Eduvest – Journal of Universal Studies
Volume 6 Number 5, May, 2026
p- ISSN 2775-3735- e-ISSN 2775-3727

Risk Management in Redesigning Main Dam for the Tiu Suntuk Dam Implementation

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Keywords
risk management; dam redesign; dam; Severity Index; ISO 31000:2018

Abstract
The redesign of the Tiu Spara Dam main dam was carried out in response to changes in technical conditions and operational needs of the project, but this process has the potential to pose various risks that can affect the stability, safety, and performance of the dam. This study aims to identify risk indicators, analyze risk levels and priorities, and formulate risk control strategies in the redesign of the Tiu Suntuk Dam main dam. The method used is a descriptive quantitative approach based on ISO 31000:2018 risk management, with data collection through field observations, interviews, literature studies, and questionnaire dissemination to experienced respondents. Risk analysis was conducted using the Severity Index method to assess the probability and impact of the risk, which was subsequently mapped into a risk matrix. The results showed that the highest risk came from the technical aspects, namely changes in soil carrying capacity, availability of materials for new designs, and suitability of dam design with actual slope conditions, all of which fall under the category of extreme risk. Therefore, it is necessary to strengthen technical investigations, design adjustments, improve work quality control, and implement systematic and integrated risk management. This research is expected to be a reference in risk management in similar dam projects to improve structural safety and the sustainability of dam functions.

INTRODUCTION

Dams have an important role in supporting water availability, flood control, and energy supply (Zhang, 2019; Muhiddin, 2025). However, they also pose significant potential hazards in the event of structural failure. Dam failure can cause flood disasters that result in substantial human, economic, and environmental losses in downstream areas. For this reason, the Indonesian government has established regulations related to dam safety to ensure that the construction, operation, and maintenance of dams are carried out in accordance with the safety rules set out in the norms, standards, guidelines, and manuals (NSPM). Regular inspections and repairs are essential to extend the service life of a dam and minimize the risk of structural failure. Risk assessment is the primary tool for determining repair priorities, considering the specific characteristics and risk level of each dam (Pamungkas et al., 2023).

In the context of a construction project, risk is an inherent factor that can arise from the planning stage through operationalization (Misra, 2020; Tinambunan, 2024). In dam projects, various risks—such as technical, labor, political, environmental, and financial—need to be identified and managed systematically (Alkhawaja & Varouqa, 2023). Particularly in the labor aspect, the risk of workplace accidents is among the highest in construction projects in Indonesia, contributing approximately 30% of total national workplace accidents (Adi, 2023). Therefore, risk management is necessary not only to ensure worker safety but also to maintain project sustainability, prevent delays, and avoid cost overruns (Yuliana, 2017; Terfiana et al., 2024). Effective risk management in dam projects must holistically include technical, labor, and environmental aspects so that negative impacts on project cost, time, and quality can be minimized.

The Tiu Suntuk Dam in West Sumbawa, West Nusa Tenggara, is one of the strategic projects developed to address water scarcity during the dry season and reduce flood risk during the rainy season (Hermawan & Susanto, 2022; Nirwono & Soetomo, 2020). However, during its implementation, there were design changes to the main dam, specifically the upstream slope, which was modified from 1:2.5 to 1:2, and an increase in elevation from +97.00 to +98.00. These changes have implications for increased technical risks, such as erosion and structural instability. In addition, environmental factors—including flooding, erosion, extreme weather, and limited road access—pose additional challenges in completing this project (Sutrisno, 2023; Marwanto & Widodo, 2023; Rahman, 2024). Geological conditions that differ from the initial planning and the potential failure of construction materials also increase the risk of project delays (Wibowo, 2023). Based on these conditions, risk management analysis of the redesign of the Tiu Suntuk Dam main dam is crucial to ensure the success and sustainability of dam operations.

The urgency of this research is further heightened by the potential consequences of inadequate risk management during dam redesign. If technical risks—such as changes in soil bearing capacity and slope instability—are not properly identified and mitigated, the structural integrity of the dam could be compromised, potentially leading to failure with catastrophic consequences for downstream communities. Moreover, the Indonesian government has invested significant resources in dam construction as part of the national food and water security program. Therefore, ensuring the safety and sustainability of these strategic assets through rigorous risk management is not merely an academic exercise but a national priority.

The novelty of this research lies in its integrated approach to risk management for dam redesign. First, this study applies the ISO 31000:2018 framework, which is more flexible and principle-based compared to previous standards, to the specific context of dam redesign. Second, this research combines the Severity Index method with risk matrix mapping to quantitatively assess both the probability and impact of risks, providing more objective prioritization than previous qualitative approaches. Third, this study specifically focuses on the redesign phase—a phase that has received limited attention in the literature, as most studies concentrate on initial construction or long-term operation. Fourth, this research develops risk variables tailored to the technical, environmental, construction, K3 (occupational health and safety), operational, and administrative challenges arising from design changes.

Based on the problem formulation, objectives, and research limitations, this study focuses on the identification, analysis, and control of risks in the redesign of the main dam of the Tiu Suntuk Dam using an ISO 31000:2018-based risk management approach. The research was conducted using a quantitative descriptive method through field observations, interviews, literature reviews, and questionnaires administered to experienced respondents, with validity and reliability testing performed using Pearson correlation and Cronbach's Alpha. Risks are analyzed using the Severity Index method to determine probability and impact levels, then mapped in a risk matrix to establish priorities and formulate control strategies that consider the technical, operational, and managerial aspects of the project.

METHOD

This research was conducted at the Tiu Suntuk, administratively the Tiu Suntuk Dam is located in Hijrah Hamlet, Mujahidin Village, Brang Ene District, West Sumbawa Regency, West Nusa Tenggara Province. Its geographical position is located at 116.927° E and 8.794° S. The location of the dam from the port of Poto Tano is about ± 30 km to the south. From Taliwang City to the east to Mujahidin Village as far as ± 12 km.

Figure 1 Location of Tiu Spara Dam

The Topographic conditions around the reservoir are hilly areas with an altitude ranging from 45-950 m above sea level. The condition of the inundation area is in the form of hills with steep slopes - quite steep consisting of forest land.

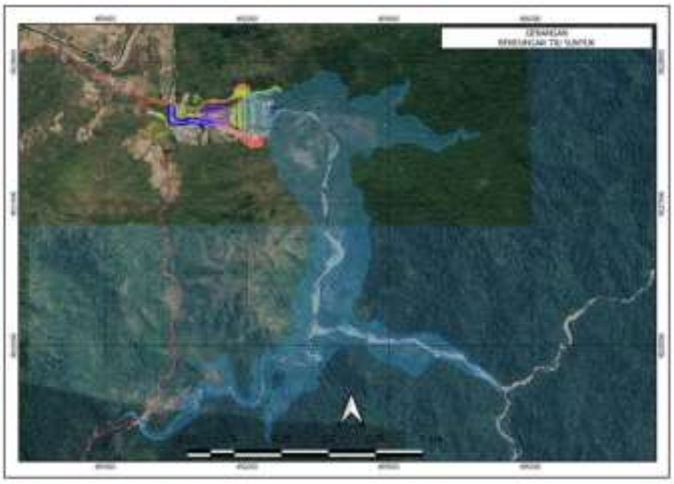

Figure 2 Topographic Map of the Tiu Spara Dam

This research is a quantitative research, data collection to identify risks is carried out by observation, questionnaires and interviews. Risk management in the Tiu S Dam construction project refers to the ISO 31000:2018 risk management process (Septianugraha et al., 2024; Tinambunan, 2024). The risk management process starts from risk identification, risk analysis, risk evaluation and response to the risk. The process to ensure that these risks remain monitored and controlled, monitoring and review as well as recording and reporting on each risk management process.

In the context of the redesign of the Tiu Suntuk's main dam, the use of ISO 31000:2018 allows the risks arising from design changes to be identified and analyzed systematically based on the actual conditions of the project. The risks analyzed include technical, environmental, construction, K3, operational, as well as administrative and regulatory risks, so that the results of the analysis are not limited to structural aspects alone, but also reflect the reality of project implementation holistically.

In addition, ISO 31000:2018 is seen as appropriate to this research approach because it does not require any specific quantitative methods, so it can be combined with risk analysis techniques relevant to the availability of data and research objectives. In this study, the Severity Index technique was used as a quantitative tool to measure the level of probability and impact of risk based on expert respondents' assessments. The results of the assessment are then mapped into a risk matrix to determine the risk priorities that require further attention and control.

The selection of ISO 31000:2018 is also supported by practical considerations that this standard is in line with risk management practices commonly applied to construction projects in Indonesia, particularly large-scale infrastructure projects involving multiple stakeholders. Thus, the results of this research are expected not only to have an academic contribution, but also to provide practical benefits for project implementers in managing the risk of redesign in a more effective and structured manner.

Based on these considerations, the use of ISO 31000:2018 in this study is considered appropriate and relevant to achieve the research objectives, namely identifying risk indicators, determining risk priorities, and formulating risk control measures in the redesign of the Tiu Suntuk's main dam.

a. Primary Data: In the process of collecting data, research subjects are needed, both respondents and experts. Research respondents are always needed every time they conduct research, both qualitative and quantitative. According to (Sugiyono, 2013), respondents are not only referred to as samples or research subjects, but also referred to as resource persons, teachers, informants or participants. Meanwhile, experts are referred to as experts who are experienced in assessing/validating a variable. The research subjects consisted of two groups, namely experts and respondents. The expert group consists of 5 people with a minimum qualification of S1 education, minimum 10 years of work experience, have intermediate certifications in the field of construction management, water resources, or construction safety, and come from academics, professionals, practitioners, or the government who have served as dam Project Managers or Irrigation Project Commitment Making Officials. Meanwhile, the group of respondents amounted to 40 people with a minimum qualification of S1 education, a minimum of 5 years of work experience, had a youth certification in a related field, and came from academics, professionals, practitioners, or the government who had served at the level of SEM, SOM, HSE Manager, or as directors/consultants supervising irrigation projects.
b. Secondary Data: Secondary data for this study was obtained from the collection of the following technical data: Profile of maindam redesign work on the Tiu Suntuk. Other research supporting documents such as literature studies and ISO 31000:2018.

The collection of research data is carried out in the following way or procedure:

a. Observation is a part of data collection. Observation means collecting data directly from the field. According to Sugiyono (2020), observation is defined as the systematic observation and recording of a phenomenon that appears in the object of research.
b. Interview is a meeting of two people to exchange information and ideas through questions and answers, so that the meaning in a certain topic can be constructed. In this case, data can be obtained by conducting interviews with the party responsible for implementing the construction of the Tiu Suntuk Dam to obtain the desired information (Sugiyono, 2020).
c. Questionnaires are a type of data collection instrument that is delivered to respondents or research subjects through a number of questions or statements (Sugiyono, 2020). The distribution of the main questionnaire to parties directly involved in the implementation activities of the Tiu Suntuk Dam Work.

Risk analysis was carried out through the distribution of questionnaires to obtain respondents' assessment of the probability and impact of each risk variable, which was then analyzed using the Severity Index (SI) method based on a five-level Likert scale (Yoyo et al., 2023; Misra, 2020). The SI value is calculated from the weight of the respondents' answers and converted into very small to very large categories according to the percentage interval adapted from previous research, thus facilitating the interpretation of the risk level. Furthermore, the probability and impact values of the conversion result are used to calculate the risk level (R) through the multiplication of the two, which serves as the basis for determining risk prioritization as well as evaluating risks that have a high frequency and significant impact on project implementation.

RESULT AND DISCUSSION

A. Dam Technical Data

The Tiu Spara Dam Planning is located in Hijrah Hamlet, Mujahidin Village, Brang Ene District, West Sumbara Regency, West Nusa Tenggara Province. The planning of this dam is because Taliwang City is the capital of West Sumbawa Regency, West Nusa Tenggara Province, which is geographically located in the downstream area of the confluence of several large rivers, including the Rea River and the Brang Ene River. This condition makes Taliwang City very vulnerable to flood disasters, considering that the existing river flow capacity is much smaller than the planned flood discharge. Major flood events were recorded in 2000 and 2007 with inundation heights of 2-3 meters, which resulted in the paralysis of urban activities, especially when the sea level was high. On the other hand, Taliwang District is also a potential agricultural area served by the Kalimantong I Irrigation Area with an irrigation area of more than 1,500 ha, but its current performance has decreased due to the limited water supply from the Brang Ene River, especially during the second and third planting seasons. Therefore, flood mitigation efforts are needed as well as improving irrigation performance through structural and non-structural approaches, especially with the construction of water storage systems such as reservoirs or dams that function as flood control as well as irrigation water supply and regulation facilities. The Topographic conditions around the reservoir are hilly areas with an altitude ranging from 45-950 m above sea level. The condition of the inundation area is in the form of hills with steep slopes and quite steep consisting of forest land.

The planning of this dam has technical data, as follows:

1. Type : Zonal Upright Core Stone
2. Elv Dam Peak : + 98.00 m
3. Elv Foundation Base : + 40.00 m
4. Dam Height : 58.00 m (from the foundation base)
5. Peak Length : 380.00 m
6. Peak Width : 12.00 m
7. Upstream Slope : 1 : 2.00

At the time of construction, it was necessary to redesign the Tiu Sto Dam maindam because the results of the advanced technical investigation showed that there was a significant difference between the initial design assumptions and the actual field conditions. Recent geological and geotechnical data identified lithological variations in the form of tufaan breccia, andesite intrusion, as well as the presence of discontinuity zones and certain levels of permeability that affect the carrying capacity and stability of the maindam foundation (Zhang, 2019; Putera et al., 2019). Analysis of slope stability under various loading conditions, including normal conditions, flood water levels, as well as Operating Base Earthquake (OBE) and Maximum Design Earthquake (MDE) earthquakes, shows the need to adjust the height and slope slope to meet the safety factors required in dam safety standards. In addition, the results of the hydrological evaluation showed that the planned flood discharge was larger than the discharge capacity in the initial design, so it was necessary to adjust the geometry of the dam body and its integration with the overflow system. The redesign is also supported by instrumentation data, the results of the test of the heap material, and the implementation of the embankment trial which indicates the need to optimize the zoning of materials and construction methods to ensure stability, waterproofing, and long-term performance of the dam in accordance with applicable technical and regulatory criteria (Satrio, 2024; Muhiddin, 2025).

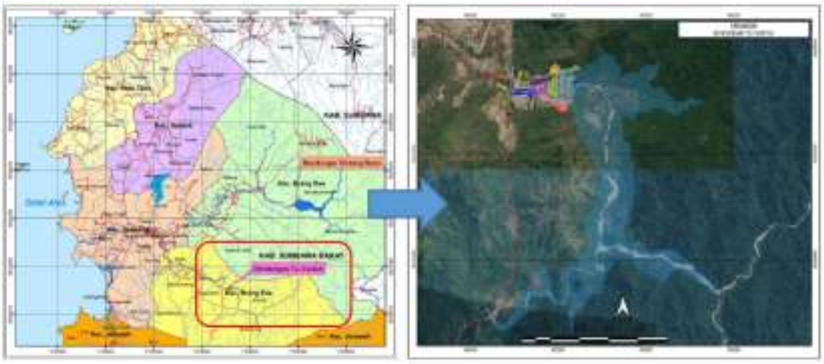

Figure 3 Condition of the Tiu Spara Dam Plan

B. Adjustment and Rationalization of Risk Variables

The initial stage of this study was to adjust and rationalize the risk variables of maindam redesign based on the activities carried out by the contractor in the implementation of dam work. This editing was carried out by several experts who have competence and experience in dam construction projects.

Table 1 Expert profile

No	Name	Departments	Education	Experience
1	Edden Umaga Dinata	Project Manager	S2	Geotechnics
2	Saefudin Zuhri, ST	Team Leader	S1 Civil Engineering	Civil Engineering / Water Resources
3	Nurul Syahid, ST	Dam Engineering Implementer	S2	Civil Engineering / Water Resources / Dams
4	And then there's the S.S. S.S., MT	Dam Planner PPK	S2	Dam planning management.
5	Yunanto Laksono	Engineer Grouting	S1	Ahli Grouting

Based on previous research on the implementation of dam work, risk is concentrated from 34 risk indicators consisting of a composition of 6 criteria, including technical aspects (12 variables), environmental aspects (6 variables), K3 aspects (3 variables), operational aspects (3 variables), and administrative & regulatory aspects (4 variables). These variables are then conducted in a Discussion Group Forum with experts to get a match based on the problem in this study. The results of the FGD obtained new variables which can be seen in the table below.

Table 2 Risk Variables for Main Dam Redesign

No	Variabel	Code	Indicator
1	Teknis	X1	Compatibility of Main dam's new design with actual slope conditions
		X2	Changes in the carrying capacity of the soil after the redesign
		X3	The need for new material specifications due to the new design
		X4	Elevation and slope geometry adjustment
		X5	Availability of materials for new designs
		X6	Equipment readiness for new working methods
		X7	Risk of slope instability after design modification
2	Environment	X8	Changes in Main dam's capacity due to redesign
		X9	Additional erosion potential due to new geometry
		X10	Changes in river flow patterns after redesign
		X11	Impact on local biodiversity
		X12	Risk of increased sedimentation
		X13	Potential pollution due to new construction methods
		X14	Potential social disruption due to design adjustments
3	Construction	X15	Construction delays due to design revisions
		X16	Increase in construction costs due to new design
		X17	Changes in machine needs
		X18	Need for material remobilization
		X19	Changes in project site access due to new design
4	K3	X20	Risk of accidents due to new working methods
		X21	Job risks on steeper slopes
		X22	Worker fatigue due to increased workload
		X23	K3 mitigation adjustments after redesign
5	Operational	X24	Decreased irrigation efficiency due to changes in geometry
		X25	Flood control system disruption
		X26	Adjustment of the raw water management system
6		X27	Changes in licensing and EIA documents due to redesign

Administrative & Regulatory	X28	Adjustment of land use permits
	X29	New technical approval requirements

The risk variables based on the adjustment results consist of 29 indicators which include technical aspects (7 variables), environmental aspects (7 variables), construction aspects (5 variables), K3 aspects (4 variables), operational aspects (3 variables), and Administration & Regulation aspects (3 variables). These new variables were then tested for validation and reality to find out that respondents had the same understanding.

1. Validity Test

The validity test aims to assess the validity or invalidity of the research instrument. In this validity test, a variable can be said to be valid if the value r of the table in the calculation is > of the r table. The r-value of the table is based on the number of study respondents. In this study, the number of respondents was 40 people with a table of r of 0.308.

Test Results:

a. If r counts > r table, then Ho is rejected. It means that it is valid
b. If r counts < r table, then Ho is accepted. It means that it is not valid

After the validity test was carried out, valid and invalid variable data were obtained. Then invalid data is set aside from the study and only valid variables are continued to be analyzed.

1) Technical Aspects

In the table below, the results of the variable validity test for the technical risk aspect will be presented.

Table 3 Validation of technical aspects categories

Code	Variable	Frequency		Impact	
		Coef. Correlation	Info.	Coef. Correlation	Info.
X1	Compatibility of Main dam's new design with actual slope conditions	0.338	Valid	0.406	Valid
X2	Changes in the carrying capacity of the soil after the redesign	0.324	Valid	0.417	Valid
X3	The need for new material specifications due to the new design	0.375	Valid	0.492	Valid
X4	Elevation and slope geometry adjustment	0.328	Valid	0.413	Valid
X5	Availability of materials for new designs	0.309	Valid	0.379	Valid
X6	Equipment readiness for new working methods	0.365	Valid	0.407	Valid
X7	Risk of slope instability after design modification	0.397	Valid	0.368	Valid

Based on the table above, it can be seen that all indicators of the technical risk category variables have a correlation coefficient value ≥ r table (=0.308) so that it can be said that all indicators are declared valid.

2) Environmental Aspects

In the table below, the results of the variable validity test for categories from environmental aspects will be explained

Table 4 Environmental Aspect Category Validation

Code	Variable	Frequency		Impact	
		Coef. Correlation	Info.	Coef. Correlation	Info.
X8	Changes in Main dam's capacity due to redesign	0.319	Valid	0.405	Valid
X9	Additional erosion potential due to new geometry	0.389	Valid	0.478	Valid
X10	Changes in river flow patterns after redesign	0.312	Valid	0.432	Valid
X11	Impact on local biodiversity	0.332	Valid	0.410	Valid
X12	Risk of increased sedimentation	0.323	Valid	0.447	Valid
X13	Potential pollution due to new construction methods	0.312	Valid	0.412	Valid
X14	Potential social disruption due to design adjustments	0.332	Valid	0.475	Valid

Based on the table above, it can be seen that all variable indicators of the environmental risk category have a correlation coefficient value of ≥ r table (=0.308).

3) Construction Aspects

In the table below, the results of the variable validity test for the category of the construction aspect will be explained

Table 5 Validation of Construction Aspects Category

Code	Variable	Frequency		Impact	
		Coef. Correlation	Info.	Coef. Correlation	Info.
X15	Construction delays due to design revisions	0.427	Valid	0.459	Valid
X16	Increase in construction costs due to new design	0.417	Valid	0.502	Valid
X17	Changes in machine needs	0.439	Valid	0.492	Valid
X18	Need for material remobilization	0.402	Valid	0.513	Valid
X19	Changes in project site access due to new design	0.471	Valid	0.595	Valid

Based on the table above, it can be seen that all variable indicators of the risk category are construction aspects. It has a correlation coefficient value ≥ r table (=0.308).

4) Aspects of Occupational Safety and Health (K3)

In the table below, the results of the variable validity test for the category of occupational safety and health (K3) aspects will be explained.

Table 6 Validation of the Category of Occupational Safety and Health Aspects (K3)

Code	Variable	Frequency		Impact	
		Coef. Correlation	Info.	Coef. Correlation	Info.
X20	Risk of accidents due to new working methods	0.318	Valid	0.455	Valid
X21	Job risks on steeper slopes	0.319	Valid	0.478	Valid
X22	Worker fatigue due to increased workload	0.389	Valid	0.432	Valid
X23	K3 mitigation adjustments after redesign	0.418	Valid	0.436	Valid

Based on the table above, it can be seen that all variable indicators of the risk category of occupational safety and health aspects have a correlation coefficient value of ≥ r table (=0.308).

5) Aspects

In the table below, the results of the variable validity test for the category of operational aspects will be explained

Table 7 Validation of Operational Aspects Category

Code	Variable	Frequency		Impact	
		Coef. Correlation	Info.	Coef. Correlation	Info.
X24	Decreased irrigation efficiency due to changes in geometry	0.402	Valid	0.419	Valid
X25	Flood control system disruption	0.489	Valid	0.589	Valid
X26	Adjustment of the raw water management system	0.421	Valid	0.518	Valid

Based on the table above, it can be seen that all variable indicators of the operational aspect risk category have a correlation coefficient value of ≥ r of the table (=0.308).

6) Administrative & Regulatory Aspects

In the table below, the results of the variable validity test for the category of Administrative & Regulation aspects will be explained.

Table 8 Validation of Administrative & Regulatory Aspects Category

Code	Variable	Frequency		Impact	
		Coef. Correlation	Info.	Coef. Correlation	Ket.
X27	Changes in licensing and EIA documents due to redesign	0.367	Valid	0.402	Valid
X28	Adjustment of land use permits	0.398	Valid	0.489	Valid
X29	New technical approval requirements	0.301	Invalid	0.421	Valid

Based on the results of the validity test in the Administrative and Regulatory aspects, the X29 indicator (Need for new technical approval) has a correlation coefficient value in the Frequency dimension of r = 0.301, which is smaller than the table r value of 0.308, so it is declared invalid in the frequency dimension. This shows that the X29 indicator does not fully represent the frequency level of risk events consistently against the frequency construct in the Administrative and Regulatory categories.

However, in the Impact dimension, the X29 indicator has a correlation coefficient value of r = 0.421, which is greater than the r of the table (0.308), so it is declared valid. This indicates that although the risk of needing new technical approvals does not occur frequently, when such risks arise can have a significant impact on project implementation, especially in terms of time, cost, and regulatory compliance.

Therefore, the X29 indicator is maintained in risk analysis, provided that the interpretation and use of this indicator is limited to the impact aspect, while the frequency aspect is used informatively and is not used as the main basis for drawing conclusions.

2. Reliability Test

The reliability test is intended to measure a questionnaire that is an indicator of a variable. Reliability is measured by Cronbach's alpha (α) statistical test. A variable is said to be reliable if it gives Cronbach's alpha value > 0.60. As for the measure of alpha stability according to Triton (2006):

a. Cronbach's Alpha value of 0.00 to 0.20 means less reliable
b. Cronbach's Alpha value of 0.21 to 0.40 means that it is somewhat reliable
c. Cronbach's Alpha value of 0.41 to 0.60 means that it is quite reliable
d. Cronbach's Alpha value of 0.61 to 0.80 means reliable
e. Cronbach's Alpha value of 0.81 to 1.00 means very reliable

Table 9 Reliability Test Recapitulation

No	Variabel	ralpha	Rkritis	Criteria
1	Technical Aspects	0.772	0.600	reliabel
2	Environmental Aspects	0.752	0.600	reliabel
3	Construction Aspects	0.764	0.600	reliabel
4	K3 Aspects	0.789	0.600	reliabel
5	Operational Aspects	0.784	0.600	reliabel
6	Administrative & Regulatory Aspects	0.793	0.600	reliabel

Remarks: declared reliable with the condition that ralpha > rcritical = 0.600 (Alpha Cronbach).

From the table above, the Alpha Cronbach value as in the table above is greater than the critical Alpha Cronbach value, which is 0.600, this indicates that the processed data is reliable.

B. Severity Index Calculation Results per Indicator

Each respondent was asked to provide an assessment of 29 risk indicators divided into six main variables: Technical, Environmental, Construction, K3, Operational, and Administrative. The assessment was carried out for two aspects:

1. Probability (P) of risk,
2. Impact (I) or the magnitude of the loss if the risk occurs. This value is then processed using the Severity Index (SI) formula:

$$\text{SI}(\%) = \frac{P \times I}{\text{maximum score}} \times 100$$

a. P = probability score (example: 1–5)
b. I = impact score (example: 1–5)
c. Maximum value = maximum probability score × maximum impact score (e.g. 5 × 5 = 25)
d. The SI results are then expressed in percentages of 0–100%, making it easier to compare between indicators.
e. The higher the SI, the greater the risk according to the respondents' perception.

Table 10 SI calculation results for each indicator

Variable	Code	Indicator	Severity Index (%)
Teknis	T1	Compatibility of Main dam's new design with actual slope conditions	90
	T2	Changes in the carrying capacity of the soil after the redesign	94
	T3	The need for new material specifications due to the new design	90

	Q4	Elevation and slope geometry adjustment	92
	Q5	Availability of materials for new designs	91
	T6	Equipment readiness for new working methods	86
	T7	Risk of slope instability after design modification	89
Environment	L1	Changes in Main dam's capacity due to redesign	75
	L2	Additional erosion potential due to new geometry	79
	L3	Changes in river flow patterns after redesign	81
	L4	Impact on local biodiversity	61
	L5	Risk of increased sedimentation	71
	L6	Potential pollution due to new construction methods	74
	L7	Potential social disruption due to design adjustments	72
Construction	K1	Construction delays due to design revisions	79
	K2	Increase in construction costs due to new design	65
	K3	Changes in machine needs	71
	K4	Need for material remobilization	71
K3	K3_1	Risk of accidents due to new working methods	70
	K3_2	Job risks on steeper slopes	80
	K3_3	Worker fatigue due to increased workload	70
Operational	O1	Decreased irrigation efficiency due to changes in geometry	59
	O2	Flood control system disruption	68
	O3	Adjustment of the raw water management system	81
Administrative	A1	Changes in licensing and EIA documents due to redesign	74
	A2	Adjustment of land use permits	75
	A3	New technical approval requirements	71

Based on Table 10, it can be seen that the indicators on the Technical variable dominate the highest SI values. The T2 indicator related to soil carrying capacity has a value of 94%, making it the indicator with the highest level of risk. This shows that respondents are very concerned about the ability of the subsoil to withstand additional loads due to changes in the geometry of the dam. If the bearing capacity of the soil is inadequate, the potential for deformation and instability of the structure will increase significantly.

Other technical indicators such as slope stability, slope material specifications, peak elevation, slope, and material availability and quality also have an SI value above 85%. This pattern shows that technical issues are the main source of risk in main dam redesign.

On the other hand, the indicator with the lowest SI value was O1 (59%) which was related to the decrease in the efficiency of irrigation functions. Although it is still included in the category of medium risk, this value shows that in the construction phase, respondents' attention is more focused on technical and environmental risks than on long-term operational risks. However, the O3 indicator (81%) signals that the adjustment of the post-construction raw water management system is still seen as quite critical.

C. Severity Index per Variable Recapitulation

To obtain a more aggregate picture of risk, the Severity Index value per indicator is then averaged for each variable. The results of the average recapitulation of SI per variable are presented in Table 11

Table 11 Average Severity Index

Variable	Severity Index Average (%)
Teknis	90,29
Environment	72,56
Construction	71,50
K3	73,33
Operational	69,33
Administrative	73,33

D. Analysis Per Variable

After recapitulating the average Severity Index for each variable, the next stage is to analyze more deeply the role of each variable in influencing the risk level of the project. This analysis is important to understand in detail the dominant factors that drive the high value of each variable, as well as identify areas that still need attention even though they are in the medium category.

The Technical variable showed the most outstanding results with an average of 90.29 percent, making it the variable with the highest level of risk in the study. Almost all technical indicators obtained a score above 85 percent, with T2 regarding the carrying capacity of the soil reaching 94 percent as the highest indicator.

Based on Table 12, the indicators on the Technical variable dominate the highest SI values:

Table 12 Summary of SI Technical Variable Calculation Results

Code	Indicator	IF (%)
T1	Compatibility of Main dam's new design with actual slope conditions	90
T2	Changes in the carrying capacity of the soil after the redesign	94
T3	The need for new material specifications due to the new design	90
T4	Elevation and slope geometry adjustment	92
Q5	Availability of materials for new designs	91
T6	Equipment readiness for new working methods	86
T7	Risk of slope instability after design modification	89

This value arises from a combination of high probability and large impact according to respondents' perceptions. For example:

T2 (soil carrying capacity): probability 5 (very likely) × impact 5 (very large)

SI = 100 × (25/25) = 100%, then adjusted the average respondent to 94%.

The main dam project involves changes in the geometry of the dam that increase the soil load, so that the potential for deformation and structural instability is the main concern. Other indicators such as slope stability, material quality, peak elevation, and slope obtained an SI of 86–92% because these technical risks were real in the field and had a direct impact on the integrity of the dam. Indicators in the Environment variable have a varied SI of 61–81%: for example, L3 related to local biodiversity reaches 81% because dam projects can disrupt the ecosystem around the site, while L4 (smaller risks such as temporary pollution) is only 61%. The Construction, K3, and Administrative variables have an average SI of 65–80%, reflecting moderate risks related to delays, work safety, or regulatory issues. Operational variables are relatively low (59–81%), but O3 on raw water management is still high (81%) because it has a major impact on post-construction functions.

Based on the description of each variable above, it can be concluded that technical risks are the main priority that must be anticipated immediately, while other variables such as environmental, K3, and administrative still require attention because even though the category is moderate, the impact can be significant if left unchecked. Operations and construction occupy lower positions on average, but contain critical indicators to watch out for. Thus, this analysis per variable provides a sharper picture of the risk priorities that must be used as a basis in the preparation of mitigation plans in the next stage.

E. Risk profile

Based on the results of the Severity Index processing, the risk profile of the main dam redesign project shows that most of the risks are concentrated in technical variables with an average value above 90 percent, followed by other variables in the medium category (70–75 percent), and only a few indicators in the low category (<65 percent). This distribution indicates that the project has a risk profile dominated by high risk, especially in technical aspects such as soil carrying capacity, material availability, and design quality. Meanwhile, environmental, K3, and administrative variables are in the category of medium risk, but still require attention because they are complex and can affect the smooth running of the project indirectly. The operational variables are relatively lower, but still display one very critical indicator (O3 with 81 percent).

Table 13 Indicator Operational Variables

Variable	Average SI (%)	Category Risk
Technical	90,29	High
Environment	72,56	Medium
Construction	71,50	Medium
K3	73,33	Medium
Operational	69,33	Medium (low-medium)
Administrative	73,33	Medium

Based on Table 13, it can be concluded that the risk profile of main dam redesign projects tends to be in the medium to high range, with the main concentration on technical variables. Environmental, construction, K3, and administrative variables are in the medium category, but still have the potential to have a significant impact if not controlled properly. The operational variable has the lowest average, but it is still classified as moderate because there is one indicator with a high risk value.

The risk profile can be described as follows:

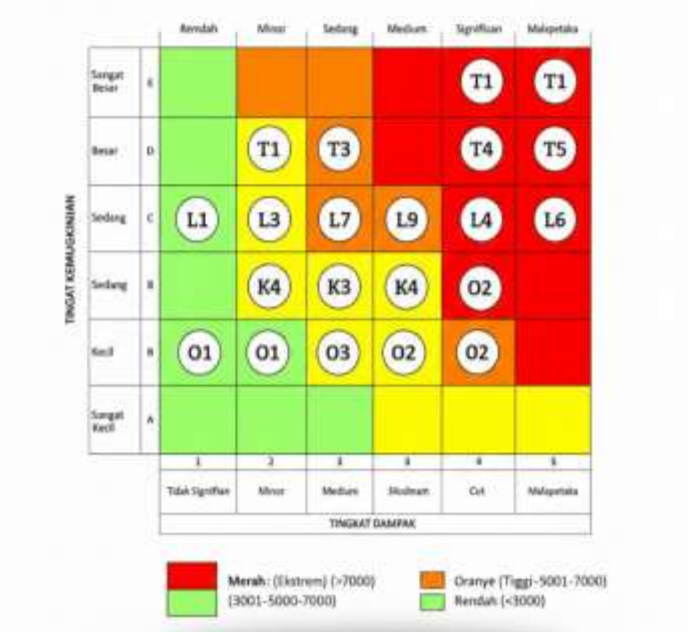

Figure 4 Risk Profile

F. Risk Matrix

The risk matrix is an analytical tool used to map the level of risk based on a combination of impact and likelihood. With this matrix, each risk can be categorized into low, medium, high, to extreme levels. The main goal is to simplify the risk prioritization process, so that handling can be focused on the risks that have the greatest urgency for the sustainability of the project.

In this study, the impact score was obtained from the results of the respondents' questionnaire on risk indicators on each variable, while the likelihood score was processed by calculating the likelihood of occurrence. The risk value is then determined through the multiplication between the impact and likelihood values, resulting in a quantitative score called the Risk Indicator.

The risk value (Risk Indicator) is calculated based on the combination of the level of likelihood of risk occurrence (Likelihood) and the level of risk impact (Severity) obtained from the results of the Severity Index. To obtain a numerical value that is more sensitive to the variation in respondents' assessments, the following formula is used:

$$\textbf{Risk Indicator} = \textbf{Likelihood} \times \textbf{Severity} \times \textbf{100}$$

The Likelihood and Severity values are the result of the conversion of the Severity Index into the Likert scale (1–5). A multiplier factor of 100 is used as a normalization factor to expand the range of risk values, so that the difference in risk levels between indicators can be seen more clearly in the risk matrix mapping process.

Based on this formula, the Risk Indicator value obtained is in the range of 100 to 2,500. However, in the practice of risk mapping in this study, the accumulation of risk values from several indicators in one variable can produce risk values on a scale of thousands. Therefore, the risk matrix categories are defined in the following value ranges: low, medium, and high risk. The score is then mapped into the risk matrix category with the following classification:

a. Low : 0 – 3000
b. Medium : 3001 – 5000
c. Height : 5001 – 7000
d. Extreme : > 7000

The results of the risk matrix mapping are shown in the following Table 14:

Table 14 Risk Matrix Mapping Results

Variable	Code	Indicator	Likelihood_ Indicators	Risk Indicator	Risk Category
Teknis	T1	Compatibility of Main dam's new design with actual slope conditions	92	8280	Extreme
	T2	Changes in the carrying capacity of the soil after the redesign	90	8460	Extreme
	T3	The need for new material specifications due to the new design	89	8010	Extreme
	T4	Elevation and slope geometry adjustment	88	8096	Extreme
	T5	Availability of materials for new designs	92	8372	Extreme
	T6	Equipment readiness for new working methods	94	8084	Extreme
	T7	Risk of slope instability after design modification	91	8099	Extreme
Environment	L1	Changes in Main dam's capacity due to redesign	67	5025	Medium
	L2	Additional erosion potential due to new geometry	68	5372	High
	L3	Changes in river flow patterns after redesign	71	5751	High
	L4	Impact on local biodiversity	68	4148	Medium
	L5	Risk of increased sedimentation	65	4615	Medium
	L6	Potential pollution due to new construction methods	68	5032	Medium
	L7	Potential social disruption due to design adjustments	72	5184	High
Construction	K1	Construction delays due to design revisions	72	5688	Height
	K2	Increase in construction costs due to new design	69	4485	Medium
	K3	Changes in machine needs	72	5112	Medium
	K4	Need for material remobilization	73	5183	High
K3	K3_1	Risk of accidents due to new working methods	50	3500	Medium
	K3_2	Job risks on steeper slopes	52	4160	Medium
	K3_3	Worker fatigue due to increased workload	49	3430	Medium
Operational	O1	Decreased irrigation efficiency due to changes in geometry	51	3009	Low
	O2	Flood control system disruption	50	3400	Medium
	O3	Adjustment of the raw water management system	51	4131	Medium
Administrative	A1	Changes in licensing and EIA documents due to redesign	49	3626	Medium
	A2	Adjustment of land use permits	51	3825	Medium
	A3	New technical approval requirements	52	3692	Medium

Based on the table, it can be seen that the Technical variable dominates the risk with the extreme category, which is indicated by the Risk Indicator score above 8000 in all technical indicators (T1–T7). This indicates that the technical aspects of the project require priority attention in risk mitigation, for example through more detailed technical planning, appropriate material selection, and strict field supervision.

Meanwhile, the risks in the Environment and Construction variables are mostly in the high and medium categories, indicating that external factors such as ecosystem conditions, erosion, and material mobilization are still quite influential. The risks in the K3, Operational, and Administrative variables are mostly in the medium to low category, so although they still need to be mitigated, the level of urgency is relatively lower than technical risks.

Thus, the results of this risk matrix analysis show that project risk management must be prioritized on technical and environmental aspects, because these two variables contribute to the highest risk score and have the potential to hinder the success of project implementation if not handled adequately. The risk matrix can be described as follows:

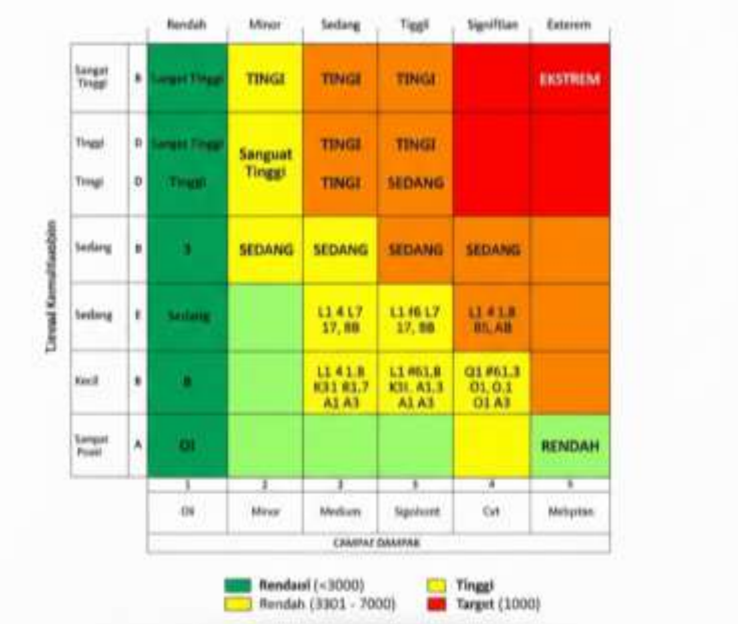

Figure 5 Risk Analysis Matrix

CONCLUSION

Based on the results of the Severity Index analysis and risk matrix mapping, it was found that the highest risk in the redesign of the Tiu Spara Dam main dam came from technical aspects, especially changes in soil carrying capacity, material availability, and design suitability with actual slope conditions, all of which are in the category of extreme risks and have great potential for dam stability and safety. These findings affirm the importance of prioritizing risk control through strengthening technical investigations, design adjustments, implementing appropriate construction methods, and improving quality control and K3. Therefore, contractors, owners, and regulators need to implement integrated risk management from the planning stage to operation, along with cross-stakeholder coordination and compliance with dam safety standards, while further research is recommended to develop a more comprehensive risk analysis approach that covers the entire life cycle of dams to improve the reliability and sustainability of water resource infrastructure.

REFERENCES

Adi, R. (2023). Analisis Risiko Keselamatan Kerja pada Proyek Konstruksi di Indonesia. Jakarta: Penerbit Teknik Konstruksi.

Alkhawaja, A., & Varouqa, A. (2023). Risk management in large construction projects: A systematic approach. *International Journal of Construction Management, 23*(2), 145–158.

Hermawan, R., & Susanto, D. (2022). Analisis risiko geoteknik pada proyek bendungan urugan. *Jurnal Sumber Daya Air, 18*(3), 201–212.

Marwanto, B., & Widodo, T. (2023). Pengaruh perubahan desain terhadap kinerja proyek bendungan. *Jurnal Manajemen Konstruksi, 12*(1), 33–44.

Misra, S. (2020). *Risk Management in Construction Projects*. New Delhi: McGraw-Hill Education.

Muhiddin, A. (2025). Analisis risiko operasional pada infrastruktur sumber daya air. *Jurnal Teknik Pengairan, 21*(1), 1–12.

Nirwono, J., & Soetomo, S. (2020). Bendungan dan ketahanan air wilayah kering Indonesia. *Jurnal Perencanaan Wilayah, 15*(2), 101–112.

Pamungkas, R., Hidayat, M., & Santoso, B. (2023). Penilaian risiko keamanan bendungan berbasis regulasi nasional. *Jurnal Infrastruktur, 11*(1), 19–30.

Putera, R., Hadi, S., & Yansen, R. (2019). Identifikasi risiko teknis pada proyek bendungan urugan. *Jurnal Rekayasa Sipil, 9*(2), 75–86.

Rahman, F. (2024). Dampak perubahan desain terhadap risiko konstruksi proyek bendungan. *Jurnal Teknik Sipil Terapan, 14*(1), 55–66.

Satrio, A. (2024). Penilaian risiko keamanan bendungan menggunakan metode Andersen pada Bendungan Haekrit. *Jurnal Teknik Sumber Daya Air, 10*(1), 41–52.

Septianugraha, D., Prabowo, A., & Lestari, S. (2024). Analisis manajemen risiko konstruksi pada proyek bendungan berdasarkan konsep ISO 31000:2018. *Jurnal Teknik Sipil, 31*(1), 1–14.

Sriharyati, L., Putri, D., & Anwar, R. (2024). Analisis manajemen risiko rencana pembangunan Bendungan Pelosika Kabupaten Konawe. *Jurnal Teknik Sipil dan Lingkungan, 19*(2), 120–132.

Sugiyono. (2013). *Metode Penelitian Kuantitatif, Kualitatif, dan R&D*. Bandung: Alfabeta.

Sugiyono. (2020). *Metode Penelitian Kuantitatif*. Bandung: Alfabeta.

Sutrisno, E. (2023). Analisis risiko cuaca ekstrem pada proyek bendungan. *Jurnal Klimatologi Terapan, 7*(1), 45–56.

Terfiana, A., Malik, R., & Hasan, F. (2024). Manajemen risiko keamanan, keselamatan, kesehatan, dan keberlanjutan kerja (K4) pada proyek jalan. *Jurnal Konstruksi, 16*(2), 88–99.

Tinambunan, R. (2024). Manajemen risiko dalam proyek konstruksi: Evaluasi dan pengembangan model. *Jurnal Manajemen Proyek, 8*(1), 1–15.

Wibowo, H. (2023). Analisis kegagalan material pada konstruksi bendungan. *Jurnal Material Konstruksi, 5*(2), 60–70.

Yoyo, A., Kurniawan, D., & Prasetyo, H. (2023). Analisis risiko pelaksanaan pembangunan Jembatan Waborobo – Batu Popi Kota Bau-Bau. *Jurnal Teknik Sipil, 29*(3), 211–223.

Yuliana, S. (2017). Risiko keselamatan kerja pada proyek konstruksi besar. *Jurnal Keselamatan Konstruksi, 4*(1), 12–22.

Zhang, L. (2019). *Hydraulic Structures and Dam Engineering*. Beijing: China Water Power Press.