ISSN 2354-9114 (online), ISSN 0024-9521 (print)
Indonesian Journal of Geography Vol 56, No 2 (2024): 253-262
DOI: 10.22146/ijg.91114 website: htps://jurnal.ugm.ac.id/ijg
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INDONESIAN JOURNAL OF GEOGRAPHY

RESEARCH ARTICLE

Flood Vulnerability Analysis Based on Gis and Remote Sensing at Silat Hulu

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Received: 2023-11-28
Revised: 2024-01-11
Accepted: 2024-06-04
Published: 2024-07-31

Keywords: Analysis, Flood Vulnerability, GIS, Remote Sensing

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Abstract A *flood* is a natural disaster that may happen anywhere and anytime. These disasters have become an annual cycle in Indonesia, and it is important to be swift in their mitigation and control. This study aims to determine the vulnerability of flooding in Silat Hulu and the extent of the area likely to be submerged. The method used was survey and secondary interpretation data. Data was from topographic maps, Sentinel 2A images, and 10 x 10 m resolution DEM images acquired on November 21, 2021, obtained from the ALOS PALSAR imagery. Data analysis using ArcGIS 10.8, using the weighted overlay spatial analysis tool. The results showed that the study location had three flood vulnerability classes: low, medium, and high. The locations with low vulnerability classes have an area of 2,921 ha, moderate have 32,683 ha, and high have 28,208 ha. Low flood vulnerability is spread to a small extent in Nangau Luan, Nangau Lungu, and Landau Badai villages. The level of vulnerability is mostly in Nangau, Nangau Lungu, and Landau Storm. The high level of vulnerability is mainly spread in the villages of Nangau Dangkan, Blimbing, Nangau Ngeri, and Nangau Lungu. GIS and remote sensing approaches are practical tools for flood-prone maps. Furthermore, GIS-based flood vulnerability mapping and remote sensing are valuable tools for estimating flood vulnerability areas.

1. Introduction

Natural disasters may happen anywhere and at any moment. These disasters have become an annual cycle in Indonesia, and it is important to be swift in their mitigation and control. Flooding is a big problem that happens sometimes when there is a lot of water that covers the land. It can be really dangerous and cause a lot of damage to houses and hurt people (Laurensz et al., 2019; Nugraha, 2018; Petrucci, 2022; Purwanto, Andrasmoro, et al., 2023). Nevertheless, people who live on riverbanks and places prone to flooding do not care about these conditions.

Changes in land use are crucial to the hydrology and hydrologic cycle of the local watershed. Apart from natural elements, numerous elements that result in flooding, such as high rainfall and land morphology, are caused by human behavior. This includes environmental degradation, climate alternations, rapid populace boom, extensive and irrelevant land use, and littering and land-use adjustments in watersheds (Caruso, 2017; Dano et al., 2019). Scientists have researched to see how changing the way we use land on the surface affects the movement of water (Abdelkarim, Gaber, Alkadi, et al., 2019; Brath et al., 2006; Mao & Cherkauer, 2009; Sheng & Wilson, 2009).

One of the factors that change land use and land cover (LULC) is influenced by efforts to meet human needs, such as the construction of housing facilities, industry, agriculture, mining, and other infrastructure (Abdelkarim, Gaber, Alkadi, et al., 2019; Rawat et al., 2013). So, some people who care about the environment and animals are worried about when people change how they use the land because it can hurt the natural places where plants and animals live (Halmy et al., 2015).

When people decide to use land differently, it can sometimes cause big problems if they don't do it right. One problem is the danger of flooding, which has become a significant challenge for many cities in developed and developing countries (Abdelkarim, Gaber, Alkadi, et al., 2019). Flood risk maps have information about floods and how often they happen. This information helps make plans for water resources and city planning. It helps us understand how likely it is for buildings and people to be in danger during a flood (Fernández & Lutz, 2010).

According to the events recorded between 1950 and 2017, most flooding occurred in the last few decades. From 2012 to 2014, it was responsible for over two-thirds of hydrological disasters, and from 2015 to 2016, this percentage increased to 90.9%. More than 60% of Asia's total economy and humans in Asia were lost from 1950 to 2016 (Abdelkarim, Gaber, Alkadi, et al., 2019; Abdelkarim, Gaber, Youssef, et al., 2019).

In the past few months, there has been a lot of rain in some parts of West Kalimantan. This rain has made the water level rise a lot and cover the land, causing floods in those areas, and one of the recent ones occurred in July at Kapuas Hulu. More people in this area are being affected now. According to the report on the development of data and information from the Regional Disaster Management Agency of Kapuas Hulu Regency, the number of affected residents is 7,357 families/ 19,121 people (BNPB, 2021).

Residents affected by the floods that occurred since July 13, 2021, are divided into several sub-districts, namely 1,147 families/4,112 people in Hulu Gurung District, 1,841 families/6,821 people in Silat Hulu, 3,879 families/6,537 people in Boyan Tanjung, 190 families/569 people in Pengkadan, 118 families/472 people in Bunut Hulu, and as many as 182 families/610 people in Silat Hilir. Meanwhile, the villages affected by the flood include Dankan, Entebi, Landau Badai, Landau Rantau, Lebak Jemah, Nanga Dankan, Nanga Luan, Nanga Lungu, Nanga Ngeri, Riam Tapang, and Selangkai (Majni, 2021).

Uncontrolled changes in land use in the upstream region can trigger flooding, mainly through high rainfall. In addition, the rise in urban activity in flooded areas can increase peak discharge and surface runoff or reduce peak time (Huong & Pathirana, 2013; Sarmah et al., 2020). So, if we want to know more about how water moves through an area, we need to learn more about how people use the land there (Adnan et al., 2020; Špitalar et al., 2014).

A comprehensive study is needed to prevent the reoccurrence of similar events. Some tools that can be used as study material are Remote Sensing and Geographic Information Systems (GIS). Both are practical and effective tools for estimating and predicting vulnerability and flood disasters (Hagos et al., 2022; Zhu & Woodcock, 2014). The Sentinel-2 Imagery as remote sensing data is considered to be effective for monitoring bodies or the bottom of waters with high accuracy (Güvel et al., 2022; Nhangumbe et al., 2023; Purwanto, Paiman, et al., 2023).

Geospatial data information in the form of items on the earth's surface with the development of Remote Sensing, and Geographic Information System (GIS) can be quickly provided and spatially analyzed. So, if we want to stop bad things from happening or make them less bad, we can do mitigation to prevent them or make them not as bad when they happen (Faizana et al., 2015; Purwanto, Andrasmoro, et al., 2023).

The current development of GIS and remote sensing science and technology can be applied in various fields, including the management of environment and natural resources as well as disaster analysis. Therefore, this study aims to determine flood vulnerability in Silat Hulu, an area likely submerged by flooding.

2. The Method

Research Area

The study area seen in Figure 1 is the Silat Hulu District of West Kalimantan Province. Upstream Silat District has an area of 63,812 hectares, equivalent to 3.56% of the Kapuas Hulu district. Astronomically, the latitude of Silat Hulu district is at 0°12’ North Latitude–0°28” North Latitude and 112°0’30” East Longitude–112°9’0” East Longitude.

Method

This study utilized a survey method and secondary data interpretation from Sentinel 2A imagery, 10 x 10 m resolution DEM images acquired on August 17, 2021, and November 21, 2021, obtained from ALOS PALSAR images. Furthermore, the data used include the height of the study location, land use and cover, river distance, amount of rainfall, and slope for data exploration using ArcGis 10.8. The stages of the research methodology are shown in Figure 2.

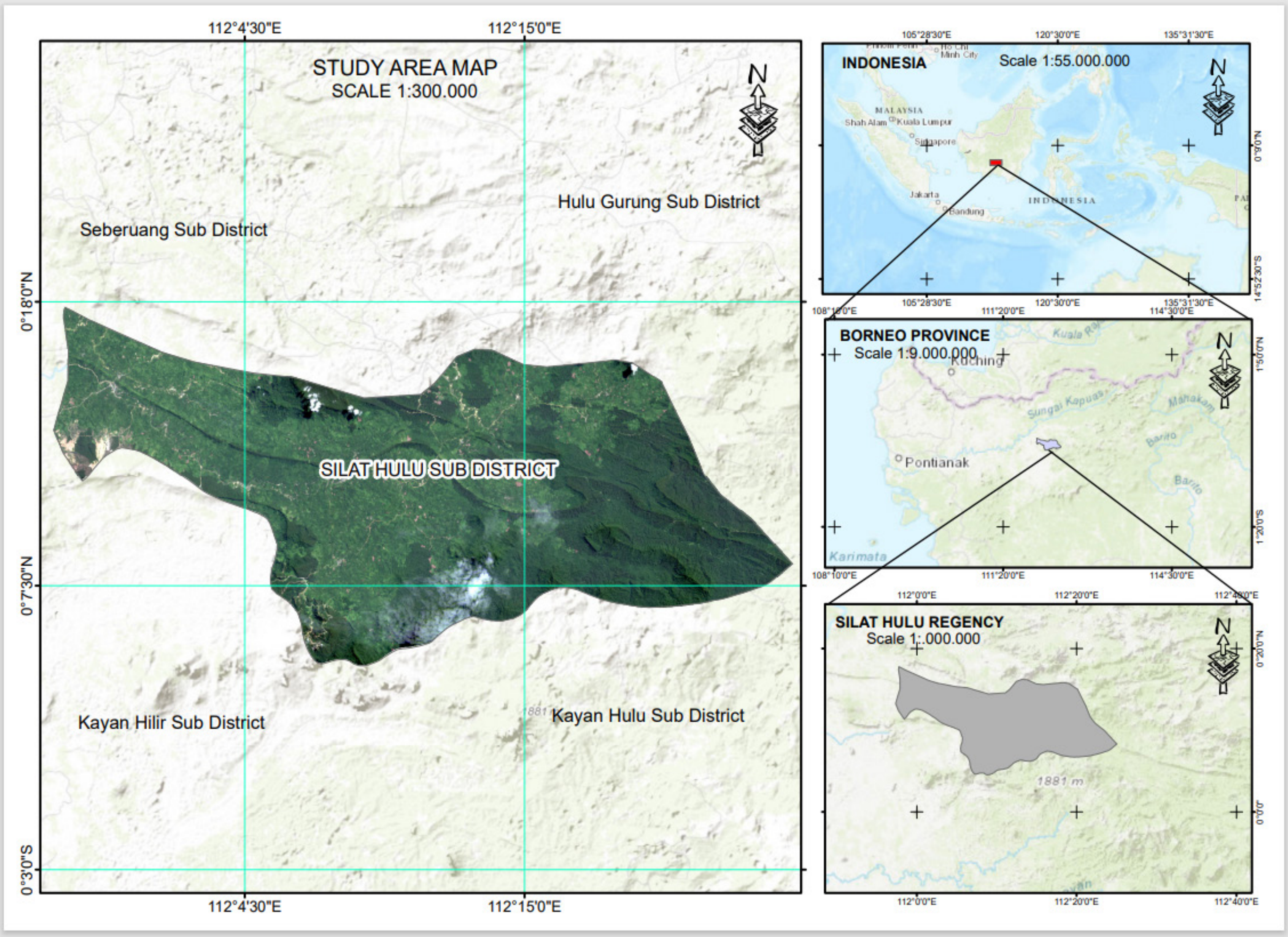

Figure 1. Research Area

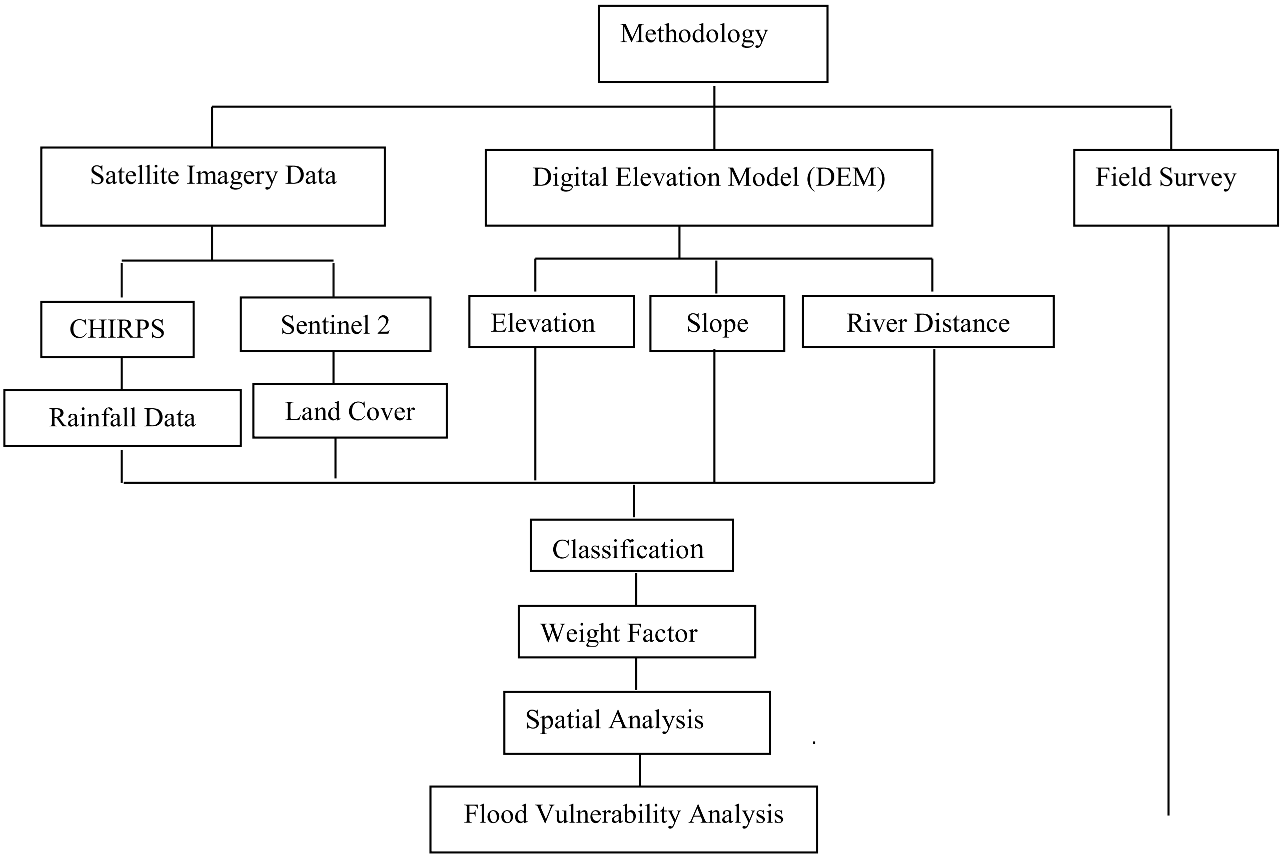

Figure 2. Research Method

The ranking classifications for each vulnerability variable are shown in the following Table.

Table 1. Elevation Rank Classification

Elevation (m)	Classification	Rank
32 - 79	Very Low	5
79- 117	Low	4
117 – 162	Moderat	3
162 – 219	Hight	2
219 - 255	Very Hight	1

Source: Analysis Results

Table 2. Classification of Slope Rank

Slope (%)	Classification	Rank
0 - 8	Flat	5
8 - 15	Sloping	4
15 – 25	Slightly Steep	3
25 – 45	Steep	2
> 45	Very Steep	1

Source: Analysis Results

Table 3. Land Use Land Cover Ranking Classification

LULC	Rank
Water Body	5
Empty Land	4
Dryland Farming	3
Shrubs	2
Secondary Dryland Forest	1

Source: Analysis Results

Table 3. River Distance Ranking Classification

Distance	Classification	Rank
0 - 0,002	Very close	5
0,002 - 0,005	Near	4
0,005 - 0,008	Moderate	3
0,008 - 0,010	Far	2
0,010 - 0,013	Very far	1

Source: Analysis Results

Table 4. Classification of Rainfall Rank

Rainfall (mm)	Klasifikasi	Rank
4.647- 4.915	Very high	4
4.378- 4.647	High	3
4.110 – 4.378	Currently	2
3.841- 4.110	Low	1

Source: Analysis Results

Weighting was carried out on each parameter to classify the level of flood vulnerability. The magnitude of the weighting value of each parameter can be seen in Table 5.

Table 5. Weighting Factors of Each Vulnerability Parameter

Parameter	Weight
Elevation	10
Slope	15
Land Use Land Cover	20
River Distance	25
Rainfall	30

Source: Analysis Results

3. Results and Discussion

From the results, several factors, which are the most critical parameters causing flood hazards in the Silat Hulu sub-district, were analyzed, with the zoning map as the final result. The five factors that caused recent flooding in the district include altitude, rainfall, slope, river distance, land use, and cover. The analysis results of these factors are as follows:

Elevation

Elevation is one of the key elements contributing to the incidence of flooding as it affects the water's flow rate. The size of the study area is based on analysis using ArcGIS 10.8, while the height is determined based on the Digital Elevation Model (DEM) image. Furthermore, the lowest region is 32 meters above sea level, while the highest is 225 meters. This result classified the area into 5 (five) classes, as shown in Figure 3.

Floods often occur in low-lying areas with the potential to concentrate water and eventually cause inundation. This is because the nature of water is always to find low places. The area is shallow and amounts to 31,706.35 Ha (48.55%) when combined. The site's altitude was reclassified on a scale of 1 to 5, with a score of 1 for the highest place and 5 for the lowest. In addition, a value of 5 was assigned to the lowest site because the area significantly contributes to flooding.

The most crucial element influencing floods is elevation. The overall relationship between elevation and flood occurrences: When elevation decreases, the frequency of flood events rises (Ramesh & Iqbal, 2022). It is well-established that areas with low elevation frequently flood during the rainy season. Referring to the aggradational nature of Silat Hulu's topography, lowlands are usually accompanied by relatively higher wadi estuary discharge and are more quickly inundated by the aggradation of water falling on highlands (Al-Taani et al., 2023).

Slope

The slope has a very dominant influence on floods and river flows. The hill makes water go faster and flows through special pathways called drainage channels and watersheds. Meanwhile, steep slopes contribute little to flooding. Therefore, the steeper the mountain, the higher the runoff, resulting in higher peak discharges. A slope class of 0–8% occupies most of the study area, meaning most is vulnerable to flood hazards. That is due to the fact steeper slopes are more prone to surface runoff, whereas flat regions are prone to waterlogging. Low slopes are more prone to flooding than high slopes. The picture became derived from the DEM, with a resolution of 10 m, the use of the Slope device in ArcMap10.8. The slope was reclassified from a scale of 1 to 5, where a score of 5 was assigned to a lower slope and 1 to a higher value. Also, five was given to low slopes because they have a more significant potential for flooding than those with high gradients, which have a low contribution (details are shown in Table 2).

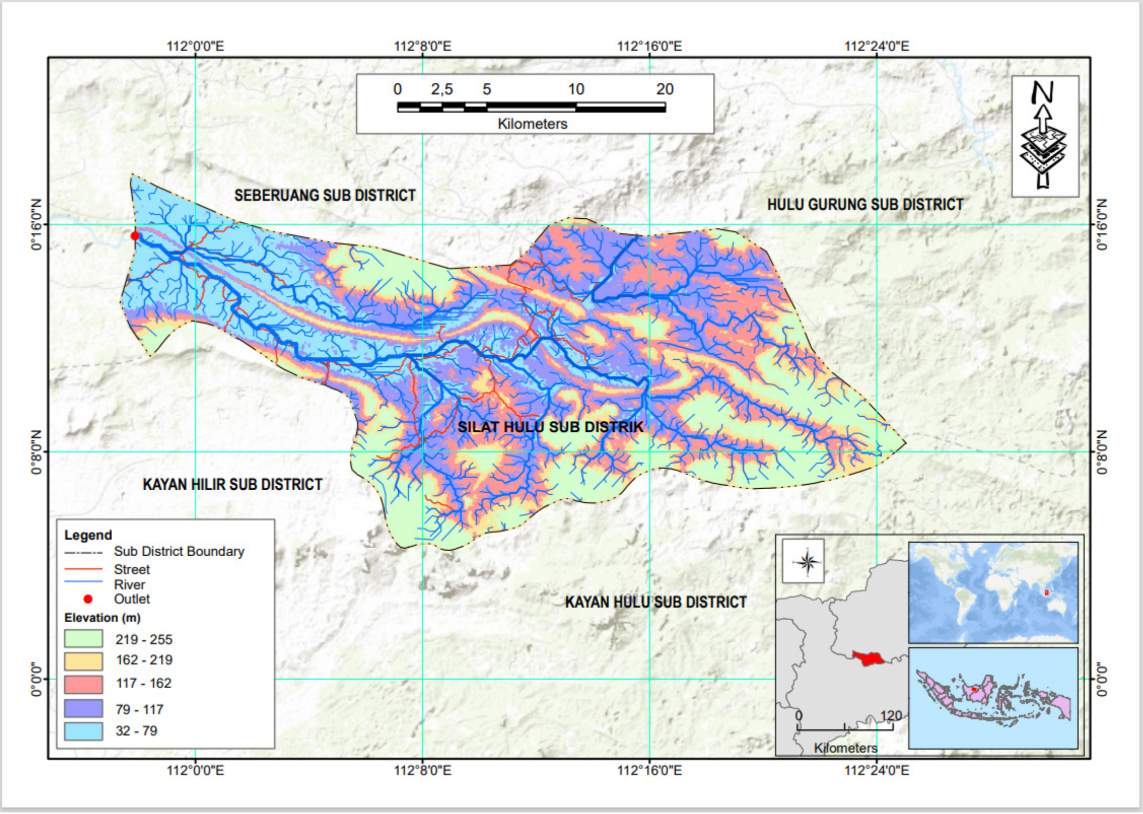

Figure 3. Elevation of the Research Area

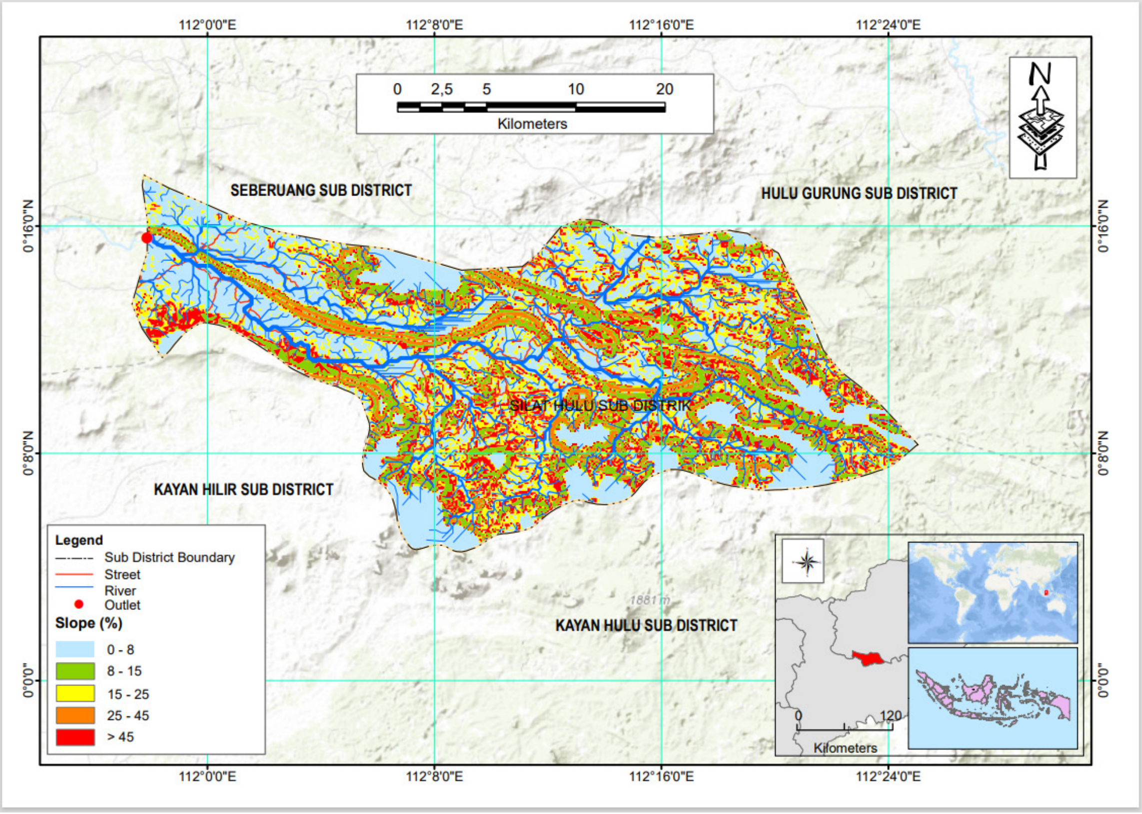

Figure 4. The Slope of the Research Area

Flat and sloping slopes allow water to pool, although there is the potential for water to seep into the ground on flat and gentle slopes. However, this will result in inundation when the infiltration capacity is exceeded, and in large numbers, there will be flooding. Furthermore, on a slope, the water does not have a chance to become a puddle, hence, it flows into the ground surface estimate. The flat and gentle slopes cover an area of 27767.72 ha (43.34%) and 13197.01 ha (20.599%). When viewed from an area with a slope and flat slope of more than 50%, the potential for flooding, in general, will spread more than half of the research area.

Low-elevation areas are more susceptible to floods and waterlogging because they often have a mild or level slope. Runoff may be disposed of rapidly on steeper slopes since they generate higher velocity than flatter or gentler slopes (Ramesh & Iqbal, 2022; Tehrany & Kumar, 2018).

Land Use Land Cover

Land use land cover and changes in land use from green open spaces to built areas, or vacant land can affect the ability of water absorption by the soil. The land use and cover area can be seen in Table 7.

Based on the data above, the secondary dryland forest has an area of 22,903.99 ha (35.09%), while bodies of water and vacant lands are 18,706.40 ha (28.66%) and 15,319.76 ha (23.47%), respectively. The potential for flooding in an area is more significant when many bodies of water support several vacant lands. The body of water directly becomes a concentrated place for water overflow. At the same time, the vacant land causes a deficient absorption of soil to rain and surface water, while the overflow or runoff is vast. Land use and cover were reclassified on a scale of 1 to 5, where a score of 1 was assigned to secondary dryland forest, while five was assigned to bodies of water. A value of 5 was given to the body of water because it significantly contributes to flooding. The land-use area can be seen in Figure 5.

The pattern of LULC determines the amount of runoff generated during rainfall events, thus affecting the water balance in an area. LULC can, therefore, influence the likelihood of flooding and its consequences (Szwagrzyk et al., 2018). Consequently, the floods that hit Silat Hulu several times caused many losses, especially in material terms. People who are mostly economically weak feel the impact. As the results of research (Adnan et al., 2020; Dube & Yadav, 2018) state that flooding and poverty occur together, especially in rural communities, because the damage caused by recurrent floods depletes assets, negatively affects agricultural income, and thus reduces people's quality of life

River Distance

The distance of the river also has a significant influence on the occurrence of flooding. The closer an area is to a river, the higher its potential to occur. Therefore, sites close to the river will be easily accessible by overflowing water. River distances were reclassified on a scale of 1 to 5. A score of 1 was

Table 6. Land Use Land Cover Area of Research

LULC	Luas (Ha)	%
Water Body	18.706,4	28,66
Empty Land	15.319,76	23,47
Dryland Farming	2.836,9	4,35
Shrubs	5.510,01	8,44
Secondary Dryland Forest	22.903,99	35,09

Source: Analysis Results (2024)

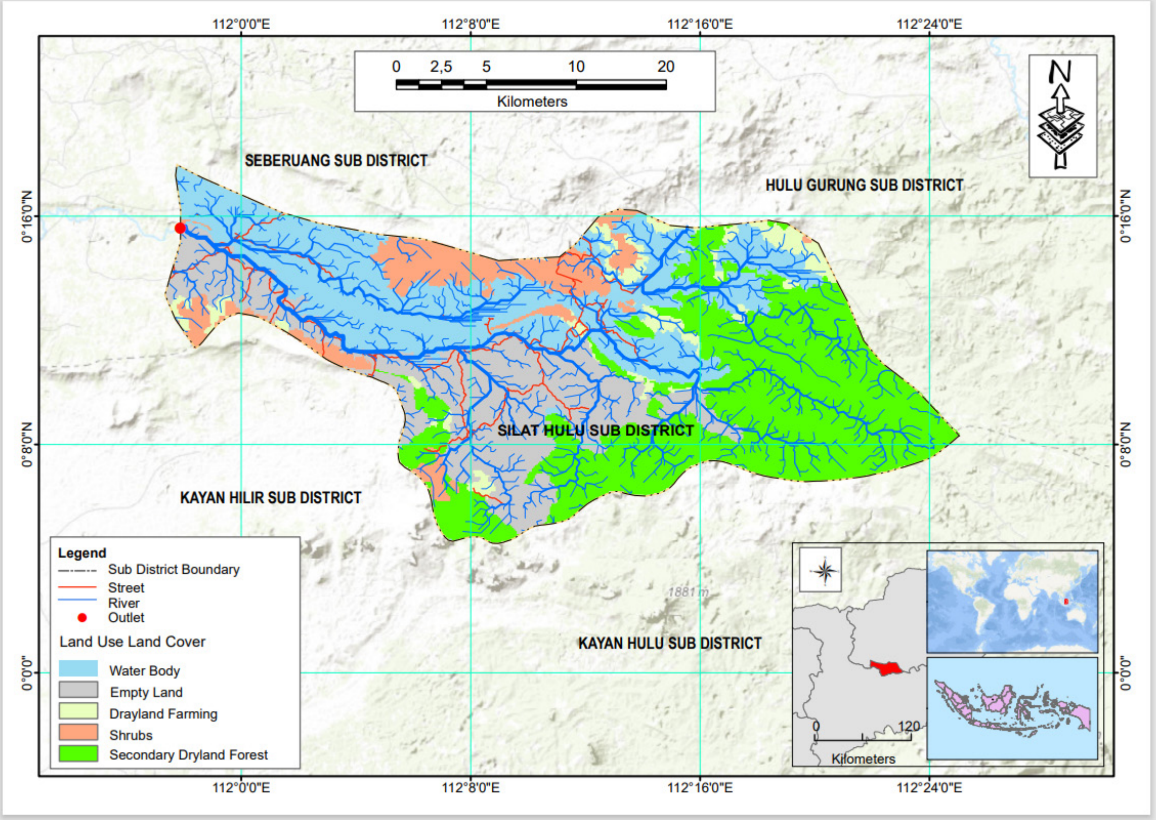

Figure 5. Land Use Land Cover Research Area

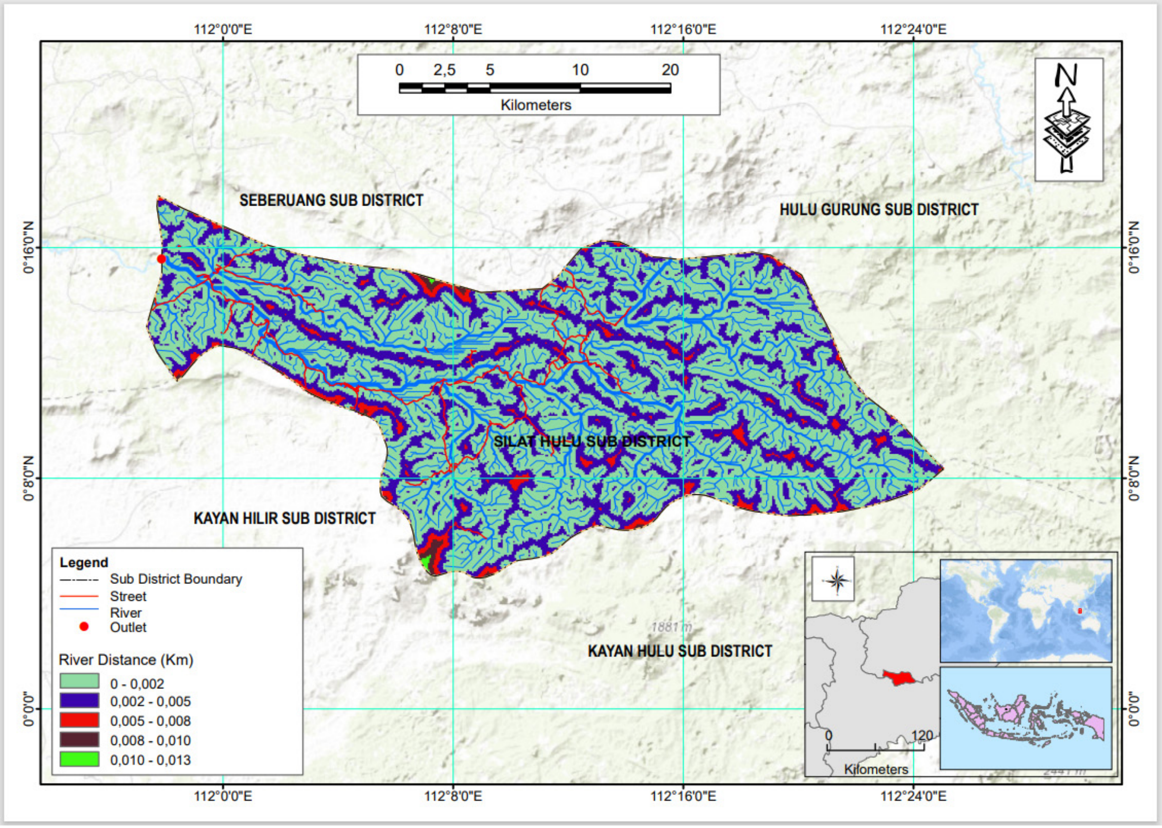

Figure 6. River Distance Map

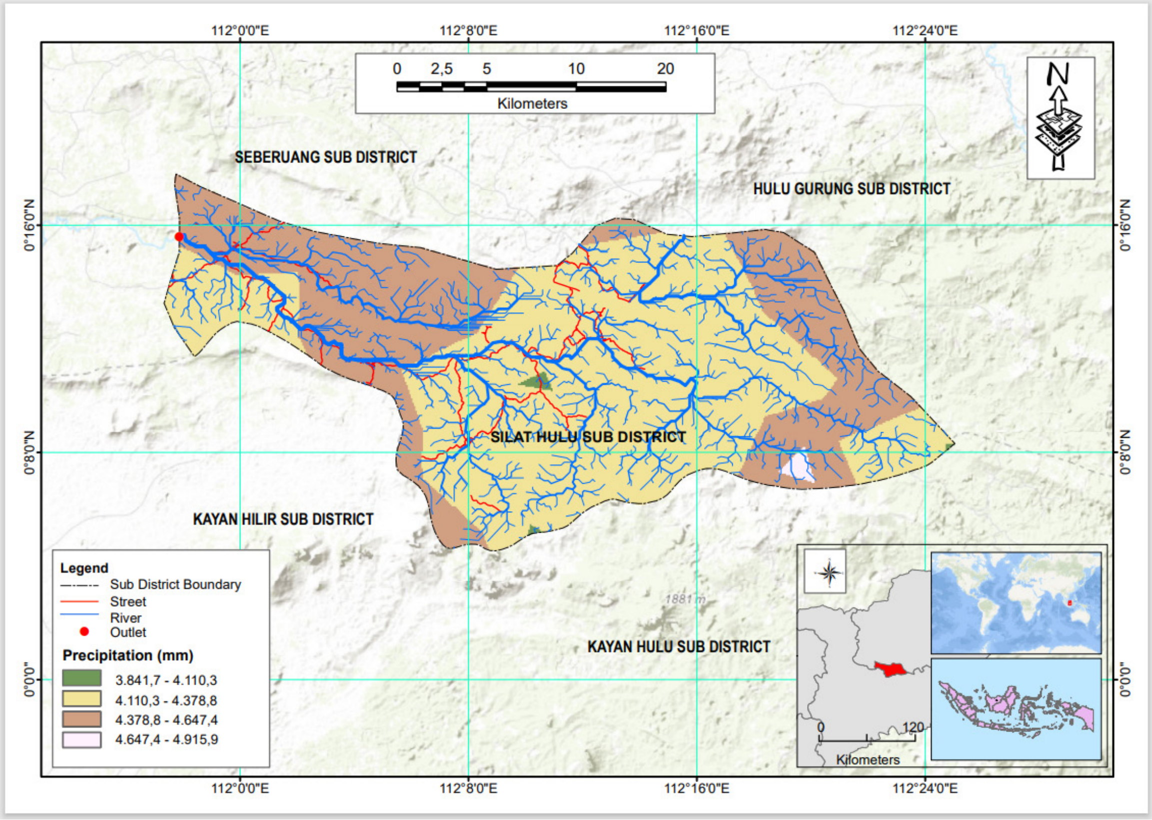

Figure 7. Rainfall Map of Research Area

assigned to the furthest distance from the river, while 5 was assigned to the closest. A value of 5 was given for the distance to the nearest river because it significantly contributes to the occurrence of flooding. Therefore, the score will be higher as the distance between an area and the river gets closer.

In the studied region, floods frequently happen beside rivers. As a result, the distance from the river is regarded as an additional geomorphological conditioning element. Furthermore, the distance from the river map was created because the river flow will destabilize the slope by eroding, weakening, or saturating parts of the material located within the river's water surface (Mojaddadi et al., 2017). The proximity of the river and drainage shows the distance from the river. The distance from the river strongly influences the distribution and intensity of floods in the region, the distance of the measuring site from the river, or both (Tien Bui et al., 2019).

Rainfall

Heavy rainfall is the leading cause of flooding when rivers can no longer accommodate or drain excess water. This results in a high runoff, causing an area to be prone to flooding. Using the inverse distance weighting interpolation method (IDW), monthly common information data during the rainy season (January to December 2022) are interpolated to produce a map based on monthly rainfall data. As seen in Table 4, the total rainfall map was graded on a scale of 1 for low rainfall values and 5 for high raifall values.

Rainfall impacts the flooding process and is crucial for reducing flood risk and local water consumption (Cheng et al., 2021). Rainfall is a source of flood flow and is crucial in determining when a flood will peak. A quick drop in the daily river flow (and water level) might result from heavier-than-usual rainfall (Ronchail et al., 2018). Similarly, rainfall significantly influences variations in the frequency of monthly floods (Cheng et al., 2021; Ronchail et al., 2018). Flooding is especially a result of excessive rainfall in many areas. it's miles now anticipated that global weather change will growth the frequency and period of extreme rainfall (Tunas et al., 2021).

Remote sensing and the GIS technique are valuable tools for examining flood vulnerability. The overlay results using the weighted overlay method between flood vulnerability factors showed that the study area has three classes of vulnerability: low, medium, and high. The locations with low, moderate, and high vulnerability classes have areas of 2,921 ha, 32,683 ha, and 28,208 ha, respectively. The flood vulnerability can be seen on the flood vulnerability map of the study area.

The slope influences the velocity of water with the flow through drainage channels and watersheds. Therefore, the steeper the slope, the higher the runoff, resulting in a higher peak discharge. The 0–8% slope class occupies most of the study area, which means most of the site is highly vulnerable to flood hazards, and this is because flat regions are prone to waterlogging. The gradient slope in drainage channels and watersheds significantly impacts the river flow velocity. Peak discharge rises with a steeper slope due to increased runoff (Rincón et al., 2018). According to earlier research, there is a greater likelihood of flooding with a lower slope gradient (Khosravi et al., 2018; Purwanto, et al., 2023; Tehrany & Kumar, 2018; Ullah & Zhang, 2020).

The rainfall maps are spatially distributed at 4,378.8 - 4,647.4 and 4,110.3 - 4,378.8 mm. High rainfall is visible in the higher and center areas, contributing notably to flooding in lower areas. Furthermore, high rainfall contributes to extreme flooding due to the high average rain experienced in the region. In addition, increased urbanization and a more impervious surface are other factors causing more overland flow and flooding. Nearly each a part of the region is prone to flooding due to high-intensity rainfall. Floods are caused mainly by precipitation when excessive rainfall and runoff overload streams and prevent them from holding onto the extra water. Elevated precipitation raises the danger of flooding because it increases runoff caused by excessive rainfall. Rainfall and floods have been linked in several earlier research (Das, 2019; Sahana & Patel, 2019; Ullah & Zhang, 2020; Zhang & Chen, 2019).

Drainage density has a considerable influence on flood susceptibility. The denser the drainage, the greater the potential

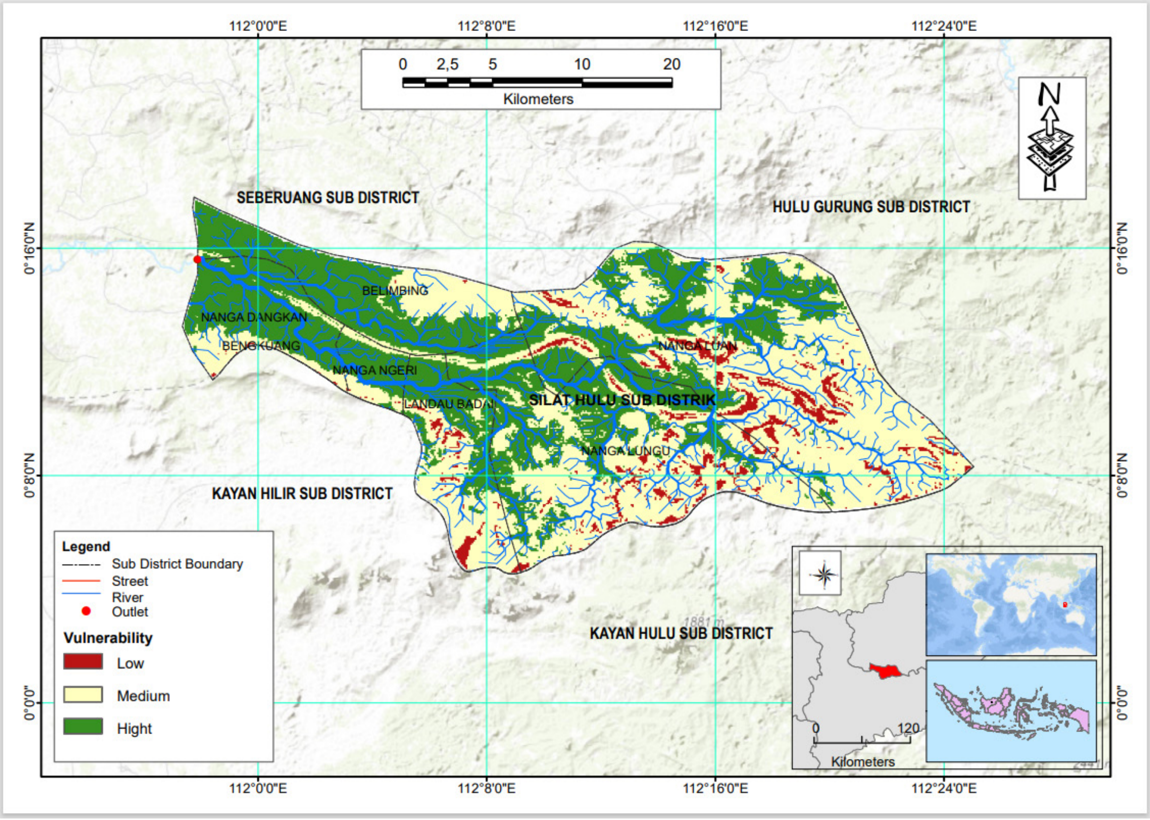

Figure 8. Flood Vulnerability Map at Silat Hulu

for flooding. Therefore, an increase in drainage density implies an increase in peak flooding. Moreover, water that the drainage or river cannot hold will overflow from several drainage channels or rivers and collect as puddles or floods. The impact of drainage density on surface runoff and flood risk is substantial. Overflowing from several drainage routes, the water that the river cannot hold condenses into puddles or floods (Das, 2019; Ullah & Zhang, 2020). Drainage density raises the likelihood of floods (Ullah & Zhang, 2020).

One factor influencing the quantity of runoff from rain is land usage. Rainwater that has exceeded the infiltration rate will become runoff. Furthermore, lands with much vegetation will experience high rainwater infiltration. This is because runoff will take more time to reach the river; hence, flooding is less likely compared to areas without vegetation. The bodies of water and vacant land, which occupy 18,706.40 ha (28.66%) and 15,319.76 ha (23.47%) of the total study area, are generally prone to flooding and are therefore given significant weight. According to Mehr & Akdegirmen, 2021; Sugianto et al., 2022, LULC alters natural drainage systems and affects surface runoff and infiltration capacity. Flooding that occurs often is thought to be caused by these variables. In the meantime, the evapotranspiration rate is also affected by the amount of plant cover and absorption rates (Das et al., 2018). These elements alter behavior and the equilibrium that exists between water distribution through rivers (Nahib et al., 2021; Sahoo et al., 2018), water evaporation (Sugianto et al., 2022), water absorption (Li et al., 2021).

In the last few months, the flood in Silat Hulu occurred because it was included in a vulnerable area and was relatively weak. Based on the flood susceptibility mapping above, mitigation can be performed the possibility of flooding in other regions. Mapping also needs to be conducted to minimize losses and damage socially, economically, and physically. Mapping of flood-prone areas can be used to make policies regarding the possibility of flood hazards.

4. Conclusion

GIS and remote sensing approaches are practical tools for flood-prone maps. Furthermore, GIS-based flood vulnerability mapping and remote sensing are valuable tools for estimating flood-prone areas. They support decision-makers and planners of water resources by helping them concentrate on particular regions so that more thorough evaluations of flood susceptibility may be conducted. This strategy has several benefits, including minimal cost, low handling requirements, and flexibility, which enable it to be used in regions with little information. Thus, this streamlined yet trustworthy approach can assist in lowering the resources needed for a relatively accurate flood risk evaluation. Moreover, the flood vulnerability maps generated in this study can significantly assist the Silat Hulu sub-district or the Kapuas Hulu Regency in implementing the necessary mitigation strategies for land use, insurance, and disaster relief. The findings demonstrated that elevation, drainage density, land cover, slope, and total rainfall must create a trustworthy map for mapping flood vulnerability.

Acknowledgment

The authors are grateful to Kementrian Pendidikan dan Kebudayaan dan Lembaga Pengelola Dana Pendidikan (LPDP) for providing opportunities and funding for scientific research grants.

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