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RISK ASSESSMENT OF GONGGANG DAM IN MAGETAN DISTRICT, EAST JAVA PROVINCE

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ABSTRACT

This study aims to assess the safety risk of the Gonggang Dam located in Magetan Regency, East Java, using traditional methods and the event tree method (Event Tree Analysis). The risk assessment is conducted by identifying potential hazards and failure modes, estimating the probability of failure, and evaluating the level of risk based on the analysis results. The results of the analysis show that the event tree method provides acceptable risk results, while the traditional method shows unacceptable risks. The priority of risk management at Gonggang Dam is focused on monitoring the dam body and inundation area to maintain safety and maximize the life of the dam. Recommendations were given to improve structural safety and regular monitoring.

KEYWORDS *Gonggang Dam, Risk Assessment, Dam Safety, Event Tree Method, Traditional Method*

INTRODUCTION

Dams are key infrastructure in water resources management, providing significant benefits to human life, including agricultural irrigation, drinking water supply, power generation and flood control. However, amidst the benefits offered, it is important to recognize that dams also carry significant risks related to their structural and operational safety.

In addition to having a variety of benefits, dams also have enormous disaster potential if they fail. Dam failure will cause a catastrophic disaster in the form of a major flood as a real threat to people's lives, especially downstream of the dam. To prevent dam failure, dam construction and management activities must be carried out based on the conception of dam safety and dam safety rules contained in various applicable norms, standards, guidelines and manuals. The conception of Dam Safety consists of 3 (three) pillars, namely: 1) structure safety in the form of safety against structural failure, safety against hydraulic failure, and safety against seepage

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failure; 2) operation, maintenance, and monitoring; and 3) emergency preparedness. (Kementerian PUPR, 2015).

To ensure the safety of the dam from dam failure, which is very risky in the area downstream of the dam, and to maximize the operation of the dam and the safety of the dam structure, an organization is needed to ensure continuous operation and maintenance, in accordance with the needs of the community. In addition, it monitors the available reservoir capacity and releases water in accordance with its benefits, carries out minor repairs to the dam body, auxiliary buildings, and maintains installed *instruments* to ensure that they are in good condition, safe and can be utilized as optimally as possible.

Law of the Republic of Indonesia Number 24 Year 2007 on Disaster Management article 40 mandates that "every development activity that has a high risk of causing a disaster is equipped with a disaster risk analysis as part of disaster management efforts". The obligation of disaster risk analysis is detailed in Government Regulation No. 21/2008 on the Implementation of Disaster Management article 12.

Gonggang Dam was completed in 2010. Gonggang Dam is located in Janggan Village, Poncol Sub-district, Magetan Regency, East Java Province, 74 km southeast of Surakarta City and 23 km southwest of Magetan City. Gonggang Dam functions as irrigation water and raw water.

One of the problems in the maintenance of dams in Indonesia is the availability of a budget. (Soentoro, Purnomo, & Susantin, 2013). For this reason, a method of prioritizing dam maintenance is needed. Risk assessment can be used to prioritize dams based on their risks. Risk assessment consists of risk analysis and risk evaluation. Directorate General of Natural Resources (2011) has developed a Risk Assessment Guideline which is hereinafter referred to as the Technical Guideline method. So this study aims to compare the results of risk assessment of dams using the traditional method and the event tree method.

Problem Formulation

Based on the background above, the problem formulation in this study is as follows:

1. What are the potential hazards and forms of failure at Gonggang Dam?
2. What is the risk ranking of potential hazards of Gonggang Dam failure?
3. What is the probability of Gonggang Dam failure?

Purpose and objectives

The purpose of this study is to conduct a risk assessment of the Gonggang Dam using several methods to obtain an overview of the safety condition of the Gonggang Dam. While the objectives of this study are:

1. Analyze the potential hazards and forms of failure at Gonggang Dam.
2. Analyze the risk ranking of potential hazards of Gonggang Dam failure.
3. Analyze the probability of failure hazard of Gonggang Dam.

Scope

The scope of this study is:

1. Identify the hazards of Gonggang Dam;
2. Identify failure *modes* using the FMECA (*Failure Mode, Effects, and Critically Analysis*) method;
3. Calculating the probability of failure modes by event tree method and traditional method;
4. Conduct risk evaluation based on the results of the risk analysis that has been carried out (traditional method and event tree method).

Research Location

The location of Gonggang Dam is in Janggan Village, Poncol Sub-district, Magetan Regency, Poncol sub-district area: 5131 ha. The administrative area is divided into 8 villages, 44 RW, 231 RT and 34 hamlets. Area boundaries:

1. North : Plaosan District, Magetan District
2. East : Parang sub-district
3. South side: Wonogiri Regency, Parang District
4. West : Wonogiri Regency

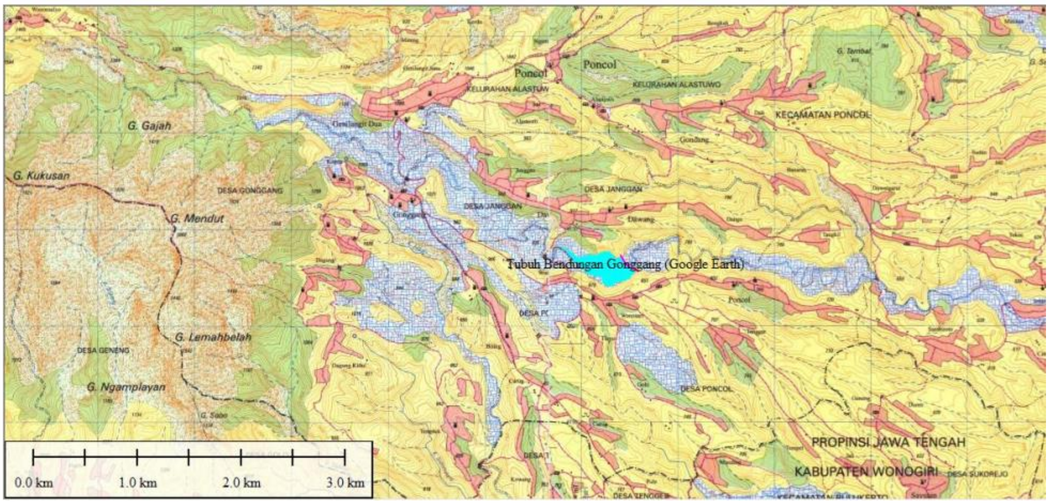

Figure 1. Location of Gonggang Dam
(BBWS Bengawan Solo 2020)

RESEARCH METHOD

Risk analysis

Risk analysis is carried out by performing a number of steps including:

1. Identify hazards by listing all potential hazards that may occur;
2. Identification of failure models consisting of listing failure modes that may occur and eliminating potential hazards and failure modes that may be negligible using the FMECA (*Failure Mode, Effects, and Critically Analysis*) method.
3. Estimating the probability of failure using the *event tree* method and traditional methods.

Risk evaluation

Risk evaluation by calculating the Annual Probability of Failure (APF) value as a result of calibration and verification based on existing dam risk criteria. APF is obtained by summing up all the probabilities of potential hazards identified in the dam components.

$APF = \sum APF_i$

Risk evaluation of dams can be seen in terms of life safety risk. In the absence of specific legal and regulatory provisions or guidelines, guidelines for tolerable life safety risks for the general public are suggested as follows:

- For existing dams, individual risk for the individual or group most at risk, with a probability of dam failure greater than 1.00E-04 per year is not acceptable, except in exceptional circumstances.
- For new dams or existing dams with dam raising, individual risk for the individual or group most at risk, with a probability of dam failure greater than 1.00E-05 per year is not acceptable, except in exceptional circumstances.
- For existing dams, a social risk higher than the limit of the curve shown in Figure 2 is not acceptable, except in exceptional circumstances.
- For new dams or existing dams with raised dams, social risks higher than the curve limit shown in Figure 3 are not acceptable, except in exceptional circumstances.

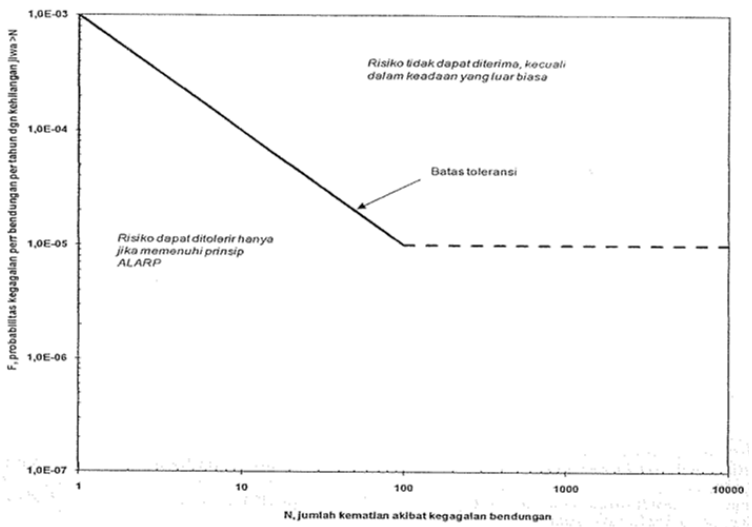

Figure 1. Social life safety risks of the old dam
(*Societal Risk Criteria*, ANCOLD, 2003)

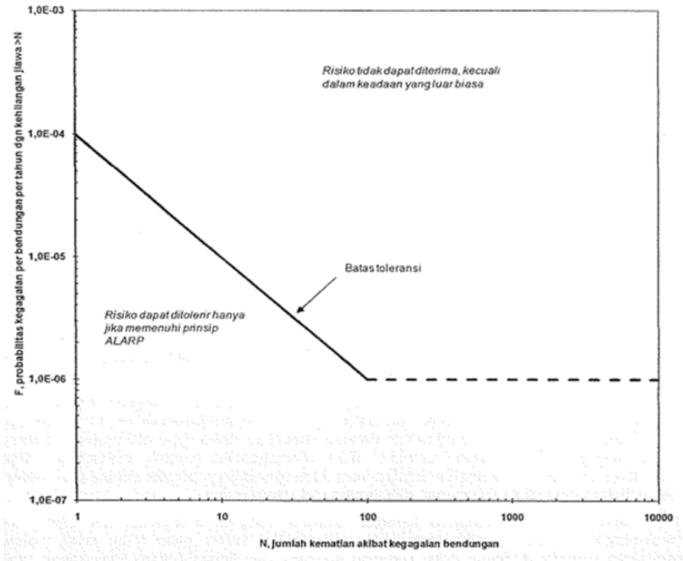

Figure 3. Social life safety risks of the old dam
(*Societal Risk Criteria*, ANCOLD, 2003)

RESULTS AND DISCUSSION

Risk analysis

Identify Risks

The risk identification of Gonggang Dam is based on the 2020 major inspection. The time period for the implementation of major inspection activities was carried out on October 09, 2019 - November 23, 2020. Activities carried out such as studying documents related to previous studies, technical discussions and dam management, observation or observation of physical field conditions and final discussions. The results of the hazard identification of Gonggang Dam are described in Table1 and Appendix 1, namely:

Table 1. Risk Identification of Gonggang Dam

No.	Component	Hazard Source Identification	Causes	Failure Mode
1.	Dam Body (Peak)	There is subsidence (deformation) at the crest of the dam body	Overloading. Low material bearing capacity	Reduced guard height, Overtopping occurs
2.	Dam Body (Peak)	there are cracks crossing the asphalt of the dam body at both the left and right ends of the dam pedestal, the cracks are	Overloading. Low material bearing capacity.	Reduced guard height, Overtopping occurs

No.	Component	Hazard Source Identification	Causes	Failure Mode
		relatively tight with openings less than 0.5 cm.		
3.	Dam Body (Upstream Slope)	There are parts that experience deformation surface or surface subsidence on the left side of the length of the dam along ± 17 m	the condition of the rip-rap is less dense and easily wobbled for sizes diameter less than 50 cm. Low material bearing capacity	Seepage through the dam body
4.	Dam Body (Downstream Slope)	There is an avalanche	occurs because of the erosion of drainage water whose channels are not made to flow to the foot drainage channel	Seepage through the dam body
5.	Dam Body (Downstream Slope)	There are wet areas or wet spots	Low material bearing capacity	Seepage through the dam body
6.	Spillway	There is trash in the olak pool	Avalanche from the valve house	Spillway clogged with trash
7.	Reservoir inundation area (right side)	There is an avalanche	due to the results of excavation at the time of construction with a slope too upright close to vertical and changes in Land Use	Sedimentation that enters the reservoir can cause the reservoir's useful life to decrease

Failure mode identification

Based on the risk identification results that have been obtained, each component is further analyzed through failure mode, effects, and critical analysis (FMECA). Based on the qualitative values of likelihood, consequence, confidence, the calculation of the qualitative value of risk (R) and hazard criticality (Cr) is carried out. Estimating the qualitative value of risk (R) and the level of hazard criticality (Cr) for each problem/potential hazard is done by taking into account the level of likelihood (P), consequence (I) and confidence (C).

Risk : R = P x I
Criticality : Cr = R x C

The results of the Gonggang Dam FMECA analysis are described in Table 2, namely:

Table 2. FMECA Analysis of Gonggang Dam

No.	Parts/Components	Possibility (P)	Consequences (I)	Confidence (C)	Risk (R)=(P)x (I)	Criticality (Cr)=(R)x (C)
1	Dam Body (Peak)	3	4	3	12	36
2	Dam Body (Peak)	2	4	3	8	24
3	Dam Body (Upstream Slope)	3	4	3	12	36
4	Dam Body (Downstream Slope)	3	2	4	4	16
5	Dam Body (Downstream Slope)	3	3	3	9	27
6	Spillway	4	1	5	4	20
7	Reservoir Inundation Area (right side)	4	3	3	12	36

After calculating the risk of potential hazards, then sorted based on the level of risk. Based on the level of hazard risk, there are 4 components with the highest priority level of risk and criticality at Gonggang Dam, namely the Dam Body (Peak), Dam Body (Upstream slope), Dam Body (Downstream slope), and Reservoir inundation area. The order of the Gonggang Dam hazard risk level is presented in table 3.

Table 3. Ranking of risk level and criticality of dam components Gonggang Dam

No.	Component	Load Condition	Hazard	Risk		Kekritisan	Order		Tinda right
				Value	Description	Value	Risk	Criticality	
1	Dam Body (Peak)	Normal State	Reduced guard height, Overtopping occurs	12	Medium	36	2	2	Analyzed

No.	Component	Load Condition	Hazard	Risk		Kekritisan	Order		Tindaright
				Value	Description	Value	Risk	Criticality	
2	Dam Body (Peak)	Normal State	Reduced guard height, Overtopping occurs	8	Low	24	5	5	Not Analyzed
3	Dam Body (Upstream Slope)	Normal State	Seepage through the dam body	12	Medium	36	3	3	Analyzed
4	Dam Body (Downstream Slope)	Normal State	Seepage through the dam body	4	Low	16	7	7	Not Analyzed
5	Dam Body (Downstream Slope)	Normal State	Seepage through the dam body	9	Medium	27	4	4	Analyzed
6	Spillway	Normal State	Spillway clogged with trash	4	Low	20	6	6	Not Analyzed
7	Reservoir Inundation Area (right side)	Normal State	Sedimentation entering the reservoir can cause overtopping	12	Medium	36	1	1	Analyzed

The components that will be further analyzed are potential hazards that have a first order risk (1) and a second order risk (2) that have a first (1) and second (2) order criticality. Other components will not be analyzed with the assumption that the risk level and criticality level are negligible. So that four (4) of the seven (7) components that will be further analyzed using the traditional method and the event tree method are:

- Dam body (Peak)
- Dam Body (Upstream slope)
- Dam body (Downstream slope)
- Reservoir inundation area

Estimated probability of failure

Event tree method

The components with the highest order of hazard risk in the FMECA analysis are estimated for their annual probability of occurrence by Event Tree Analysis (ETA). ETA analysis describes the process mechanism or scenario of a failure that may occur as a result of an initial event. The probability is determined using the design criteria assumptions, Tables 2.6 and 2.1. The results of the Gonggang Dam event tree analysis are depicted in Appendix 2.

Each component will be categorized into Extreme, High, Medium, Low and Normal categories. The lack of literature that explains the details of determining the category, so in this study the criteria for determining the category used are as follows:

a. Normal : The component is working normally or the component has been repaired
b. Low : This category is not used
c. Medium : Damage is not repaired, there are problems due to causes but the component is working normally, and there is a problem due to the cause that the component is not working normally and is not overtopping.
d. High : Overtoping but the dam did not collapse
e. Extreme : Overtoping so that the dam collapses

A recapitulation of the categorization results is presented in **Error! Reference source not found.** 4.

Table 4. Summary of hazard probabilities Gonggang Dam

No.	Component	Causes	Failure Mode	Extreme	High	Medium	Low	Normal
1	Dam Body (Peak)	Subsidence (deformation) of the crest of the dam body	Dam collapse	1.0E-11	9.0E-11	1.99E-08	0.000E+00	9.910E-01
2	Dam Body (Slope)	Avalanches and seepage	Dam collapse	1.00E-10	9.00E-10	1.08E-07	0.000E+00	9.910E-01
3	Reservoir inundation area	Reservoir Sedimentation	The useful life of the reservoir is decreasing	0.000E+00	0.000E+00	1.99E-08	0.000E+00	9.910E-01
Total				**1.1E-10**	**1.0E-9**	**1.48E-07**	**0.000E+00**	**2.97**

Traditional method

The method of analyzing the results of hazard identification of Gonggang Dam was also carried out using the traditional method by determining failure modes and probabilities. The probability was determined using the design criteria assumptions, The results of the Gonggang Dam traditional method analysis are plotted in Figure 4, Figure 5, and Figure 6. The probability of harm of the traditional analysis of Gonggang Dam is described in table 5.

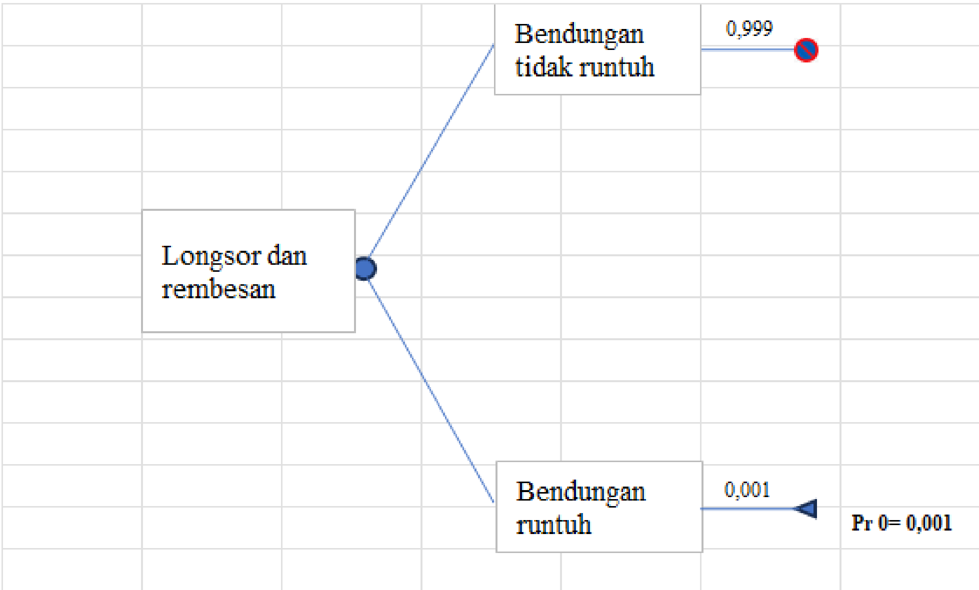

Figure 7. Traditional Analysis of the Body Dam (Downstream Slope) to *Potential Landslides and Seepage*

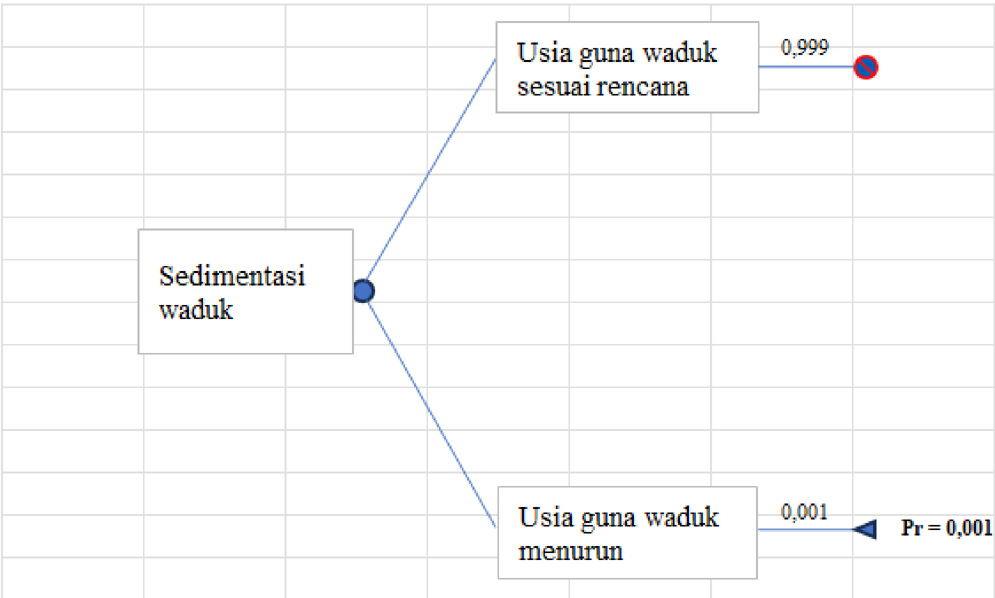

Figure 8. Traditional Analysis of Reservoir Inundation Area on Reservoir Sedimentation

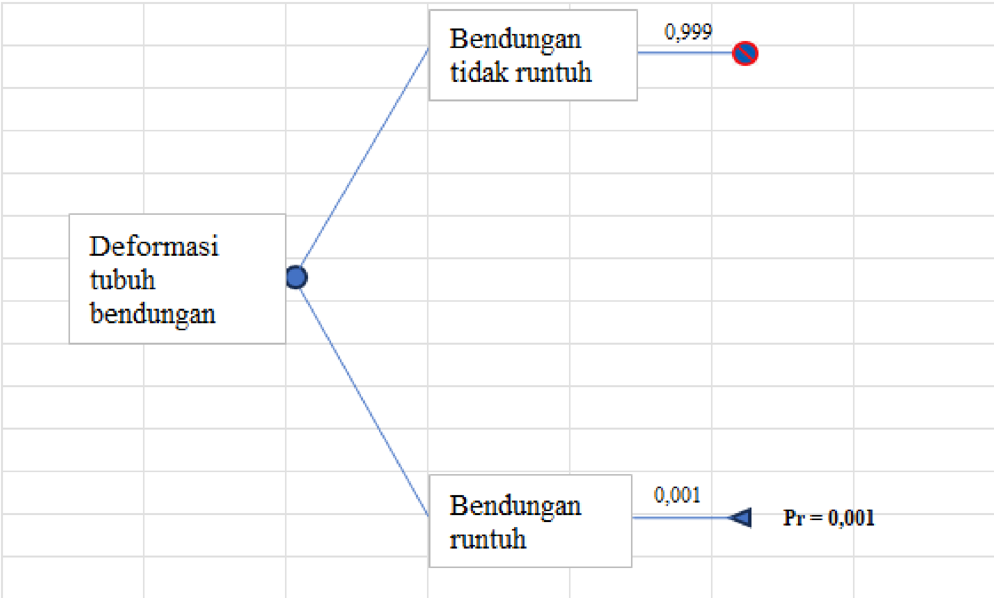

Figure 6. Traditional Analysis of the Body
Dam (Peak) to Overtopping Potential

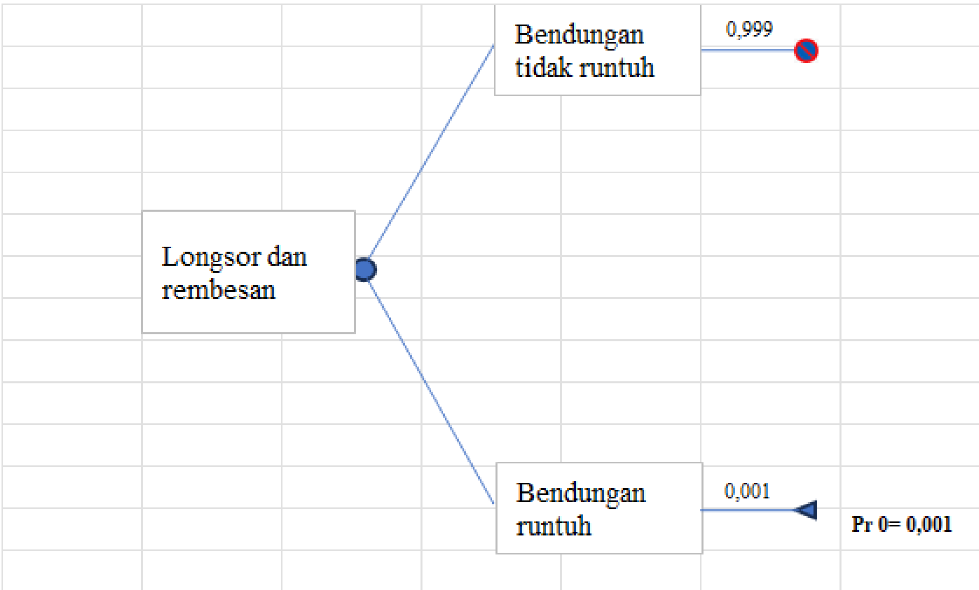

Figure 7. Traditional Analysis of the Body
Dam (Downstream Slope) to Potential Landslides and Seepage

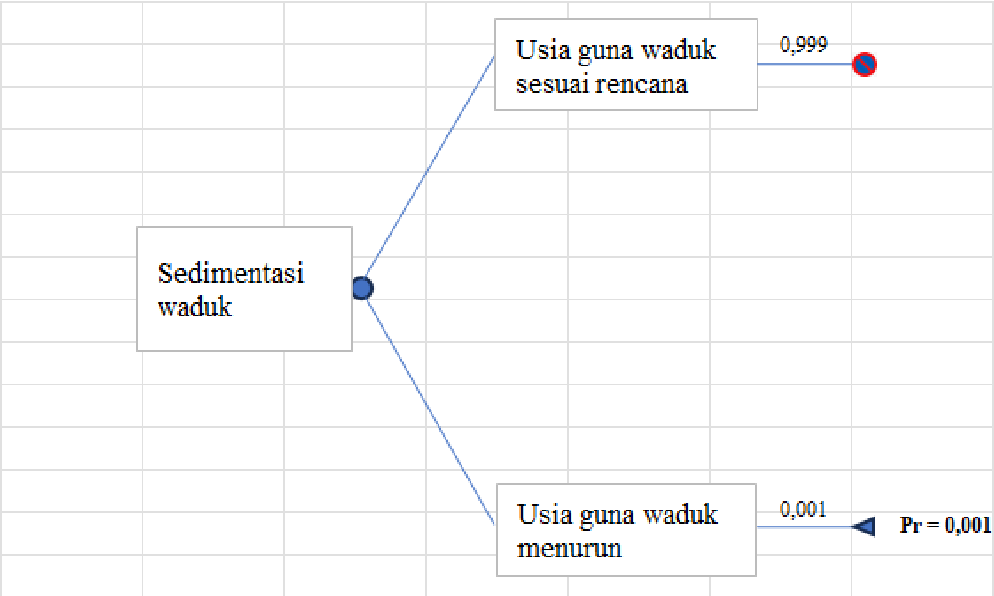

Figure 8. Traditional Analysis of Reservoir Inundation Area on Reservoir Sedimentation

Table 5. Hazard probability of traditional analysis Gonggang Dam

No.	Component	Causes	Probability
1	Dam Body (Peak)	Dam crest is paved with asphalt pavement, overloaded	0,001
2	Dam Body (Downstream slope)	Drainage not functioning properly & Low material bearing capacity	0,001
3	Reservoir inundation area	Land use change	0,001

Risk Evaluation

The APF is obtained by summing up all the probabilities of potential hazards identified in the dam components.

$APF = \sum APF_i$

$APF_{\text{Peak dam body}} =$ 1.0E-11

$APF_{\text{Downstream slope dam body}} =$ 1.0E-10

$APF_{\text{Reservoir inundation area}} =$ 1.0E-12

Thus the total APF is obtained:

APF= 1.0E-11 + 1.0E-10 + 1.0E-12

= 1.11E-10 < 1.0E-04

The probability value of the risk of failure of the Gonggang Dam in every 1 (one) year based on the event tree is acceptable because the value is smaller than the required APF value of 1.0E-04.

The APF is obtained by summing up all the probabilities of potential hazards identified in the dam components.

APF = $\sum APF_i$

$APF_{Tubuh\ dam\ peak}$ = 1.0E-3

$APF_{Tubuh\ dam\ slope\ hilir}$ = 1.0E-3

$APF_{Daerag\ puddle\ waduk}$ = 1.0E-3

Thus the total APF is obtained:

APF= 1.0E-1+ 1.0E-1+1.0E-3

= 3.0E-3 > 1.0E-04

Meanwhile, the traditional method is not acceptable because it is greater than 1.0E-04.

Social Risks

The social risk evaluation is plotted according to the following graph from the guideline on risk assessment, ANCOLD 2003:

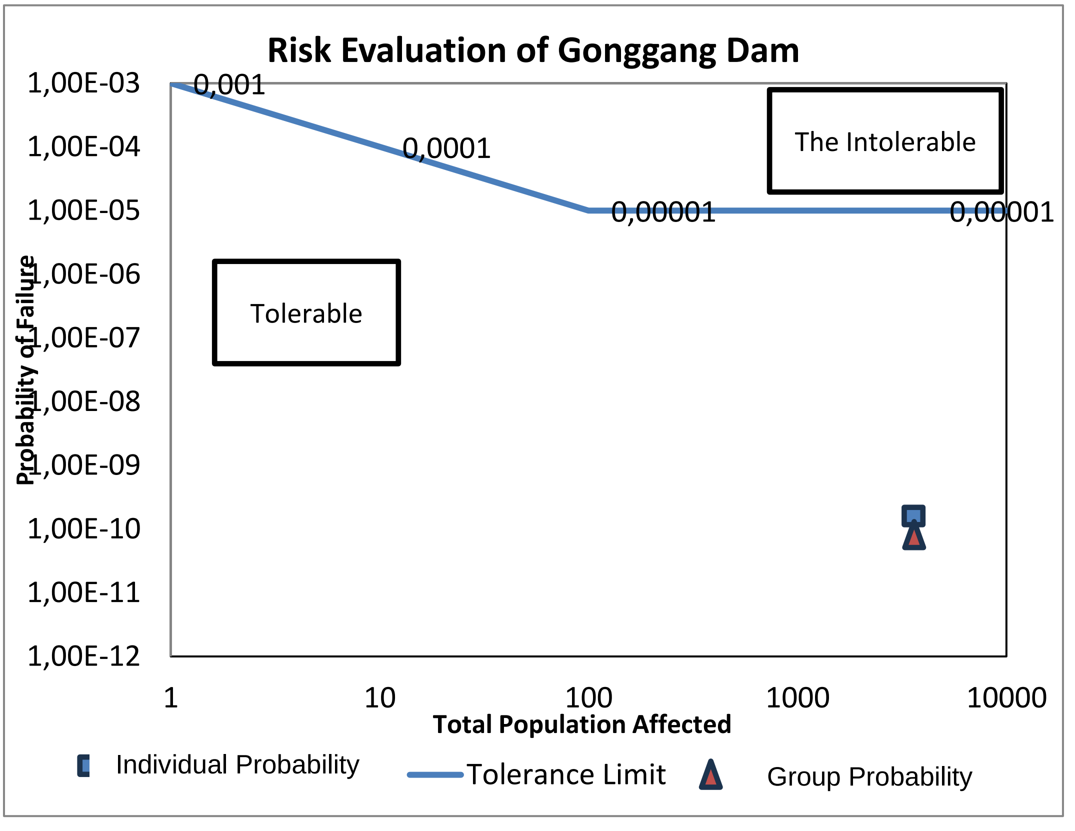

Figure 9. ETA method risk evaluation

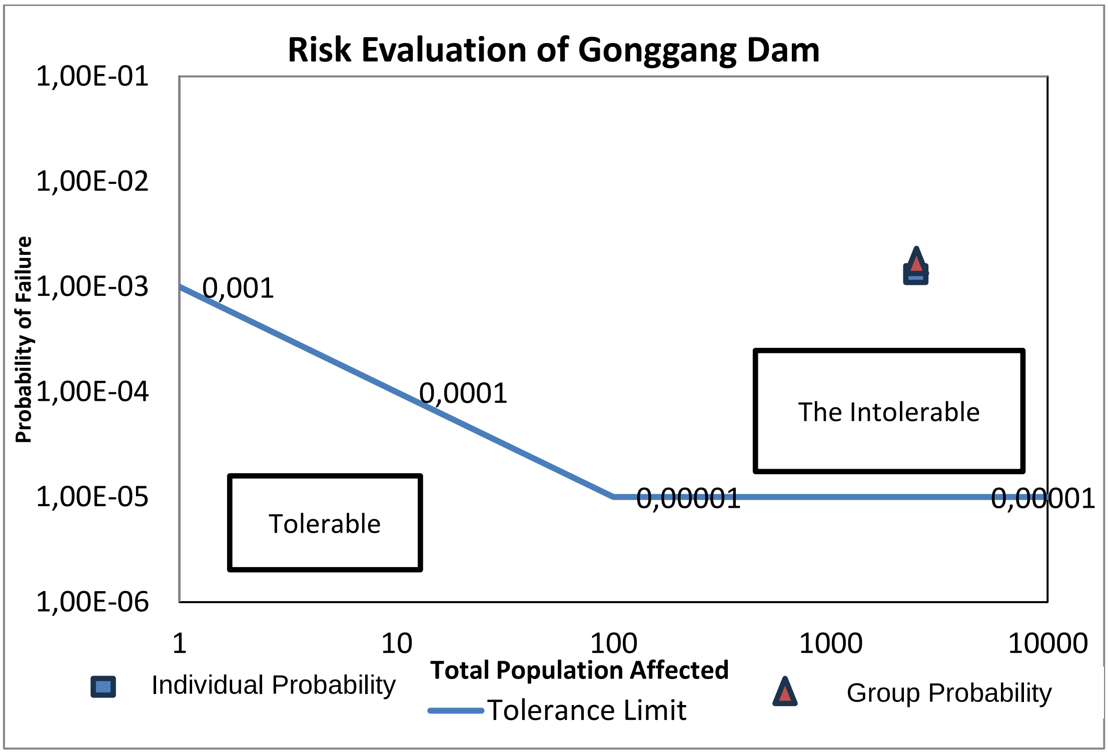

Figure 10. Traditional method risk evaluation

Risk Reduction Handling

The priority scale for risk management of Gonggang Dam based on risk analysis is on the dam body crest and dam body slope. Risk handling that can be done for risk reduction include:

Table 6. Risk reduction measures for Gonggang Dam

No.	Component	Problems	Risk reduction measures
1.	Dam body at crest and slope	There is subsidence (deformation) of the dam body crest and cracks	- On the upstream slope of the dam body, visible symptoms of deformation need to be monitored regularly. - The cracks on the crest of the dam body need regular monitoring to determine the continuation of the cracks. - Seepage on the downstream slope needs to be monitored regularly for discharge. - The seepage investigation plan on the downstream slope will use pit tests which are a series of geotechnical investigations. The pit test will be carried out in the dry season using 2 adjacent investigation points with a

	distance of approximately 15 m. The purpose of this pit test is to determine the direction of the water coming out of the pit test hole made and take soil samples to be tested and confirmed the soil parameters with the test results that have been carried out during construction.

CONCLUSION

The conclusions of this research are as follows: 1. Risk assessment using the traditional method shows that the risk of Gonggang Dam is unacceptable because this method does not describe in detail each possibility. 2. Risk assessment using the event tree method shows that the risk of Gonggang Dam is acceptable. 3. The results of a risk assessment that meets or does not imply that the dam is in a dangerous condition, but is used as an assessment tool in order to make decisions on determining dam maintenance priorities. 4. The order of the priority scale of risk management of the Gonggang Dam using the event tree method is the Dam body (slope), Dam Tubunh (Peak), and Reservoir Inundation Area with a value of 1x10-10, 1x10-11, 1x10-12.

Suggestions for sustainability are as follows: 1. It is always necessary to improve the parameters related to dam safety to reduce the possibility of collapse. 2. Risk assessment needs to be carried out with several methods to serve as a comparison because each method has advantages and disadvantages. 3. Risk management of the Gonggang Dam on the dam body and reservoir inundation area is in the form of monitoring instrumentation on the dam body and repairing cracks by grouting or plastering and pickling according to the situation. Then for the Reservoir Inundation Area, periodic water quality testing is needed as well as repairs to the upstream reservoir and stone masonry for slope areas.

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