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Dam-Break Flood Modeling and Risk Assessment using HEC-RAS 2D: for Ladongi Dam, Southeast Sulawesi, Indonesia

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Abstract

Dam-break floods pose severe threats to human safety, infrastructure, and economies, especially in embankment dams. The Ladongi Dam, located in East Kolaka Regency, Southeast Sulawesi, Indonesia, is classified as a high-hazard structure, making its potential failure a significant concern. This study aims to assess dam-break flood hazards and risks using HEC-HMS to simulate rainfall, runoff and dam-break hydrographs, and HEC-RAS 2D to model downstream flood propagation and inundation characteristics. The results show that under the Probable Maximum Precipitation (PMP = 550.7 mm), the dam and spillway can safely manage the PMF without overtopping. Under a piping failure scenario, simulations indicate an inundated area of 76.7 km² across three sub-districts, with a peak flow velocity of 23.48 m/s, a water depth exceeding 10 m, and a flood duration of more than 24 hours. Risk assessment integrating hazard, vulnerability, and capacity indices shows the highest risk level in Ladongi Sub-district (0.67), while Dangia (0.57) and Loea (0.62) are classified as medium risk. These results highlight that non-structural mitigation measures such as early warning systems, evacuation planning, and community preparedness can enhance community capacity and contribute to reducing the overall flood risk index in the affected region.

Keywords: *Dam-break; 2D Hydraulic Modeling; Risk Assessment; HEC-RAS; Ladongi Dam*

1. Introduction

The construction of the Ladongi Dam in East Kolaka Regency, Southeast Sulawesi, is part of the National Strategic Project (PSN) based on Presidential Regulation No. 109 of 2020. Construction of the Ladongi Dam began in 2016, and it was officially inaugurated in 2021 with a storage capacity of 45,95 million m^3. Dam-break floods pose a serious threat to downstream communities, causing potential damage to infrastructure as well as risks to human lives and property, which has made this issue a primary concern among researchers (Kusuma, 2019; Suprapto et al., 2021; Zhang et al., 2024; Zhou et al., 2025).

Dam failures often result from piping and overtopping, particularly when construction, operation, or maintenance deviates from safety standards (Froehlich, 2008; Jibhakate et al., 2024). Overtopping occurs when reservoir water exceeds dam capacity and spills downstream (Elalfy et al., 2025; Verma et al., 2023), while piping involves internal erosion through the dam body or foundation (Adityawan et al., 2023; Wang et al., 2018). As an embankment dam, Ladongi is more susceptible to these mechanisms, which account for most historical failures worldwide (Ferrari et al., 2023; Froehlich, 2008).

Recent studies, such as Demir et al. (2025), on the Doğantepe Dam in Türkiye, have demonstrated the effectiveness of HEC-RAS 2D in simulating piping-induced dam failures, accurately capturing inundation depth and flow velocity across complex terrain. Similarly, (Lim et al., 2024) in the Way-Ela Dam case in Indonesia showed that fully two-dimensional models provide a more reliable representation of flood extent compared to one-dimensional or coupled 1D–2D approaches.

Building on previous studies, comprehensive approaches that integrate hydrological modelling, two-dimensional flood simulation, and BNPB-based risk assessment remain uncommon in Indonesia. This study applies an integrated framework to enhance dam safety evaluation and flood risk management for newly constructed high-hazard dams, offering actionable insights to policymakers and practitioners for strengthening disaster preparedness and response.

According to the Decree of the Director General of Water Resources from the Ministry of Public Works and Housing, number 257/KPTS/D/2011, regarding the Guidelines for Dam Hazard Classification, the Ladongi Dam is classified as Extreme, with a Risk Factor Value of greater than 30. This classification is based on dam capacity, dam height, evacuation needs, and the level of downstream damage.

Given its classification as an extreme hazard dam, Ladongi required careful evaluation of potential failure scenarios. This study applies hydrological modelling with HEC-HMS to assess dam safety under extreme rainfall conditions, two-dimensional hydraulic simulations with HEC-RAS to model downstream flood propagation, and a risk index framework based on BNPB guidelines to evaluate hazard, vulnerability, and capacity. The objective is to develop a flood risk map as an initial step toward mitigation planning. The novelty of this research lies in its comprehensive approach, which integrates modified parameters and leverages multi-source data to provide risk assessments for a newly constructed high-hazard dam in Indonesia.

2. Materials and Methods

2.1. Study Location

The study is located on the Ladongi River, which is part of the Lasolo-Konaweha River Basin under the authority of the Sulawesi IV River Basin Management Organization, Kendari, Ministry of Public Works. Ladongi Dam is located in Ladongi Village, East Kolaka Regency, Southeast Sulawesi Province, geographically, between 4°08’52”–4°08’53” South Latitude and 121°52’43”–121°53’34” East Longitude as shown in Figure 1.

2.2. Required Data

The data used in this paper were obtained from several relevant agencies. The precipitation data were obtained from the hydrology unit of the Sulawesi IV River Basin Management Organization, specifically from the Lambuya Rainfall Station, for the years 2003-2023. Topographic data were obtained from the Geospatial Information Agency (DEM National) with a resolution of 8.25 x 8.25 meters. Land use information was obtained from the Ministry of Environment and Forestry of the Republic of Indonesia for the year 2022. Technical specifications of dams were provided by the Sulawesi IV River Basin Management Organization, Kendari, as presented in Table 1. In addition, socio-industry data were obtained from the Central Statistics Agency of East Kolaka Regency. These datasets from different agencies serve as valuable sources of information for the analysis conducted in this paper.

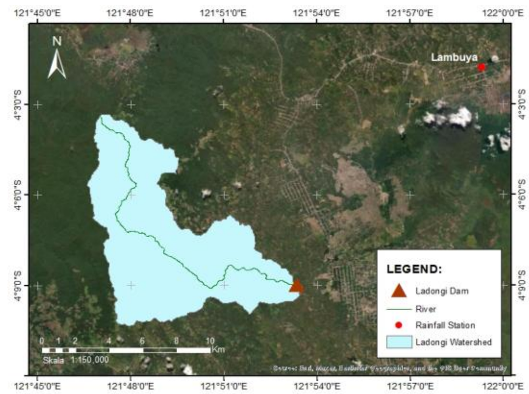

Figure 1. Ladongi Watershed and Ladongi Dam

2.3. Research Methodology

The research methodology consists of several stages, as illustrated in Figure 2.

2.3.1. Hydrological Modeling

The first step involved assessing the quality of rainfall data from the Lambuya rainfall station, which included tests for consistency (RAPS), outliers (U.S. Water Resources Council method), trend (Spearman rank correlation), stability (mean and variance), and independence. The results confirmed that the data were reliable and suitable for subsequent hydrological analysis.

Table 1. Technical Data of Ladongi Dam

No	Unit	Value
1	Dam Type	Embankment Dam
2	Top Dam Elevation	+ 126 m
3	Dam Crest Elevation	+ 70 m
4	Dam Crest Length	417 m
5	Dam Crest Width	12 m
6	Total Storage Volume	45,95 million m^3
7	Effective Storage Volume	28,69 million m^3
8	Dead Storage Volume	14,75 million m^3
9	Area at (NWL)	64,14 Ha
10	Flood Water Level (FWL)	+ 122,6 m
11	Normal Water Level (NWL)	+ 119,8 m
12	Low Water Level (LWL)	+ 96,0 m
13	Left Side Slope	1 V : 1,979 H
14	Right Side Slope	1 V : 2,961 H
15	Spillway Type	Overflow
16	Crest Spillway Type	Ogee Spillway
17	Spillway Width	30 m

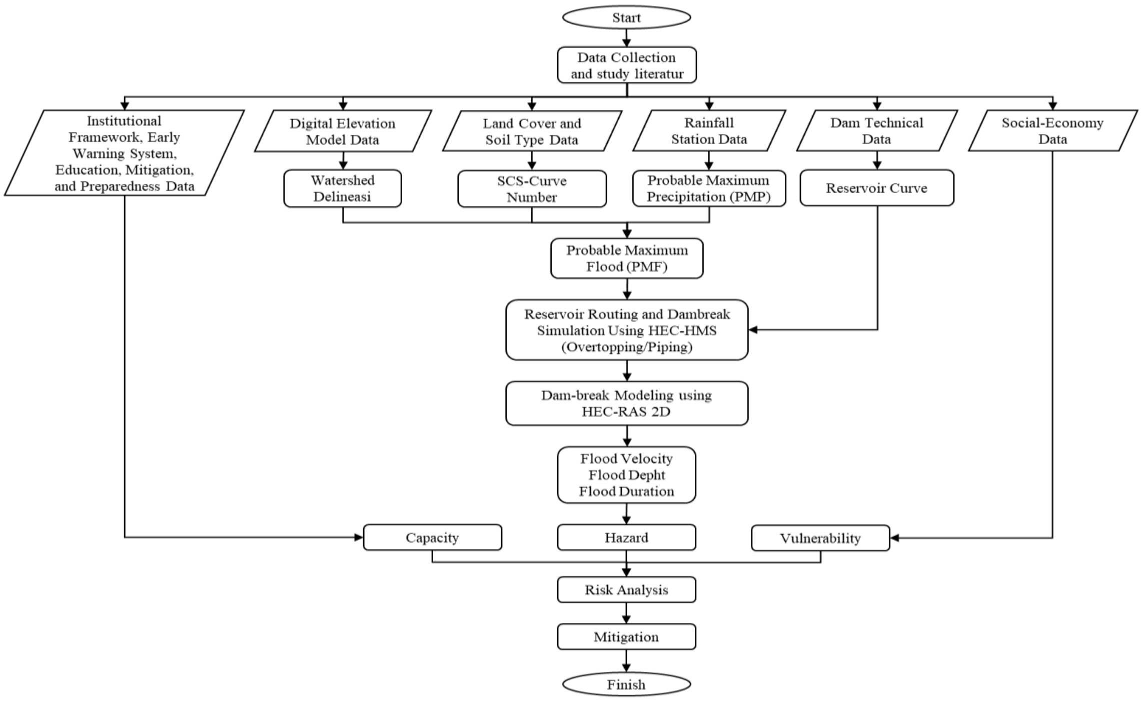

Figure 2. Research Methodology

A Probable Maximum Precipitation (PMP) analyses using the Hershfield method and estimating infiltration losses using the SCS Curve Number method, based on land cover and soil type. The design runoff hydrograph was developed using the Snyder method. All hydrological analysis were performed in accordance with the guidelines issued by the Dam Management Agency and the National Standardization Agency, specifically the "Procedures for Calculating Planned Flood Discharge."

2.3.2. *Hydraulic Modeling*

HEC-HMS was used to simulate inflow hydrographs and determine the maximum discharge conditions, representing the worst-case scenario for risk analysis (Pambudi & Sriyana, 2024; Supratman et al., 2025). Subsequently, HEC-RAS was used to model the two-dimensional downstream floodplain following dam failure. The flood mapping output from HEC-RAS included inundation area, flow velocity, water depth, and flood (Adityawan et al., 2024; Sandi et al., 2022).

Dam breach parameters refer to the various factors that influence the behavior of water flow when a dam fails or collapses (Huseiny et al., 2024). The physical description of the dam failure will consist of the height of the breach (H_b), starting water-surface elevation or critical overtopping depth at which breach formation begins (H_w), average width (B_{ave}), and side slopes in *H:V* (Huseiny et al., 2024).

2.3.3. *Risk Parameters*

In this study, flood velocity, depth, and duration were utilized as hazard indicators in the risk analysis (Adityawan et al., 2024; Nurhakim et al., 2025). Capacity was evaluated based on indicators of Institutional Components, Early Warning Systems, Education, Mitigation, and Community Preparedness at the sub-district level. Vulnerability was assessed through a socio-industrial analysis. The overall flood risk analysis was conducted by integrating the hazard, capacity, and vulnerability parameters.

The concept of disaster risk can be defined as the combination of hazard, vulnerability, and capacity (Keaokiriya et al., 2022; Supratman et al., 2025). In simple terms, risk can be formulated as the potential for adverse effects or losses resulting from the interaction of hazards and vulnerabilities, taking into account the capacity to cope with or manage the risk (BNPB, 2012). The formulation of risk can be expressed as Equation (1).

$$Risk = \sqrt[3]{Hazard \times Vulnerability \times (1-Capacity)} \qquad (1)$$

1. Hazard Parameters

The flood depth hazard level is classified based on several previous studies that have determined hazard parameters in dam failure simulation processes, including velocity (v), depth (h), and duration (d). We attempted to combine hazard parameters according to Mani et al. (2014) and Álvarez et al. (2017) as listed in Table 2.

Table 2. Classification of Hazard Parameters

No	Hazard Value	Depth (h)	Velocity (v)	vh	Duration (d)
1	Low	<0,5 m	<0,5 m/s	<0,25 m	< 25 hours
2	Medium	0,5 – 1 m	0,5 – 1 m/s	0,25 – 0,5 m	> 25 hours
3	High	> 1 m	> 1 m/s	> 0,5 m	> 25 hours

Among the hazard parameters, velocity is the most significant destructive potential in dam-break scenarios. The weighting of hazard parameters was conducted using the Analytical Hierarchy Process (AHP) (Jayadi et al., 2020; Mulyadi et al., 2014) with relative significance of each factor, namely depth, duration, and velocity. Here, pairwise comparisons and weight calculations are conducted to ensure a rational and structured evaluation. The final weights are presented in Equation (2).

$$\begin{aligned} Hazard &= (35\%\ x\ Depth\ Score) + \\ &(15\%\ x\ Duration\ Score) + (50\%\ x\ Velocity\ Score) \end{aligned} \quad (2)$$

2. Vulnerability Parameters

Vulnerability is a condition of a community or society that leads to or causes an inability to deal with the threat of disaster (Oriandra et al., 2024). It is calculated based on BNPB Regulation No. 2 of 2012, with the components outlined in Table 3. Vulnerability is obtained after calculating the social, Infrastructure, economic, and environmental vulnerability index scores as expressed in Equation (3).

$$\begin{aligned} \text{Vulnerability} = &(40\%\ \text{x Social Vulnerability}) + \\ &(25\%\ \text{x Infrastructure Vulnerability}) + \\ &(25\%\ \text{x Economic Vulnerability}) + \\ &(10\%\ \text{x Environmental Vulnerability} \end{aligned} \quad (3)$$

Table 3. Classification of Vulnerability Parameters

Component/ Parameter	Index Class			Weight (%)
	Low	Medium	High	
Social Vulnerability Indicator				
Population Density (People/km^2)	<500	500-1000	>1000	60
Sex Ratio (%)	<20%	20-40%	>40%	10
Age Ratio (%)	<20%	20-40%	>40%	10
Disability Ratio (%)	<20%	20-40%	>40%	10
Poverty Ratio (%)	<20%	20-40%	>40%	10
Environmental Vulnerability Indicator				
Protected Forest (Ha)	<20	20 – 50	>50	30
Natural Forest (Ha)	<25	25 – 75	>75	30
Primary Mangrove Forest (Ha)	<10	10 – 30	>30	5
Secondary Mangrove Forest (Ha)	<10	10 – 30	>30	5
Swamp (Ha)	<10	10 – 30	>30	20
Shrubs/Thickets (Ha)	<10	10 – 30	>30	10
Infrastructure Vulnerability Indicator				
House (million Rp)	<400	400-800	>800	40
Public Facilities (million Rp)	<500	500-1.000	>1.000	30
Critical Facilities (million Rp)	<500	500-1.000	>1.000	30
Economic Vulnerability Indicator				
Productive Land (million Rp)	<50	50-200	>200	60
GRDP* (million Rp)	<100	100-300	>300	40

**GRDP = Gross Regional Domestic Product*

3. Capacity Parameters

The capacity parameter calculation is based on BNPB Regulation No 2 of 2012 listed in Table 4. This study is still limited to a two-dimensional spatial flood inundation modeling approach, as it uses a DEM with a spatial resolution of 8.25 m. Either, it did not include field validation of the simulated inundation extent or an evaluation of the practical implementation and effectiveness of non-structural mitigation measures such as early warning systems and evacuation planning.

Table 4. Classification of Capacity Parameters

Component/ Parameter	Index Class			Weight (%)
	Low	Medium	High	
nstitutional Regulations for Disaster Management	Resilience Lv. 1 and 2	Resilience Level 3	Resilience Lv. 4 and 5	20
Early Warning and Disaster Risk Assessment				20
Disaster Education				20
Reduction of Basic Risk Factors				20
Development of Preparedness at All Levels				20

3. Result and Discussion

3.1. Hydrological Analysis

Before conducting the hydrological analysis, the rainfall data series from the Lambuya rainfall station was first evaluated for quality and reliability through a series of statistical tests. The results are summarized in Table 5.

Based on the table above, data from the Lambuya Rainfall Station meet the criteria of consistency, outlier limits, absence of trends, stability, and independence. Therefore, the data is considered suitable for use in hydrological analysis.

Next, a Probable Maximum Precipitation (PMP) analysis was performed using the Hershfield method based on the regional maximum rainfall. The calculation results indicate a PMP rainfall of 550.7 mm. Subsequently, the water loss is determined using the SCS

CN (Curve Number) infiltration method. Flood discharge analysis is conducted for a 24-hour rainfall duration using the PSA 007 rainfall distribution for simulations in the reservoir as shown in Figure 3.

Table 5. Summary of Statistical Test of Lambuya Rainfall Statio

No.	Test	Result
1	Consistency Test (Rescaled Adjusted Partial Sums Method)	Accepted
2	Outlier Test (US Water Resource Method)	
	- Upper Outlier	Accepted
	- Lower Outlier	Accepted
3	Trend Test (Spearman Method)	No trend
4	Stability Test (mean dan variance Method)	
	- Varian Stability	Stable
	- Mean Stability	Stable
5	Independence Test	Independent

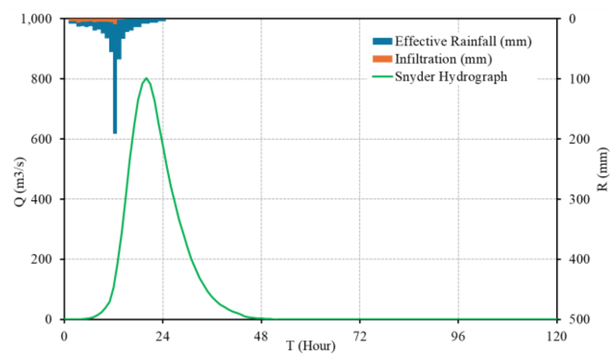

Figure 3. PMP Effective Rainfall and PMF Hydrograph.

3.2. *Dam-Break Modeling*

The failure analysis of Ladongi Dam was conducted using HEC-HMS software to assess the potential for overtopping under PMP (Probable Maximum Precipitation) rainfall events. The input data included: the Digital Elevation Model (DEM) of the Ladongi Watershed, PMP rainfall data, and technical specifications of the dam, such as the dimensions (elevation, width, and length) of the dam body and spillway structures (apron, channel, and beacon), reservoir storage curve, and the slope of the right and left abutment, watershed water losses were estimated using the SCS-CN method, with a Curve Number of 78.73 and an imperviousness of 6.71%. The runoff hydrograph was generated using the Snyder method, with a time lag of 8.15 hours and a peaking coefficient of 0.75.

Based on the simulation results using the Probable Maximum Flood (PMF) discharge at the Ladongi Dam reservoir, the storage graph shows that the Maximum Flood Water Level reaches an elevation of +124.7, which is still below the dam crest elevation of +126. Therefore, it can be concluded that overtopping does not occur.

These simulation results are in line with the study by Zhang et al. (2024), which emphasized that modern embankment dams are generally designed to withstand PMF conditions without structural failure. This also highlights the critical importance of spillway capacity in preventing overtopping failures, as noted by Elalfy et al. (2025) and Verma et al. (2023) is shown in Figure 4.

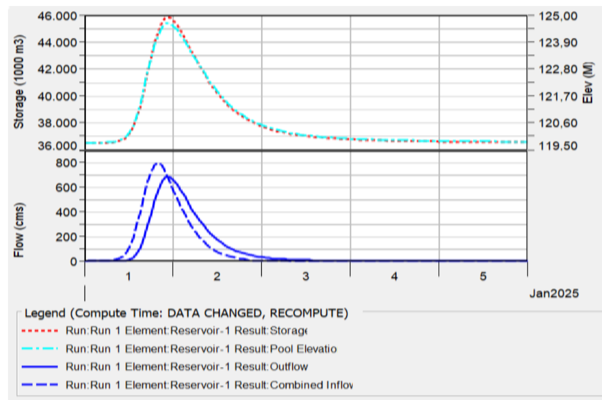

Figure 4. Overtopping Outflow Discharge Simulation

3.3. *Flood Area Modeling*

Based on the simulation results of the PMF flood discharge at the Ladongi Dam and according to the Guidelines for Preparing Emergency Action Plans for Dams issued by the Ministry of Public Works and Housing in 2019. It is explained that the first step in determining potential flood inundation areas due to dam failure is to assess the following three conditions (1) Dam failure under sunny weather conditions, with the reservoir water level at normal pool level; (2) Dam failure with the reservoir water level at the design flood elevation, where the inflow hydrograph equals the design flood; and (3) The dam failure occurred when the reservoir water level reached the crest of the dam. Therefore, considering the guideline, it is determined that the condition examined in this dam failure flood modeling is the piping scenario.

In the setup process of the HEC-RAS 2D model, three main components must be defined as follows (1) Storage Area, this refers to the part of the dam that functions to store water retained by the Ladongi Dam. The required input includes the Elevation–Storage Volume Curve of the Ladongi Dam under Normal Water Level conditions at an Elevation of +119,80, with a total storage of 36,50 million m³; (2) SA/2D Connection Data, this consists of the dam's technical data, including the dam crest length, dam width, left side slope, right side slope, failure mode, and other parameters based on the breach method proposed by Froehlich (2008); and (3) 2D Flow Area Data refers to the floodplain data obtained from the digitized HEC-RAS 2D model, which follows the contour elevations downstream of the dam. The HEC-RAS modeling results have produced flood depth, velocity, duration, area, and time arrival information downstream of the dam. Arrival Time information is used as a mitigation to create an Evacuation Route Map. The modeling output was then translated into visualizations, as shown in Figures 5, 6, 7, and 8.

There are no previous studies reporting dam-break modeling results at the Ladongi Dam; therefore. validation was conducted by comparing the simulated patterns with findings from similar embankment dam studies. The simulation produced a maximum velocity of 23.48 m/s. an average velocity of 0.69 m/s. and flood depths exceeding 10 m with an inundation extent of 76.7 km² under the piping scenario.

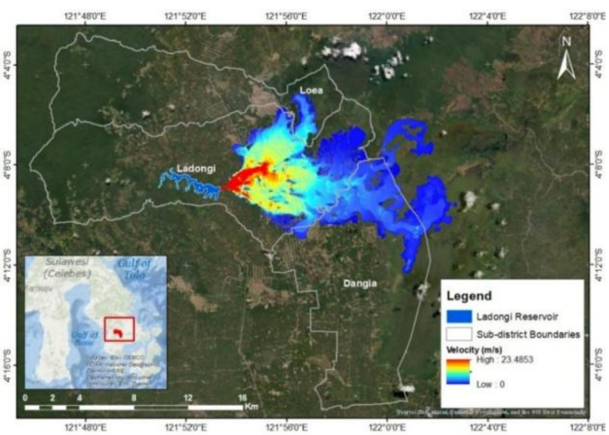

Figure 5. Flood Velocity Map

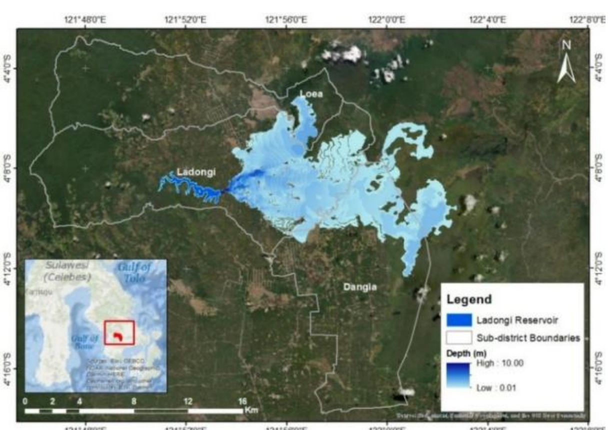

Figure 6. Flood Depth Map

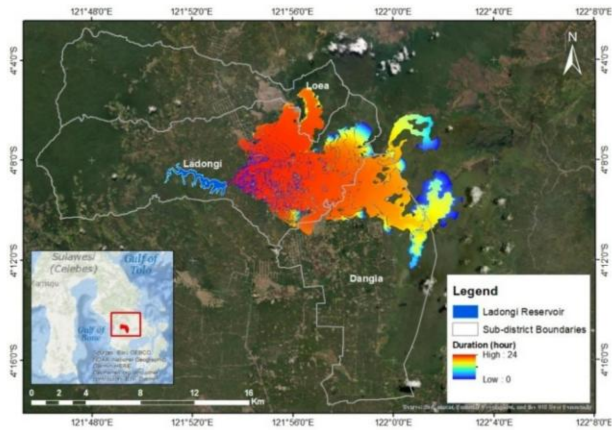

Figure 7. Flood Duration Map

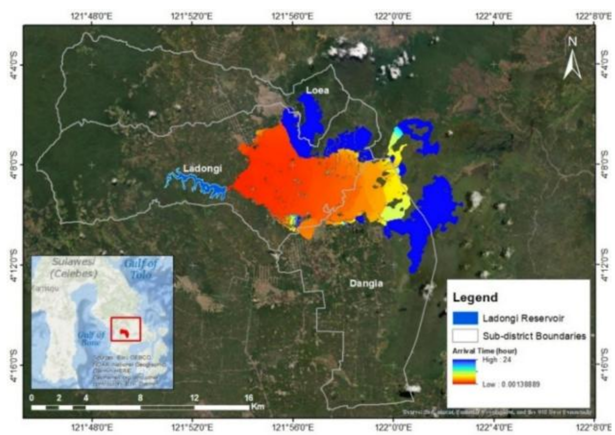

Figure 8. Flood Arrival Time Map

Comparable outcomes were reported by (Demir et al.. 2025) at the Doğantepe Dam with velocities around 20 m/s and depths over 12 m. Huseiny et al. (2024) at the Pidekso Dam with depths up to 11 m. and (Lim et al.. 2024) at the Way-Ela Dam showing velocities near 18 m/s and inundation exceeding 70 km². Although direct numerical comparison is limited by differences in dam geometry and topography. the similarity in flood characteristics indicates that the model provides realistic and reliable results for extreme failure scenarios. In Ladongi Sub-district. the inundation affected residential areas by 11.52% and productive lands. such as rice fields and plantations. by 68.91% of the total affectedarea.

3.4. Risk Analysis

Assessing the potential risk of a dam break flood disaster necessitates the consideration of three primary factors: hazard. vulnerability. and capacity. The hazard index is calculated based on the flood depths. velocities. and durations obtained from previous modeling. The resulting hazard index for each district is compiled in Figure 9 and Table 6.

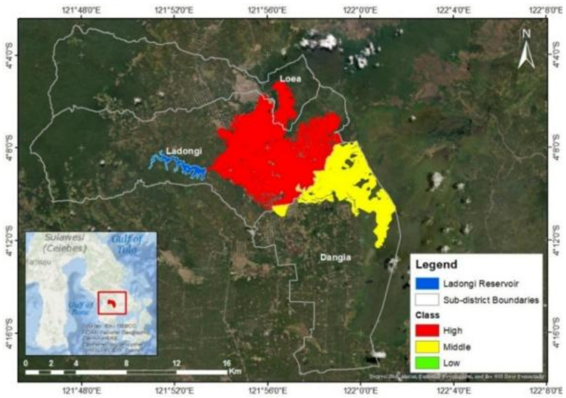

Figure 9. Flood Hazard Map

Table 6. Hazard Index

Sub-District	Criteria	Flood Area (km^2)	Score	Index	Class
	Low	5.74	0.33		
Dangia	Middle	15.96	0.67	0.617	Middle
	High	2.20	1.00		
	Low	8.04	0.33		
Ladongi	Middle	6.42	0.67	0.845	High
	High	34.02	1.00		
	Low	0.52	0.33		
Loea	Middle	1.36	0.67	0.813	High
	High	2.42	1.00		

Based on Table 6. the flood hazard analysis due to the dam break of the Ladongi Dam shows different threat index scores in each district. Ladongi district has the highest index at 0.845, classified as a high hazard level. with a high-category inundation area reaching 34.018 km². Loea district is also in the high hazard category with an index of 0.813, due to the accumulation of medium- and high-category inundation areas. Meanwhile, Dangia district has an index of 0.617 and is classified as medium hazard, as it has the largest medium-category inundation area. 15.96 km².

The supporting map of the classification results is presented in the following figure. where the red-colored areas represent regions with a high hazard level. predominantly covering the Ladongi and Loea areas. The yellow color indicates a medium hazard level in the Dangia area. The inundation area from the dam break spreads widely across the northern and central parts of the study area. indicating that Ladongi sub-district is the most affected region.

The vulnerability index is derived through a socio-industrial analysis that encompasses demographic data. social conditions. health indicators. economic factors. infrastructure conditions. and environmental aspects. The results of the vulnerability index for each village are summarized in Table 7.

Table 7. Vulnerability Index

Sub-District	Vulnerability				Index	Class
	Social	Eco.	Infra.	Enviro.		
Dangia	0.43	1.00	0.33	0.47	0.55	Middle
Ladongi	0.43	1.00	0.80	0.47	0.67	High
Loea	0.43	1.00	0.33	0.33	0.54	Middle

Dangia and Loea districts have a medium vulnerability index. while Ladongi district falls into the high vulnerability category due to its high physical vulnerability score. Ladongi serves as the economic center of East Kolaka Regency. hosting a significantly greater number of hospitals. health centers. places of workship. and schools compared to Loea and Dangia. Therefore. in the event of a flood caused by the Ladongi Dam break. the physical losses experienced in the Ladongi sub-district would be substantial.

The flood vulnerability map due to the Ladongi Dam break is presented in Figure 10. The red color indicates areas with high vulnerability. which are found in the Ladongi Sub-district. while the yellow color represents low vulnerability areas. namely in the Loea and Dangia Sub-districts.

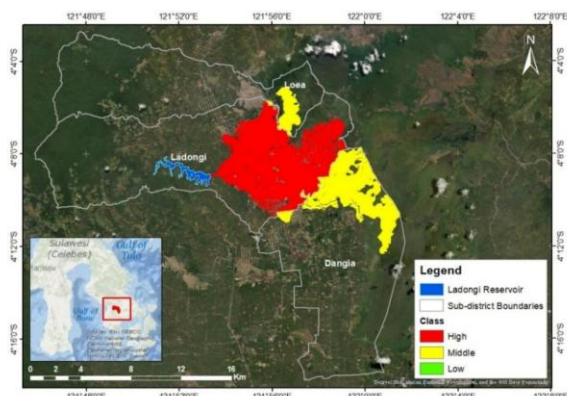

Figure 10. Flood Vulnerability Map

Furthermore, the capacity index is determined by analyzing institutional regulations for disaster management, early warning, disaster risk assessment, disaster education, basic risk reduction, and preparedness at all levels using the modeling results from the previous sub-chapter (Figure 11 and Table 8).

Table 8. Capacity Index

Sub-District	A	B	C	D	E	Index	Class
Dangia	1.00	0.33	0.33	0.33	0.33	0.46	Middle
Ladongi	1.00	0.33	0.33	0.33	0.33	0.46	Middle
Loea	1.00	0.33	0.33	0.33	0.33	0.46	Middle

Note:
A: Institutional Regulations for Disaster Management
B: Early Warning and Disaster Risk Assessment
C: Disaster Education
D: Reduction of Basic Risk Factors
E: Development of Preparedness at All Levels

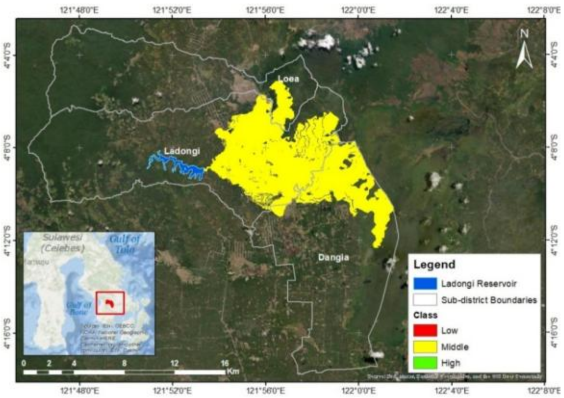

Figure 11. Flood Capacity Map

Based on the hazard indeks, vulnerability indeks, and capacity index. The risk index was calculated based on the BNPB Regulation No. 02 of 2012. The Risk Index is presented in Table 9.

Table 9. Risk Index

Sub-district	Hazard Index	Vulnerability Index	Capacity Index	Risk Index	Class
Dangia	0.62	0.55	0.47	0.57	Middle
Ladongi	0.85	0.67	0.47	0.67	High
Loea	0.81	0.54	0.47	0.62	Middle

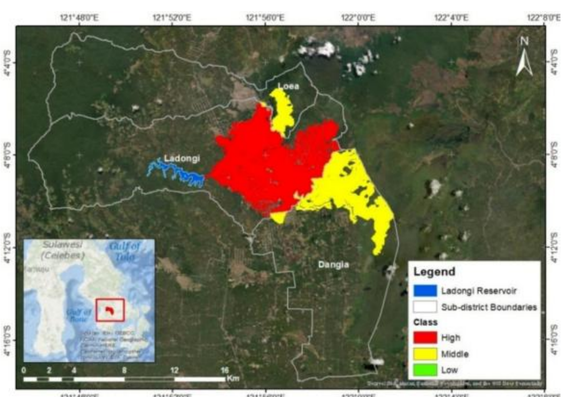

Figure 12. Risk Index Map

The moderate risk index was obtained in Dangia District at 0.566 and in Loea District at 0.616. The High Risk Index was found in Ladongi District with a value of 0.670. The Risk Index Map is presented in Figure 12.

3.5. Mitigation

Ladongi Sub-district serves as the economic center of East Kolaka Regency, with the most comprehensive economic infrastructure (such as delivery services, banks, and post offices) and public facilities (including a regional hospital. mosque. and church) compared to other districts (Central Statistics Agency of East Kolaka Regency). Therefore, mitigation efforts are necessary considering the high flood risk index due to potential dam failure in the Ladongi Sub-district.

According to Huseiny et al. (2024), structural mitigation has a limited impact on reducing flood inundation and requires substantial construction costs. For example, at Pidekso Dam, an emergency spillway and compound channel reduced inundation by only 8.4%. Therefore, regular monitoring and maintenance of dams and spillways are essential to ensure their proper functioning, effectiveness, and minimize the risk of dam failure during flood events.

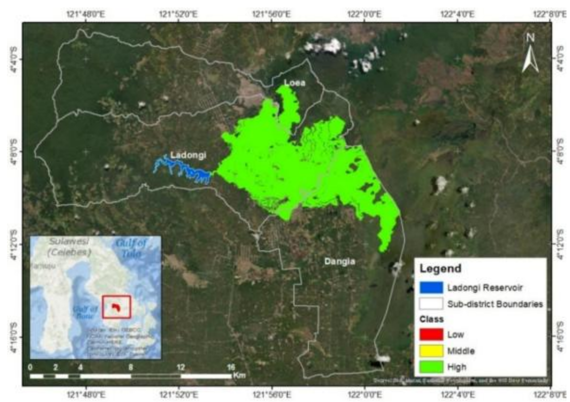

Figure 13. Capacity Index Map after Non-structural Mitigation

Table 10. Capacity Index after Non-Structural Mitigation

Sub-district	A	B	C	D	E	Index	Class
Dangia	1.00	0.67	0.67	0.33	0.67	0.67	High
Ladongi	1.00	0.67	0.67	0.33	0.67	0.67	High
Loea	1.00	0.67	0.67	0.33	0.67	0.67	High

Note:
A: Institutional Regulations for Disaster Management
B: Early Warning and Disaster Risk Assessment
C: Disaster Education
D: Reduction of Basic Risk Factors
E: Development of Preparedness at All Levels

Non-structural mitigation (see Figure 13 and Table 10) can serve as an alternative approach to enhance the capacity index, thereby reducing the overall flood risk index. The proposed measures include: (1) an Early Warning System (EWS) to provide timely alerts before a disaster, allowing communities sufficient time to evacuate or take protective actions while improving preparedness and emergency response; (2) Evacuation Route Mapping to ensure communities can reach safe zones quickly and efficiently, supporting organized evacuations and minimizing confusion during emergencies; and (3) Community Awareness and Education Campaigns to increase public understanding of hazards, evacuation procedures, and early warning signs, fostering a disaster-aware and preparedness-oriented community.

The implementation of non-structural mitigation is expected to enhance Early Warning Systems, Disaster Risk Assessment, Disaster Education, and Preparedness, increasing the resilience level from 2 to 4. Consequently, the capacity index increased to 0.67 across all sub-districts (see Figure 14 and Table 11), reducing the flood risk index from 0.57 to 0.48 in Dangia, 0.67 to 0.57 in Ladongi, and 0.62 to 0.53 in Loea. Although the risk class remained "Medium," the results indicate that improved community capacity can significantly reduce flood risk.

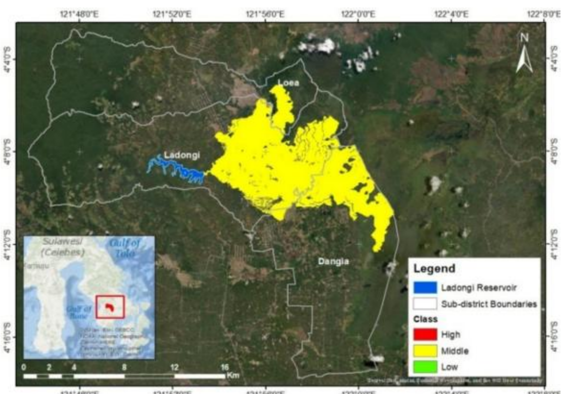

Figure 14. Risk Index Map after Non-structural Mitigation

Table 11. Risk Index After Non-structural Mitigation

Sub-district	Hazard Index	Vulnerability Index	Capacity Index	Risk Index	Class
Dangia	0.62	0.55	0.67	0.48	Middle
Ladongi	0.85	0.67	0.67	0.57	Middle
Loea	0.81	0.54	0.67	0.53	Middle

4. Conclusion

This study successfully assessed dam-break flood risk at Ladongi Dam using hydrological modeling with HEC-HMS, two-dimensional hydraulic simulations with HEC-RAS, and a BNPB-based risk index approach. Hydrological analysis indicated that the dam can safely manage PMF discharge without overtopping, while a piping failure scenario would cause extensive inundation with high velocities, deep flooding, and prolonged duration across three sub-districts. Risk assessment identified Ladongi as the most vulnerable, followed by Loea and Dangia, reflecting differences in exposure and socioeconomic conditions. Furthermore, non-structural mitigation, including early warning systems, evacuation route planning, and community preparedness, effectively increased capacity and reduced the overall flood risk index, highlighting the need to prioritize these measures to protect downstream communities, critical infrastructure, and local livelihoods. However, this study is limited by the absence of historical dam-break data for calibration, DEM resolution, and simplified material properties. Future research should incorporate higher-resolution data and field validation to improve model accuracy and applicability.

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