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Mapping Flood-Prone Zone Using CMA and NDWI in Muaradua District, South OKU

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ABSTRACT

Flooding is a recurring disaster in Indonesia, especially in vulnerable areas such as Muaradua District, South Ogan Komering Ulu. This study aims to delineate flood-prone zones using an integrated approach that combines Composite Mapping Analysis (CMA) and the Normalized Difference Water Index (NDWI). Six environmental parameters river density, soil type, land cover, rainfall, elevation, and slope gradient were processed using Geographic Information Systems (GIS) to generate a vulnerability index. Sentinel-2 imagery was used to detect actual inundation through NDWI computation. The findings show that 43.08% of the study area is slightly vulnerable, 33.02% vulnerable, and 4.59% very vulnerable, while NDWI analysis revealed that 12.31% of the total area was inundated. High-risk villages such as Pasar Muaradua and Pancur Pungah exhibited flood exposure levels exceeding 29%. Spatial overlay analysis demonstrated strong concordance between model-based vulnerability and observed inundation, validating the robustness of the integrated method. These results provide critical input for spatial planning and targeted flood mitigation efforts in the region.

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1. INTRODUCTION

Flood disasters consistently rank among the most recurrent and destructive hydrometeorological hazards in Indonesia, with significant socioeconomic and environmental implications. According to the Indonesian Disaster Management Agency (BNPB), more than 1,200 flood events will be recorded in 2023 alone, reflecting a persistent pattern exacerbated by urban expansion, deforestation, and inadequate drainage infrastructure. Among the most affected regions is South Sumatra Province, where the South Ogan Komering Ulu (OKU) Regencyincluding Muaradua District has repeatedly experienced flood incidents attributed to the overflow of the Komering River and topographic vulnerability. The urgent need for improved spatial planning and mitigation has been accentuated by the increased flood frequency observed in the last five years, particularly in low-lying areas adjacent to major watercourses. Advancements in remote sensing and geospatial analysis have enabled more efficient identification and mapping of flood-prone areas. Tools such as the Normalized Difference Water Index (NDWI) have proven effective in distinguishing water bodies using satellite imagery, while methods like Composite Mapping Analysis (CMA) allow the integration of diverse environmental variables into a coherent spatial framework for vulnerability assessment (Hisyam et al., 2024; Xue et al., 2022). Prior studies have successfully employed these tools in flood modeling and hazard zoning, emphasizing their utility in regions lacking comprehensive hydrological infrastructure (Ahmad et al., 2025; AlAli et al., 2023). Nevertheless, research applying these methods specifically to sub-district scales in high-risk zones remains limited, underlining the necessity of localized studies to inform targeted flood risk mitigation and disaster preparedness strategies.

Despite the availability of national and regional flood hazard assessments, existing flood-prone mapping often lacks spatial resolution and local relevance, particularly at the sub-district level, such as in Muaradua. The prevailing methods typically generalize flood vulnerability across large areas, overlooking localized topographic, hydrological, and land-use variations that critically influence inundation risk. Consequently, decision-makers and planners face limitations in formulating site-specific mitigation strategies, leaving communities in highly exposed areas insufficiently protected. Muaradua District, situated along the Komering River and characterized by complex elevation gradients and dense settlements, exemplifies such a vulnerable locality where precise flood risk delineation is urgently needed. To address this limitation, a comprehensive spatial analysis method integrating Composite Mapping Analysis (CMA) and the Normalized Difference Water Index (NDWI) offers a viable solution. The CMA approach facilitates a multi-parameter evaluation by assigning scores and weights to critical environmental factors such as rainfall, slope, elevation, soil type, land use, and river density, while NDWI enables temporal detection of water bodies using remote sensing (Chen, 2022; M Amen et al., 2023). The integration of these two methods enhances the spatial and temporal precision of flood hazard assessments, thus providing a robust basis for localized flood risk zoning and informed disaster-mitigation planning. By tailoring the analysis to Muaradua's geomorphological and hydrological characteristics, this approach addresses a crucial knowledge gap and supports evidence-based intervention strategies.

Flood vulnerability mapping using geospatial methods has been widely studied, with Composite Mapping Analysis (CMA) recognized for its ability to integrate multiple environmental parameters in a spatial framework. The application of CMA in flood hazard modeling, by assigning weighted values to variables such as rainfall, topography, and land use, yields a vulnerability index that spatially delineates flood-prone zones. Their approach emphasized the importance of overlapping analysis in classifying hazard levels, proving effective in regions where field data are scarce, but thematic maps are available. We applied the scoring and weighting method in the Sampang Regency and successfully generated a spatial vulnerability map, highlighting the importance of integrating hydrogeomorphological features with land use dynamics. Remote sensing methods have advanced with the development of indices such as the Normalized Difference Water Index (NDWI), which enhances water feature detection using satellite imagery (Ahmad et al., 2025). Applied NDWI to delineate inundated areas in lowland Java using Landsat imagery and validated the approach using ground data and visual interpretation. Their study revealed that NDWI derived from green and near-infrared (NIR) bands effectively distinguished between water and non-water surfaces, making it suitable for monitoring seasonal flood patterns (AlAli et al., 2023). Originally, the NDWI formulation was introduced, and subsequent studies have confirmed its applicability for dynamic water body detection, particularly during flood events (Anderson et al., 1976). Recent studies have emphasized the synergistic value of combining CMA and NDWI for a comprehensive flood risk assessment. The combined use of these methods allows for both structural and temporal characterization of flood hazards, yielding results that are not only spatially accurate but also adaptable to real-time conditions. In the context of areas like Muaradua District, where physical surveys are constrained by terrain or access, this hybrid methodology enables a cost-effective and data-efficient approach to flood vulnerability mapping and mitigation planning.

The primary objective of this study is to analyze and delineate flood-prone areas in Muaradua District, South Ogan Komering Ulu Regency, using an integrated approach that combines Composite Mapping Analysis (CMA) and the Normalized Difference Water Index (NDWI). By synthesizing environmental parameters such as rainfall, slope, elevation, soil type, land cover, and river density into a spatial vulnerability model and validating it through remote sensing-based inundation detection, this study aims to produce a comprehensive and localized flood risk map that supports spatial planning and disaster mitigation strategies. The novelty of this research lies in its integration of CMA and NDWI at the sub-district scale, which remains underexplored in the existing literature. While both methods have been individually applied in broader regional contexts, their combined use in a localized framework enables a multidimensional understanding of flood risk, both spatially and temporally (AlAli et al., 2023; Hadian et al., 2022). The study hypothesizes that the combined methodology will yield more accurate and actionable results compared to traditional mapping approaches, particularly in complex terrain such as Muaradua, where geomorphological and hydrological factors interact intricately with human settlement patterns. The scope of this study is confined to Muaradua District, which encompasses 14 administrative villages with diverse topographic and hydrological characteristics. The analysis covers both structural flood vulnerability based on spatial parameters and dynamic flood behavior observed through satellite imagery across seasonal periods. The outputs are intended not only for academic contribution but also to provide practical guidance for local authorities in formulating flood mitigation infrastructure, such as retarding basins and integrating flood hazard considerations into land use planning and development control policies.

2. METHOD

2.1. Study Area

This study was conducted in Muaradua District, South Ogan Komering Ulu Regency, South Sumatra Province. The district is geographically situated along the Komering River and features varied topographic conditions, including high hills, lowlands, and areas of dense settlement. The area is frequently affected by seasonal flooding owing to hydrometeorological factors and geomorphological vulnerabilities. This site was selected based on the high frequency of flood events recorded over the past five years.

2.2. Materials

The materials used in this study comprised both spatial and non-spatial datasets, which were essential for generating flood vulnerability and inundation maps. Rainfall data were sourced from the Meteorological, Climatological, and Geophysical Agency (BMKG), while elevation and slope information were obtained from the Digital Elevation Model (DEM) datasets. Soil types and land-use characteristics were derived from thematic maps provided by the Geospatial Information Agency (BIG). Hydrographic and topographic data were used to analyze the river network and drainage density within the study area. In addition, Sentinel-2 satellite imagery was employed for the computation of the Normalized Difference Water Index (NDWI). Several software platforms supported data processing and spatial analysis, including ArcMap 10.8 for GIS analysis, Global Mapper 23 for satellite image correction and classification, Microsoft Excel for scoring and weighting procedures, and Google Earth Pro for cross-validation of the mapped results.

2.3. Methodology

This study employed an indirect mapping approach by integrating Composite Mapping Analysis (CMA) and the Normalized Difference Water Index (NDWI). The CMA method was used to determine flood vulnerability zones based on a weighted overlay of six environmental parameters: rainfall, elevation, slope, soil type, land use, and river density. Each parameter was classified into subclasses and assigned scores and weights reflecting their relative contributions to flood risk.

Sentinel-2 imagery was processed to derive NDWI values using the green (band 3) and near-infrared (band 8) bands. The NDWI values were thresholded at 0.3 to classify water and non-water areas, following the method introduced (McFeeters, 1996). The inundation maps from different seasonal periods were overlaid to determine the areas consistently affected by flooding.

2.4. Parameter Analysis

Each parameter in the study was analyzed to assess its contribution to flood vulnerability. Rainfall data were evaluated by classifying and scoring the monthly averages based on the defined intensity ranges. The scoring scheme used for rainfall classification is detailed in Table 1, where increasing precipitation levels are associated with higher flood vulnerability.

Table 1. Rainfall Classification

Classification	Rainfall (mm/month)	Score
Very Light Rain	< 50 mm/month	1
Light Rain	50 - 100 mm/month	2
Moderate Rain	100 - 300 mm/month	3
Heavy Rain	300 - 500 mm/month	4
Very Heavy Rain	> 500 mm/month	5

Source: (Haacke & Paton, 2023)

Elevation and slope parameters were derived from Digital Elevation Model (DEM) data. The classification of slope gradients, which influence runoff speed and accumulation, is summarized in Table 2.

Table 2. Slope Classification

Classification	Slope (%)	Score
Very Steep	> 45%	1
Steep	25 - 25%	2
A bit Steep	15 - 25%	3
Sloping	8 - 15%	4
Flat	< 8%	5

Source: (Rosen et al., 2023)

Soil types were categorized according to their infiltration capacity, which affects the extent to which rainfall contributes to the surface runoff. The classifications based on soil sensitivity are presented in Table 3.

Table 3. Soil Type Classification

Soil Type	Sensitivity	Score
Regosol, Litosol, Organosol, Renzina	Very Sensitive	1
Andosol, Laterik, Grumosol, Podsol, Podsolic	Sensitive	2
Brown Forest Land, Mediterranean Land	Medium Sensitivity	3
Latosol	A bit sensitive	4
Aluvial, Planosol, Grey Hydromorph, Groundwater Lateric	Insensitive	5

Source: (Handiani & Purnomo, 2024)

Land cover characteristics, particularly vegetation and built environments, influence water absorption and surface runoff. The classifications used for the land cover types are shown in Table 4.

Table 4. Land Cover Classification

Absorption Potential	Land Cover	Score
Low	Forest	1
Medium Low	Bush	2
Medium	Farms/Gardens	3
Medium High	Ponds	4
High	Settlement	5

Source: (Anderson et al., 1976)

River density reflects the frequency and distribution of water channels, which directly impacts flood potential. Table 5 illustrates the classification system based on river density per square kilometer.

Table 5. River Density Classification

Classification	River Density (km/km²)	Score
Very loose	< 0,62	1
loose	0,62 - 1,44	2
Medium	1,45 - 2,27	3
Tight	2,28 - 3,10	4
Vey Tight	> 3,10	5

Source: (Hoshino & Yamada, 2023)

All thematic layers were subsequently reclassified and assigned their respective weights. These weighted layers were overlaid in ArcMap to generate a composite flood vulnerability map. The resulting map was then integrated with the NDWI-based inundation layer to produce a comprehensive spatial delineation of flood-prone areas in the study region.

2.5. Equation Models

Flood vulnerability scoring and spatial mean calculations were performed using a set of quantitative equations designed to process and integrate spatial parameters. These equations facilitate the transformation of spatial data into numerical indices that represent flood susceptibility.

Equation (1) is used to calculate the Flood Prone Ratio, which represents the proportion of a specific parameter class area that contributes to flood-prone regions:

$$Rr = \frac{Rb}{L} \tag{1}$$

where Rr is Ratio of Areas Prone to Flooding; Rb is Region Susceptible to Flooding; L is Area of the Parameter.

Equation (2) computes the Potential Flood Area Ratio, which quantifies the share of each class within the total flood-prone area:

$$Rl = \frac{Rb}{\sum Rb} \tag{2}$$

Where Rl is Rasio of Potential Flood Area; Rb is Area of potential banji prone area; ∑Rb is Total area of potential flood-prone area.

Equation (3) is used to calculate Mean Spatial as follows:

$$Mean\ Spatial = \sum Rr_n . Rl_n \tag{3}$$

where Rr is the flood-prone ratio, Rl is Ratio of the flood-prone potential area, and n is the parameter.

Equation (4) is used to calculate the combined index in the form of flood value:

$$C = \sum X . W_n \tag{4}$$

where C is Combined index in the form of flood value, Xi is the value of the criteria of the flood cause parameter, In is Weight of the flood cause parameters, and n is the parameter.

Equation (5) was applied to determine the classification interval, which divides the composite index into several vulnerability classes.

$$Ki = \frac{Cmaks - Cmin}{K} \tag{5}$$

where K is Total interval class, Cmaks is Maximum flooding value, and Cmin is Minimum flood value.

Equation (6) represents the NDWI formula, which is a standard remote sensing technique for water body identification.

$$NDWI = \frac{Green - NIR}{Green + NIR} \quad (6)$$

Where NDWI is Normalized Difference Water Index; Green is Band 3 Landsat 8 Level 1; NIR is Band 5 Landsar 8 Level 1

3. RESULTS AND DISCUSSION

3.1. Results

This section presents the core findings of the flood vulnerability and inundation assessment in Muaradua District. Based on Composite Mapping Analysis (CMA) of six spatial parameters, river density, soil type, land cover, rainfall, elevation, and slope gradient, the district was categorized into four vulnerability classes.

Table 6. Land Cover Classification

Class	Vulnerability Index Range	Area (km²)	Percentage (%)
Safe	166.5789 - 220.9067	48.03	19.31
Relatively Vulnerable	220.9068 - 275.2345	107.16	43.08
Prone	275.2346 - 329.5623	82.14	33.02
Very Vulnerable	329.5624 - 338.8901	11.41	4.59

The spatial distribution of vulnerability levels derived from the CMA method is illustrated in the following map, which visualizes the classification from safe to very vulnerable zones based on integrated spatial parameters.

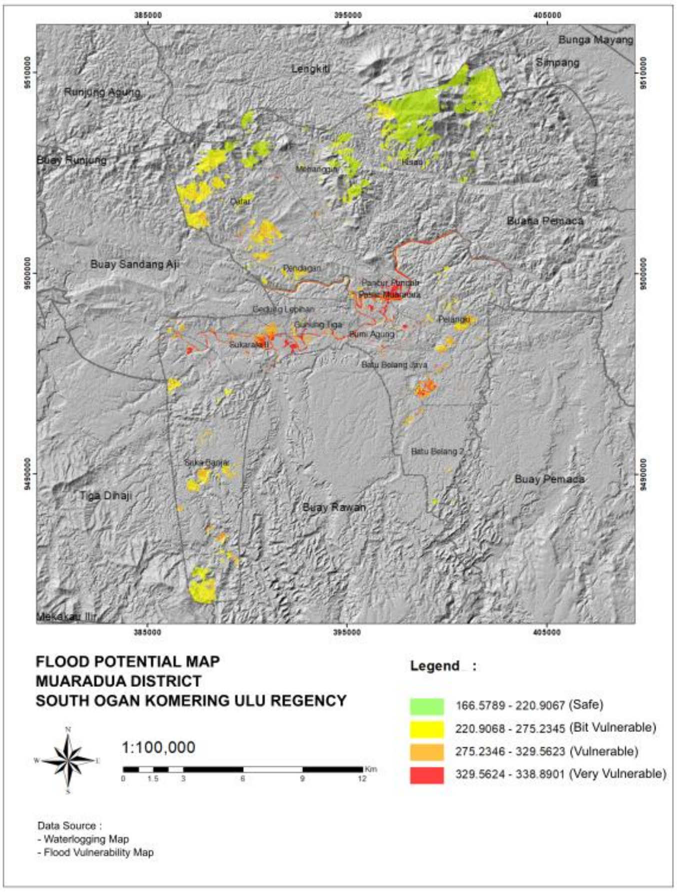

Figure 1. Flood Vulnerability Map.

The NDWI analysis based on Sentinel-2 imagery revealed that 30.62 km² or 12.31% of the total area is inundated. Pasar Muaradua and Pancur Pungah were identified as the most affected, with inundation levels of 41.41% and 29.79%, respectively.

Table 7. Flood Inundation Potential by Village

Village	Area (km²)	Flooded Area (km²)	Percentage (%)
Pasar Muaradua	1.28	0.53	41.41
Pancur Pungah	0.47	0.14	29.79
Kisau	47.98	11.46	23.88
Datar	27.24	5.82	21.37
Mehanggin	21.75	2.93	13.47

Overlay analysis showed strong spatial concordance between CMA-based vulnerability and NDWI-based inundation, particularly in the 'Very Vulnerable' class, which overlaps with inundation in 25.59% of its area. Surprisingly, 24.03% of the 'Safe' category also experienced flooding, indicating influence from local drainage issues or extreme weather.

Table 8. Concordance Between Vulnerability Class and Inundation Area

Vulnerability Class	Area (km²)	Flooded Area (km²)	Percentage (%)
Safe	48.03	11.54	24.03
Slightly Vulnerable	107.16	10.07	9.40
Vulnerable	82.14	5.48	6.67
Very Vulnerable	11.41	2.92	25.59

These findings affirm the effectiveness of the CMA and NDWI integration in identifying flood rone areas. The approach provides practical insights for spatial planning and structural flood mitigation, particularly in critical villages like Pasar Muaradua.

3.2. Discussion

The integration of the CMA and NDWI methods in this study provides strong empirical evidence for identifying spatial flood vulnerability and actual inundation zones. The consistency between the classified "Very Vulnerable" zones and NDWI-confirmed inundated areas (25.59% spatial overlap) demonstrates high predictive reliability. This validates the CMA model's ability to incorporate multiple environmental parameters into flood risk evaluation (AlAli et al., 2023; Melo et al., 2024).

However, the surprising presence of in 24.03% of areas classified as "Safe" indicates limitations in static spatial modeling. This suggests that non-structural factors such as inadequate drainage infrastructure, temporary land use changes, or climate anomalies may influence flood occurrences, aligning with previous findings on the unpredictability of hydrometeorological hazards (Criss & Nelson, 2022).

From a practical perspective, the results emphasize the critical need for structural mitigation strategies in densely populated and low-elevation areas, such as Pasar Muaradua and Pancur Pungah. These regions, though geographically limited in area, represent a disproportionate share of flood impacts and should be prioritized for interventions like retarding basins or improved drainage systems (Handiani & Purnomo, 2024).

Furthermore, this study affirms that a remote-sensing-based approach remains highly valuable for areas with limited ground data availability. It offers an efficient and scalable model for local governments to continuously monitor and update flood risk maps, thereby contributing to long-term resilience planning in flood-prone regions.

4. CONCLUSIONS

This study successfully applied an integrated approach using Composite Mapping Analysis (CMA) and the Normalized Difference Water Index (NDWI) to map flood-prone areas in

Muaradua District, South Ogan Komering Ulu. The results showed that 43.08% and 33.02% of the region fell under the slightly vulnerable and vulnerable categories, respectively, with actual inundation recorded in 12.31% of the total area. Pasar Muaradua and Pancur Pungah villages were the most at risk, with inundation levels exceeding 29%.

This study demonstrates the effectiveness of combining spatially weighted environmental parameters with remote sensing techniques to capture both the structural and temporal dimensions of flood vulnerability. The high spatial concordance between the modeled vulnerability zones and NDWI-derived inundation maps validates the robustness of the approach.

These findings offer valuable reference for policymakers and local planners in designing targeted flood mitigation strategies and land use policies. Future research should incorporate higher-resolution imagery, time-series flood event data, and socioeconomic variables to further refine vulnerability assessments and support adaptive community-based flood management practices.

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