

Drought Analysis Using Remote Sensing in Bojonegoro

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Abstract

Bojonegoro Regency is one of the rice-producing areas but is prone to drought, as occurred in 2019-2020. Remote sensing is a solution for mitigation and adaptation to reduce the impact of drought. The study aimed to determine the spatial and temporal distribution of drought in Bojonegoro Regency in 2023. This study utilizes GEE, a cloud-based computing platform used to analyze land cover parameters, rainfall, LST, NDVI, NDWI, and NDDI. The results showed that rainfall in Bojonegoro varies, with the highest levels occurring in January-March and the lowest levels, marking the peak of the drought, in July-September. The LST category is very high and evenly distributed across the entire region from July to December. The average NDVI values obtained from July to December fall into the moderate category, but in some locations, they fall into the low vegetation category. NDWI classification falls into the moderate category from July to December. Meanwhile, the peak of drought (NDDI) occurs from July to December. This study is useful for supporting drought mitigation and adaptation strategies for farmers in Bojonegoro Regency based on spatial and temporal patterns.

1. Introduction

The Bojonegoro Regency Disaster Management Agency reported in 2020 that drought affected 16 subdistricts in Bojonegoro Regency (Setiyoningrum et al., 2023). This condition can impact crop growth and production. Drought can occur due to low rainfall, low groundwater storage, and transpiration rates exceeding plant water uptake (Latifa et al., 2020).

The drought in Bojonegoro Regency can be monitored using remote sensing, serving as a mitigation and adaptation measure for farmers in the event of future droughts. Mitigation refers to a set of actions aimed at minimizing disaster risks through both physical development measures and the enhancement of awareness and capacity to respond effectively to potential disasters. Meanwhile, adaptation is the adjustment of natural systems by humans in response to actual climate stimuli or their effects, which pose a threat (Nurdjanah, 2015). Several mitigation measures implemented include rotational irrigation technology, low-emission rice varieties, and efficient fertilization technology. Several adaptation measures can be taken to address the impacts of climate change, such as using fast-maturing rice varieties (e.g., Ciherang, Silugonggo, and Inpari 1) and drought-tolerant varieties. The application of adaptive cropping patterns is also part of the adaptation strategy (Wihardjaka et al., 2020).

Drought monitoring through remote sensing can be done using the Google Earth Engine (GEE) platform to analyze satellite imagery. GEE operates by storing data on various servers located around the world (Wachid et al., 2022). One index that can be used for drought data processing is Normalized Difference Drought Index (NDDI), along with several supporting components, such as land cover analysis, rainfall, Land Surface Temperature (LST), Normalized Difference Vegetation Index (NDVI), and Normalized Difference Water Index (NDWI).

NDDI is an algorithm that can be used to assess the impact of drought on plants. This index is calculated using a combination of NDVI and NDWI because it provides relevant information for monitoring and assessing drought conditions. NDVI is an algorithm used to determine vegetation conditions. Meanwhile, NDWI is used to measure land moisture levels in the area. If the NDWI value is low, the area may be water, which can lead to drought. By combining these two parameters, we can obtain an overview of drought levels in the area (Rahman et al., 2017). This study aimed to establish the spatio-temporal drought in Bojonegoro Regency in 2023.

2. Research Methods

2.1. Research Location

This study was done in Bojonegoro Regency, which is located at 112°25'–112°09' Longitude and 60 59'–70 37' Latitude, with the research period from September to December 2023. Bojonegoro Regency covers an area of 2,307 km² and consists of 28 subdistricts (Figure 1).

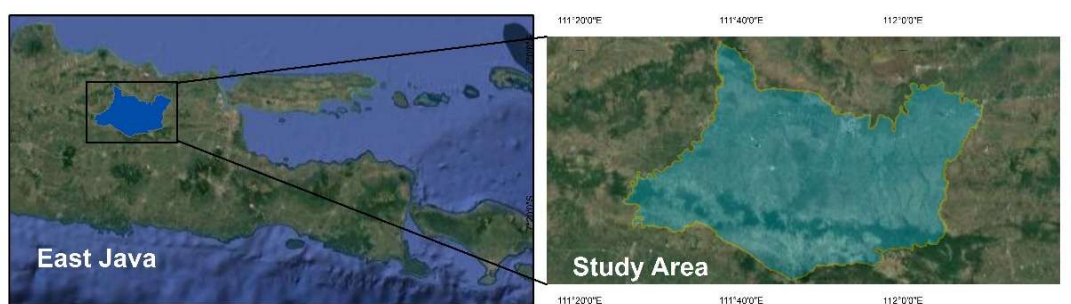


Figure 1. Map of Bojonegoro

2.2. Research Implementation

The tools and materials used in this research comprised both hardware and software components that supported spatial analysis, data processing, and field validation. The hardware included computers or laptops with at least 4 GB of RAM, which served as the primary devices for data processing and geospatial analysis. In addition, a mobile phone was utilized for field data collection, geolocation, and on-site verification. Writing instruments were used to record observations and field notes complementing digital data. The software tools included QGIS 3.36 and ArcGIS for spatial data processing, map production, and analysis, while Google Earth Engine was used for cloud-based processing of remote sensing datasets. Avenza Map was used as a mobile mapping application to facilitate offline navigation and data visualization during fieldwork. The research also used the Rupa Bumi Indonesia (RBI) Map of Bojonegoro Regency as a base map. Furthermore, Landsat 8 imagery from 2023 served as the primary data source for remote sensing analysis, and CHIRPS rainfall data were incorporated as supporting climatological information to enhance interpretation of environmental variables.

2.3. Data Analysis

This study uses rainfall analysis, LST, NDVI, NDWI, and NDDI. Rainfall data is sourced from CHIRPS for the period January–December 2023. Each pixel value will be classified according to the Meteorology, Climatology, and Geophysics Agency / BMKG (2023), namely low (0–100 mm month⁻¹), medium (100–300 mm month⁻¹), high (300–500 mm month⁻¹), and very high (>500 mm month⁻¹).

LST is an indicator for determining ground surface temperature. LST values are obtained from band 10 of the Landsat 8 image. Where LST will be in degrees Celsius. The LST values obtained will be classified according to Liwan et al. (2023), namely very low (<20 °C), low (20–25 °C), moderate (25–30 °C), high (30–35 °C), and very high (>35 °C).

NDVI is an index that indicates vegetation density. The method used in this study uses Landsat 8 imagery, specifically Bands 4 (RED) and 5 (NIR). NDVI can be calculated using the Formula 1 (Fadlin et al., 2020). The NDVI values are then classified based on greenness levels (Table 1).

$$\frac{\text{Band NIR} - \text{Band RED}}{\text{Band NIR} + \text{Band RED}} \quad (1)$$

Table 1. NDVI Classification

NDVI	Vegetation level
<-0.03	Land with no vegetation
-0.03-0.15	Land with very low vegetation
0.16-0.25	Land with low vegetation
0.26-0.35	Land with moderate vegetation
0.36-1	Land with high vegetation

Source: Adinda et al. (2020)

NDWI is an index used to determine moisture levels. The material used in this study was Landsat 8 imagery, specifically bands 3 (Green) and 5 (NIR). The NDWI calculation used in Formula 2 (Husna et al., 2022), then classification is carried out according to Table 2.

$$\frac{\text{Band Green} - \text{Band NIR}}{\text{Band Green} + \text{Band NIR}} \quad (2)$$

Table 2. NDWI Classification

NDWI	Water level
-1 < NDWI < 0	non water body
0 < NDWI < 0.33	moderate
0.33 < NDWI < 1	high

Source: Lestari et al. (2018)

NDDI can evaluate, monitor, and identify drought. The method used in this study utilizes Landsat 8 imagery, specifically bands 3, 4, and 5. NDDI calculation can be used as a Formula 3 (Gulacsi et al., 2015). NDDI classification using the criteria in Table 3

$$\text{NDDI} = \frac{\text{NDVI} - \text{NDWI}}{\text{NDVI} + \text{NDWI}} \quad (3)$$

Table 3. NDDI classification

NDDI	Drought level
-0.05-<0.01	normal
0.01-<0.15	low
0.15-<0.25	moderate
0.25-<1	high
>1	Very high

Source: Cahyono et al. (2023)

3. Results and Discussion

The CHIRPS results showed that rainfall in Bojonegoro varies every 3 months (Figure 2). January-March falls into the high (300-500 mm month⁻¹) to very high (>500 mm month⁻¹) category. These months represent the peak rainfall months of 2023. From April to June, the average rainfall based on the map is between 150-300 mm month⁻¹, which is classified as moderate. July to September is the peak of the dry season with rainfall of 100-200 mm month⁻¹ (moderate category). Finally, October-December had rainfall ranging from medium (200-300 mm month⁻¹) to high (400-500 mm month⁻¹).

Rainfall is one of the climate elements that plays an important role in providing water for plants. According to Paski et al. (2017), the optimal rainfall to support rice plant growth is around 150-200 mm per month, with an even distribution over 4 months. January-March are wet months, but this does not limit rice planting because rice requires at least four consecutive wet months for optimal growth. Wet months are characterized by rainfall of more than 200 mm month⁻¹, evenly distributed, with rain falling every week to prevent drought stress on plants.

The Land Surface Temperature (LST) in Bojonegoro Regency generally falls within the very high category, indicating a consistently elevated thermal condition across the region. During January to March, the average LST values were predominantly high, as shown in Figure 3. This pattern corresponds to the late rainy season, when increased cloud cover and soil moisture tend to moderate surface heating. However, from April through December, average LST values increased notably, shifting into the very high temperature category across most areas. This rise is strongly associated with the onset and persistence of the dry season, characterized by reduced precipitation, lower soil moisture, and intensified solar radiation. Despite this overall trend, several localized areas remained in

the high temperature category, which may be attributed to variations in land cover, such as agricultural zones, forested regions, or areas near rivers that retain higher moisture levels. These spatial variations suggest that surface characteristics and land use play significant roles in local thermal dynamics. Overall, the temporal and spatial distribution of LST in Bojonegoro Regency reflects the strong interaction between climatic seasonality, land surface properties, and anthropogenic land-use patterns.

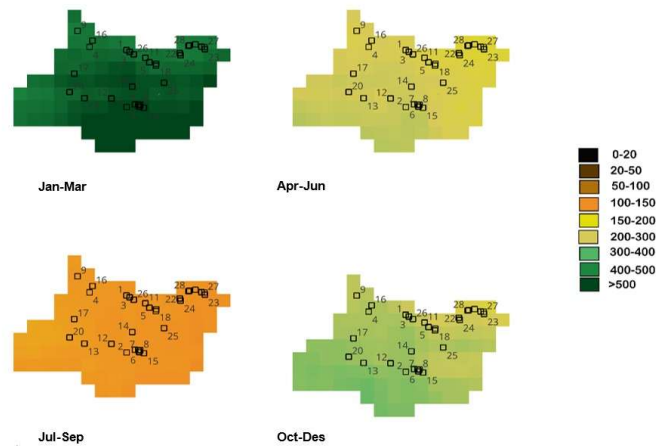


Figure 2. Map of rainfall (mm month⁻¹)

High temperatures can affect plant growth processes by reducing the availability of water, both for plants and in the soil, which is necessary to support growth processes. In addition, rainfall availability can also determine crop yields, especially when combined with significant temperature increases that can cause yield declines. This is because higher soil surface temperatures are associated with lower the rainfall in an area (Herlina et al., 2020). This is also found in other areas in East Java, namely in Bangkalan Regency, which has a high LST value in the range of 24.75-38.87 °C (Rahman et al., 2024).

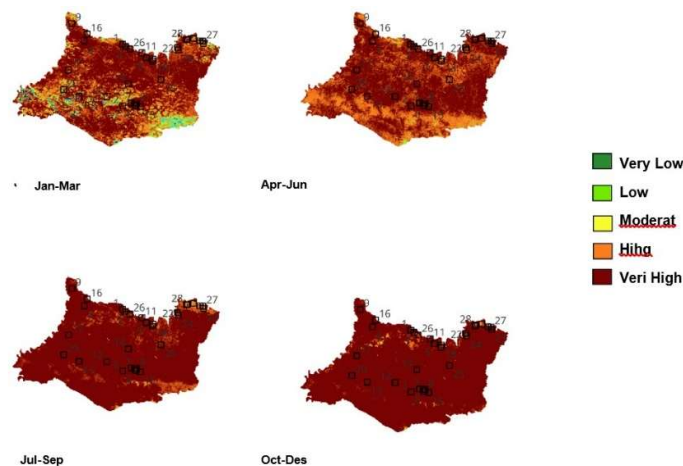


Figure 3. Map of land surface temperature

The NDVI analysis generally shows land categories with moderate to high vegetation. In general, January to June were classified as high vegetation months. From July to December, the average NDVI values obtained are classified as moderate (Figure 4). The relationship between NDVI and rice growth phases is determined by the range of NDVI values in each phase. According to Yudistira et al. (2019), NDVI is an index that measures the level of greenness or photosynthetic activity of plants, so it can be used to classify vegetation. In non-vegetation areas, including water bodies, built-up areas, bare land, and deforestations areas, the NDVI ratio will be low. In

contrast, in areas with very dense and healthy vegetation, the ratio of high near-infrared to low red reflectance will produce a high NDVI.

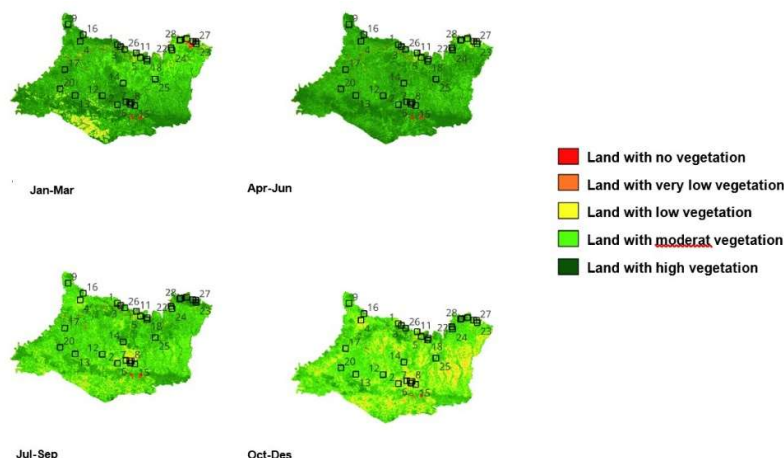


Figure 4. NDVI map

The results of the NDWI analysis in Bojonegoro Regency in 2023 show significant spatial and temporal variations in surface moisture (Figure 5). In general, the period from January to June had high NDWI values, indicating high moisture conditions due to rainfall and soil saturation during the rainy season. Conversely, from July to December, NDWI values decreased to moderate levels, in line with reduced rainfall and increased air temperatures during the dry season. High NDWI values indicate areas with high water content, such as rice fields, rivers, and wetlands. In contrast, low values reflect dry conditions and decreased vegetation moisture, especially in rainfed agricultural areas. The decline in NDWI during the dry season suggests an increased drought risk in the region. According to Artikanur et al. (2022), low NDWI values can serve as an indicator of drought severity, as they reflect reduced surface moisture and increased vegetation stress.

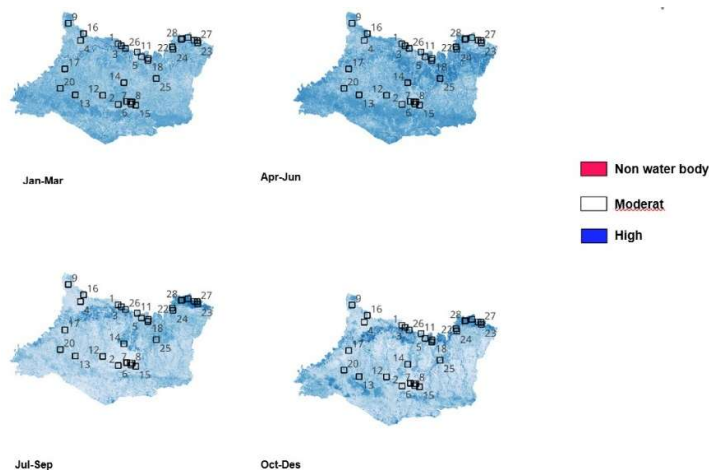


Figure 5. NDWI map

The results of the NDDI analysis in 2023 in Bojonegoro Regency produced a map with varying values (Figure 6). Within a year, the NDDI was classified as moderate to very severe. In general, from January to June, the average NDDI value was classified as moderate. Then, from July to December, the average NDDI value was classified as very severe. One method for mapping drought is to use Landsat 8 satellite imagery data that integrates NDDI. This method aims to identify the dominant parameters that influence the level and spatial distribution of land drought. NDDI was derived by comparing NDVI and NDWI to characterize the spatio-temporal drought distribution in cropland. NDDI was a relatively new index (Luqman et al., 2021).

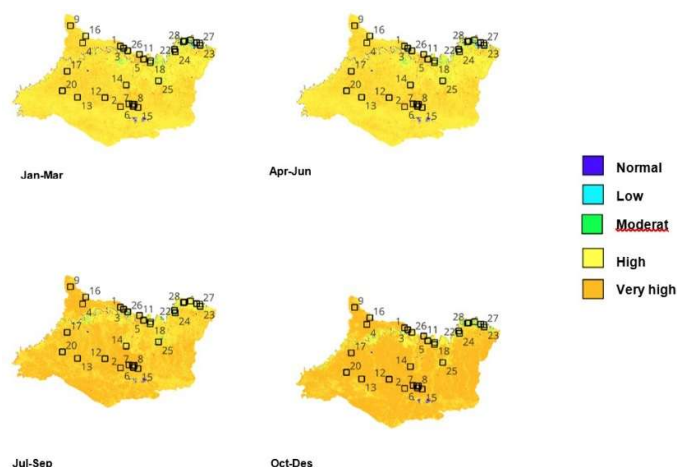


Figure 6. NDDI map

The results of the spatio-temporal drought analysis indicate that during July–September 2023, Bojonegoro Regency experienced widespread drought, with approximately 78% of the total area categorized as severe to very severe drought, while around 22% remained in the moderate category. These conditions correspond to the peak of the dry season, when rainfall intensity is minimal and evapotranspiration rates are relatively high, leading to a significant reduction in soil moisture. The spatial pattern shows that the central and southern regions of Bojonegoro were most affected, reflecting their limited surface water retention capacity and higher exposure to prolonged dry spells. In contrast, several northern areas displayed moderate drought levels, likely influenced by the hydrological effects of the Bengawan Solo River and surrounding wetlands, which maintain relatively stable moisture levels.

During October–December 2023, drought conditions intensified further, with approximately 90% of the area experiencing very severe drought. Only small portions in the northern corridor, particularly along the Bengawan Solo River, remained within the high to moderate category, demonstrating the river's critical role as a natural moisture buffer in mitigating extreme dryness. This progression illustrates a clear temporal trend in drought severity, linked to the seasonal decline in precipitation and the increase in land surface temperature. The spatial differentiation in drought intensity across Bojonegoro highlights the combined influence of climatic factors, land cover variability, and proximity to water bodies on local hydrological resilience. Overall, integrating of temporal and spatial drought information provides essential insights for local governments and communities to formulate evidence-based decisions on land and water resource management, and to develop adaptive strategies for drought mitigation, agricultural planning, and risk communication (Rahman et al., 2024).

4. Conclusion

The highest rainfall occurred in January–March, while the lowest rainfall (drought) occurred in July–September. LST values were generally high and very high, with only a small portion falling into the very low, low, and moderate categories in January–March. NDVI values generally fall into the moderate (July–December) and high (January–June) categories. NDWI in January–June had a high moisture value, while July–December belongs to the moderate category. The drought level (NDDI) is very severe from July to December. The results can be used by the government and the community for water resource planning, drought mitigation and adaptation, and communication of risk information to affected communities.

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