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GIS-Based Spatial Modeling for Drought Vulnerability Mapping with Field Validation in Sukabumi Regency, Indonesia

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ABSTRACT

Purpose of the study: This study aimed to identify and map drought vulnerability levels in Sukabumi Regency, Indonesia, using GIS-based spatial modeling integrated with remote sensing and field validation to provide reliable spatial information for drought risk assessment and mitigation planning.

Methodology: A quantitative descriptive approach was employed using Geographic Information Systems (GIS), Landsat imagery, and remote sensing techniques. ArcGIS 10.8 software was used for spatial analysis through scoring and overlay methods. Primary data were obtained from field observations and interviews, while secondary data included rainfall, land use, soil type, slope, NDVI, and land surface temperature datasets.

Main Findings: Results revealed that drought vulnerability in Sukabumi Regency was classified into low, moderate, high, and very high categories. High vulnerability covered the largest area, accounting for 1,815.68 km² (44.02%), followed by very high vulnerability with 1,278.83 km² (31.00%). Field validation at thirty observation points confirmed the consistency between spatial modeling results and actual drought conditions.

Novelty/Originality of this study: Novelty of this study lies in the integration of GIS-based spatial modeling and remote sensing with field validation through observations and interviews conducted in districts with the highest drought potential. This approach enhances the reliability of drought vulnerability mapping and provides more comprehensive spatial information for supporting disaster mitigation and regional planning.

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1. INTRODUCTION

Climate change and environmental degradation have increased the frequency and intensity of drought events in many regions around the world, including Indonesia. Drought is one of the major hydrometeorological hazards affecting water availability, agriculture, and ecosystem sustainability. Understanding the spatial distribution of drought vulnerability is essential for supporting effective disaster mitigation and resource management [1], [2]. Recent advances in geospatial technologies have enabled more efficient analysis of

environmental phenomena [3]-[5]. In this regard, Geographic Information Systems (GIS) and remote sensing have become important tools for spatial modeling and drought vulnerability mapping.

Sukabumi Regency is one of the regions in West Java Province that frequently experiences drought during the dry season. Despite having abundant water resources and favorable geomorphological conditions, several areas still face difficulties in accessing clean water [6]-[8]. Rapid land-use changes caused by urban expansion, industrial development, and decreasing green open spaces have contributed to the reduction of groundwater recharge areas. These conditions have increased the susceptibility of several districts to seasonal drought events [9]-[11]. Furthermore, the lack of comprehensive spatial information regarding drought-prone areas has become a challenge for local authorities in implementing effective mitigation measures.

Previous studies have demonstrated the effectiveness of GIS and remote sensing techniques in identifying and mapping drought-prone areas. Various parameters, including rainfall, land use, soil characteristics, vegetation conditions, and topographic factors, have been widely used to assess drought vulnerability [12]-[14]. The results of these studies indicate that geospatial approaches can provide valuable spatial information for drought management. However, most previous studies primarily relied on secondary spatial data and focused on producing thematic maps [15]-[17]. Consequently, the reliability of the generated maps has often not been supported by direct field observations and local community information.

The limitations of previous studies reveal an important research gap that requires further investigation. Most drought vulnerability studies have not integrated spatial analysis with field verification to confirm the accuracy of the mapping results [18]-[20]. In addition, studies focusing specifically on Sukabumi Regency remain relatively limited compared to other regions in Indonesia. The absence of field-based validation may reduce the representativeness of spatial models in describing actual drought conditions [21]-[23]. Therefore, there is a need for a more comprehensive approach that combines GIS-based spatial modeling with field observations and interviews to improve the accuracy of drought vulnerability assessment.

Accurate information on drought vulnerability is essential for supporting sustainable environmental management and disaster risk reduction. Spatial information regarding drought-prone areas can assist policymakers in formulating appropriate mitigation and adaptation strategies [24], [25]. The availability of reliable drought vulnerability maps can also help prioritize areas requiring immediate intervention and resource allocation. Moreover, such information is important for increasing community preparedness against drought-related hazards [26], [27]. Therefore, drought vulnerability mapping plays a significant role in supporting regional planning and sustainable development efforts.

The novelty of this study lies in the application of GIS-based spatial modeling integrated with remote sensing data and field validation through observations and interviews conducted in areas with the highest drought potential in Sukabumi Regency. Unlike previous studies that mainly depended on secondary spatial datasets, this study incorporates actual field conditions to improve the reliability of the analysis [28], [29]. The integration of GIS techniques, remote sensing, and field verification is expected to provide a more comprehensive understanding of drought vulnerability patterns. This approach enables the production of spatial information that is both scientifically robust and practically relevant for disaster mitigation planning. Therefore, the findings of this study are expected to contribute to the advancement of geospatial applications and drought risk management in Indonesia.

2. RESEARCH METHOD

2.1. Study Area and Research Design

This study employed a quantitative approach combined with descriptive analysis to investigate drought vulnerability in Sukabumi Regency, Indonesia. The study area was selected because several districts in the region frequently experience water shortages during the dry season. A GIS-based spatial modeling approach integrated with remote sensing techniques was applied to assess drought vulnerability patterns [30], [31]. In addition, field observations and interviews were conducted to support and validate the results obtained from spatial analysis. The overall research framework is presented in Figure 1.

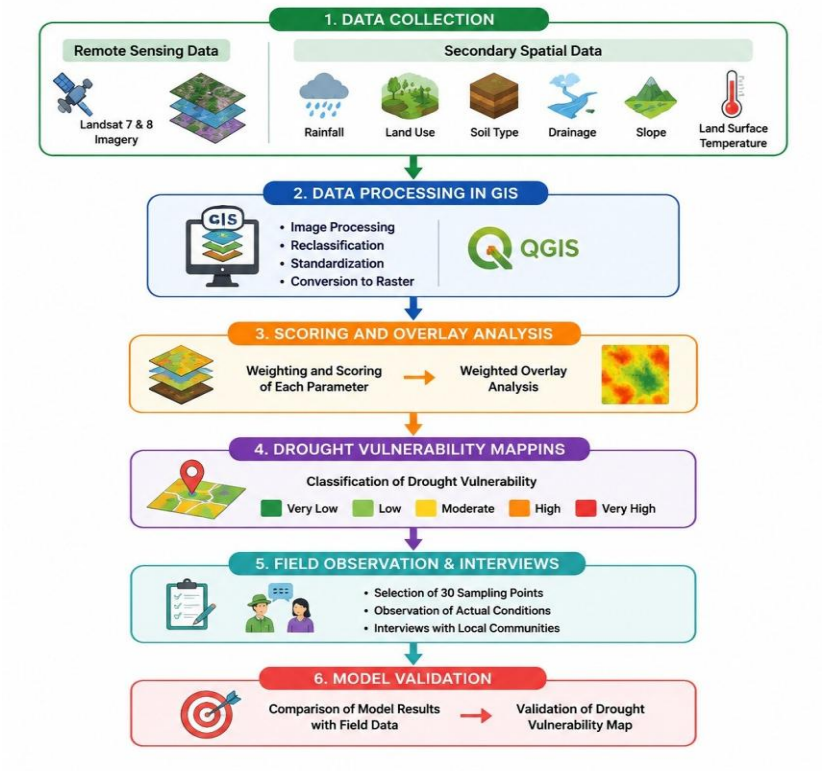


Figure 1. Research Framework

2.2. Data Collection

The study utilized both primary and secondary data sources to analyze drought vulnerability in Sukabumi Regency. Secondary data consisted of Landsat imagery, rainfall data, soil maps, land use maps, drainage conditions, slope maps, and land surface temperature data obtained from relevant institutions and satellite observations. Primary data were collected through field observations and structured interviews to verify the spatial analysis results. A total of 30 observation points located in three districts with the highest drought vulnerability levels were selected using purposive sampling. Furthermore, interviews involving 15 respondents were conducted to obtain supporting information regarding local drought conditions.

2.3. GIS-Based Spatial Modeling

Spatial modeling was performed using Geographic Information Systems (GIS) and remote sensing techniques to identify drought-prone areas. Several environmental parameters, including rainfall, land use, soil type, drainage conditions, vegetation index (NDVI), slope, and land surface temperature, were analyzed and assigned scores based on their influence on drought occurrence. Each thematic layer was processed individually before being integrated using the overlay technique to produce a drought vulnerability map [32], [33]. The resulting map classified drought vulnerability into several categories ranging from low to high vulnerability. This approach enabled the visualization and assessment of spatial patterns of drought vulnerability across Sukabumi Regency.

Table 1. Parameters Used in GIS-Based Spatial Modeling

No.	Parameter	Data Source	Analysis Method
1	Rainfall	BMKG	Scoring
2	Land Use	Landsat Imagery	Classification and Scoring
3	Soil Type	BAPPEDA	Scoring
4	Drainage Condition	SRTM Data	Flow Accumulation and Scoring
5	NDVI	Landsat Imagery	Vegetation Index Analysis
6	Land Surface Temperature	Landsat Imagery	LST Analysis
7	Slope	DEM/SRTM Data	Scoring

2.4. Field Validation and Data Analysis

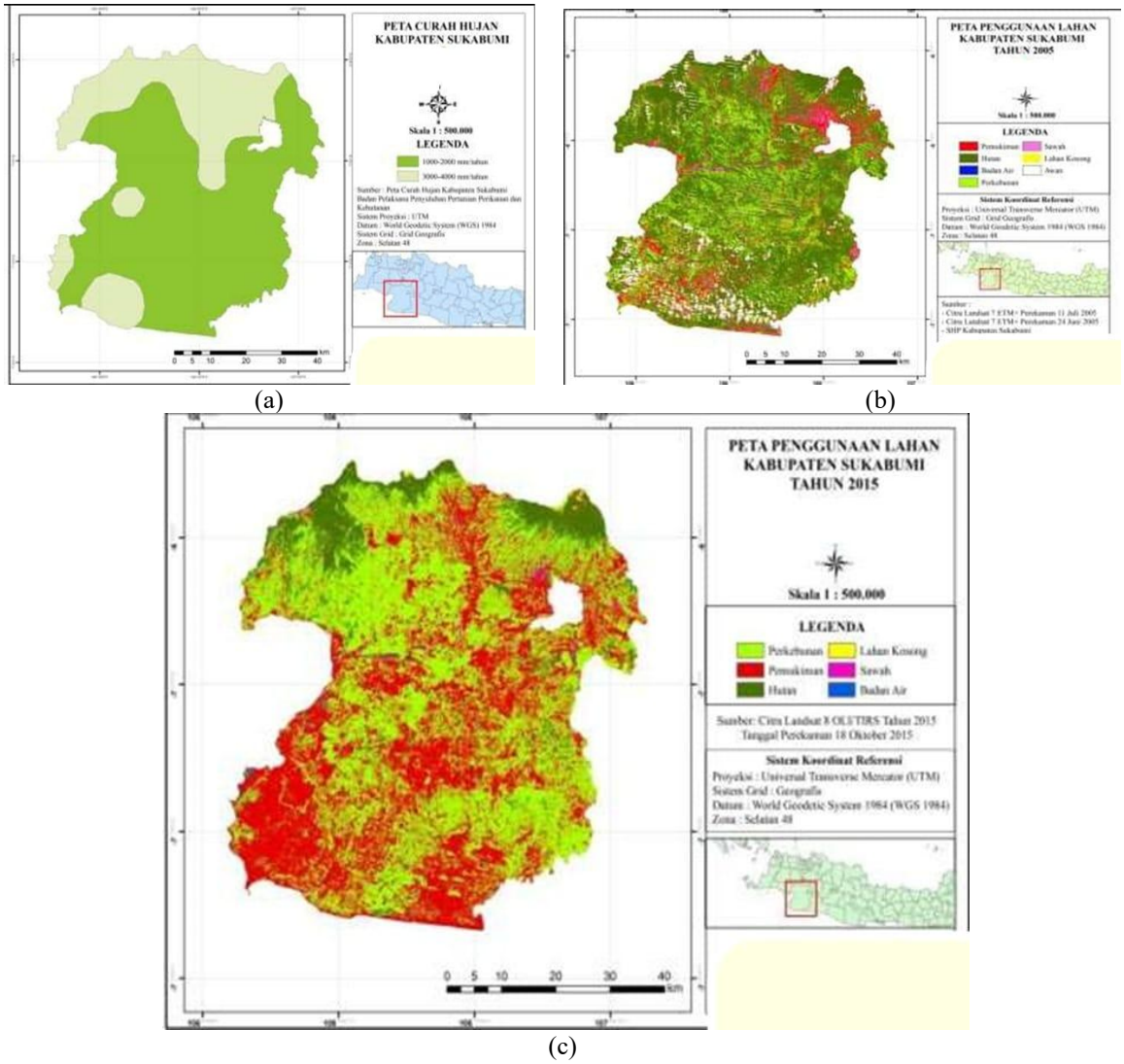
Field validation was conducted to evaluate the accuracy of the GIS-based spatial modeling results. Observations and interviews were carried out in three districts identified as having the highest drought

vulnerability levels. The field survey involved 30 sampling points to compare actual conditions with the vulnerability map produced through spatial analysis. Information obtained from local communities was used to strengthen the interpretation of drought conditions in the study area. Therefore, the integration of GIS analysis and field validation provided a more reliable representation of drought vulnerability in Sukabumi Regency.

3. RESULTS AND DISCUSSION

3.1. Spatial Characteristics of Drought-Related Parameters

The spatial distribution of drought-related parameters exhibited considerable variability across Sukabumi Regency. Several environmental factors, including rainfall, land use, soil type, slope, vegetation conditions, and land surface temperature, contributed differently to drought vulnerability. The analysis of each parameter revealed distinct spatial patterns that influenced the susceptibility of specific areas to drought occurrence. Variations in these parameters were identified through GIS processing and remote sensing analysis. The spatial characteristics of the drought-related parameters are presented in Figure 2.



(c)

Figure 2. Selected Drought-Related Parameters in Sukabumi Regency: (a) Rainfall, (b) NDVI, and (c) Land Surface Temperature

3.2. GIS-Based Spatial Modeling of Drought Vulnerability

The integration of drought-related parameters through GIS-based spatial modeling generated a comprehensive drought vulnerability map for Sukabumi Regency. The overlay analysis enabled the classification of areas according to their levels of vulnerability. The resulting map illustrated the spatial variation of drought vulnerability across the study area. Areas with high vulnerability were predominantly concentrated in districts

characterized by limited water availability and unfavorable environmental conditions. The results of the spatial modeling are presented in Figure 3.

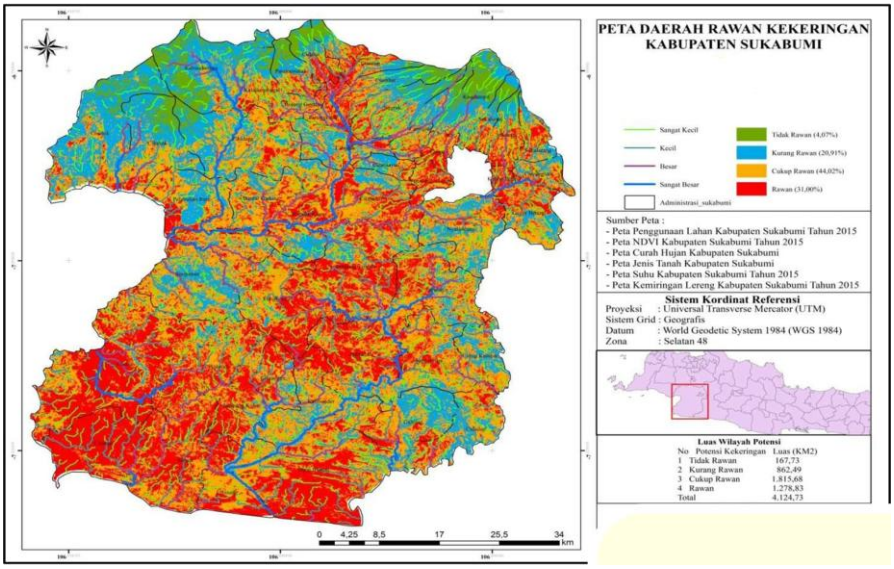


Figure 3. Drought Vulnerability Map of Sukabumi Regency

3.3. Distribution of Drought Vulnerability Levels

The drought vulnerability map classified the study area into several vulnerability categories ranging from low to high levels. Each category occupied different proportions of the total area of Sukabumi Regency. The distribution of vulnerability levels indicated that some districts were more susceptible to drought than others. This spatial variation reflects the influence of environmental and climatic conditions within the region. The classification and area distribution of drought vulnerability are summarized in Table 2.

Table 2. Distribution of Drought Vulnerability Classes

Vulnerability Level	Area (km²)	Percentage (%)
Low	167.73	4.07
Moderate	862.49	20.91
High	1,815.68	44.02
Very High	1,278.83	31.00
Total	4,124.73	100.00

3.4. Field Validation Results

Field validation was conducted to evaluate the consistency between the GIS-based spatial modeling results and actual conditions in the study area. A total of 30 observation points located in three districts with the highest drought vulnerability levels were selected for verification. Information obtained from field observations and interviews generally supported the results of the spatial analysis. Communities residing in highly vulnerable areas reported seasonal water shortages and limited access to clean water during the dry season. A summary of the field validation results is presented in Table 3.

Table 3. Summary of Field Validation Results

District	Number of Observation Points	Validation Result
District A	10	Suitable
District B	10	Suitable
District C	10	Suitable

Results obtained from the GIS-based spatial modeling revealed that drought vulnerability in Sukabumi Regency varied across the study area. Areas classified as high and very high vulnerability occupied larger proportions than those categorized as low vulnerability, indicating that drought remains a significant environmental issue in the region. Spatial variations in drought vulnerability were influenced by differences in rainfall, vegetation conditions, land surface temperature, land use, and topographic characteristics. Integration of these parameters through overlay analysis enabled the identification of areas that are more susceptible to drought occurrence. Findings from this analysis confirm the importance of geospatial approaches in understanding the spatial characteristics of drought vulnerability.

Field validation through observations and interviews generally supported the results generated by the GIS-based spatial model. Communities residing in highly vulnerable areas reported experiencing seasonal water shortages and difficulties in obtaining clean water during the dry season. Consistency between field conditions and the spatial model indicates that the resulting drought vulnerability map provides a reliable representation of actual environmental conditions. Furthermore, the validation process strengthened the interpretation of spatial patterns identified through remote sensing and GIS analysis. Integration of spatial data and field information therefore contributed to improving the reliability of drought vulnerability assessment in Sukabumi Regency.

Findings of this study are generally consistent with previous studies highlighting the effectiveness of GIS and remote sensing techniques for drought vulnerability assessment. Previous investigations have demonstrated that environmental parameters such as rainfall, land use, vegetation conditions, and temperature play important roles in determining drought susceptibility [34], [35]. Similar spatial patterns observed in this study suggest that areas with lower vegetation density and higher temperatures tend to experience greater drought vulnerability. However, many earlier studies primarily relied on secondary spatial data and focused on map generation without direct verification of field conditions [36]. Evidence provided by the present study further supports the importance of field validation in strengthening the credibility and representativeness of GIS-based drought assessments.

Novelty of this study lies in the integration of GIS-based spatial modeling with field validation through observations and interviews conducted in districts with the highest drought potential. Unlike previous studies that mainly emphasized spatial analysis, this research incorporated actual field conditions to verify the consistency of the generated maps [37]. Combination of remote sensing data, GIS techniques, and field verification offers a more comprehensive approach to drought vulnerability assessment. Such an approach not only improves the reliability of spatial information but also enhances the practical relevance of the findings for disaster mitigation efforts [38], [39]. Consequently, this study contributes to the advancement of geospatial applications for drought risk analysis in Indonesia.

Results generated in this study have several important implications for environmental management and disaster risk reduction. Spatial information derived from drought vulnerability mapping can serve as a reference for local governments in identifying priority areas requiring mitigation measures and water resource management strategies [40], [41] Information provided by the generated maps may also support regional planning policies aimed at strengthening resilience to drought hazards. Increased awareness and preparedness among communities located in highly vulnerable areas can be achieved through the utilization of accurate spatial information [42]. Practical benefits offered by GIS and remote sensing applications therefore contribute to promoting sustainable development and reducing drought-related risks.

Despite its contributions, several limitations should be acknowledged in this study. Spatial modeling relied on a limited number of environmental parameters, which may not fully represent the complexity of drought processes. Field validation was conducted using only thirty observation points distributed across three districts with the highest vulnerability levels. Temporal variations in drought conditions were not extensively considered because the analysis utilized data representing specific periods. Future studies are therefore recommended to incorporate additional parameters, larger validation samples, and multi-temporal datasets to improve the accuracy and comprehensiveness of drought vulnerability assessments.

CONCLUSION

GIS-based spatial modeling integrated with remote sensing and field validation successfully identified the spatial distribution and vulnerability levels of drought-prone areas in Sukabumi Regency, Indonesia. Results demonstrated that areas classified as high and very high vulnerability occupied a considerable proportion of the study area, indicating that drought remains a significant environmental challenge requiring appropriate mitigation efforts. Consistency between spatial modeling results and field observations confirmed that the integration of GIS analysis with direct validation provides a reliable representation of actual drought conditions. Findings obtained in this study support the importance of geospatial technologies as effective tools for drought vulnerability assessment and regional disaster risk management. Practical implications of the generated drought vulnerability map can assist policymakers and local authorities in formulating sustainable water resource management and drought mitigation strategies. Future studies are recommended to incorporate additional environmental parameters, larger validation samples, and multi-temporal datasets to improve the accuracy and applicability of drought vulnerability assessments in different regions.

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