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Flood inundation hazard mapping and vulnerability analysis in the downstream area of the Cipunagara River Basin of Indonesia using Google Earth Engine

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Abstract. Tidal flooding is a natural phenomenon where seawater enters land areas with high sea levels. Tidal flooding is caused by factors, namely forest area decline, land degradation, hydrological conditions disturbances, household waste, improper drainage, and rising tides. The North Coast of Java that has the potential to be affected by tidal flooding is the downstream area of the Cipunagara River Basin, Subang Regency. Factors causing disasters include runoff from the Cipunagara river, sea water intrusion, changes in coastal land use, sea level rise, and the presence of river water overflows every year, which play a role in the expansion of the tidal area of flood inundation. The purpose of this study is to map the risk of tidal flooding based on the hazard index, vulnerability index. The determination of the risk index is carried out using a spatial method to identify the hazard index and vulnerability index, by scoring or overlaying through the GEE and ArcGIS 10.8 applications, as well as qualitative descriptive methods in determining disaster capacity. The high-vulnerability category for tidal flooding is found in the villages of Legon Kulon, Patimban, Pusakaratu, Mundusari, Rancasari, Pamanukan Sebrang, Mulyasari, Pamanukan Hilir, Pamanukan, Lengkong Jaya, and Pusakajaya with a tidal flood vulnerability index scoring range, which is 3.2 – 3.8. The moderate vulnerability category was found in the villages of Bobos, Karangmulya, Rancadaka, and Gempol with a scoring range of 2.6 – 3.2. While the category of low tidal flood vulnerability index was in Tegalurung, Mayangan, Legon Wetan, Pengarengan, and Ranca Hilir with a tidal flood vulnerability index score range of 2.0 – 2.6. This vulnerability index will be expanded to determine the Capacity index and Risk index for the same location of study.

1. Introduction

The ongoing phenomenon of climate change is leading to rising sea levels, primarily due to the melting of polar ice caps. This presents a significant challenge for archipelagic nations around the globe. It is predicted that by 2100 sea level will rise due to global warming as high as 440 mm to 740 mm [1]. The consequence is the rise of issues in coastal regions, including tidal flooding or coastal inundation. Tidal flooding is caused by several factors, namely a decrease in forest area, land degradation, disturbance of hydrological conditions, household waste, improper drainage,

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and rising tides [2]. This disaster will have a greater impact and intensity along with the phenomena of global warming and climate change [3]. The North Coast of Java, the East Coast of Sumatra, Kalimantan, the South Coast of Sulawesi, and other small islands are lowland coastal areas in Indonesia [4]. The downstream region of the Cipunagara River Basin, located on the North Coast of Java, is potentially vulnerable to tidal flooding, particularly in Subang Regency. Disasters are influenced by factors such as runoff from the Cipunagara River, seawater intrusion, alterations in coastal land use, rising sea levels, and annual river water overflows, which contribute to the expansion of the tidal flood inundation area. Over time, the impact of tidal flooding is expected to intensify, with a growing area experiencing inundation from these floods year after year. Developing tidal flood risk mapping for the downstream Cipunagara watershed is crucial. Key factors in disaster risk mapping encompass hazard mapping and vulnerability analysis. Disaster risk mapping is designed to reduce the impacts and losses from disasters by employing disaster risk management strategies. The use of map visualization techniques is anticipated to expedite the management of tidal flood inundation issues in the downstream region of the Cipunagara watershed.

2. Methodology

2.1 Research data and equipment

The study utilizes both secondary and primary data. Secondary data consists of supporting information gathered from relevant agencies and institutions, whereas primary data is collected directly from the research site using the methods outlined in Table 1. The types and sources of data used are shown in Table 1 and Table 2.

Table 1. The type of tools and devices utilized.

Tools and Devices	Utility
Field survey device:	
1. GPS	Positioning and tracking the coastline
2. Camera	Documentation of conditions in the field
Data analysis tools:	
1. Computer Hardware and Software (ArcGIS 10.8 and Google Earth Engine)	Data analysis tools

Table 2. Data types and their sources

No	Data Type	Data Properties		Source
		Primary	Secondary	
1	Subang Regency Administration Map		√	https://tanahair.indonesia.go.id/
2	Data Digital Elevation Model (DEM)		√	https://developers.google.com/earth-engine/datasets/catalog/USGS_SRTM
3	*Global Surface Water* (GSW) 1996-2020		√	https://global-surface-water.appspot.com/
4	SHP Cipunagara Watershed Administration		√	https://tanahair.indonesia.go.id/

No	Data Type	Data Properties		Source
		Primary	Secondary	
5	Subang in Figures 2020		√	https://subangkab.bps.go.id/
6	Coordinate Point of Each Land Cover Class	√		Direct collection on the spot
7	Inundation Height Data Measurement	√		Direct collection on the spot

2.2 Data processing stage

2.2.1 Rob flood hazard index

The assessment of tidal flood hazards is conducted using data from areas susceptible to flooding, taking into account factors such as river flow distance, proximity to the shoreline, inundation height, and the extent of river and tidal flooding, in accordance with Head of BNPB Regulation No. 2 BNPB of 2012 [5]. The scoring of the Hazard Index is presented in Table 3 below.

Table 3. Composing parameters and scoring of the hazard index.

No	Hazard Index Parameters	Weight (%)	Hazard Index		
			Low	Medium	High
1.	River Flow Distance	15	>500 m	201-500 m	0-200 m
2.	Coastline Distance	15	>500 m	201-500 m	0-200 m
3.	Flood Height	20	0.0-0.2 m	0.2-0.5 m	> 0.5 m
4.	River Flood Area	25	0-4 ha	4-8 ha	>8 ha
5.	Tidal Inundation Area	25	0-4 ha	4-8 ha	>8 ha

Hazard Index = (0.15 * River Flow Distance score) + (0.15 * Coastline Distance score) + (0.2 * Flood Height score) + (0.25 * River Flood Area score) +(0.25 * Tidal Inundation Area score) (1)

Determine the classification of scoring results with the following formula:

$$\frac{\text{Highest Score} - \text{Lowest Score}}{3\ (\text{Number of Classes})} \tag{2}$$

Value Score each parameter based on Regulation of the Minister of Public Works and Housing 12/PRT/M/2014 [6, with modification]:
- In the LOW hazard class has a score of 1
- In the MEDIUM hazard class has a score of 3
- In the HIGH hazard class has a score of 5

2.2.2 Rob flood vulnerability index

- Social vulnerability

Social vulnerability consists of parameters of population density and vulnerable groups. Vulnerable groups consist of the ratio of sex, the ratio of the vulnerable age group, the ratio of the poor, and the ratio of the population with disabilities. The preparation parameters are presented in Table 4.

Table 4. Compiling parameters and scoring of social vulnerability. [5]

Parameters	Weight (%)	Class		
		Low	Medium	High
Population density	60	<5 soul/ha	5-10 soul/ha	>10 soul/ha
Vulnerable Group - Gender Ratio (10%) - Ratio of Vulnerable Age Groups (10%) - Poor Population Ratio (10%) - Disabled Population Ratio (10%)	40	>40 <20	20-40 20-40	<20 >40

- Physical vulnerability

Physical vulnerability encompasses the parameters of residential properties, public amenities, and essential facilities. The cumulative value in rupiah of these properties, amenities, and facilities is determined according to the hazard classification of the impacted region.

Table 5. Table of physical vulnerability parameters. [5]

Parameters	Weight (%)	Class		
		Low	Medium	High
House	40	<400 million	400 - 800 million	>800 million
Public facilities	30	<500 million	500 million -1 billion	> 1 billion
Critical Facilities	30	<500 million	500 million -1 billion	> 1 billion

Physical Vulnerability = (0.4 * House score) + (0.3 * Public facilities score) + (0.3 * Crisis Facility score) (3)

Calculation of the value of each parameter (except House) is carried out based on:
- In the LOW hazard class has 0% effect
- In the MEDIUM hazard class has a 50% effect
- In the HIGH hazard class has 100% effect

The calculation of the House parameter value is carried out based on:
- In the LOW hazard class, the number of houses affected is multiplied by 5 million
- In the MEDIUM hazard class, the number of houses affected is multiplied by 10 million
- In the HIGH hazard class, the number of houses affected is multiplied by 15 million

- Economic vulnerability

Economic vulnerability is characterized by parameters such as the contribution of Gross Regional Domestic Product (GRDP) and productive land. These parameters are detailed in Table 6.

- Environmental vulnerabilities

Environmental vulnerability is determined by parameters such as protected forests, natural forests, mangroves, shrubs, and swamps. Each of these parameters can be identified through land cover data. The parameters prepared are displayed in the following Table 7.

Table 6. Table of economic vulnerability parameters. [5]

Parameters	Weight (%)	Class		
		Low	Medium	High
Productive Land	60	<50 million	50 - 200 million	>200 million
GDP	40	<100 million	100 – 300 million	> 300 million

Economic Vulnerability = (0.6 * Productive Land score) + (0.4 * GDP score) (4)

Calculation of the value of each parameter is carried out based on:
- In the LOW hazard class has 0% effect
- In the MEDIUM hazard class has a 50% effect
- In the HIGH hazard class has 100% effect

Table 7. Table of environmental vulnerability parameters. [5]

Parameters	Weight (%)	Class		
		Low	Medium	High
Protected forest	30	<20 ha	20 - 50 ha	>50 ha
Natural Forest	30	<25 ha	25 - 75 ha	>75 ha
Mangrove/Mangrove	20	<10 ha	10 - 30 ha	>30 ha
Shrubs	10	<10 ha	10 - 30 ha	>30 ha
Swamp	10	<5 ha	5 - 20 ha	>20 ha

Environmental Vulnerability = (0.3 * Protected Forest Score) + (0.3 * Natural Forest Score) +(0.2 * Mangrove Score) + (0.1 * Shrubs Score) + (0.1 * Swamp Score) (5)

Calculation of the value of each parameter is carried out based on:
- In the LOW hazard class has 0% effect
- In the MEDIUM hazard class has a 50% effect
- In the HIGH hazard class has 100% effect

- Vulnerability Index

The vulnerability index for each threat is derived by integrating the scores of social, physical, and economic vulnerabilities, applying the respective weights to each component as outlined in [5].

$$FVI = (SVIx\ 40\%) + (PVI\ x\ 25\%) + (EVI\ x\ 25\%) + (ENVI\ x\ 10\%) \quad (6)$$

where:
FVI : Flood Vulnerability Index
SVI : Social Vulnerability Index
PVI : Physical Vulnerability Index
EVI : Economic Vulnerability Index
ENVI : Environmental Vulnerability Index

2.2.3 Rob flood capacity index

Regional capacity in disaster management is a crucial parameter for determining the success of disaster risk reduction. It is imperative that regional capacity aligns with the National Disaster Management System as stipulated in Law Number 24 of 2007 on Disaster Management and its subsequent regulations. The capacity index values are categorized into five levels of regional achievement in disaster management. These levels are detailed in Table 8.

Table 8. Levels of regional achievements in disaster management. [5]

Levels	Information
1	Regions have had minor achievements in disaster risk reduction efforts by implementing some advanced actions in plans or policies.
2	The regions have implemented several disaster risk reduction actions with achievements that are still sporadic due to the absence of systematic institutional and/or policy commitments.
3	The commitment of the government and several communities regarding disaster risk reduction in an area has been achieved and supported by systematic policies, but the achievements obtained with these commitments and policies are considered not comprehensive, so they are still not significant enough to reduce the negative impacts of disasters.
4	With the support of commitments and comprehensive policies in disaster risk reduction in an area, successful achievements have been obtained, but it is recognized that there are still limitations in commitment, financial resources, or operational capacity in implementing disaster risk reduction efforts in the area.
5	Comprehensive achievements have been achieved with adequate commitment and capacity at all levels of the community and levels of government

The determination of flood capacity index will be completed in the next stage of research.

2.2.4 Mapping of rob flood risk index

Determination of the risk index is carried out using a spatial method to identify the hazard index and vulnerability index, by scoring and overlaying through the ArcGIS 10.8 application and qualitative descriptive methods in determining disaster capacity, and to recommend structural and non-structural mitigation based on the description of the index. risk seen from the results of the table and visual form in the form of a map. The formula for determining the risk index is as follows [5]:

$$\text{Risk (R)} = \text{Hazard (H)}\ \frac{\text{Vulnerability (V)}}{\text{Capacity (C)}} \tag{7}$$

Determine the classification/class of the Risk Index scoring results with the following formula [6]:

$$\frac{Highest\ Score\ -\ Lowest\ Score}{3\ (Number\ of\ Classes)} \tag{8}$$

3. Results and discussion

3.1. Rob flood hazard index

The classification of the tidal flood hazard index for each village, derived from overlaying various parameters such as distance from river flow, distance from shoreline, inundation height, area of river flooding, and area of tidal flooding per village in the downstream region of the Cipunagara watershed, is depicted in Table 9.

Table 9. Class of rob flood hazard index per village.

Nu	Village	Score					Weight (%)					Score Flood Rob	Rob Flood Class
		RD	CD	FH	RF	IT	RD	CD	FH	RF	IT		
1	Tegalurung	1	3	3	5	5	15	15	20	25	25	3.7	High
2	Mayangan	5	5	5	5	5	15	15	20	25	25	5.0	High
3	Legon Wetan	3	5	5	5	5	15	15	20	25	25	4.7	High
4	Legon Kulon	3	1	3	5	5	15	15	20	25	25	3.7	High
5	Pangarengan	5	3	5	5	5	15	15	20	25	25	4.7	High
6	Bobos	5	1	3	5	1	15	15	20	25	25	3.0	Medium
7	Karangmulya	5	1	3	5	1	15	15	20	25	25	3.0	Medium
8	Patimban	5	3	5	5	5	15	15	20	25	25	4.7	High
9	Rancadaka	1	1	3	5	1	15	15	20	25	25	2.4	Medium
10	Gempol	1	1	1	1	1	15	15	20	25	25	1.0	Low
11	Pusakaratu	1	1	1	5	1	15	15	20	25	25	2.0	Low
12	Mundusari	3	1	1	1	1	15	15	20	25	25	1.3	Low
13	Rancasari	1	1	1	1	1	15	15	20	25	25	1.0	Low
14	Pamanukan S	5	1	3	5	1	15	15	20	25	25	3.0	Medium
15	Mulyasari	3	1	1	3	1	15	15	20	25	25	1.8	Low
16	Pamanukan H	3	1	1	1	1	15	15	20	25	25	1.3	Low
17	Pamanukan	3	1	1	1	1	15	15	20	25	25	1.3	Low
18	Ranca Hilir	3	1	3	5	1	15	15	20	25	25	2.7	Medium
19	Lengkong Jaya	3	1	1	1	1	15	15	20	25	25	1.3	Low
20	Pusakajaya	1	1	1	3	1	15	15	20	25	25	1.5	Low

Information:
RD : River Distance
CD : Coastline Distance
FH : Flood Height
RF : River Flood
IT : Inundation Tidal

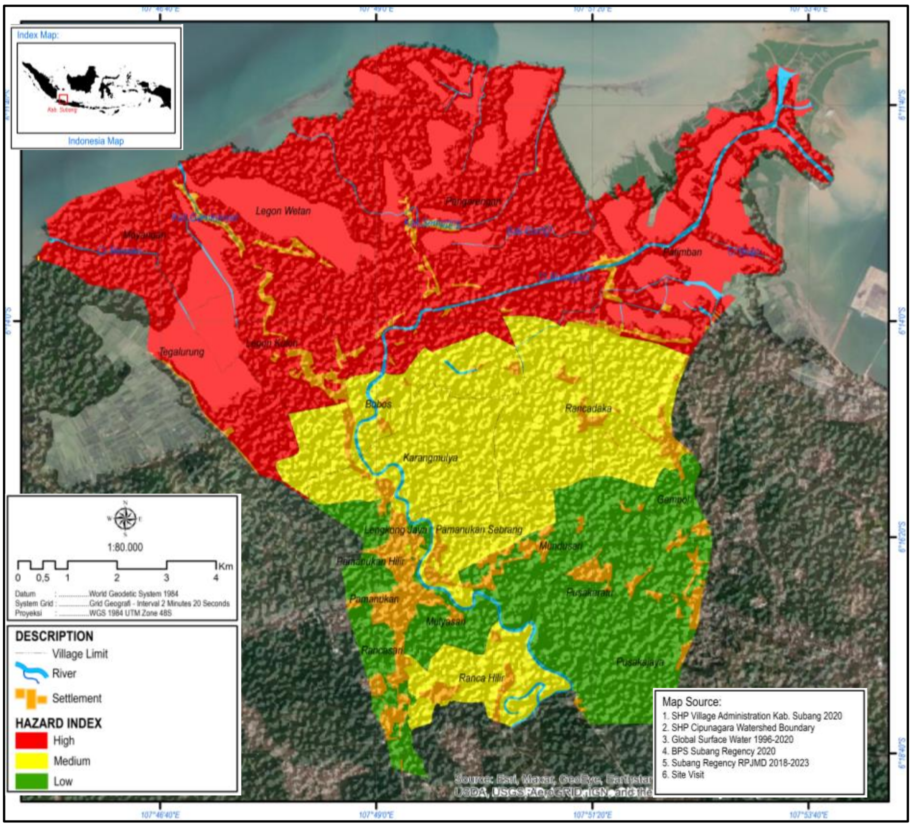

Figure 1. Map of flood hazard index per village.

According to Table 9, the villages with the highest tidal flood hazard index are Tegalurung, Mayangan, Legon Wetan, Legon Kulon, Pangarengan, and Patimban. The villages with a medium tidal flood hazard index include Bobos, Karangmulya, Rancadaka, Pamanukan Sebrang, and Ranca Hilir. The villages with a low-category tidal flood hazard index include Gempol, Pusakaratu, Mundusari, Rancasari, Mulyasari, Pamanukan Hilir, Pamanukan, Lengkong Jaya, and Pusakajaya. The map depicting the tidal flood hazard index for each village in the downstream region of the Cipunagara watershed is illustrated in Figure 1.

3.2. Rob flood vulnerability index

The assessment of vulnerability to flood disasters is conducted according to disaster risk assessment standards. The assessment categorizes vulnerability into four indices: social vulnerability index, physical vulnerability index, economic vulnerability index, and environmental vulnerability index. The assessment of the index allows for the determination of the potential number of populations exposed, environmental damage, and potential losses due to tidal floods. The analysis of the tidal flood vulnerability index for each village in the downstream area of the Cipunagara watershed is detailed in Table 10.

Table 10. Rob flood vulnerability index per village.

Nu	Village	Score				Weight (%)				Score Flood Rob	Rob Flood Class
		SVI	PVI	EVI	ENVI	SVI	PVI	EVI	ENVI		
1	Tegalurung	1	1	5	5	40	25	25	10	2.4	Low
2	Mayangan	1	1	5	5	40	25	25	10	2.4	Low
3	Legon Wetan	1	1	5	5	40	25	25	10	2.4	Low
4	Legon Kulon	3	5	5	1	40	25	25	10	3.8	High
5	Pangarengan	1	1	5	5	40	25	25	10	2.4	Low
6	Bobos	3	1	5	1	40	25	25	10	2.8	Medium
7	Karangmulya	3	1	5	1	40	25	25	10	2.8	Medium
8	Patimban	1	5	5	5	40	25	25	10	3.4	High
9	Rancadaka	3	1	5	1	40	25	25	10	2.8	Medium
10	Gempol	3	1	5	1	40	25	25	10	2.8	Medium
11	Pusakaratu	5	1	5	1	40	25	25	10	3.6	High
12	Mundusari	5	1	5	1	40	25	25	10	3.6	High
13	Rancasari	5	1	5	1	40	25	25	10	3.6	High
14	Pamanukan S.	5	1	5	1	40	25	25	10	3.6	High
15	Mulyasari	5	1	5	1	40	25	25	10	3.6	High
16	Pamanukan H.	5	1	5	1	40	25	25	10	3.6	High
17	Pamanukan	5	1	5	1	40	25	25	10	3.6	High
18	Ranca Hilir	1	1	5	1	40	25	25	10	2.0	Low
19	Lengkong Jaya	5	1	5	1	40	25	25	10	3.6	High
20	Pusakajaya	5	1	5	1	40	25	25	10	3.6	High

Information:
SVI : Social Vulnerability Index
PVI : Physical Vulnerability Index
EVI : Economic Vulnerability Index
ENVI : Environmental Vulnerability Index
FVI : Flood Vulnerability Index

Results Based on the scoring and weighting of all parameters the highest tidal flood vulnerability index was found in Legon Kulon Village, Patimban Village, Pusakaratu Village, Mundusari Village, Rancasari Village, Pamanukan Sebrang Village, Mulyasari Village, Pamanukan Hilir Village, Pamanukan Village, Lengkong Jaya Village, and Village Pusakajaya with a tidal flood vulnerability index scoring range, which is 3.2 – 3.8. The category of moderate tidal flood vulnerability was found in Bobos Village, Karangmulya Village, Rancadaka Village, and Gempol Village with a scoring range of 2.6 – 3.2. While the tidal flood vulnerability index with a low-class category is found in Tegalurung Village, Mayangan Village, Legon Wetan Village, Pengarengan

Village, and Ranca Hilir Village with a tidal flood vulnerability index score range of 2.0 – 2.6. The tidal flood vulnerability index map is presented in Figure 2.

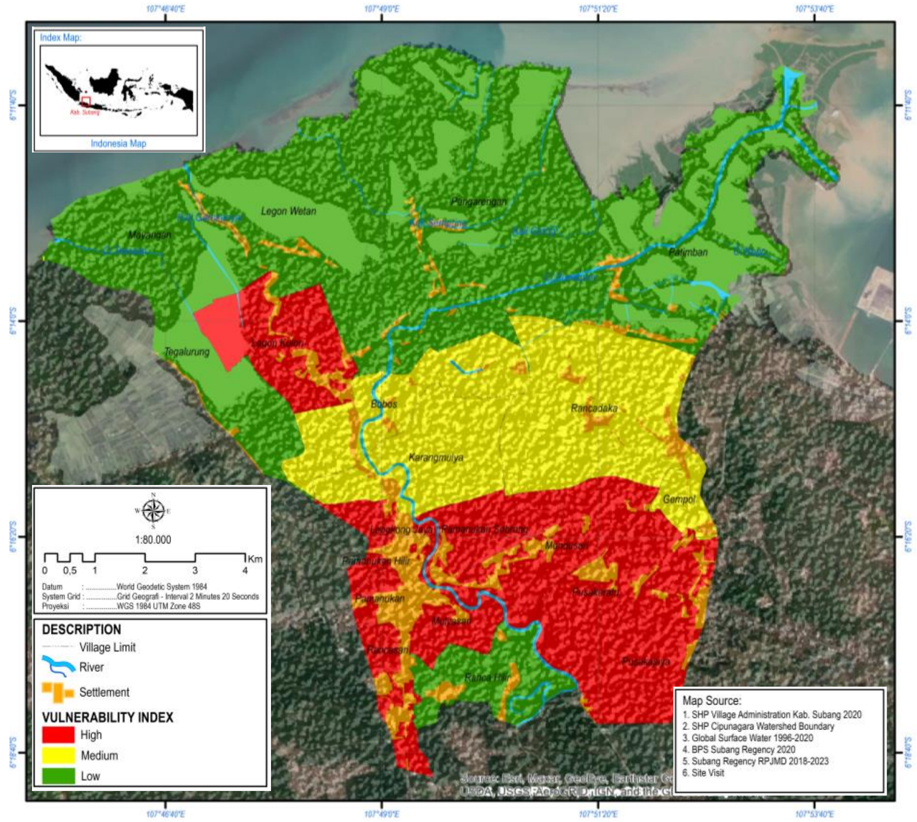

Figure 2. Map of rob flood vulnerability index per village.

4. Conclusion

The tidal flood vulnerability index per village in the downstream area of the Cipunagara watershed is divided into three classes. Based on the result analysis and compared each vulnerability index output, the high-vulnerability category for tidal flooding is found in Legon Kulon Village, Patimban Village, Pusakaratu Village, Mundusari Village, Rancasari Village, Pamanukan Sebrang Village, Mulyasari Village, Pamanukan Hilir Village, Pamanukan Village, Lengkong Jaya Village, and Village Pusakajaya with a tidal flood vulnerability index scoring range, which is 3.2 – 3.8. The moderate vulnerability category was found in Bobos Village, Karangmulya Village, Rancadaka Village, and Gempol Village with a scoring range of 2.6 – 3.2. While the category of low tidal flood vulnerability index was in Tegalurung Village, Mayangan Village, Legon Wetan Village, Pengarengan Village, and Ranca Hilir Village with a tidal flood vulnerability index score range of 2.0 – 2.6. Once the vulnerability index is determined, the next stage is to set up to which the region has the critical vulnerability and more consideration. Futher more, the administrative policy will recommend for villages that have low tidal flood vulnerability risk focus on environmental management, especially on the management of river border areas and coastlines.

Reference

[1] Intergovernmental Panel on Climate Change (IPCC), Sixth Assessment Report (2023). Climate Change: Mitigation of Climate Change. Cambridge: Cambridge University Pr.

[2] Marwah, S. and Alwi, L.O. (2014). Analysis of the Impact of Land Use Change on Tidal Flood in Kendari City. International Journal of Applied Science and Technology, Vol. 4, No. 7, December 2014.

[3] Marfai, M.A., Mardiatno, D., Cahyad, A., and Nucifera, F. (2013). Spatial Modeling of Rob Flood Hazard Based on Climate Change Scenarios and Its Impacts in Coastal Pekalongan. Jurnal Bumi Lestari, Vol. 13, No. 2, August 2013: 244-256.

[4] Numberi, F. (2009). Climate Change, its Implications for Marine, Coastal and Small Island Life. Jakarta: Citrakreasi Indonesia

[5] National Disaster Management Agency (BNPB). (2012). Head of BNPB Regulation Number 2 of 2012 on General Guidelines for Disaster Risk Assessment. Jakarta: National Disaster Management Agency.

[6] Ministry of Public Works and Housing. (2014). Regulation of the Minister of Public Works and Housing on the Implementation of Urban Drainage Systems No. 12/PRT/M/2014. Jakarta: Ministry of Public Works and Housing.