukmani and Manjula, 2010). Despite the fact that agriculture is still the district's primary economic sector, it is marked by a high degree of instability and uncertainty. The crop yield, particularly in dryland agriculture, is always uncertain and heavily dependent on the amount, distribution, and availability of moisture during the season of growth, despite the development of various improved techniques (Ray, 2016, Sattar et al., 2021). Success of crop depends on sowing window, evapotranspiration, water or soil moisture availability during the entire growing stage, type of soil, depth of soil, length of growing period, variety of seedling selected to suit with the agro climatic zone etc. (Tilahun, 2006, Arya and Stroosnijder, 2011, Rao et al., 2000, David et al., 2013).

Drought is a common occurrence in the climate. It may happen virtually anywhere, however, the way it manifests differs from area to region, making a universal description impossible (Ghosh et al., 2021). Also drought can reduce nutrient uptake by roots and induce nutrient deficiency by decreasing the diffusion rate of nutrients from soil to root, creating restricted transpiration rates and impairing of active transport and membrane permeability (Viets, 1972; Alam, 1999)

Thus, planning agricultural patterns and irrigation schedules is impossible without accurate knowledge on agro-climatic conditions (Mondal, 1991). Farmers can benefit from having an early warning on the weather by using it wisely and developing mitigating methods for its beneficial effects as well as its unfavourable ones. Consequently, it is necessary to research the region's climatic resources in order to boost crop production. Hargreaves, defines the MAI as the ratio of potential evapotranspiration to assured rainfall forecast, whereas Thornthwaite and Mather (1955) correlate it with the ratio of actual and potential evapotranspiration. Understanding and applying the MAI were particularly crucial in tropical regions where moisture availability fluctuates significantly across both temporal and spatial scales. By incorporating such indices into crop planning (Praveen et al., 2023, Kokilavani et al., 2016), and management protocols, farmers can optimize resource distribution, mitigate risks stemming from climatic fluctuations, and ultimately fortify agricultural resilience and productivity amidst evolving weather patterns (Goswami et al., 2022). Researchers like Gangane et al., 2017, Makawana et al., 2021 carried out works on MAI for crop planning in various parts of the country.

MAI computed for each week and assessment (Sattar et al., 2019, Aatralarasi et al., 2021, Lagna et al., 2023) is made to identify the periods of insufficient moisture which indicates the crop wise number of very deficit, moderate deficit, and somewhat deficit periods specifically during crop growth stage (early, vegetative and reproductive growth stage). This analysis is quite important for rainfed agriculture in deciding the suitability of crop, selection of variety (short or long duration crop), rain water harvesting possibility, number of critical irrigations required to protect the crop (Alanka and Vennapu, 2021, Sattar et al., 2021). The major objectives of this work were to analyse Moisture Adequacy Index (MAI) for the major crops like groundnut, maize and sorghum grown in Ananthapur district by categorising the drought periods.

2. MATERIALS AND METHODS

The study was undertaken for 63 mandals of Ananthapur district for 45 years (1971 to 2015) of daily climate data, was used in analyzing MAI for the major crops grown in Ananthapur Dist, Viz., groundnut, maize, redgram, sorghum and cotton during the crop growing season.

2.1. Study area

Ananthapur district, Andhra Pradesh which lies under rain shadow region was in the semi-arid/arid part of the peninsula, with an average annual rainfall of 530 mm, of which 310 mm rainfall received during *kharif* season was inducing the farmer to supplemental irrigation. The district constitute 78% of red alfisol soils, while black soils constitute up to 20% of the region's total area (Rukmani and Manjula, 2010). The major crops in terms of area were 86% Groundnut, followed by sunflower, red gram, sorghum, maize, cotton etc. The main crop was Groundnut which was grown in 8.0 lakh hectares in red soil under rainy conditions. Considering rainfall indices, the district had been partitioned into four rainfall zones

2.2. Data used

Daily meteorological data (Temperature minimum & maximum and rainfall data) collected from IMD for the period of 45 years (1971–2015) of 63 mandals of Ananthapur district (Figure 1). Temperature data were used to calculate actual evapotranspiration.

2.3. Seasonal rainfall variability

The rainfall database for each district was analyzed to find the standard deviation (SD) and coefficient of variation

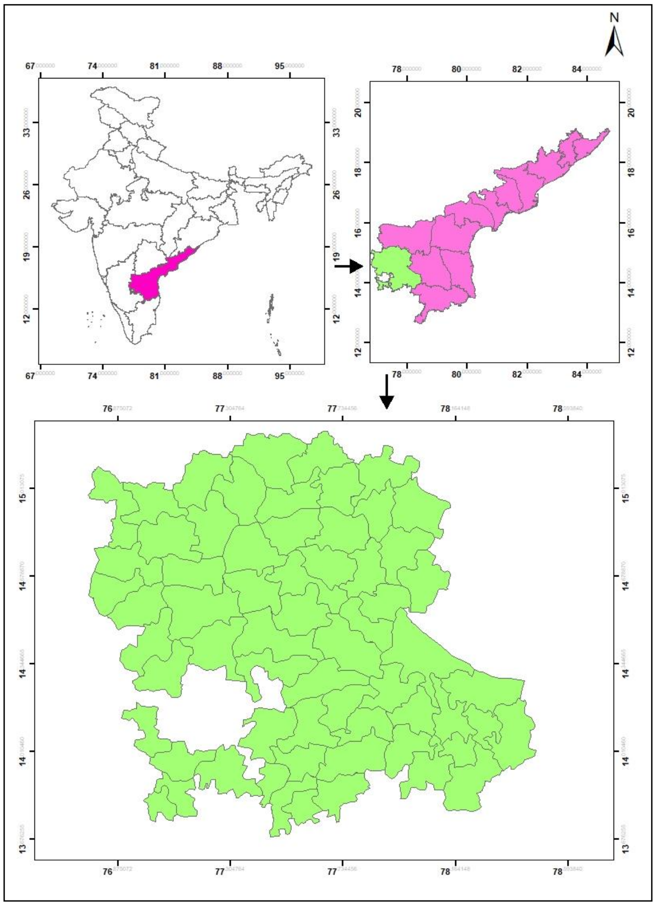

Figure 1: Location map of Ananthapur district of Andhra Pradesh

(CV) on seasonal and annual basis. The mean annual rainfall for each of the districts along with SD and CV were worked out. For seasonal distribution of rainfall, the total rainfall during each of the season viz., pre-monsoon, monsoon, post-monsoon and winter season were found out.

Standard deviation (SD)

It characterized as the square root of the mean of the squares of deviations of the rainfall value from the arithmetic mean of all such rainfall. It was a proportion of inconstancy or the dissipate or the scattering about the mean value. SD for seasonal and annual rainfall was worked out.

$SD=\sqrt(\sum(X-X)/2a$

where, =Mean rainfall, X=Rainfall frequency, n=number of years

Moisture Adequacy Index (MAI) can vary depending on the specific methodology or approach employed. One commonly used formula was the Thornthwaite-Mather method, developed by Thornthwaite and Mather in 1955. This method utilizes temperature and precipitation data to estimate potential evapotranspiration, which was then used to calculate the moisture balance. Whereas, Hargreaves-Samani method was a simplified and widely used empirical method for estimating PET. It requires only minimum and maximum air temperature data. The method was based on the relationship between temperature and PET and had been found to provide reasonably accurate estimates in areas with limited weather data.

Once the potential evapotranspiration (PET) was calculated, it was compared to actual evapotranspiration (AET) or water requirement of a specific system. The moisture adequacy index (MAI) was then calculated as the ratio of actual evapotranspiration to potential evapotranspiration:

MAI=AET/PET

The MAI provides an indication of the moisture status and water availability in a particular region or ecosystem. A value above 1 suggests a surplus of moisture, while a value below 1 indicates a deficit. The MAI was often used in agricultural, hydrological and ecological studies to assess moisture conditions, make informed decisions, and plan for water management strategies.

2.4. Computation of weekly moisture adequacy index

The Moisture Adequacy Index (MAI) was a measurement used to assess the availability of moisture in a particular region or ecosystem. It provides valuable information regarding the adequacy of water supply for various purposes such as agriculture, forestry and ecological balance. The MAI takes into account various factors like precipitation, evapotranspiration, and soil water-holding capacity to determine the moisture conditions in a given area.

The MAI was calculated using mathematical formulas that consider the balance between water inputs (such as rainfall) and outputs (such as evaporation and transpiration). These calculations were typically based on long-term climate data and historical records of precipitation and evapotranspiration rates. By analyzing these factors, the MAI provides a quantitative measure of the moisture status and helps in understanding the water availability in a region.

One commonly used equation to calculate the MAI was the Thornthwaite-Mather method, which was developed by C.W. Thornthwaite and J.R. Mather in 1955. This method uses temperature and precipitation data to estimate potential evapotranspiration, which was then used to calculate the moisture balance. The MAI was expressed as a ratio or percentage, with values above 1 indicating surplus moisture, and values below 1 indicating a deficit.

The Moisture Adequacy Index had been widely applied in various fields, including agriculture, hydrology, and climate studies. It helps farmers in making informed decisions about irrigation requirements and crop selection. It also assists water resource managers in planning water allocation and forecasting drought conditions. It helps optimize water usage, prevent water stress or overwatering, and enhance crop productivity by maintaining optimal soil moisture conditions for plant growth. Additionally, the MAI was utilized by ecologists to evaluate the impact of moisture availability on plant growth, species distribution, and ecosystem dynamics.

The moisture adequacy index was estimated by the formula,

MAI=AE/PE×100

where,

AE=Actual evapo-transpiration.

PE=Potential evapo-transpiration.

AE was estimated using the water balance model of (Thornthwait and Mather, 1955) and PE was calculated using (Hargreaves, 1985)

Agricultural droughts during cropping season (years) were classified into four groups based on average MAI during the season proposed by Hargreaves, 1974.

MAI ≤0.33: This range indicates a very deficit. It suggests that the available moisture was significantly lower than what was required for optimal crop growth. In such conditions, crops may suffer from water stress, leading to reduced yields and potential crop failure.

0.34 ≥ MAI ≤ 0.67: This range represents a moderate deficit. While the moisture availability was better than in the severe deficit range, it was still below the desired level for optimal crop growth. Crops may exhibit some level of stress and yield potential might be compromised.

0.75≥ MAI ≤1.00: This range indicates a slight deficit. While there was still a shortfall in moisture compared to the ideal conditions, it was relatively less severe. Crops may experience minor stress, but their growth and yield potential were generally maintained

1.01≥ MAI ≤1.33: This range represents adequate moisture availability. The available moisture was sufficient to meet the crop's water requirements for optimal growth. Crops in this range were generally healthy and their growth and yield potential were not significantly affected

1.34≥ MAI: This range indicates surplus moisture. The available moisture exceeds the crop's water requirements. While excess moisture can sometimes lead to water logging and other related issues, it generally ensures ample water supply for crop growth, resulting in good yields. Under such conditions water harvesting structures need to be planned

In the present study frequency of very deficit weeks and combination of very deficit and moderate deficit weeks were computed and mapped to assess the severity of drought and requirement of protective irrigation (Jadhav et al., 2015).

3. RESULTS AND DISCUSSION

3.1. Moisture adequacy index

MAI was computed for 45 years (1971-2010) for each week and for different growth stages of crop and assessment was made to identify the periods of insufficient moisture. MAI computed at mandal level (63 mandals) for Ananthapur district which was used to indicate the crop wise number of very deficit, moderate deficit, and somewhat deficit periods specifically during crop growth stage (early, vegetative and reproductive growth stage). Sowing of crop was assumed to have taken place after receipt of 25 mm in 1 day or 40 mm in consecutive 3 days.

3.2. Crop planning

To maximize agricultural productivity during this *kharif* season, a suitable cropping system should be adopted that takes into consideration the prevailing moisture conditions and the specific needs of the crops. It was essential to consider factors such as local soil conditions, availability of irrigation facilities, market demand, and individual farm characteristics while selecting the most suitable cropping system for a specific area by studying water balance models of particular region (Subramaniam and Rao, 1984). Major crops grown in the district were groundnut, redgram, maize, sorghum etc.

During the study period groundnut crop in early stage showed more number of very deficit weeks (more than 25% weeks during the study period) in 13 out of 63 mandals which were in western part of Ananthapur district. Whereas remaining mandals showed 16 to 25% very deficit weeks except Lepakshi mandal which ranged between 6 to 15% during the study period. Except Kanaganepalli mandal exhibited less than 6% very deficit weeks throughout the development stage. Only two mandals, one from north showed very deficit weeks during the reproductive stage of groundnut (i.e., Vidapanakal) and the other from the central part (i.e., Kambadur) showed more than 25% very deficit weeks and around 15 mandals (Figure 2) showed less than 16% very deficit weeks. Similarly, combined moderate and very deficit (Mod & VD) weeks were assessed and observed that the western part of Ananthapur district had more than 55% during the three stages of crop growth during the study period. In areas where sufficient soil moisture and irrigation facilities were available, dual cropping can be practiced during the *kharif* season. For example, a combination of groundnut as the main crop and short-duration vegetables like okra or cowpea as intercrops can be grown to maximize land productivity.

During early growing stage of maize 13 mandal showed (more than 25%) very deficit moisture, whereas combine moderate and very deficit were (more than 50%) in 25 mandals. During development stage very deficit was acceptable range (with below 12%) in all other mandals

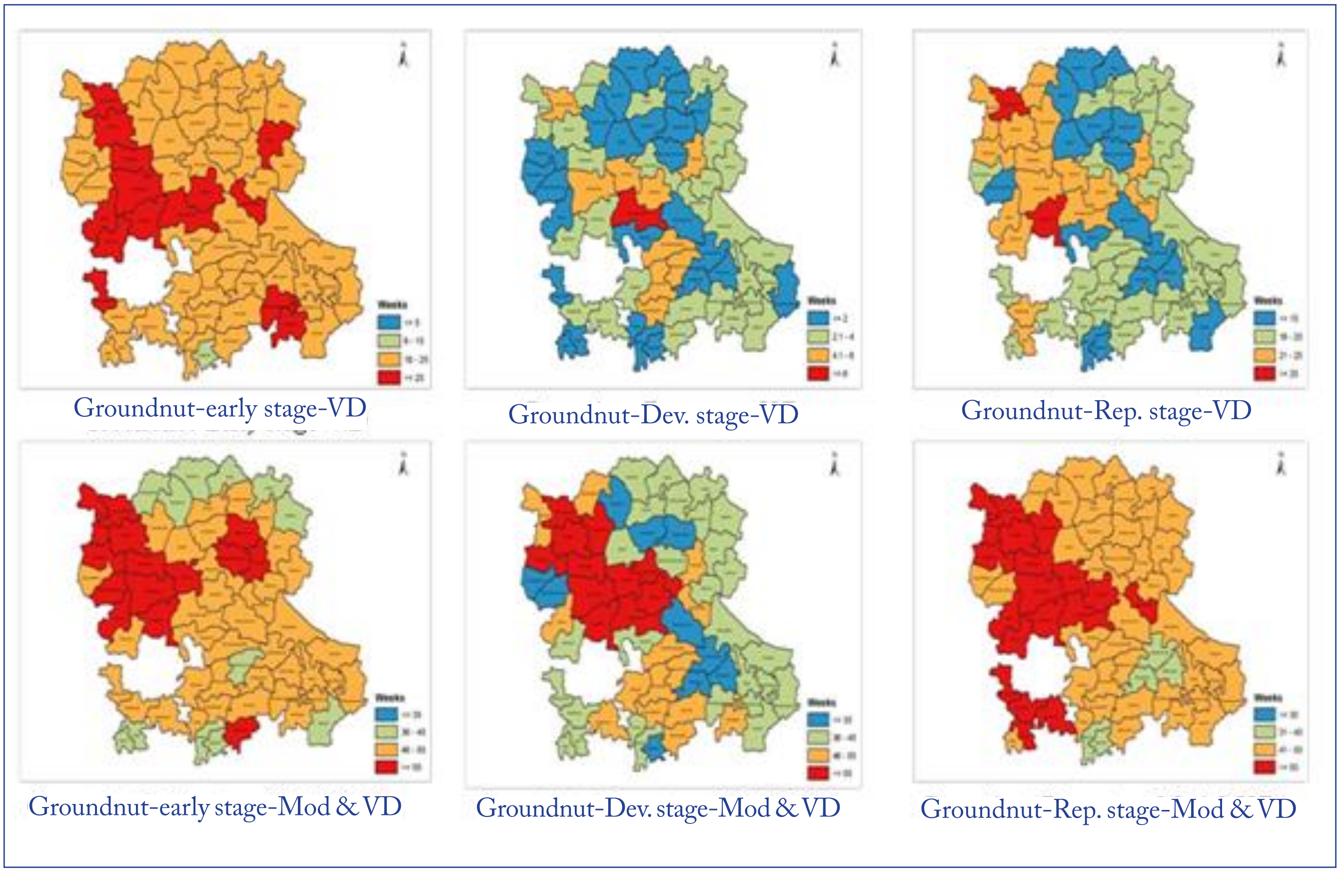

Figure 2: Maps showing groundnut crop early, developmental and reproductive stage frequency MAI showing very deficit weeks and combine moderate and very deficit weeks

except one mandal which showed above 11% very deficit but combine moderate and very deficit up to 65% with more than 50% in 27 mandals. Similarly during reproductive stage very deficit weeks showed more than 25% in 18 mandals with maximum 31% of duration of crop growth and combine moderate and very deficit were (more than 50%) in 25 mandals during reproductive stage (Figure 3). Drought interrupts by restricting leaf growth, plant height, and tassel architectural traits. This lowers crop output since plants need enough photosynthesis to reach the requisite stature (Aslam et al., 2015) protective irrigation had to be planned to save the crop and attain yield.

Sorghum very deficit during early and development stage showing less than 25% and 9% of growing period respectively in all the mandals, while during reproductive stage entire district except 11mandals were showing more than 15 to 27% of very deficit period (Figure 4). Similarly combine moderate and very deficit weeks were higher during reproductive stage. Sorghum sensitivity to drought stress was greater during reproductive stages than during the vegetative stage. Sorghum yield was a function of the number of harvested panicles, seeds per panicle, and individual seed weight. All of which can be affected by duration and severity of drought during reproductive stages. Though sorghum can extract water from deep in the soil profile and remove most of the apparent available water because it had more secondary roots per unit of primary roots than other cereal crops, studies reveal that water deficit significantly reduces shoot elongation and root growth (Khalil et al., 2020). Thus drought tolerant hybrids had to be selected rather than relying yield alone (Assefa et al., 2010).

Similar such studies in different regions were studied for spatial and temporal variations for long-term climate data. Alanka and Vennapu, 2021 revealed that in Srikakulam district of Andhra Pradesh that seasonal variations in PET values across mandals, with higher levels in summer and central regions, emphasize the need for strategic water management and drought planning to ensure sustainable and resilient farming in the district. Similarly, study conducted at Gujarat by Makwana et al., 2021 identified the ideal sowing period for *kharif* crops, offering valuable guidance for enhancing rainwater use efficiency in agricultural planning and irrigation management. While similar such studies were conducted in different states of the country to find suitable crop sowing window and prolonged drought periods to suggest water management

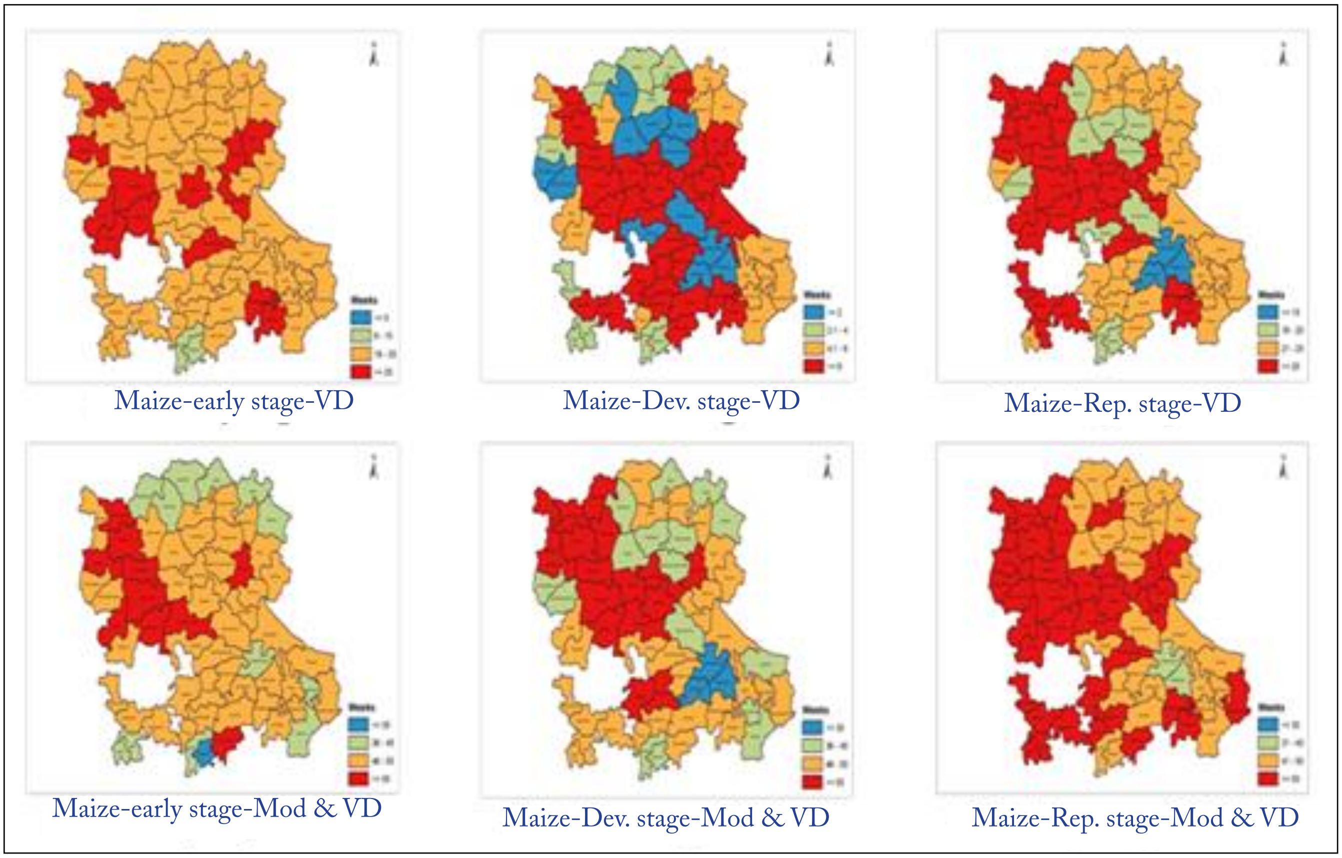

Figure 3: Maps showing maize crop early, developmental and reproductive stage frequency MAI showing very deficit weeks and combine moderate and very deficit weeks

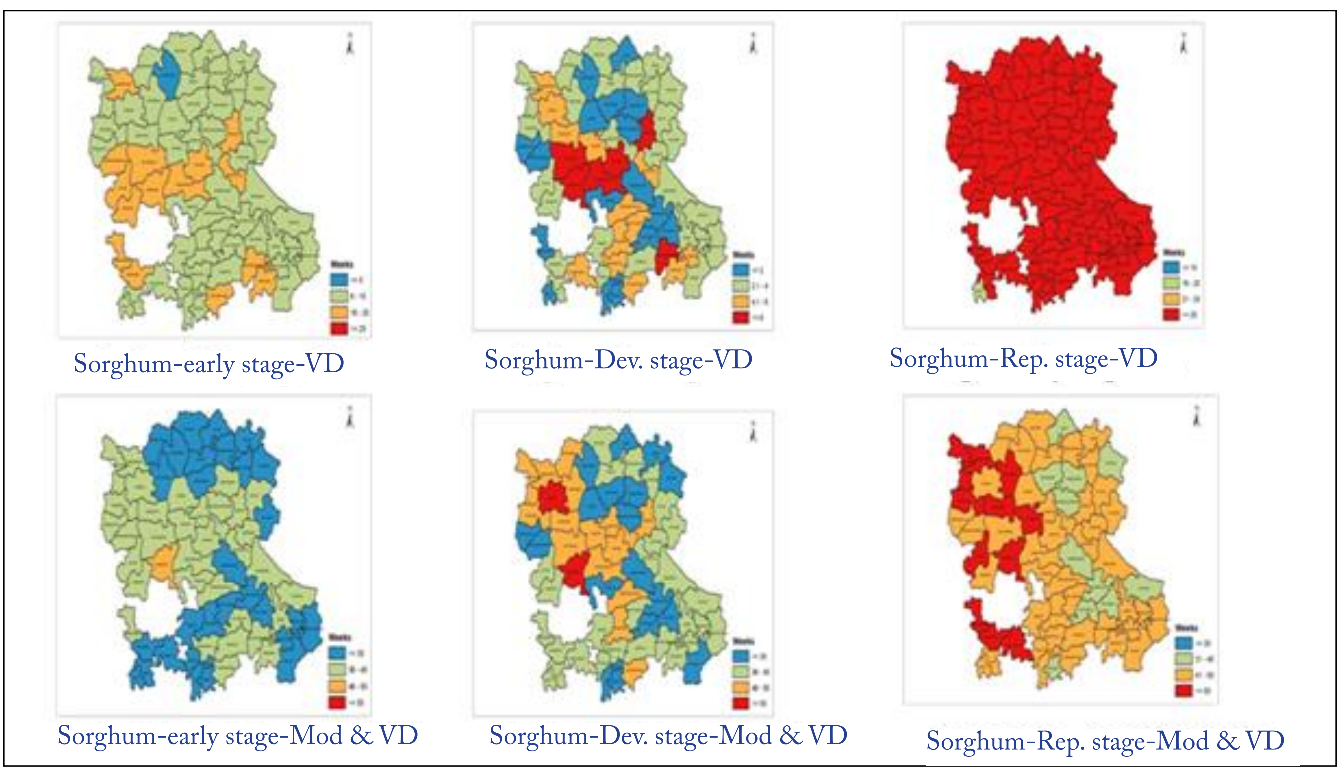

Figure 4: Maps showing sorghum crop early, developmental and reproductive stage frequency MAI

techniques like Goswami et al., 2022 also recommended the suitable crop sowing window for Assam and Praveen et al., 2023 analyzed different indices to monitor drought analysis for Bihar region. Lagna et al., 2023 emphasizes the importance of adapting crop planning to changing rainfall patterns and moisture availability, advocating for diverse cropping systems, including multi-tier and multi-cropping, to improve yields, encourage sustainable agriculture, and ensure better income for farmers.

Adopting good agricultural practices, such as minimum tillage, integrated management of fertilizers, insects, pests, diseases, and weeds, crop rotation, intercropping, and relay cropping, along with the use of new cultivars, had the potential to enhance the productivity and rainwater-use efficiency of dryland crops. The findings from the research will be valuable to agricultural scientists, researchers, decision-makers, and policy planners working in agricultural crop planning and irrigation management in semi-arid regions by improving rainwater-use efficiency in dryland farming.

While the current study provides valuable insights into the MAI and drought periods for Ananthapur district, further research was needed in several areas like development of drought resistant crop varieties, climate change impact assessment as climate modeling and long-term projections can help design adaptive strategies for farming under evolving weather conditions, water management technologies and soil health and moisture retention to reduce the impact of drought on crop yields.

4. CONCLUSION

This study investigated into the impact of MAI on crop planning in semi-arid regions, marked by erratic rainfall and limited groundwater. Analysis revealed that sorghum showed drought in over 25% of its growth period during the reproductive stage. Similarly, maize exhibited more weeks of severe deficit during developmental and reproductive stages. Groundnut was found most suitable for the region with supplementary irrigation. Mandals like Atmakur and Rapthadu showed significant moisture deficits, highlighting the need for strategic irrigation planning.

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