Remote Sensing and GIS Approaches for Agricultural Drought Severity Assessment: A Comprehensive Review

Kusum Rawat[1*], P. V. Singh[2], Manisha Dhapola[3] and Himanshu Bharti[4]

[1,2]Department of Soil and Water Conservation Engineering, G. B. Pant University of Agriculture and Technology, Pantnagar, Udham Singh Nagar, Uttarakhand 263145, India

[3,4]Department of Civil Engineering, G. B. Pant University of Agriculture and Technology, Pantnagar, Udham Singh Nagar, Uttarakhand 263145, India

rawatkusum88@gmail.com, er.pvsingh@gmail.com, manishadhapola27@gmail.com, himanshubharti5@gmail.com

ABSTRACT

A natural hazard caused by prolonged drought, drought has a significant effect on ecosystems, agriculture, and socioeconomic systems. Drought develops gradually, unlike abrupt natural disasters, making it challenging to identify, track, and measure. It poses major risks to crop productivity and livelihoods by negatively affecting vegetation growth, soil moisture, and water availability. Many satellite-based indices have been developed at the regional and national levels to monitor and assess drought and address these issues. Both meteorological and satellite-derived indices are frequently used to identify various types of droughts, including hydrological, agricultural, and meteorological. Global sensors such as NOAA-AVHRR and MODIS are widely used for vegetation analysis and drought assessment. Key meteorological parameters, including precipitation, temperature, humidity, and evapotranspiration, are essential for determining drought severity. These factors are used to create drought indices that account for precipitation shortages, climatic dryness, and delayed hydrological responses such as decreased soil moisture, declining reservoir levels, and weakened crop health. In order to analyze drought patterns, comprehend spatial-temporal variability, and pinpoint vulnerable areas, long-term historical records of satellite imagery and climate data are essential. Remote sensing is a useful tool for agricultural drought assessment and for well-informed decision-making, as the agricultural sector is particularly vulnerable to drought stress. Governmental organizations and local authorities can create efficient drought management and mitigation plans by integrating satellite-derived drought data with GIS. The importance of remotely sensed data in agricultural drought assessment is emphasized in this review, along with its potential to boost resilience, increase drought preparedness, and promote sustainable agricultural management.

Keywords: *Drought, Remote sensing, Drought monitoring, GIS, Satellite data.*

1. Introduction

A drought occurs when the actual moisture availability at a specific location consistently falls below climatologically expected or adequate levels, typically over several months [18]. The main cause of it is insufficient soil moisture for crop production, which drastically reduces agricultural output. Researchers, policymakers, and the general public are interested in drought because it creates imbalances in food supply and demand, with major economic implications. One natural disaster that is difficult to predict and study is drought [15]. Insufficient or irregular rainfall worsens crop impacts by reducing soil moisture [2]. Numerous meteorological parameters, including temperature, precipitation, humidity, soil moisture, and evapotranspiration, can be used to define and quantify drought conditions. Drought is hard to define and monitor for three main reasons: [i] it develops slowly, with no clear beginning or end; [ii] there is no universally accepted definition for it; and [iii] its effects are often non-structural and can affect large areas [22]. Drought can be measured using both meteorological and satellite-based indices. Satellite-derived indices that have gained popularity recently include the Normalized Difference Vegetation Index [NDVI], Soil Adjusted Vegetation Index [SAVI], Land Surface Temperature [LST], Albedo, Temperature Condition Index [TCI], and Vegetation Condition Index [VCI].

2. Drought Characterization

Drought characterization is crucial for effective drought management and the development of mitigation strategies. A useful technique for converting vast volumes of meteorological, hydrological, and agricultural data into quantitative information that can be utilized for planning, monitoring, and evaluation is the use of drought indices [23]. Meteorological, agricultural [agro-meteorological], hydrological, and socioeconomic drought are the four main categories of drought [4].

2.1. Meteorological or Climatological Drought

Meteorological drought is identified by precipitation deficits. When rainfall falls below a certain threshold, drought conditions are triggered. Meteorologists define partial drought as at least 29 consecutive days with an average daily rainfall of less than 0.2 mm, while absolute drought is defined as 15 consecutive days with daily rainfall of less than 0.2 mm [1].

2.2. Drought in Agriculture or Agro-Meteorology

Agricultural drought, also known as soil moisture drought, occurs when meteorological drought and high potential evapotranspiration combine to result in insufficient soil moisture for crop growth [10]. It is characterized by soil moisture levels that are much below what is ideal for healthy plant development at various growth stages, which results in lower yields and developmental stress [24]. Both climatic and hydrological droughts, as well as discrepancies between actual and potential evapotranspiration, contribute to soil moisture depletion [16]. Agricultural drought is commonly tracked and predicted using indicators based on soil moisture or comparable metrics.

2.3. Hydrological Drought

Hydrological drought occurs when surface and groundwater resources, such as lakes, reservoirs, rivers, and aquifers, are insufficient to meet normal demands [24]. It is caused by a combination of temperature anomalies, precipitation shortages, and human demands on water resources [10]. Lack of rainfall causes drought, but not all meteorological droughts progress to hydrological drought; the transition from meteorological to hydrological [and agricultural] drought is gradual and governed by complex physical processes. In addition to precipitation deficits, factors such as inadequate water storage, snow accumulation, and cold temperatures can exacerbate hydrological drought [24].

2.4. Drought in Socioeconomics

Socioeconomic drought is the term used to describe the connection between drought conditions and human activity. It occurs when demand for an economic resource surpasses supply due to weather-related water shortages [16]. Some data, including crop yields, wildfire frequency, water quality, and remotely sensed vegetation stress, provide direct or indirect indicators of the effects of socioeconomic drought, despite the paucity of research on the topic [9]. State that predicting these parameters can be viewed as a rough estimate of socioeconomic drought prediction. Several indices, including the Social Water Stress Index [SWSI], have been developed to assess water scarcity while accounting for environmental, social, and economic factors that influence water availability, consumption, and susceptibility [16].

3. Remote sensing and Geographic Information Systems [GIS]

Remote sensing and [GIS] are crucial instruments for gathering, evaluating, and interpreting spatial data. Using satellites or aerial sensors, remote sensing provides timely, extensive observations of Earth's surface. These spatial datasets can then be stored, integrated, and analysed for mapping and decision-making using GIS. Monitoring environmental changes, managing natural resources, and assisting with urban and regional planning are all made easier by the combination of remote sensing and GIS. When combined, they offer a thorough framework for sustainable development and spatial analysis, as shown in Tables 1 and 2.

3.1 Drought Assessment Using Remote Sensing Indices and GIS

Table 1. Commonly used drought indices and their applications

Index	Description	Application
NDVI	Normalized Difference Vegetation Index derived from satellite reflectance	Vegetation stress & greenness mapping
SPI	Standardized Precipitation Index using rainfall deviation	Meteorological drought monitoring
VCI	Vegetation Condition Index using NDVI normalization	Crop condition & vegetation drought severity
LST	Land Surface Temperature	Thermal drought stress & evapotranspiration anomaly
SPEI	Standardized Precipitation Evapotranspiration Index	Climatic water balance and drought severity

Table 2. Vulnerability Assessment using GIS

Technique	Description	Reference
Weighted Overlay Analysis	Assigns weights to multiple factors that contribute to vulnerability, combining them to produce a vulnerability map.	Hagenlocher et al., 2013
Fuzzy Logic Models	Classifies susceptibility levels and handles uncertainty in drought-related data.	Ayoade, 2004
Multi-Criteria Decision Analysis [MCDA]	Integrates socioeconomic and environmental factors to assess and map drought vulnerability.	Dalezios et al., 2012
GIS Spatial Analysis	Enables identification of high-risk areas, aiding in resource management and mitigation planning.	,

4. Need for the review

One of the most complex and destructive natural disasters, drought affects water resources, agriculture, ecosystems, and socioeconomic stability worldwide. Because of its complexity and spatial-temporal variability, drought is still difficult to characterize, monitor, and predict despite a great deal of research. For drought assessment, a variety of techniques and indices have been developed, each with unique benefits and drawbacks. These methods and indices are based on agricultural, hydrological, meteorological, and remote sensing data. However, a thorough evaluation of current methodologies, identification of research gaps, and establishment of standardized frameworks for effective drought monitoring are required due to the rapid advancement of geospatial technologies, climate models, and data-driven approaches. To synthesize current knowledge, compare the efficacy of different indices and models, and direct future research toward more precise and comprehensive drought management strategies, a systematic review of drought assessment is crucial.

5. Literature Review

Ayoade, J., [2004]. Focus on tropical regions, particularly Nigeria. An extensive review of climatological concepts and their use in tropical areas can be found in the book "Introduction to Climatology for Tropics", which provides a comprehensive overview of these concepts and their application in tropical regions. It discusses how droughts, water resources, and agricultural productivity are affected by climate variables such as temperature, humidity, evaporation, and rainfall. Understanding climate variability and its impact on socioeconomic activities in tropical regions is the main goal of the work. Because it is textbook-based, the work is primarily conceptual and relies on meteorological observations rather than satellite sensors. It discusses the use of meteorological data, including temperature and precipitation records, for assessing climate and drought. Instead of focusing on a specific research period, the book summarizes current and historical climatological data relevant to tropical regions. The book is fundamental resource for comprehending tropical climatic variability, rainfall patterns, drought. It establishes the foundation for both meteorological and agricultural drought evaluations by offering theoretical insights into the different kinds of droughts, their causes, and their effects on agriculture, water resources, and society.

Dalezios, N.R., Bampzelis, D., and Domenikiotis, C., [2009]. Greece, this study suggests an integrated methodological approach for mitigating drought in Greece at both local and regional levels. To identify drought-prone locations and create alternate mitigation techniques, it integrates hydrological, meteorological, and agricultural data. In order to reduce the socioeconomic effects of drought, the technique places a strong emphasis on proactive planning and adaptation strategies. Rainfall, temperature, and streamflow data are among the meteorological and hydrological observations that are the main source of information for this study. Although the system permits the incorporation of remote sensing data for vegetation and water monitoring, no direct use of satellite sensors was made.
To determine the intensity and frequency of drought, the study is based on long-term historical meteorological and hydrological information [particular years are not indicated explicitly]. The paper's main contribution is the introduction of a methodical framework for drought assessment and mitigation planning that incorporates many data sources. It emphasizes how crucial it is to integrate agricultural, hydrological, and meteorological indicators for proactive drought management. The methodology offers a useful strategy that can be applied to other areas with comparable climatic circumstances in order to identify susceptible areas and develop alternative solutions to lower the danger of drought.

Ghulam, A., Qin, Q., and Zhan, Z., [2007]. China [study focused on regional drought assessment] the Perpendicular Drought Index [PDI], a unique method for measuring meteorological drought, is presented in this paper. By reducing the drawbacks of conventional drought indices like the Standardized Precipitation Index [SPI] and Palmer Drought Severity Index [PDSI], the PDI is intended to enhance drought identification, especially in areas with erratic rainfall patterns. Temperature and rainfall records from the past are used in this investigation. The methodology is based on data from climate observations; no satellite sensors were used. To assure accurate drought evaluation, the study uses long-term historical climatic information; exact years are not stated directly, although they span several decades. In regions with erratic precipitation patterns, the PDI offers a more reliable and sensitive way to identify drought occurrences. The index is a helpful tool for monitoring and managing drought since it makes it possible to better characterize the onset, intensity, and duration of drought. The study shows how PDI might enhance regional drought mitigation strategy and supplement current drought indicators.

Md. Anarul Haque Mondol, Iffat Ara, Subash Chandra Das, [2017]. Bangladesh, the paper presents a spatial and temporal analysis of meteorological drought in Bangladesh using the Standardized Precipitation Index [SPI]. The authors used monthly rainfall records from 30 meteorological stations across Bangladesh for the period 1981–2010, and applied the SPI method to characterize drought occurrence. They then mapped drought severity using the Inverse Distance Weighted [IDW] interpolation technique to produce drought index maps of the country. The results indicate that drought is a recurrent phenomenon in Bangladesh, happening on average every 2.5 years during the study period. The study identifies that droughts were particularly prominent in the northern, south-western, and eastern regions of Bangladesh. The work contributes by providing spatially explicit drought index maps that can support disaster management, drought planning and adaptation strategies in Bangladesh.

Alireza Shahabfar & Josef Eitzinger, [2013]. Iran [semi-arid regions], the study used monthly rainfall and temperature data from 40 meteorological stations in Iran. In "Spatio-Temporal Analysis of Droughts in Semi-Arid Regions by Using Meteorological Drought Indices", Shahabfar & Eitzinger [2013] compare and evaluate six meteorological drought indices, Percent of Normal [PN], Standardized Precipitation Index [SPI], China-Z Index [CZI], Modified CZI [MCZI], Z-Score [Z], and the Aridity Index of de Martonne [I], to assess drought dynamics across six climatic regions of Iran. They analyse data from a network of meteorological stations covering the period 1950 to 2005 to characterise spatial and temporal patterns of drought in the semi-arid to arid climate of Iran. The study finds that, considering data availability constraints and regional climatic variation, the Z-Score, CZI, and MCZI show strong performance and represent viable alternatives or complements to SPI in Iran's context. They note that the best performing index varies by climatic region and time scale [monthly, seasonal, annual]. For example, MCZI correlates strongly with SPI in mountainous and semi-mountain regions, while CZI and Z-Score perform better in the desert and semi-desert zones. The authors discuss implications for drought monitoring and management, stressing the importance of selecting indices suited to regional data availability and climatic conditions. They highlight that meteorological drought does not always translate immediately into hydrological or agricultural drought, given complexity in the propagation of precipitation deficits through soil, vegetation, and water systems.

P. Chopra, [2006]. India [Gujarat] the study employed satellite remote sensing [specifically NOAA-15] in combination with GIS analysis and focused on historic drought conditions in Gujarat over a period of approximately 30 years [covering several decades to pinpoint drought-risk zones]. Chopra [2006] presents a methodology to assess drought risk in the State of Gujarat, India, by integrating remote sensing data and geographic information system [GIS] techniques. The author uses satellite imagery from NOAA-15 to derive vegetation and drought-related indices, and overlays these with meteorological and spatial data in GIS to map drought-prone zones. Through processing a ~30-year historical dataset, the study identifies regions of Gujarat that consistently show higher vulnerability to drought, based on vegetation stress, rainfall deficiency, and associated spatial factors. The work provides a zonation of drought risk, which helps in prioritising mitigation planning and resource allocation. The integration of remote sensing enables assessment of large-scale spatial patterns, while GIS supports spatial analysis and mapping of risk zones. The study underscores that remote sensing/GIS are effective tools for drought risk assessment and emphasizes their utility for decision-makers in drought-mitigation planning in semi-arid regions like Gujarat.

Ali Ahmed Ali Dhaifallah, Noorazuan Bin MD. Hashim, Azahan Bin Awang, 2018, Yemen [specifically the Tihama Plain], Satellite imagery from Landsat TM5 [1985] and Landsat OLI8 [2015]. The study uses the Normalized Difference Vegetation Index [NDVI] derived from these sensors to assess vegetation decline as an indicator of drought. The study assessed drought risk in the Tihama Plain region of Yemen by analysing changes in vegetation cover and sand dune deposits over the 30-year period using Landsat imagery and GIS techniques. Through NDVI mapping and GIS analysis, the authors quantify how drought has expanded in severity spatially: they found a 26% increase in areas under severe drought and an approximately 64% increase in moderate drought zones between 1985 and 2015. Simultaneously, areas under mild or normal rainfall decreased, indicating a worsening drought situation. The study demonstrates how remote sensing plus GIS can monitor long-term drought dynamics in data-sparse environments and provides a map-based risk assessment that can inform drought mitigation and management strategies.

Anurag Malik, Anil Kumar, Ozgur Kisi, Najeebullah Khan, Sinan Q. Salih & Zaher Mundher Yaseen, 2021, India specifically the state of Uttarakhand, in the Himalayan foothill region. Monthly rainfall data from meteorological stations [i.e., ground-observed rainfall] was used; the study did not employ satellite sensor data. The study applied the Effective Drought Index [EDI] to quantify both dry and wet climate conditions across 13 districts of Uttarakhand. It categorised events [normal, moderate drought / wet, severe drought / wet, extreme drought / wet] using runs-theory based truncation levels on the EDI values. The probabilities of occurrence [PO] of normal conditions varied across stations [e.g., ~68% for Almora & Dehradun, ~72% for Bageshwar, ~44% for Pantnagar]. Moderate drought and moderate wet events were more frequent than severe or extreme events at most stations. The findings help delineate the spatial variation in dry and wet conditions, and the authors suggest that the results can support water-storage and drought mitigation strategies [e.g., storing surplus during wet years for use during drought years].

A. P. Dimitrakopoulos, M. Vlahou, Ch. G. Anagnostopoulou, I. D. Mitsopoulos, 2011, Greece. The study uses observed wildfire occurrence and burned-area statistics, as well as the Standardised Precipitation Index [SPI] derived from precipitation data. The paper investigates the relationship between drought and wildland fires across Greece and explores the implications of climatic change for this relationship. Using SPI as the drought indicator and national fire statistics, the authors found a statistically significant positive correlation between drought episodes and wildfire activity [both number of fires and area burned] across Greece for the period 1961–1997. In the more humid and cooler regions of Northern and Western Greece, both summer [SPI6 October] and annual drought [SPI12 September] were significantly correlated with fire occurrence and extent. In contrast, in the drier and hotter regions of Southern and Central Greece, the correlation was significant only with summer drought episodes. The study also identifies that around 1978 Greece entered a period of prolonged drought, and during 1978–1997 the correlation shifted: drought became strongly correlated with area burned rather than simply fire occurrence. The authors caution that while drought is not the sole driver of wildfires, its influence appears to be increasing over time, possibly under climate change. They suggest that changing climate , leading to more frequent or intense droughts , may heighten the fire risk in Mediterranean environments such as Greece.

Anurag Malik & Anil Kumar, 2020, India , specifically the state of Uttarakhand in the Indian Himalayas the study used monthly rainfall data from meteorological stations to compute the Effective Drought Index [EDI]; it did not rely on satellite sensor imagery.

While the exact start-end years for each station are not explicitly stated in the source I found, the authors used long-term historical rainfall data across 13 stations in Uttarakhand for modelling [preceding the publication]. The paper investigates the prediction of meteorological drought using heuristic modelling approaches, with EDI as the target drought indicator. The authors applied three modelling techniques: [1] Co-Active Neuro Fuzzy Inference System [CANFIS], [2] Multi-Layer Perceptron Neural Network [MLPNN], and [3] Multiple Linear Regression [MLR]. Using autocorrelation and partial autocorrelation analysis, lagged rainfall inputs were selected for each model. The models were trained and tested at 13 meteorological stations in Uttarakhand. They found that CANFIS and MLPNN outperformed the MLR in terms of forecasting accuracy for EDI, indicating the advantage of heuristic/soft-computing methods over simple linear regression in this regional context. The authors suggest that the results are useful for operational drought forecasting and management in mountainous/hilly regions where rainfall variability is a major concern.

Himangshu Sarkar, Sandeep Soni, Ishtiyaq Ahmad & M. K. Verma , 2020, India , Upper Seonath Sub-Basin, Durg district, Chhattisgarh , the paper indicates drought years such as 2000 and 2002 were critical; long-term rainfall records were analysed for spatio-temporal drought assessment [exact full span not clearly stated]. The study integrates remote sensing [NDVI from NOAA-AVHRR] and GIS with meteorological drought index [SPI] to assess agricultural drought in the Upper Seonath Sub-Basin. It identified extreme drought events in the study area, notably the year 2002 when over 60% of the area was under dry conditions. A very strong correlation [$R^2 \approx 0.95$] was found between SPI and Rainfall Anomaly Index [RAI] in the region. The study also established a relationship between the Vegetation Condition Index [VCI] and crop yield for the main unirrigated crops, with $R^2 \approx 0.62$. The methodology offers a spatial drought vulnerability map and suggests that such integrated remote sensing + GIS frameworks can guide decision-making for reservoir use and drought mitigation in agricultural catchments.

S. Krishnakumar, V. Sreevidhya, S. Vivek, V. Priya., 2024, India, a part of the Coimbatore region in Tamil Nadu, the comparative analysis for years 2000 and 2020 [for the satellite imagery/LULC change] alongside rainfall/meteorological data covering the temporal span implied between these years. The study integrates remote sensing and GIS techniques to assess drought vulnerability in a part of Coimbatore district. It distinguishes between agricultural drought [using NDVI/VCI derived from Landsat imagery for the years 2000 and 2020] and meteorological drought [using SPI from rainfall data]. It also performs Land Use / Land Cover [LULC] change analysis between 2000 and 2020 to examine how built-up/industrial expansion and conversion of cropland, plantations, water bodies and forested areas have influenced drought vulnerability. The weighted overlay approach combining NDVI, VCI, seasonal rainfall and SPI are used to map spatial-temporal drought risk zones. Results show increasing vulnerability from 2000 to 2020, with specific areas [e.g., Sultanpet, Singanallur, Thalakkarai, Sethumadai, Kariyambalayam, Koolarpatti, Kuniyamuthur] most severely affected in 2000 and additional areas [e.g., Karumathampatti, Sulur, Kuniyamuthur, Kinathukadavu, Periya Negamam, Pollachi, Anaimalai, Kottur, Aliyar] showing higher vulnerability in 2020. The change in land cover due to urbanisation and industrialisation is identified as a key factor increasing drought vulnerability in the region.

6. Conclusions

Together, the reviewed literature demonstrates the importance of remote sensing, GIS, and meteorological data for understanding, evaluating, and mitigating drought across diverse climatic and geographic contexts. Research from Bangladesh, China, Greece, and India [Uttarakhand, Chhattisgarh, Tamil Nadu, and Gujarat] has shown that drought is a complex risk that impacts weather, agriculture, hydrology, and socioeconomics. These studies have demonstrated the effectiveness of meteorological indices such as SPI, CMI, and EDI, as well as satellite-derived vegetation indices such as NDVI, VCI, and SAVI, in assessing the severity, spatial extent, and temporal dynamics of drought.

In regions like Uttarakhand and Coimbatore, combining long-term rainfall data with remote sensing enables the identification of drought-prone zones and the prediction of future drought episodes using heuristic or machine learning techniques [e.g., CANFIS, MLPNN]. Because terrain and climate variability significantly affect the spread of drought, the studies emphasize the need for region-specific drought indices in semi-arid and arid regions, including parts of Greece and Iran. The importance of tracking soil moisture and reservoir levels, along with climate data, is underscored by studies on hydrological drought, which show that precipitation deficits may not immediately lead to water scarcity. Socioeconomic drought is rarely studied, but it is increasingly linked to the integration of agricultural, water-use, and environmental data, highlighting the cascade effects of drought on human systems.

These studies collectively demonstrate that integrated methodologies incorporating remote sensing, GIS, and meteorological indices yield high-resolution, spatially explicit insights into drought patterns, facilitating effective risk assessment and management. Moreover, historical analysis spanning decades demonstrates the increasing intensity and frequency of droughts, frequently aggravated by land-use changes and climate variability. The synthesis of these works underscores the significance of integrating multi-source data for proactive drought mitigation, agricultural planning, and sustainable water resource management. Subsequent research should emphasise real-time monitoring, predictive modelling, and the integration of socioeconomic factors to bolster drought resilience at both regional and local levels.

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