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Emergency action plan for flood disaster mitigation caused by dam failure (case study: Wadaslintang Dam, Indonesia)

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Abstract. The Wadaslintang Dam in Central Java Province is a crucial water storage structure with benefits like irrigation, hydropower, and flood control, which is densely populated downstream. However, the risk of dam failure requires an Emergency Action Plan (EAP) to mitigate flood disasters. The implementation and effectiveness of an Emergency Action Plan protects human lives, help safeguard critical infrastructure, supports economic stability, and fosters community resilience in the face of various emergencies and disasters. This study aims to identify potential risks and consequences associated with the failure of the Wadaslintang dam and its correlation with the EAP. The plan outlines specific steps and procedures to be taken in the event of a dam failure, considering the potential risks and impacts of such an incident and collecting topographic and population data to create evacuation route maps. In conclusion, the EAP for Wadaslintang Dam is essential to minimize risks and protect the affected population during flood disasters. By implementing the plan, coordinating agencies, and ensuring regular updates, the safety and well-being of the population can be safeguarded.

Keywords: dam failure, emergency action plan, Wadaslintang Dam

1. Introduction

A dam is a structure that serves various purposes and can supply water for human and other living beings' needs [1]. However, besides its benefits, dams also pose potential dangers that can threaten human lives and properties, especially in areas downstream of the Dam [2]. Dam failure can occur due to overtopping, where water spills over the Dam's crest, causing erosion and landslides on the dam body, particularly in earth-filled dams. Failure can also result from leakage, which gradually carries away dam materials through a phenomenon known as piping or seepage erosion. Due to dam failure, the water stored in the Dam will flow downstream with a large volume and high velocity. If the river channel downstream cannot handle the floodwater discharge, it will overflow into the surrounding residential areas, public facilities, and agricultural lands along both sides of the river channel. Therefore, it is essential to analyze the hydraulic conditions of the river channel and valley downstream of the Dam, especially in the event of dam failure.

In a dam failure, a large volume of water will flow downstream quickly and in a short period. This results in a sudden and rapidly advancing flood, which can cause significant casualties. Therefore, a dam break analysis simulation is necessary to estimate the flood hydrograph at various points along the river. From there, the flood discharge, velocity, floodwater elevation, arrival time of the flood, and recession time can be predicted. These parameters will be used to plan an Emergency Action Plan for the Dam, which includes evacuation and sheltering measures for affected residents. Furthermore, the analysis results will help determine the hazard classification level of dam failure, considering the extent of flood impact and the number of downstream inhabitants at risk of flooding. The socio-economic development in the vicinity of the reservoir, due to the growing population and community developments downstream of the Dam, leads to an increased classification of dam hazard [3], [4], [5].

Development of the Emergency Action Plan for dam failure is an effort to minimize the potential loss of life and property resulting from the failure of the Dam. An emergency action plan is a formal document that identifies potential emergency conditions that may occur at a dam and outlines initial steps and actions to be taken by the dam owner to minimize property damage and loss of lives [6]. In case of dam failure, the emergency action plan for a dam becomes a guide for the dam owner, dam builder, dam operator, and relevant authorities to take necessary actions in case there are signs of dam failure or when a dam failure occurs [7]. In an emergency action plan, preparation of an evacuation plan, the impact on affected residents, the estimation of material losses, and expenses during evacuation analysis are essential for the Local Government in the affected location for preparing for the emergency condition.

Some previous study of dam break analysis and Emergency Action Plan (EAP) discusses the effect of dam failure in the downstream area [8], [9], [10], but not much study on the estimation of impact from the dam break on necessary expense in the impacted area. This paper aims to develop an EAP for flood disaster mitigation caused by dam failure as the further analysis from dam break analysis and evacuation plan map in the high population growth downstream of the Dam, using the Wadaslintang Dam as a case study.

2. Materials and Methods

2.1. Study Area

Wadaslintang Dam is one of the large dams with a height of 116 meters and an effective storage capacity of 456.73 million m^3. It was constructed in 1982 and completed in 1989. Administratively, the Wadaslintang Dam is situated on the border between the Wadaslintang Sub-District in Wonosobo Regency and the Paduroso Sub-District in Kebumen Regency, Central Java Province, Indonesia. The geographical coordinates of the Dam's location are approximately 7°34'39" S latitude and 109°46'58" E longitude.

Based on the assessment carried out in 2021, the Wadaslintang Dam has a storage capacity of around 450,619,000 cubic meters. It serves several purposes, including irrigation for a technical area spanning 33,279 hectares, producing hydroelectric power with a capacity of 92,000,000 kWh per year from two 8 MW power generators, and meeting the raw water requirements for industries and communities in the surrounding area.

The technical data of the Wadaslintang Dam are as follows:

1. Reservoir
   a. Location : Bedegolan River
   b. Watershed Area : ± 196.24 km^2
   c. Average River Flow : ± 15.00 m^3/s
   d. Maximum Reservoir Capacity : ± 443,000,000 m^3
   e. Effective Reservoir Capacity : ± 408,000,000 m^3
   f. Flood Water Level : +190.30 m
   g. Normal Water Level : +185.00 m
   h. Water Level : +124.00 m
   i. Reservoir Area at FWL : ± 14.60 km^2
   j. Reservoir Area at NWL : ± 13.30 km^2
   k. Green Belt : From Elevation +185 m to Elevation +191 m

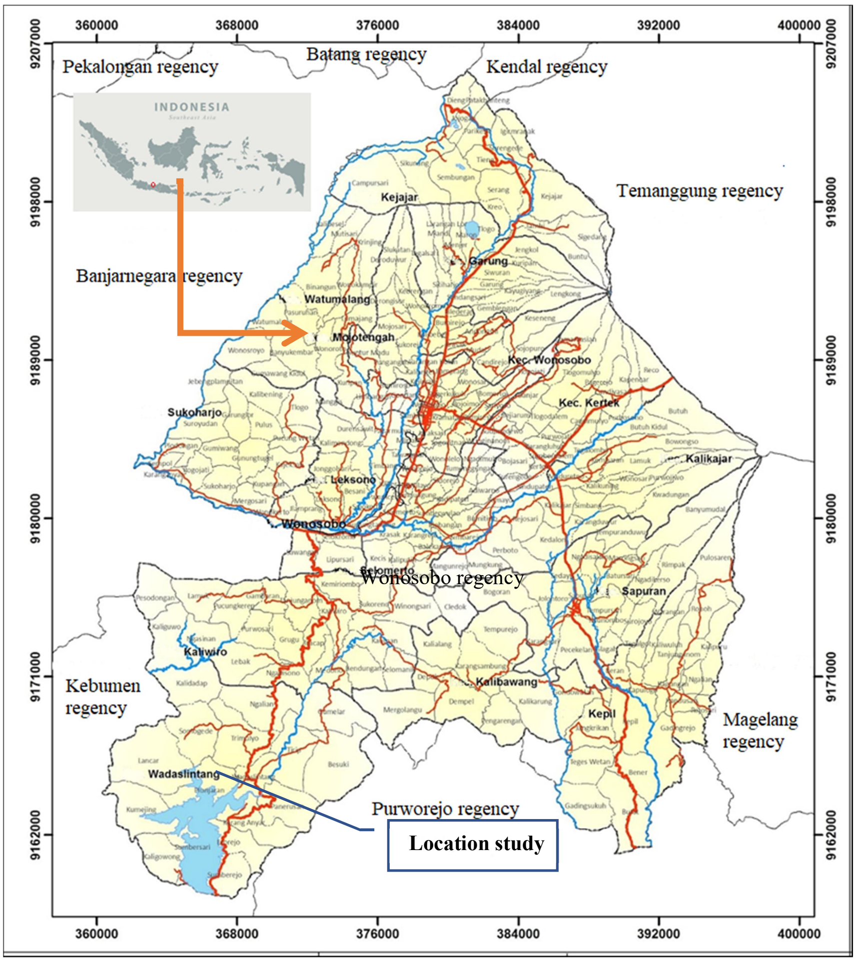

Figure 1. Location Map of Wadaslintang Dam at the Boundary of Wadaslintang Sub-District, Wonosobo Regency, and Padureso Sub-District, Kebumen Regency

2. Dam
    a. Dam Type : Earthfill with Impermeable Layer Core
    b. Volume : ± 8,200,000 m³
    c. Height : ± 125.00 m
    d. Crest Length : ± 650.00 m
    e. Crest Width : ± 10.00 m
    f. Crest Elevation : +192.10 m
3. Spillway
    a. Height : Approximately 35 m at Elevation +110 m
    b. Spillway Type : Free Ogee Overflow with Flip Bucket
    c. Chute Length : ± 341 m
    d. Width : ± 54 m
    e. Design Flood Discharge : ± 3,880 m³/s
    f. Capacity : ± 1,570 m³/s
4. Diversion Tunnel
    a. Type : Circular Concrete
    b. Diameter : ± 4.50 m
    c. Length : ± 729.70 m
    d. Capacity : ± 208.00 m³/s

5. Intake Structure and Water Regulation Tunnel
   a. Intake Structure Elevation : +123.00 m
   b. Gates : Hemispherical Bulkhead
   c. Tunnel Diameter : ± 3.00 m
   d. Tunnel Length : ± 437.00 m
6. Hydroelectric Power Plant (HPP)
   a. Turbines : Francis Type
   b. Number of Units : 2
   c. Installed Capacity : ± 16 MW (2 x 8 MW)
   d. Annual Production : ± 92,000,000 kWh
   e. Design Head : ± 92.00 m
   f. Maximum Head : ± 115.00 m
   g. Minimum Head : ± 57.50 m
   h. Maximum Discharge : ± 24.00 m³/s

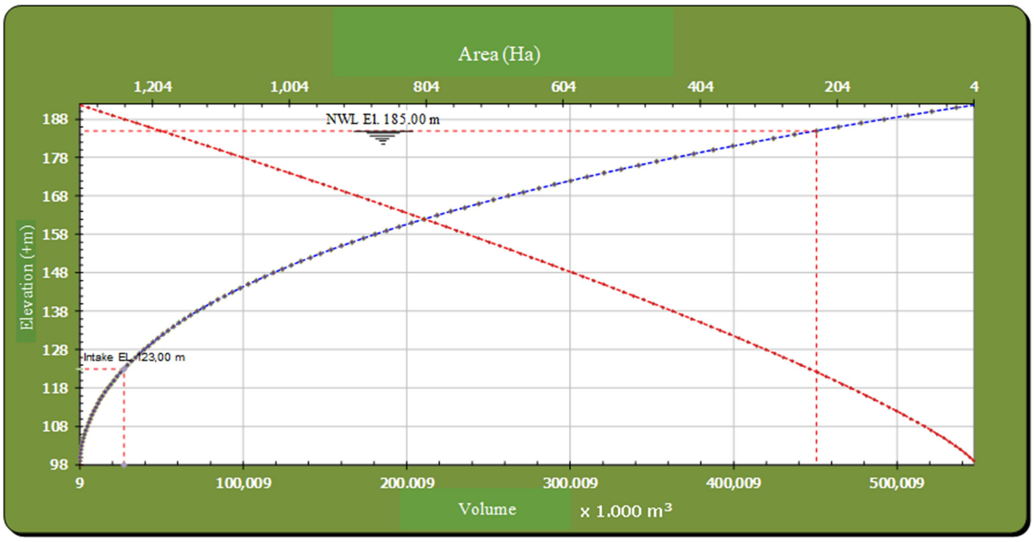

Figure 2. Curve capacity of Wadaslintang dam

In addition to the Kali Gede River, the Wadaslintang Reservoir is fed by several other rivers: Pandagan River, Kebokuning River, Lancar River, Larangan River, Cibulu River, Terbang River, and Wuni River. At the downstream of the reservoir, the outflow enters the Bedegolan River, flowing southward through the villages of Sendangdalem, Rahayu, Sidototo, Pejengkolan, and Balibangsal in the Padureso Sub-District, towards Kabuaran, Sidogede, Tersobo, and Prembun villages in the Prembun Sub-District. The outflow then meets the Kedunggupit River in the Tersobo Village of the Prembun Sub-District in Kebumen before finally merging into the Indian Ocean as the Kali Gentan River in the Ukirsari Village of the Grabag Sub-District in Purworejo. This point is approximately 30 km away from the reservoir.

In other words, the Kedunggupit River serves as a lateral inflow that is believed to significantly impact flood flow and the stability of the Wadaslintang Dam. On the other hand, the Pucang River and Lereng Rivers, originating from the west and east, converge with the Rowo Village's main river. However, they are estimated to have a less significant impact on flood flow, located around 3 km from the confluence, resulting in less notable flood effects. In the end, the Wadaslintang River flows into the Indian Ocean, so flood routing calculations in the reservoir's downstream area must consider tidal fluctuations in the Indian Ocean, particularly at the Mawar Estuary in the Kebumen Regency.

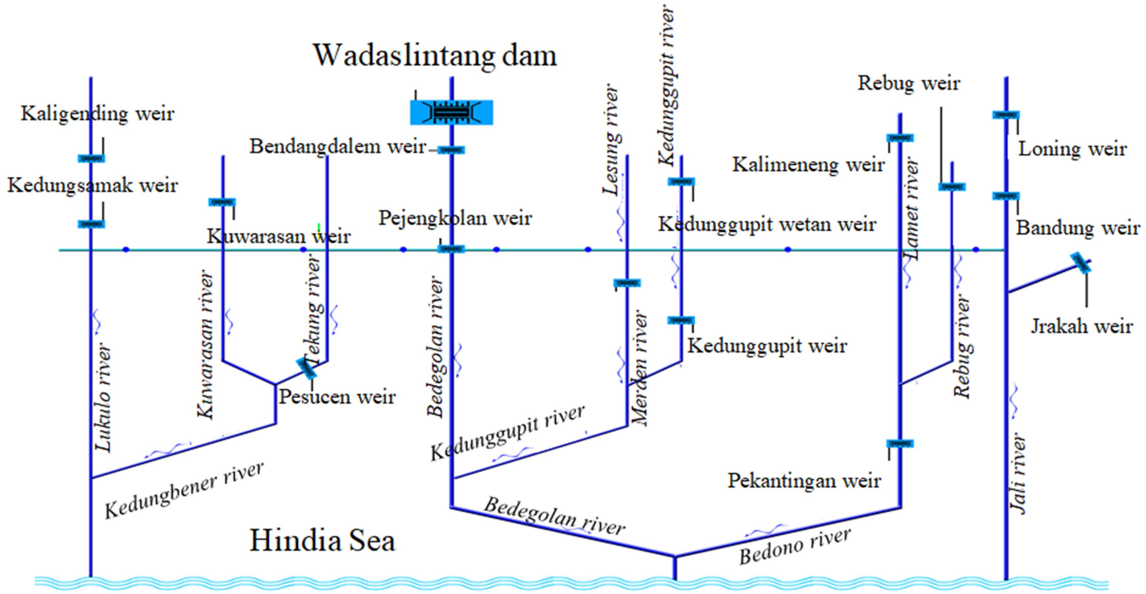

Figure 3. Scheme of Wadaslintang Dam River system

2.2. Affected Areas

The term "affected areas" refers to the regions or areas that will experience impacts or changes due to a specific event or project. In the context you mentioned earlier, two surveys cover affected areas. One is the water infrastructure inventory survey and the Mapathon digital survey. In the water infrastructure inventory survey, the affected areas encompass the entire main river channel downstream of the reservoir. The dam failure simulation will impact this area, so it is crucial to understand the types of water structures and their conditions as part of preparedness and risk assessment. The water infrastructure inventory survey is an activity that involves mapping and recording all the structures located along the main river channel downstream of the reservoir. This survey aims to identify the types of structures along the main river channel and to record longitudinal and cross-sectional sections of these structures. These structures play a significant role in the dam failure simulation as they are considered internal boundaries that will affect the simulation.

The survey aims to understand the types of water structures along the main river channel and record longitudinal and cross-sectional sections of these structures. These structures are considered internal boundaries in the dam failure simulation. Additionally, the measurements of these water structures are used to assist in the delineation of the DEM (Digital Elevation Model) in the same coordinates. Therefore, a mapathon digital survey is conducted in the affected areas and their surroundings. The digitization mapathon survey is an activity to collect geographic data in the affected areas and their surroundings using digital technology. The focus of this survey is on existing infrastructure in the area.

Additionally, the survey includes collecting data related to social, economic, and population parameters. The affected areas in this survey include the areas around the project or event location being mapped. Geographic and socio-economic data are collected from these areas for further analysis related to the ongoing project or event. Collecting social, economic, and population data involves using secondary data published by the Central Bureau of Statistics.

These secondary data are used as the main source of information, but the survey also involves collecting primary data through sampling methods to confirm the accuracy of the secondary data. Digitization mapathon surveys have been conducted in the affected areas and their surroundings for all existing infrastructure. Additionally, social, economic, and population parameters data are collected using secondary data published by the Central Bureau of Statistics, supplemented by primary data collection through sampling.

2.3. Hazard classification and danger zone

The determination of dam hazard classification is aimed at assessing the level of danger posed by a dam. Some standards are available for classifying the hazard classification [3], [4], [5]. This enables efforts to anticipate and maximize the rescue of lives and property downstream of a dam, as well as preventive measures to avoid dam failures. Meanwhile, hazard zones are determined based on flood arrival times and other considerations related to disaster management. In Zone 1, the affected areas are prioritized for immediate evacuation when the disaster alert status is ALERT, while in Zone 2, evacuation can occur when the disaster alert status reaches the WARNING level. This zoning helps in organizing and prioritizing evacuation efforts during dam-related emergencies. The classification of dam hazards is determined based on Indonesian government regulations, specifically referencing the Decree of the Director General of Water Resources No. 257/KPTS/D/2011[11], regarding the Guidelines for Dam Hazard Classification.

Table 1. Classification of dam hazard [11]

Amount of household	Downstream distance from Dam (km)				
	0 - 5	0 - 10	0 - 20	0 - 30	0 - >30
0	1	1	1	1	1
1 – 20	3	3	2	2	2
21 - 200	4	4	4	3	3
> 200	4	4	4	4	4

Remark:
1 = low hazard
2 = middle hazard
3 = high hazard
4 = very high hazard

2.4. Economic loss analysis

The economic loss analysis in the EAP is intended to provide further motivation to all stakeholders to prioritize preventive measures against the possibility of dam failure [2]. This includes conducting routine comprehensive inspections, implementing continuous and planned reservoir management practices, and updating the EAP documents in line with the latest developments. The calculation of the losses to be borne in each affected area follows the criteria as outlined below [12]:

$$\text{Flood Loss} = \text{Volume of Damage} \times \text{Degree of Damage} \times \text{Unit Price of Material} \quad (1)$$

where Volume of Damage is the quantity or volume of material damaged, Degree of Damage is The degree of material damage according to assumptions, and Unit Price of Material is The unit price of material according to BNPB unit price). Using this formula, the economic losses resulting from the dam failure can be estimated based on the volume of material damage, the degree of damage, and the unit price of the materials involved.

3. Result and Discussion

Dam break analysis was simulated in four scenarios, where the outflow hydrograph for the failure is presented in Figure 4. From the simulation, dam failure caused by the upper piping scenario with a flood peak of 264,702 cubic meters per second is estimated to have the greatest impact downstream of the Wadaslintang Dam. Based on the Flood Inundation Map resulting from the dam failure simulation, which falls within the inundation boundaries, there are an estimated 309 villages/communities that are administratively located in 9 districts of Kebumen Regency and nine districts of Purworejo Regency, Central Java Province. It is estimated that the population at risk amounts to 317,406 individuals or 79,247 households.

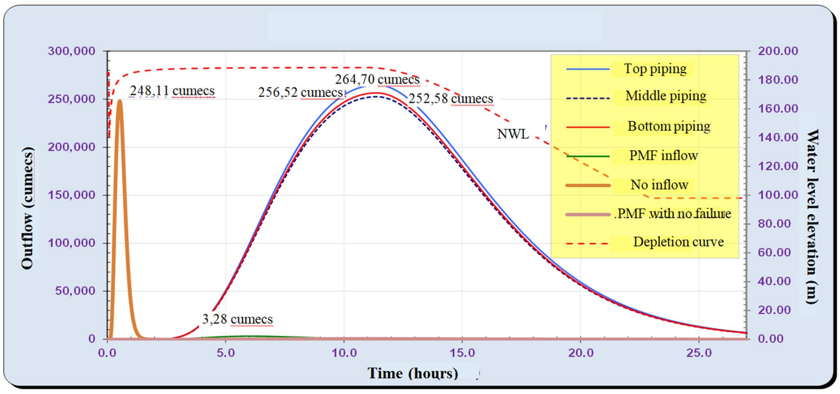

Figure 4. The outflow of dam break analysis for Wadaslintang dam in different scenarios

Table 2. Peak Discharge Outflow of Wadaslintang Dam Failure

Peak Outflow of Flood Caused by Wadaslintang Dam Failure (m^3/sec)			
Top piping	Middle piping	Lower piping	Sunny Day
264.70	252.58	256.52	248.11

With a reservoir volume of 450.619 million cubic meters based on bathymetry and tachymetry measurements in the year 2021 and a PMF inflow of 3,281.46 cubic meters per second, the simulation of the failure of the Wadaslintang Dam results in an outflow of 264.70 cubic meters per second. The population at risk is estimated to be 317,406 individuals or 79,247 households, administratively located within 309 villages in 9 Kebumen Regency and 9 Purworejo Regency, Central Java Province. These areas fall into the category of vulnerable areas or areas likely to be affected by flooding due to dam failure. Therefore, these populations must be evacuated in the ALERT and WARNING EAP conditions. Locations impacted that are approximately ±6.0 km from the Dam or have a flood arrival time of less than 1-hour fall into hazard zone category 1. Residents in all villages/communities in this area should be evacuated promptly at the latest when the ALERT status is issued, or residents in Padureso District and Poncowarno District, Kebumen Regency. Locations impacted by the dam failure that are approximately ±6.0 km or more from the Dam or have a flood arrival time of more than 1 hour fall into hazard zone category 2. If the emergency worsens and escalates to ALERT status, residents in hazard zone 2 should be evacuated immediately.

The term "population at risk" refers to those residing in flood-prone areas affected by the dam failure or within the flood inundation boundaries resulting from the dam failure simulation. The flood characteristics in the affected villages/communities reflect an average flood depth of 5.00 meters, which is caused by the failure of the Wadaslintang Dam with the upper piping scenario. The average flood propagation speed is 0.66 meters per hour. The estimated flood arrival time ranges from 0.75 to 35.30 hours, with receding times between 21.20 and 140 hours. The flood area in each village/community varies from 2.44 hectares to 359.12 hectares, with a total inundation area of approximately 30,336 hectares.

Table 3. Amount of Wadaslistang dam failure affected area

Dam	Scenario	Affected area				
		Village	District	Regency	People	Household
Wadaslintang	PMF - top piping	309	18	2	317,406	79,247

In the event of a flood emergency, to provide sufficient time for the evacuation efforts of residents in flood-prone areas due to the dam failure, the residents in those vulnerable areas need to be categorized based on the classification of hazard zones. The classification of hazard zone areas is based on the arrival time of the flood, the distance of settlements from the Dam, and the planned evacuation management system. Therefore, from Table 3, based on the regulations in Table 1, the classification of the risk of the Wadaslintang Dam failure is categorized into Very High Hazard.

It is related to infrastructure and resources available for transportation, including vehicles, roads, railways, airports, and other facilities enabling people and goods movement. These resources are essential for disaster management and evacuation planning to ensure the efficient and safe transportation of individuals in cases of emergency or disaster. In order to support the disaster mitigation efforts mentioned above, the potential availability of transportation facilities in the affected area should be utilized to minimize loss of life and property without relying on transportation assistance from outside the region. With a transport capacity of 274,770 people compared to the number of evacuees at 245,330 people, it can be concluded that by utilizing the transportation resources available in the affected area, all evacuees can be transported to evacuation locations, provided that it is accompanied by effective disaster management.

The railway lines connecting Yogyakarta to Jakarta and Yogyakarta to Bandung intersect with the flood-prone area affected by the failure of the Wadaslintang Dam along the Kutoarjo-Kebumen section. To secure these railway lines in case of Wadaslintang dam failure, the Wadaslintang Dam Emergency Action Plan must involve PT. KAI DAOP V Purwokerto and PT. KAI DAOP VI Yogyakarta in the action planning.

Using the standard INASafe-BNPB format. The simulation results for the dam collapse, with the most extensive impact, show losses to residential and public buildings in the affected area amounting to IDR 1,715,166,400,000.00. The summary calculation of losses to road infrastructure resulting from the InaSAFE run. In the event of the Wadaslintang Dam failure, preceded by upper piping, the estimated value of losses to road infrastructure is projected to reach IDR 163,802,435,000.00, with footpaths/tracks dominating the losses.

Agricultural commodities in the affected area are dominated by rice, corn, and a small portion of leguminous crops and horticultural products. The estimated loss in agricultural cultivation is projected to reach IDR 167,825,576,000.00 in the event of the Wadaslintang Dam collapse. The magnitude of this loss is attributed to the fact that downstream of the Wadaslintang Dam is an agricultural area with rice and corn as the dominant commodities. The estimated losses to be borne by livestock farmers in the flood-prone area due to the collapse of the Wadaslintang Dam are estimated to reach IDR 92,666,975,000.00.

In the current reservoir volume condition in 2021, if the Wadaslintang Dam were to collapse, it is estimated that the losses to be borne in the flood-prone area due to the failure of the Wadaslintang Dam would amount to IDR 2,139,461,386,000.00 with the details shown in Figure 5.

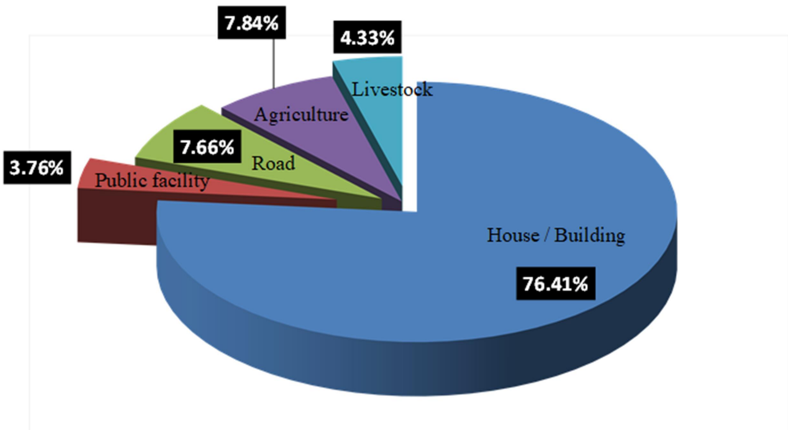

Figure 5. The proportion of loss in the affected area

Based on Figure 5, it can be concluded that the proportion of losses caused by damage to agricultural cultivation and damage to houses or buildings dominates the extent of losses in the event of the Wadaslintang Dam failure.

The cost of evacuation is one of the loss components that must be considered in the loss analysis, where the cost components refer to the National Disaster Management Agency (BNPB) standard. The cost consists of rice, drinking water, clean water, evacuation equipment, sanitation, cleaning services, and additional rice for evacuees and personnel, with a total estimated weekly cost of IDR 172,338,939,000.00. The results of the InaSAFE run are presented; it is estimated that 245,330 people need to evacuate.

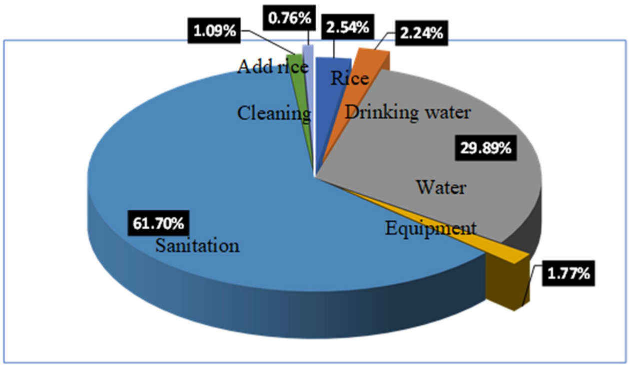

Figure 6. Cost of evacuation proportion for refugee

4. Conclusion

In summary, this comprehensive analysis clearly explains the potential risks and consequences of the Wadaslintang Dam failure. It underscores the importance of proactive disaster preparedness, including evacuation planning, infrastructure resilience, and risk mitigation measures, to protect the affected population and minimize economic losses in such a catastrophic event.

The dam failure modeling analysis for the Wadaslintang Dam indicated that approximately 317,406 people living across 309 villages in Kebumen and Purworejo Regencies are at risk of potential flooding. The average flood depth is estimated at 5.00 meters, with a propagation speed of 0.66 meters per hour. The flood arrival time ranges from 0.75 to 35.30 hours, and the recession time ranges from 21.20 to 140 hours. The available transportation can accommodate 274,770 people, while the estimated number of evacuees is 245,330. The estimated losses due to dam failure are valued at IDR 2,139,461,386,000.00, with evacuation costs amounting to IDR 172,338,939,000.00 per week. Developing the Emergency Action Plan for the Wadaslintang Dam is a crucial step in ensuring the safety and well-being of the downstream population. By implementing the plan and coordinating various agencies and stakeholders, the risks associated with dam failure can be minimized, and the potential impacts of flood disasters can be mitigated effectively.

The EAP is a proactive measure to protect human life, property, and the environment from the devastating consequences of dam failure-induced floods. To support EAP, Concrete steps and strategies for disaster preparedness are crucial to ensure the safety of individuals and communities, including investing in early warning systems for dam failure disasters and ensuring that people know how to respond when warnings are issued, conduct regular training sessions and educate the community about disaster risks and how to mitigate them. Regular updates on the Emergency Action Plan, training for dam operators, and socialization for the communities will contribute to the successful implementation of the plan and enhance overall emergency preparedness in the region.

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