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Flood hazard mapping using QGIS Spatial Analysis in Bangko and Masjid Watershed at Riau, Indonesia

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***Abstract**. Floods are natural events that are dangerous to humans and property and cause environmental and economic losses. Riau Province is currently one of the richest provinces in Indonesia, and its resources are dominated by natural resources, especially oil and natural gas. This study was conducted to assess the extent to which flood-prone areas in the Bangko and Masjid watersheds in Riau Province. This study aims to obtain a flood Hazard map based on slope, land cover, elevation, rainfall, buffer zone, and soil type with GIS Software, which is also needed to determine Riau Province pipeline networks. Based on mapping results, in the Bangko watershed, 61% of the total area is vulnerable to flooding, and 20% has high to very high vulnerability, while in the Masjid watershed, 84% of the area is vulnerable to flooding, and 11% of the total area having high to very high vulnerability. This is due to the low watershed elevation, flat slope, high rainfall, and residential areas close to the river in the watershed. Therefore, it is very important to create an easy-to-understand and easy-to-understand flood hazard map that emphasizes the mitigating effects of management.*

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INTRODUCTION

In terms of environmental and economic repercussions, flooding is an overflowing river discharge event (Pabi et al. 2021). In 2018, the floods in Rokan Hilir Regency and Dumai City caused significant damage to the residents of Riau. More than half a million people were evacuated from their houses due to heavy rains. It is impossible to prevent flooding completely. However, flood hazard mapping can help reduce its impact (Musolino et al. 2021). In essence, the mapping is a dominating characteristic marker on the spike area, which will be viewed as closeness in the future so that essential considerations may be made for various flood-causing conditions (Sachdeva and Kumar 2022). Flooding can be produced by various human and natural factors (Ezzine et al. 2020). It is important to consider natural factors, such as the characteristics of the river flow area. This is due to the unique properties of each basin. A river flow area is a zone of water flow from the river to the soil or surface, aided by gravity, that contains ecosystems with flora, wildlife, and humans (Ariyani et al. 2020). The characteristics of the Bangko and Masjid basins area indicate the subjectivity of flood hazard-related confounders within the mapping parameters (Toosi et al. 2020).

Flood hazard mapping is utilized to identify flood-prone locations along the river when the runoff discharge exceeds the river's capacity, considering the inundated area's development value and the flood susceptibility level along the watersheds (Desalegn and Mulu 2021; Uddin and Matin 2021). The flood hazards maps of the Bangko and Masjid basins are the beginning stage in Rokan Hilir Regency and Dumai City's planning toward hazard mitigation management (Mudashiru et al. 2021; Bourenane et al. 2019). Detailed mapping of flood-prone areas with expansive regions is an easily solvable issue. The primary constraints include the algorithm and hardware, cost, lack of data, and insufficient understanding of how inundation occurrences occur in various river floodplains (Costa et al. 2019). Society must access flood hazard maps provided for the region for the maps to be effective. New methods, such as remote sensing is performed with the help of the Geographic Information System (GIS) to provide societies with collaborative flood hazard mapping solutions (Auliagisni et al. 2022). Due to its capacity to manage spatial data, the Geographic Information System (GIS) is an ideal demonstrative tool for assessing spatial data on flood risk (Shale et al. 2020). The Quantum GIS (QGIS) system is used to follow remote sensing technology advancements to map flood hazards (Lei et al. 2021). Quantum GIS uses satellite spatial data in its implementation. Spatial data variability was used to determine river flow characteristics, slope, land cover, elevation, rainfall intensity, and soil type in mapping the flood hazard of the Bangko and the Masjid watershed (Stephens and Bledsoe 2020).

METHOD

Location and Research Time

Riau is one of Indonesia's regions with the most incredible opportunity for regional expansion. The development of this area is not far from the growing population of settlements and plans for other infrastructure and facilities. In the central part of Sumatra Island's east coast and surrounding the Malacca Strait, Riau Province's location necessarily involves flood risk management to facilitate the province's expansion policy. River management should be implemented as part of a successful regional expansion strategy. It's because rivers are the lifeline of the entire ecosystem. One of the rivers that cross Riau Province is the Banko River and the Masjid River (Figure 1). The Bangko River is located in Rokan Hilir Regency (1°40'58.70" N, 100°5338.06" E) with a watershed area of 29,977 ha. Masjid River is located in Dumai City (1°37'11.66" N, 101°20'17.47" E) with a watershed area of 31,274 ha.

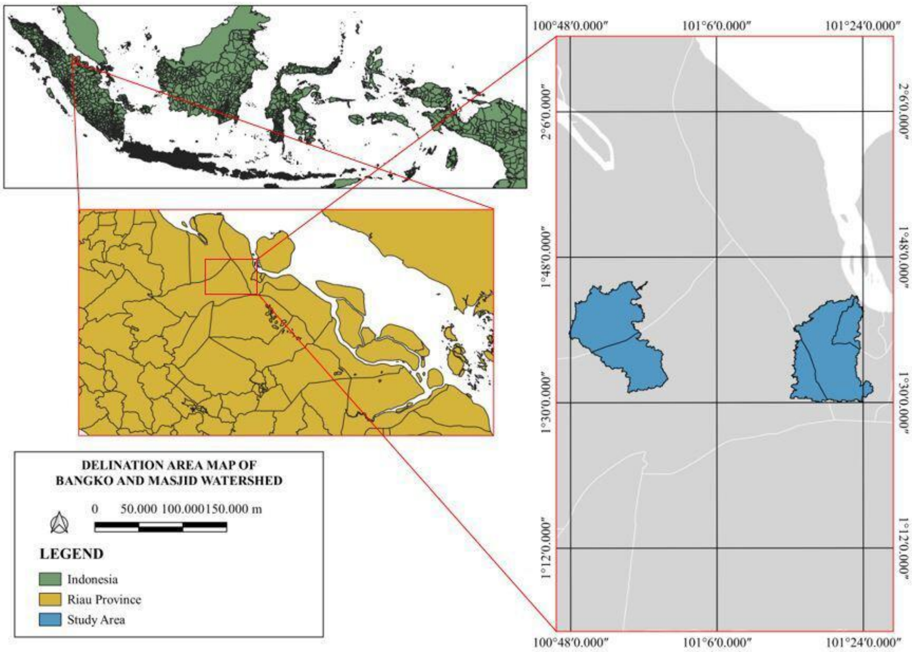


Figure 1 Research study area

Data and Method

Due to the general spatial unpredictability of the significant forces, determining the risk of flooding depends on the specific environment. The analytical test for minimizing the subjectivity of watershed characteristics was selected using an assessment related to the availability and quantity of sample data (Toosi et al. 2019). In this paper, the data required includes DEM, Landsat, CHIRPS, and HR data, which have different roles in determining the characteristics of the watershed, as shown in Table 1.

Table 1 Research data

No.	Data	Output
1.	DEM	Slope, water flow, buffer zone, and elevation
2.	Landsat OT.8 USGS	Landcover
3.	CHIRPS	Rainfall
4.	FAO Soil Map of The World	Soil type

Analysis Method

The research was conducted using a remote sensing method with the help of the QuantumGis application (Figure 2). QGIS is based on Shuttle Radar Topography Mission SRTM and DEM data for the study area, which was researched and edited according to the needs of the mapping projection using the UTM WGS 1984 coordinate system (Suthirat et al. 2020).

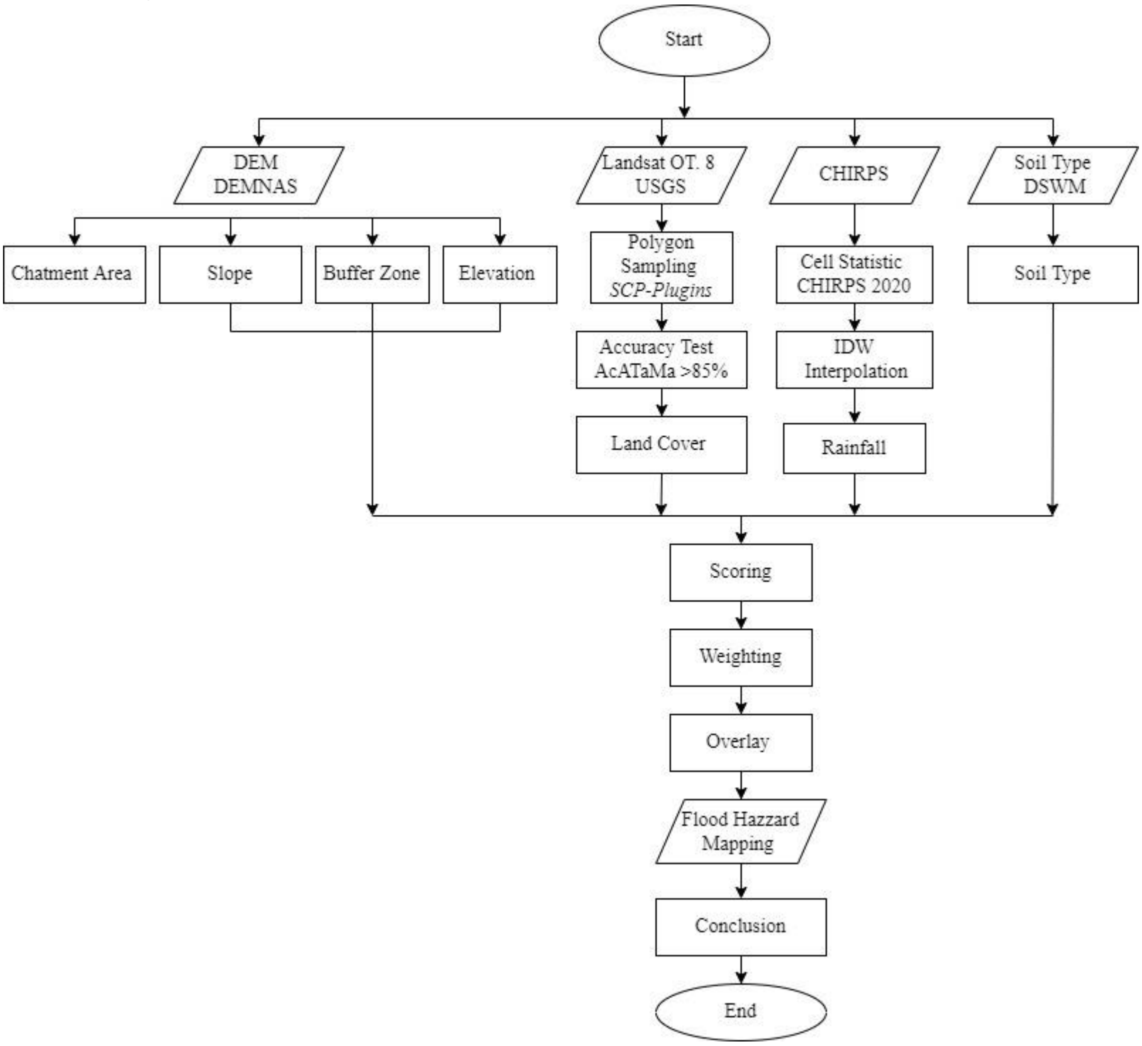


Figure 2 Research Flowchart

Digital Elevation Model (DEM)

The Digital Elevation Model (DEM) forms a basis for topographical watershed delineation parameters such as catchment area, slope, river flow, and land elevation (Janizadeh et al. 2021; Elmoustafa 2012). Each watershed has unique topographic characteristics that further affect the slope, river flow, and elevation.

a. Slope factor

   The slope represents one of the effective elements of flooding. Surface tilt can improve hazard indicators from flash flooding in prone areas. Slope affects watershed sensitivity to water flow velocity (Elmoustafa 2012).

b. River flow

   River flow analyzes the river's safe distance using the buffer method. The buffer method is used to see the secure distribution of the river within the radius of the right and left buffer zones (Lee et al. 2021). Water safety distance can implement as a qualitative approach with access to more open space to benefit various groups of individuals and ecosystems by managing flood hazards (Münch et al. 2016).

c. Elevation factor

   The land elevation is the distance seen from sea level and measured in meters or feet. The elevation classification is categorized into five classes. The lower an area is, the greater the potential for flooding, and the higher a site is, the safer it will be for flood disasters. This is because the water flows relative to the lowlands. Due to its location and elevation, low-lying areas tend to have a greater chance of being inundated (Seejata et al. 2018).

Landsat 8 USGS

Landcover maps are used in land cover mapping parameters. The land cover map is a visualization of human activities on the earth's surface by classifying land use in general as rain, rice fields, lakes, fields, rivers, and settlements (Tian et al. 2015). Land cover data accuracy must be carried out to see the map's compatibility with the field's location. The land cover map accuracy test used a random method with the help plugin QGIS AcATAMA Accuracy test results must reach or exceed 85%. The greater the percentage of results obtained, the mapping results are closer to the truth of the visual interpretation of utilization in the field (Deng et al. 2019; Breinl et al. 2021). The accuracy test was carried out using the kappa equation to calculate all the diagonal elements of the matrix on the map (Butt et al. 2015).

CHIRPS

CHIRPS is an infrared rainfall database combining three rainfall information, namely global climatology, satellite rainfall forecasts, and in-situ rainfall observations. The CHIRPS map is used to see rainfall height in the Bangko watershed and the mosque in mm. The height of rainfall is essential to the resulting flood discharge from a practical and theoretical perspective. The rainfall distribution is determined by the climatological situation of the location to obtain the average annual rainfall value (Breinl et al. 2021).

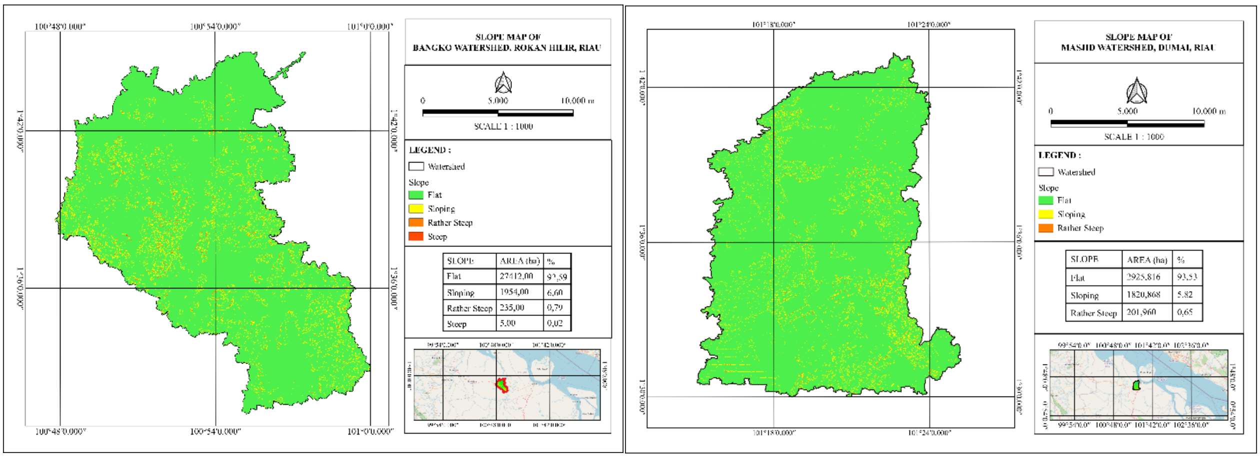
Digital Soil Map World (DSMW)

Digital Soil Map World, managed by the Food and Agriculture Organization (FAO) or United Nations Educational, Scientific and Cultural Organisation (UNESCO), is used to analyze soil types in the Bangko and Masjid watershed in their sensitivity to rainwater infiltration. Soil characteristics such as type, texture, and soil permeability determine the amount of rainfall infiltration before it finally overflows and affects flood susceptibility. Some soil types can quickly generate runoff without infiltration, even in dry conditions. Runoff from heavy rainfall tends to be faster and more extensive with clay than with sand (Elkhrachy 2015; Rimba et al. 2017).

RESULT AND DISCUSSION

Slope Factor Result

The Bangko and Masjid watershed (Figure 3) has a flat slope with a slope percentage between 0% and 8%, according to the analysis results. Flat-sloped areas tend to be downstream of the river due to their lower position. This results in a flood-inundated basin due to rainfall discharge flow. The flatter the slope of a watershed, the slower the runoff flow with the potential for large floods, whereas, in a watershed with a steep slope, there is the potential for a fast surface runoff with the potential for minor flooding, so that rainwater flows directly and does not inundate the catchment area.

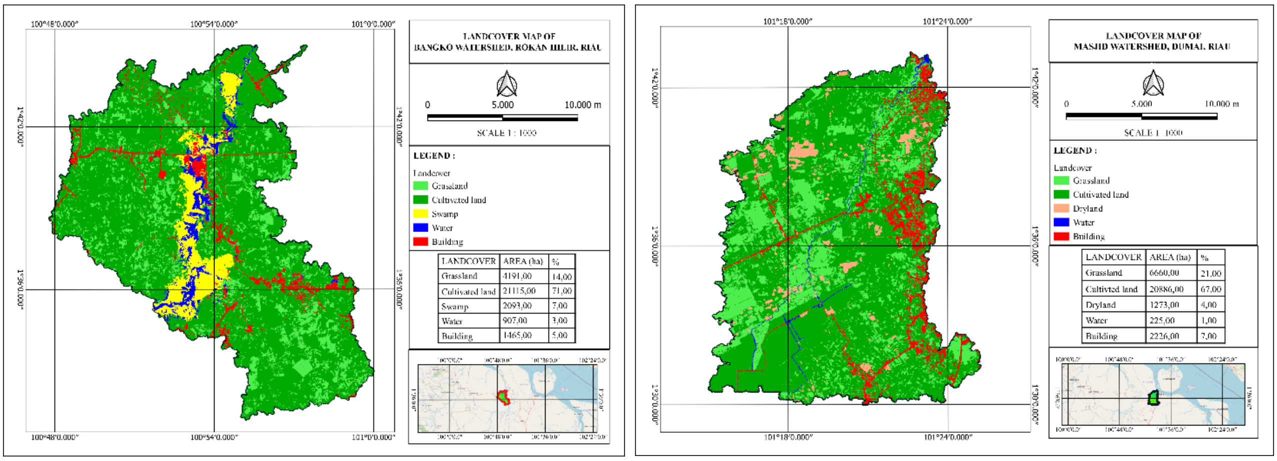


(a) (b)

Figure 3 Slope Map; (a) Bangko Watershed, (b) Masjid Watershed

Landcover Result

The embodiment of human activities on the earth's surface can be seen in its land use (Clegg et al. 2021). Land use maps are used to view land use in the research area. The Bangko watershed (Figure 4a) comprises five services: grassland, cultivated land, swamp, water bodies, and buildings. Meanwhile, the categorization of the land cover of the Masjid watershed (Figure 4 b) into grassland, cultivated land, dryland, water bodies, and buildings.



(a) (b)

Figure 4 Landcover; (a) Bangko Watershed, (b) Masjid Watershed

Map accuracy tests determine the percentage of the map's similarity with the field's location. The test was conducted using the kappa percentage value to determine the correctness of the AcATaMa plugins matrix. Based on the overall mapping accuracy (Tables 2 and 3), the Bangko watershed land cover map was 94% accurate, whereas the Masjid Watershed map was 99% accurate.

Table 2 Accuracy Test Result of Bangko Watershed

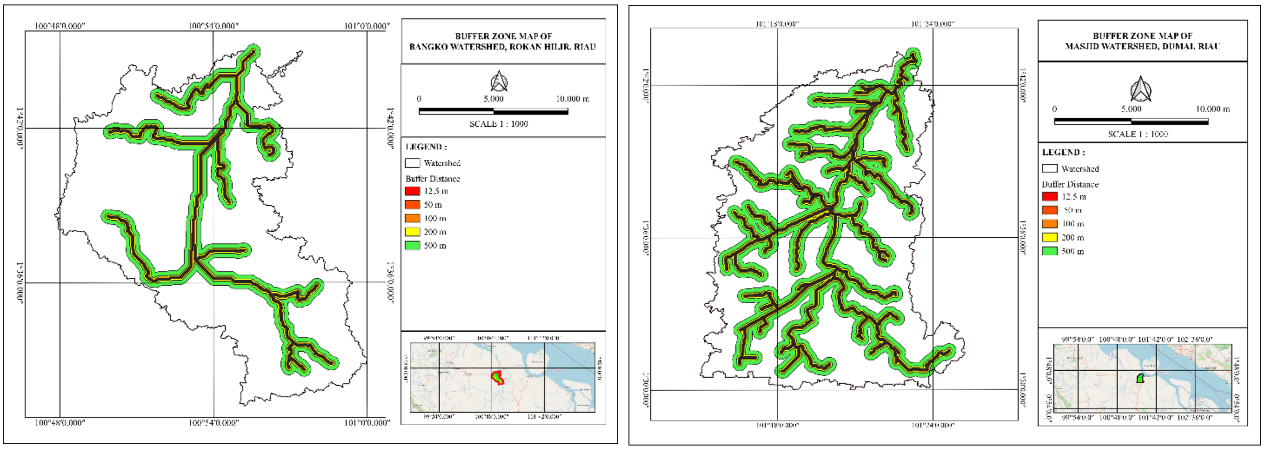
		Classified values (Bangko Watershed)				
		1 (Grassland)	**2 (Cultivated land)**	**3 (Swamp)**	**4 (Water)**	**5 (Building)**
Thematic Raster Classes	1	0.88901	0.03768	-	-	-
	2	-	0.94915	-	-	-
	3	0.11099	-	0.91954	-	-
	4	-	-	-	1.00000	-
	5	-	0.01317	0.08046	-	1.00000
Accuracy value		0.94302				

Table 3 Accuracy Test Result of Masjid Watershed

		Classified Values (Masjid Watershed)				
		1 (Grassland)	**2 (Cultivated land)**	**3 (Dryland)**	**4 (Water)**	**5 (Building)**
Thematic Raster Classes	1	1.0000	-	-	-	-
	2	-	0.98586	-	-	-
	3	-	0.01202	1.0000	-	-
	4	-	0.00212	-	1.0000	-
	5	-	-	-	-	1.0000
Accuracy value		0.9904				

Buffer Zone

The river flow buffer analysis was performed in five lengths: 12.5 m, 50 m, 100 m, 200 m, and 500 m (Figure 5). The closer the distance to the river's original flow, the greater the degree of danger. Conversely, the greater the distance between the buffer and the river flow, the safer it’s from the flood coverage area.

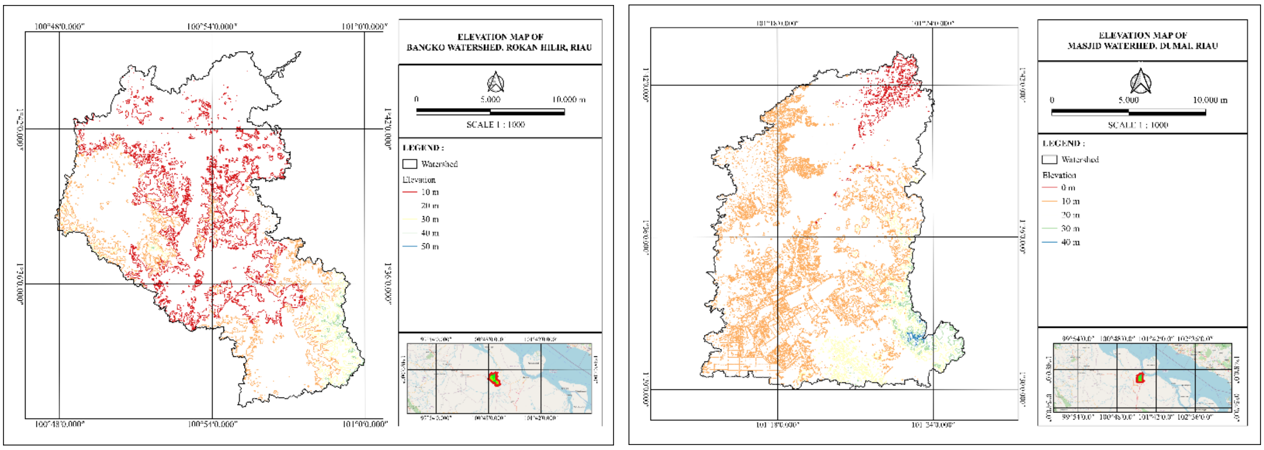


(a) (b)

Figure 5 Buffer Zone; (a) Bangko Watershed, (b) Masjid Watershed

Elevation Factor

Land elevation maps are carried out to see the height of an area from sea level. The lower the elevation, the closer the site is to sea level or parallel. The Bangko watershed is at an elevation of 10–50 meters from sea level. Meanwhile, the Masjid Watershed is divided into two elevations; in the lower reaches of the watershed, the elevation is at an altitude of 0 meters or equivalent to sea level, and in the middle to upstream Masjid watershed has an elevation of 10–50 meters above sea level (Figure 6).

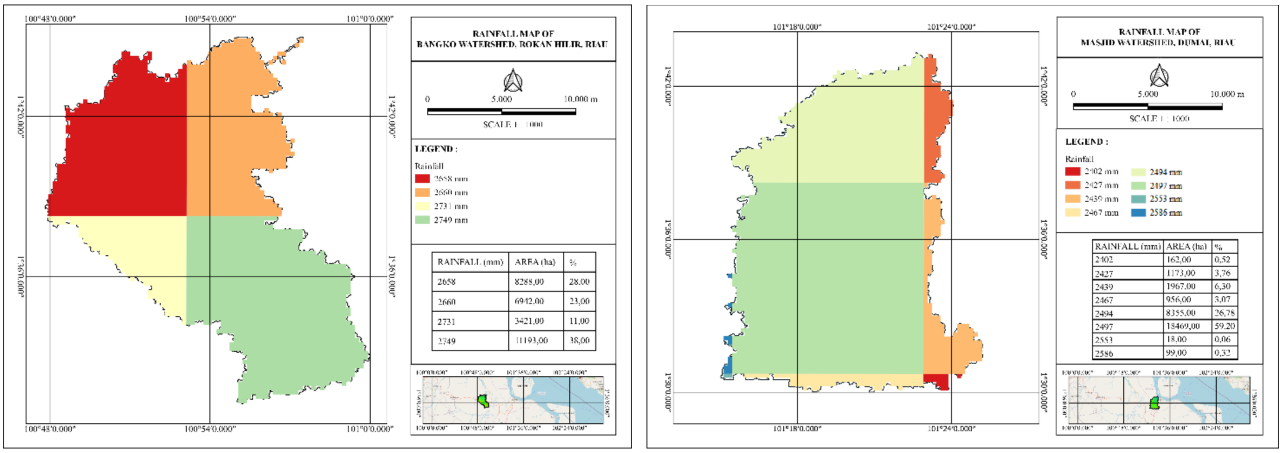


(a) (b)

Figure 6 Elevation; (a) Bangko Watershed, (b) Masjid Watershed

Rainfall Factor

The annual precipitation height in a region is also a mapping element for flood threats. The rainfall intensity affects the runoff discharge or the groundwater infiltration discharge (Ariyani et al. 2021). The Bangko and Masjid Watersheds (Figure 5) are known to get annual average rainfall of more than 2,000 millimeters. The Bangko watershed has a yearly maximum height of 2,749 mm, whereas the Masjid Watershed has a maximum annual size of 2,586 mm (Figure 7).



RAINFALL (mm)	AREA (ha)	%
2658	8288,00	28,00
2660	6942,00	23,00
2731	3421,00	11,00
2749	11193,00	38,00

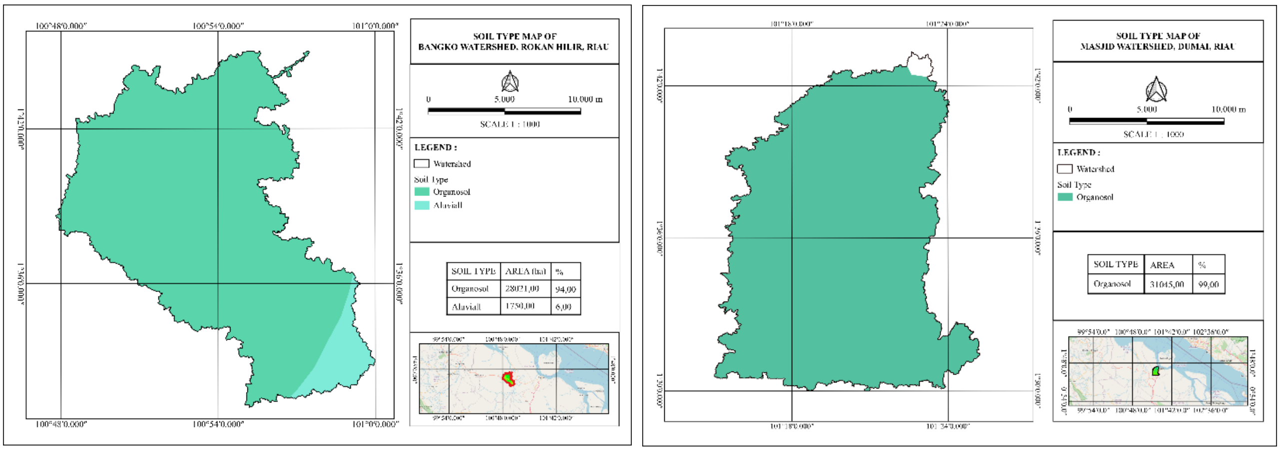
RAINFALL (mm)	AREA (ha)	%
2402	162,00	0,52
2427	1173,00	3,76
2439	1967,00	6,30
2467	956,00	3,07
2494	8355,00	26,78
2497	18469,00	59.20
2553	18,00	0,06
2586	99,00	0,32

(a) (b)

Figure 7 Rainfall; (a) Bangko Watershed, (b) Masjid Watershed

Soil Type

Soil classification map applying the Dudol-Soepraptohardjo system (1957–1961) to identify soil types. Soil mapping the Bangko Watershed comprises two distinct types of soil 94% organosol and 6% mediterranean. On the other hand, the Masjid Watershed has 99% of its area covered with organosol soil. Due to their presence in aquatic environments, organosol soils have high moisture levels. Therefore, the account of infiltration wear on the ground is sympathetic. In contrast to the type of Mediterranean Soil with a moderate infiltration sensitivity, the soil permeability is low (Figure 8).

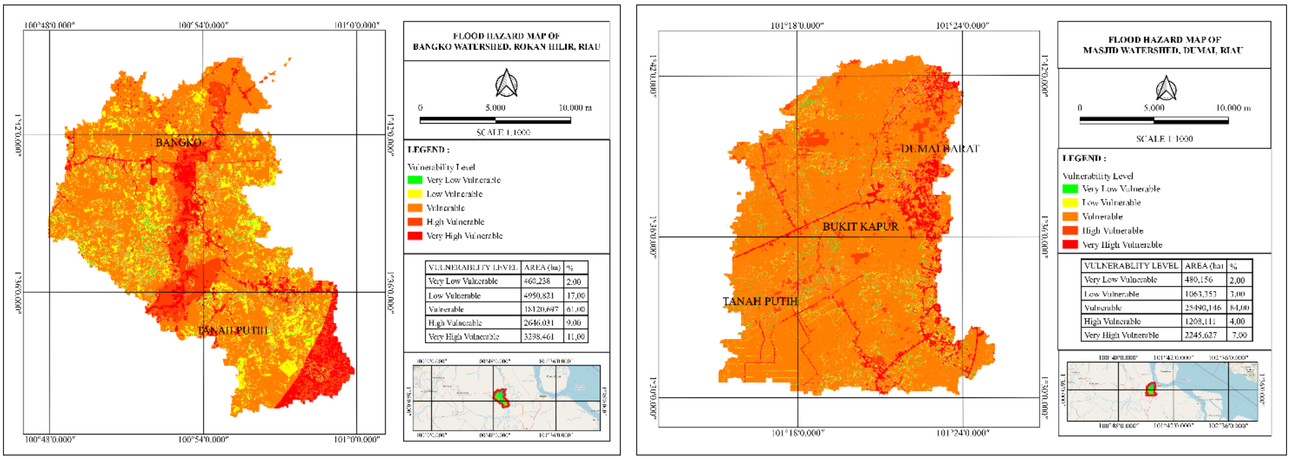


(a) (b)

Figure 8 Soil type; (a) Bangko Watershed, (b) Masjid Watershed

Flood Hazard Analysis

Flood hazard mapping is carried out by combining all parameters using the overlay method and calculating the weight of vulnerability to produce a flood hazard map. Flood hazard maps were classified and obtained five classes of flood vulnerability (Figure 9). The flood hazard map of the Bangko watershed map found that 61% of the area is in the flood-ne class. In Tanah Putih, it has a high flood vulnerability; this is due to the type of Mediterranean Soil and residential areas. Meanwhile, on the flood hazard map of the Masjid Watershed, 84% of the area is prone to flooding. This is due to the watershed's low elevation and flat slope. In Dumai Barat, high flood vulnerability is caused by the existence of occupied residential areas close to the river.



(a) (b)

Figure 9 Flood hazard mapping; (a) Bangko Watershed, (b) Masjid Watershed

CONCLUSION

Based on the analysis that has been done, it can be concluded that the Bangko River Watershed, with an area of 29,028 ha, has a flat slope of 0–8% with a land cover dominated by plantations designated for oil palm. The safe distance from the Bangko River to the right of the river is set at 12.5 meters to 500 meters from the river. The watershed elevation is at an altitude of 10–50 meters above sea level. This means that the watershed is located on the seacoast or downstream of the river. The Bangko watershed has organosol soils with high infiltration sensitivity in the north and middle of the watershed and Mediterranean soils in the south with moderate infiltration sensitivity. Based on the CHIRPS analysis, the rainfall in the Bangko watershed reaches 2,749 mm (>2,000 mm), so it is fairly high. Based on the mapping results, it can be seen that the Bangko and Tanah Putih sub-districts have a high vulnerability to flooding.

Meanwhile, the Masjid watershed, with a watershed area of 31,274 ha, has a slope of 0–8% or is flat with a land cover dominated by oil palm plantations. The northern part of the watershed is at an elevation of 0 meters or equivalent to sea level, so the risk of tidal flooding in this area can occur. In the middle to the south, it is at an elevation of 10–50 meters above sea level or on the sea coast. The buffer method carries a safe distance from the river with a distance of 12.5–50 meters from the right and left of the river. Based on the CHIRPS analysis, the rainfall in the Sungai Masjid watershed reaches the high category (> 2,000 mm), 2,586 mm. However, this can be balanced with organosol watershed soil types with high rainfall infiltration sensitivity to minimize rainfall runoff. Based on the results of the mapping parameters, it can be seen that the Bukit Kapur and Tanah Putih sub-districts have a high vulnerability to flooding.

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