MIKAILALSYS
Journal of Multidisciplinary Sciences

e-ISSN : 2987-2286
p-ISSN : 2987-3924
Index: Harvard, Boston, Sydney, Copernicus, Sinta 4, Scilit, Semantic, Google, etc

https://doi.org/10.58578/mikailalsys.v4i3.12469

Classification of Flood-Prone Areas in Padang City Using Landsat-9 Satellite Imagery

Ramona Fitria, Pakhrur Razi, Yohandri, Nofi Yendri Sudiar
Universitas Negeri Padang, Indonesia
ramonafitria09@gmail.com; fhrrazi@fmipa.unp.ac.id

Submitted:	Revised:	Accepted:	Published:
Sep 18, 2026	Oct 17, 2026	Oct 28, 2026	Nov 2, 2026

Abstract

Flood-susceptibility mapping requires spatial information that captures the combined influence of hydrological conditions, topography, soils, and land cover. This study classified and mapped flood-prone areas in Padang City by integrating six parameters: rainfall, elevation, slope, distance from rivers, soil type, and land use/land cover. A quantitative spatial approach using Geographic Information Systems (GIS) was employed. Land cover was classified from Landsat-9 Collection 2 Level-2 imagery using the Classification and Regression Trees (CART) algorithm in Google Earth Engine. The six parameters were subsequently scored, weighted, and integrated through weighted-overlay analysis. The land-cover classification achieved an overall accuracy of 85.17%, while the overlay analysis delineated five flood-susceptibility classes. Moderate susceptibility occupied the largest area, covering 30,675.414 ha (45.79%), followed by high susceptibility at 17,631.140 ha (26.32%), low susceptibility at 17,226.524 ha (25.72%), very high susceptibility at 1,420.275 ha (2.12%), and very low susceptibility at 31.048 ha (0.05%). These findings reveal substantial spatial variation in flood susceptibility across Padang City, with moderate susceptibility predominating. The study provides an integrated spatial assessment to support disaster mitigation and environmentally responsive land-use planning.

Keywords: Flood Susceptibility Mapping; Landsat-9; Geographic Information Systems; Weighted Overlay Analysis; Padang City

Mikailalsys is licensed under a Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International License

INTRODUCTION

Flooding remains one of the most persistent hydrometeorological hazards worldwide, with consequences that extend beyond physical inundation to the disruption of livelihoods, mobility, public services, and community well-being (Millat-e-Mustafa, 2025; Shah et al., 2025). The challenge is particularly pronounced in rapidly developing urban areas, where intense rainfall interacts with land-use change, limited infiltration, drainage constraints, and settlement expansion. Climate projections indicate that many parts of East and Southeast Asia are likely to experience increasingly intense rainfall events, potentially increasing the frequency and severity of flooding in exposed areas (Intergovernmental Panel on Climate Change, 2022). Indonesia faces this challenge on a recurring basis because of its climatic and geographical characteristics. Data from the National Disaster Management Agency show that floods continue to account for a substantial proportion of hydrometeorological disasters in the country; for example, 115 flood events were recorded in May 2024 alone, representing approximately 75% of all disasters reported during that month (Badan Nasional Penanggulangan Bencana, 2024). These conditions underline the need for spatially explicit information that can identify areas where the physical environment makes communities more susceptible to flooding.

Padang City, located on the western coast of Sumatra, represents an urban setting in which flood susceptibility is shaped by the interaction of rainfall, topography, river systems, coastal lowlands, and continuing land development. The city contains coastal and low-lying areas that are particularly sensitive to inundation, while parts of the urban landscape are exposed to recurrent flooding during periods of intense rainfall (Rasyda et al., 2015; Sukenti et al., 2026). Recent studies continue to identify flooding as an important concern for the city. Darmawan et al. (2023), for example, identified variations in flood susceptibility across Padang and reported very high susceptibility in several northern areas, including Koto Tangah, Nanggalo, and Padang Utara. Mulia & Handayani (2024) likewise found that areas classified as highly flood-prone expanded between 2011 and 2022. Such findings indicate that flooding in Padang is not merely a temporary response to heavy rainfall but a spatial problem associated with the interaction between environmental conditions and the changing urban landscape.

Flood susceptibility is produced by multiple physical processes rather than by a single environmental factor. Flooding may occur when water exceeds the capacity of rivers or

drainage channels and subsequently inundates adjacent land (Samanta et al., 2018) . Rainfall influences the amount of water entering a catchment, while elevation and slope affect the direction, velocity, and accumulation of surface runoff. Proximity to rivers determines the degree to which surrounding areas are exposed to overflowing channels, whereas soil characteristics influence infiltration and water retention. Land cover is equally important because changes from vegetated or permeable surfaces to built-up areas may reduce infiltration and increase surface runoff. Flood susceptibility assessment therefore requires the simultaneous consideration of several spatially distributed conditioning factors rather than an interpretation based solely on rainfall or historical flood occurrence (Samanta et al., 2018; Shekar & Mathew, 2023). Multi-parameter assessment is particularly relevant for urban areas such as Padang, where natural terrain and human-modified land surfaces coexist within the same hydrological system.

Geographic Information Systems (GIS) and remote sensing provide an effective framework for examining these interacting factors spatially. Earlier studies have demonstrated that scoring, weighting, reclassification, and spatial overlay can combine different flood-conditioning variables into interpretable susceptibility classes. Fajri & Widayanti (2018) incorporated slope, land use, and soil infiltration to classify flood susceptibility in Sekarbela, Mataram, while Matondang et al. (2013) examined flood-prone zones in Kendal by considering topography, land use, and drainage conditions. Krisnandi & Prabowo (2021) combined Landsat 8 imagery and Digital Elevation Model (DEM) data through scoring, weighting, and overlay procedures to map tidal-flood susceptibility in Pekalongan. Similar GIS-based studies have incorporated elevation, slope, rainfall, distance from rivers, land use/land cover, drainage characteristics, and soil properties because these variables represent different components of the processes controlling water accumulation and inundation (Samanta et al., 2018). Collectively, these studies demonstrate the value of integrating multiple geospatial datasets for identifying spatial differences in flood susceptibility.

Remote sensing strengthens such analysis by providing consistent observations of land-surface conditions over extensive areas without requiring direct observation at every location. Satellite imagery is particularly valuable for deriving land-cover information because vegetation, water bodies, built-up surfaces, and other land-cover categories have distinct spectral responses. Landsat-9 provides an important source of such information through its Operational Land Imager-2 (OLI-2) and Thermal Infrared Sensor-2 (TIRS-2). The OLI-2

sensor has a 14-bit radiometric resolution, allowing it to distinguish 16,384 intensity levels and thereby capture relatively subtle variations in surface reflectance (Geological Survey, 2022). The Landsat archive can also be accessed and processed through Google Earth Engine, a cloud-based platform designed for large-scale geospatial analysis and equipped with extensive collections of satellite and environmental datasets (Gorelick et al., 2017). These capabilities make Landsat imagery particularly useful for generating land-cover information that can subsequently be integrated with other flood-conditioning variables.

Previous flood-mapping research in Padang provides an important empirical foundation, although differences in parameter selection and data sources remain evident. Fahmi (2021) mapped flood-prone areas using land cover, slope, rainfall, drainage, landform, and river-buffer parameters and found that highly susceptible areas were concentrated largely in the western part of the city. Hidayatullah et al. (2023) examined flood susceptibility in the Batang Kuranji watershed using weighted and overlaid flood-conditioning parameters. Darmawan et al. (2023) applied a GIS-based Composite Mapping Analysis using rainfall, slope, land cover, and soil type, whereas Mulia & Handayani (2024) incorporated slope, rainfall, distance from rivers, land cover, and soil type to examine changes in flood susceptibility between 2011 and 2022. Saffitri & Ashar (2023) further emphasized the role of heavy rainfall, drainage conditions, river capacity, and declining infiltration areas in shaping flood conditions in Padang. These studies confirm the usefulness of GIS-based approaches while also showing that flood-susceptibility outcomes depend considerably on the environmental variables and spatial datasets included in the analysis.

The existing literature leaves room for a more integrated classification that explicitly uses Landsat-9-derived land-cover information alongside a broader set of physical flood-conditioning parameters for Padang City. Earlier local studies have employed different combinations of rainfall, slope, land cover, soil, drainage, river proximity, and landform Darmawan et al. (2023); Fahmi (2021); Mulia & Handayani (2024) , while studies outside Padang similarly demonstrate that the reliability and spatial interpretability of susceptibility mapping benefit from combining hydrogeomorphological and land-surface variables (Samanta et al., 2018). The present study responds to this methodological space by integrating Landsat-9-derived land cover with rainfall, elevation, slope, distance from rivers, and soil type. Each parameter represents a distinct physical dimension of flood susceptibility and is reclassified according to its relative influence before being combined through spatial analysis. The contribution of the study therefore lies not in introducing GIS-based flood

mapping to Padang for the first time, but in applying an integrated parameter framework in which recent-generation Landsat imagery provides the land-cover component of the susceptibility classification.

The resulting classification has practical significance because a flood-susceptibility map translates complex environmental conditions into spatial information that can be more readily interpreted for disaster mitigation and land-use planning. Flood-prone land becomes particularly consequential when it intersects with settlements, agricultural areas, infrastructure, and other locations where people live and conduct daily activities (Anderson et al., 2022). Spatial identification of susceptible areas can therefore support decisions concerning development control, preparedness, evacuation planning, and the prioritization of mitigation measures. Such information is especially relevant for Padang, where previous research has documented both recurrent flooding and changes in the spatial extent of susceptible areas (Darmawan et al., 2023; Mulia & Handayani, 2024). A spatial classification should consequently be understood not only as a cartographic product but also as an evidence base for reducing the potential human and material consequences of future flooding.

This study aims to classify and map flood-prone areas in Padang City by integrating Landsat-9-derived land-cover information with rainfall, elevation, slope, distance from rivers, and soil-type parameters through spatial analysis. The study seeks to determine the spatial distribution of different levels of flood susceptibility across the city and to produce a flood-susceptibility map that can provide supporting information for disaster mitigation and flood-risk reduction. By bringing together satellite-derived land-cover information and multiple physical characteristics of the landscape, the study is expected to provide a more spatially differentiated understanding of where flood susceptibility is concentrated within Padang City and to support planning efforts that are more responsive to the environmental conditions experienced by local communities.

METHODS

This study employed a quantitative-spatial approach using Geographic Information Systems (GIS) to classify flood susceptibility across Padang City, West Sumatra, Indonesia. The study area was bounded by the administrative territory of Padang City, located approximately between 00°44'00"–01°08'35" S and 100°05'05"–100°34'09" E. Rather than

using a population and respondent sample, the analysis was based on spatial datasets representing the entire study area. Six flood-conditioning parameters were examined: rainfall, elevation, slope, distance from rivers, soil type, and land use/land cover. Secondary data consisted of Landsat-9 Collection 2 Level-2 imagery obtained through Google Earth Engine/USGS, rainfall records for 2022–2024 from BMKG and PSDA, river-network data, Digital Elevation Model (DEM) data, soil-type data, and the administrative boundary of Padang City. These parameters were selected to represent rainfall conditions, terrain characteristics, proximity to drainage networks, surface infiltration characteristics, and land-surface conditions associated with flood susceptibility.

Spatial data processing was performed using ArcMap/ArcGIS and Google Earth Engine. Rainfall observations were interpolated using the Inverse Distance Weighted (IDW) method to generate a continuous rainfall distribution, while SRTM DEM data at 30-m spatial resolution were processed to derive elevation and slope. River-network data were transformed into distance classes through buffer analysis at 0–25 m, 25–50 m, 50–75 m, 75–100 m, and >100 m, and soil data were spatially adjusted to the study boundary. Land use/land cover was derived from Landsat-9 Collection 2 Level-2 imagery in Google Earth Engine. Image processing included temporal and spatial filtering, cloud masking using QA_PIXEL, median compositing, reflectance-scale transformation, selection of SR_B1–SR_B7 bands, and training-sample preparation. A supervised Classification and Regression Trees (CART) algorithm was then applied to generate the land-cover map, and classification performance was evaluated using a confusion matrix before the resulting map was incorporated into the flood-susceptibility analysis.

All six parameters were clipped to a common study boundary and reclassified into five classes, with scores ranging from 1 to 5 according to their relative contribution to flood susceptibility. The standardized spatial layers were subsequently integrated using a weighted-overlay analysis in ArcGIS. The total flood-susceptibility value was calculated using the following equation:

$$N = \Sigma (Si \times Bi)$$

where N represents the total flood-susceptibility value, Si represents the score assigned to the i-th parameter, and Bi represents the weight assigned to the i-th parameter. The resulting values were then classified into five levels of flood susceptibility: very low, low, moderate, high, and very high. The final analysis was conducted descriptively and spatially

by examining the area and geographic distribution of each susceptibility class across the 11 districts of Padang City. The resulting flood-susceptibility map was used to identify spatial patterns and areas with comparatively higher susceptibility to flooding.

RESULTS

1. Spatial Characteristics of Flood-Susceptibility Parameters

The flood-susceptibility analysis incorporated six spatial parameters: rainfall, distance from rivers, slope, elevation, soil type, and land use/land cover. Processing of rainfall observations from seven BMKG and PSDA stations for 2022–2024 produced average monthly rainfall values ranging from 109.83 to 425.40 mm. As presented in Figure 1, Rainfall Distribution Map of Padang City, rainfall was spatially distributed into five classes, ranging from very low to very high. The high-rainfall class occupied the largest area, covering 33,008.24 ha (49.31%), followed by the moderate class with 23,723.90 ha (35.44%). The very high rainfall class covered 6,380.85 ha (9.53%), whereas the low and very low classes accounted for 4.43% and 1.30%, respectively. Thus, approximately 84.75% of the mapped area fell within the moderate and high rainfall classes.

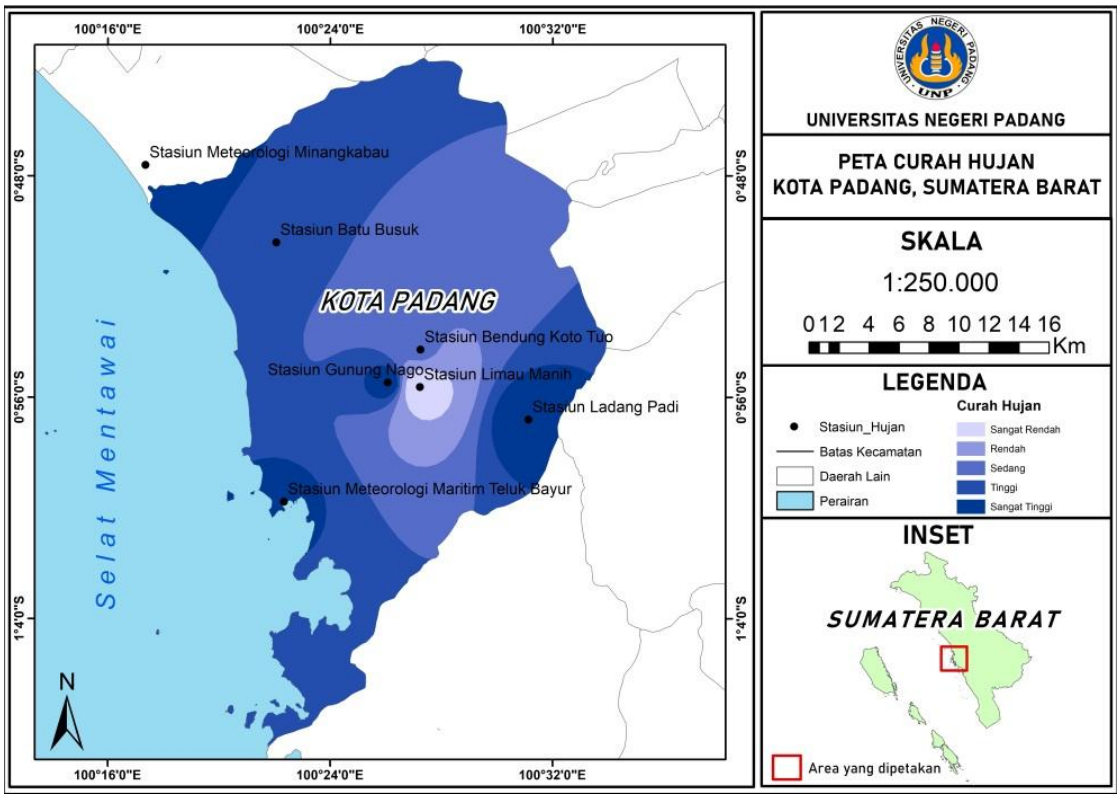


Figure 1. Rainfall Distribution Map of Padang City

The river-distance analysis divided the study area into five buffer zones: 0–25 m, 25–50 m, 50–75 m, 75–100 m, and >100 m. Figure 2, Distance from Rivers Map of Padang City, presents the spatial distribution of these classes. Areas located more than 100 m from a river accounted for the largest proportion, covering 28,097.35 ha (41.95%). Areas within 0–25 m of a river covered 11,353.44 ha (16.95%), while the 25–50 m zone occupied 10,654.15 ha (15.91%). The 50–75 m and 75–100 m classes represented 13.88% and 11.32%, respectively.

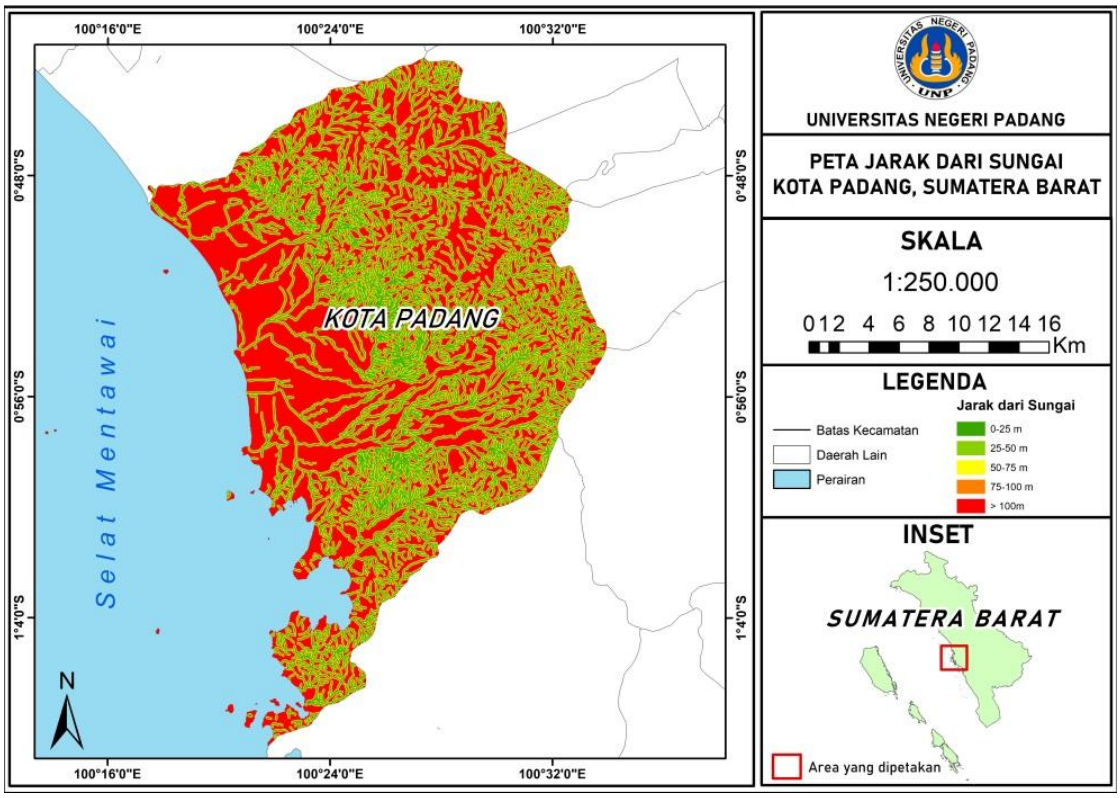


Figure 2. Distance from Rivers Map of Padang City

Topographic analysis identified substantial variation in slope and elevation across Padang City. As shown in Figure 3, Slope Map of Padang City, the steep slope class (25–45%) had the largest mapped area at 18,014.46 ha (26.47%), closely followed by the very steep class (>45%) at 17,200.54 ha (25.30%) and the moderately steep class (8–25%) at 16,345.30 ha (24.03%). Gentle slopes (3–8%) covered 17.59%, while flat areas (0–3%) accounted for 6.60%. Elevation patterns are presented in Figure 4, Elevation Map of Padang City. The 100–1,000 m elevation class was the most extensive, covering 35,627.63 ha (52.00%), followed by the 9–100 m class at 13,587.65 ha (19.83%). Areas above 1,000 m accounted for 16.25%, while elevations of 3–9 m and 0–3 m represented 7.95% and 3.97%, respectively.

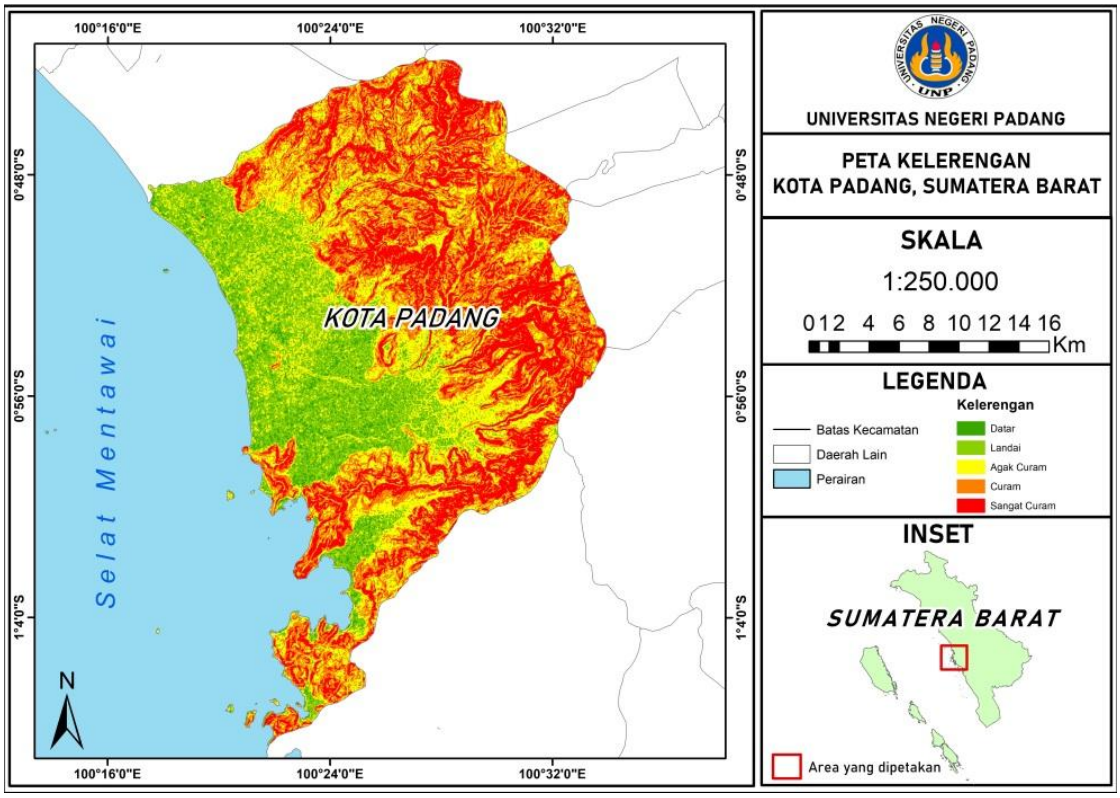


Figure 3. Slope Map of Padang City

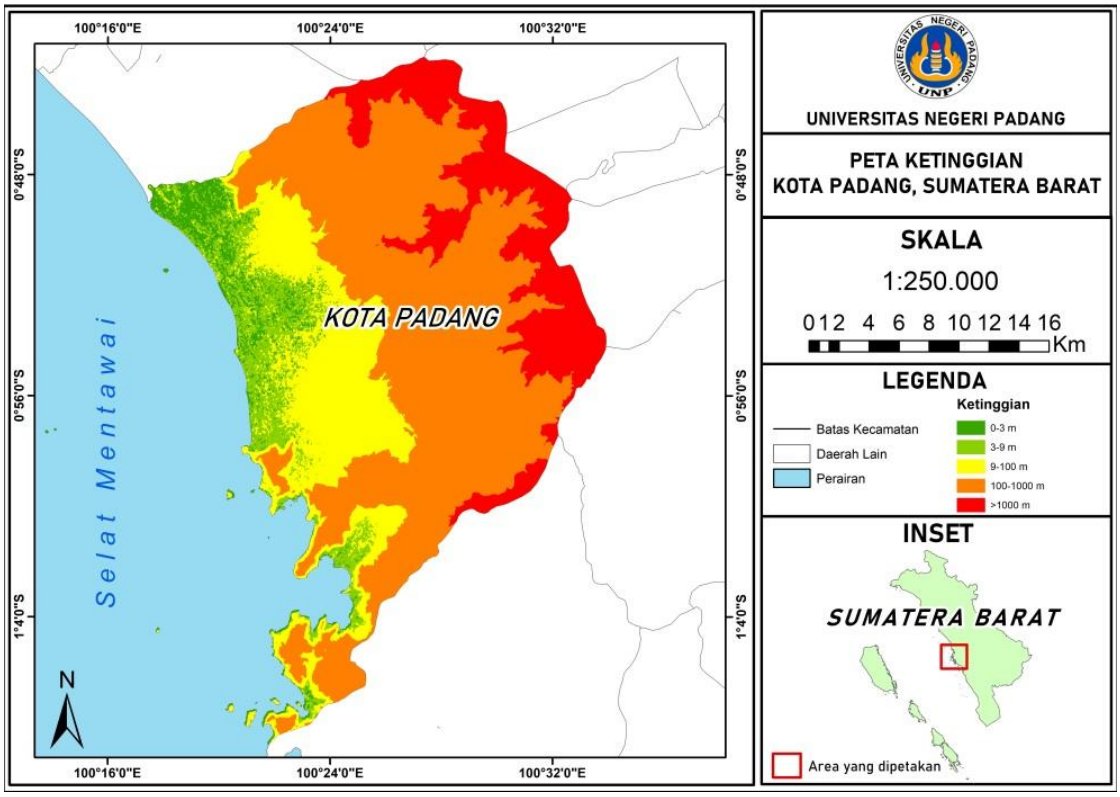


Figure 4. Elevation Map of Padang City

Soil mapping identified three soil types across the study area, as illustrated in Figure 5, Soil Type Map of Padang City. Dystric Cambisols constituted the dominant soil type, covering 43,002.80 ha (61.76%) of the mapped area. Humic Nitosols occupied 18,646.84 ha (26.78%), whereas Humic Andosols covered 7,973.85 ha (11.45%). The spatial extent of these soil classes was subsequently incorporated as one of the six layers used in the flood-susceptibility overlay.

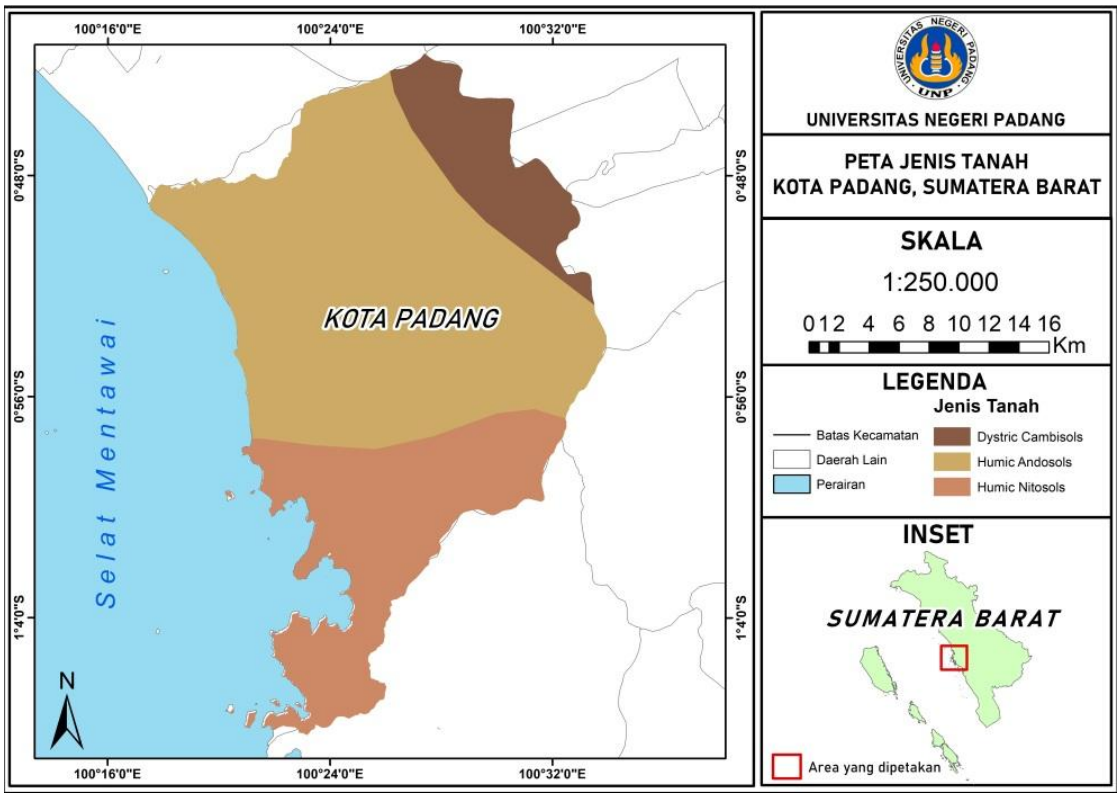


Figure 5. Soil Type Map of Padang City

2. Landsat-9 Land-Cover Classification

Land use/land cover was classified from Landsat-9 Collection 2 Level-2 imagery using the supervised Classification and Regression Trees (CART) algorithm in Google Earth Engine. Five land-cover classes were identified: agricultural land, water bodies, built-up land, forest, and open land. Validation using a confusion matrix produced an overall classification accuracy of 85.17%. Figure 6, Land Use/Land Cover Map of Padang City, shows the spatial distribution of the five classes. Forest was the dominant land-cover category, covering 44,140.77 ha (65.96%), followed by agricultural land at 13,806.86 ha (20.63%). Built-up land occupied 6,566.21 ha (9.81%), open land covered 2,074.23 ha (3.10%), and water bodies accounted for 348.36 ha (0.52%). The total area represented by the five classified land-cover categories was 66,936.43 ha.

Table 1. Distribution of Landsat-9 Land-Cover Classes in Padang City

Land-Cover Class	Area (ha)	Percentage (%)
Agricultural land	13,806.86	20.63
Water bodies	348.36	0.52
Built-up land	6,566.21	9.81
Forest	44,140.77	65.96
Open land	2,074.23	3.10
Total	66,936.43	100.00

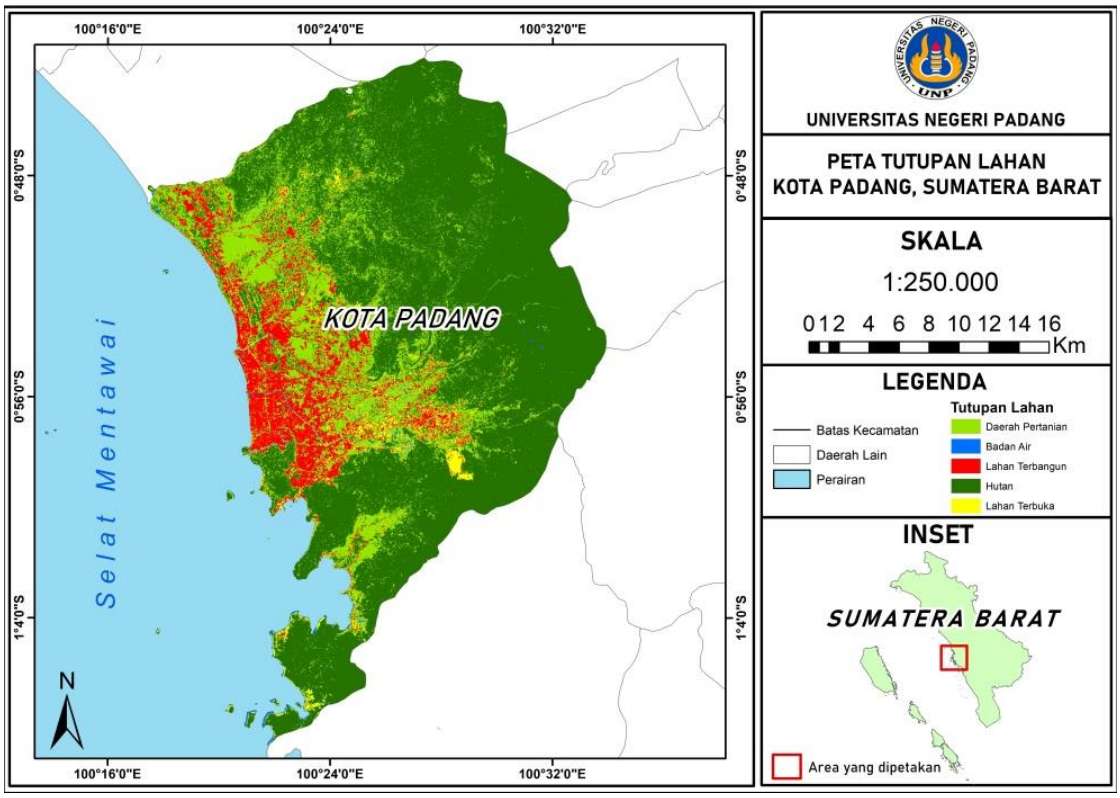


Figure 6. Land Use/Land Cover Map of Padang City

3. Classification of Flood Susceptibility

The six spatial parameters were integrated through scoring, weighting, and spatial overlay to produce the final flood-susceptibility classification. The observed composite values ranged from 0.60 to 5.80 and were divided into five classes: very low (0.60–1.64), low (>1.64–2.68), moderate (>2.68–3.72), high (>3.72–4.76), and very high (>4.76–5.80). The spatial distribution of these classes is presented in Figure 7, Flood-Susceptibility Map of Padang City, while their corresponding areas and percentages are summarized in Table 2.

Table 2. Flood-Susceptibility Classification in Padang City

Susceptibility Class	Composite Value	Area (ha)	Percentage (%)
Very low	0.60–1.64	31.048	0.05
Low	>1.64–2.68	17,226.524	25.72
Moderate	>2.68–3.72	30,675.414	45.79
High	>3.72–4.76	17,631.140	26.32
Very high	>4.76–5.80	1,420.275	2.12
Total	—	66,984.401	100.00

As shown in Table 2, the moderate-susceptibility class was the most extensive, covering 30,675.414 ha or 45.79% of the study area. The high-susceptibility class occupied 17,631.140 ha (26.32%), while the low-susceptibility class covered 17,226.524 ha (25.72%). The two extreme categories represented considerably smaller portions of the mapped area: the very high class covered 1,420.275 ha (2.12%), whereas the very low class occupied only 31.048 ha (0.05%). Moderate and high susceptibility together accounted for 48,306.554 ha (72.12%) of the study area. When the high and very high classes were considered together, they covered 19,051.415 ha, equivalent to approximately 28.44% of the classified area.

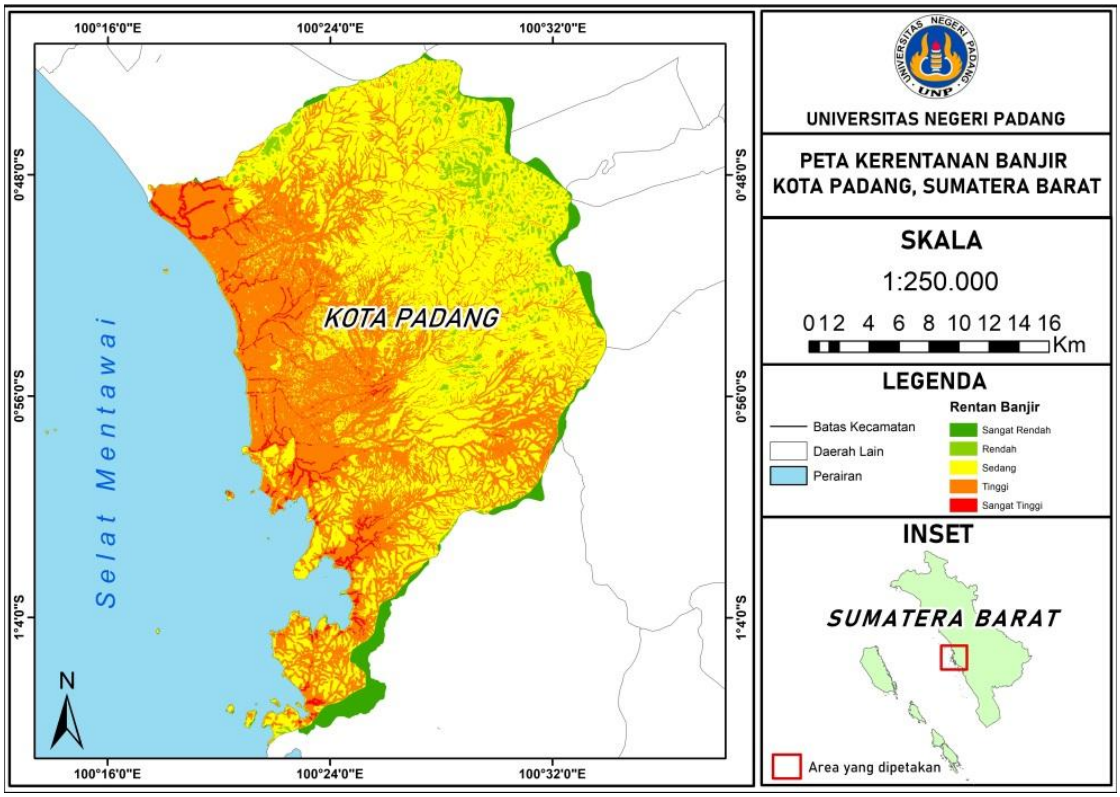


Figure 7. Flood-Susceptibility Map of Padang City

4. Spatial Distribution of Flood Susceptibility by District

The final susceptibility layer was intersected with the administrative boundaries of the 11 districts of Padang City to examine variations in the spatial distribution of the five susceptibility classes. Table 3, Distribution of Flood-Susceptibility Classes by District in Padang City, presents the area of each susceptibility class within each district. The results indicate considerable spatial variation among districts, with moderate and high susceptibility classes occurring extensively across the city.

Table 3. Distribution of Flood-Susceptibility Classes by District in Padang City

District	Very Low (ha)	Low (ha)	Moderate (ha)	High (ha)	Very High (ha)	Total (ha)
Bungus Teluk Kabung	5.273	972.958	4,992.543	1,983.119	222.237	8,176.130
Koto Tangah	9.613	6,719.804	8,546.626	6,129.343	567.591	21,972.977
Kuranji	0.000	431.946	2,072.308	2,600.743	50.898	5,155.896
Lubuk Begalung	0.152	161.105	1,395.782	1,265.880	135.907	2,958.826
Lubuk Kilangan	3.002	1,226.943	5,873.484	1,150.873	4.671	8,258.973
Nanggalo	0.000	0.000	97.760	785.922	44.622	928.304
Padang Barat	0.565	1.445	29.596	449.550	60.295	541.451
Padang Selatan	0.690	35.715	572.926	530.603	152.571	1,292.506
Padang Timur	0.000	0.000	52.489	746.979	57.396	856.864
Padang Utara	0.571	6.065	79.782	664.905	69.971	821.294
Pauh	11.183	7,670.542	6,962.119	1,323.222	54.114	16,021.179

Koto Tangah recorded the largest absolute area in the high-susceptibility class, reaching 6,129.343 ha, followed by Kuranji (2,600.743 ha) and Bungus Teluk Kabung (1,983.119 ha). Koto Tangah also had the largest moderate-susceptibility area at 8,546.626 ha, followed by Pauh (6,962.119 ha) and Lubuk Kilangan (5,873.484 ha). These figures represent absolute areas and should therefore be distinguished from the proportional distribution within each district.

The very high-susceptibility class was present in all 11 districts, although its extent varied substantially. Koto Tangah had the largest absolute very high-susceptibility area at 567.591 ha, followed by Bungus Teluk Kabung (222.237 ha), Padang Selatan (152.571 ha), and Lubuk Begalung (135.907 ha). At the other end of the classification, the very low-susceptibility class accounted for only 31.048 ha citywide and was absent from Kuranji, Nanggalo, and Padang Timur. The low-susceptibility class was most extensive in Pauh (7,670.542 ha) and Koto Tangah (6,719.804 ha), while no area classified as low was recorded

in Nanggalo or Padang Timur. Overall, the district-level results demonstrate that flood susceptibility was spatially heterogeneous, with different susceptibility classes occurring within the same administrative areas rather than forming a uniform district-wide pattern.

DISCUSSION

The spatial classification demonstrates that flood susceptibility in Padang City is not evenly distributed across the urban landscape. The moderate class accounts for the largest proportion of the study area (45.79%), followed by the high class (26.32%), while 2.12% is classified as very highly susceptible. Taken together, the moderate and high classes cover 72.12% of the mapped area. This pattern suggests that flood susceptibility in Padang is better understood as a spatial continuum than as a condition confined to a small number of isolated locations. The city contains coastal lowlands, river corridors, developed urban areas, and higher terrain within the same administrative boundary, allowing combinations of rainfall, elevation, slope, river proximity, soil characteristics, and land cover to produce different susceptibility levels across relatively short distances. Such spatial heterogeneity reinforces the importance of assessing multiple environmental factors simultaneously rather than treating rainfall or any other single parameter as a sufficient indicator of flood susceptibility.

The distribution of the individual parameters provides further insight into the resulting susceptibility pattern. Most of the mapped area falls within moderate and high rainfall classes, while areas located close to rivers remain distributed throughout several parts of the city. Elevation and slope vary markedly, reflecting the transition between the relatively low-lying western urban and coastal areas and the higher terrain toward the eastern part of Padang. These physical differences influence where water is likely to accumulate or move across the landscape. Similar relationships have been reported in GIS-based flood studies in Indonesia. Romadhon & Aziz (2022), for example, found that highly susceptible areas in Semarang were associated with low elevations, flat slopes, proximity to rivers, and settlement-dominated land use. Ismanto et al. (2023) likewise incorporated elevation, slope, rainfall, river distance, soil type, and land use/land cover when mapping flood susceptibility in Sumedang. The convergence of these parameters across different geographic settings indicates that flood susceptibility emerges from interactions among terrain, hydrological proximity, surface characteristics, and rainfall rather than from an individual environmental condition.

Land cover adds an important surface dimension to this interaction. The Landsat-9 classification indicates that forest remains the dominant mapped land-cover class (65.96%), followed by agricultural land (20.63%), while built-up land accounts for 9.81%. The CART classification achieved an overall accuracy of 85.17%, providing a reasonably strong basis for incorporating the classified land-cover layer into the susceptibility model. Land-cover composition is relevant because different surfaces regulate rainfall differently: vegetated areas generally provide greater opportunities for interception and infiltration, whereas impervious urban surfaces can accelerate runoff when rainfall exceeds drainage capacity. The importance of land use/land cover within flood-susceptibility modeling is also evident in previous research. GIS-based studies have repeatedly included land cover alongside rainfall, slope, elevation, soil, and hydrological variables because changes in surface characteristics modify how water is retained or transferred across the landscape (Romadhon & Aziz, 2022; Saffitri & Ashar, 2023).

The district-level results reveal a more detailed pattern that would be obscured if susceptibility were interpreted only at the city scale. Koto Tangah contains the largest absolute area classified as highly susceptible (6,129.343 ha) and also the largest very highly susceptible area (567.591 ha). Kuranji and Bungus Teluk Kabung also contain substantial high-susceptibility areas. This pattern partly corresponds with the findings of Darmawan et al. (2023), whose GIS-based Composite Mapping Analysis identified the northern part of Padang, including Koto Tangah, Nanggalo, and Padang Utara, as having particularly high flood susceptibility. Their study combined rainfall, slope, land cover, and soil type, whereas the present study extends the spatial characterization by incorporating elevation and distance from rivers in addition to these parameters. Despite differences in parameter configuration, both analyses indicate that flood susceptibility within Padang varies substantially among and within districts.

The findings also correspond with the temporal analysis conducted by Mulia and Handayani (2024). Their comparison of flood susceptibility in Padang between 2011 and 2022 showed that highly susceptible areas increased and expanded beyond the western urban area toward the northern, southern, and eastern parts of the city. Their model incorporated slope, rainfall, distance from rivers, land cover, and soil type. The present results similarly show that moderate, high, and very high susceptibility classes are distributed across multiple districts rather than being restricted to a single section of Padang. The similarity between these spatial patterns is noteworthy because the present study derives its land-cover

information from Landsat-9 and integrates six conditioning parameters. Together, the findings suggest that flood susceptibility in Padang should not be conceptualized solely as a coastal or western-city problem; susceptible zones occur across administrative boundaries and reflect different combinations of environmental conditions.

A comparable pattern has also been documented outside Padang. A GIS-based multi-criteria assessment in Kathmandu found that 56% of the study area was classified as having moderate flood potential and 32% as high flood potential, with river distance, rainfall, and land use/land cover among the influential criteria. Research in eastern India similarly identified highly susceptible areas particularly along river corridors when rainfall, elevation, slope, river distance, land use/land cover, soil, and other environmental variables were analyzed together. These comparisons do not imply that flood processes are identical across cities. Rather, they support the broader observation that multi-criteria spatial analysis can reveal susceptibility patterns that arise from locally specific combinations of topographic, hydrological, and land-surface conditions.

The findings have practical implications for disaster mitigation and urban planning in Padang City. The presence of moderate-to-high susceptibility across a large proportion of the mapped area indicates that flood mitigation should not focus exclusively on locations categorized as very highly susceptible. The very high class occupies only 2.12% of the city, but the much broader moderate and high zones represent areas where changing rainfall, drainage performance, river conditions, or land development may still create meaningful exposure. Districts such as Koto Tangah require particular attention because of the large absolute extent of high and very high susceptibility zones. At the same time, district size needs to be considered carefully; a larger susceptible area does not necessarily mean that the entire district experiences the same level of susceptibility. Spatially detailed maps are therefore more useful for local planning than district-wide labels because they can help identify specific zones where land-use control, drainage improvement, river management, preparedness measures, and evacuation planning may be prioritized.

The study also contributes methodologically by demonstrating how Landsat-9-derived land-cover information can be combined with rainfall, elevation, slope, river proximity, and soil characteristics within a GIS-based susceptibility framework. Landsat-9 allows recent land-surface conditions to be represented spatially, while GIS provides a common analytical environment in which datasets with different physical meanings can be

standardized and integrated. This approach complements earlier Padang studies rather than replacing them. Darmawan et al. (2023) used four principal parameters, while Mulia & Handayani (2024) incorporated five factors in their GIS analysis. The present six-parameter configuration offers another representation of the city's physical susceptibility and emphasizes the value of integrating satellite-derived land-cover data with topographic, hydrological, climatic, and soil information.

Several limitations should be considered when interpreting these findings. First, the resulting map represents flood susceptibility rather than direct observations of flood occurrence or flood depth. A location classified as highly or very highly susceptible should therefore not be interpreted as a location that will inevitably experience flooding. Second, the analysis depends on the spatial resolution, temporal coverage, classification accuracy, and quality of the input datasets. Although the Landsat-9 land-cover classification achieved an overall accuracy of 85.17%, classification errors may still influence the subsequent overlay. Third, rainfall was represented using observations from 2022–2024, meaning that longer-term climatic variability and individual extreme rainfall events were not explicitly modeled. The susceptibility model also does not directly simulate discharge, drainage capacity, flood depth, duration, or flow velocity. Model validation against historical flood inventories or independently observed inundation data would further strengthen confidence in the resulting susceptibility classes. Previous research has demonstrated the value of validating GIS-based susceptibility models using observed flood locations or remotely sensed flood extents (Ismanto et al., 2023). Future research could therefore integrate longer rainfall records, historical flood inventories, higher-resolution elevation and land-cover data, drainage-network characteristics, and hydrological or hydraulic modeling to provide a more comprehensive representation of flood processes in Padang City.

CONCLUSION

Based on the research findings and discussion, this study concludes that flood susceptibility in Padang City is spatially heterogeneous and reflects the combined influence of rainfall, elevation, slope, distance from rivers, soil type, and land use/land cover. The integration of these six parameters through GIS-based spatial analysis produced five susceptibility classes: very low, low, moderate, high, and very high. The moderate-susceptibility class occupied the largest area, covering 30,675.414 ha (45.79%), whereas the

very low class accounted for only 31.048 ha (0.05%). At the district level, Koto Tangah had the largest absolute area classified as highly susceptible, while Pauh had the largest area within the low-susceptibility class. Land-cover information derived from Landsat-9 imagery using the CART algorithm achieved an overall accuracy of 85.17%, providing an adequate spatial dataset for integration with the other flood-conditioning parameters.

The resulting flood-susceptibility map provides a spatial representation of areas that require different levels of attention in flood mitigation and land-use planning in Padang City. The findings should, however, be interpreted as a classification of susceptibility based on the environmental parameters included in the model rather than as a direct prediction of actual flood occurrence, depth, or duration. Future studies should therefore incorporate historical flood records and field-based validation to examine the correspondence between the modeled susceptibility classes and observed flood events. The use of updated environmental parameters, higher-resolution spatial data, longer rainfall records, and more detailed information on drainage conditions would also strengthen future assessments and support more locally responsive flood-risk reduction strategies.

REFERENCES

Anderson, C. C., Denich, M., Warchold, A., Kropp, J. P., & Pradhan, P. (2022). A systems model of SDG target influence on the 2030 Agenda for Sustainable Development. *Sustainability Science, 17*(4), 1459–1472. https://doi.org/10.1007/s11625-021-01040-8

Darmawan, R. R. (2024, May 23). *[Update] Satu Warga Agam Ditemukan, Total Korban Meninggal Galodo Sumbar 62 Orang*. Badan Nasional Penanggulangan Bencana. https://www.bnpb.go.id/berita/update-satu-warga-agam-ditemukan-total-korban-meninggal-galodo-sumbar-62-orang

Darmawan, Y., Mashuri, I., Jumansa, M. A., Aslam, F. M., & Azzahra, A. (2023). Analisis Daerah Rawan Banjir dengan Metode Composite Mapping Analysis (CMA) di Kota Padang. *Geomatika, 29*(2), 89–98. https://www.big.go.id/uploads/content/produk/Geomatika/Vol29.2/JIGVol29No2.2023.pdf

Fahmi, L. A. (2021). *Pemetaan Daerah Rawan Banjir Wilayah Kota Padang Menggunakan Sistem Informasi Geografis (SIG)* [Undergraduate thesis, IPB University]. IPB University Repository. https://repository.ipb.ac.id/handle/123456789/108808

Fajri, A. S., & Widayanti, B. H. (2018). Analisis Kerentanan Daerah Rawan Banjir Berbasis Sistem Informasi Geografis (Studi Kasus: Kecamatan Sekarbela–Kota Mataram). *Jurnal Planoearth, 3*(1), 36–43. https://doi.org/10.31764/jpe.v3i1.218

Gorelick, N., Hancher, M., Dixon, M., Ilyushchenko, S., Thau, D., & Moore, R. (2017). Google Earth Engine: Planetary-scale geospatial analysis for everyone. *Remote Sensing of Environment, 202*, 18–27. https://doi.org/10.1016/j.rse.2017.06.031

Hidayatullah, S., Daoed, D., Nurhamidah, N., & Nifen, S. Y. (2023). Analisis Kerentanan dan Rawan Banjir DAS Batang Kuranji Kota Padang. *CIVED, 10*(1), 110–117. https://doi.org/10.24036/cived.v10i1.122344

Intergovernmental Panel on Climate Change. (2022). *Climate change 2022: Impacts, adaptation and vulnerability*. Cambridge University Press. https://doi.org/10.1017/9781009325844

Ismanto, R. D., Fitriana, H. L., Manalu, J., Purboyo, A. A., & Prasasti, I. (2023). Development of flood-hazard-mapping model using random forest and frequency ratio in Sumedang Regency, West Java, Indonesia. *Geomatics and Environmental Engineering, 17*(6), 129–157. https://doi.org/10.7494/geom.2023.17.6.129

Krisnandi, R., & Prabowo, A. (2021). Utilization of Landsat 8 imagery and DEM data to determine the level of vulnerability and mitigation of rob floods in the Pekalongan region, Central Java. In *Prosiding Seminar Nasional ReTII Ke-16* (pp. 408–416). https://journal.itny.ac.id/index.php/ReTII/article/view/2625

Matondang, J. P., Kahar, S., & Sasmito, B. (2013). Analisis Zonasi Daerah Rentan Banjir dengan Pemanfaatan Sistem Informasi Geografis (Studi Kasus: Kota Kendal dan Sekitarnya). *Jurnal Geodesi Undip, 2*(2). https://ejournal3.undip.ac.id/index.php/geodesi/article/view/2442

Millat-e-Mustafa, M. (2025). Rethinking flood management strategies: Addressing frequently overlooked challenges for enhanced community resilience and effective risk reduction. *International Journal for Humanitarian Studies, 6*(3), 5–17. https://doi.org/10.4103/JAHS_20250603_5

Mulia, F. A., & Handayani, W. (2024). Pemanfaatan Sistem Informasi Geografis untuk Pemetaan Kerawanan Bencana Banjir Kota Padang Tahun 2011–2022. *Geoid, 19*(2), 192–201. https://doi.org/10.12962/geoid.v19i2.1205

Rasyda, M. H., Widada, S., & Rochaddi, B. (2015). Analisa Spasial Daerah Banjir Genangan (Rob) Akibat Kenaikan Muka Air Laut di Kota Padang. *Journal of Oceanography, 4*(2), 379–385. https://ejournal3.undip.ac.id/index.php/joce/article/view/8382

Romadhon, M. R., & Aziz, A. (2022). Determination of flood susceptibility index using overlay-scoring data method based on geographic information system (GIS) in Semarang City, Central Java, Indonesia. *AgriHealth: Journal of Agri-Food, Nutrition and Public Health, 3*(2), 104–123. https://doi.org/10.20961/agrihealth.v3i2.60451

Saffitri, V., & Ashar, F. (2023). Pemetaan dan Analisis Daerah Rawan Banjir di Kota Padang. *Jurnal Applied Science in Civil Engineering, 4*(1), 83–89. https://asce.ppj.unp.ac.id/index.php/ASCE/article/view/332/

Samanta, S., Pal, D. K., & Palsamanta, B. (2018). Flood susceptibility analysis through remote sensing, GIS and frequency ratio model. *Applied Water Science, 8*(2), Article 66. https://doi.org/10.1007/s13201-018-0710-1

Shah, A. A., Ullah, W., Khan, N. A., Khan, A., Alotaibi, B. A., Alam, E., & Ullah, A. (2025). Health and livelihood impacts of flood hazards on internally displaced persons in Pakistan. *International Journal of Disaster Risk Reduction, 119*, Article 105295. https://doi.org/10.1016/j.ijdrr.2025.105295

Shekar, P. R., & Mathew, A. (2023). Flood susceptibility mapping of the Peddavagu River Basin using GIS-AHP techniques. In K.-S. Kasiviswanathan, B.-S. Soundharajan, S. Patidar, J. He, & C. S. P. Ojha (Eds.), *Modeling and mitigation measures for managing extreme hydrometeorological events under a warming climate* (Vol. 14, pp. 125–141). Elsevier. https://doi.org/10.1016/B978-0-443-18640-0.00011-0

Sukenti, D., Tambak, S., Fabria, R., Siregar, E. P., & Shomary, S. (2026). Analisis Kebutuhan Model Penilaian Menulis Berbasis STEM untuk Meningkatkan Keterampilan Berpikir Kritis Mahasiswa. *GERAM (Gerakan Aktif Menulis), 14*(2), 317–332. https://doi.org/10.25299/geram.2026.28168

U.S. Geological Survey. (2022). *Landsat 9*. https://www.usgs.gov/landsat-missions/landsat-9