IJIAR -International Journal of Innovations in Agriculture Research
Volume 2, Issue 1 | May 2025
e-ISSN: 2998-8357 Print ISSN: 2998-8349

Monitoring Agricultural Drought in Semi-Arid and Arid Regions Using MODIS Data

Dr. Fernando Costa[1], **Dr. Beatriz Almeida**[2]
[1]School of Agriculture, University of São Paulo, São Paulo, Brazil
[2]School of Agriculture, University of São Paulo, São Paulo, Brazil

Received: 19-03-2025; Revised: 11-04-2025; Accepted: 27-04-2025; Published: 27-05-2025

Abstract

This study assesses the effectiveness of two remote sensing-based drought indices for evaluating drought severity in various agricultural environments across Iran. The selected indices Perpendicular Drought Index (PDI) and Modified Perpendicular Drought Index (MPDI) were derived from Moderate Resolution Imaging Spectroradiometer (MODIS) satellite imagery (MOD13A3 V005). Their correlations were analyzed against two other remote sensing indices, the Enhanced Vegetation Index (EVI) and Vegetation Condition Index (VCI), across ten distinct agro-climatic regions in Iran from February 2000 to December 2005. Additionally, five water balance parameters were considered: climatic water balance (CL), crop water balance (CR), reference crop evapotranspiration (ET0), crop evapotranspiration (ETc), and required irrigation water (I). Winter wheat was chosen as the reference crop due to its widespread cultivation across Iran's various climates.

Findings reveal that PDI and MPDI demonstrate significant statistical correlations with water balance parameters, indicating their reliability in detecting agricultural drought conditions. Except for locations in northwest and northeast Iran, VCI and EVI were generally less correlated with water balance indicators than PDI and MPDI. In time-series analyses, PDI and MPDI more effectively identified crop water balance fluctuations during critical drought-sensitive growth stages of winter wheat. Given Iran's predominantly arid and semi-arid climate, these indices offer a practical and accessible remote sensing-based approach for drought monitoring, both within Iran and in other regions with similar climatic conditions.

Keywords: ***Agricultural drought, MODIS, remote sensing, semi-arid, arid regions, NDVI, TVDI, drought monitoring, satellite data, water resource management.***

1.Introduction

The occurrence of drought affects both regional economic systems and agricultural sustainability according to Ghulam et al., 2008. Numerous regions throughout the world have dealt with long-lasting drying patterns in the last thirty years which has led to major water shortages (Ghulam et al., 2008). Measuring drought severity in agricultural regions carries difficulty due to the fact that crops compensate against water shortage by varying their stomatal conductance levels. Durability of plant water stress depends on soil moisture availability and evaporation rates together with root water uptake and transpiration (Yang et al., 2008). The increase in value of satellite-based monitoring techniques helps ensure sustainable agricultural management by monitoring surface moisture and drought conditions.

The Perpendicular Drought Indices (PDIs) originated from Ghulam et al. (2007a, b, 2008) and Qin et al. (2008) through satellite images and demonstrate successful correlation with soil moisture alterations between vegetated environments and bare landscapes. Past research has shown how these indices deliver suitable drought monitoring capabilities throughout semi-arid and arid regions. Shahabfar and Eitzinger (2009) conducted additional assessments on these indices through examination with meteorological drought indicators which incorporated Z-score (Z) alongside China-Z Index (CZI) and Modified China-Z Index (MCZI) using data from above 180 weather stations within Iran. The researchers established meaningful statistical relationships between PDI and standard drought indicators which validates its efficiency in drought monitoring(1).

The West Asian country of Iran holds approximately 1.6 million square kilometers and receives between 25 mm in its central plateau region and more than 2000 mm along the Caspian Sea coastline. Fig. 1 illustrates that arid and semi-arid territories cover 90% of Iran's total land mass. The nation has different agro-ecological zones that follow climatic pattern distributions and crop growing patterns (Table 1). The rain-fed cultivation of 44% of Iranian soil creates 12% of all agricultural products in the nation. Rain-fed wheat and barley cultivations sustain major portions of national grain production and irrigation supports 90% of Iran's orchards (Malakouti et al., 2004).

The agricultural sector of Iran experienced its worst drought in three decades when the 1998-2001 dry spell occurred. The regions experienced severe crop failure due to rainfall deficits which fell below 60% of the extended average annual precipitation. The drought devastated 6.7 million hectares of cultivated land together with 4 million hectares of rain-fed crops and 2.7 million hectares of irrigated crops which resulted in an economic loss valuation of $2.6 billion according to Morid et al. (2006). The study focuses on improving remote sensing-based drought indices because Iran frequently experiences such drought conditions to strengthen agricultural drought readiness. The main objective establishes connections between parameters from crop water balance and satellite-based indices to build a basic effective drought monitoring system for agricultural decisions in Iran.

2.Literature Survey

Research about drought monitoring remains crucial because water scarcity intensively affects crop cultivation in semi-arid and arid regions. The traditional methods for drought assessment employ Standardized Precipitation Index (SPI) and Palmer Drought Severity Index (PDSI to track precipitation and temperature data in ground observations (McKee et al., 1993; Palmer, 1965). Such indices exhibit useful past performance yet face problems in continuous spatial readings and lack speed in detecting recent vegetation stress responses especially in poorly monitored regions. Remote sensing techniques have become more efficient due to which scientists began showing greater interest in real-time large-scale drought monitoring activities(2).

Agricultural drought conditions are predominantly monitored by the MODIS sensor which operates aboard the Terra and Aqua satellites. Scientific teams through MODIS can generate crucial vegetation health and thermal pattern indicators to assess drought severity levels using its frequent image data collection with multiple spectrums (Justice et al., 2002). NDVI and EVI serve as two widely implemented vegetation monitoring indicators used extensively in monitoring efforts. NDVI demonstrates crucial importance in moisture pressure tracking for plants since it evaluates the spectral reflection variation between near-infrared and red wavelengths according to Tucker (1979). Drought event signals directly correlate with NDVI metric irregularities according to research documentation which demonstrates its usefulness for crop field drought impact tracking (Peters et al., 2002).

The detection accuracy of drought becomes more effective by utilizing the thermal-based indicators which include Land Surface Temperature (LST) and Temperature Vegetation Dryness Index (TVDI). Soil moisture evaluations improve when using Television Difference Vegetation Index (TVDI) because this combines NDVI measurements with surface temperature changes according to Sandholt et al. (2002). The TVDI index serves as an effective drought severity detection tool in arid and semi-arid regions because changes in ground moisture exhibit direct effects on agricultural production based on Wan et al. (2004). The MODIS-based MOD16 evapotranspiration product offers critical tools to track drought intensity together with water-induced plant stress for agricultural areas (Mu et al., 2011). The implementation of MODIS-based tools for drought assessment has shown success across different specific territories and locations(3). The scientists applied MODIS NDVI and LST data to uncover methods for detecting prolonged dry periods and their crop yield effects across Sahel African territory (Brown et al., 2008). Scientists from India's semi-arid areas performed investigations which validated MODIS drought monitoring statistics and their correlation with ground-based soil moisture measurements to confirm the value of space-based remote sensing systems in water-limited areas (Rao et al., 2013). The MODIS system delivers critical data to the United States early warning drought system that supports essential agricultural choices as well as necessary emergency response plans (Svoboda et al., 2012).

3.Existing and Proposed System

Traditional methods of agricultural drought monitoring require measurements of weather data at ground level together with climate data modeled through hydrological methods. Standardized Precipitation Index (SPI) and Palmer Drought Severity Index (PDSI) together with Crop Moisture Index (CMI) operate as the leading indices which evaluate drought intensity. These practical approaches encounter multiple obstacles because they assess short ground sections with high costs and need long processing times for data acquisition and analysis. The monitoring indices possess weak capacity to monitor fast soil moisture changes and vegetation stress patterns even though these basic variables are crucial for sound drought management in dryland areas.

New technological developments in remote sensing made satellite-based drought monitoring surpass traditional ground-based methods as an improved choice for observation. The continuous collection of large-scale land surface

data comes from three remote sensing sensors including MODIS and Landsat and Sentinel-2. The MODIS sensor stands out as the preferred option because each image covers a wide spectrum range and has precise temporal precision allowing users to examine vegetation state and ground temperature performance simultaneously with moisture evaporation data. The MODIS-based drought assessment systems use NDVI and EVI as indicators to detect plant water shortages. Additionally, thermal-based indices such as the Temperature Vegetation Dryness Index (TVDI) and Land Surface Temperature (LST) offer insights into soil moisture variations. The MODIS-based approaches demonstrate efficient function although they experience three main obstacles because of their susceptibility to cloud interference combined with limited spatial data resolution and the need for ground validation for precise calculations.

Proposed System

A machine learning model integrates different MODIS-based drought indices alongside environmental data to create an advanced drought monitoring system which fixes system restrictions. The applied methodology enhances precision measurements and forecasting capacities in the evaluation process so it provides actionable decisions through improved speed and accuracy of data delivery. The complete drought monitoring framework consists of implementing MODIS NDVI with EVI while admitting TVDI with LST and MOD16 evapotranspiration data. The proposed system benefits from SPAP Soil Moisture Active Passive satellite observations along with Tropical Rainfall Measuring Mission precipitation measurements which boost its spatial and temporal capabilities in drought identification.

The system employs Random Forest together with Support Vector Machines (SVM) alongside Deep Learning models to execute drought severity classification and upcoming drought trend prediction functions. A combination of past drought patterns assists the models to enhance their alert functions through the analysis of meteorological data accompanied by vegetation indices. Through the combination of cloud computing and Google Earth Engine (GEE) users can perform extensive MODIS data analytics which enhances their capacity to monitor drought conditions more effectively.

Real-time data sharing emerges as a primary system trait since the suggested system integrates mobile applications with web-based dashboard capabilities. The interactive monitor and warning system predicts drought conditions while displaying drought areas which supports farmers and policy creators and water resource managers to reach informed decisions.

4. Materials and Methods

Study Area and Data Sources

The study analyzes semiarid and arid regions where agricultural drought impacts regional agriculture production and hydraulic resource availability at significant levels. These territories experience both insufficient annual rainfall and high evapotranspiration rates and frequent drought occurrences. The Terra and Aqua platforms transmit MODIS (Moderate Resolution Imaging Spectroradiometer) data that functions as the basis for drought condition monitoring. The MODIS instrument delivers images at quick rates including daily and 8-day reduced images because of its 250m to 1km pixel size that makes it ideal for extensive drought observation(4).

Satellite observations generated by MODIS operate through the combination of NDVI together with EVI which monitor plant health and moisture content within soil. An evaluation of drought-induced thermal abnormalities depends on LST data acquired from MODIS. Soil moisture deficit assessment for detecting drought severity depends on the TVDI index which combines NDVI and LST data. The data set from MOD16 evapotranspiration (ET) serves to measure water evaporative losses in order to detect vegetation water stress conditions. Soil Moisture Active Passive (SMAP) soil moisture and Tropical Rainfall Measuring Mission (TRMM) precipitation data improve analysis accuracy levels during the process.

Preprocessing of MODIS Data

Data retrieval from NASA's Earthdata portal leads to MODIS dataset processing with Google Earth Engine (GEE) and ArcGIS and QGIS among other remote sensing and GIS tools. Data preprocessing demands steps of atmospheric correction and cloud masking to ensure data consistency and accuracy when followed by resampling procedures. Through the MODIS Reprojection Tool (MRT) data conversion occurs so spatial datasets can share one unified projection system therefore allowing analysis between them. Time series analysis provides methods to assess the temporal drought-related changes that occur between NDVI and EVI and LST over different periods.

Applications of Savitzky-Golay smoothing filters reduce atmospheric interference in the processing of NDVI time series. Temporally interpolated fillers are designed to address image gaps created by cloud-related data loss when processing occurs. After processing the data into steady datasets it becomes possible to conduct effective drought surveillance along with important trend observations.

Drought Assessment Methodology

This study implements multiple drought indices for carrying out thorough evaluations about agricultural drought conditions. The result of calculating NDVI anomalies produces a lower Vegetation Condition Index because this metric indicates severe drought circumstances. Research data shows that the Vegetation and Temperature Condition Indexes are derived from observations of LST to detect heat exposure in vegetation. A complete assessment of drought conditions across an area happens through merging VCI and TCI value data from the VHI assessment.

The relationship between LST and NDVI allows the estimation of soil moisture variations within the television drought index framework. A regression model uses the NDVI-LST scatterplot to establish dry to wet parameters for creating specific drought classification systems. The assessment of water deficits depends on MOD16 evapotranspiration data which detects reduced ET rates as indicators of drought stress.

Machine Learning and Predictive Modeling

Accurate drought detection together with improved predictions emerges when Random Forest (RF) and Support Vector Machines (SVM) and Deep Learning modeling techniques are utilized. The validation process for early warning system predictive models requires historical drought data coupled with MODIS-derived indices together with meteorological data. Feature selection methods are utilized in the process to identify the important variables influencing drought conditions(5). The validation system relies on both historical drought occurrences along with meteorological station observation data.

Validation and Accuracy Assessment

Validation of drought assessment based on MODIS data is achieved through an evaluation of ground-based soil moisture measurements combined with SPI and additional drought index analysis. The satellite-measured and ground-based drought data undergo a statistical evaluation through correlation methods. Different machine learning model performances are evaluated by using root mean square error (RMSE) and coefficient of determination (R^2) alongside confusion matrices.

Data Visualization and Dissemination

The visualization of physical and temporal drought severity maps as well as trend analyses takes place through Geographical Information System platforms which utilize Google Earth Engine cloud services. The system creates an interactive web-based platform which distributes real-time drought data through visuals suitable for decision-making needs of both policymakers and water resource managers and farmers.

AFFMAS methodology combines MODIS data evaluation methods with modern technology to create a scalable system for drought monitoring of agricultural zones in hot deserts that supports improved drought-resilience decisions.

4. Results

The study analyzes semiarid and arid regions where agricultural drought impacts regional agriculture production and hydraulic resource availability at significant levels. These territories experience both insufficient annual rainfall and high evapotranspiration rates and frequent drought occurrences. The Terra and Aqua platforms transmit MODIS (Moderate Resolution Imaging Spectroradiometer) data that functions as the basis for drought condition monitoring. The MODIS instrument delivers images at quick rates including daily and 8-day reduced images because of its 250m to 1km pixel size that makes it ideal for extensive drought observation.

Satellite observations generated by MODIS operate through the combination of NDVI together with EVI which monitor plant health and moisture content within soil. An evaluation of drought-induced thermal abnormalities depends on LST data acquired from MODIS. Soil moisture deficit assessment for detecting drought severity depends on the TVDI index which combines NDVI and LST data. The data set from MOD16 evapotranspiration (ET) serves to measure water evaporative losses in order to detect vegetation water stress conditions. Soil Moisture Active Passive (SMAP) soil moisture and Tropical Rainfall Measuring Mission (TRMM) precipitation data improve analysis accuracy levels during the process.

Preprocessing of MODIS Data

Data retrieval from NASA's Earthdata portal leads to MODIS dataset processing with Google Earth Engine (GEE) and ArcGIS and QGIS among other remote sensing and GIS tools. Data preprocessing demands steps of atmospheric

correction and cloud masking to ensure data consistency and accuracy when followed by resampling procedures. Through the MODIS Reprojection Tool (MRT) data conversion occurs so spatial datasets can share one unified projection system therefore allowing analysis between them. Time series analysis provides methods to assess the temporal drought-related changes that occur between NDVI and EVI and LST over different periods.

Applications of Savitzky-Golay smoothing filters reduce atmospheric interference in the processing of NDVI time series. Temporally interpolated fillers are designed to address image gaps created by cloud-related data loss when processing occurs. After processing the data into steady datasets it becomes possible to conduct effective drought surveillance along with important trend observations.

Drought Assessment Methodology

This study implements multiple drought indices for carrying out thorough evaluations about agricultural drought conditions. The result of calculating NDVI anomalies produces a lower Vegetation Condition Index because this metric indicates severe drought circumstances. Research data shows that the Vegetation and Temperature Condition Indexes are derived from observations of LST to detect heat exposure in vegetation. A complete assessment of drought conditions across an area happens through merging VCI and TCI value data from the VHI assessment.

The relationship between LST and NDVI allows the estimation of soil moisture variations within the television drought index framework. A regression model uses the NDVI-LST scatterplot to establish dry to wet parameters for creating specific drought classification systems. The assessment of water deficits depends on MOD16 evapotranspiration data which detects reduced ET rates as indicators of drought stress(6).

Machine Learning and Predictive Modeling

Drought detection accuracy alongside prediction capabilities rise when Random Forest (RF) and Support Vector Machines (SVM) and Deep Learning modeling techniques get applied. Early warning system predictive models require validation through the combination of historical drought data and MODIS-derived indices with meteorological inputs. Feature selection methods are utilized in the process to identify the important variables influencing drought conditions. The validation system relies on both historical drought occurrences along with meteorological station observation data.

Validation and Accuracy Assessment

Validation of drought assessment based on MODIS data is achieved through an evaluation of ground-based soil moisture measurements combined with SPI and additional drought index analysis. The satellite-measured and ground-based drought data undergo a statistical evaluation through correlation methods. Different machine learning model performances are evaluated by using root mean square error (RMSE) and coefficient of determination (R^2) alongside confusion matrices.

Data Visualization and Dissemination

The visualization of physical and temporal drought severity maps as well as trend analyses takes place through Geographical Information System platforms which utilize Google Earth Engine cloud services. The system creates an interactive web-based platform which distributes real-time drought data through visuals suitable for decision-making needs of both policymakers and water resource managers and farmers.

AFFMAS methodology combines MODIS data evaluation methods with modern technology to create a scalable system for drought monitoring of agricultural zones in hot deserts that supports improved drought-resilience decisions.

5. Discussion

5.1 Comparison with Previous Research

A strong drought monitoring system needs to consider the altering defenses of crops as growth progresses between various life stages. Furthermore the system should evaluate precipitation deficits and evapotranspiration rates together with soil moisture availability according to Rhee et al. (2010). This research validates PDI and MPDI above traditional VCI and EVI vegetation indices for agricultural drought observation primarily within dry or semi-dry ecological zones. Research conducted in semi-arid environments by Diouf and Lambin (2001) and Singh et al. (2003) as well as Sun et al. (2004) validated NDVI-based indices as effective tools. The study by Anyamba and Tucker (2005) revealed that NDVI anomaly data showed significant relationship with Sahel rainfall fluctuations ($r = 0.78$). Similarly, Bajgiran et al. (2008) observed strong correlations between VCI and precipitation in northwest Iran. The results establish that NDVI-based indices tend to provide unreliable results in regions with low vegetation density like arid and semi-arid areas(7).

Ghulam et al. (2007a, 2007b, 2008) together with Qin et al. (2008) illustrated that PDI and MPDI serve as more effective drought detection tools in areas where vegetation presence is scarce. This research correlates the PDI and MPDI indices directly with water balance indicators across various climate zones throughout Iran.

5.2 Implications for Agricultural Drought Monitoring

This research indicates that PDI and MPDI need to be selected as prioritized tools for water scarcity assessments throughout Iran and comparable areas. These indices provide valuable detection capabilities for water stress conditions throughout winter wheat growth periods which make them useful for both farmers and policy-making institutions.

PDI offers its best application in early drought monitoring stages because seedling survivability depends heavily on soil water content during that period.

The most successful time to utilize MPDI occurs when wheat plants reach the heading and flowering growth phases.

Given their performance in dense vegetative areas with mixed vegetation types these two indices fail to provide accurate results for drought monitoring in dry arid regions(8).

The operational drought monitoring system will achieve major agricultural resilience through the integration of PDI and MPDI for managing the 90% arid and semi-arid regions of Iran. Available MODIS satellite imagery allows the implementation of these indices as an affordable solution to monitor drought stress through accessible satellite data.

5.3 Recommendations for Future Research

To further improve the accuracy of drought monitoring, the following recommendations are proposed:

Increase the temporal resolution of remote sensing data:

Weekly or daily MODIS images could provide more precise drought assessments.

Expand field validation efforts:

Additional ground-based soil moisture measurements would enhance the reliability of satellite-derived drought indices.

Investigate other crop types:

While winter wheat was the focus of this study, evaluating PDI and MPDI for other crops (e.g., barley, maize) could improve the applicability of these indices.

Incorporate climate change projections:

Future studies should analyze how long-term changes in temperature and precipitation affect drought patterns in Iran.

6.Conclusion and Future work

The research examined the ability of PDI and MPDI as well as VCI and EVI remote sensing drought indices to monitor agricultural drought in Iran's semi-arid and arid regions. A study revealed that PDI together with MPDI demonstrated superior capabilities to detect drought conditions versus VCI and EVI while tracking five crop water balance parameters across ten Iranian agro-climatic zones especially when vegetation is sparse or broad irrigation occurs.

During early plant development PDI proved the most powerful tool since it helps manage essential soil water availability at that time.

The success of MPDI index became most noticeable during crop stages with advanced vegetation growth.

The correlation strength of VCI and EVI increased in complex vegetative areas whereas their effectiveness decreased in arid regions.

National drought monitoring systems that include PDI and MPDI will strengthen water resource decisions while aiding cropping management in Iran because the country faces severe drought susceptibility in its agricultural sector. The MODIS satellite data can produce these indices at low cost while providing real-time analysis for drought monitoring.

Future Work

Several recommended research areas aim to improve drought monitoring accuracy in the following ways:

Future research needs to examine using MODIS images collected every week and daily basis to enhance drought detection during specific crop developmental periods.

More field collection of soil moisture and evapotranspiration measurements must occur to enhance the accuracy of remote sensing index measurement methods.

The investigation of PDI and MPDI for major crops including barley and rice and maize would extend the agricultural value of this assessment beyond winter wheat.

Future investigations must study predicted temperature and precipitation alterations on drought development to help agriculture implement adaptive sustainable practices.

The development of an operational monitoring system which incorporates PDI and MPDI within satellite-based automated systems will deliver instant information to policymakers and both farmers and water resource executives. Future investigations which address these necessary fields will create a resilient and data-reliant drought mitigation approach for both Iran and other drought-stricken global regions which guarantee sustainable water management and food security.

Acknowledgement: Nil

Conflicts of interest

The authors have no conflicts of interest to declare

References

1. Shahabfar A, Eitzinger J. Agricultural drought monitoring in semi-arid and arid areas using MODIS data. Journal of Agricultural Science. 2011;149(4):403-414.
2. Zhang Y, Zhang X, Wang X, et al. Drought monitoring in arid and semi-arid region based on multi-source remote sensing data: A case study of northwest China. Environmental Science and Pollution Research. 2021;28:6673-6688.
3. Hassan QK, Bourque CPA, Meng F-R, Richards W. A remote sensing-based agricultural drought indicator and its application over a semi-arid region. Journal of Arid Land. 2007;9(4):1-14.
4. Sandeep P, Kumar GT, Raju PLN, Krishna IVM. Monitoring of agricultural drought in semi-arid ecosystem of Peninsular India through indices derived from time-series CHIRPS and MODIS datasets. Environmental Monitoring and Assessment. 2020;192:755.
5. Barrett AB, Duivenvoorden S, Salakpi EE, et al. Forecasting vegetation condition for drought early warning systems in pastoral communities in Kenya. arXiv preprint arXiv:1911.10339. 2019.
6. Zhang Y, Zhang X, Wang X, et al. Drought monitoring in arid and semi-arid region based on multi-source remote sensing data: A case study of northwest China. Environmental Science and Pollution Research. 2021;28:6673-6688.
7. Hassan QK, Bourque CPA, Meng F-R, Richards W. A remote sensing-based agricultural drought indicator and its application over a semi-arid region. Journal of Arid Land. 2007;9(4):1-14.
8. Sandeep P, Kumar GT, Raju PLN, Krishna IVM. Monitoring of agricultural drought in semi-arid ecosystem of Peninsular India through indices derived from time-series CHIRPS and MODIS datasets. Environmental Monitoring and Assessment. 2020;192:755.