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Flood Assessment Through Integrated-Mixed-Method in The Western Downstream Area of Citanduy River Basin, Pangandaran Regency

Dyah Rina Syafitri[1], Safira Arum Arysandi[1], Alvian Aji Purboyo[1], Amelia Fitri[1], Yenni Febriani[1], Wanda Fitri Tjahyanityasa[1], Nila Puspita Sari[1], Sitti Khafifatul Mar'ath[1], Safinatunnajah[1], Aghnia Candra Satyaningrum[1], Noorhadi Rahardjo[2], Sudrajat[3], Djati Mardiatno[3], Rini Rachmawati[4]

[1]Magister Program of Geography, Universitas Gadjah Mada, Yogyakarta, Indonesia
[2]Department of Geographic Information Science, Universitas Gadjah Mada, Yogyakarta, Indonesia
[3]Department of Environmental Geography, Universitas Gadjah Mada, Yogyakarta, Indonesia
[4]Department of Regional Development Geography, Universitas Gadjah Mada, Yogyakarta, Indonesia

Correspondence E-mail: dyahrinasyafitri@mail.ugm.ac.id

ABSTRACT

This study aims to describe the latest representation of flood vulnerability distribution in the study area using an integrated-mixed-method, includes: 1) AHP weighting based on expert interviews; 2) land use classification by the random forest algorithm; 3) Flood Hazard Map modeling using weighted overlay; and 4) hazard maps validation and historical flood analysis. Geographic Information System based on application (ArcGIS) and could (GEE) are the analytical tools in this study, supported by secondary data, such as 1) Sentinel 2A for land use models, 2) DEM for elevation and slope models, 3) buffer models for river distance and 4) CHIRPS for rainfall. The flood hazard with low and very-low levels is so minimal that it is less visible on the map. While the moderate level of flood hazard class counted as 12.6 Ha, mostly located in the eastern part of the study area (Padaherang and Kalipucang sub-districts).The high-level flood hazard class occupied about 2041.17 Ha, spread over built-up land use. The Very-high hazard class is 22652.11 Ha and mostly located in villages directly adjacent to the Citanduy River.

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1. INTRODUCTION

Flooding is the occurrence of inundation in the floodplain as a result of water and river runoff caused by the flow of water flowing in the river exceeding its flowing capacity (Agustina, 2021). Flood is a hydro-meteorological natural disaster that causes puddles on the earth's surface and often causes material losses to the community and at worst kills people. Pangandaran is one of the prone areas to floods, especially floods controlled by river overflows. Based on the 2022 risk index value, Pangandaran has a moderate risk class and is ranked 11th out of 27 regencies in West Java. Besides, this region also becoming 5th the most vulnerable and need to reduce at least 30% Disaster Risk Index by 2019 (Badan Penanggulangan Bencana Daerah, 2023).

Flood disaster is one of the dominant hazards in the Pangandaran regency recently. Based on the Pangandaran National Disaster Management Authority (BPBD) Disaster Report document, in October 2022 floods and landslides and several trees fell due to high-intensity rain accompanied by strong winds. It occurs in 4 sub-districts of Pangandaran Regency, namely Kalipucang, Parigi, Cijulang, and Pangandaran. This flood disaster affected 2,034 households or equivalent to 5,969 people. Furthermore, on July 8, 2023, floods engulfed, especially in areas adjacent to the Citanduy River (Sidamulih District, Parigi District, and Pangandaran District). This flood incident affected a number of 708 families or 2,128 people, with 708 housing (Badan Penanggulangan Bahaya Daerah (BPBD), 2023). Historically, frequent floods around the Citanduy River actually have occurred since 1996 (Maulana & Rosalina, 2022). Floods in the area around the Citanduy River also often inundate rice fields, causing crop failures that cause material losses mainly for farmers.

The latest flooding followed by landslides on July 7 2023 at some points in Pangandaran Regency, cited based on the Pangandaran Regency's BPBD (National Disaster Management Authority) Press Release Number 265/Pers-Pusdatin KK/BNPB/Dis.02.01/VII/2023. This incident caused 253 families or 759 people to be affected even though they chose to stay at home. Overflow inundated 30 cm of the resident's houses, while several roads were submerged by 50 cm and were inaccessible. Floods and landslides were controlled by extreme weather on the previous day.

Recent research related to flood hazard modeling has previously been carried out by (Haris et al., 2022). Analysis Hierarchy Process (AHP) method was used in order to form the flood hazard maps in Kuningan Regency. The parameters used are rainfall, land use, soil type, slope, and elevation. The method used produces a fairly good map of the flood hazard class distributions.

Another study conducted by (Fristyananda & Idajati, 2017) used the same flood hazard modeling by the AHP method supported with Expert Choice software. The research area was conducted in the Kali Lamong Watershed, Gresik Regency. In contrast to (Haris et al., 2022) 's research, the parameters used are inundation area, inundation duration, and inundation depth. This study generated a flood hazard class distribution map which was divided into three classes (low, medium, and high).

Research related to flood hazard classification using the AHP method was also conducted by (Umar et al., 2021) in Bangun Rejo Village, Tenggarong Seberang, Kutai Kartanegara, East Kalimantan. From this research, a flood hazard class distribution map was presented with an exact value of areas, which was divided into three classes, namely safe (38.93% of the total area), vulnerable (43.44% of the total area), and very vulnerable (17.61% of the total area).

Climate change has become reasoned by the increasing trend of global warming in the last few decades (Hanif, et al., 2021). Climate change and erratic weather, massive changes in land use, and a relatively high frequency of floods have made the Pangandaran regency can hardly optimize its natural potential. Therefore, a spatial approach analysis is needed to be conducted regarding the effect of flood hazards in the Pangandaran Regency (Junivan et al., 2018), while GIS is an option to optimize these processes. The main goal in this research is to know the class of flood hazard distributions and its intensity affects Mangunjaya, Padaherang, and Kalipucang Districts, Pangandaran Regency. Understanding the class of flood hazard distribution can be used as

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considerations in disaster mitigation and decision-making related to the direction of land development and optimization in this area.

On flood analysis, land use, specially built areas, is considered as an environmental component that is prone to changes (Sugandi, et al., 2021). On the other hand, routine flooding tends not to be followed by land use changes and modifications in Pangandaran Regency, especially the Mangunjaya, Padaherang, and Kalipucang Districts. This means that losses due to floods potentially recur in the affected areas especially rice fields. This is evidenced by the fact that not many affected rice fields have been customized and still tend to bear losses due to flooding. Losses due to floods are shown by the reduced frequency of harvests and agricultural products, infrastructure not optimally functioning, disruption of community services, as well as disrupting of economic activities through agriculture, SMEs, and tourism services. Several steps to minimize losses have also been initiated by the government, although they have not been maximized yet in the implementation stage (Pratama et al., 2020).

This study was conducted to represent the latest data regarding the distribution of flood hazard classes in the Mangunjaya, Padaherang, and Kalipucang areas which are directly adjacent to the Citanduy River. Through integrated planning steps, this study presents 1) land use classification maps and their validation; 2) an AHP-based flood distribution map based on expert interviews; and 3) historic flood analysis. The results of this study are expected to be a reference for the government in order to prepare more accurate and representative mitigation plans. Thus the vision of Pangandaran Champion Regency can be achieved through resilience and sustainability.

2. METHODS

Study Area

The research was conducted in Pangandaran Regency with study coverage areas: 1) Mangunjaya District, 2) Padaherang District, and 3) Kalipucang District, of Pangandaran Regency. The three sub-districts were chosen with several considerations: 1) the historically high frequency of flood events which tend to be routine; 2) the location that is directly adjacent to the Citanduy River which is allegedly the main control for flood events in Pangandaran; 3) the function of these areas as an economic activity. The scope of the study area spatially can be seen in the **Figure 1** below:

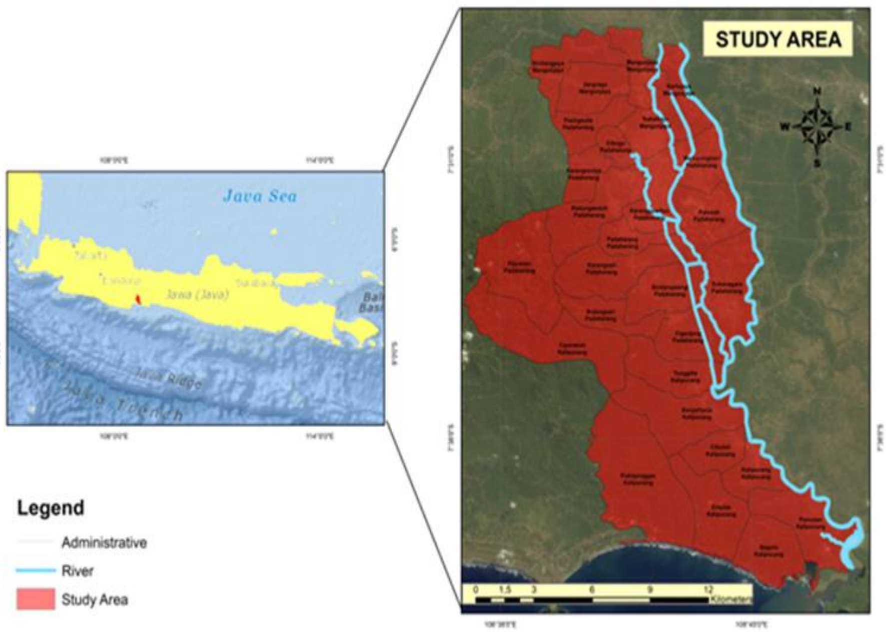

Figure 1. Study area

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Data and Data Acquisition

The data and data acquisition methods used in this study are presented in **Table 1** below:

Table 1. Data and data acquisition method

No	Data	Data type	Data acquisition method
1.	Weight determination based on expert interview		
	Priority order and weight for each parameters of flood assessment	Primary	experts in depth interview by National Disaster Management Authority (BPBD in indonesia)
2.	Land use classification map of 2023 and validation		
	Sentinel 2A Imagery data	Secondary	downloaded data from: https://scihub.copernicus.eu/
	Comparison matrix and accuracy calculation	Primary	Ground checking observation
3.	AHP-based flood hazard distribution map		
	Rainfall	Secondary	CHIRPS data, downloaded by https://data.chc.ucsb.edu/products/CHIRPS-2.0/
	Elevation	Secondary	DEM processing
	Slope	Secondary	DEM processing
	distance from river	Secondary	Buffer analysis by stream systems
	land use	Secondary	Land use classification map of 2023
4.	Flood distribution map validation based on historical analysis		
	In depth interviews of floods historical events	Primary	community in depth interviews
	Flood distribution map	Secondary	previous modelling

Source: Author, 2023

Analytical Method

The analytical method used in this study is an integrated mixed method which includes: 1) AHP weighting determination based on expert interviews; 2) Classification of land use and Validation 3) Compilation of Flood Hazard Distribution Map; 4) Validation of flood hazard distribution maps and historical flood analysis. Each method of analysis is presented as follows:

1. **AHP Weighting Determination based on Experts Interviews**

AHP is an effective qualitative method used in flood hazard analysis by utilizing GIS modelling (Bathrellos et al., 2017; Olii et al., 2021). This method is also recommended on a regional to global scale and alleged that the data provides good accuracy within flood hazard modeling (Gigović et al., 2017). AHP analysis is used to determine the weight of each flood parameter based on expert interviews. The interview results form the basis for determining the priority level and weight of the assessed parameters (Dhiniati & Dinata, 2022). The class of interest intensity indicators in determining priorities is described by **Table 2** below:

Table 2. interest intensity indicators

Interest intensity	Explanation
1	just as important
2	not too important

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3	quite important
4	quite more important
5	high importance
6	higher importance
7	very important
8	more very important
9	the most important

Source: (Saputra et al., 2020)

Eigenvalue (λ), consistency index (CI), and random comparison index (RI) are then calculated and used to determine the consistency ratio (CR). The consistency ratio is used to define the consistency level of each parameter's weight value. The consistency index (CI) is an index value based on the eigenvalue of each parameter. CI is calculated by thehighest Eigenvalue, and n (the number of parameters used) by the follows equation:

$$CI = \frac{\lambda_{max} - n}{n - 1}$$

While the random consistency index (RI) is a table value based on the number of n or parameters described, described in **Table 3** as follows:

Table 3. Table value of random consistency index

Number of parameters (n)	Random consistency index (RI)
1	0,00
2	0,00
3	0,58
4	0,90
5	1,12
6	1,24
7	1,32
8	1,41
9	1,45
10	1,49

Source: (Saputra et al., 2020)

The consistency ratio is used to measure the result's suitability when determining priority weights. The value of the consistency ratio (CR) must be lower than <0.1 to be accepted. Meanwhile, CR is the comparison between the consistency index (CI) and the random comparison index (RI) that is calculated based on the following equation:

$$CR = \frac{CI}{RI}$$

2. Classification of Land Use

The classification of land use in this study is the step of preparing one of the flood indicators. Land use map are modeled using the Sentinel A2 imagery data. Land use model formed by Random forest algorithm and classified six different category of land use.

This study used the Google Earth Engine cloud-based web platform, which has now become a trend in analyzing the Earth's surface (Amelia & Darmansyah, 2023; Papilaya, 2022; Rahmawati et al., 2022)

The ability of the Google Earth Engine (GEE) to access various sources of satellite data and its ability to perform global-scale geospatial analysis, becoming consideration factors in this study

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(Gorelick et al., 2017; Mutanga & Kumar, 2019). The land use model utilizes Sentinel 2A Imagery data and the Random Forest Algorithm.

The sentinel 2A imagery data with a spatial resolution of 10 up to 60 meters, was provided by the European Space Agency (ESA) (Awaliyan & Sulistyoadi, 2018; Li et al., 2021). The imagery data used is an image with <30% cloud cover during the July 2022 – June 2023 observation period. The Random Forest algorithm utilizes a training site that was built in the classification stage. The classification classes used are water bodies, forests, built-up land, plantations, rice fields, and gardens/moors. The spatial representation of the map depicted in the ArcMap application becomes a land use classification map.

Validation was carried out to assess the model's accuracy. The validation method used is ground checking, by comparing the model data with actual data on the earth's surface (Foody, 2002; Warrens & Pratiwi, 2016; Yang & Zhou, 2015). The validations assessed were Overall Accuracy and the Kappa Index as the most commonly used accuracy methods in land cover and use modelling. The calculation of these two calculations utilizes a cross-tab comparison then calculated by a specific equation. The overall accuracy and Kappa equations used are (Fleiss, 1981; Napitupulu, 2014; Yang & Zhou, 2015):

$$Overall\ Accuracy = \frac{Jumlah\ data\ sesuai}{Jumlah\ total\ sampel} \times 100\%$$

$$Kappa = \frac{N \times \left[\sum_i^k Nilai\ data\ benar \times \sum_i^k (Baris \times Kolom)\right]}{N^2 - \sum_i^k (Baris \times Kolom)}$$

The Kappa value interpretation on the land use classification refers to (KLHK (Kementerian Lingkungan Hidup Dan Kehutanan), 2020) which is a calculation based on (Cohen, 1968). These indicators are presented in **Table 4** below:

Table 4. Index Kappa Interpretation

Index value	Interpretation
< 0	Bad chance of accuracy
0,01 – 0,20	Little chance of accuracy
0,21 – 0,40	Chance of accuracy enough
0,41 – 0,60	Moderate chance of accuracy
0,61 – 0,80	Good chance of accuracy
0,81 – 0,99	Chances of very good accuracy (almost perfect)

Source: (KLHK, 2020)

3. Compilation of Flood Hazard Distribution Map

Flood Hazard Distribution Map was modeled by Weighted Overlay analysis on ArcGIS. This method is a spatial analysis to calculate several parameters with different priority weights to determine the distribution of area classes. The Weighted Overlay method, which is collaborated with determining weights through AHP, is commonly used in various studies, including being considered good in flood hazard assessment (Ayenew & Kebede, 2023; Desalegn & Mulu, 2020; Nahin et al., 2023; Utama et al., 2022; Yassar et al., 2020).

The weighting in the AHP based on the expert interviews model is the standard for normalizing the calculation of the flood hazard. The flood hazard map in this analysis uses the following

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indicators: 1) rainfall; 2) elevation; 3) slopes; 4) distance from the river; 5) land use. Each parameter is weighted with the AHP result in the previous process. Each vulnerability assessment indicator is described as follows:

1) Rainfall

Rainfall data were obtained from Climate Hazards Group Infrared Precipitation with Stations (CHIRPS), which is global rain data that combines satellite observations, rain stations observations on Earth, and the predictors of rainfall based on altitude and geographic location(Funk et al., 2015; Funk et al., 2014). CHIRPS data can be accessed at https://data.chc.ucsb.edu/products/CHIRPS-2.0/ with a spatial resolution of 0.05°. CHIRPS data used in this study is monthly data with a span of 10 years from 2013 to 2022. Rainfall data analysis was carried out using the Inverse Distance Weight (IDW) interpolation method by the ArcMap application from ArcGIS, furthermore classified to interpret the annual rainfall distribution in the study area (Yudanegara et al., 2021). Rainfall is the most important parameter for Flood assessment (Parsian et al., 2021). Elevation

The Digital Elevation Model (DEM) is a relief model of the earth's surface which is described from the height values at the X and Y coordinate points. DEM data were obtained from aerial photographs, satellite data, topographic map data, and field measurements. The DEM model is illustrated with ArcGIS to see the elevation distribution within the research area. Elevation has a significant influence on flooding occurrence on the nature basis assumption that the fluid flows towards the lower areas. Particularly in the study of Pangandaran Regency, several areas have a height lower than the river, so it tends to increase the potential affected by floods (Amin et al., 2022; Darmawan et al., 2017; Irawan et al., 2018).

2) Slopes

The slope is modeled using DEM data by slope analysis with ArcGIS application. The result of this process is raster data which shows the distribution of the area's slopes. The constructed slope area is divided into 5 classes which are assessed based on their indications of the flooding. The smoother or gentler the slope, the higher potential to be affected by flooding since water tends to move slowly (Karondia et al., 2022).

The basin topography also makes the area more prone to flooding (Darmawan et al., 2017).

3) Distance from the River

The distance from the river in this study was mapped using the buffer method. Buffer is modelled from the river and irrigation channels that pass through the study area. Buffer is a method used in geospatial models to describe the proximity or coverage area to a certain center point (Junyar et al., 2020). The center point of the Buffer can be a point, line, or polygon.

This method is widely used in the analysis of influence and impact distribution. Stream flow buffer is used to determine the zoning distance of the river which is categorized into classes: 0-100 m; >100-200m; >200-300m; >300-500m; and >500m. Rivers which are considered the main controlling factor causing flooding are an important indicator in hazard assessment (Aziza et al., 2021; Putra et al., 2021). The assumption is that the closer an area is to a river, the more it is potentially affected by flooding (Glenn et al., 2012; Sebayang & Rosanti, 2022).

4) Land Use

The land use indicators used in this study are the results of land use classification maps using Sentinel 2A by random forest algorithm. Land use is an important indicator to flood hazard assessment (Hani et al., 2021). Several kinds of land use have different responses to water movement and drive different potential flood hazards.

4. Validation of Flood Hazard Distribution Maps and Historical Flood Analysis

This step is the validating processes of flood events in the study areas that have been mapped by the model. Validation was carried out by agencies and community interviews using incidental sampling-depth community interviews method. The site of community interviews was

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predetermined as validation points. The validation bases questions used are: 1) whether there is a flood event; 2) the intensity and magnitude

of the incident; 3) recent events; 4) impact and loss; 5) follow-up and government participation in anticipating losses. These results are described and supported by map visualization as a validation of the flood area.

Research Flowchart and Process

All the process used in this study shown by following **Figure 2**:

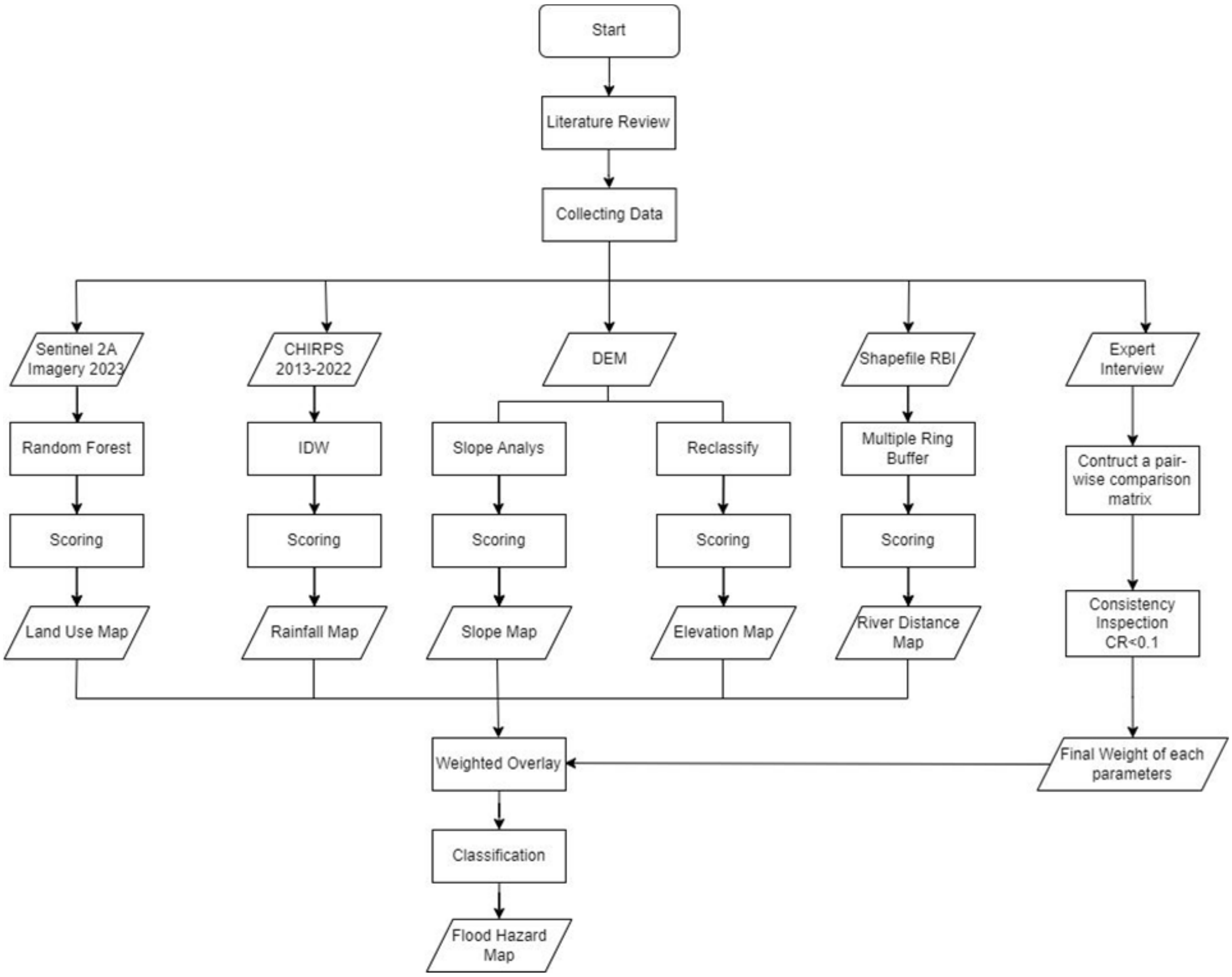

Figure 2. Research's flowchart and process

Data Representation

The results and representation of the results obtained in this study are described in the following **Table 5**:

Table 5. Result and representation

No	Result	Representation
1	AHP weighting determination based on expert interviews	The calculations results and AHP priority weights
2	Classification of land use and	Land Use Classification Map

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	accuracy calculation	
3	Compilation of Flood Hazard Distribution Map	Flood hazard distribution map
4	Validation of flood hazard distribution maps and historical flood analysis	Descriptive analysis of historical event and validation map

Source: Author, 2023

3. RESULTS AND DISCUSSION

1. *Analytical Hierarchy Process* (AHP)

Analytical Hierarchy Process (AHP) analysis is used to determine weight values of flood hazard parameters, which are: rainfall, elevation, slope, land use, and distance from the river. The pairwise comparison assessment was determined based on expert interviews, meanwhile in this case, were the flood disaster rapid assessment team at National Disaster Management Authority (BPBD) of Pangandaran Regency. The result of this process is a pairwise comparison matrix which is presented in **Table 6**. For the next step, the value of the pairwise comparison matrix is normalized and analyzed to obtain the weight of each parameter and further to see the consistency of the AHP value.

Table 6. Pairwise Comparison Matrix

Pairwise Comparison Matrix					
	Rainfall	Elevation	Slope	Land Use	Distance from River
Rainfall	1	4	7	9	5
Elevation	0.25	1	5	7	3
Slope	0.14	0.2	1	2	0.5
Land Use	0.11	0.14	1	1	0.2
Distance from River	0.2	0.33	2	5	1
Total	1.7	5.68	15.5	24	9.7

Source: Author, 2023

Table 7. Normalized Criteria Matrix

Normalized Criteria Matrix						Total	Priority (Weight)	*Eigen Value*
	Rainfall	Elevation	Slope	Land Use	Distance from River			
Rainfall	0.59	0.70	0.45	0.38	0.52	2.63	0.53	0.90
Elevation	0.15	0.18	0.32	0.29	0.31	1.25	0.25	1.41
Slope	0.08	0.04	0.06	0.08	0.05	0.32	0.06	0.99
Land Use	0.07	0.03	0.03	0.04	0.02	0.18	0.04	0.89
Distance from River	0.12	0.06	0.13	0.21	0.10	0.62	0.12	1.20
Total	1	1	1	1	1	5	1	5.38

Source: Author, 2023

Table 7 shows the priority value (weight) which is calculated from the average criteria comparison for each parameter. The parameters with the highest weight are rainfall and elevation. This result is generally reliable, as we see that floods events occur in the western part of the Citanduy River mainly caused by high rainfall intensity followed by increasing volume of water in the Citanduy River. In addition, the contrast elevation gap of the Citanduy River and its surround, which is relatively higher, will easily drive overflow and cause flooding when the river is no longer able to hold water.

Eigenvalue (λ) is used to count the consistency index (CI) by comparing it with the table value of the random consistency index (RI), so we can get the value of consistency ratio (CR). The count of CR is supposed to be lower than 0,1 so the weight of the AHP model can be used for analysis.

Consistancy Index (CI) =	0.096
Random Consistancy Index (RI) =	1.12
Consistency Ratio (CR) =	0.086

Consistency Ratio shows a number of 0.086 or lower than 0,1 and indicate that the decision maker formed by Pairwise Comparison Matrix is consistent and acceptable. It means that the AHP model can be used for the next analysis. In the analytical process, we use the classification of each parameter based on **Table 8** bellow:

Table 8. Classification of Each Parameter

Parameters	**Classifications**	**Score**	**Weight**
Rainfall	<1500 mm/year	1	0.53
	>1500-2000 mm/ year	2	
	>2000-2500 mm/ year	3	
	>2500-3000 mm/ year	4	
	>3000 mm/ year	5	
Elevation	0-50 m	5	0.25
	>50-100 m	4	
	>100-150 m	3	
	>150-200 m	2	
	>200 m	1	
Slope	0-8%	5	0.04
	>8-15%	4	
	>15-25%	3	
	>25-45%	2	
	>45%	1	
Land Use	water body	5	0.12
	rice field	4	
	built-up area	3	
	garden/moor and plantation	2	
	Forest	1	
Distance from River	0-100 m	5	0.06
	>100-200 m	4	
	>200-300 m	3	
	>300-500 m	2	
	>500 m	1	

Source: Author, 2023

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2. Rainfall

Through the rainfall analysis shown by the map in **Figure 3** indicate that overall parts of the study area have a very high annual rainfall of >3000 mm/year. Whereas rainfall parameter has the highest weight among other parameters, so it highly contributes in to flood hazard events. The very high rainfall intensity might cause enhancement of water volume within the Citanduy River and further would intensify the risk of the overflowing. When the river's capacity is unable to accommodate the high volume of water, flooding cannot be avoided. Based on National Disaster Management Authority (BPBD) data, flood events in Pangandaran Regency occur regularly during the rainy season.

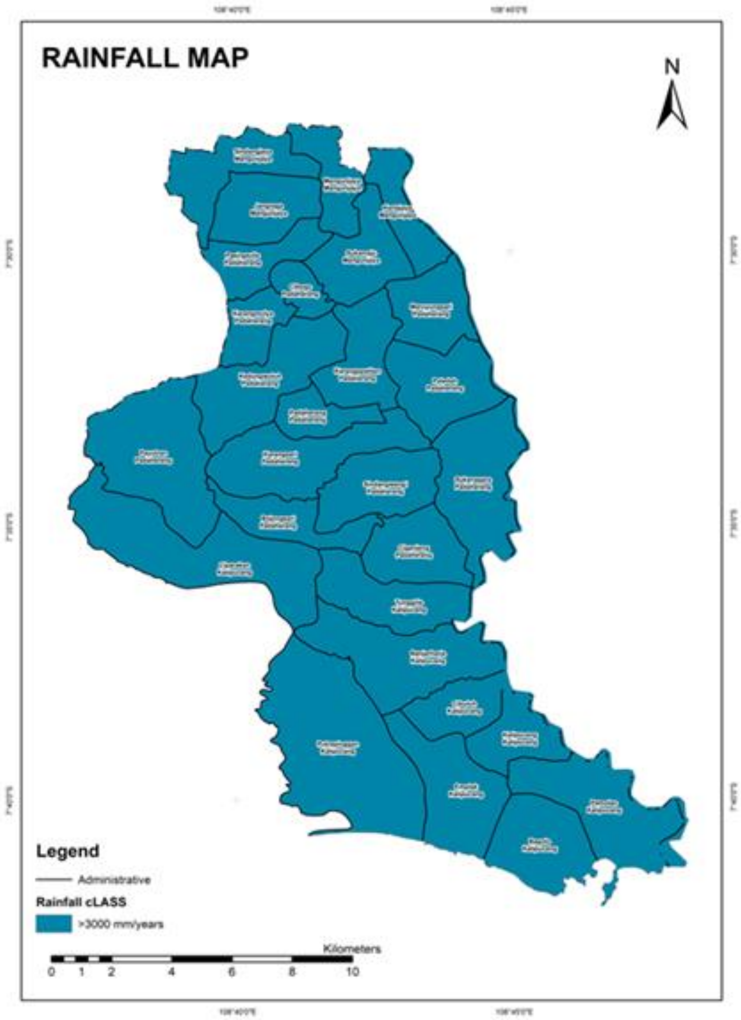

Figure 3. Rainfall Map

3. Land use

Through the classification results, the Land Use Land Cover (LULC) distribution map was obtained which consisted of 6 different classes, namely: water body, rice field, built-up area, garden/moor, plantation, and forest in **Figure 4**.

The analysis results show that land use dominated by forests counted 11804.48 Ha or 47.8% of the total study area, followed by rice fields counted 7191.46 Ha or 29%. This count followed by plantation, built-up area and water bodies. The Forest is located in the east of Padaherang and Kalipucang District, which is relatively higher elevation and located quite far from Citanduy River. Based on these conditions the potential for flood hazard that might occur can be lower in the forest area.

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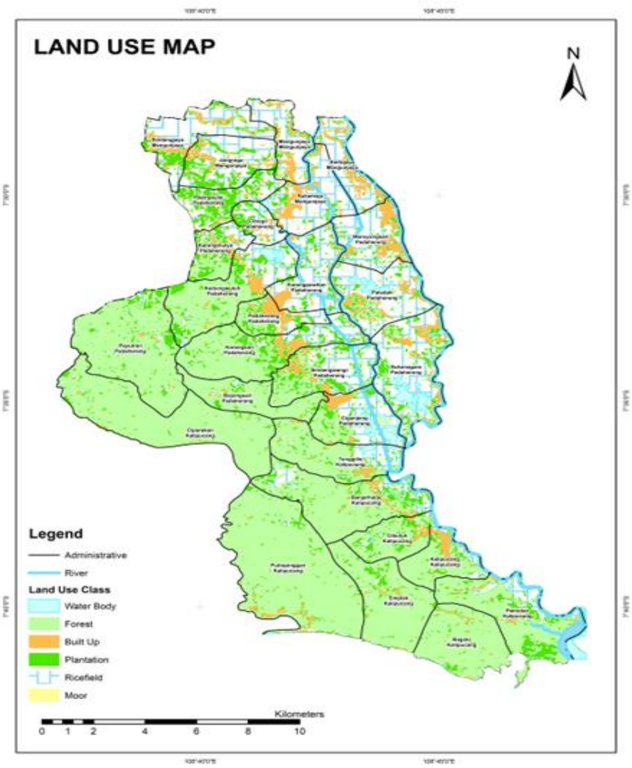

Figure 4. Land Use Map

Meanwhile, rice fields are mostly located along the Citanduy River with lower elevation and flat topography. The soil characteristics of the rice fields in the study area are abundant water of soil, even in some areas are constantly flooded and often called swamps by the local residents. Some examples of this condition are located in Paledah and Sukanagara Village. These conditions indicate that the infiltration level of soil within the rice fields is relatively low and has a higher potential for flood hazard.

In order to see the accuracy and suitability level of the map model, an error matrix analysis is carried out. This validation phase is using ground checking method which is arranged into an error overall accuracy matrix as shown in **Table 9** below. The overall accuracy calculation result for land use map counted 81%, which is still 4% below the minimum level of land use classification. However, depend on imagery data resolution used, the scale of analysis, and the coverage area, an accuracy of 80-85% is already ideal for use (Sutanto, 2010).

Table 9. Matrix Error Overall Accuracy

		Land use within the validation ground						
		Forest	**Plantation**	**Garden / Moor**	**Rice Field**	**Water Body**	**Built-Up Area**	**Total Rows**
Land use within the map	***Forest***	6	0	0	0	0	1	7
	Plantation	0	5	0	1	0	1	7
	Garden/Moor	0	0	7	0	0	2	9
	Rice Field	0	0	1	12	0	1	14
	Water Body	0	0	0	1	8	0	9
	Built-Up Area	0	2	1	2	0	16	21
	Total Columns	6	7	9	16	8	21	67

Source: Author, 2023

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(M. R. Pratama & Riana, 2022) also classify an accuracy level above 75% as acceptable in land use classification. Although basically, high accuracy results are difficult to achieve in various classification classes and require more validation points (Baillarin et al., 2012; FAO (Food and Agriculture Organization of the United Nations), 2016). Meanwhile, the Kappa index was calculated to see the consistency and reliability of the results between the model and validation data. The Kappa result in this model is 0.76 which belongs to the good accuracy probability class and acceptable to be used.

4. Elevation

The land elevation indicator has a significant impact on the flooding causes, with an AHP priority weight value of 0.25. Based on **Figure 5**, it can be seen the various elevation value within Mangunjaya, Padaherang, and Kalipucang districts. This range varies between 0 to > 200 meters above sea level. The most dominant elevation class is 0 to 50 meters above sea level, which covers about 13,710 Ha from 24,719 Ha of the total study area. This flat class of elevation has a high potential for flooding by the principle of water movement, which is flow from a higher to a lower elevation. That makes the flat slope in low elevation will have a greater level of vulnerability to flooding.

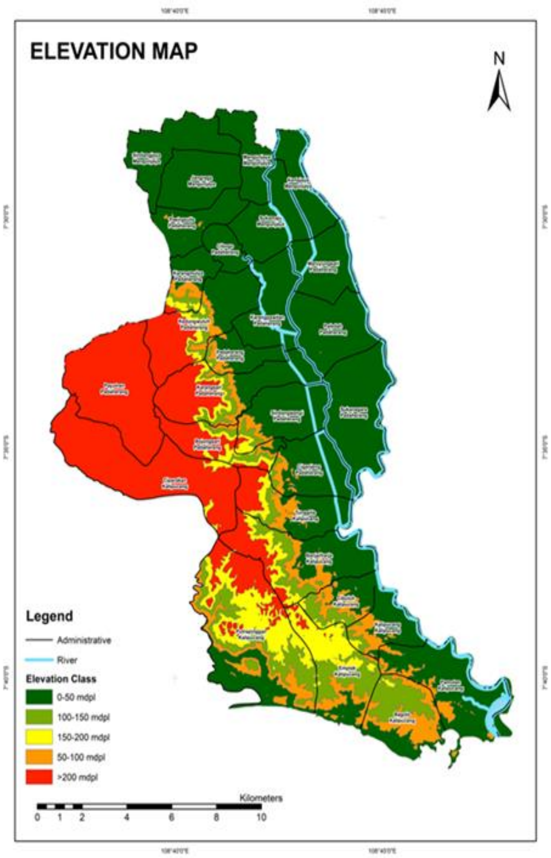

Figure 5. Elevation Map

5. Slopes

The slope parameter within this study has an AHP priority weight value of 0.04 while the distribution of slope classes shown by **Figure 6** bellow. Based on Figure 8, it can be seen the variation of slope over Mangunjaya, Padaherang and Kalipucang Districts in the range of 0 to 45%. The slope class with the most dominant is 0 – 8% and indicates as the gentle sloping category.

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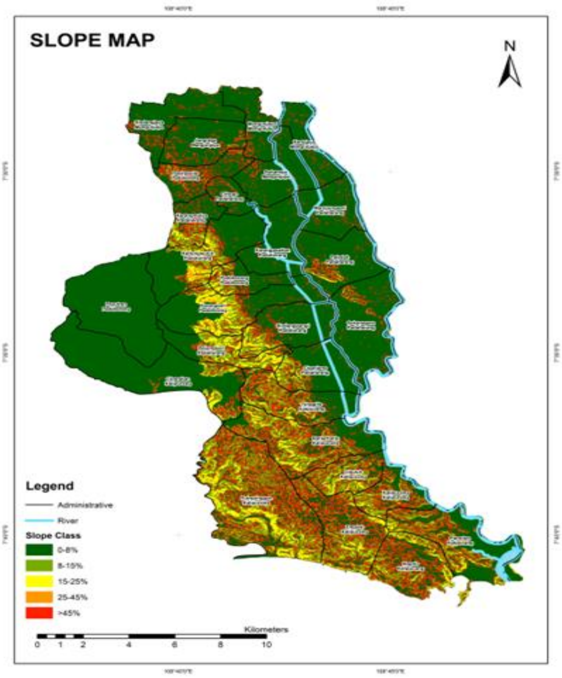

Figure 6. Slope Map

This class was mapped about 15,961 Ha from 24,719 Ha of the total study area. It can be assumed that the study area has a higher potential for flooding caused by the gentler slope characteristics. It's related to the slower movement of surface runoff and the greater inundation possibility driven by the gentler slope.

6. Distance from the River

Based on **Figure 7**, the distance from the river in Mangunjaya, Padaherang, and Kalipucang Districts varies between 0 to > 500 m. The buffer distance parameter from the Citanduy River and several irrigation systems, become parameters that determine whether an area has a potential of flooding. The closer distance from the water system, the higher flooding potential might occur. The distance class from the river that is most prone to flooding is a range of 0 – 300 meters from the river. The area included in this class is counted in 3,747 Ha from 24,719 Ha of the total study area.

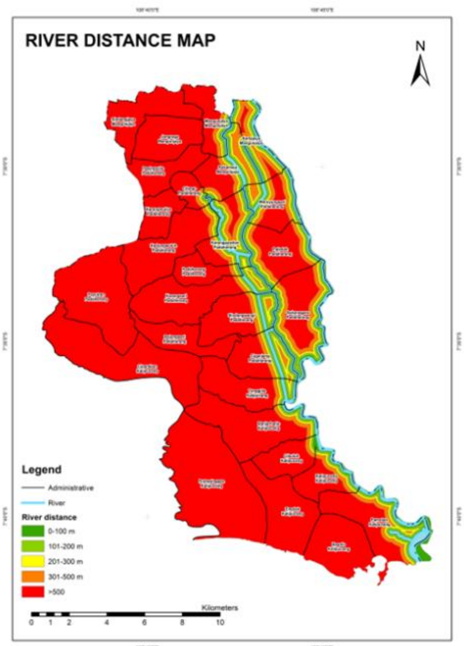

Figure 7. River Distance Map

7. Flood Hazard Distribution Map

The weighted overlay is modelled with the ArcGIS application and generates the flood hazard classes distribution map in **Figure 8**. Based on figure 8 the flood hazard level is classified into 5 classes, namely very low, low, medium, high and very high.

The flood hazard with low and very low classes is so minimal that it is less visible on the map. While the moderate level of flood hazard class visualized by the yellow area counted as 12.6 Ha. The moderate class area is located in the eastern part of the study area, especially in Padaherang and Kalipucang sub-districts. This area has a flat topography of 0-8% with an elevation of >200 meters above sea level. In addition, the land use is dominated by forest and the location is quite far from the Citanduy River. These characteristics might lower the potential of flood runoff in this area. However, the extreme rain coupled with massive forest land degradation might enhance the runoff possibility. The flood event in this area might be categorized as flash flood in a short duration. Moreover, the high-level flood hazard class is visualized with an orange area. This area is occupied at 2041.17 Ha, spread over built-up land use. This class mostly has a 50-200m elevation above sea level and a slope of 15-25%. It shows their association with the Citanduy River, that this area comes near to the water system.

The area that is classified as very high hazard is 22652.11 Ha and is mostly located in villages directly adjacent to the Citanduy River. This area has a flat topography and very low elevation. Besides, this area is close to the main channel and irrigation system of the Citanduy River.

Flood hazard intensity along the Citanduy River is caused by high rainfall while the River capacity is unable to accommodate flood discharge. According to (Hariati et al., 2020)'s research, the frequency and intensity of rainfall in the Citanduy watershed area increased from 2006 to 2016 which caused a flood enhancement downstream. In addition, (Almubdiu et al., 2019) in his research through flow hydraulics analysis on the Citanduy River's cross-section using the HEC-RAS Program, indicated that flood overflows in several places exceeded the river banks. (Maulana & Rosalina, 2022) also state that there are indications of the Citanduy River sections experiencing an overflow with variations of ±40-80cm when modeled with a 25 years return period.

When the high intensity of rainfall occurs, the runoff originating from overflowing rivers would easily inundates this area. The type of land use in this area is dominated by rice fields. Based on its origin, most of the rice fields in Paledah and Kartanegara Village are naturally formed lakes or pools of water above the ground surface. The land use change of this area to the rice field is driving the changes in the natural system and causing floods. The rice fields are relatively lower than the elevation of the Citanduy River so overflow from the river is easily inundates.

Floods in the study area still occur regularly, especially during the rainy season. This temporal event is indicated by the increasing water discharge due to shipments from Tasik, Ciamis, and Banjar Regencies. Based on the results of observations and interviews, flooding in the Mangunjaya District area was mainly caused by water addition from upstream. These conditions lead to overflowing because the Citanduy River's irrigation gates were unable to pass all amounts of water at once. Besides, flood events in the Padaherang District area are mainly controlled by the elevation gap, where the Citanduy River is physically higher than the surrounding areas. So the overflows of water would fill and inundates the surrounding area that dominates by rice fields. Meanwhile, flood events around Kalipucang (Dusun Pamotah, Bagolo, Kalipucang) are mostly controlled by silting due to sedimentation and sea tides in the estuary.

The surveys and historical validation of floods through community interviews at several sample points in **Figure 9** show that flood events have occurred almost regularly within the past 2 years. The flood events occurred at different duration and intensities at each sample location point. The last flood incident occurred in Mangunjaya District (February 2023) where the flood inundated rice fields due to heavy rains. It caused water discharge enhancement so that the Citanduy River overflowed. In contrast to the flood incident in Kalipucang District (October 2022), the flood

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inundated the road system to residential areas by approximately 70 cm. In the Mangunjaya and Padaherang sub-districts, the flood events only inundated rice fields. In addition, in the Kalipucang sub-district located around the estuaries, floods inundated the rice fields to residential areas.

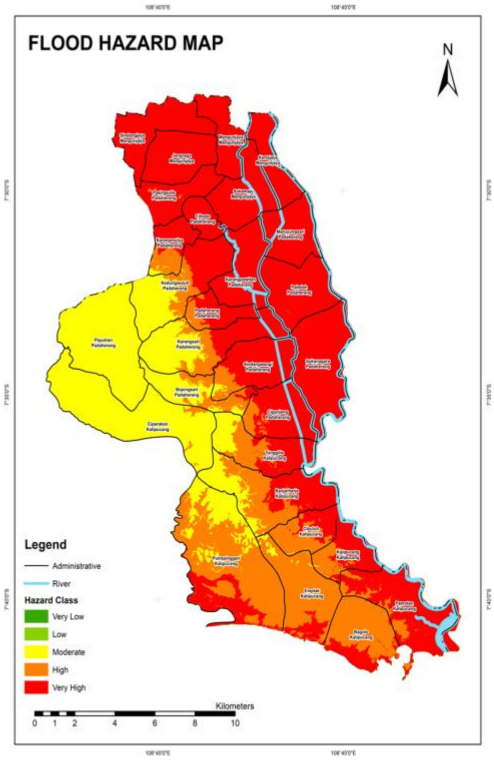

Figure 8. Flood Hazard Distribution Map

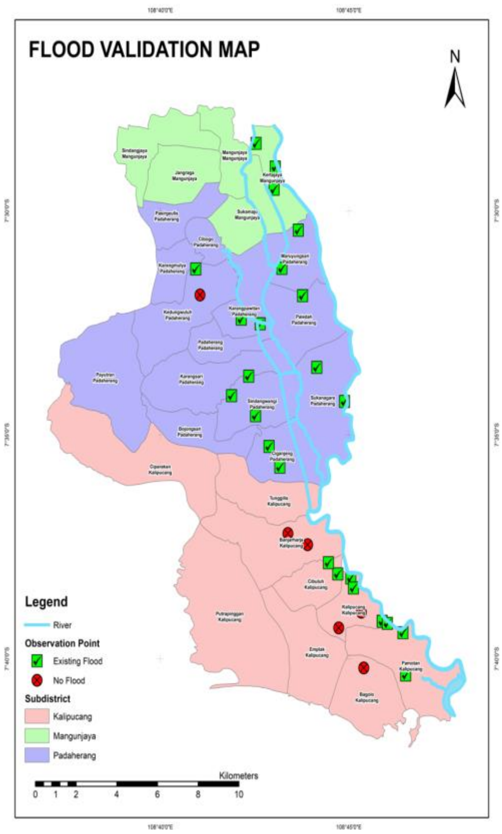

Figure 9. Flood Validation Map

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4. CONCLUSION

Based on calculations results using the AHP method, shown that the weight of the determinants of the most flood hazard parameters in Pangandaran Regency is rainfall of 0.53%, followed by elevation of 0.25%, land use of 0.12%, distance from the river of 0.06%, and the slope of 0.04%. The flood hazard with low and very-low levels is so minimal that it is less visible on the map. While the moderate level of flood hazard class counted as 12.6 Ha, mostly located in the eastern part of the study area (Padaherang and Kalipucang sub-districts).The high-level flood hazard class occupied about 2041.17 Ha, spread over built-up land use. The Very-high hazard class is 22652.11 Ha and mostly located in villages directly adjacent to the Citanduy River.

Based on the results of observations and interviews, flooding in the Mangunjaya District area was mainly caused by water addition from upstream. Besides, flood events in the Padaherang District area are mainly controlled by the elevation gap, where the Citanduy River is physically higher than the surrounding areas. Meanwhile, flood events around Kalipucang (Dusun Pamotah, Bagolo, Kalipucang) are mostly controlled by silting due to sedimentation and sea tides in the estuary.

As recommendation part, we point that recurring and intensive flooding occurs in the western downstream area of the Citanduy River Basin (including Kalipucang, Padaherang, and Mangunjaya Districts, Pangandaran Regency) needs some specific methods to overcome. Those specific methods can be facility constructions to accommodate overflows, community empowerment, and so land use adjustment in order to adapt into the recurring flood plains. As its purpose, this research can be a consideration in order to form a detailed plan to optimize the anticipation, mitigation, and customization process of land use in this area. This research also can be reference for future researcher to see further development of Pangandaran Regency enhancement in hazard mitigation in the future. Furthermore, the losses caused by flood can be minimalized while resiliencies formed in Pangandaran Regency.

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