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Risk Assessment with ICOLD Method Modified with Loss of Life Index in Kedung Ombo Dam

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Abstract : *Newly constructed dams and especially old dams pose a significant risk of disaster considering that Indonesia is located in an earthquake-prone area. As a developing country, people's activities are often endangered by occupying or living in disaster-prone areas. If this disaster risk is not considered, it will result in fatalities. Currently, the Emergency Action Plan (EAP) owned by dams in Indonesia is to limit the population (PAR) and has not taken into account the risk of only exceeding life. In this study, assessing the operating population (PAR) will reduce the life loss index to predict the number of fatalities in the Kedung Ombo Dam collapse disaster as a further consideration in assessing dam safety risks. The procedure carried out is to make a fatality prediction index as the development of a fatality risk index on the ICOLD method which is always used in Indonesia. From the results of the development, it is found that the original risk index can be reduced. Efforts such as the implementation of early warning systems, short-term and long-term can have a significant effect on reducing security risk indeks.*

Keywords *- dam, ICOLD, kedung ombo, loss of life, development*

I. INTRODUCTION

Indonesia has a long history of dam construction with an extensive network of more than 2,200 dams. Of all these dams, 213 are classified as large dams according to [1]. Nearly half of the dams owned by the Ministry of PUPR are more than 25 years old, some of which were built before Indonesia's independence in 1945.

The limited hydrological record means that many of the older dams may not be designed to accommodate the expected changes in runoff and increased variability of rainfall. Dam areas, especially those close to settlements, generally face the threat of pollution and siltation [2]. Both hydrodynamic and social factors have a major impact on the loss of life due to dam failure [3].

Changes in people's views in the last few decades, especially in terms of dam safety, it is necessary to develop methods or parameters to see the level of disaster risk. The level of disaster risk is very important to note because Indonesia is a country prone to earthquakes. The downstream part of the dam, especially the old dam, is one of the disaster-prone areas that is a place to live and a space for community activities. In the Guidelines for Determining the Classification of Dam Hazards in Indonesia in 2011 [4], the Emergency Action Plan (EAP) was made only for Population At Risk (PAR) but did not accommodate the index of loss of life due to dam collapse.

In this study, a risk assessment will be carried out at the Kedung Ombo Dam where this dam is one of the oldest dams in Indonesia. The population downstream of the Kedung Ombo Dam is very large, which automatically becomes part of the disaster risk in the event of a dam collapse. Predicting the number of measurable loss of life will improve disaster preparedness.

II. METHODOLOGY

In this study, a dam collapse scenario is needed as a basis for estimating the population at risk (PAR) and obtaining flood characteristics. Dam collapse analysis uses the Zhong Xing HY-21 software where in tracking flood waves due to dam collapse used in the software uses a method known as the dynamic wave

method [5]. This method is based on the unsteady flow used to trace the flood hydrograph due to dam collapse. This method is based on an extended version of the original equation by Barre de Saint-Venant [6], namely:
Equation of conservation of mass:

$$\frac{\partial Q}{\partial x} + \frac{\partial s}{\partial t}(A + A_0) - q = 0 \qquad (1)$$

Equation of conservation of momentum:

$$\frac{\partial}{\partial t}(sQ) + \frac{\partial}{\partial x}(\beta Q^2) + gA\left(\frac{\partial h}{\partial x} + S_f + S_e + S_i\right) + L' = 0 \qquad (2)$$

Where h = water level elevation, A = active cross section of flow, A_o = cross section of the inactive flow of the flow (off channel), s = sinuosity factor which varies with h, x = longitudinal distance by valley, t = time, q = side inflow or outflow per long distance along the valley (inflow "+" and outflow "-"), β = momentum coefficient for velocity distribution, g = acceleration due to gravity, S_f = boundary friction slope and S_e = spreading-narrowing slope.

To solve the two equations, a finite difference method known as the Preissman Scheme is used [7] (Fig. 1). Zhong Xing HY-21 has several advantages compared to previously known software where for the same purpose there is no need for input data in the form of longitudinal sections and cross sections of rivers downstream of the reservoir and the drawing of flood maps due to dam collapse is not done manually [8]. However, to give us enough confidence in the results of flood tracking in the downstream area of the reservoir using the Zhong Xing HY-21, then as a flood tracking control, HEC-RAS is also carried out [9]. Meanwhile, to find out the flood-affected area, it is enough to do it by overlaying a flood map with a map of the administrative area with the help of GIS.

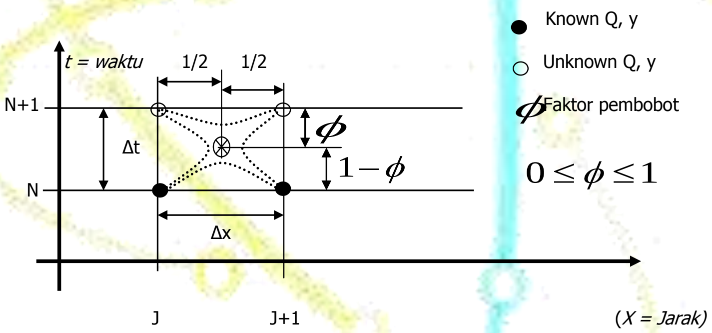

Fig 1. Preissman Schema [7]

In the collapse scenario [10], a failure analysis was carried out on several failure scenarios, namely (a) Dam collapse due to piping at the bottom of the EL reservoir. 50.50 m with QPMF design inflow discharge (b) Dam collapse due to piping in the EL. 65.00 m with QPMF design inflow discharge (c) Dam collapse due to piping at spillway elevation EL. 90.00 m with QPMF design inflow discharge (taking into account sea tides) (d) The dam collapses due to overtopping during PMF flooding, ie the dam seems to have avalanche and decreases so that the top of the dam becomes EL. 94.60 m(e) Dam collapse due to piping at spillway elevation EL. 90.00 m without inflow or when there is no rain (f) Dam collapse due to piping at spillway elevation EL. 90.00 m with a QPMF design inflow discharge (without taking into account sea tides) (g) Emergency Spillway collapse during PMF (h) Overflow in the spillway during PMF flooding and (i) Analysis of downstream river flow capacity, where the discharge is found to be able to withstand the riverbed downstream is 350 m^3/sec.

The output obtained from the analysis of the dam collapse is in the form of a flood hydrograph at each analyzed location. The output in the form of a map of flood inundation that occurs is overlaid with a map of existing settlements and infrastructure to find out which residential areas and public infrastructure are included in the flood hazard classification of dam collapse. Estimated magnitude of impact or consequence as a result of dam failure (collapse) taking into account the characteristics of inundation areas downstream, life safety, financial losses, and others. The estimation of the magnitude of the probability of the risk of dam failure is carried out based on an assessment of the estimated probability of failure and the consequences of its failure.

For predictive modeling of loss of life (LoL) the method used is to use the regression equation from the research results of [11]. From the results of his research, it was found that the predicted number of LoL, with PAR > 10,000 people, was much less than PAR < 10,000 people. From these two conditions, two LoL equations are obtained as follows:

PAR without an early warning system:

LoL = 0.7535(PAR)0.76 (3)

PAR with an early warning system:

LoL = 0.0002(PAR) (4)

For PAR response to disasters is measured through the index from Graham [12] (Table 1).

Table 1. PAR Vulnerability Level to Flood Category [12]

Flood Severity	**Warning Times (Minutes)**	**Flood Severity Understanding**	**Fatality Rate (Fraction of people at risk expected to die)**	
			Average	**Range**
High	no warning	No applicable	0.75	0.30 – 1.00
	15 60	Vague	Use the values shown above and apply to the number of people who remain in the dam failure floodplain after warnings are issued. No guidance is provided on how many people will remain in the floodplain.	
		Precise		
	>60	vague		
Medium	no warning	Not applicable	0.15	0.03 – 0.35
	15 – 60	Vague	0.04	0.01 – 0.08
		Precise	0.02	0.005 – 0.04
	>60	Precise	0.03	0.005 – 0.06
		Precise	0.01	0.002 – 0.02
Low	no warning	No applicable	0.01	0.0 – 0.02
	15 – 60	Vague	0.007	0,0 – 0.015
		Precise	0.002	0.0 – 0.004
	>60	Vague	0.0003	0.0 – 0.0006
		Precise	0.0002	0.0 – 0.0004

In determining the classification of disasters, the determination of the index refers to the classification of potential disasters from ICOLD [13] where the magnitude of the discharge, with parameter H2(V)1/2, indicates that water damage consists of 2 factors, namely the height of the inundation (H) and the magnitude of the flow velocity (V), can be seen in Table 2.

Table 2. Vulnerability Level of Potential Disaster Classification [13]

Component $H^2(V)^{1/2}$	Potential Disaster Classification		
	Low – (I) $H^2(V)^{1/2} < 20$	Moderate – (II) $20 < H^2(V)^{1/2} < 100$	High – (III) $H^2(V)^{1/2} \geq 100$
Life Safety Risk (PAR become LoL)	≈ 0	< 10	≥ 10
Risk of Economy	Low	Moderate	High/ Extreme
Risk of Socio – Economic Disruption	Low	High	Extreme

To increase the Risk Index to the LoL index, the determination of the Risk Index is based on the follow-up to the short-term (early warning system) and long-term (disaster-based spatial planning) programs that have been carried out on dams in Indonesia, which in its implementation will determine the level of risk anticipation. the amount of LoL in the event of a disaster.

The development of LoL index predictions can also be developed on the risk rating parameters of the ICOLD Modified Method. Various factors considered in the risk assessment of the ICOLD Modification method [14] are the technical physical conditions of the dam such as reservoir capacity, dam height, structural deficiencies or defects, the impact of dam failure on the downstream area exposed to risks and business risks for the owner. In addition, for dams that have been built and operating, factors related to the implementation of dam safety are also considered [15].

The risk class assessment of each deficiency can be carried out using Tables 4 and 5. The use of Tables 4 and 5 in conducting a risk class assessment must be carried out carefully, because the severity of a deficiency in a particular dam raises the possibility that the dam should be included in the class. higher risk. If efforts to reduce the LoL factor can be accommodated in a measurable form and downstream there is a disaster-based spatial design accompanied by an early warning system, then the recommended extreme risk level can be reduced by 12 digits to a low or medium category. Reference recommendations for reducing the risk of loss of life index can be seen in Table 3.

Table 3. Recommendations for Reducing LoL Risk Value in the Modified ICOLD Method [11]

No.	Benchmark Reference	Risk Reduction	Number of Parameter PAR			
			>250.000 (Extreme)	10.000-250.000 (High)	1 – 10.000 (Moderate)	0 (Low)
1	Long and short term efforts implemented	100 %	12	8	4	0
2	Short term efforts implemented	50%	6	4	2	0
3	Long and shorts term efforts not implemented	0 %	0	0	0	0

Table 4. Guidelines for determining deficiency risk classes related to flood capacity and static stability [16]

Impact Category	Extreme	High	Moderate	Low
Deficiency Regarding Flood Capacity				
Rating Factor	**6**	**4**	**2**	**0**
Capacity	Insufficient overflow capacity (Determination based on existing deficiency).			Assign this class only when there are no adverse deficiencies.
Structure Overview		Damage caused by insufficient spillway structure.	Deficiencies in electromechanical equipment.	
Deficiencies related to Static Stability				
Rating Factor	**18**	**12**	**6**	**0**
Filter		No filter	Insufficient Filter	Assign this class only when there are no adverse deficiencies.
Piping through dams and foundations	Active seepage	Saturated area (Reservoir almost full)	Moist area (Reservoir is almost full)	
Sinkholes	Many, big, Collapse	Limited, big, collapse		
Conduit		Pipes are not lined with concrete, in vertical trenches there are no cutoffs or filter layers.	Pipes are lined with concrete, in vertical trenches there are no cutoffs.	
Crack	Transverse to top with depth > 50% freeboard	Transverse to the top, with depth < 50% freeboard.	Longitudinal crack, Erosion	

Slope instability	Poor mixing, High piezometric pressure	The slope (fill) is steeper than 2H:1V.,The phreatic line at the edge of the slope	Poor compaction, Trees on the edge of the slope, Holes on the edge of the slope	
Decrease/movement			Excessive decrease/decrease and/or movement	
Foundation geology		Unsuitable geological features (structural or geomorphological)		
Conduit structure	Steel pipe, not covered with concrete	Steel pipe not covered with concrete	Buried conduit damage	

Table 5. Guidelines for determining deficiency risk classes related to earthquake resistance [16]

Impact Category	**Extreme**	**High**	**Moderate**	**Low**
Deficiencies related to Earthquake				
Rating Factor	**6**	**4**	**2**	**0**
Design Overview		Insufficient requirements for seismic load design		
Available freeboards	< 5% high		< 10% high	
eometry/ materials/ features		The slope is steeper than 2H:1V. There is a structure at the crest.	Poor compaction. Ancillary structures of equipment that are susceptible to hazards.	Assign this class only when there are no adverse deficiencies.
Liquid material	Saturated loose sand at the edge of the slope or foundation	Unsaturated loose sand at the edges of slopes or foundations.	Sand on slopes or foundations.	
Reservoir area instability		Rim slope > 1:1	landslide that has been identified on the rim of the reservoir.	

Table 6 is used in determining the risk values used for dams in Indonesia. Each of these factors is assigned a risk value with a very high, high, medium and low risk classification. The next stage is to classify based on the sum of the values of all factors. Dams that have a total value in the range of 0-15 are included in category I (low), 16-45 are included in category II (medium), 46-75 are included in category III (high) and greater than 75 are included in category IV (very high).

Table 6. Guidelines for determining deficiency risk classes related to earthquake resistance [16]

Risk Class		**EXTREME**		**HIGH**		**MODERATE**		**LOW**	
		Parameter	Val.	Parameter	Val.	Parameter	Val.	Parameter	Val.
Contribution to risk (appropriate assessment given)									
Reservoir Capacity (juta m^3)		> 120	6	120 – 1	4	1 – 0,1	2	< 0,1	0
Dam high (m)		> 45	6	45 – 30	4	30 – 15	2	< 15	0
Evacuation Needs (Number of people)		> 250.000	12	10-150rb	8	1 – 10 rb	4	0	0
Downstream Damage Potential (against existing structures)		Extreme	18	High	12	Moderate	8	Low	4
Business Risk for owners as a result of Dam Failure		Extreme	12	High	6	Moderate	4	Low	2
Additional Factors for an Existing Dam	Availability of construction & maintenance data.	High	0	Moderate	1	Low	2	Tidak ada	3
	Availability of processed instrumentation and observation data.	High	0	Moderate	1	Low	2	Tidak ada	3
	The level of effort put into the previous security evaluation.	High	0	Moderate	1	Low	2	Tidak ada	3
	New or upcoming downstream developments.	High	3	Moderate	2	Low	1	Tidak ada	0
Additional factors for overcoming structural deficiencies	Flood capacity due to dam failure.	Extreme	6	High	4	Moderate	2	Low	0
	Static stability with respect to dam failure.	Extreme	18	High	12	Moderate	6	Low	0
	Earthquake resistance.	Extreme	12	High	8	Moderate	4	Low	0
Risk Class			**I (Low)**	**II (Moderate)**		**III (High)**		**IV (Extreme)**	

Total Risk Value	**0 – 15**	**16 – 45**	**46 – 75**	**76 – 90**

III. RESULTS AND DISCUSSION

III.1 Flood Routing

Flood routing analysis is required for use in dam failure analysis. Flood investigation uses a discharge of 350 m3/sec which is the flow capacity of the Serang River downstream of the Kedungombo Reservoir. The results of flood routing in the downstream area of the reservoir using the Zhong Xing HY-21 and controlled using HEC-RAS can be seen in Table 7.

Table 7. Comparison of water levels in Serang River (Calculation Results)

No	Cross Section	Q 350 m³/s	
		Hec-Ras (m)	ZhongXing (m)
1	Cross-1	29.5	29.7
2	Cross-2	28.8	28.2
3	Cross-3	27.9	27.2
4	Cross-4	27	26.7
5	Cross-5	26.4	26
6	Cross-6	25.8	25.7
7	Cross-7	25.4	25
8	Cross-8	24.8	24.5
9	Cross-9	24	24.2
10	Cross-10	23.2	23.5
11	Cross-11	22.8	23
12	Cross-12	21.8	21

III.2 Dam Break Analysis

Based on the five dam collapse scenarios, the Kedungombo Dam collapse outflow hydrograph was obtained, where the collapse caused by the upper piping scenario with a flood peak of 334.152 m^3/sec is estimated to have the greatest impact on the downstream area of the Kedungombo Dam followed by bottom piping with a peak flood of 327.351 m^3/sec, the middle piping with a peak flood of 323.808 m^3/sec, and overtopping conditions with a peak discharge of 316.339 m m^3/sec (Figure 2 and Table 8).

Thus, the Kedungombo Dam collapse scenario which begins with the occurrence of piping is chosen as the basis for the Kedung Ombo Dam risk assessment.

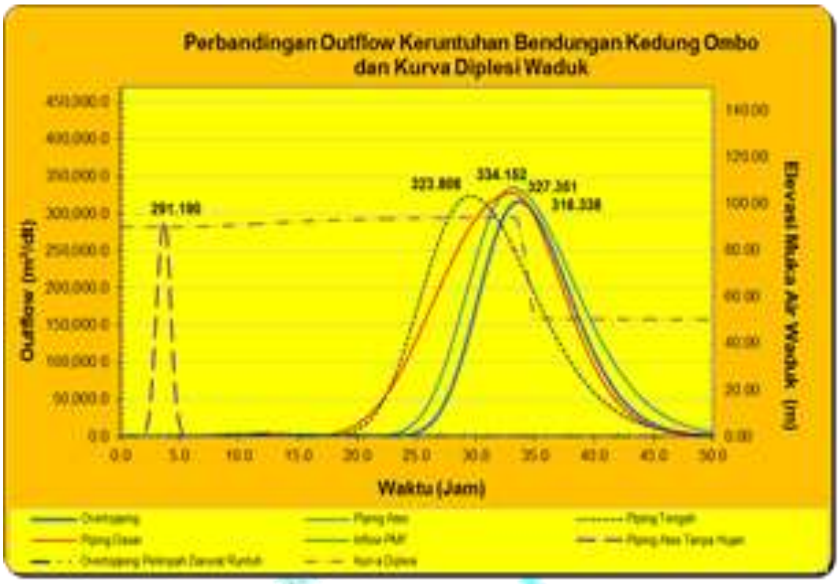

Fig 2. Inflow-Outflow hydrograph of the collapse of the Kedungombo Dam (Calculation Results)

Table 8. Peak Flood Discharge for Each Collapse Scenario (Calculation Results)

Outflow of Peak Flood Dam Collapse (m3/s) and Area of Inundation (ha)				
Upper Piping	Middle piping	Basic Piping	Over topping	No Rain
334.152	323.808	327.351	316.339	291.190
143.413	143.148	143.387	143.089	133.848

III.3 Population Affected by Risk (PAR)

What is meant by people at risk (PAR) are residents who live in areas prone to flood hazard caused by a dam collapse or residents who live within the flood inundation limits resulting from a simulation of a dam collapse. In the analysis of the dam collapse, residents who are estimated to be at risk are administratively included in the area of 429 villages/kelurahan located in 42 sub-districts in 6 regencies, namely Grobogan, Boyolali, Demak, Kudus, Pati and Jepara districts, Central Java Province.

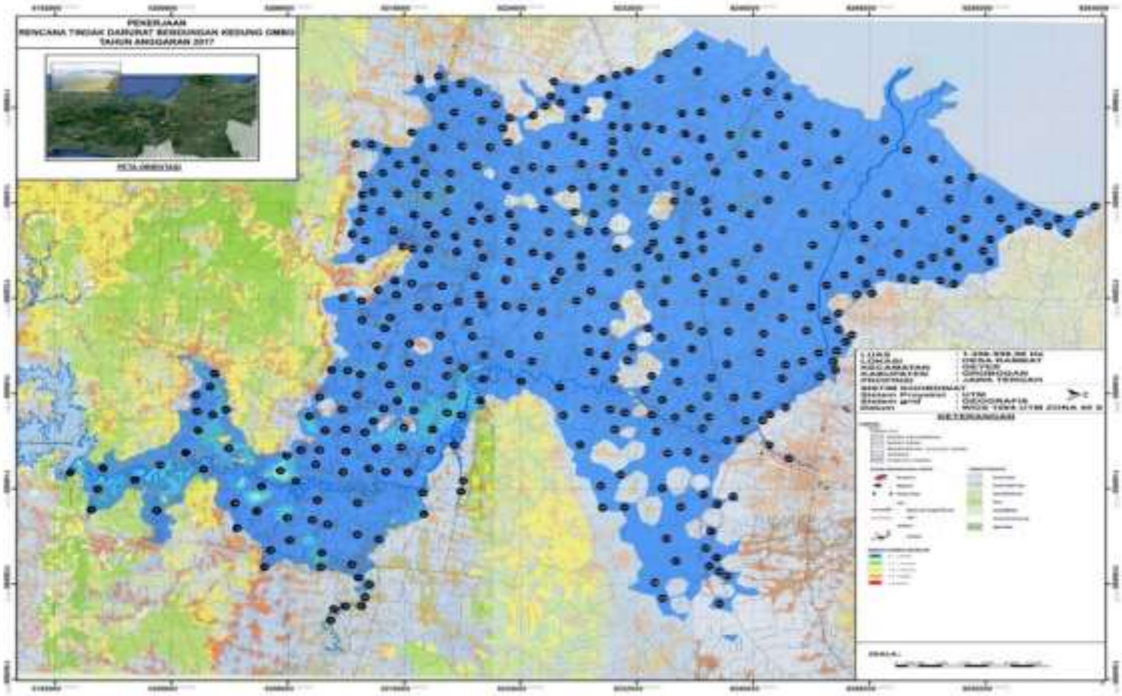

Fig 3. Flood Map due to Kedungombo Dam Collapse (Upper Piping)

It is estimated that the population that will be affected by flooding due to the collapse of the Kedungombo Dam is 1,486,217 people and 430,994 families where the largest PAR are in Demak Regency as many as 772,696 people and Grobogan Regency PAR as many as 492,201 people (Figure 4).

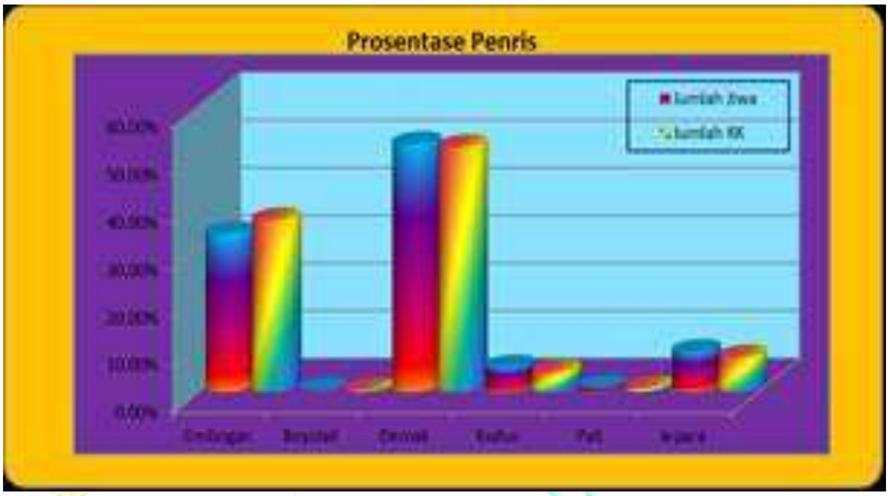

Fig 4. Proportion of PAR Per District (Calculation Results)

III.4 Determining Disaster Classification Using the ICOLD Method (2018)

The flood characteristics in the affected villages reflect that the average flood depth that occurs is 3.25 m for the upper piping collapse condition with an average speed of 0.32 m/s. Flood arrival time is estimated between 0.5 hours to 5.0 hours and receding time between 10 hours to 150 hours. The characteristics of the average flood in the nearest district are in Kab. Grobogan and Kab. Demak has a value of Q = 5.89 m^3/s, H = 4.23 meters and V = 0.43 m/s. By using the ICOLD equation in Table 2, the value of H2(V)1/2 = 11.91 is obtained where this value is included in the potential Low Risk (I) classification.

Characteristics of the average flood in districts other than Kab. Grobogan and Kab. Demak is considered as another location further afield having values of Q = 52.24 m^3/s, H = 7.13 meters and V = 2.23 m/s. By using the equation in Table 2, the value of H2(V)1/2 = 77.74 is obtained, where this value is included in the potential for Medium Risk (II) classification.

III.5 ICOLD (2018) Modified Method with Loss of Life (LoL)

LoL prediction at the nearest location, namely Kab. Grobogan and Kab. Demak is calculated with 2 conditions (a) without an early warning system and (b) with an early warning system. Without an early warning system, LoL prediction using equation (1) results in a LoL value of 32,707 people. With an early warning system, LoL prediction using equation (2) results in a LoL value of 253 people.

LoL predictions at other more distant locations, namely Kab. Boyolali, Kab. Kudus, Kab. Pati and Kab. Jepara is calculated with 2 conditions (a) without an early warning system and (b) with an early warning system. Without an early warning system, LoL prediction using equation (1) results in a LoL value of 8,696 people. With an early warning system, LoL prediction using equation (2) results in a LoL value of 44 people.

III.6 Loss of Life Prediction (LoL) with Graham's Equation (1999)

The first thing that must be determined to process Graham's (1999) equation is to determine the flood category at the Kedung Ombo Dam. Because the flood category at Kedung Ombo Dam is a high category and the flood arrival time is estimated to occur within 0.5 hours from the onset of the collapse or the beginning of the flood caused by a rainstorm and the response rate to flooding has been estimated, the PAR severity level becomes LoL. can be adjusted according to Table 1.

Based on Table 1, no guidance is given on how many people will remain in the floodplain. Therefore, the amount of PAR in the catchment area is determined directly without using the value of vulnerability.

III.6 Development of LoL index on Modified ICOLD Method

The total risk assessment for the Kedungombo Dam related to static stability can be seen in Table 10. The total risk assessment is calculated based on the guidelines in Table 4 to Table 6. From the calculation results, the total risk assessment for the Kedungombo Dam is 65. The risk index with a value of 65 is for the Kedung Ombo Dam. included in the high risk class. Based on the equation in Table 3, if long-term and short-term efforts are implemented, the risk value can be reduced by 12 points so that the Kedung Ombo Dam risk index becomes 53. If short-term efforts are implemented, the risk value can be reduced by 6 points so that the Kedung Ombo Dam risk index to 59. If long-term and short-term efforts are not implemented, the risk value cannot be reduced so that the Kedung Ombo Dam risk index remains at 59.

Table 10. Total risk assessment of Kedungombo Dam

Influence/Impact Factors	Quantity	Classification and Value				Risk Value
		ST	T	S	R	
1. Reservoir capacity (million m^3)	723	6	-	-	-	6
2. Dam high (m)	61	6	-	-	-	6
3. Peoples evacuated (number of people)	1,486,217	12	-	-	-	12
4. Potential downstream damage (to existing structures)	High	12	-	-	-	12
5. Business risk due to dam failure	High	6	-	-	-	6
Sub-total (5):		42	0	0	0	42
6. Security management:						
a. Availability of construction and maintenance records	Moderate	-	-	1	-	1
b. Availability of operated instrumentation and monitoring records	Moderate	-	-	1	-	1
c. The level of effort put into the safety evaluation	Low	-	2	-	-	2
d. New or upcoming downstream developments	Very High	3	-	-	-	3
Sub-total (6):		3	2	2	0	7
7. Structural issues related to the impact of dam failure:						
a. Regarding flood transfer capacity	Low	-	-	-	0	0
b. Regarding static stability	High	-	12	-	-	12
c. Regarding earthquake resistance	Moderate	-	-	4	-	4
Sub-total (7):		0	12	4	0	16
Total						**65**
Classification						**III (High)**

IV. CONCLUSION

Problems related to prediction of loss of life (LoL) based on PAR and awareness of life safety in the event of a disaster are the main things to minimize the risk of loss of life. Efforts to minimize the risk of loss of life can be applied to the downstream location of the Kedung Ombo Dam where in this location many residents live with disaster risks, whether low, high or extreme levels of risk. The prediction of the number of fatalities depends on PAR, the distance between PAR and the dam, and the characteristics of the flood when the dam collapses. From the calculation results, the early warning system at the Kedung Ombo Dam can reduce the risk so that the death toll can be reduced by almost 100%. The implementation of short-term (early warning systems) and long-term (plan-based spatial planning) programs can reduce the risk of fatalities in the event of a disaster.

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