Monitoring of agricultural drought using remote sensing data in the Sebou watershed, Morocco

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Abstract. Drought is a climatic phenomenon that can adversely affect the environment and human activities. Currently, agricultural drought has become a concern in countries where agriculture largely depends on rainfall and is highly vulnerable to climatic variability. The study of drought requires the availability of hydroclimatic and remote sensing data. Based on these data, researchers have proposed several indices (SPI, SPEI, PDSI, VCI, VHI, etc.) that allow the monitoring of the spatiotemporal evolution of drought. This study focuses on remote sensing data to illustrate agricultural drought in the Sebou watershed from 2010 to 2023. We used the NDVI derived from MODIS (Moderate Resolution Imaging Spectroradiometer) satellite images to calculate the Vegetation Condition Index (VCI) during the crop growth season. The analysis of the VCI over 14 years shows that the Sebou watershed has undergone droughts of varying severity, with a notable increase in drought events from 2016 to 2023. In 2016, approximately 50% of the basin experienced extreme agricultural drought. Thus, we found that the VCI is a valuable indicator that reflects the vegetation's response to the rainfall deficit recorded in recent years.

Keywords: Agricultural drought, Remote sensing, MODIS, VCI, Sebou watershed.

1 Introduction

Drought is a climatic phenomenon that can adversely affect the environment and human activities. In the semi-arid regions of the southern Mediterranean, the recurrence of droughts has significantly impacted arable land suitable for rainfed agriculture [1]. The vulnerability of these crops to climatic variability is evident in the yield losses experienced across various countries. This situation is expected to worsen in the coming years, especially as future climate change scenarios strongly agree on an increased frequency of droughts in the Mediterranean basin [2]. In Morocco, the recurrence of droughts of varying intensities, durations, and spatial extents poses an obstacle to the development of agriculture [3]. The frequency of droughts has greatly affected more than 90% of the country's agriculture, which depends on rainfall [4]. These unfavorable climatic conditions (increased temperatures and decreased precipitation) have caused adverse effects on the economy and society.

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The spatiotemporal analysis of drought using hydroclimatic data relies on indices widely utilized by researchers across different regions worldwide (SPI, SPEI, PDSI). These indices are understood as numerical indicators of drought severity [5]. Detecting agricultural drought requires a dense network of measurements from rain gauge stations. However, obtaining precise precipitation data is particularly challenging in complex terrains characterized by a low density of climate stations. Thus, acquiring in situ data in many countries is a principal challenge for researchers, as these data are often inaccessible, incomplete, and costly. To address the data problem, the development of remote sensing provides a practical alternative for studying agricultural drought at different spatial and temporal scales. The Normalized difference vegetation index (NDVI) derived from remote sensing data is among the most commonly used indices for studying agricultural drought [6-9], as it is an excellent indicator of vegetation stress. This study relies on utilizing NDVI derived from MODIS (Moderate Resolution Imaging Spectroradiometer) satellite images (MOD13Q1) to compute the Vegetation Condition Index (VCI), which allows the illustration of agricultural drought in the Sebou watershed. Specifically, the main objectives of this study are: 1) analyzing the severity of agricultural drought in the Sebou watershed from 2010 to 2023. 2) highlighting VCI anomalies in the study area.

2 Study area

Located in northwestern Morocco, the Sebou watershed is considered one of the most significant basins in terms of hydrology and agriculture. It covers an area of 40,000 km², representing approximately 6% of the national territory. From south to north, this basin exhibits notable topographic and lithological diversity. These characteristics affect the distribution of precipitation in different parts of the basin and control the flow regime. The climate is Mediterranean, characterized by spatial and temporal irregularity of precipitation [10]. The average annual rainfall across the entire Sebou basin is 600 mm. Annual mean temperatures range between 10 and 20 degrees Celsius (ABHS), with peaks during the summer and lows during the winter. Thus, the Sebou basin is the most important farming region, with nearly 20% of the irrigated agricultural land and 20% of the farming land in Morocco. Despite the basin's importance in the national economy, climate changes observed in recent decades have led to severe droughts [11-13], which can have unfavorable impacts on water resources and precipitation-dependent agricultural production.

3 Methodology and data

In this study, the spatiotemporal analysis of agricultural drought is supported by MODIS data downloaded from the NASA website (https://ladsweb.modaps.eosdis.nasa.gov/search/). These data, widely used by researchers [6-8, 14, 15], are available at a temporal resolution of 16 days and a spatial resolution of 250 meters. The selected MODIS images (MOD13Q1) for monitoring agricultural drought in the Sebou basin span 14 years. The NDVI derived from MODIS images forms the basis for calculating the VCI (Eq. 1) during the rainy crop growing period from 2010 to 2023. This index, recommended by the World Meteorological Organization [15], is a valuable indicator that reflects vegetation response to precipitation impact. VCI values range from 0 to 100, with higher values indicating better vegetation growth (No drought). Conversely, lower VCI values indicate poor vegetation growth, indicating extreme drought. In this study, we distinguished five classes of agricultural drought based on VCI values: no drought (40-100), mild drought (30-40), moderate drought (20-30), severe drought (10-20), and extreme drought (< 10). Additionally, we calculated the

VCI anomaly (Eq. 2) to illustrate VCI variations over the study period. VCI anomalies (AVCI) help identify dry or wet years in the Sebou watershed.

$$\mathrm{VCI} = \frac{NDVI_i - NDVI_{min}}{NDVI_{max} - NDVI_{min}} \quad (1)$$

Where, VCI: Vegetation Condition Index, $NDVI_i$: the mean values for the main growing season (March and April), $NDVI_{min}$ and $NDVI_{max}$: the minimum and maximum of NDVI values calculated for each pixel during the study period.

$$\mathrm{AVCI} = \frac{\mathrm{VCI_i} - \mathrm{VCI_{mean}}}{\mathrm{VCI_{mean}}} \quad (2)$$

Where, AVCI: Vegetation Condition Index anomaly, VCI_i: is the VCI value in a specific period, VCI_{mean}: is the average VCI over the study period.

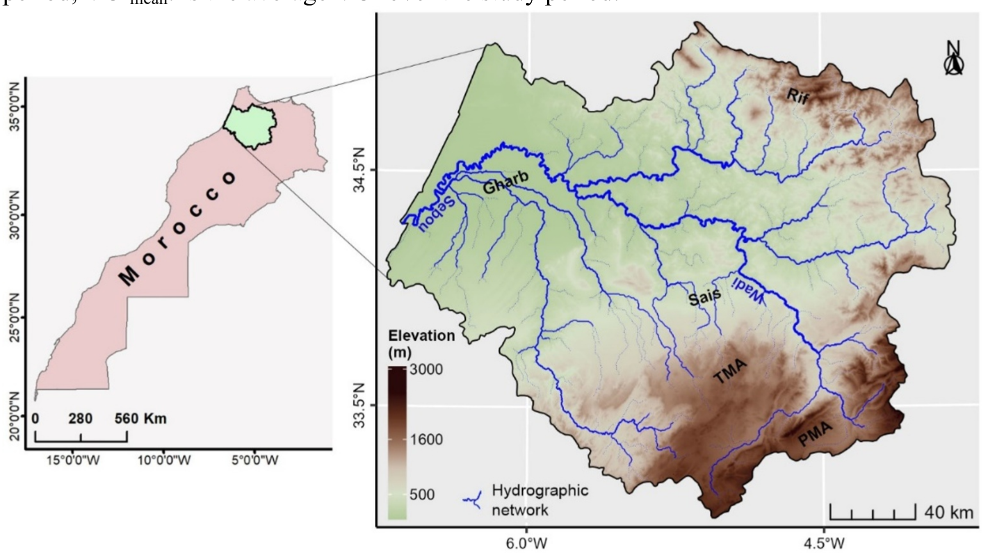

Fig. 1. Study area location. TMA: Tabular Middle Atlas; PMA: Pleated Middle Atlas

4 Results and discussion

The VCI derived from the NDVI vegetation index is a crucial indicator for analyzing and monitoring agricultural drought under various environmental conditions. In this study, we considered the rainy crop growing period (March and April) to illustrate the spatiotemporal variation of VCI. Studying the VCI during this period of the year allows us to observe the vegetation's response to changes in precipitation amounts. The results obtained from processing MODIS satellite images over 14 years (2010-2023) show that the Sebou watershed has experienced remarkable VCI variations. Figure 2 indicates that the severity of agricultural drought varies from year to year and across different locations in the basin. The analysis of VCI over the study period (Figures. 2 and 3) shows that in 2016, the Sebou basin underwent extreme agricultural drought, affecting approximately 50% of the total basin area. During 2012, 2020, 2022, and 2023, over 25% of the Sebou basin area encountered severe to extreme droughts. Thus, the severity of drought varies across different locations in the basin. In 2012, the northern part of the Sebou watershed (Ouergha watershed) was considered one of the areas most affected by extreme drought. In 2020 and 2022, severe to extreme drought categories are visible in the intermediate part of the study area (Gharb and Sais, etc.). Additionally, the southern region (Tabular, Pleated Middle Atlas) of the basin experienced extreme droughts in 2018 and 2023. During 2010, 2011, 2013, 2014, 2015, 2019, and 2020, the study area experienced low drought severity.

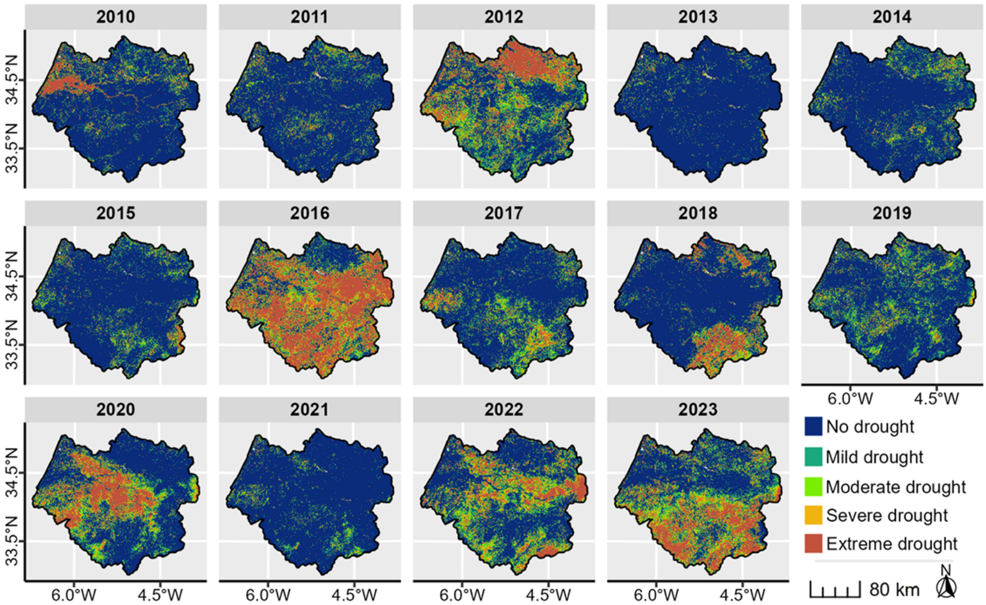

Fig. 2. Spatio-temporal distribution of the mean VCI during the growing season of rainfed crops in the Sebou watershed from 2010 to 2023

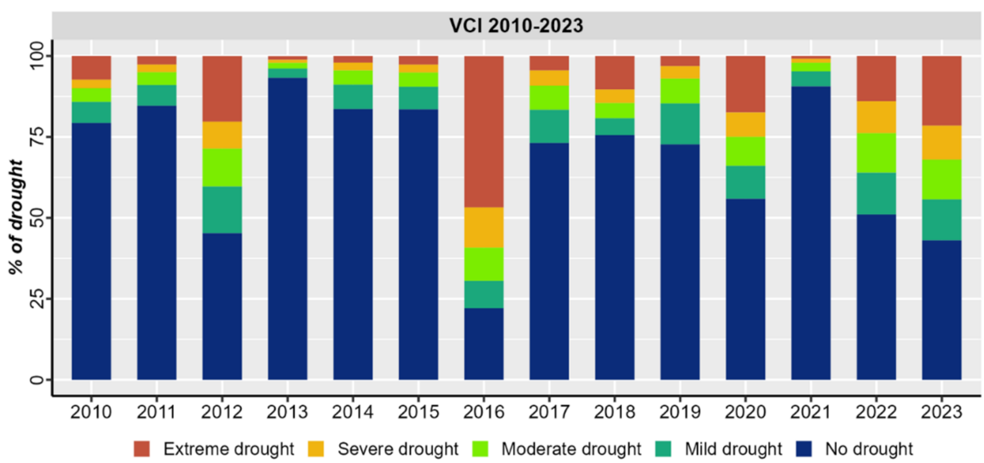

Fig. 3. Variations in the area (%) of different drought categories within the Sebou watershed

To analyze the characteristics of drought during the rainy crop growing season in the Sebou watershed, we studied vegetation conditions Index anomalies (AVCI). Figure 4 depicts the AVCI, illustrating drought anomalies from 2010 to 2023. From 2010 to 2015, negative AVCI values were low in the study area. In recent years, negative AVCI values have increased significantly (2016, 2020, 2022, and 2023), with high values observed in 2016 (-0.6). Additionally, positive anomalies have been very weak compared to the first period.

Over the studied period, remote sensing monitoring suggests that the Sebou watershed experienced extreme agricultural droughts for several years. The recurrence of agricultural droughts of varying severity is associated with the observed rainfall deficits in recent years. The SPI (Standardized Precipitation Index) calculated by El-Bouhali et al. 2024 [11] shows that the Sebou watershed has undergone extreme meteorological, agricultural, and hydrological droughts. The SPI analysis also indicated a high frequency of agricultural droughts over the past decades, with values exceeding -2. The highest AVCI observed in 2016 coincides with extreme droughts. The frequency of agricultural droughts has led to significant losses in rainfed crop production. This finding is based on Bouras et al. 2020 [1], demonstrating a significant correlation between the VCI drought index and yield anomalies across a large portion of the Sebou watershed. Hence, the authors highlighted that the agricultural season of 2015-2016 underwent a poor harvest throughout the study period.

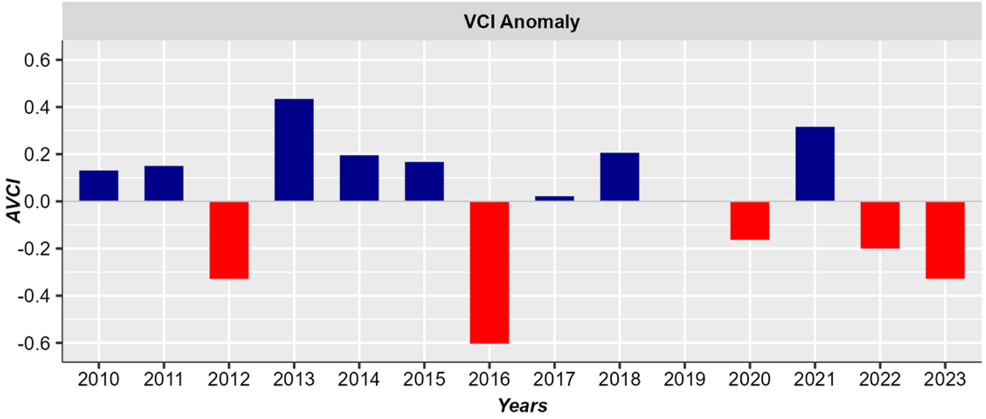

Fig. 4. VCI anomaly during the growing season of rainfed crops in the Sebou watershed

5. Conclusion

In this study, the use of the VCI index derived from remote sensing data shows that the Sebou basin experienced extreme agricultural droughts from 2010 to 2023. In 2016, approximately 50% of the basin experienced extreme drought, with the highest AVCI values observed during the study period. The recurrence of agricultural droughts of varying severity across the entire Sebou basin is related to decreased rainfall. The frequency of extreme droughts has impacted the productivity of rainfed crops, which occupy a large portion of the study area. Monitoring agricultural drought has revealed that rainfed agriculture in the Sebou basin is significantly susceptible to changes in climate conditions. Precipitation variability can lead to low land productivity and consequently trigger food security challenges. Studying the spatiotemporal variation of agricultural drought in the Sebou watershed has indicated their severity and frequency. The findings from this work can provide valuable insights for developing policies capable of mitigating the socio-economic consequences of drought.

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Author contribution
All authors contributed to the study and approved the final manuscript. Abdelaziz El-Bouhali: Conceptualization, Methodology, Software, Data analysis, Writing – original draft. Khadija El Ouazani Ech-Chahdi: Methodology, Data analysis, Writing - Review & editing. Mhamed Amyay: Supervision, Writing – review & editing, Validation.
Ethics approval and consent to participate
Not applicable.

Consent for publication
All authors have agreed to publish this article.
Competing interests
The authors declare that they have no competing interests.
Data availability statement
Data will be made available on request.
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