

ASSESSING DROUGHT DYNAMICS IN NORTHEASTERN ALGERIA USING THE VEGETATION HEALTH INDEX DERIVED FROM MODIS DATA

Rabah MAYOUF^{1*}, & Mohamed Tahar HANAFI^{2,3}

¹Faculty of Life and Natural Sciences, Department of Agronomy, Echahid Hamma Lakhdar University, El Oued, Algeria

²Laboratory of Biology, Environment and health, Department of Biology, Faculty of Life and Natural Sciences, Echahid Hamma Lakhdar University, El Oued, Algeria

³Scientific and Technical Research Centre for Arid Areas (C.R.S.T.R.A), Omar El Barnaoui, Campus of Mohamed, Khider University of Biskra, 07000, Biskra, Algeria

*Corresponding author: mayouf-rabah@univ-eloued.dz

Abstract: This study focuses on drought monitoring in Tebessa, Algeria, utilizing remote sensing techniques and various drought indices. The research employs data from MODIS (Moderate Resolution Imaging Spectroradiometer) satellites and utilizes the Google Earth Engine (GEE) platform for data processing and analysis. The study area, Tebessa Province in northeastern Algeria, is characterized by an arid to semi-arid climate, making it particularly vulnerable to drought. The research uses three main indices to assess drought conditions; The (VCI) stands for Vegetation Condition Index, the (TCI) for Temperature Condition Index and the (VHI) for Vegetation Health Index. These indices are calculated using NDVI (Normalized Difference Vegetation Index) and Land Surface Temperature (LST) data from MODIS products spanning from 2001 to 2024. The results show varying drought conditions across different periods, 2005-2006 recorded severe dry conditions in the central and southern areas, 2009-2010 recorded extreme drought in the southern region, with moderate to mild conditions in the central zone, for 2022-2023 recorded widespread extreme drought conditions, particularly affecting the central parts. The TCI consistently indicated wet conditions in most years, especially in 2002, 2009, and 2019, highlighting its sensitivity to seasonal temperature variations. The VCI and VHI analyses revealed distinct spatial variations in drought impacts, with central zones being particularly vulnerable. The study observed declining trends in TCI, VCI, and VHI values over time, suggesting worsening drought conditions potentially driven by climate change. This trend could lead to more frequent and severe droughts, further stressing local vegetation. The research confirms the effectiveness of MODIS-derived drought indices, particularly the VHI, in monitoring regional drought dynamics. It emphasizes the importance of these tools for identifying areas at risk of vegetation degradation and predicting potential decreases in crop yields.

Keywords: Drought monitoring, NDVI, TCI, VCI, VHI, Remote sensing, Tebessa, Algeria

1. INTRODUCTION

Drought is a critical environmental challenge with far-reaching consequences for ecosystems, agriculture, and water resources. With the progression of climate change, both the occurrence and intensity of drought events have escalated, necessitating more advanced methods for effective monitoring and management (Harry et al., 2019). The breadth of the effects of drought across vast areas cannot be fully captured by traditional drought

assessment techniques, which frequently rely on observations from the ground (Zhang et al., 2023). Technologies for remote sensing have become indispensable for thorough and scalable drought monitoring in this regard.

Remote sensing offers a unique capability to observe and analyze ecological responses to drought over extensive areas. The integration of ecological indexes like the Vegetation Health Index (VHI), Temperature Condition Index (TCI), and Vegetation Condition Index (VCI) that use satellite data from

MODIS (Moderate Resolution Imaging Spectroradiometer) have shown to be very useful in detecting and quantifying drought conditions (Taheri Qazvini & Carrion, 2023). These indices provide critical insights into the health of vegetation and surface temperatures, enabling a more detailed understanding of drought dynamics across diverse ecosystems.

The Google Earth Engine (GEE) platform, leveraging its robust cloud-based computational power, has significantly improved the capacity for near real-time drought condition monitoring. By leveraging extensive satellite datasets, GEE allows for continuous spatiotemporal analysis of drought, offering unprecedented opportunities for large-scale environmental monitoring (Cammalleri et al., 2019). This study focuses on Tebessa, a region in northeastern Algeria that lies at the intersection of the Tell Atlas and the Sahara Desert. Tebessa's climate, ranging from arid to semi-arid, is distinguished by elevated temperatures and sparse, unpredictable precipitation, makes it highly vulnerable to drought. The region's reliance on agriculture and rangelands, both of which are sensitive to climatic variations, underscores the importance of effective drought monitoring. Through the application of VCI, TCI, and VHI indices within the GEE platform, this research aims to track drought patterns in Tebessa from 2001 to 2024, offering a comprehensive view of the region's ecological response to drought. This research is anticipated to yield important insights into the

ecological consequences of drought in Tebessa, aiding in the creation of strategies to mitigate drought-related challenges. By leveraging remote sensing technologies alongside ecological assessments, this research seeks to advance our understanding of drought dynamics in arid and semi-arid regions and to support the sustainable management of these fragile ecosystems.

2. MATERIAL AND METHODS

2.1 Study area

Tebessa Province, situated in northeastern Algeria, spans approximately 13,261 km² and comprises 28 administrative municipalities. Geographically, it lies at the juncture of the Saharan Atlas Mountains and the Sahara Desert, between latitudes 35°10' to 35°22' north and longitudes 7°13' to 7°55' east, with elevations ranging from -1 to 1713 meters (Figure 1). This region is distinguished by its diverse geomorphology and high ecological significance (Mihi et al., 2022). The province experiences a semi-arid to arid climate, characterized by intense heat during the summer months, where temperatures frequently surpass 40°C, and cooler winters with sporadic frost events. Annual precipitation is highly variable, ranging from 200 to 400 mm, which contributes to the frequent occurrence of severe drought conditions. These conditions are further exacerbated by elevated evapotranspiration rates and the scarcity of water resources.

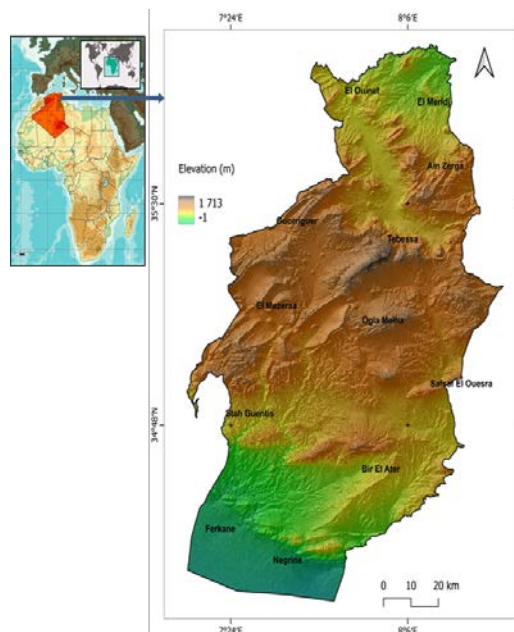


Figure 1. Localization of the study area

The predominant soil types in Tebessa are calcareous, with low organic content, shallow depth, and a high propensity for erosion and desertification, particularly in areas where soil moisture retention is inadequate. Urbanization in the region is primarily concentrated around the city center, leading to significant anthropogenic pressures on surrounding agricultural and natural ecosystems (Macheroum & Chenchouni, 2022). Hydrologically, the region is characterized by ephemeral wadis, which play a critical role in groundwater recharge; however, their sporadic flow and the region's erratic precipitation patterns pose substantial challenges for sustainable water resource management (Boudjabi & Chenchouni, 2022). The native vegetation is dominated by xerophytic species, which are well-adapted to the arid conditions and are vital for maintaining soil stability. However, unsustainable practices such as overgrazing, coupled with the impacts of climate change, have led to significant degradation of rangelands and accelerated processes of desertification. The agricultural sector, which is focused on drought-tolerant crops like cereals and olives, heavily depends on irrigation, thereby placing additional stress on the region's limited water resources (Macheroum & Chenchouni, 2022).

2.2. MODIS time series data

This study employed the MODIS (Moderate Resolution Imaging Spectroradiometer) data to monitor drought conditions using the Vegetation Condition Index (VCI), Temperature Condition Index (TCI), and Vegetation Health Index (VHI). Monthly NDVI (Normalized Difference Vegetation Index) data were sourced from the MOD13A2 Version 6.1 product, which provides 16-day composite images at a 1 km spatial resolution. Additionally, Land Surface Temperature (LST) data were retrieved from the MOD11A2 Version 6.1 product, which offers 8-day composite images with a 1 km spatial resolution, spanning from 2001 to 2024.

The LST values in the MOD11A2 dataset represent the simple average of daily LST measurements over the 8-day period, with quality assurance (QA) flags reflecting the predominant QA status across the dataset. The MODIS data were accessed and processed through the Google Earth Engine (GEE) platform, which facilitated efficient handling of large-scale time series data.

Both the NDVI and LST data were utilized as provided, without additional geometric or radiometric corrections, ensuring consistency and reliability in the analysis. The indices VCI, TCI, and

VHI were then calculated to assess drought severity and spatiotemporal patterns across the study period, leveraging the computational capabilities of GEE to support real-time and large-scale drought monitoring.

2.3. METHODOLOGY

2.3.1 Normalized Difference Vegetation Index (NDVI)

The NDVI is a widely utilized metric for assessing and quantifying vegetation dynamics, particularly in relation to surface reflectance. It serves as an indicator of the density and health of vegetation within a given area. Developed by Rouse et al., (1974), the NDVI is calculated as the ratio of the difference between reflectance values in the near-infrared (NIR) and red (RED) bands to the sum of these reflectance values. The formula for NDVI (Kogan, 1997) is expressed as:

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

where:

NIR represents the reflectance in the near-infrared band, which is strongly reflected by healthy vegetation.

RED denotes the reflectance in the visible red band, which is absorbed by chlorophyll in green plants.

This index effectively highlights areas of active photosynthesis, enabling the monitoring of vegetation cover and health across diverse landscapes.

2.3.2 Vegetation Condition Index (VCI)

The VCI is a key metric derived from the NDVI, used to evaluate the relative condition of vegetation in a specific area. It is a pixel-based indicator that measures vegetation health by comparing current NDVI values to the historical range of NDVI values at each grid cell, taking into account the minimum and maximum NDVI values recorded over a multi-year period (Kogan, 1995).

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

The VCI normalizes these NDVI values, providing insights into vegetation conditions over time, typically ranging from 2001 to 2024 in this study. The index is expressed on a scale from 0 to 100, where values near 0 indicate extremely poor vegetation conditions, often associated with severe drought, and values near 100 represent optimal vegetation health. A VCI of 50 suggests average

vegetation conditions, offering a balanced view of growth dynamics across the study period.

2.3.3 Temperature Condition Index (TCI)

The Temperature Condition Index (TCI) is designed to evaluate vegetation stress by analyzing fluctuations in land surface temperature (LST). Developed from the observation of LST data over time, TCI measures how current temperature conditions compare to the historical extremes recorded for each pixel. The index is calculated by normalizing the LST values (Kogan, 1995), which involves comparing the current LST with the maximum and minimum temperatures observed over a specified period. The TCI scale ranges from 0 to 100, where lower values indicate higher temperature stress—typically associated with drought conditions—and higher values suggest more optimal temperature conditions for vegetation growth. This index is particularly useful in understanding the thermal stress experienced by vegetation, offering a detailed perspective on how temperature variability influences vegetation health across different environmental settings.

$$TCI = 100 * \frac{(LST_{max} - LST)}{(LST_{max} - LST_{min})} \quad (3)$$

Table 1. Classification of VCI, TCI and VHI drought condition (Kogan, 2001)

Values	Drought Classes
<10	Extreme Drought
<20	Severe Drought
<30	Moderate Drought
<40	Mild Drought
>40	No Drought

2.3.4 Vegetation Health Index (VHI)

The Vegetation Health Index (VHI) is a composite drought index specifically designed to evaluate vegetation response to drought conditions, especially in arid, semi-arid, and sub-humid regions. It integrates the Vegetation Condition Index (VCI) and the Temperature Condition Index (TCI) to provide a comprehensive measure of vegetation health, accounting for both moisture and thermal stress (Table 1). By combining these indices, the VHI captures the synergistic effects of vegetation greenness and land surface temperature, making it a robust indicator for assessing the impact of drought on plant vitality (Kogan, 1997).

$$VHI = 0.5 * VCI + (1 - 0.5) * TCI \quad (4)$$

VHI values range from 0 to 100, with lower values indicating poor vegetation health, often associated with severe drought, and higher values

reflecting healthier vegetation. This index is particularly valuable in remote sensing applications for monitoring vegetation dynamics over extensive areas, offering critical insights into the interaction of various environmental stresses on ecosystem health.

3. RESULTS AND DISCUSSION

Figure 3 compares the regions impacted by drought, using categorized information from the annual VCI, TCI, and VHI indices for the category above 60. It shows that the TCI index is confirmed for most of the year, compared to the VCI and VHI indices. For example, in 2002, 2009, 2019, most of the study area experienced wet years for the VCI and had a VHI greater than 60; the study area experienced a wet period during each year for the TCI, which can be explained by the temperature difference between winter and summer. The spatial distribution and variations of TCI values are presented in figure 3, TCI measure the heat and coolness of the land surface on a scale from 0 to 100. Values below 10 indicate extreme conditions, while values under 40 signal moderate drought situations (Bhuiyan, 2008). According to Karnieli et al., (2010), the TCI is more responsive to soil moisture levels when leaves fall during the dry season and is more attuned to water content in the canopy when leaves are saturated during the wet season. The results reveal that TCI reached a minimum during the 2005-2006 period, with average values in the northern and central regions, and slightly higher values in the southern region of the study area during the 2009-2010 period. In 2022-2023, were observed in the center of the studied area.

TCI values are inversely related to drought: as TCI decreases, drought intensity increases. Similar to LST, the spatiotemporal analysis of TCI shows that intense drought conditions were mainly concentrated in the southern region of the examined zone in 2009-2010, while in 2022-2023, severe drought with extreme concentration was detected in the middle section of the investigated area. The deterioration in vegetation density could be linked to climatic conditions in the study area (Mihi et al., 2022; Neffar et al., 2013).

The area affected by drought, according to the TCI index, was generally significant in the Tebessa region between June and October during the 2022-2023 period, corresponding to the dry season. This observation could be explained by the fact that the index calculation takes into account the land surface temperature. Thus, during dry periods or high heat, this can lead to the identification of vast areas

considered to be in a drought situation (Bouzekri et al., 2023). Cao et al., (2016) reported that the TCI effectively characterized the evapotranspiration phenomenon and consequently demonstrated good responsiveness to variations in precipitation and soil moisture.

For VCI the variation across time and space (Figure 3), according to Kogan, (1995) is more effective than the NDVI in assessing water stress in plants. The VCI accurately reflects how weather impacts vegetation growth or decline. It evaluates plant cover health in an ecosystem by contrasting present NDVI readings with the lowest and highest NDVI values on record collected over multiple years. Examination of VCI patterns across space and time indicates that drought occurs repeatedly in steppe regions, affecting most areas in the majority of years studied. In 2005-2006, severe dry conditions were particularly prevalent in the central zone and the extreme south of the study area. Comparable severe dry spells were noted in the southern zone during 2009-2010, while the central zone experienced moderate to mild drought conditions.

The study region faced extreme drought conditions in 2022-2023, with the central parts being particularly affected. During this period, the western and southern areas of the study region also experienced severe drought conditions. These observations suggest that the region in question likely experienced insufficient rainfall as well as significant temperature fluctuations during the mentioned periods. (Boudjemline & Benlabiod, 2022; Mihi et al., 2022). According to findings presented by Tesfaye et al., (2019), when there is a link between a decrease in precipitation and an increase in temperature, it may result in decreased water levels availability and a rise in the occurrence of droughts.

According to the study conducted by Belala et al., (2018), steppes are particularly vulnerable to

erosion from wind and water. This susceptibility is intensified by the excessive use of renewable natural resources in the most vulnerable regions, leading to multiple degradation processes and a swift rise in desertification. According to the study conducted by Gouveia et al., (2017), some regions are more prone to a deterioration of plant health due to an increased contribution of VCI (Vegetation Condition Index) or TCI (Thermal Condition Index). Regarding the Euro-Mediterranean area, the findings of this study highlighted that the effect of humidity conditions are usually more pronounced in drier regions where water is a limiting factor, while the opposite is observed in humid regions where high temperature conditions predominate and were solar energy limits plant growth.

Figure 3 illustrates the spatio-temporal evolution of the annual Vegetation Health Index (VHI) in the study area. The VHI, which integrates local biophysical conditions (soil and slope) and climate, is a valuable tool for monitoring effective vegetation drought across different agro-meteorological regions (Bhuiyan et al., 2006). The VHI analysis reveals distinct trends over time. In the 2005-2006 period, the entire study area is characterized by low vegetation cover with limited development of sparse vegetation in the northern and southern parts, while the western and central region are subject to moderate to mild drought. In the 2009-2010 period, the region experiences moderate drought, a consequence of sufficient precipitation and limited water stress (Figure 4). In the 2022-2023 period, a significant deterioration is observed, with almost the entire study area classified as being in high drought. The VHI indicates extreme drought conditions, particularly intensified in certain areas. This VHI analysis facilitates the determination of "hot spots" especially in the central regions of the study area where vegetation stress is severe. It is important to note that vegetation health is influenced by several factors, including rainfall variability, high temperatures, and topographic parameters such as

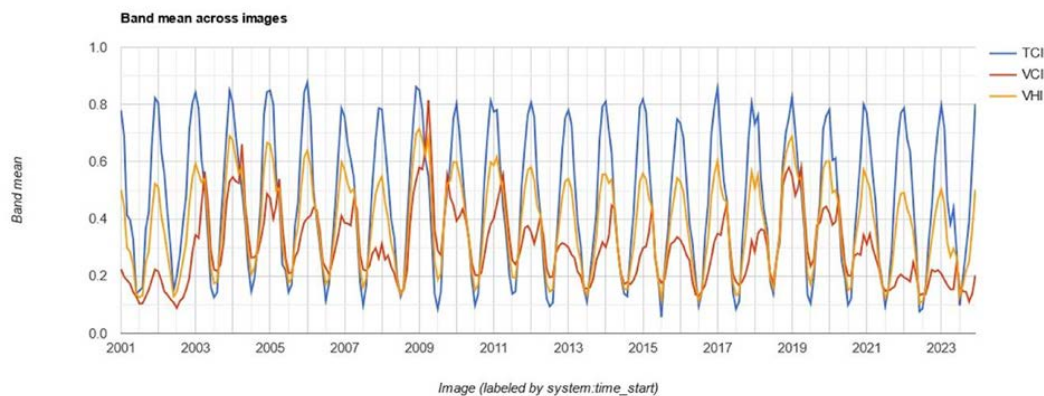


Figure 2. Annual VCI, TCI, and VHI indices during 2001–2023

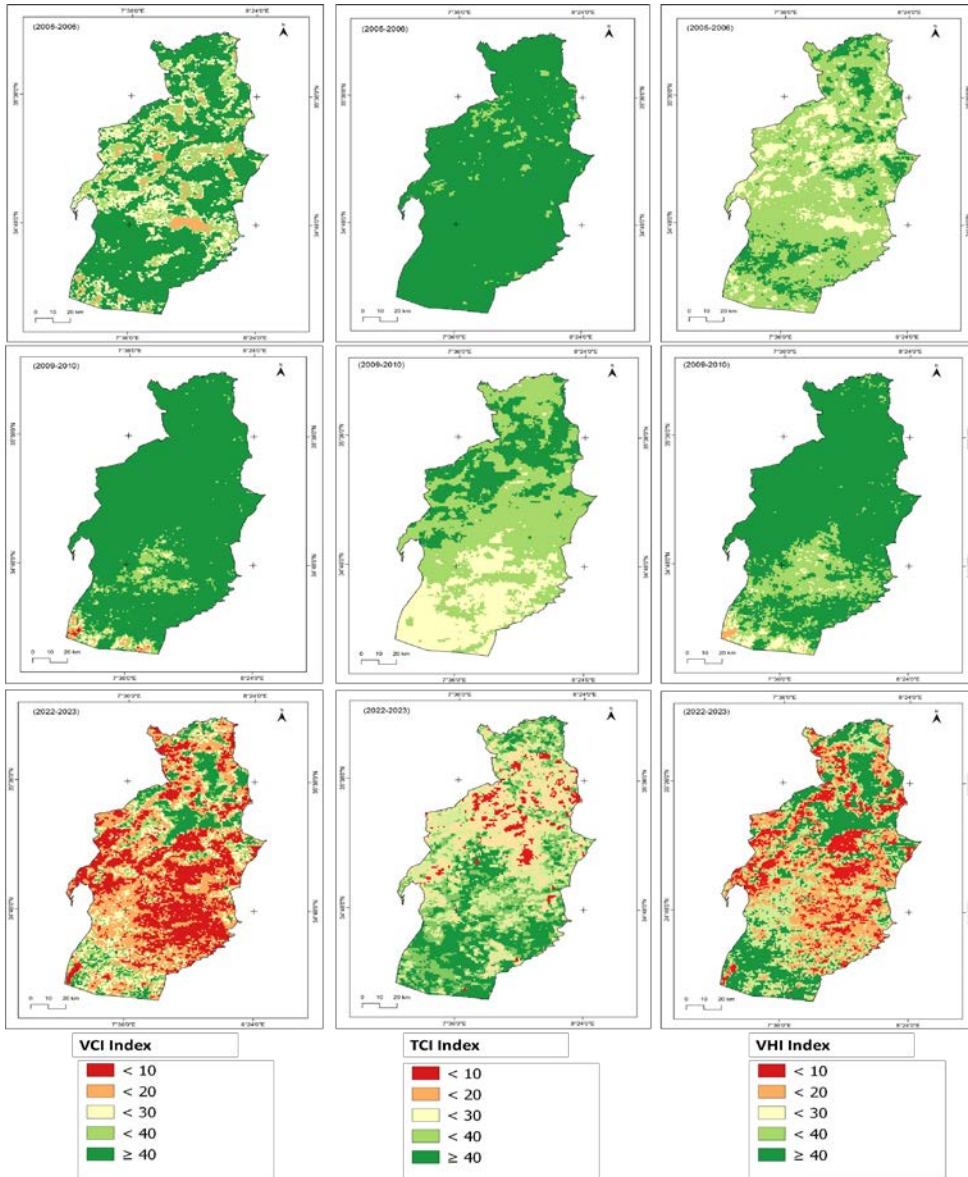


Figure 3. The drought monitoring maps during the period from 2005-2006; 2009-2010; 2022-2023

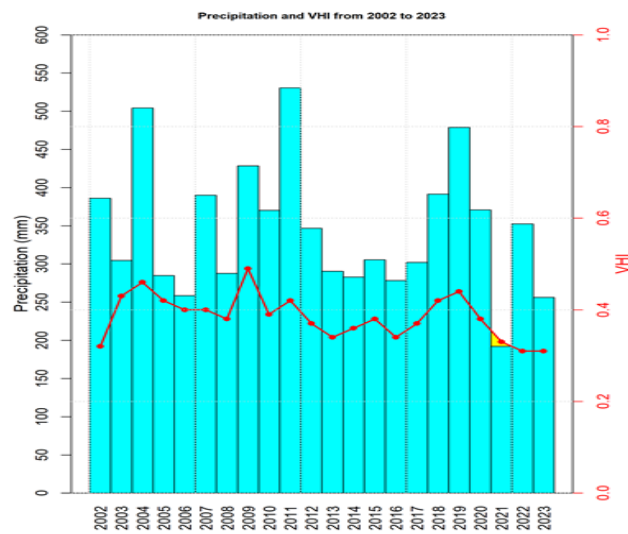


Figure 4. Correlation between VHI and annual mean precipitation during the period from 2002 to 2023

slope orientation. These elements have a significant impact on vegetation density and species diversity (Macheroum et al., 2021). Chirouze et al., (2014) reported that plants in semi-arid and arid environments are especially susceptible to climate factors, particularly concerning water availability and temperature fluctuations. In these regions, infrequent rainfall leads to water scarcity, putting stress on vegetation. Additionally, high temperatures can negatively impact plant health and induce heat stress. These combined factors significantly affect the overall well-being and survival of vegetation in such challenging climates.

Climate change could potentially lead to a decline in VHI, TCI, and VCI values. As a result, drought conditions would likely be intensified contributing to elevated soil water evaporation or increased heat stress on plants (Anderegg et al., 2013). This suggests that global warming may exacerbate the challenges faced by plant life in affected areas, further compromising vegetation health and resilience. Through the TCI, VCI, and VHI indices, we assessed how different types of vegetation respond to drought in order to better understand the impact of drought on different types of vegetation.

4. CONCLUSION

Drought is defined as a complicated environmental disaster, highly influenced through variations in the climate and their alteration. The use of MODIS-based data, especially the Vegetation Health Index (VHI), proves to be a robust tool for drought monitoring, effectively integrating the Vegetation Condition Index (VCI) and Temperature Condition Index (TCI). The TCI consistently indicated wet conditions in most years, with significant peaks in 2002, 2009, and 2019. These trends highlight TCI's sensitivity to seasonal temperature variations, reinforcing its reliability as a climatic indicator.

The study identified severe drought conditions during 2005-2006 and 2009-2010, particularly in the southern and central regions. In 2022-2023, extreme drought conditions intensified, especially in the central areas, suggesting a recurring drought phenomenon linked to rising temperatures and decreasing precipitation. Analysis of the VCI and VHI indicated distinct spatial variations in drought impacts, with the central zones being particularly vulnerable to climatic fluctuations. The study observed declining trends in TCI, VCI, and VHI values, indicating worsening drought conditions potentially driven by climate change. This trend

could result in more frequent and severe droughts, further stressing local vegetation. The effects of drought on the plants health and ecosystem stability were underscored, with rainfall variability and high temperatures identified as key factors influencing vegetation resilience in Tebessa.

The research confirms the sensitivity and reliability of MODIS-derived meteorological and agricultural drought indices, particularly the VHI, in effectively monitoring regional drought dynamics. The findings demonstrate advancements in using VHI for drought monitoring, identifying areas at risk of vegetation degradation, and predicting potential decreases in crop yields. This information is vital for enhancing future water resource management in agriculture and other socio-economic sectors.

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