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Flood mitigation strategies for settlement area in Kediri District

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Abstract. *According to the Disaster Risk Index released by BNPB in 2013, Kediri District is one of the administrative areas in East Java with a high flooding disaster index. This flooding was also caused by population and residential increases. Based on BPS data from Kediri Regency, until 2019, there was an increase in the population of 0.5-1%. Until 2019, the population increased by 8%, accompanied by an increase in residential areas by 25%. Act Law Number 24 of 2007 Article 47 states that to reduce disaster risk for people living in disaster-vulnerability areas, so has to identify the vulnerability of flooding area, do an evaluation of the land suitability for residential area, after that have to take some mitigation strategies. Technically, before developing a mitigation strategy, it is necessary to identify areas vulnerable to flooding using the Flood Vulnerability Index method. After that, an evaluation of the land suitability of residential areas vulnerable to flooding is carried out using the Multi Criteria Evaluation method, followed by an analysis of the carrying capacity of the residential environment. The last, for determining the priority of the flood disaster mitigation strategy and the authorized institution using the Simple Multi-Attribute Rating Technique Exploiting Ranks method. The results showed that areas with a high flood vulnerability index were Badas, Kras, and Ringinrejo. The existing residential land is not suitable for settlement and has a low carrying capacity. So there are five criteria obtained along with alternative mitigation strategies suitable for being applied in Kediri District.*

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INTRODUCTION

According to the IRB (Disaster Risk Index) released by BNPB in 2013, it shows that Kediri Regency is one of the administrative areas in East Java that has a high disaster index, one of which is flooding. DIBI (2016) also stated that flooding is one of the disasters with high intensity, including Kediri Regency. A total of 1 635 294 people live in Kediri Regency. Based on BPS data from Kediri Regency, from 2012 to 2019, there has been an increase in the population of 0.5-1%. From 2007 to 2019 the population increased by 8%, accompanied by an increase in the number of residential areas by 25%. However, from 2007-2019 green areas such as plantations, forests, and agriculture, decreased by 45%, 1%, and 38% from the previous. The population problem is one of the main problems in developing countries, including Indonesia. Uncontrolled population growth will encourage changes in land use, especially for housing and development facilities. That factors can increase the risk of flooding in this area, so we have to take some actions to reduce the risk. Sustainable development that pays attention to land suitability can reduce the risk of flooding (Iswandi, 2016). Other than that, according to Act Law Number 24 of 2007 Article 47, we have to take mitigation actions to reduce disaster risk for people living in disaster-vulnerability areas.

Technically, to determine the distribution of flooding vulnerability areas in Kediri Regency, it is necessary to conduct a vulnerability assessment using the Flood Vulnerability Index (FVI) by considering social, economic, and environmental components (Balica *et al*., 2012). After that, losses caused by flood disasters can be anticipated by assessing environmental aspects, one of which is by evaluating land suitability, especially in residential areas located in flood-vulnerability areas. Evaluation of land suitability can be done using the Multi Criteria Evaluation (MCE) method (Muta'ali, 2012). This method considers several environmental factors such as rainfall, slope, geological conditions, soil types, flood susceptibility maps, and landslide susceptibility maps.

In addition, the carrying capacity of settlements needs to be calculated to determine the projected future needs of residential land and can be used as a reference for determining strategies in developing residential areas that are in accordance with the conditions of Kediri Regency (Pantow *et al*., 2018). In addition to the technical and environmental aspects, the aspect that affects the mitigation actions of a region is the institutional aspect. As an official institution, the Regional Apparatus Work Unit (SKPD) must play a role in determining strategies to mitigate flood disasters that are suitable to be applied in Kediri Regency. To determine the right strategy from the institutional aspect, the method that can be used is the Simple Multi Attribute Rating Technique (SMARTER-ROC) (Okfalisa and Gunawan, 2014). Therefore, this study aims to determine areas that are vulnerable to flooding in Kediri Regency, evaluate the suitability of land and the carrying capacity of the residential environment in flood-vulnerability areas in Kediri Regency, and determine suitable mitigation strategies to deal with flood disasters in Kediri Regency.

METHOD

Location and Time

The research was conducted in Kediri Regency, East Java Province. Astronomically Kediri Regency is located at 7°36’12’’-8°0’32’’ S and 111°47’05”-112°18’20’’ E. Based on its geographical position, Kediri Regency is surrounded by five regencies with the northern boundary of Nganjuk Regency and Jombang Regency, the southern boundary of Blitar Regency and Tulungagung Regency, the western boundary of Tulungagung Regency and Nganjuk Regency, while the eastern boundary is Jombang Regency and Malang Regency. The area of Kediri Regency is 1 386.05 km^2 with 26 districts. The topography (the shape of the earth's surface) in the Kediri Regency consists of lowlands and mountains through which the Brantas River flows, which divides from south to north. The air temperature ranges from 23°C to 31°C, with an average height of 81 meters above sea level. Rain occurred almost throughout 2019. The highest rainfall occurred in March, with a total of 360 mm, while the rainiest days occurred in January (BPS, 2020). The study began in February 2021 and ended in April 2021.

Collecting Method

The types of data needed in this study are primary and secondary data. Primary data is data obtained directly from the field, while secondary data is obtained through literature and data-providing agencies.

Primary Data

Primary data was obtained from the first questionnaire which was filled out by the people of Kediri Regency. This questionnaire is needed as supporting data for the discussion of technical aspects in determining the FVI index to identify flood-vulnerability areas. The questionnaire uses an attitude rating scale, which means that raw data in the form of numbers will be interpreted in a qualitative sense (Singarimbun *et al*., 1989). The distribution of the questionnaire is based on the number of samples taken by the proportional random sampling technique. The proportional random sampling technique is a sampling technique where all members have the same opportunity to be sampled according to their proportions according to the number of populations (Sugiyono, 1999). The proportion will be adjusted to the total population or population density in each sub-district in Kediri Regency. The higher the population or population density, the higher the sample taken in the sub-district. So that the number of samples obtained is representative, the number of samples is determined by the slovin formula (Umar, 2000):

$$n = \frac{N}{N(d^2)+1} \tag{1}$$

Note: n= total sample; N= total population; d= precision/error

In accordance with the total population in Kediri Regency of 1 635 400 (BPS, 2020) and a precision of 5%, this requires 400 people, 400 respondents spread over 26 sub-districts with the distribution according to the formula proposed by Sugiyono (2010) as follows:

$$Sample = \frac{Population\ density\ sub\text{-}district}{Total\ population\ density\ district} \times n \tag{2}$$

Note: n= total number of samples

The second questionnaire is used to determine the priority of flood disaster mitigation strategies from the institutional aspect. Respondents are representatives of the authorities of the Regional Government Work Unit (SKPD) in accordance with the divisions related to the discussion of flood disaster mitigation strategies in Kediri Regency. They are National Disaster Management Authority (BPBD), Environmental Service (DLH), Development Planning Agency at Sub-National Level (BAPPEDA), Residential Office (PERKIM), and Public Works-Human Settlements and Spatial Planning (PUPR).

Secondary Data

Secondary data were obtained from the literature and data provider agencies. Secondary data is needed for data analysis from technical and environmental aspects. The technical aspects are analyzed using the Flood Vulnerability Index (FVI) method, which will produce a flood vulnerability index, while the environmental aspects use the Multi Criteria Evaluation (MCE) method and analysis of the carrying capacity of the residential environment, list of secondary data at Table 1.

Data Analysis Method

The analytical method used in this study is a mathematical approach that is collected from secondary data or primary data. The method used is as follows:

The Weighting of the Flood Vulnerability Questionnaire

The rating scale for the questionnaire used is 1-3, for exposure and susceptibility the weighting conversion is in accordance with Table 2 while for resilience, the weighting conversion is in accordance with Table 3.

Table 1 Matrix of types, data sources, and analysis methods of flood vulnerability mitigation models

Purpose	Data type	Data form	Data source	Analysis method	Output
Technical Aspect Analysis					
Zoning of flood-vulnerability areas of exposure	Secondary data	Population density (KP)	BPS Kediri district	GIS FVI	Flood vulnerability map (social, economic, and environmental)
		Distance to river (J)	Analysis results		
		Number of Industries (JI)	BPS Kediri district		
		River discharge (D)	BPS Kediri district		
		Rainfall (CH)	Department of Agriculture and Plantations Kediri district		
		Topography (T)	BIG		
Zoning of flood-vulnerability areas susceptibility components	Secondary data	Population Age (UP)	BPS Kediri district	GIS FVI	Flood vulnerability map (social, economic, and environmental)
		Land use (PL)	BIG		
Technical Aspect Analysis					
Zoning of flood-vulnerability areas susceptibility components	Primary data	Level of education (TP)	Susenas Kediri district 2013		
		Poverty level (TK)	Social Services Kediri district		
		Quality of Residence (KTT)	Questionnaire I		
Zoning of flood-vulnerability areas resilience component	Primary data	Flood insurance (AB)	Questionnaire I	GIS FVI	Flood vulnerability map (social, economic, and environmental)
		Technology adoption rate (TAT)	Questionnaire I		
		Monthly income level (TPP)	Questionnaire I		
		Ready for flood/ finance, infrastructure (K)	Questionnaire I		
		Capacity DAM/ Infrastructure (KD)	Questionnaire I		
		Transportation infrastructure (IST)	Questionnaire I		
		Information and communication tools (A)	Questionnaire I		
		Medical facility (FK)	Questionnaire I		
		Reforestation (R)	Questionnaire I		

Environmental Aspect Analysis					
Land suitability evaluation on settlements in flood-vulnerability areas	Secondary data	Geological Map Slope map Soil type map Forest area map Flood vulnerability map Landslide vulnerability map Rainfall data	Directorate of Geology RBI Land Center of Kementan PUPR Analysis results Analysis results Water Service	GIS MCE	Map of land suitability for residential areas in disaster-vulnerability areas
Analysis of the carrying capacity of the residential environment	Secondary data	Population Data Land Suitable for Residential Area of land requirement m^2/kapita	BPS Kediri district Analysis results SNI 03-1733-2004	$DDPm$	Residential carrying capacity analysis data
Mitigation strategy for	Primary data	Identity of decision-making	Questionnaire II	SMARTER-ROC	Flood disaster mitigation strategy in
Institutional Aspect Analysis					
residential areas in flood-vulnerability areas		expert			Kediri Regency
Mitigation strategy for residential areas in flood vulnerability areas	Secondary data	Criteria for flood disaster mitigation strategies Alternative criteria for flood disaster mitigation strategies	BNPB	SMARTER-ROC	Flood disaster mitigation strategy in Kediri district

Source: Analysis results (2021)

Table 2 Exposure and susceptibility weighting conversion

Vulnerability	Indicator	Weight (%)
Low	1	33.33
Medium	2	66.67
High	3	100

Table 3 Conversion weighting resilience

Vulnerability	Indicator	Weight (%)
High	1	33.33
Medium	2	66.67
Low	3	100

Flood Vulnerability Index (FVI)

Flood Vulnerability Index (FVI) is applied to measure flood vulnerability. The FVI method uses three flood vulnerability factors, namely exposure (E), susceptibility (S), and resilience (R). Exposure and susceptibility positively affect flood vulnerability, while resilience negatively affects flood vulnerability. The main components used to assess flood vulnerability are social, economic, and environmental/physical. The three components of the vulnerability index are aligned with the components for displaying indicators (Balica *et al*., 2012). The FVI formula is as follows:

$$FVI = \frac{(E \times S)}{R} \tag{3}$$

Balica *et al*., (2012) and Jelmer (2013) stated that the Flood Vulnerability Index (FVI) in each component could be expressed by developing formula (3). The formulas are expressed in equations below:

$$FVI_{social} = \frac{KP \times UP \times TP \times KTT}{TAT \times K \times IST \times A \times FK} \tag{4}$$

$$FVI_{environmental/physical} = \frac{CH \times T \times PL}{KD \times R} \tag{5}$$

$$FVI_{economic} = \frac{J \times JI \times D \times TK}{AB \times TPP} \tag{6}$$

Multi Criteria Evaluation (MCE)

Land suitability analysis for residential areas is generated from overlaying several thematic maps that become research inputs, including a) slope maps, b) flood vulnerability maps, c) landslide susceptibility maps, d) rainfall maps, e) soil type maps, and f) geological map. Indicators and sub-indicators in the MCE analysis on land suitability analysis for settlements based on USDA (1971) and Muta'ali (2012). The weighting can be seen in Table 4.

Table 4 Land suitability criteria for settlements with the MCE Method in Kediri District

Indicator	Sub Indicator	Weight	Rating
Slope (%)	0-8	14.5	4
	9-15		3
	16-26		2
	>27		1
Flood Vulnerability	Low	25.2	3
	Medium		2
	High		0
Landslide Vulnerability	Low	27.2	3
	Medium		2
	High		0
Rainfall (mm/year)	<4 000	7.6	4
	4 000-4 500		3
	4 500-5 000		2

Soil Type	Aquic Eutrudepts, Typic Endoaquepts, Fluvaquentic Eutudepts, Andic Dystrudepts, Typic Eutrudepts, Vitrandic Eutrudepts, Typic Udipsamments, Fluventic Epiaquepts, Arenic Eutrudepts	8.5	4
	Mollic Hapludalfs, Typic Hapludalfs, Typic Udivitrands, Typic Hapludands		1
Geological Type	Aluvial, Endapan Teras, Endapan Lahar	7.8	4
	Morponit Sedudo, Morfoset Argohalangan, Morphonit Klotok, Gajahmungkur Morponit, Batuan Gunungapi Tua Anjasmara, Formasi Kalipucang, Gunungapi Muda Anjasmara, Batuan Gunungapi Tua Kelud, Gunungapi Muda Kelud, Formasi Wonosari		1

Source: USDA (1971); Muta'ali (2012); Analysis results (2021)

Carrying Capacity of Settlements (DDPm)

The carrying capacity of a residential area can be interpreted as the ability of an area to provide residential land to accommodate a certain number of residents to live properly. According to Muta'ali (2015), the carrying capacity of settlements can be calculated using the formula:

$$DDPm = \frac{LPm/JP}{\alpha} \qquad (7)$$

Note: DDPm for the carrying capacity of settlements, LPm for the suitable land area for settlements, JP for the total population, and the coefficient of space requirement/capita (m^2/capita).

The area of land requirement m^2/capita refers to the Indonesian National Standard (SNI) Number 03-1733-2004 concerning Procedures for Planning for the Housing Environment, which is 26 m^2/capita. Furthermore, after obtaining the value of the carrying capacity of the settlement, the optimal population can be calculated as follows:

$$JPo = DDPm \times JP \qquad (8)$$

Note: JPo for optimal population, DDPm for the carrying capacity of settlements, and JP for total population.

SMARTER-ROC

SMARTER is one of the decision support techniques in policy analysis. SMARTER is a multi-criteria decision making technique developed by Edwards and Baron in 1994. This technique is a modification of the Simple Multi Attribute Rating Technique (SMART) technique (Okfalisa and Gunawan, 2014). The multi-criteria decision-making technique is based on the theory that each alternative from a number of criteria has values and each criterion has a weight that describes how important it will be compared to other criteria. The weighting of Rank-Order Centroid (ROC) on SMARTER is based on the criteria's level of importance or priority using a range from 0 to 1, and respondents give numbers 1-100. SMARTER with ROC weighting is more accurate than Analytical Hierarchy Process (AHP) weighting, based on the sensitivity value to measure the accuracy of a value. The ROC weighting sensitivity value is smaller than the AHP weighting sensitivity value (Kusmiyanti *et al.*, 2017). The formula used is as follows:

$$W_b = \frac{Value}{Total\ value} \tag{9}$$

$$W_i = \left(\frac{1}{k}\right) \sum_{i=1}^{k} \left(\frac{1}{i}\right) \tag{10}$$

$$U_{ij} = \frac{Alternative\ Total\ Value}{Total\ Respondent} \tag{11}$$

$$U_{ij} *= \sum_{i=1;j=1}^{i=k;j=n} W_i U_{ij} \tag{12}$$

Note: W_b : The weight of the i-th criteria; Value: values ranging from 0-100 given by expert respondents against certain criteria; Total Value: total value obtained from all respondents; W_i : average criteria weight; i: number of respondents; k: number of criteria; U_i = average alternative value; U_{ij} *: ROC/priority value; U_{ij}: the i-th alternative value of the k-th criterion.

RESULTS AND DISCUSSION

In the Figure 1, the higher the weighting value of the exposure and susceptibility components, the higher the level of flood vulnerability. On the contrary, the higher the weighting of the resilience component, the lower the level of flood vulnerability. The results showed that the social aspect of flood vulnerability in Kediri Regency was the highest among the other two aspects. According to Munyai *et al.* (2019) and Balica *et al.* (2012), several social aspects that can impact flood vulnerability are population density (KP), population age (UP), education level (TP), quality of residence (KTT), level of technology adoption (TAT), preparedness in dealing with floods (K), transportation infrastructure (IST), information and communication tools (A), and health facilities (FK). Based on the calculation of social FVI, the exposure component consists of population density (KP). In contrast, the susceptibility components include population age (UP), an education level (TP), and quality of residence (KTT).

The level of technology adoption (TAT), preparedness in dealing with flood disasters (K), transportation infrastructure (IST), information and communication tools (A), and health facilities (FK) are included in the resilience component. Several environmental/physical aspects that can be used to determine the flood vulnerability index using the FVI Method are rainfall (CH), topography (T), land use (PL), DAM capacity/drainage infrastructure (KD), and reforestation (R). In calculating the environmental/physical FVI, the exposure component consists of rainfall (CH), topography (T), and land use (PL), while the susceptibility component includes the capacity of DAM/drainage infrastructure (KD. Reforestation (R) consists of the resilience component. Several economic aspects that can be used to determine the flood vulnerability index using the FVI Method are distance to the river (J), the number of industries (JI), discharge (D), poverty level (TK), flood insurance (AB), and monthly income level (TPP). In the calculation of economic FVI, the exposure component consists of the distance to the river (J), the number of industries (JI), and discharge (D), while the susceptibility component includes the poverty level (TK). Flood insurance (AB) and monthly income level (TPP) are components of resilience.

Nine sub-districts have a high-status social FVI index, one sub-district has a high-status environmental/physical FVI index, and no sub-district has a high economic FVI index. After being average, the highest FVI index in Kediri Regency is in three sub-districts, namely Kras, Ringinrejo, and Badas Districts. The most influential indicators of social FVI are high population density, productive age of the population, and level of technological adaptation. The increase in population increases the opening of residential land, so vegetation areas are reduced, and flooding occurs, especially in areas with poor drainage. The higher the dependency ratio, the higher the level of vulnerability to disasters because the higher the burden that must be borne by the productive age population to finance the lives of people who are not or are not productive.

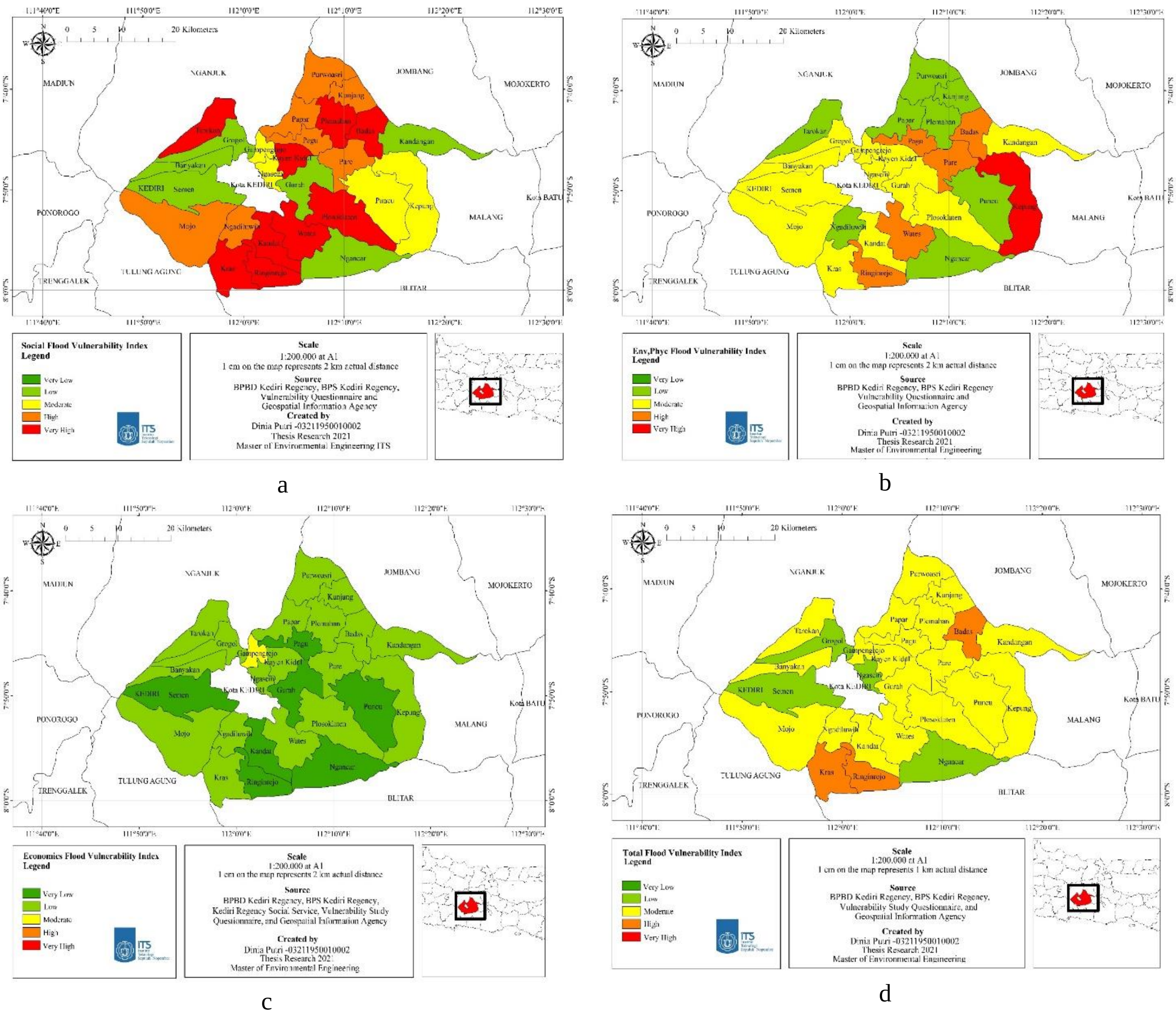

Figure 1 a) Social Flood Vulnerability Index; b) Environmental/Physical Flood Vulnerability Index; c) Economic Flood Vulnerability Index; d) Total Flood Vulnerability Index (Source: Analysis results 2021)

The results of land suitability can found in the Figure 2 analysis by overlaying flood susceptibility maps, landslide susceptibility maps, annual rainfall maps, geological maps, slope maps, and soil type maps show that the total land in Kediri Regency which is very suitable for settlement is 8 344.69 hectare (ha) (19.68), according to 18 694.15 ha (44.08%), according to marginal 10 995.14 ha (25.93%), and not suitable with an area of 4 374.02 ha (10.31%). According to the research conducted, the most influential thing on land suitability is landslide susceptibility with a weight contribution of 27.2%. Areas that have high flood vulnerability, namely the Districts of Badas, Kras, and Ringinrejo, have standing settlements on land with marginal and inappropriate status and low carrying capacity. So these areas should not be suitable for residential development.

What needs to be done is relocation or evaluation for environmental improvement to increase the carrying capacity of the environment. Thus, to overcome the risks that arise, it is necessary to determine criteria and alternative flood mitigation strategies that are appropriate to be applied in Kediri Regency, especially social aspects. The criteria and alternatives are improving infrastructure resilience-improving health service performance in existing disaster scenarios and we can identify, understand, and use current and future risk scenarios by conducting disaster threat studies.

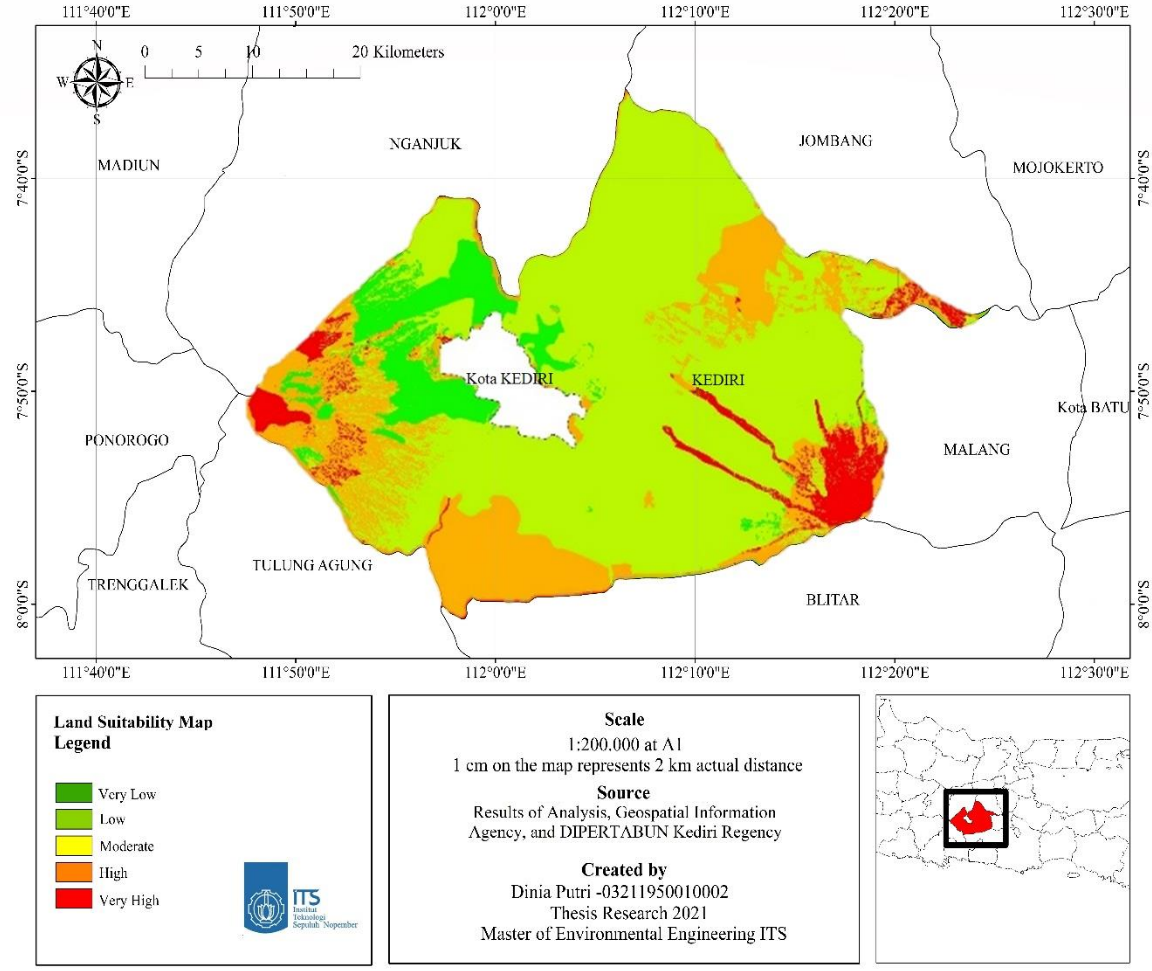

Figure 2 Land suitability map of Kediri Regency (Source: Analysis Results, 2021)

For the economic aspect, it is necessary to strengthen financial capacity for disaster resilience-making financial plans and budgets for resilience, including funds for contingency plans, while for the environmental aspect the criteria and mitigation alternatives are the development and design of a disaster-resilient city by making a zoning plan for the use of space and preserving the area. Buffers and ecosystem services by identifying transboundary environmental problems. The implementer of the mitigation strategy activities is the BPBD (Regional Disaster Management Agency) of Kediri Regency assisted by SKPD (Regional Work Units) according to the type of activity. The flood disaster mitigation strategy and the concept of residential development should be prioritized for the Badas, Kras, and Ringinrejo sub-districts.

CONCLUSION

Based on the results of the research, the areas with a high flood susceptibility index are in the Districts of Badas, Kras, and Ringinrejo. The results of the evaluation of residential land in the three areas also stand on land that is not suitable for settlement and has low carrying capacity. So that five criteria are obtained along with alternative mitigation strategies that are suitable to be applied in Kediri Regency, especially in residential areas that are prone to flooding according to social, economic, and environmental aspects.

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