Mapping Flood-Prone Areas Based on Geographic Information System Using Composite Mapping Analysis

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Abstract

Floods are destructive, very detrimental, and require a long time to recover. To overcome the impact of flooding on the people of East Aceh Regency, research related to the mapping of flood-prone areas in East Aceh District. In the mapping process using Quantum Geographic Information System (QGIS) Desktop and the research methodology used is Composite Mapping Analysis (CMA) which consists of the process of determining the class of each parameter, determining the weight of each parameter by combining each parameter which includes the scoring process for each parameter, then overlaying the parameters used, performing calculations and producing a relative weight or spatial mean, and combining the spatial mean to produce a value for the weight of each flood parameter. The results of the study obtained the weight of rainfall of 23.85%; land slope parameter of 27.25%; the land height parameter is 24.7%5 and the flow density parameter is 24.15%, and the result is that the area of flood-prone areas has been divided into 3 classes, that is the very vulnerable class has an area of 230.099 ha (42.6%), the vulnerable class has an area of 224.732 ha (41.6%), and the bit vulnerable class has an area of 85.416 ha (15.8%).

Keywords: Mapping Flood, GIS, Composite Mapping Analysis, QGIS

1. Introduction

Meteorological factors that influence the occurrence of floods are the intensity, distribution, frequency, and time frame of the rain. Climate change has an impact on changes in temperature, rainfall, and evapotranspiration. This can cause several things, including changes in the hydrological cycle, reducing lake levels and affecting watershed water availability [1]. The physical characteristics of the watershed that affect the occurrence of flooding are the area of the watershed, the slope of the land, the elevation, the water content of the soil and soil features [2]. Areas that are relatively flat and have large watersheds are physical factors in the area that causes flooding [3] [4] and [5]. Indonesia is prone to various natural disasters due to its geographic location and topographic conditions [6]. According to data from the Agency of National Disaster Management (BNPB) Geospatial field, from January-August 2020 there have been approximately 726 flood disasters in all regions in Indonesia. This of course has a fatal impact on public safety. Lack of information about flood-prone areas is also one of the factors contributing to a large number of casualties and material losses. Based on data from the Agency of Regional Disaster Management (BPBD) East Aceh, as many as 226 villages in East Aceh are prone to flooding during the rainy season [7]. Many impacts or damage are caused by floods [8]. If there is a lack of spatial information, it can increase the impact and damage in the future.

To reduce or overcome the impact caused by the flood disaster on the comfort and safety of the people in East Aceh Regency, one of the efforts that can be made is to identify flood-prone areas by using an approved Geographic Information System (GIS). The results of the analysis can be used as a reference to improve community preparedness and can be used as a basic reference in making prevention efforts from the East Aceh Regency Government against the presence of areas indicated by flooding and the results of the analysis will be implemented and visualized into a web-based GIS [9] and [10].

GIS is a system that can be used as a spatial decision support system. Spatial data is geographically referenced data or a representation of earth objects. Spatial data consists of 2 formats, namely raster data and vector data. Raster format data has a grid/cell/pixel. Vector data itself has the form of points, lines and polygons. The ability to manage large data sets from multiple sources, formats, and scales supports analysts to approach environmental studies in different ways [11]. Non-spatial data is attribute data from spatial data which contains a description of spatial data. Non-spatial data is presented in tabular form, while spatial data is geographically referenced data or is usually referred to as a map. The function of the map is to provide an indication of the position or location on the earth's surface, show the shape of the earth's surface, show the size of the earth's surface, and show the potential of an area to support the regional income and as risk management in taking natural disaster mitigation policies and others. The purpose of maps in general is to convey information, analyse spatial data, store information, and assist in making designs such as residential roads, transportation routes, and others [12]. Quantum GIS (QGIS) is an open-source GIS processing software that is user-friendly [13]. QGIS can be run on various operating systems, for example, Linux, Unix, Mac, OSX, Windows, and Android. QGIS has many formats and functionality in vector, raster, and databases [14].

2. Method

This research was conducted in the Regency of East Aceh. East Aceh Regency has an area of 6,040.60 Km^2 or 10.53 % of the total area of Aceh Province, Indonesia (Figure 1).

The data used in this research are a map of Rupa Bumi Indonesia (RBI), 30 m spatial resolution Digital Elevation Model (DEM) derived from Shuttle Radar Topography Mission (SRTM). December 2021 rainfall data, and flood incidents data in East Aceh Regency during 2016-2021. To analyze flood-prone areas, the Composite Mapping Analysis (CMA) method is used, the process of which combines several layers of spatial data to create important correlations in the relationship between spatial data. Spatially, the CMA method uses polygon overlay functions or manipulates rasters from a GIS. In conducting data analysis, it takes the weight value of each parameter used, and each of these parameters has its classification class or a scoring process will be carried out later. Determining the weight of the flood parameter is done by using a composite method. In the process of the CMA method, a ranking or scoring process is carried out for each parameter that causes flooding in which the score refers to previous research.

After the process is complete, it will produce the area (ha) of the distribution of the flood area and the area of the flood-prone area. Furthermore, the merging process will be carried out which is an analytical technique to find and record areas covered by two different themes and later will obtain the relative weight or spatial mean. Next, a composite process will be carried out for each parameter, and the weight of each parameter that causes flooding will be obtained [15].

3. Result and Discussion

3.1 Map Layout

Based on Figure 2, this is a rainfall map that is the result of processing the average daily rainfall data in December 2021 using the ArcGIS application. The following are the stages of processing rainfall data: a) Plot rainfall points, b) input rainfall points into ArcGIS, c) interpolate rainfall points, and d) spatial data modelling. The consideration of rainfall as a factor in flood susceptibility analysis is a must since we cannot think about flood occurrence without it. It is the most crucial triggering factor for the occurrence of floods because flood inundation is due to a huge volume of runoff flows as a result of excessive heavy rainfall or prolonged rainfall [16] and [17]. Rainfall values range from 3-7 mm/day, the darker the blue colour, the higher the average daily rainfall value, the higher the risk of flooding.

Based on Figure 3, this is a map of the slope of the land which is the result of data processing or SRTM-DEM analysis. The shaded area symbol that has a color in the legend shows that starting from green which has a land slope value of 0-8%, it is an area with a low land slope but has the highest flood risk in its class and is moving towards red which has a land slope value of more than 45%. which shows that the percentage of the land slope is higher but the risk of flooding will be lower. The slope of the land controls the velocity of surface water flow. As the slope decreases, the velocity of surface water flow decreases, and the amount of water over the land and the probability of a flood increases [18] [19] and [20].

Based on Figure 4, this is an elevation map that is the result of data processing or SRTM-DEM analysis.

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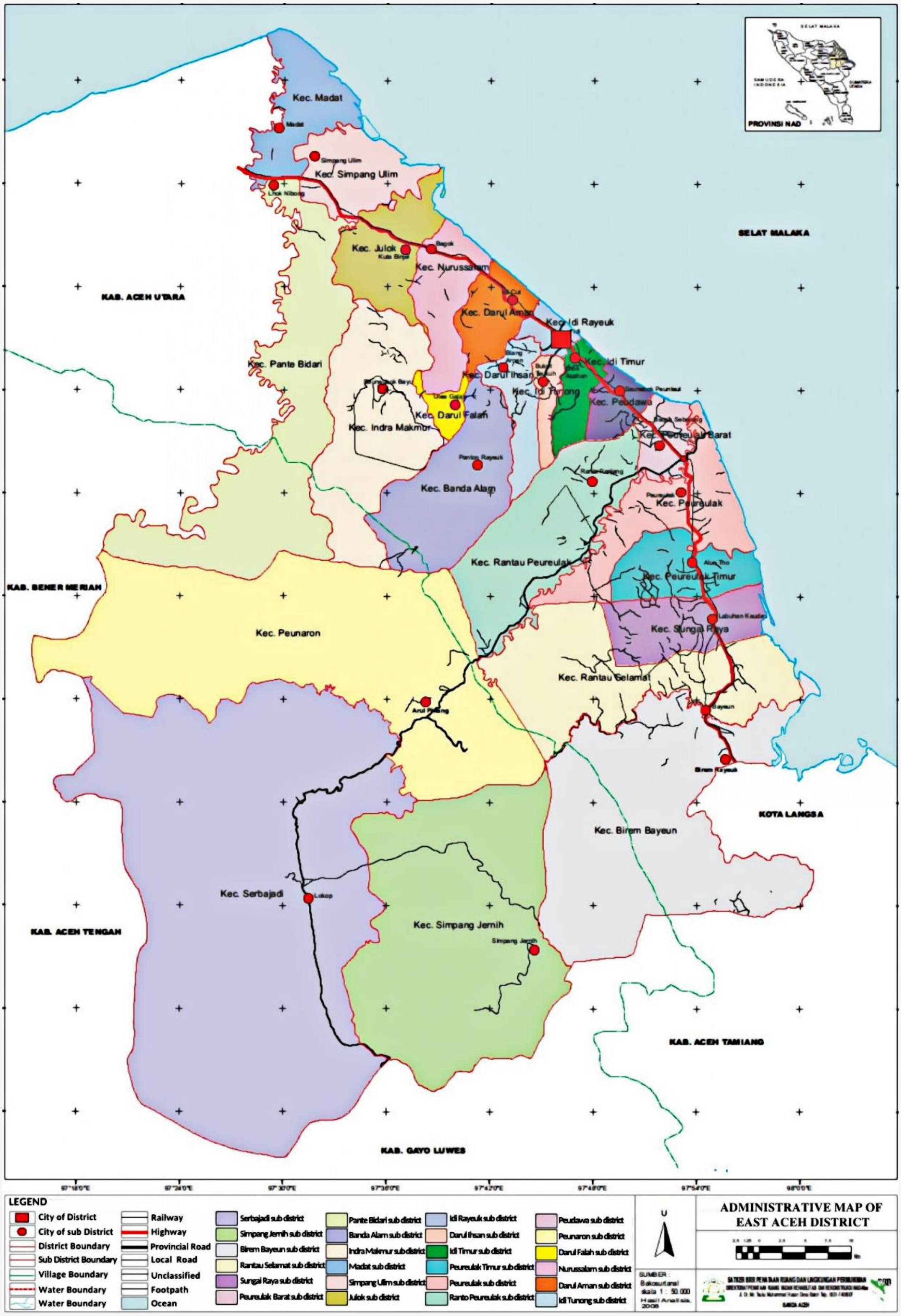

Figure 1: Map of research location in East Aceh Regency

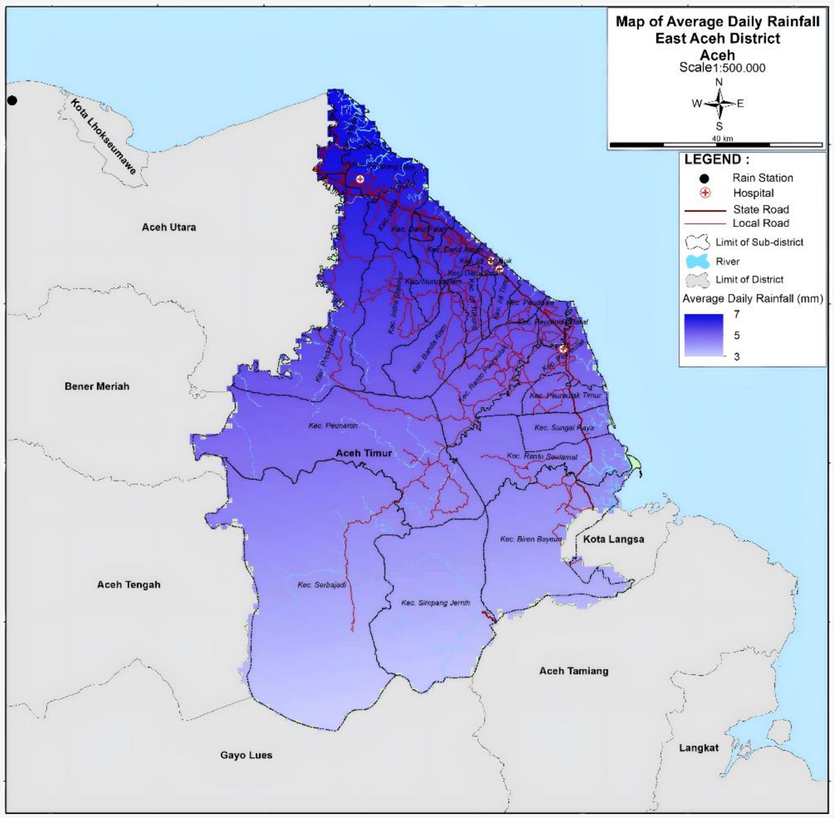

Figure 2: Rainfall map

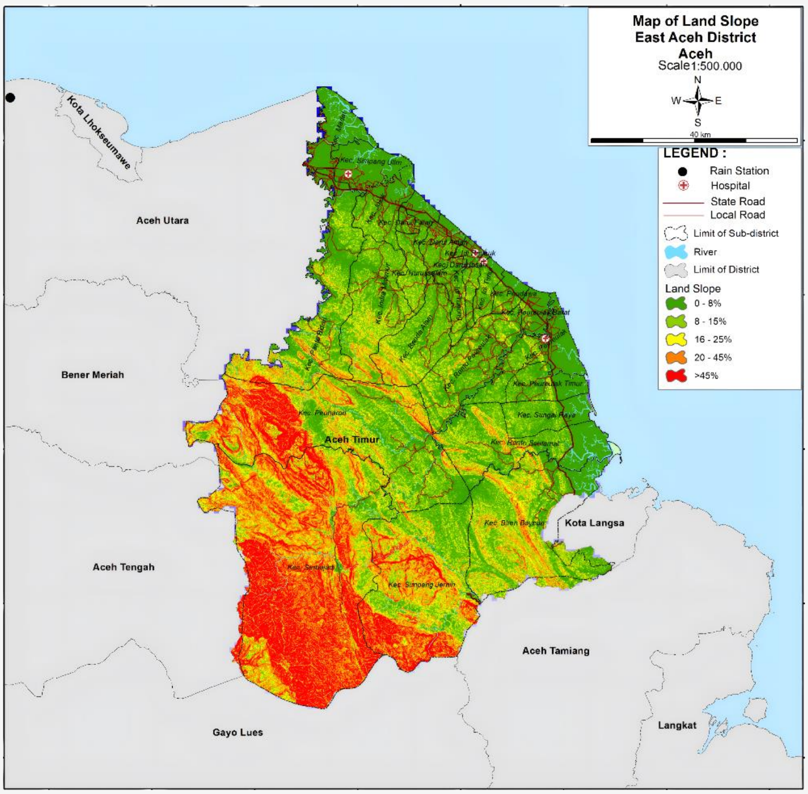

Figure 3: Land slope map

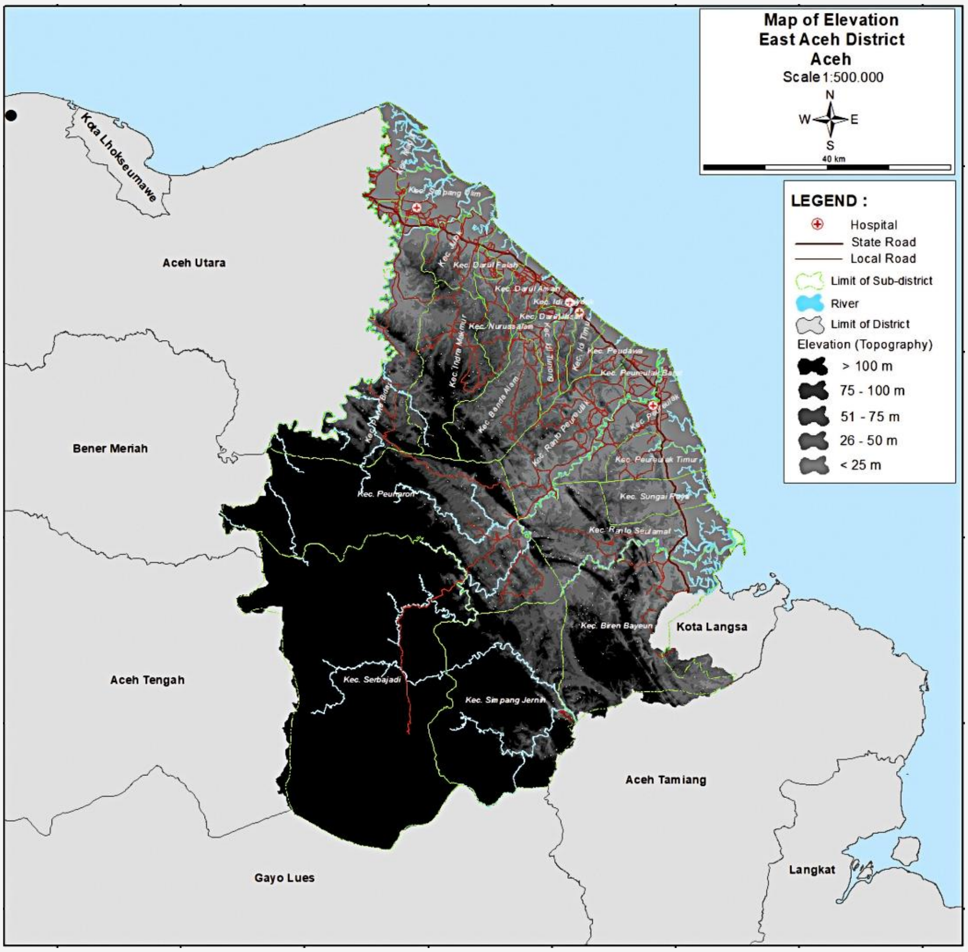

Figure 4: Elevation map

The shaded area symbol that has a color in the legend shows that starting from red which has a land height value of more than 100 m, it is an area with a high land height but has a non-risk flood in its class and is moving towards green which has a land height value of less than 25 m. which shows that the percentage of land height is lower but the risk of flooding will be high. It can be seen on this altitude map, that the area that belongs to the high vulnerability class is an area that is very close to the coast. Generally, the lower elevated areas have a higher probability of flood occurrences compared to higher elevated areas because lower elevated areas have comparatively higher river discharge and get flooded faster by the flow of high water [21] and [22]. Based on Figure 5, this is a flow density map which is the result of data processing for watersheds (watersheds) and SRTM-DEM analysis [23]. The blue line symbol shows the river and the gray symbol shows the boundaries between other Regencys.The shading symbol for the flow density area per watershed which has a color in the legend indicates that starting from a light blue color which has a density value of very rarely has the high risk of vulnerability in its class, and the darker blue color indicates that the area has a flow density value. very dense, where the area has a non-risk of vulnerability.

3.2 Determination of Flood Parameter Weight

To calculate the parameter weights of the 4 parameters used (rainfall parameters, land slope parameters, altitude parameters, and flow density parameters) the first step to calculate the weights using the CMA method is to first overlay the 4 parameters used, overlay the 4 parameters are processed using QGIS software to produce a flood hazard map.

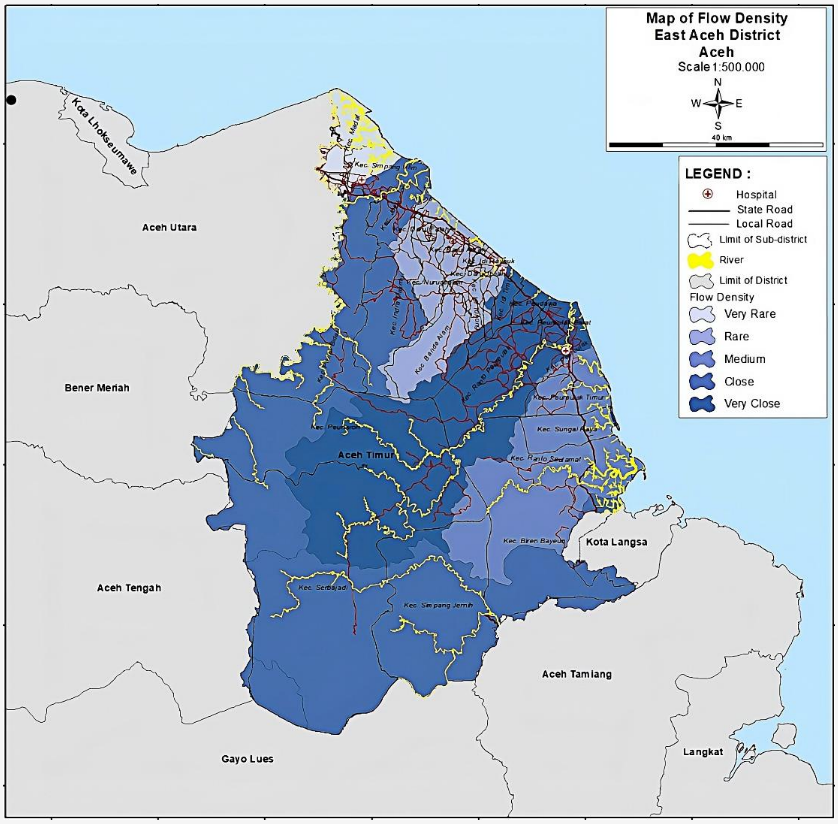

Figure 5: Flow density map

After the process of overlaying the flood incident map and the flood susceptibility map to produce a map of flood-prone areas, the next step is to obtain the parameter weights of each parameter that causes flooding, calculating the spatial mean of the 4 parameters that cause flooding, namely rainfall parameters, land slope parameters, altitude parameters, and flow density parameters. The following is the calculation of the spatial mean of each of these parameters. The results of the calculation of the spatial mean are then used to calculate the weights of all the parameters that cause flooding as presented in equation 1.

$$Weight = \frac{Mean\ Spatial\ (Variable)}{Total\ Mean\ Spatial} \times 100$$

Equation 1

To get the value of flood vulnerability and classify it into 3 classes of vulnerability, namely high, moderate, and non, the calculation process is carried out with equation 2

$$C = w_1x_1 + w_2x_2 + w_nx_n$$

Equation 2

Where:

C = Flood vulnerability
w_1 = Flood incident parameter weight
x_1 = Score of the flood-causing parameter
i/n = Parameters total

After getting the value of the total number of parameter scores, then the value of the x parameter scores is added up according to the class score, then the results are added up with the total flood incidence, resulting in the highest value data and the lowest value data. After getting the highest data value and the lowest data value, the interval width of the three vulnerability classes is determined from equation 3.

$$K_i = \frac{Xt - Xr}{K}$$

Equation 3

Where:

Ki = Interval width
Xt = Highest data
Xr = Lowest data
K = Interval numbers

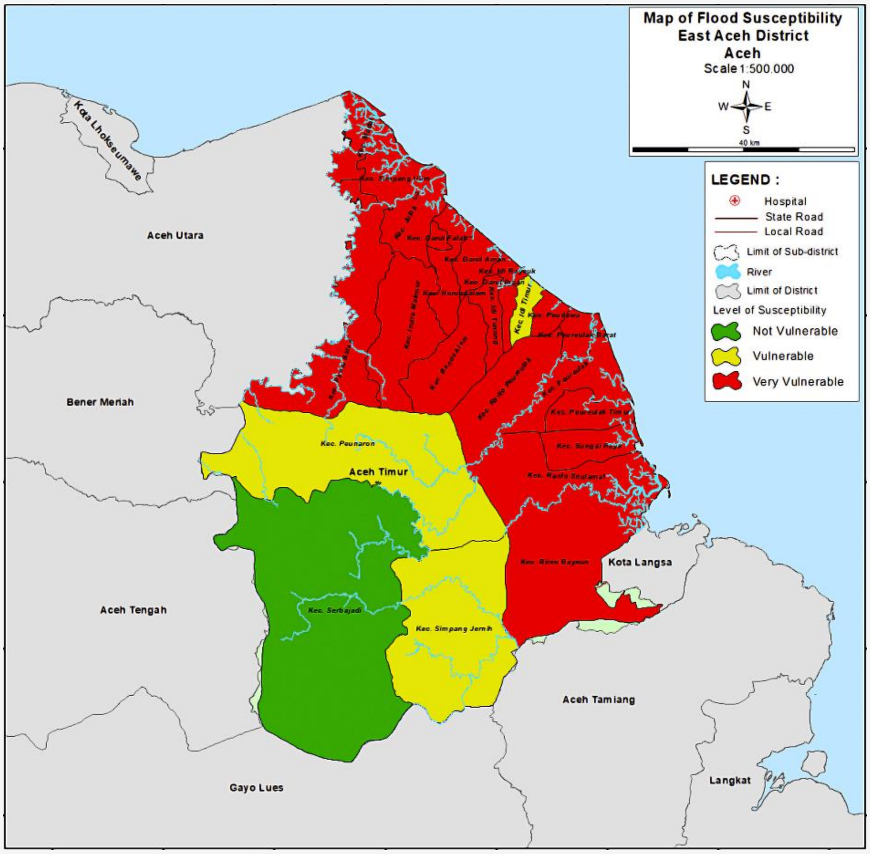

Figure 6: Flood hazard map

Based on Figure 6, the shaded symbol for the area that has green color indicates that the area has a low level of vulnerability, the yellow color indicates that the area has a high level of vulnerability, and the red color indicates that the area has a very vulnerable level of vulnerability. Furthermore, the flood susceptibility map is overlaid with a flood incident map which is a map resulting from data processing of flood incidents in East Aceh Regency in 2016-2021 obtained from the BPBD (Regional Disaster Management Agency) of East Aceh Regency. It can be seen in Figure 7, that the regional shading symbol shows the number of times flooding has occurred in a sub-Regency in 6 years. The gray color shows the number of flood incidents 0-3 times, the orange color shows the number of flood incidents 4-16 times, the green color shows the number of flood incidents 16-25 times, and the blue color shows the number of flood incidents 26-39 times, the red color shows the number of flood incidents. flood incidents 40-58 times. Based on the analysis, obtained from flood recapitulation data for 2016-2021 East Aceh Regency, Peureulak sub-Regency, Ranto Peureulak sub-Regency, and Idi Tunong sub-Regency are the 3 sub-Regencys most frequently hit by floods in East Aceh Regency, the intensity of the incident reaches 40-58 times.

The process of overlaying flood susceptibility maps and flood incident maps results in a map of flood-prone areas as shown in Figure 8. The black line symbol shows the boundaries between sub-Regencys, the blue line symbol shows the river and the gray symbol shows the boundaries between other Regencys. The shaded area symbol that has yellow color indicates that the area has a low level of vulnerability, the orange color indicates that the area has a high level of vulnerability, and the red color indicates that the area has a very vulnerable level of vulnerability. The results of the analysis of flood-prone areas in the East Aceh Regency are divided into 3 classes, namely very vulnerable, vulnerable, and not vulnerable classes. The sub-Regencys that are classified as very vulnerable include: Darul Falah sub Regency, Nurussalam sub Regency, Pante Bidari sub Regency, Ranto Peureulak sub Regency, Juloksub Regency, Banda Alam sub Regency, Peudawa sub Regency, Peureulak sub Regency, Sungai Raya sub Regency, Peureulak

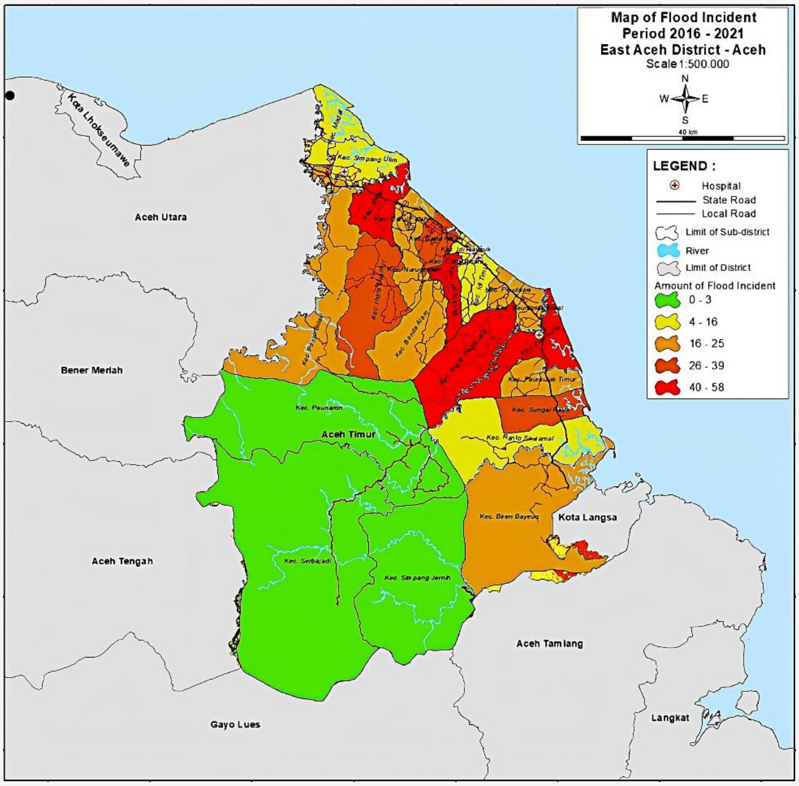

Figure 7: Flood incident map

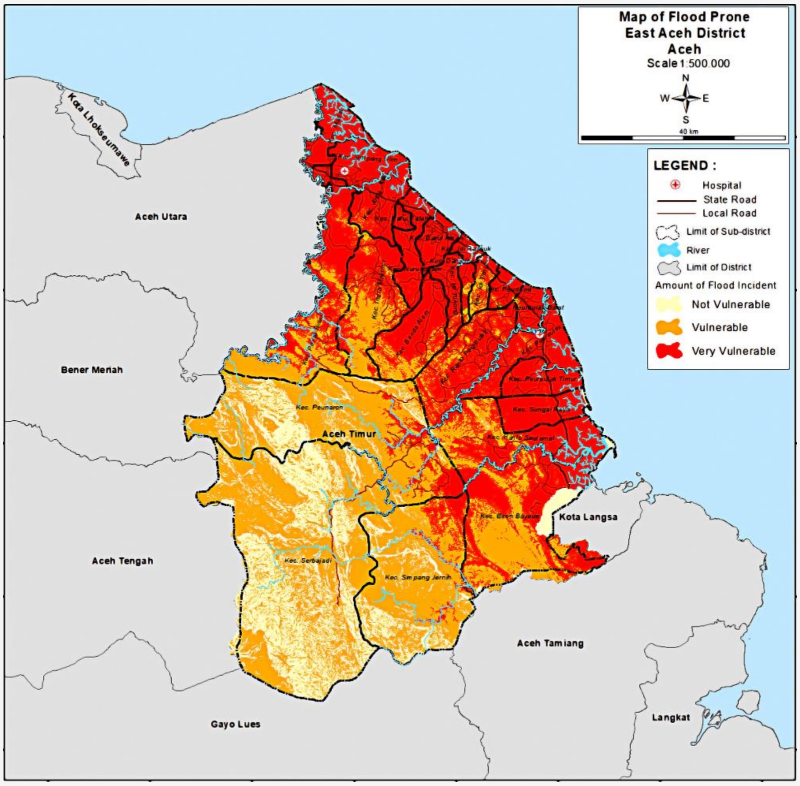

Figure 8: Flood prone map East Aceh Regency

Table 1: Calculation of the spatial mean of rainfall parameters

Daily Average Rainfall (mm)	Area (ha)	Flood Prone (ha)	Flood Prone Ratio	Flood Prone Area Ratio
<20	540,246.94	460,372.04	0.85	1.00
21-40	-	-	-	-
41-75	-	-	-	-
75-150	-	-	-	-
>150	-	-	-	-
Total	**540,246.94**	**460,372.04**	***Mean Spatial***	**0.85**

Table 2: Calculation of spatial mean of land slope parameter

Land Slope	Area (ha)	Flood Prone (ha)	Flood Prone Ratio	Flood Prone Area Ratio
45%	66,968.97	877.30	0.01	0.00
26-45%	82,903.16	68,387.45	0.82	0.15
16-25%	80,866.47	81,110.63	1.00	0.18
8-15%	112,366.38	112,610.56	1.00	0.24
0-8%	197,141.96	197,386.11	1.00	0.43
Total	**540,246.94**	**460,372.04**	***Mean Spatial***	**0.97**

Table 3: Calculation of spatial mean from elevation parameter

Elevation (m)	Area (ha)	Flood Prone (ha)	Flood Prone Ratio	Flood Prone Area Ratio
>100	248,609.88	167,332.95	0.67	0.36
75-100	38,198.69	38,508.76	1.01	0.08
51-75	60,203.14	60,592.68	1.01	0.13
26-50	80,593.31	80,976.64	1.00	0.18
<26	112,641.92	112,961	1.00	0.25
Total	**540,246.94**	**460,372.04**	***Mean Spatial***	**0.88**

Table 4: Calculation of spatial mean from flow density parameter

Flow Density	Area (ha)	Flood Prone (ha)	Flood Prone Ratio	Flood Prone Area Ratio
Very tight	136,948.26	114,144.35	0.83	0.25
Tight	261,112.20	203,062.68	0.78	0.44
Medium	80,275.02	80,257.87	1.00	0.17
Rare	45,996.17	46,492.95	1.01	0.10
Very Rare	15,915.29	16,414.18	1.03	0.04
Total	**540,246.94**	**460,372.04**	***Mean Spatial***	**0.86**

Table 5: The results of the calculation of the weight of the parameters that cause flooding Using CMA method

No	Flood Parameters	*Mean Spatial*	Weight
1	Rainfall	0.85	23.85
2	Land Slope	0.97	27.25
3	Elevation	0.88	24.75
4	Flow Density	0.86	24.15

Table 6: Total score of flood vulnerability parameter value

Score Class (x)	Rainfall (w_1)	Land Slope (w_2)	Elevation (w_3)	Flow Density (w_4)	Flood incident (w_5)	Total
1	23.85	27.25	24.75	24.15	3	103
2	-	54.5	49.5	48.3	16	168.3
3	-	81.75	74.25	72.45	25	253.45
4	-	109	99	96.6	39	343.6
5	-	136.25	123.75	120.75	58	438.75

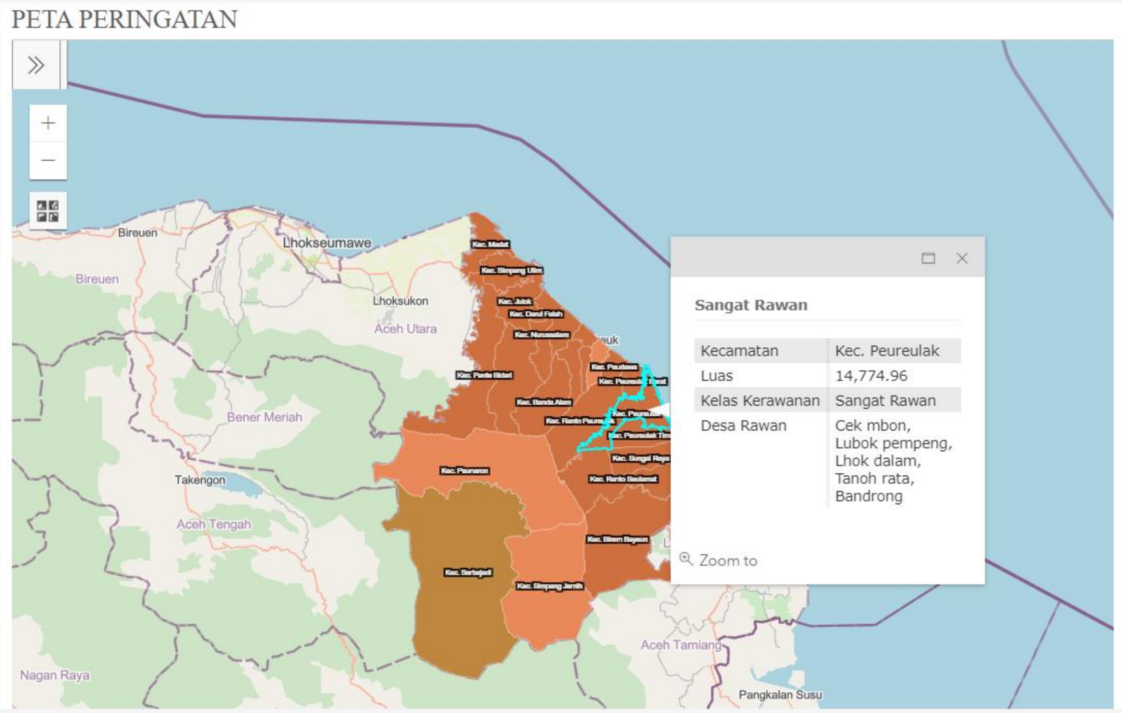

Figure 9: Area identification of highly vulnerable

Timur sub Regency, Idi Rayeuk sub Regency, Idi Tunong, Simpang Ulim sub Regency, Indra Makmur sub Regency, Darul Aman sub Regency, Birem Bayeun, Peureulak Barat sub Regency, Darul Ihsan sub Regency, Madat sub Regency, and Rantau Selamat sub Regency. Sub Regencys belonging to the vulnerable class include Simpang Jernih sub Regency, Peunaron sub Regency, and Idi Timur sub Regency. The sub-Regencys that are included Peureulak Timur, Idi Rayeuk, Idi Tunong, Simpang Ulim, Indra Makmur, Darul Aman, Birem Bayeun, Peureulak Barat, Darul Ihsan, Madat, and Rantau Selamat.

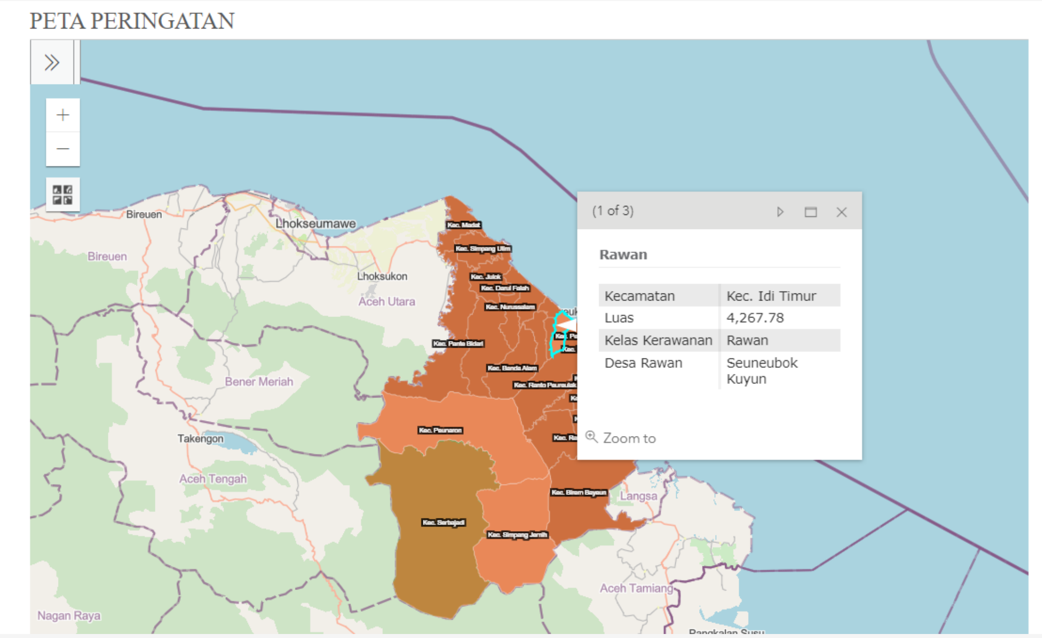

Figure 10: Area identification vulnerable

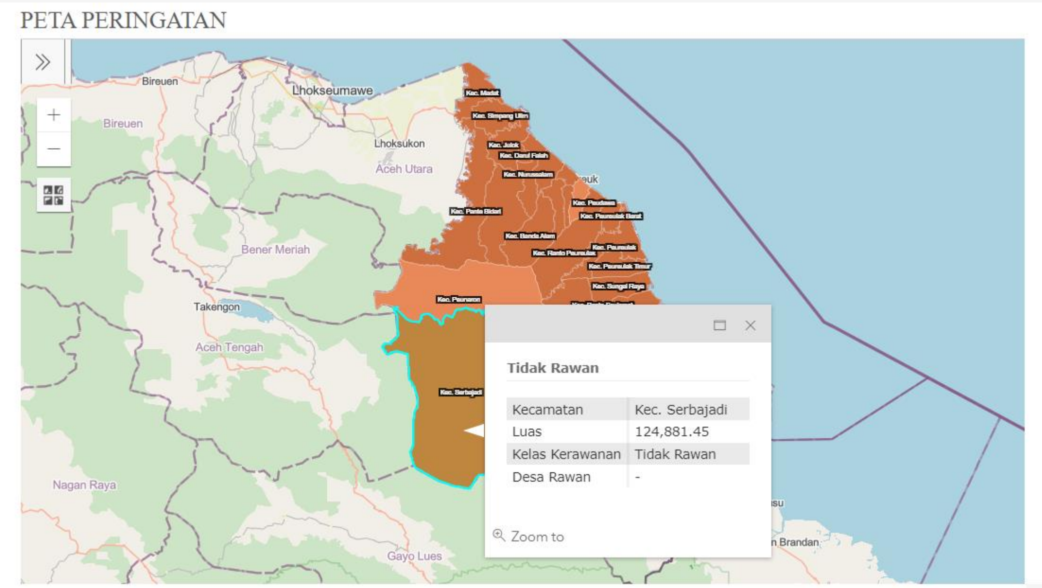

Figure 11: Identification of non-flood prone areas

3.3 Display of East Aceh Flood Prone WebGIS

Figure 9 shows the identification page for highly vulnerable areas. On the page view, the sub-Regencys identified as highly vulnerable areas have a deep orange color compared to the base maps of other sub-Regency administrative boundaries. In the pop up display, there is information on the name of the sub Regency, the area in hectares, information on the class of vulnerability and the village that has vulnerability in that sub Regency. Figure 10 is a display of the identification page for vulnerable areas. This vulnerable area is marked with bright orange color identification. Sub-Regencys belonging to the vulnerable class include Simpang Jernih, Peunaron, and Idi Timur sub-Regency. in the non-prone class are only the Serba Jadi sub Regency. Figure 11 shows the identification page for areas that are not vulnerable.

This non-prone area is indicated by the identification of the brown color of the area. In the pop-up display, there is information on the name of the sub Regency, the area in hectares, information on the class of vulnerability and the village that has vulnerability in that sub Regency. The sub-Regency that is included in the non-prone class is the Serba Jadi sub-Regency.

4. Conclusion

The results of the calculation of the weights that are calculated mathematically from each parameter, are then the rainfall weight is 23.85%; the land slope parameter is 27.25%; the elevation parameter is 24.75% and the weight of the flow density parameter is 24.15%. The results obtained are that the area of flood-prone areas has been divided into 3 classes, namely the very vulnerable class has an area of 230,099 ha (42.6%), the vulnerable class has an area of 224,732 Ha (41.6%), and the non-prone class has an area of 85,416 ha (15,8%). The results of the analysis of flood-prone areas in the East Aceh Regency are divided into 3 classes, namely very vulnerable, vulnerable, and not vulnerable classes. The sub-Regencys that are classified as very vulnerable include: Darul Falah, Nurussalam, Pante Bidari, Ranto Peureulak, Julok, Banda Alam, Peudawa, Peureulak, Sungai Raya, Peureulak Timur, Idi Rayeuk, Idi Tunong, Simpang Ulim, Indra Makmur, Darul Aman, Birem Bayeun, Peureulak Barat, Darul Ihsan, Madat, and Rantau Selamat sub-Regency. sub-Regencys belonging to the vulnerable class include Simpang Jernih, Peunaron, and Idi Timur. The sub-Regencys that are included in the non-prone class are only the Serba Jadi sub-Regency.

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