

Analysis of Flood Susceptibility in Pati Regency Using Geographic Information Systems (GIS) and Analytical Hierarchy Process (AHP)

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Abstract

Floods are disasters that often occur in Indonesia. Society and the environment feel the negative impacts of flooding. Floods are ranked as the second most frequent disaster in Indonesia according to the Indonesian Disaster Information Data (DIBI) from the National Disaster Management Agency (BNPB). This research aims to conduct a flood susceptibility analysis in Pati Regency. The method used in this research is Analytical Hierarchy Process (AHP) combined with Geographic Information Systems (GIS). This research uses ten factors that influence flood susceptibility, there are Topographic Wetness Index (TWI), Elevation, Slope, Precipitation, Land Use and Land Cover (LULC), Normalized Difference Vegetation Index (NDVI), Distance from Rivers, Distance from Roads, Drainage Density, and Soil Type. The results of this research show that there are four levels of flood susceptibility in Pati Regency, there are low level reaching 3.47%, moderate level reaching 64.85%, high level reaching 31.62%, and very high level reaching 0.07%.

Keywords: *Flood, Geographic Information System (GIS), Analytical Hierarchy Process (AHP)*

INTRODUCTION

Floods are a disaster that often occurs in Indonesia. According to the Indonesian Disaster Information Data (DIBI) from the National Disaster Management Agency (BNPB), in the 2014-2023 period, there were 8,313 flood events which made floods ranked second as the most frequently occurring disaster in Indonesia. Floods are natural events that occur in an area with varying intensities, where excessive amounts of water are on land that is usually dry (Sebastian, 2008). Floods have a major impact on society and the environment. Flood disasters cause suffering for people living in areas prone to flooding (Matondang et al., 2013). Floods that hit an area can result in major losses, including loss of life and damage to property (Marfai et al., 2008).

Pati Regency is one of the cities where almost every year it is hit by floods (Andhesta & Rahayu, 2017). The region of Pati Regency, especially the northern part, has a very high level of flood vulnerability (Savitri et al., 2022). Floods in the Pati Regency can be caused by several things, are the topography of the Juwana River basin which tends to be sloping, shallowing of the Juwana River and high sedimentation in the Juwana River (Marhendi et al., 2017). The flow of urbanization that has occurred in Pati Regency has become one of the factors causing flooding in the area (Handayani et al., 2020). The process of urbanization, which involves the movement of people from rural to urban areas, has led to an increase in population density in urban areas. This has an impact on increasing the need for infrastructure and development, such as building houses, roads and other public facilities. As a result, green land and water absorption areas are reduced significantly, increasing the risk of flooding when the rainy season arrives. In addition, inadequate drainage systems to handle the increasing volume of water resulting from urbanization also contribute to flooding problems. Another cause of flooding is climate change resulting in deviations in rainfall patterns and rising sea levels (Rudiarto et al., 2018).

To deal with flooding problems in Pati Regency efforts that need to be made are not only disaster mitigation activities related to the community, but efforts also need to be made to map

areas that are susceptible to flooding. One effective way to map susceptibility to flood is through digital mapping using Geographic Information Systems, which helps identify areas that have the potential for flood disasters. The research aims to conduct a flood susceptibility analysis in the Pati Regency area to determine the classification of flood susceptibility levels and map locations that are susceptible to flooding using the Analytical Hierarchy Process (AHP) combined with a Geographic Information System (GIS). This research uses ten factors that influence flood susceptibility, there are Topographic Wetness Index (TWI), Elevation, Slope, Precipitation, Land Use or Land Cover (LULC), Normalized Difference Vegetation Index (NDVI), Distance from Rivers, Distance from Roads, Drainage Density, and Soil Type.

RESEARCH METHODS

The study area of this research is Pati Regency, Central Java Province as seen in Figure 1. There are several types of data used in this research. The first data is SRTM Digital Elevation Model (DEM) data (OpenTopography, 2013). The DEM data is processed to obtain the Topographic Wetness Index (TWI), Elevation, Slope, and Drainage Density factors. The second data is data from the Climate Hazards Center InfraRed Precipitation with Station data (CHIRPS) which is processed into a precipitation factor. The third data is Sentinel 2 data which is processed into Land Use or Land Cover (LULC) factors (Karra et al., 2021). The fourth data is Landsat 8 image data which is processed into the Normalized Difference Vegetation Index (NDVI) factor. The sixth data is Rupa Bumi Indonesia (RBI) from the Geospatial Information Agency (BIG) which is processed into factors such as Distance from Rivers and Distance from Roads. Next, the FAO-UNESCO Soil Map of the World data is the Soil Type factor.

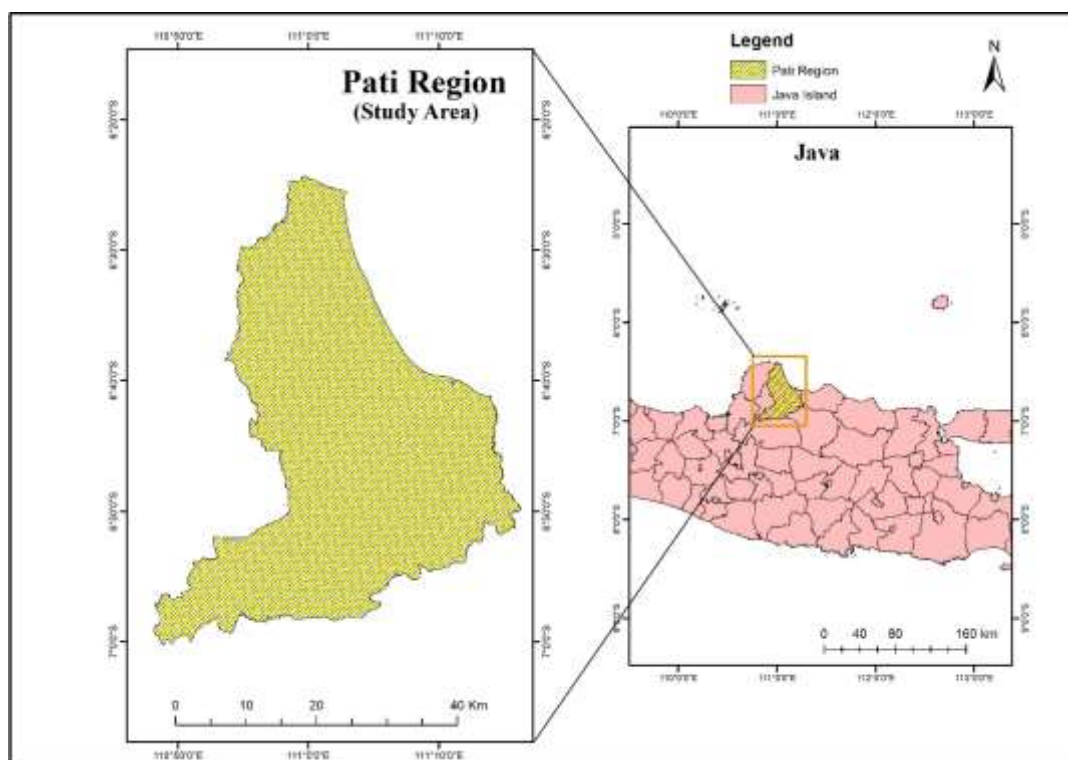


Figure 1. Study Area

After each data is collected and processed into flood susceptibility factors, the next step is factor classification and scoring. The score given to each factor is determined based on how much influence it has on flood susceptibility. Factors with higher scores indicate a greater

influence on flood occurrence. The classification and score of each factor can be seen in Table 1 to Table 10. There are five classifications of flood susceptibility, there are very low (score 1), low (score 2), moderate (score 3), high (score 4), and very high (score 5).

Table 1. Topographic Wetness Index classification

No	Topographic Wetness Index	Score
1	-4.33 - -1.44	1
2	-1.43 - -0.08	2
3	-0.07 - 1.39	3
4	1.4 - 3.57	4
5	3.58 - 10.7	5

Source: (Tolosa et al., 2019)

Table 2. Elevation classification

No	Elevation (m)	Score
1	<10	5
2	10.01 - 50	4
3	50.01 - 100	3
4	100.01 - 200	2
5	>200	1

Source: (Septian et al., 2023)

Table 3. Slope classification

No	Slope (%)	Score
1	0-8	5
2	8.01 - 15	4
3	15.01 - 25	3
4	25.01 - 40	2
5	> 40	1

Source: (Rahmanizah et al., 2023)

Table 4. Precipitation classification

No	Precipitation (mm/month)	Score
1	> 500	5
2	401 - 500	4
3	301 - 400	3
4	201 - 300	2
5	<200	1

Source: (Rahmanizah et al., 2023)

Table 5. Land Use or Land Cover classification

No	Land Use or Land Cover	Score
1	River, Urban	5
2	Agriculture land	4
3	Wetland, shrubs, bare land	3
4	Low vegetation	2
5	Mixed forest	1

Source: (Swain et al., 2020)

Table 6. Normalized Difference Vegetation Index classification

No	Normalized Difference Vegetation Index	Score
1	<-0.02	5
2	-0.02 - 0.30	4
3	0.31 - 0.40	3
4	0.41 - 0.50	2
5	0.51 - 1	1

Source: (Swain et al., 2020)

Table 7. Distance from Rivers classification

No	Distance from Rivers (m)	Score
1	0 - 50	5
2	51 - 100	4
3	101 - 250	3
4	251 - 500	2
5	>500	1

Source: (Rahmanizah et al., 2023)

Table 8. Distance from Roads classification

No	Distance from Roads (m)	Score
1	0 - 25	5
2	26 - 50	4
3	51 - 100	3
4	101 - 150	2
5	>150	1

Source: (Swain et al., 2020)

Table 9. Drainage Density classification

No	Drainage Density (m/km ²)	Score
1	0-150	1
2	151 - 210	2
3	211 - 250	3
4	251 - 300	4
5	>300	5

Source: (Osman & Das, 2023)

Table 10. Soil Type classification

No	Soil Type	Score
1	Alluvial, Planosol, Gray hydromorph, Lateric groundwater	5
2	Latosol	4
3	Mediterranean soil, brown forest soil	3
4	Andosol, Laterik, Grumusol, Podsol, Podsollic	2
5	Regosol, Litosol, Organosol, Renzina	1

Source: (Rahmanizah et al., 2023)

After getting the classification and score for each factor, the next step is to carry out the weighting process for each flood susceptibility factor using the Analytical Hierarchy Process method. The final step is to overlay the ten factors based on weighting values to obtain the level of flood susceptibility.

RESULT AND DISCUSSION

The results of weighting using the Analytical Hierarchy Process (AHP) method are shown in Figure 2. The allocation of weights for each factor is as follows: Topographic Wetness Index (TWI) at 13.78%, Elevation at 12.07%, Slope at 9.90%, Precipitation at 13.45%, Land Use or Land Cover (LULC) at 6.62%, Normalized Difference Vegetation Index (NDVI) at 5.87%, Distance from Rivers at 14.08%, Distance from Roads at 5.59%, Drainage Density at 9.32%, and Soil Type at 9.32%. These weights reflect the relative contribution of each factor to flood susceptibility in the study area. Distance from the rivers obtains the highest weight, indicating a significant influence on flood potential, followed by the Topographic Wetness Index (TWI) and Precipitation, which also have substantial impacts in determining flood susceptibility. Conversely, Land Use or Land Cover (LULC) and Normalized Difference Vegetation Index (NDVI) are given lower weights, portraying a smaller role in contributing to flood susceptibility. The weighting derived from this Analytical Hierarchy Process (AHP) is utilized to create a flood susceptibility map.

Matrix											normalized principal Eigenvector
	TWI	Elevation	Slope	Precipitation	LULC	NDVI	Distance from river	Distance from road	Drainage density	Soil type	
TWI	1	1	1	1	3	5	1	3	1	1	13.78%
Elevation	2	1	1	1	2	3	1	3	1	1	12.07%
Slope	3	1	1	1	3	1	1/2	1	1	1	9.90%
Precipitation	4	1	1	1	3	2	2	3	1	1	13.45%
LULC	5	1/3	1/2	1/3	1	1	1/3	3	1	1	6.62%
NDVI	6	1/5	1/3	1	1/2	1	1/5	1	1	1	5.87%
Distance from river	7	1	2	1/2	3	5	1	3	1	1	14.08%
Distance from road	8	1/3	1/3	1	1/3	1	1/3	1	1	1	5.59%
Drainage density	9	1	1	1	1	1	1	1	1	1	9.32%
Soil type	10	1	1	1	1	1	1	1	1	1	9.32%

Figure 2. The result of AHP Weighting

The mapping results of the Topographic Wetness Index (TWI), Elevation, Slope, and Precipitation of Pati Regency are presented in Figure 3. It can be observed that Pati Regency is predominantly characterized by low Topographic Wetness Index (TWI) values. Low Topographic Wetness Index (TWI) values indicate a low level of flood susceptibility. The mapping results of the Elevation in Pati Regency indicate that it has many low elevations, implying higher susceptibility to floods. The mapping results of the Slope in Pati Regency indicate that many areas have low slope values. Low Slope values imply a high level of flood susceptibility. The mapping results of Precipitation in Pati Regency show that the region has two classifications, there are 0-200 mm/month (very low flood vulnerability) and 201-300 mm/month (low flood vulnerability).

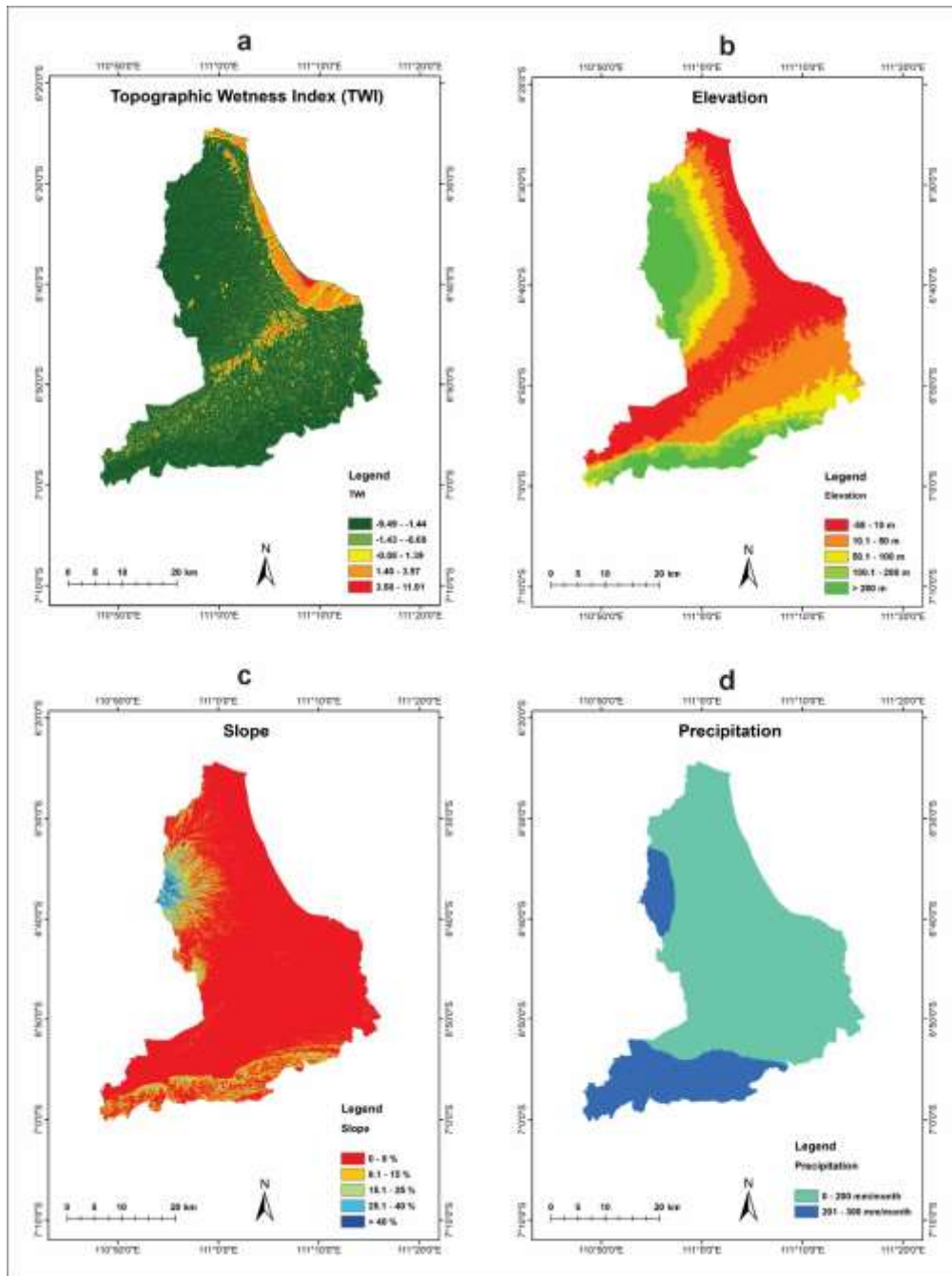


Figure 3. a) Topographic Wetness Index (TWI) Map, b) Elevation Map, c) Slope Map, d) Precipitation Map

The mapping results of Land Use or Land Cover (LULC), Normalized Difference Vegetation Index (NDVI), Distance from Rivers, and Distance from Roads in Pati Regency are presented in Figure 4. The mapping results of Land Use or Land Cover (LULC) show that Pati Regency has five classifications. Rivers and settlements with very high flood susceptibility are mostly located on the northern side. The mapping results of the Normalized Difference Vegetation Index (NDVI) in Pati Regency indicate values ranging from -0.02 to 0.3, which means high flood susceptibility. The mapping results of Distance from River reveal that Pati Regency has numerous rivers, resulting in many areas with very high flood susceptibility. The mapping results of Distance from Road in Pati Regency indicate that areas close to roads have high flood susceptibility.

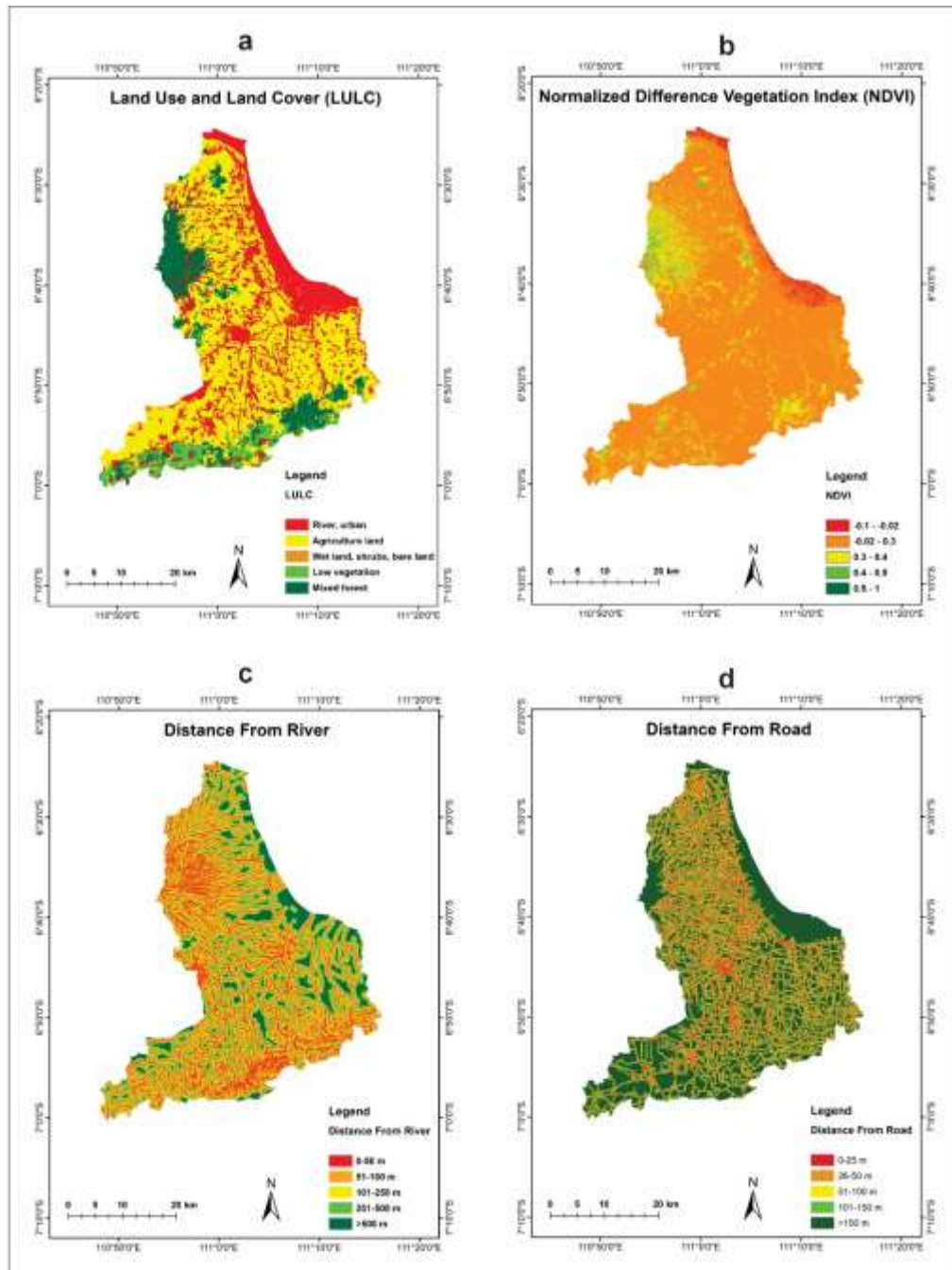


Figure 4. a) Land Use or Land Cover (LULC) Map, b) Normalized Difference Vegetation Index (NDVI) Map, c) Distance from Rivers Map, d) Distance from Roads Map

The mapping results of Drainage Density and Soil Type in Pati Regency are presented in Figure 5. In the Drainage Density map of Pati Regency, the region is predominantly characterized by areas with low Drainage Density, indicating low flood susceptibility. Some areas exhibit high Drainage Density, correlating to high flood susceptibility. The mapping results of Soil Type in Pati Regency show four classifications. Very low flood susceptibility by Litosol, Organosol, and Renzina. Low flood susceptibility by Andosol, Laterik, Grumusol, Podsol, Podsollic. High flood susceptibility by Mediterranean soil. Very high flood susceptibility by Alluvial, Planosol, Gray hydromorph, Lateric groundwater.

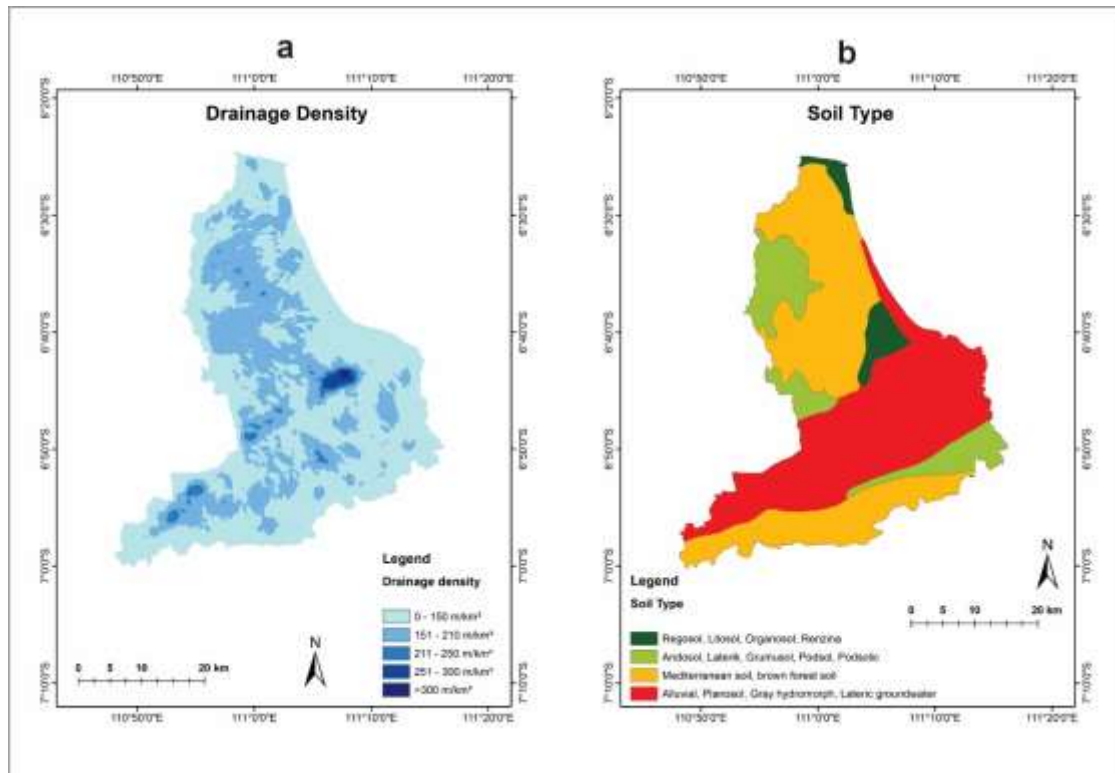


Figure 5. a) Drainage Density Map, b) Soil Type Map

The results of flood susceptibility mapping in Pati Regency are presented in Figure 6. The results of research conducted on flood susceptibility in Pati Regency show the distribution and level of flood vulnerability in the area. From the results of this research, it was identified that there are four different categories of flood vulnerability levels. First, the level of flood vulnerability is low which covers around 3.47% of the Pati Regency area, indicating areas where the risk of flooding is relatively smaller compared to other areas. The low flood susceptibility level predominantly exists in high elevations. Second, the moderate level of flood vulnerability, which is the dominant category, covers 64.85% of the Pati Regency area. This indicates that most of Pati Regency is at risk of moderate-intensity flooding, where the impact of flooding can vary but is not too severe. Third, the level of flood susceptibility is high which covers 31.62%. Moderate and high flood susceptibility levels are evenly spread across nearly all areas of Pati Regency. Fourth the level of very high flood vulnerability covers 0.07%. This indicates an area that is highly susceptible to flooding with impacts that can be very detrimental. The very high flood vulnerability level is concentrated in the central region of Pati Regency.

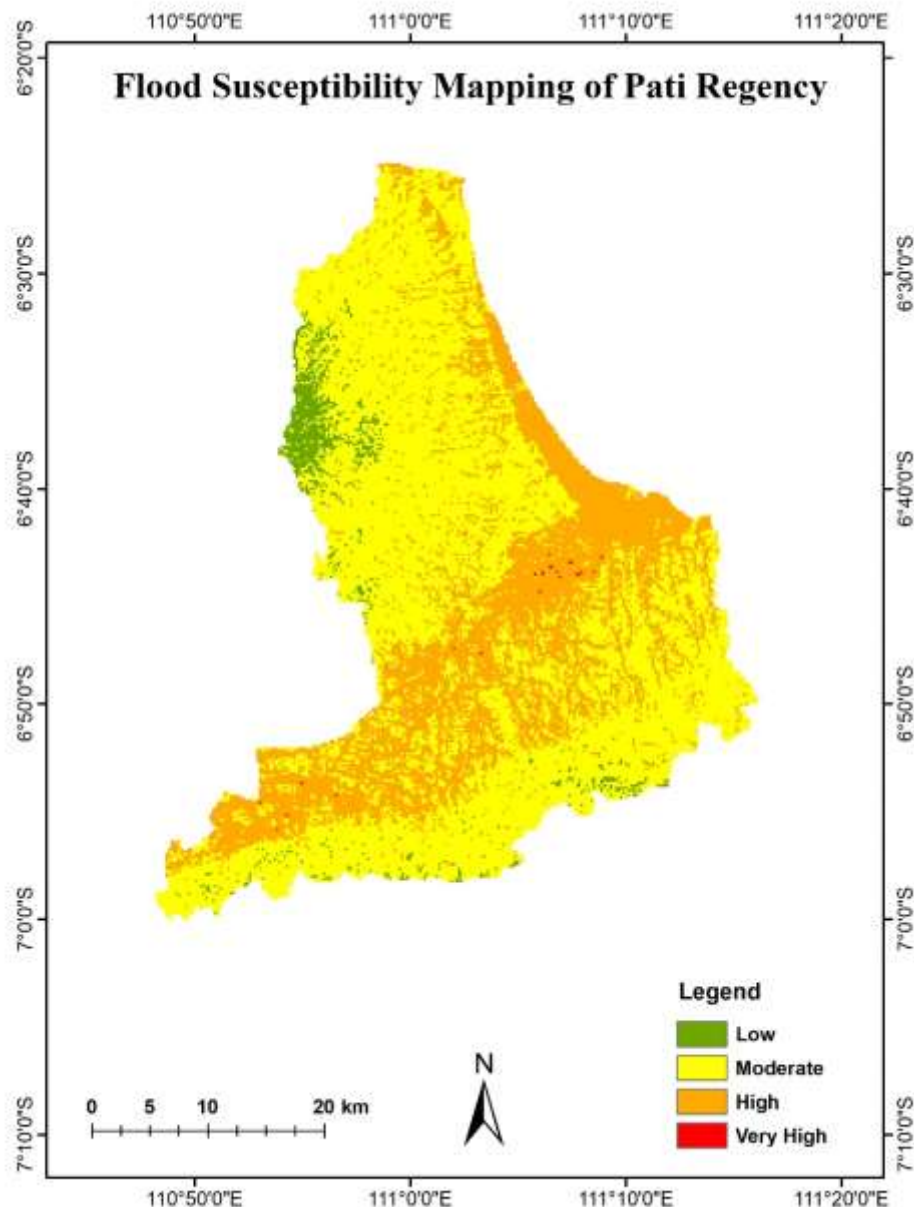


Figure 6. Flood Susceptibility Mapping of Pati Regency

CONCLUSION

Pati Regency has four flood susceptibility levels there are low level reaching 3.47%, moderate level reaching 64.85%, high level reaching 31.62%, and very high level reaching 0.07%. The low flood susceptibility level predominantly exists in high elevations. Moderate and high flood susceptibility levels are evenly spread across nearly all areas of Pati Regency. The very high flood vulnerability level is concentrated in the central region of Pati Regency. This research aims to provide insights to the local government to aid in designing policies regarding flood risk reduction efforts. The approach used in this study holds the potential to be applied in

analyzing other disaster risks, aiming to achieve better understanding and more directed decision-making.

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