



GIS-Based Flood Risk Mapping in Kluet Tengah Subdistrict, South Aceh

Helmi Hasan Basri^{1*}, Bakruddin B²

^{1,2} Sekolah Tinggi Ilmu Kehutanan Pante Kulu, Provinsi Aceh, Indonesia

¹helmiusi@gmail.com, ²bakry.klt@gmail.com



*Corresponding Author

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ABSTRACT

Flooding is one of the most frequent hydrometeorological disasters in South Aceh Regency, particularly in Kluet Tengah Subdistrict, where overflow from the Menggamat River causes recurrent inundation of settlements, agricultural areas, and other land uses. This study aims to map flood risk spatially in Kluet Tengah Subdistrict using a Geographic Information System (GIS)-based overlay approach. The analysis was conducted using land cover and slope parameters derived from satellite imagery, Digital Elevation Model (DEM) data, and supporting records of flood events from relevant disaster management agencies. Spatial data were processed through clipping, classification, and overlay analysis to produce flood risk categories. The results show that high-risk areas are concentrated in lowland zones with flat to gentle slopes (0–30%), particularly in settlements, rice fields, and open land. Moderate-risk areas are associated with moderately steep slopes (30–50%) dominated by mixed gardens and shrubland, while low-risk areas are mainly located in steep to very steep uplands (>50%) covered by protected forest and the Gunung Leuser National Park area. These findings indicate that the interaction between land cover and slope plays an important role in shaping flood risk distribution in the study area. The resulting flood risk map can support spatial planning, disaster mitigation, and sustainable land management in flood-prone regions of South Aceh.

INTRODUCTION

Flooding is one of the most frequent hydrometeorological disasters in Indonesia and continues to pose serious environmental, social, and economic challenges. National disaster records indicate that floods remain among the most common disaster events, affecting settlements, infrastructure, agricultural land, and community livelihoods in many regions of the country (Badan Nasional Penanggulangan Bencana [BNPB], 2021). In South Aceh Regency, one of the flood-prone areas is Kluet Tengah Subdistrict, where overflow of the Menggamat River frequently inundates settlements, agricultural land, and public infrastructure. These flood events occur almost every year, particularly during periods of intense rainfall, and often disrupt local livelihoods and regional economic activities (Aceh Disaster Management Agency, 2025; South Aceh Regional Disaster Management Agency, 2024). News coverage has also documented flood inundation in Kluet Tengah, further confirming the recurring nature of flood impacts in the area (Kanal Aceh, 2024).

Kluet Tengah Subdistrict is characterized by diverse land cover and topographic conditions, ranging from lowland settlements and agricultural areas to protected forest and mountainous terrain in the upper catchment. These physical characteristics strongly influence hydrological processes, particularly infiltration, runoff, and the accumulation of surface water. Low-lying areas with flat to gentle slopes are generally more susceptible to flooding because water tends to accumulate more easily, while upland forested areas often function as natural hydrological buffers that reduce runoff and help maintain watershed stability (Nguyen et al., 2023; Sima et al., 2021). Therefore, understanding the spatial relationship between land cover and slope is essential for identifying flood-prone zones and supporting more effective flood mitigation in the study area.

The impacts of flooding in Kluet Tengah extend beyond temporary inundation. Recurrent flood events can damage houses, transportation networks, drainage systems, and agricultural fields, while also reducing land productivity and increasing the vulnerability of local communities. In areas where settlements and productive land are concentrated in floodplains, the absence of spatially explicit flood information may hinder effective mitigation planning and land-use management (Susilo et al., 2020; Zahra & Rahmawati, 2021). This condition highlights the need for flood risk mapping as an evidence-based tool to support local decision-making, particularly in regions where flood events repeatedly affect both human activities and environmental resources.

Geographic Information System (GIS) technology has been widely applied in flood-related studies because it enables the integration, analysis, and visualization of spatial data from multiple environmental parameters. GIS-based approaches are particularly useful for identifying flood-prone areas, analyzing the spatial distribution of hazard, and supporting disaster risk reduction planning (Nguyen et al., 2023; Zahra & Rahmawati, 2021). Previous studies have shown that factors such as land cover, slope, rainfall, and topographic conditions play important roles in shaping flood susceptibility and flood risk patterns (Sima et al., 2021; Susilo et al., 2020). In this context, GIS provides a practical and





efficient framework for assessing flood risk at the local scale.

Several previous studies have highlighted the importance of spatial analysis in flood assessment. Nguyen et al. (2023) demonstrated that geospatial modeling can effectively assess flood impacts in agricultural landscapes and support adaptation strategies. Sima et al. (2021) emphasized the importance of spatial flood risk estimation in reducing potential losses in rural areas. In Indonesia, Susilo et al. (2020) showed that hydrological extremes such as floods and droughts significantly increase rural vulnerability, while Zahra and Rahmawati (2021) underlined the relevance of GIS-based flood hazard modeling in Aceh Province. These studies confirm that spatial approaches are valuable for understanding flood dynamics and for designing mitigation measures suited to local environmental conditions.

Despite the growing use of GIS in flood studies, spatially explicit flood risk mapping for Kluet Tengah Subdistrict remains limited. Most available information on floods in the area is still descriptive and event-based, relying mainly on disaster reports and news coverage rather than integrated spatial assessment (BNPB, 2021; Kanal Aceh, 2024; Aceh Disaster Management Agency, 2025). As a result, there is still limited understanding of how land cover and topographic conditions shape the spatial distribution of flood-prone areas in the subdistrict. This study addresses that gap by applying a GIS-based overlay analysis using land cover and slope data to map flood risk in Kluet Tengah Subdistrict, South Aceh.

This study aims to analyze and map the spatial distribution of flood risk in Kluet Tengah Subdistrict using a GIS approach based on land cover and slope parameters. The resulting flood risk map is expected to provide useful information for disaster mitigation, land-use planning, and sustainable environmental management in flood-prone areas of South Aceh.

METHODS

Study Area

This study was conducted in Kluet Tengah Subdistrict, South Aceh Regency, Aceh Province, Indonesia. The area was selected because it frequently experiences flooding caused by overflow of the Menggamat River, particularly during periods of high rainfall. Kluet Tengah has diverse topographic and land cover characteristics, ranging from lowland settlements and agricultural areas to protected forest and mountainous terrain. These conditions make the subdistrict suitable for spatial analysis of flood risk using Geographic Information System (GIS) techniques.

Data Sources

This study used both spatial and non-spatial data.

- Spatial data included:
 - Administrative boundary map of Kluet Tengah Subdistrict;
 - Land cover data derived from medium-resolution satellite imagery (Landsat 8/OLI and Sentinel-2);
 - Digital Elevation Model (DEM) data for slope analysis;
 - River network and topographic base map; and
 - Supporting spatial information related to flood occurrence.
- Non-spatial data included:
 - Historical flood event records obtained from the Regional Disaster Management Agency (BPBD) of South Aceh and the Aceh Disaster Management Agency (BPBA);
 - Rainfall data from BMKG Tapaktuan; and
 - Secondary references relevant to flood conditions in the study area.

The spatial datasets were used as the main basis for flood risk mapping, while rainfall and flood event records were used as supporting information to strengthen the interpretation of the spatial analysis.

Software and Tools

The spatial analysis was carried out using ArcGIS 10.8, while image interpretation and supporting data processing were conducted using ENVI 5.6. These tools were used for image processing, slope derivation, spatial classification, and overlay analysis.

Research Procedure

The research was conducted through several stages, as follows:

- Data Preparation
All spatial data were collected and prepared in a consistent coordinate system. The datasets were then clipped to the administrative boundary of Kluet Tengah Subdistrict in order to ensure that all analyses were limited to the study area.
- Land Cover Classification
Land cover data were classified into several categories representing the dominant surface conditions in the study





area, including protected forest, mixed gardens, shrubland, open land, settlements, rice fields, water bodies, and the Gunung Leuser National Park area. This classification was used to identify surface characteristics that may influence infiltration and runoff processes.

- Slope Analysis

Slope data were derived from DEM data using the slope analysis function in GIS. The resulting slope values were classified into five classes: flat (0–15%), gentle (15–30%), moderately steep (30–50%), steep (50–70%), and very steep (>70%). These classes were used to represent topographic conditions related to the potential accumulation or flow of surface water.

- Overlay Analysis

Flood risk mapping was carried out using a spatial overlay between land cover and slope maps. This overlay approach was used to identify areas with different levels of flood risk based on the interaction between surface conditions and terrain characteristics. In general, areas with low infiltration capacity and flat to gentle slopes were interpreted as having higher flood risk, while forested areas on steep slopes were interpreted as having lower flood risk.

- Flood Risk Classification

The flood risk level was classified into three categories: low, moderate, and high. High-risk areas were associated with lowland land cover types such as settlements, rice fields, and open land located on flat to gentle slopes. Moderate-risk areas were associated with mixed gardens and shrubland on moderately steep slopes. Low-risk areas were generally found in protected forest and upland areas with steep to very steep slopes.

Data Analysis

The analysis in this study was descriptive-quantitative and spatial in nature. The output of the analysis was a flood risk map showing the spatial distribution of low, moderate, and high flood risk areas in Kluet Tengah Subdistrict. The resulting map was then interpreted to explain the relationship between topographic characteristics, land cover, and flood risk distribution across the study area.

RESULTS

Land Cover Distribution

The land cover analysis indicates that Kluet Tengah Subdistrict is dominated by protected forest and the Gunung Leuser National Park area, particularly in the upstream and mountainous parts of the region. These areas are characterized by dense vegetation cover, which contributes to higher infiltration capacity and better hydrological function. In contrast, settlements, rice fields, mixed gardens, shrubland, and open land are generally concentrated in the lower and more accessible parts of the subdistrict, especially along the Menggamat River corridor.

This spatial pattern shows a clear contrast between upstream conservation areas and downstream productive and inhabited land. Forested areas tend to reduce surface runoff, while built-up and cultivated land cover types are more likely to increase water accumulation, particularly during periods of heavy rainfall. The distribution of land cover in the study area is presented in Figure 1.

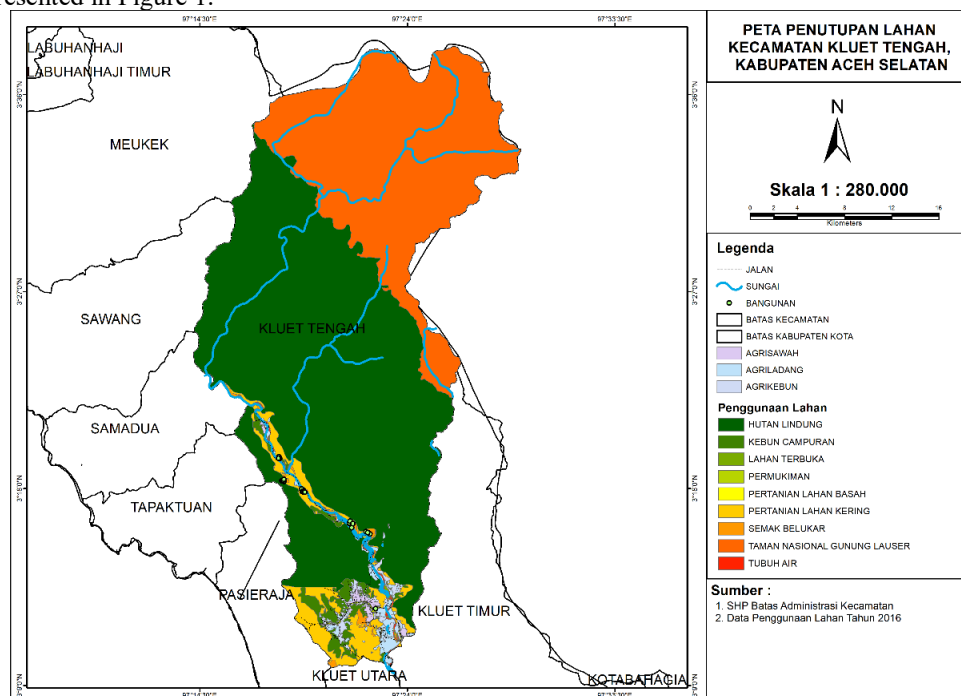


Figure 1. Land Cover Map of Kluet Tengah Subdistrict





Slope Characteristics

The slope analysis shows that the topography of Kluet Tengah Subdistrict is highly variable. Approximately 40% of the study area consists of flat to gentle slopes (0–30%), 35% is classified as moderately steep (30–50%), and 25% falls within steep to very steep categories (>50%). Flat to gentle slopes are mainly found in riverine lowlands and valley areas, while steeper slopes are concentrated in the upstream and mountainous zones.

These topographic differences influence the spatial distribution of flood-prone areas. Low-gradient terrain tends to facilitate water accumulation and inundation, whereas steeper terrain generally promotes runoff and reduces the duration of water retention on the land surface. The slope distribution of the study area is shown in Figure 2

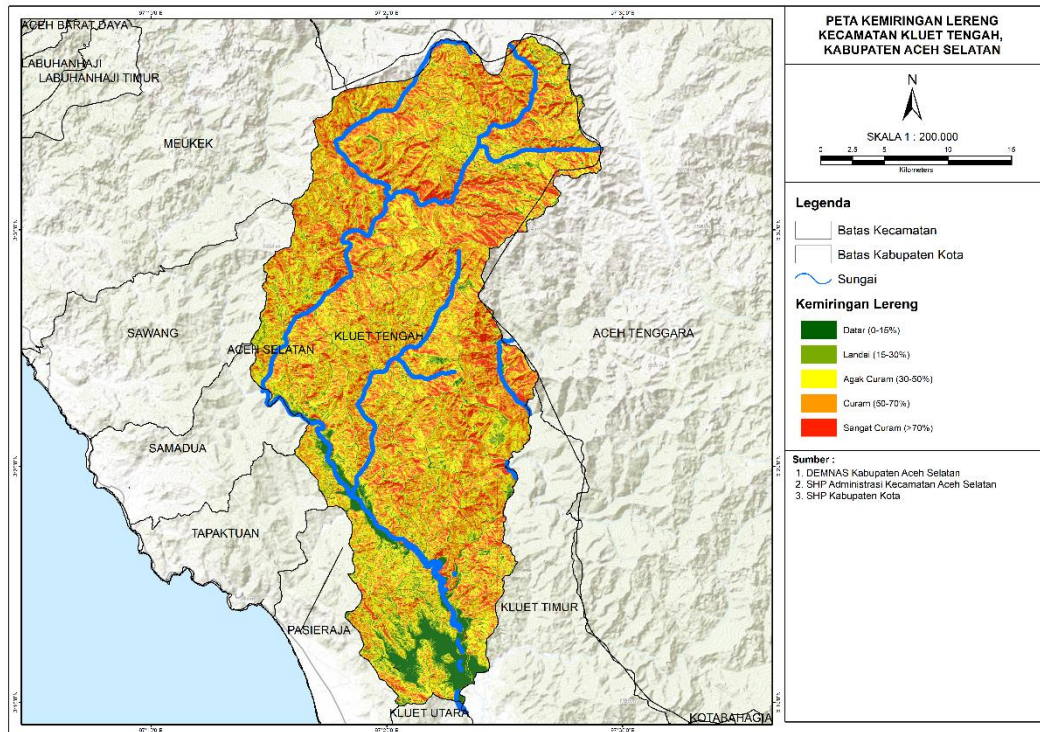


Figure 2. Slope gradient map of Kluet Tengah Subdistrict

Flood Risk Distribution

The overlay of land cover and slope maps produced three categories of flood risk: high, moderate, and low. The results show that high-risk areas account for 25% of the total area, moderate-risk areas cover 45%, and low-risk areas represent 30%.

High-risk areas are concentrated in lowland zones with flat to gentle slopes and are dominated by settlements, rice fields, and open land. These areas are considered more vulnerable because they have lower infiltration capacity and are more likely to experience water accumulation during periods of intense rainfall or river overflow. Moderate-risk areas are mostly located on moderately steep slopes and are associated with mixed gardens and shrubland, where runoff can still occur but water accumulation is less intensive than in lowland areas. Low-risk areas are mainly found in steep to very steep uplands dominated by protected forest and the Gunung Leuser National Park area, where dense vegetation cover helps maintain hydrological stability.

Overall, the results indicate that flood risk in Kluet Tengah Subdistrict is spatially concentrated in low-lying and intensively used areas, while upland forested regions tend to have lower flood susceptibility. The while the summary of flood risk categories is shown in Table 1.

Table 1. Flood Risk Distribution in Kluet Tengah Subdistrict

Risk Category	Percentage of Area	Main Characteristics	Dominant Land Cover
High	25	Located on flat–gentle slopes (0–30%) with low infiltration capacity	Residential areas, rice fields, open land
Moderate	45	Residential areas, rice fields, open land Moderately steep slopes (30–50%); partially capable of retaining runoff but still prone to flooding	Mixed gardens, scrub
Low	30	Steep–very steep slopes (>50%) with dense vegetation that maintains hydrological functions	Protected forest, Gunung Lauser National Park





The classification shows that flood risk is strongly associated with the combined influence of land cover and slope. Areas with more intensive land use in lowland terrain tend to experience higher risk, while vegetated uplands show lower susceptibility to flooding.

DISCUSSION

The results of this study indicate that flood risk in Kluet Tengah Subdistrict is strongly shaped by the interaction between land cover and slope. Areas located in lowland zones with flat to gentle slopes were classified as having higher flood risk, particularly where settlements, rice fields, and open land are concentrated. This pattern is consistent with recent studies showing that low-gradient terrain tends to favor water accumulation, especially when combined with land uses that reduce infiltration and increase surface runoff (Ashfaq et al., 2025; Husein et al., 2025).

Topographic conditions are a key factor in explaining this spatial pattern. Flat and gently sloping areas generally retain runoff longer than steeper terrain, making them more prone to inundation when rainfall intensifies or river discharge exceeds channel capacity. Recent studies have identified slope as one of the most influential factors in flood-susceptibility mapping, often alongside elevation, rainfall, drainage density, and distance from rivers (Ashfaq et al., 2025; Islam et al., 2025). In this context, the concentration of high-risk zones in the lowlands of Kluet Tengah reflects the hydrological tendency of low-relief terrain to collect and retain water.

Land cover also plays an important role in determining flood risk distribution. Settlements, open land, and cultivated areas generally have lower infiltration capacity than forested land, so they are more vulnerable to standing water during periods of intense rainfall or river overflow. By contrast, protected forest and the Gunung Leuser National Park area in the uplands help reduce runoff and maintain watershed stability. This interpretation is in line with recent studies emphasizing that land-use change, built-up expansion, and the reduction of vegetated cover are closely associated with increasing flood susceptibility, while vegetation cover contributes to water retention and infiltration (Giofandi et al., 2024; Handyastono et al., 2025).

The contrast between upstream forested areas and downstream inhabited or cultivated land also has an important watershed-management implication. The upper catchment functions as a hydrological buffer, whereas the downstream lowlands face greater flood exposure because they are more intensively used for settlement and production. Similar spatial relationships have been reported in recent Indonesian and international studies, where cultivated and urban-use zones tend to overlap with moderate to high flood susceptibility classes, creating challenges for land-use planning and disaster mitigation (Giofandi et al., 2026; Handyastono et al., 2025). Therefore, maintaining upland vegetation cover is important not only for ecological conservation but also for reducing downstream flood impacts.

From a practical perspective, the flood risk map generated in this study can support local planning, disaster preparedness, and land management in Kluet Tengah. GIS-based flood studies have shown that susceptibility maps are useful for identifying areas that require priority intervention, evaluating land-use compatibility, and guiding mitigation measures in data-scarce regions (Ashfaq et al., 2025; Pimenta et al., 2025). In the case of Kluet Tengah, the map can help local stakeholders identify lowland areas where development control, drainage improvement, and community-based adaptation measures should be prioritized.

At the same time, this study should be understood as a preliminary spatial assessment rather than a full hydrological prediction model. Recent literature shows that flood-susceptibility mapping commonly integrates a broader set of conditioning factors, including rainfall, distance from rivers, drainage density, soil type, topographic wetness index, and elevation, often combined with validation using observed flood inventories or accuracy testing (Ashfaq et al., 2025; Husein et al., 2025; Islam et al., 2025). Compared with these more comprehensive approaches, the present study uses a simplified overlay of land cover and slope, which is useful for initial screening but may not capture the full complexity of flood processes in the study area.

Several limitations should therefore be acknowledged. First, the analysis did not directly incorporate other influential variables such as soil properties, rainfall intensity, drainage characteristics, and river proximity. Second, the use of medium-resolution imagery may reduce classification precision in areas with mixed or fragmented land cover. Third, the absence of formal validation using observed inundation extent means that the resulting map should be interpreted cautiously as a generalized flood-risk representation. Future studies should incorporate additional hydro-geomorphological variables, adopt weighted or statistical modeling approaches, and validate the results using historical flood inventory or remotely sensed inundation data to improve model reliability and operational usefulness (Ashfaq et al., 2025; Giofandi et al., 2026; Islam et al., 2025).

CONCLUSION

This study demonstrates that flood risk in Kluet Tengah Subdistrict, South Aceh, is strongly influenced by the interaction between land cover and slope. Areas with flat to gentle slopes and intensive land use, particularly settlements, rice fields, and open land, were identified as having the highest flood risk, whereas upland areas with steep slopes and dense vegetation cover showed lower flood risk. These findings confirm that topographic conditions and land cover characteristics are important determinants of flood-prone areas, as also emphasized in recent GIS-based flood studies (Ashfaq et al., 2025; Islam et al., 2025).





The GIS-based overlay approach used in this study provides useful preliminary information for spatial planning, disaster mitigation, and environmental management in Kluet Tengah Subdistrict. However, because the model was based mainly on land cover and slope, future studies should incorporate additional environmental variables and higher-resolution spatial data to improve the accuracy and applicability of flood risk assessment (Giofandi et al., 2026; Husein et al., 2025).

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