JOURNAL INFORMATIC, EDUCATION AND MANAGEMENT (JIEM)
Vol. 7, No. 1, February 2025, pp. 42 ~ 50
ISSN: 2716-0696, DOI 10.61992/jiem.v7i1.123

Drought Monitoring Using Integrated Satellite Imagery, Weather Data, And Geographic Information Systems

Sudarma
Universitas Gunung Leuser

Article Info

Article history:
Received 31 January 2025
Revised 15 February 2025
Accepted 28 February 2025

Keywords:
Drought Monitoring,
Satellite Imagery,
Geographic Information Systems

ABSTRACT

Drought, intensified by climate change, poses a significant threat, especially to agricultural regions, necessitating effective monitoring and adaptation strategies (Netshimbupfe et al., 2022; Raksapatcharawong, 2019). This paper explores the integration of satellite imagery, weather data, and Geographic Information Systems to improve drought monitoring accuracy and effectiveness. By combining diverse data sources, a comprehensive approach to drought assessment can be created, facilitating timely interventions and mitigation planning (Łągiewska & Bartold, 2025). The study reviews existing methodologies, examines the potential of advanced remote sensing techniques, and emphasizes the role of GIS in spatial analysis and visualization of drought-related information. The focus is on developing a robust framework that can provide detailed insights into drought conditions, supporting sustainable water resource management and agricultural resilience.

Corresponding Author:
Sudarma | Universitas Gunung Leuser
Email: sudarmaja26@gmail.com

1. Introduction

The escalating impacts of climate change have made the African continent more vulnerable than ever, with projections indicating that drought events will become more frequent and intense in many regions, including Southern Africa (Netshimbupfe et al., 2022). The SADC countries receive an average rainfall of less than 500 mm annually, lower than the world's average of 860 mm per annum (Netshimbupfe et al., 2022). This region's fragile agricultural systems are particularly susceptible to the combined effects of severe drought and high temperatures, leading to significant crop yield losses and threatening food security (Lu et al., 2019; Netshimbupfe et al., 2022). The integration of satellite imagery, weather data, and Geographic Information Systems offers a promising avenue for enhanced drought monitoring, enabling more informed and timely interventions to mitigate the adverse consequences on agricultural communities and economies (Meng et al., 2025). Water stress, exacerbated by climate change, increasingly affects water availability, livelihoods, and environmental functions, especially in agriculture and food security (Bwire et al., 2024). Urgent intervention is required to reduce water use; management methods need to be developed by introducing drought and heat-tolerant plants like amaranths in this region (Netshimbupfe et al., 2022).

The ability to accurately monitor and predict drought conditions is crucial for ensuring food supply and agricultural sustainability, particularly in regions where agriculture forms a significant pillar of the economy (Netshimbupfe et al., 2022). Remote sensing technologies, which gather data from sensors on satellites or aircraft, offer a potent tool for overseeing agricultural water resources. These technologies capture detailed images of the Earth's surface and collect key environmental data like soil moisture, vegetation cover, and water distribution, all of which are critical in agricultural production (Ye et al., 2024). By analyzing these satellite images, we can gain invaluable insights into the dynamics of water use in agriculture, detect inefficiencies, and identify areas vulnerable to water scarcity. Combining this data with weather information and Geographic Information Systems allows for comprehensive drought monitoring, which is essential for implementing effective measures to reduce water use and ensure sustainable agricultural practices.

Drought Monitoring Techniques

Drought indices, derived from meteorological data, remote sensing data, and hydrological models, serve as valuable tools for characterizing drought severity, duration, and spatial extent. The integration of satellite-derived vegetation indices with meteorological drought indices provides a more comprehensive assessment of drought conditions, capturing both the physical and biological impacts of drought on agricultural systems. Effective management of water resources is essential to environmental stewardship and sustainable development. GIS (geographic information system) models can be effectively utilized to assess water quality, thereby aiding in the promotion of sustainable water resource management (Usali & Ismail, 2010). GIS, remote sensing, and statistical methods serve as valuable tools for recognizing and evaluating natural hazards. By integrating diverse data sources and employing advanced analytical techniques, drought monitoring systems can provide timely and accurate information to support decision-making in agriculture.

Remote Sensing in Drought Assessment

Remote sensing data, including satellite imagery and aerial photography, offer a unique perspective on drought conditions, allowing for the assessment of vegetation health, soil moisture content, and land surface temperature over large areas. The techniques used in remote sensing can be used to monitor groundwater storage changes, transitioning from basic reliance on limited data to complex machine learning algorithms that integrate satellite measurements (Ibrahim et al., 2024). The development of remote sensing techniques, like radar, now offer new possibilities to estimate rainfall from space

(Najmaddin et al., 2017). The integration of remote sensing data with weather data and GIS platforms provides a comprehensive approach for drought monitoring and assessment. By using remote sensing data along with Geographic Information System a detailed database can be developed and analyzed to better understand previous and future behaviors of lakes toward climate change impacts (Hussain & Bano, 2019).

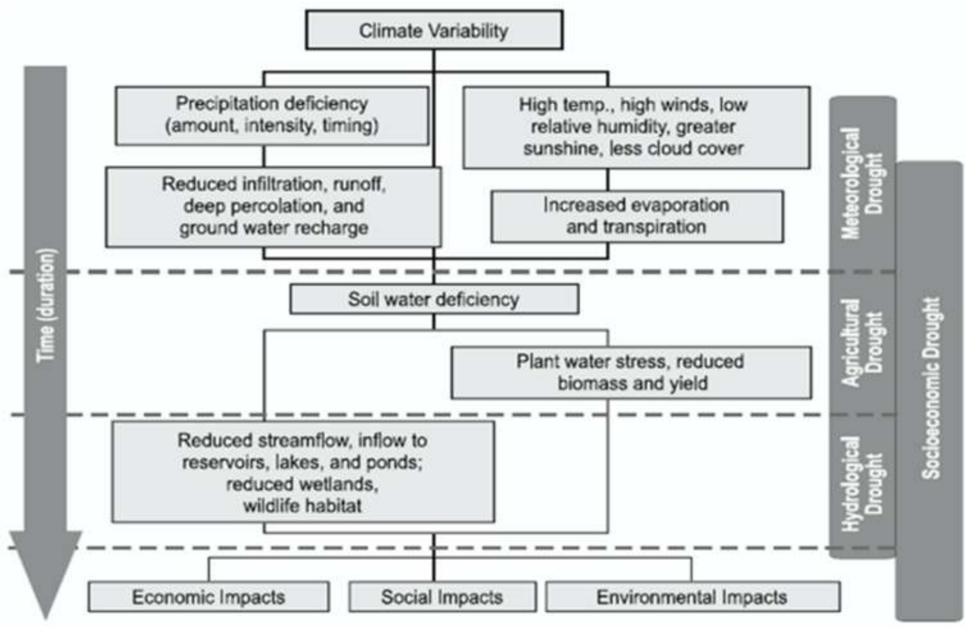

Figure 1. Drought Classification

GIS for Drought Management

Geographic Information Systems play a crucial role in drought management by providing a platform for integrating and analyzing spatial data related to drought conditions, vulnerability, and impacts. GIS facilitates the creation of drought risk maps, which delineate areas most susceptible to drought impacts based on factors such as precipitation patterns, soil types, land use, and population density. GIS-based spatial analysis enables the identification of critical infrastructure, such as water reservoirs and irrigation systems, that may be at risk during drought events.

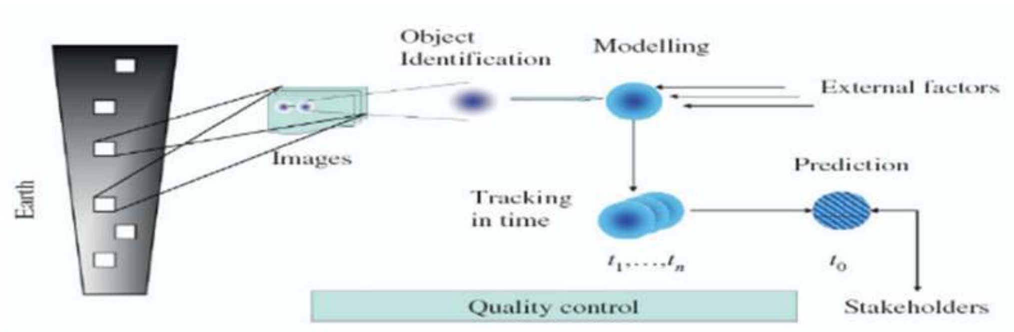

Figure 2. An Artifact For The Process Of Knowledge Discovery From Satellite Imageries

GIS tools also support the development of decision support systems that aid in drought planning and response efforts. GIS provides spatial data management and analysis tools that assist in organizing, storing, editing, analyzing and displaying positional and attribute information about geographical data (Boitt et al., 2023). The integration of GPS and GIS, along with remotely sensed data, is a resource for monitoring water bodies (Jaywant & Arif, 2024).

2. Materials and Methods

By integrating satellite imagery, weather data, and GIS platforms, decision-makers can gain a more holistic understanding of drought dynamics and implement targeted interventions to mitigate the impacts on agricultural systems (Mallick et al., 2019) (Arunkumar et al., 2020). GIS-based hydrological analysis has a wide range of applications in natural events that demand research, planning, and optimum management (Chalkias et al., 2016). GIS, such as popular ArcGIS products and other commercial or open source software, are required to process the original remote sensing images and videos, and carry out spatial analysis, modeling, and visualization (Wang & Xie, 2018). Remote sensing imagery can also be processed using digital image processing software such as ERDAS imagine.

3. Methodology

An effective drought monitoring system hinges on the integration of diverse data sources, combining the strengths of satellite imagery, weather data, and GIS platforms. Satellite remote sensing plays a pivotal role, as it enables the continuous collection of data at global scales, offering insights into crop growth, irrigation practices, and crop losses (Karthikeyan et al., 2020). By assimilating digital data, including hydrometeorological monitoring and forecasts, remote sensing of near-ground atmospheric layer parameters, and underlying surface conditions, it becomes possible to enable water storage in the root zone within a specific irrigated field (Zeyliger & Ermolaeva, 2021). Weather data, including precipitation, temperature, and evapotranspiration rates, provide essential context for understanding drought severity and progression (Lillo-Saavedra et al., 2021). GIS platforms are employed to analyze and visualize spatial data, facilitating the identification of drought-prone areas, assessing the impact on agricultural lands, and supporting decision-making processes (Lillo-Saavedra et al., 2021).

4. Results and Discussion

The incorporation of satellite and aerial imagery has emerged as a robust method for observing crop development, assessing soil moisture content, and identifying other key elements affecting crop health (Fuentes-Peñailillo et al., 2024). Data from remote sensors provides unique spatial and temporal insights into land surface characteristics, including the environmental impacts on crop growth, that are invaluable for predicting crop yields and monitoring vegetation conditions (Al-Gaadi et al., 2016). Vegetation indices are useful for detecting natural disturbances in simpler forest ecosystems with single-layer canopies (Research Project Content, n.d.). These indices are especially crucial in regions prone to drought, where they facilitate close monitoring of vegetation health, thereby aiding in timely drought detection and management. The utilization of advanced vegetation indices derived from satellite imagery, such as the Enhanced Vegetation Index, has proven effective in monitoring vegetation health and detecting early signs of drought stress (Research Project Content, n.d.).

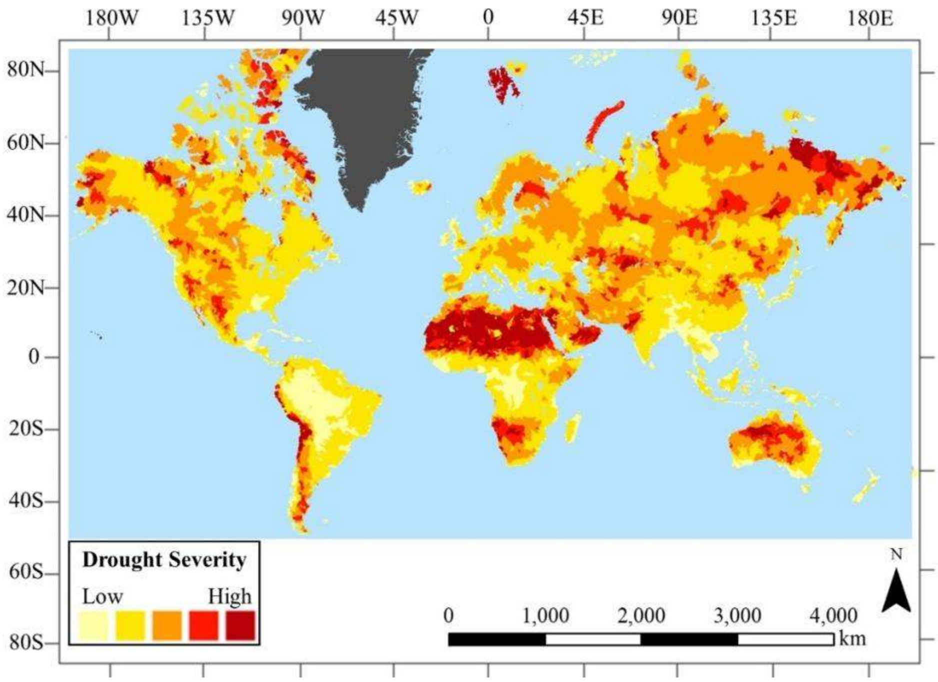

Figure 3: Agricultural Drought Monitoring

GIS platforms enable the integration of remote sensing data with other relevant spatial datasets, such as soil types, land use patterns, and hydrological networks. This integration facilitates comprehensive drought risk assessment and vulnerability mapping, allowing for the identification of areas most susceptible to drought impacts (Chavan et al., 2020). GIS tools also support the development of drought monitoring dashboards, providing decision-makers with real-time information on drought conditions and potential impacts on agriculture (Todorović & Steduto, 2003). This helps in the analysis of geographical phenomenon factors, changes, and magnitudes of change; these tools are useful for studying seasonal environmental conditions, climate change, and ecosystem management (Mallick et al., 2019). By combining satellite imagery, weather data, and GIS platforms, decision-makers can gain a more holistic understanding of drought dynamics and implement targeted interventions to mitigate the impacts on agricultural systems.

5. Conclusion

Combining remote sensing and GIS has proven useful in natural resources management, agriculture, environmental issues, and water resources (Ojo & Ilunga, 2018). The integration of satellite imagery and weather data through GIS offers a powerful approach for enhanced drought monitoring, providing valuable insights into drought conditions and their impacts on agricultural systems (Patra & Mishra, 2024). These technologies offer great methods to identify the parameters that influence the spatial distribution of groundwater and provide data to decision makers (Arabameri et al., 2020). Further research should focus on refining drought monitoring algorithms, incorporating new data sources, and developing decision support tools to enhance the effectiveness of drought management strategies. . The utilization of high-resolution satellite imagery, coupled with advanced data analytics techniques, holds great promise for improving drought monitoring and prediction accuracy (Singh, 2018).

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