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Flood Hazard Risk Assessment based on Multi-criteria Spatial Analysis GIS as Input for Spatial Planning Policies in Tegal Regency, Indonesia

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Abstract

Recent discussions on flood disasters concern the risk factors and causes between nature and anthropogenic activities. This disaster requires serious handling, which needs to be analysed, especially in areas affected by flooding with the Tegal Regency, Indonesia case study. The weakness of the existing mitigation efforts still needed comprehensive analyses, requiring a multi-criteria assessment based on GIS spatial analysis. The GIS method used is a raster calculator and weighted superimpose by setting several calculation variables from both physical and non-physical aspects to support the multicriteria spatial analysis. The results show that spatially, more than 30% of areas with a high-risk index are located in the downstream or coastal regions of Tegal Regency. However, the index of capacity and resilience in several flood-affected sub-districts is at an index above 0.5, so they have good strength to disasters such as the four sub-districts of Adiwerna, Bumijawa, Bojong, and Kramat. From the analysis results, land use change is the biggest problem that affects the number of the flood event. With this condition, the appropriate mitigation effort for Tegal Regency is strengthening the spatial planning policy and increasing the capacity, especially in disaster governance in a high-risk area. Thus, the vulnerability and hazard factors will be anticipated with high community participation in strengthening the capacity index.

Keywords: GIS spatial analysis; Flood disaster; Capacity Index; Land Use change

Introduction

Recent discussions on flood disaster are about the risk factors and causes between nature and anthropogenic activities such as land conversion that converts protected areas into agriculture and settlements (Bae & Chang, 2019; Liu & Ran, 2021; Sipos et al., 2022; Vaggela et al., 2022; Villarreal-Rosas et al., 2022; Wisha et al., 2022). Natural physical changes due to anthropogenic factors have occurred in several regions of the world (Kaliraj et al., 2017; Shao et al., 2020; Szilassi et al., 2022). That is as consequence of the large rate of urbanization, as predicted by the WHO that 60% of the world's population will live in urban areas by 2050 (Sejati et al., 2019; WHO, 2014). With this population growth, the need for land for food crops and settlements increases which has an impact on the conversion of land which is now a threat to environmental sustainability (Han et al., 2022; Sejati et al., 2018).

In some areas, land conversion, especially in the highlands, has resulted in flooding, especially due to the loss of conservation areas in the mountains and

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watersheds that have been converted into settlements and agriculture (Bae & Chang, 2019). Flood problems have occured in many countries, especially in fast-growing countries. It happens in several country like in Asia aspects (Ishiwatari & Sasaki, 2021; Venkatappa et al., 2021; Yang et al., 2021), Western Europe (Figueiredo et al., 2020), Africa (Nkeki et al., 2022), and America (Palacio-Aponte et al., 2022) that are growing economically strong but ignore environmental sustainability, Indonesia, one of Asian country, has a similar problem, which is on the north coast of Java (Bott et al., 2020; Irawan et al., 2021).

Meteorological factors, such as extreme weather or high rainfall, are the leading causes of flooding (Faccini et al., 2018; Hartanto & Rachmawati, 2017). In addition, flood risk is exacerbated by massive urbanization and land use change (Handayani et al., 2020; Jodar-Abellan et al., 2019). One part of the north coast of Java that experiences high disaster risk in flood areas is Tegal Regency. Based on data from the Regional Disaster Management Agency of Tegal Regency, there have been 16 flood disasters recorded during November 2021. Land use change and high intensity of rainfall caused this disaster. It resulted in overflowing river water and caused residents' settlements to be flooded.

The increasing number of disaster events must be analyzed like the coverage of disaster affected areas and the level of disaster risk. Furthermore, the analysis must be able to explain disaster events spatially so that geospatial technology-based analysis is necessary. Previous research on the flood with a geospatial approach has focused on several topics (de Vries, 2021). The topic is implementing geospatial technology for flood risk mapping (Dejen & Soni, 2021; Rezaie-Balf et al., 2022). Another topic was also interesting such as identifying and assessing flood vulnerability (Liu et al., 2021; Saur & Rathore, 2022; Singh & Pandey, 2021), factors towards the occurrence of flood disasters (Kieu & Tran, 2021; Psomiadis et al., 2020), the impact of flooding on property prices (Balogun et al., 2020), and predicting spatial flooding (Nguyen et al., 2020).

There is a lack of studies on assessing flood by combining physical and socio-economic factor, as in the research of Monteil et al. (2022), which emphasizes the use of physical and environmental variables to take into account disaster risk in flood-affected areas. An interesting topic also conducted by El-Saoud & Othman (2022), which assessed flood risk with several variables that cause flooding. Based on these studies, the use of physical and environmental vulnerability variables combined with the consideration of the socio-economic vulnerability of the community in mapping flood risk has not been widely carried out. It will increase the level of accuracy that is more detailed and on target in making policy for flood disaster risk management. Based on these conditions, the purpose of this paper is to provide an assessment of flood risk from various variables, both physical and social variables. This research explores disaster risk mapping based on the level of disaster, vulnerability, and the capacity of regions and communities to deal with floods and be the part of efforts to strengthen geospatial community-based disaster risk management policies.

Data and Methods

Study area

The research study area focuses on Tegal Regency (Figure 1). Tegal Regency is one of the regencies located in Central Java Province, Indonesia. Tegal Regency is directly adjacent to the north coast of the Java Sea. It has three main watersheds: the Kaligung, Pemali, and Rambut watersheds and the Cacaban Reservoir as water storage.

Study Methods

The risk assessment based on two aspects of spatial conern; physical and socio-economic aspects. The physical aspect is analyzed from physical and environmental vulnerability as well as disaster hazard. Some spatial data sources are from InaRisk (Indonesian Disaster Geoportal) (The Disaster Mitigation Agency of Indonesia, 2012). At the same time, the socio-economic aspect is analyzed from socio-cultural and economic vulnerability as well as regional resilience and disaster preparedness. The social aspect is obtained by a participatory mapping process so that the community capacity aspect can be appropriately mapped, describing the regional resilience level (Figure 2).

Hazard Assessment

The disaster hazard assessment aims to identify elements at risk of causing harm, especially to the community (Chen et al., 2022). The flood hazard assessment uses InaRISK data from the National Agency for Disaster Management. InaRISK data processing uses GIS software, which is then grouped into 3 (three) hazard classes, namely low class ($H < 0.333$), medium class ($0.333 < H < 0.666$), and high class ($0.666 < H$).

Flood hazard mapping involves hydrological analysis of potential flood inundation (Kocsis et al., 2022). The method of making a disaster hazard map is to identify potential areas of flood inundation and then

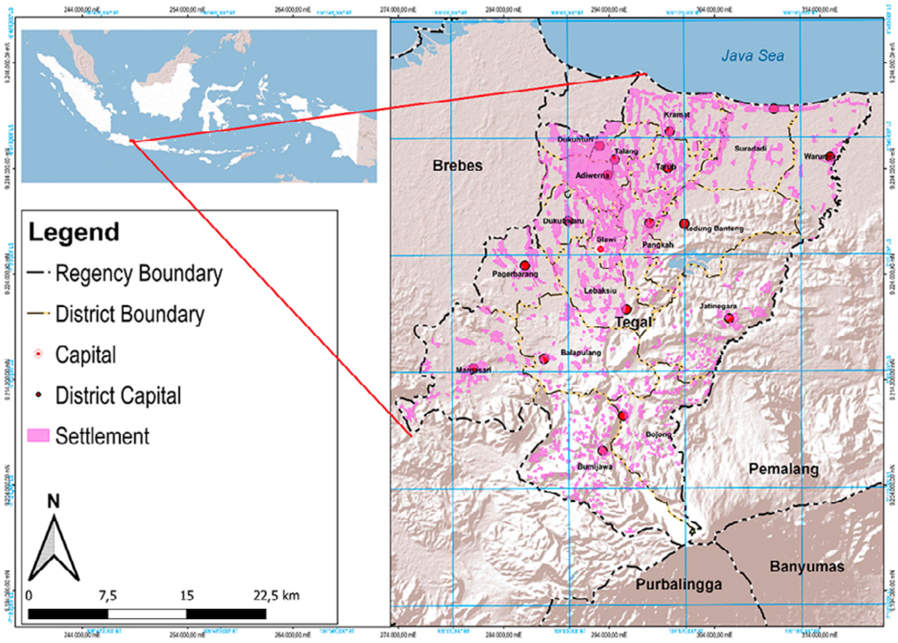

Figure 1. Tegal Regency as Study Area
Source: Authors, 2022

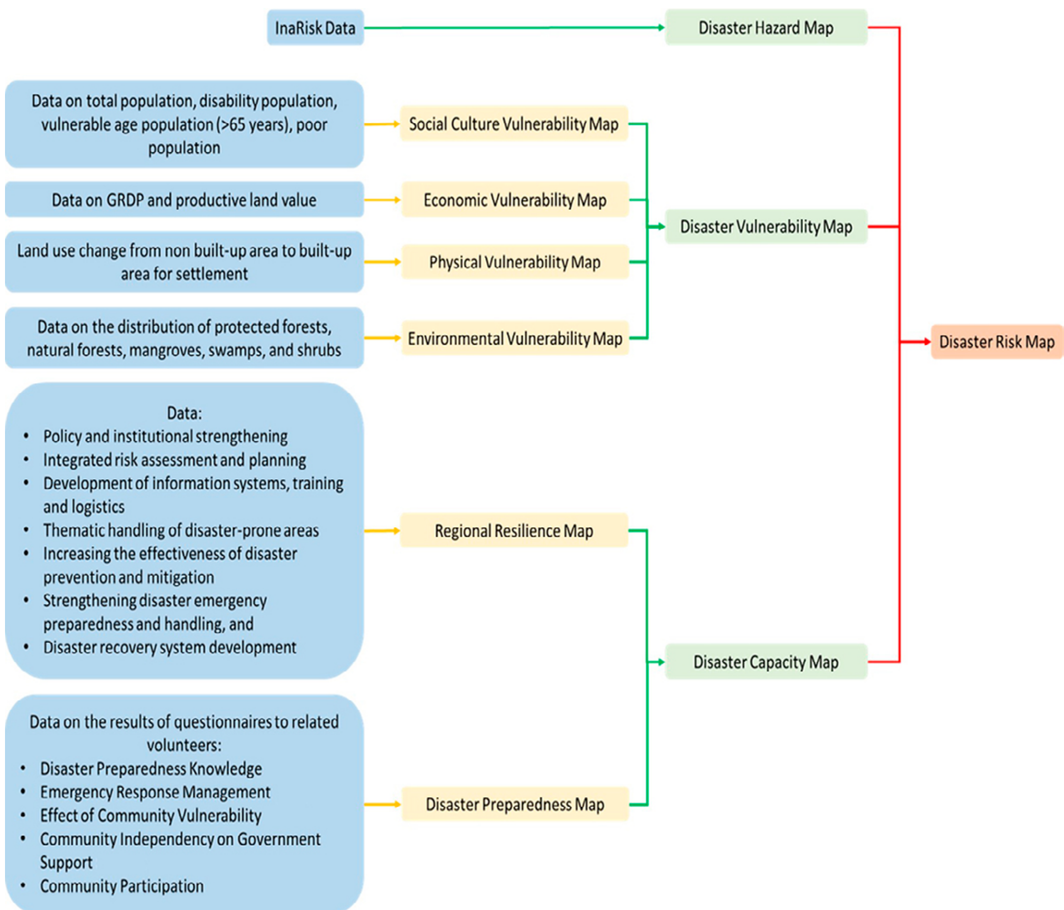

Figure 2. Disaster Risk Analysis Model
Source: Author Identification, 2022

Table 1. List of Data

№	Data Type	Data Form	Data source	Year
	Flood Disaster Data			
1	Administration Boundary	Vector (Polygon)	Geospatial Information Agency of Indonesia	2022
2	National DEM (DEMNAS)	Raster	Geospatial Information Agency of Indonesia	
3	Watershed Boundary Map	Vector (Polygon)	Ministry of Environment and Forest	
4	River Network Map (RBI)	Vector (Polyline)	Geospatial Information Agency of Indonesia	
5.	Landsat Satellite Imagery	Raster	USGS	2012, 2022
	Flash Flood Disaster Data			
1	Main river	River Network	Geospatial Information Agency of Indonesia	2022
2	Main topography	DEMNAS	Geospatial Information Agency of Indonesia	
3	Potential for hazard location	InaRisk	National Agency for Disaster Management	

Source: Author Identification, 2022

estimate the height of the inundation. The preparation of the disaster hazard map uses the data such as administration boundary, DEM, Watershed Boundary, river network, and Satellite imagery (Table 1).

Disaster Vulnerability Assessment

Vulnerability refers to the condition of a community that causes an inability to deal with disasters. This vulnerability assessment is needed to determine the factors that affect the community's ability to deal with disasters. The higher the level of community vulnerability to disasters, the greater the losses obtained by the community. The vulnerability assessment consists of several constituent components: social, physical, economic, and environmental.

The social vulnerability uses several ratio data, namely population density data and vulnerable groups consisting of data on gender, population with disabilities, age group over 65 years, and poor population. This data uses the latest 2021 data sourced from the Central Statistics Agency in the form of the Tegal Regency document in figures and data from the Ministry of Social Affairs in the form of the Social Welfare Integrated Data document. Social vulnerability analysis uses parameters in the form of weighting for each indicator based on the participatory process, shown in Table 2.

The social vulnerability analysis approach is in the form of dasymetric mapping, resulting in a more realistic spatial distribution of the population. The spatial distribution method of population density is carried out through a proportional distribution based on the InaRiskPop (The Disaster Mitigation Agency of Indonesia, 2012) data correction with the following equation.

$$\text{Pij} = \frac{\text{Prij}}{\sum_{i,j=1}^{n} \text{Prij}} \cdot \text{Xdi}$$

Information:

- Pij: Total population in the i-th and j-th grids/cells
- Prij: The population of InariskPop data on the ith residential grid/cell in the jth village administration unit (if Pri = 1 and Prj = 0, then Prij = min (Prij)
- Xdi: Total population in the ith village administration unit

The minimum Prij value is the minimum value on the grid/cell in the village area.

Table 2. Social Vulnerability Parameters

Parameter	Weight (%)	Class		
		Low	Medium	High
Population density	60	<500 people/km²	500-1000 people/km²	>1000 people/km²
Sex ratio (10%)	40	>40	20-40	<20
Poverty ratio (10%)		<20%	20-40%	>40%
Disabled people ratio (10%)				
Age group ratio (10%)				

Social Vulnerability Calculation:

$$\left(0.6\cdot\frac{\mathrm{Log}\left(\frac{\text{Population density}}{0.01}\right)}{\mathrm{Log}\left(\frac{100}{0.01}\right)}\right)+(0.1\cdot\text{sex ratio})+(0.1\cdot\text{poverty ratio})+(0.1\cdot\text{disabled people ratio})+(0.1\cdot\text{age ratio})$$

Calculation of the value of each parameter is carried out based on:
- Low hazard class has 0% influence
- Medium hazard class has 50% effect
- High hazard class has 100% influence

Source: National Agency for Disaster Management with modification, 2022

The economic vulnerability uses GRDP data and the value of productive lands such as rice fields, plantations, and ponds. Economic vulnerability analysis uses the latest data from BIG for productive land data and Central Statistics Agency for GRDP data for Tegal Regency. The parameters of the analysis of the economic vulnerability assessment are shown in Table 3. The analytical approach used is the Multi-Criteria Decision Analysis (MCDA) method to obtain the value of the economic vulnerability index using the following equation (The Disaster Mitigation Agency of Indonesia, 2012).

$$Ve = FM\left(0.6v_{pd}\right) + FM\left(0.4v_{ip}\right)$$

Information:
- Ve: economic vulnerability index
- FM: *fuzzy* membership function
- V_{pd}: GDP contribution index
- V_{ip}: index of productive land loss

The physical vulnerability uses settlement data in the form of housing density, both permanent, semi-permanent, and non-permanent houses, and also land use change from non-built-up area to built-up area for settlement. The source of physical vulnerability data is from InaRisk for data on public and critical facilities. At the same time, the number of houses per village is obtained through Village Potential data with an average population value of 5 people/per house. The calculation of house density is the division between the built area or village area by the area (ha) multiplied by the unit of each parameter. The land use change assessment is conducted by spatial analysis using Spatio-temporal data from Landsat in 2012 and 2022 (20 years). The parameters used in the physical vulnerability analysis are shown in Table 4. The equations used for the physical vulnerability analysis are as follows.

$$r_{ij}=\frac{P_{ij}}{5}\text{and if } P_{ij}<5, \text{ so } r_{ij}=1$$

Table 3. Economy Vulnerability Parameters

Parameter	Weight (%)	Class		
		Low	Medium	High
Productive land	60	<50 million IDR	50-100 million IDR	>200 million IDR
GDP	40	<100 million IDR	100-300 million IDR	>300 million IDR
Calculation Economy vulnerability = (0.6 * productive land score) + (0.4 * GDP score)				

Calculation of the value of each parameter is carried out based on:
- Low hazard class has 0% influence
- Medium hazard class has 50% effect
- High hazard class has 100% influence

Source: National Agency for Disaster Management with modification, 2022

Table 4. Physical Vulnerability Parameters

Parameter	Weight (%)	Class		
		Low	Medium	High
House	40	<400 million IDR	400-800 million IDR	>800 million IDR
Other built-up areas	30	<500 million IDR	500 million – 1 million IDR	>1 million IDR
Calculation of the value of each parameter is carried out based on: • Low hazard class has 0% influence • Medium hazard class has 50% effect • High hazard class has 100% influence				

Source: National Agency for Disaster Management with modification, 2022

Information:

- r_{ij}: the number of houses in the i-th and j-th grids/cells
- P_{ij}: the number of population in the i-th and j-th grids/cells

The environmental vulnerability uses data on the distribution of protected forests, natural forests, mangroves, swamps, and shrubs. The data source was obtained from the Ministry of Public Works and Housing document in 2012. The parameters for assessing environmental vulnerability are shown in Table 5.

$$V=FM(W.v1)+FM(W.v2)...FM(W.vn)$$

Information:

- *V*: Vulnerability index value/ vulnerability component
- *v*: Index of vulnerability components/composition parameters
- *w*: Weight of each vulnerability component/composition parameter
- *FM*: Fuzzy membership function
- *n*: Number of vulnerability components/component parameters

Table 5. Environment Vulnerability Parameters

Parameter	Class		
	Low	Medium	High
Protected forest	<20 ha	20-50 ha	>50 ha
Natural forest	<25 ha	25-75 ha	>75 ha
Mangrove forest	<10 ha	10-30 ha	>30 ha
Shrubs	<10 ha	10-30 ha	>30 ha
Swamp	<5 ha	5-20 ha	>20 ha
Calculation of the value of each parameter is carried out based on: • Low hazard class has 0% influence • Medium hazard class has 50% effect • High hazard class has 100% influence			

Source: National Agency for Disaster Management with modification, 2022

The method used to combine all components of vulnerability is the MCDA spatial method, which is a combination of several criteria spatially based on the value of each criterion (Fernández & Lutz, 2010; Malczewski, 1999). The overlay of criteria is carried out by the spatial process using mathematical operations based on the score and weight of each component. The weighting of the flood hazard vulnerability components is 40% social vulnerability, 25% physical vulnerability, 25% economic vulnerability, and 10% environmental vulnerability. The following is a general equation used:

Capacity Assessment

Capacity is the ability of the region and the people of the Tegal Regency to take action to reduce the level of threat and loss due to flooding. Disaster capacity assessment aims at disaster management by reducing risks arising from disasters. Assessment of disaster capacity uses components of regional resilience and community preparedness for disasters.

Regional resilience data collection uses the focus group discussion (FGD) method and distributes questionnaires that need to be responded to by various parties managing disasters in Tegal Regency. The components of the preparation of regional resilience studies consist of strengthening policies and institutions; risk assessment and integrated planning; development of information systems, education, training, and logistics; thematic handling of disaster-prone areas; increasing the effectiveness of disaster prevention and mitigation; strengthening disaster emergency preparedness and handling; and development of disaster recovery systems.

The community preparedness index is an assessment carried out by survey methods and interviews with government officials or community leaders. The questionnaire data collection technique was stratified by random sampling in several villages that were affected by the disaster. The components of the community preparedness assessment consist of knowledge of disaster preparedness, emergency response management, the influence of community vulnerability, community independence from government support, and community participation. The class division of regional resilience and community preparedness is divided into three groups, namely low level (0 indexes 0.4), medium level (0.4 < index 0.8), and high level (0.8 < index 1). The assessment results of disaster resilience and community preparedness are in the form of index values converted into spatial data (Table 6).

Table 6. Weighting and Index Component Capacity Disaster

Component	Weight (%)	Class		
		Low (0 - 0.333)	Medium (0.334 - 0.666)	High (0.667 – 1.000)
Regional Resilience	40	Value transformation 0 – 0.40	Value transformation 0.41 – 0.80	Value transformation 0.81 – 1
Preparedness Public	60	<0.33	0.34 – 0.66	0.67 – 1.00

Source: National Agency for Disaster Management with modification, 2022

Disaster Risk Assessment

The disaster risk assessment is composed of analyzing disaster hazard, disaster vulnerability, and disaster capacity. The disaster risk is determined in a calculation involving the three components in the following equation:

$$\text{Disaster Risk} = \text{Hazard (H)} \cdot \frac{\text{vulnerability(V)}}{\text{capacity(C)}}$$

This study can be developed for the analysis process using a geographic information system to describe the level of disaster risk in flood-affected areas (Santos et al., 2020; Wiratmaja & Sejati, 2021). The results of the disaster risk assessment are displayed in a disaster risk map, where the calculation uses a geographic information system; disaster risk is determined in the following equation:

$$R = \left(H \cdot V \cdot (1\text{-}C)\right)^{1/3}$$

Results

Potential Vulnerability of Flood Disaster

The flood disaster vulnerability assessment is divided into 4 (four) components, namely social, economic, physical, and environmental vulnerability. The other aspect, like social vulnerability, was identified by the number of people exposed to disasters, which considers the vulnerable age groups, the poor, and the disabled. Economic and physical vulnerabilities were identified in the form of nominal rupiah losses experienced by the Tegal Regency. Meanwhile, an environmental vulnerability was identified as an area damaged by flooding.

Flood disasters can potentially affect the activities of the residents of Tegal Regency. the population of Tegal Regency potentially exposed to flood disasters is included in the medium vulnerability class. The number of people exposed to the disaster was as many as 740,586 people. Kramat Subdistrict, with the highest exposed population in Tegal Regency, reached 100,464 people, followed by Talang and Adiwerna Subdistricts. On the other hand, there is a potential for the lowest exposed population in Jatinegara District, which reaches 4,423 people and Bumijawa District, with 4,285 people exposed (Table 7).

The flood disaster harmed 89,063 people in the vulnerable age group. Furthermore, the poor numbered 6,393 people and 5,064 people with disabilities were also exposed to the flood disaster. The distribution of the population exposed to the class disaster was in the sub-districts of Adiwerna, Dukuhturi, Lebaksiu, Slawi, and Talang. It requires special attention to plan disaster management so as not to disturb and harm

Table 7. Potential Flood Disaster Social Vulnerability (people)

Subdistrict	Population Exposed	Vulnerable Age Population	Poor Resident	Persons with Disabilities	Class
Adiwerna	84,086	10,332	708	481	Medium
Balapulang	5,573	686	130	49	Low
Bojong	9,176	1,033	277	72	Low
Bumijawa	4,285	415	204	19	Low
Dukuhturi	77,766	9,159	375	503	Medium
Dukuhwaru	32,263	4,172	381	219	Low
Jatinegara	4,223	547	125	46	Low
Kedung Banteng	21,761	3,109	274	215	Low
Kramat	100,464	12,380	310	509	Low
Lebaksiu	14,622	2,058	216	137	Medium
Margasari	48.103	5,871	667	381	Low
Pagerbarang	12,936	1,740	155	103	Low
Pangkah	55,569	6,741	430	439	Low
Slawi	41,548	5,315	193	245	Medium
Suradadi	49,305	6,019	294	337	Low
Talang	91,373	8,798	551	461	Medium
Tarub	48,835	6,319	856	498	Low
Warureja	38,698	4.369	247	350	Low
Total	740,586	89,063	6,393	5,064	Medium

Source: Analysis Results, 2022

the community in their daily activities. The distribution of potential social vulnerability in Tegal Regency in 2021 is shown in Figure 5.

Meanwhile, the potential losses caused by floods in each sub-district in Tegal Regency with a nominal loss of 2,162,287 million rupiah. Kramat Subdistrict experienced the most significant physical loss in Tegal Regency, as much as 259,256.80 million rupiahs. It also happened to the Subdistricts of Suradadi, Margasari and Warureja, with physical losses of more than 200,000 million rupiahs (Table 8).

Tegal Regency is not only experiencing physical losses but also has a high potential for economic losses. The total loss received by Tegal Regency due

Table 8. Potential Loss Disaster Floods in the District Tegal

Subdistrict	Million Rupiah				Hectares	
	Physical Loss	Physical Class	Economic Loss	Economy class	Environmental Area	Environmental Class
Adiwerna	164,868,90	High	299.73	Medium	1.02	Low
Balapulang	56,812.50	High	189.89	Medium	18.44	Low
Bojong	54,275.00	High	211.30	High	3.58	Low
Bumijawa	30,422.09	High	103.79	Low	7.86	Low
Dukuhturi	136,441.90	High	340.14	Medium	2.97	Low
Dukuhwaru	80,298.04	High	324.61	Medium	1.30	Low
Jatinegara	93,805.00	High	282.84	Medium	24.96	Medium
Kedung Banteng	166.730.00	High	339.44	Medium	109.22	High
Kramat	259,256,80	High	933.71	High	2.48	Low
Lebaksiu	47,869.58	High	212.22	High	0.07	Low
Margasari	219,212.70	High	897.21	High	1.69	Low
Pagerbarang	32552.67	High	188.15	Low	0.05	Low
Pangkah	102,395,00	High	328,70	Low	4.00	Low
Slawi	63.998.18	High	73.95	Low	4.81	Low

Subdistrict	Million Rupiah				Hectares	
	Physical Loss	Physical Class	Economic Loss	Economy class	Environmental Area	Environmental Class
Suradadi	231,799.20	High	933.31	High	0.89	Low
Talang	129,376.00	High	308.65	Medium	0.44	Low
Tarub	89,098.46	High	378.39	Medium	3.15	Low
Warureja	203.075.00	High	1149.09	High	24.65	Medium
Total	2,162,287.00	High	7,495.13	High	211.56	High

Source: Analysis Results, 2022

to the flood disaster reached 7,495.13 million rupiah. Warureja District obtained the highest loss of 1,149.09 million rupiahs. The same thing happened to the Districts of Kramat, Suradadi, Margasari, Lebaksiu, and Bojong, which experienced high losses in the economic component. Meanwhile, low losses were identified in Bumijawa, Pagerbarang, Pangkah, and Slawi subdistricts.

Furthermore, the results of land use change modelling based on satellite imagery from 2012 and 2022 show significant changes to land-use types in the Tegal Regency. Table 9 shows the most significant change between 2012-2022. On the other hand, there was an increase in rice fields covering an area of 8,571.29 ha. The mapping of land use change in the Tegal Regency can be seen in Figure 3.

Floods hurt the environment in the form of forests, swamps, and other green open spaces. The flood caused a high-grade loss of 211.56 ha of the environment in Tegal Regency. Kedung Banteng District experienced the highest environmental loss, with an affected area of 109.22 ha. Medium-class environmental

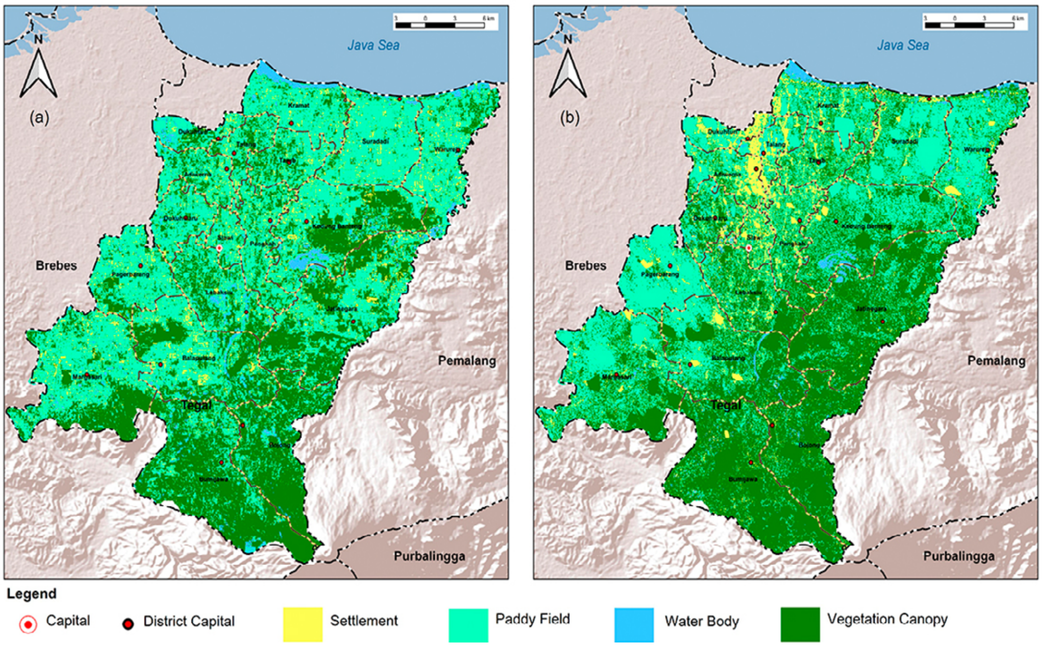

Figure 3. Land Use Change of Tegal Regency in (a) 2012 and (b) 2022
Source: Analysis Results, 2022

Table 9. Changes in Land Use in 2012 and 2022

Types of Land Use	Year (ha)		(ha)
	2012	2022	2012-2022
Settlement	9,424.10	10,701.84	1,277.74
Paddy field	39,003.19	47,574.48	8,571.29
Water Body	2144.70	3,287,77	1,143.06
canopy	47,665.14	36,676.89	- 10,988.26
Total Area	99,457.92	99,457.92	

Source: Analysis Results, 2022

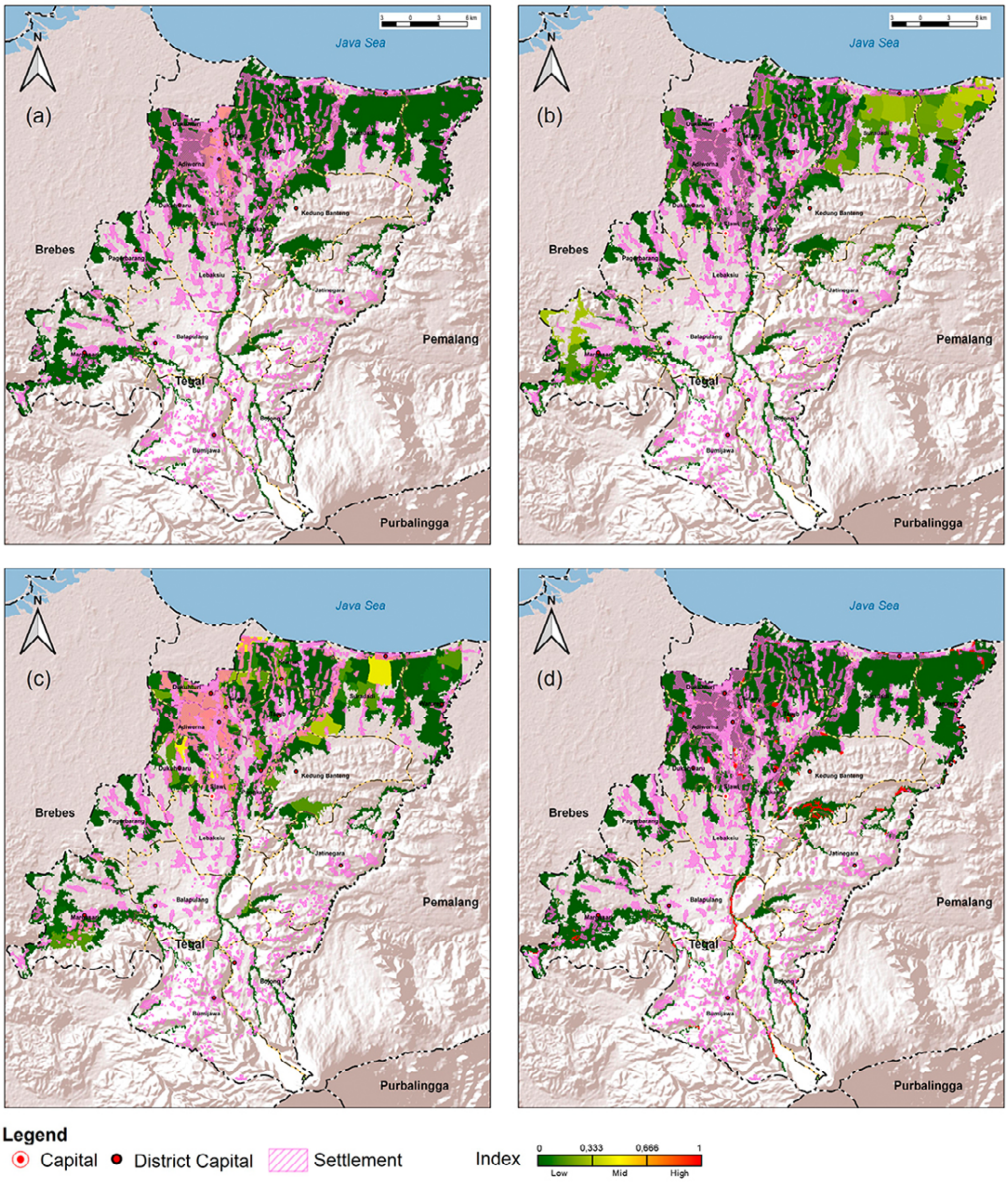

Figure 4. Map of Social (a), Economic (b), Physical (c), and Environmental (d) Vulnerability of Tegal Regency in 2022
Source: Analysis Results, 2022

losses reaching 24.96 ha can occur in the Jatinegara and Warureja sub-districts. In comparison, other sub-districts receive low-class environmental losses, with the smallest impacted environmental area of 0.05 ha in the Pagerbarang District (Figure 4).

Based on the analysis of the components of disaster vulnerability (social, economic, physical, and environmental vulnerabilities), it can be concluded that Tegal Regency is identified as experiencing a high class of vulnerability to flood disasters. Several sub-districts that experienced high vulnerability were in Adiwerna, Dukuhturi, Margasari, and Suradadi sub-districts. Meanwhile, the vulnerability is in the Kramat, Lebaksiu, Slawi, and Talang sub-districts (Figure 6).

Identification of potential flood hazards using InaRisk data analyzed by GIS. The analysis results show that every sub-district in Tegal Regency has the potential to experience flooding. Potential disaster hazard is classified into 3 (three) classes, namely low, medium, and high hazard potential. Based on Table 10, Tegal Regency has a relatively high potential for flood hazards. Warureja sub-district is the sub-district with the largest affected area reaching 4,437.90 ha. The Subdistricts of Margasari, Kramat, and Suradadi are potentially dangerous to flooding with an affected area of more than 3,000 ha. Some areas have moderate potential for flood hazards, namely Pagerbarang District, with an affected area of 804.96 hectares (Figure 5).

Table 10. Potential Area Flood

Subdistrict	Area (Hectares)				
	Low	Medium	High	Total	Class
Adiwerna	63.99	1,427.76	740.61	2232.36	High
Balapulang	58.59	471.51	316.98	847.08	High
Bojong	120.42	429.30	330.48	880,20	High
Bumijawa	81.27	213.21	203.58	498.06	High
Dukuhturi	62.91	897.84	683.01	1,643.76	High
Dukuhwaru	18.72	1,021.32	306.36	1,346.40	High
Jatinegara	42.21	494.19	625.05	1161.45	High
Kedung Banteng	0.00	726.93	1,060.83	1,787.76	High
Kramat	130.77	1983.87	1,584.90	3,699.54	High
Lebaksiu	29.43	678.24	197.64	905.31	High
Margasari	95.13	2,320.65	1,311.57	3,727.35	High
Pagerbarang	38.79	667.08	99.09	804.96	Medium
Pangkah	77.67	960.21	511.74	1,549.62	High
Slawi	17.64	444.15	215.73	677.52	High
Suradadi	17.01	1,843.47	1,275.93	3,136,41	High
Talang	88.02	990.81	479.25	1558.08	High
Tarub	72.99	1,138,05	411.57	1,622.61	High
Warureja	141.57	2,690.19	1,606.14	4.437.90	High

Source: Analysis Results, 2022

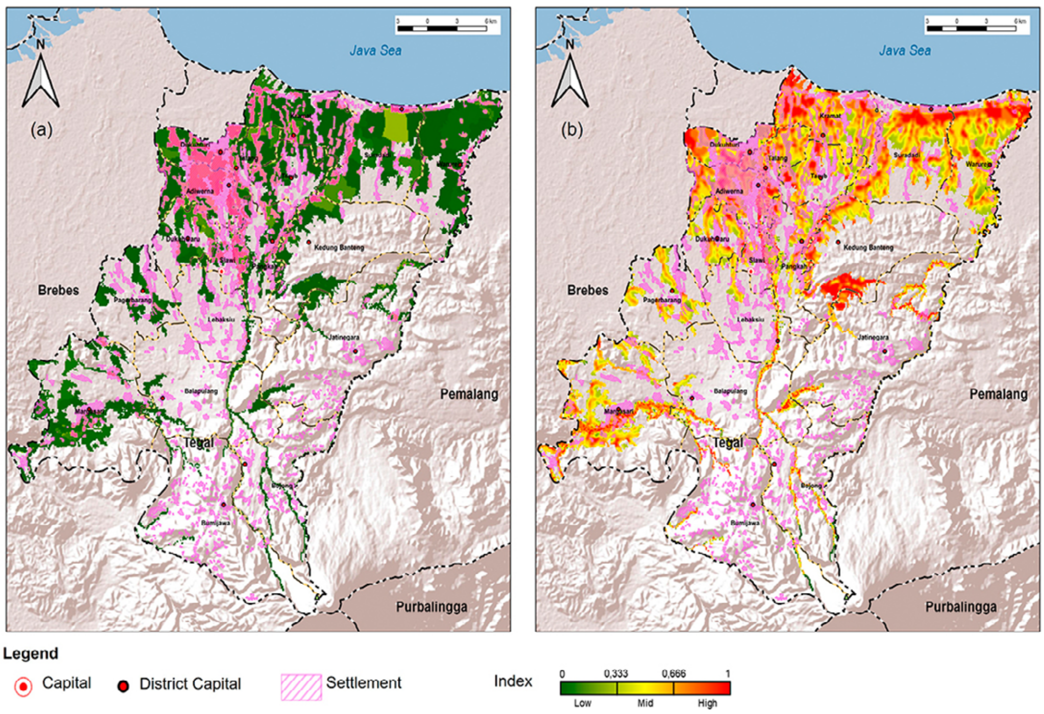

Figure 5. Map of Vulnerability (a) and Hazard (b) Flood Disaster in Tegal Regency in 2022
Source: Analysis Results, 2022

Community Capacity

Resilience and disaster preparedness are the basis for analyzing Tegal Regency's capacity to deal with floods. Table 11 shows that regional resilience in all areas of the Tegal Regency tends to be moderate, which is indicated by the index value reaching 0.66. However, community preparedness for floods is still relatively low, with the index value only reaching 0.32 and 0.43 as the highest index value, which is only in Adiwerna, Bojong, Bumijawa, and Kramat Districts.

Table 11. Community Capacity in the District Tegal

№	Subdistrict	Regional Resilience Index	Preparedness Index	Capacity Index	Capacity Class
1	Adiwerna	0.66	0.43	0.52	High
2	Balapulang	0.66	0.29	0.44	Medium
3	Bojong	0.66	0.43	0.52	High
4	Bumijawa	0.66	0.43	0.52	High
5	Dukuhturi	0.66	0.29	0.44	Medium
6	Dukuhwaru	0.66	0.29	0.44	Medium
7	Jatinegara	0.66	0.35	0.47	Medium
8	Kedung Banteng	0.66	0.29	0.44	Medium
9	Kramat	0.66	0.43	0.52	High
10	Lebaksiu	0.66	0.29	0.44	Medium
11	Margasari	0.66	0.29	0.44	Medium
12	Pagerbarang	0.66	0.29	0.44	Medium
13	Pangkah	0.66	0.29	0.44	Medium
14	Slawi	0.66	0.29	0.44	Medium
15	Suradadi	0.66	0.29	0.44	Medium
16	Talang	0.66	0.29	0.44	Medium
17	Tarub	0.66	0.29	0.44	Medium
18	Warureja	0.66	0.29	0.44	Medium
Tegal Regency	0.66	0.32	0.46	Medium	

Source: Analysis Results, 2022

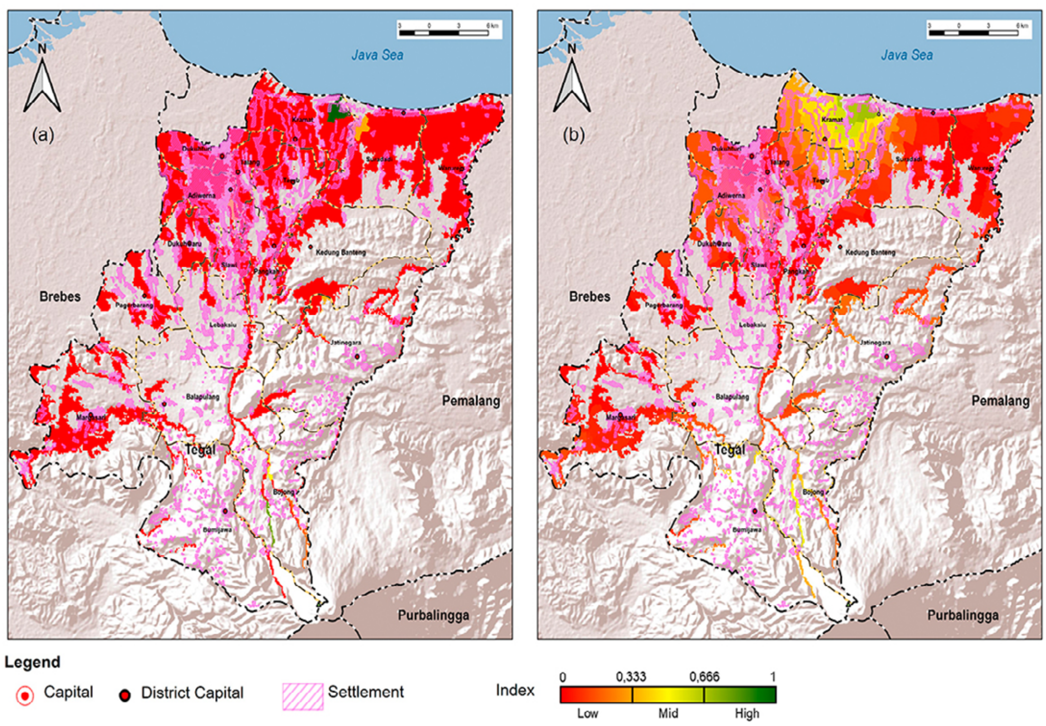

Figure 6. Map of Preparedness (a) and Capacity (b) for Flood Disaster of Tegal Regency in 2022
Source: Analysis Results, 2022

Based on the results of the analysis of regional resilience and community preparedness shows the results of the calculation of the capacity index (Table 11). The average value of the disaster capacity index is 0.46, indicating that Tegal Regency has a medium-class capacity in dealing with floods. There are four area has a high capacity to deal with flood disasters namely adiwerna, Bojong, Bumijawa, and Kramat (capacity index 0.52) (See Figure 6).

Risk Assessment

Based on the calculation of the level of hazard, vulnerability, and capacity, the flood risk level can be obtained and is shown in Table 12. Low risk of disasters occurs in all sub-districts, with the largest affected area being Warureja District (3,790.08 Ha). The moderate risk with the highest affected area is in Kramat District (1,160.64 Ha). Furthermore, the high risk with the largest affected area is in Adiwerna District (394.11 Ha). However, several sub-districts do not potentially risk flooding, namely the Balapulang, Bojong, and Bumijawa sub-districts.

Overall, Tegal Regency is classified as having a high-class flood risk (Table 12). Adiwerna, Dukuhturi, Slawi, and Talang sub-districts are some areas with high risk. The largest area with the potential for moderate risk of flooding is in Warureja District, covering an area of 4,238.55 Ha. Bumijawa sub-district is recorded to be at low risk of disaster, with the affected area reaching 384.21 ha (Figure 7).

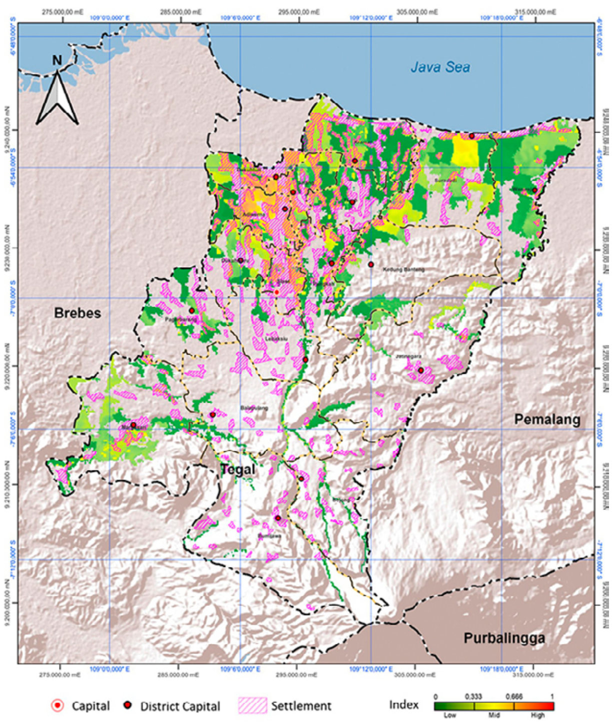

Figure 7. Flood Risk Assessment Result for Tegal Regency in 2022
Source: Analysis Results, 2022

Table 12. Disaster Risk Floods in the Tegal District

Subdistrict	Area (Hectares)				
	Low	Medium	High	Total area	Class
Adiwerna	832.32	917.91	394.11	2144.34	High
Balapulang	721.98	36.27	-	758.25	Low
Bojong	687.78	38.79	-	726.57	Low
Bumijawa	366.12	18.09	-	384.21	Low
Dukuhturi	637.65	756.63	183.51	1,577.79	High
Dukuhwaru	655.29	588.69	16.83	1,260.81	Medium
Jatinegara	818.01	179.19	9.54	1006.74	Low
Kedung Banteng	1,311.39	325.71	72.72	1,709.82	Medium
Kramat	2,411.19	1,160.64	11.07	3,582.90	Medium
Lebaksiu	719.01	102.87	0.09	821.97	Medium
Margasari	2,739.24	594.00	33.75	3,366.99	Medium
Pagerbarang	682.56	80.37	2.61	765.54	Low
Pangkah	892.71	533.70	62.28	1,488.69	Medium
Slawi	183.96	329.58	133.29	646.83	High
Suradadi	1,577.61	1,429.20	71.01	3,077,82	Medium
Talang	649.98	709.65	170.46	1,530.09	High
Tarub	1,140.66	388,98	7.20	1,536.84	Medium
Warureja	3,790.08	426.69	21.78	4,238.55	Low

Source: Analysis Results, 2022

Based on the analysis of flood risk, which is influenced by the components of disaster hazard, vulnerability, and capacity, it can be concluded that the root cause of the disaster occurred. Floods are hazardous to hit the lowlands and coastal areas of Tegal Regency. The occurrence of flooding is relatively caused by high intensity of rainfall, causing sea level rise, which then inundates residential areas. In general, floods occur around the Gung, Kumisik, Cadas, and Kaligung rivers. It causes damage to infrastructure and the environment.

Discussion

Following disaster theory, risk value is strongly influenced by the type of hazard, vulnerability, and capacity index in an area. The hazard and vulnerability model has been analyzed spatially, showing the distribution of hazard and risk areas. The two most essential things in reducing risk are reducing vulnerability and increasing capacity (Etkin, 2016; Wisner et al., 2005). Based on the analysis results, it is obtained that most zones with a high hazard level have high vulnerability. Capacity building in disasters is essential because natural and human disasters can occur anytime and anywhere. When a disaster occurs, a community's ability to respond and cope with an emergency can be vital in minimizing the resulting negative impacts.

The analysis results show that the value of the regional resilience index is 0.66. the regional resilience index is sourced from Indonesia's disaster mitigation agency for Tegal District. The Preparedness Index is an index generated from community preparedness patterns such as ownership of disaster management resources, facilities and the presence of volunteers in disaster management. From these indexes, it can be seen that the value of capacity in each region. The area where the value of the capacity index is above 0.5 has a high capacity for handling the disaster. For example, adiwerna is an area with a high-risk level of physical vulnerability in the form of the type of land use, namely settlements with medium density. Under these conditions, the choice that can be taken to reduce risk is to increase capacity. If look at the calculation results, the most extensive capacity index is in the four sub-districts, namely Adiwerna, Bojong, Bumijawa, and Kramat.

Recognizing that disasters are holistic, not bound by certain disciplinary or political boundaries, delineating risk classes is very helpful in analyzing a condition in the future which is essential in spatial planning (Etkin, 2016; Kaiser et al., 1995; LeGates, 2023). It is in line with spatial planning theory, where future situations can anticipate needing to be included in a more comprehensive spatial planning target. Spatial planning instruments should be the first step in strengthening capacity and reducing physical vulnerability. However, the existing regional spatial planning has little influence in anticipating areas that have a high-risk value (Etkin, 2016; Wisner et al., 2005).

Disaster mitigation and regional spatial planning have a close relationship because regional spatial planning can affect disaster risk and mitigation efforts that can be carried out. Regional spatial planning can affect disaster risk in several ways. In areas near high-risk zones, spatial planning should consider these risks and take mitigation measures to reduce their impact. Likewise, with flood-prone locations, it is necessary to pay attention to land use and utilization of river flows.

In addition, good spatial planning can help minimize disaster risk and accelerate mitigation efforts. An example of mitigation measures that can be taken through spatial planning is Establishing buffer zones: In spatial planning, areas around disaster-prone zones can be designated as buffer zones to reduce risks and minimize disaster impacts (Hervás & Bobrowsky, 2009).

Furthermore, river border areas with a distance of 100 m should be used as river border-protected areas (Loveridge et al., 2017). However, in reality, land conversion in the upstream and riverbank areas of Tegal Regency is used for built-up land, affecting the runoff in the watershed. Some of the most significant risks occur in the downstream area, where the slope is quite gentle and suitable for settlement development. However, matters related to disaster risk should be the primary concern in determining residential areas.

Land use planning should minimize disaster risk. For example, we are avoiding building settlements around rivers prone to flooding. Furthermore, good spatial planning and diaster governance can also improve infrastructure and strengthen buildings and roads to increase the value of resilience in the face of disasters (Handayani et al., 2019). Disaster mitigation and regional spatial planning must complement each other because regional spatial planning can affect disaster risk and affect mitigation efforts that can be carried out (Bae & Chang, 2019). Therefore, good spatial planning can help minimize disaster risk and accelerate mitigation efforts.

The results of this study have confirmed previous studies. For instance studies from Chirisa (2021), Kodag et al. (2022), Ner et al. (2022), Thoyibah & Pamungkas (2021), and Young et al. (2019) that show the several things must be considered such as building resilience and management. The resilience of supporting infrastructure to cope with disasters and post-disaster recovery, fulfilment of sanitation and clean water needs, spatial planning that is resilient to disasters, and protection of ecosystems through the preservation of the availability of green open spaces. Of these criteria, some are not met in residential areas, especially in spatial planning, which should be able to regulate the distribution of population density and the distribution of population settlements.

Several disaster theories also explain that capacity needs to be increased to reduce disaster risk, and vulnerability must be reduced (Monteil et al., 2022; Santos et al., 2020). Based on the distribution of disaster risk in the watershed area, it is necessary to increase the handling capacity of the villages traversed by the watershed, especially in strengthening disaster-resilient villages in each region. The most dominant aspect of vulnerability is the aspect of physical vulnerability, with a loss value of IDR 2,162,287,000,000. A large number of losses in the physical aspect should have been anticipated earlier with spatial planning instruments so that when a disaster occurs, it will not affect the physical condition of the area.

The land use change from 2012-2022 showed a change in the upstream of the river, the majority of which were canopied plants, which changed by 10,988.26 ha. It indicates an indication of land use change which can be fatal in a disaster. Some of the activities carried out in the river's upper reaches are of concern because the protected forest has turned into potato plants. In addition to not having a strong root system, potato plants cannot store much water, which makes runoff from rain unbearable in highlands or upstream rivers.

The facts obtained from this study indicate that spatial planning has not been able to become an instrument for controlling environmental quality. The comparison between the flood risk model and the Tegal Regency spatial plan shows that spaces with high disaster risk are not a priority in the determination as protected areas and are instead planned to remain built and economic growth areas. This comparison is shown in Figure 8, where several areas in the Districts of Adiwerna, Dukuhturi, Slawi, Talang, Margasari, and Suradadi at risk of disaster are still designated to be planned as residential areas. With the results of this study, spatial planning should consider disaster risk aspects in an area so that the growth of settlements is not only based on the strategic location of the location, but also pays attention to natural sustainability factors and the people living in the area.

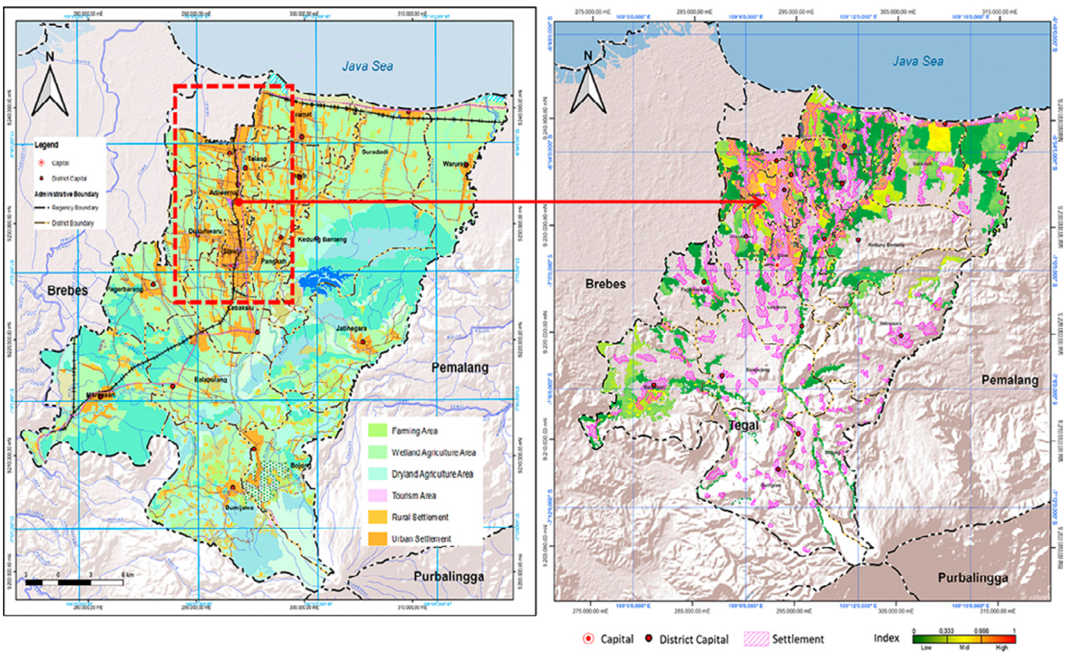

Figure 8. Settlement in spatial Planning (a) is in medium-high risk area (b)
Source: Analysis Result, 2022

Conclusion

This study succeeded in modelling spatial-based disaster risk with multi-criteria regarding the relationship of land use change with flood risk from various criteria. From the analysis results, it can be concluded that high risk is settlements that do not receive attention in controlling the use of space, especially spatial planning. These facts prove that multi-criteria modelling can help in detailing the results of the analysis, especially for evaluating disaster risk areas and spatial planning.

Critical findings in this research are that the highest level of risk is in most areas with residential land use, which has a high vulnerability index above 0.5. Under these conditions, disaster mitigation efforts cannot be carried out by intervening only at the level of vulnerability but also by considering regional capacity and level of preparedness. The four high-risk areas already have a high capacities index like the four sub-districts, namely Adiwerna, Bojong, Bumijawa, and Kramat, with a capacity index of > 0.5. It proves that spatial distribution is essential to see the overall disaster risk model, especially related to spatial planning policies in high-risk locations.

The results of the comparison with the spatial plan show that there is no spatial policy intervention. This evidence is shown by the designation of high-disaster-risk areas as medium-density residential areas. It is dangerous for the sustainability of the community in that location and also shows that weak regulations in minimizing the impact of disasters are a major problem in developing countries like Indonesia. Disaster management and spatial planning should be the main thing in disaster mitigation efforts, especially flood disasters.

Furthermore, several recommendations can be given such as efforts to control land use change especially in controlling the growth of residential areas in high and medium-risk areas. This phenomenon shows that spatial planning has not been able to become an instrument for disaster control and disaster risk reduction at a more detailed level. So, the policies made are also often contrary to the community's real needs and far from disaster risk reduction efforts.

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