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The Relationship Between Risk Factors in Dam Maintenance Work and Dam Maintenance Performance

Abby Dermawan Atlan[1*], Yusuf Latief[2], Toha Saleh[3], Naufal Budi Laksono[4]
Universitas Indonesia, Indonesia
Email: abby.dermawan@ui.ac.id

ABSTRACT

Dam maintenance is a crucial aspect of water infrastructure management to ensure its continued functionality in flood control, clean water supply, and irrigation. A number of dam failures, such as those at Situ Gintung and Cisadane Dam, demonstrate the importance of a risk-based maintenance strategy to reduce the impact of dam failures on society and the environment. This study aims to analyze the relationship between risk factors in dam maintenance work and the resulting maintenance performance. This study uses a mixed-method approach, with archive analysis to identify the main risk factors in five aspects (working methods, labor, equipment, materials, and the environment) as well as a survey of 30 professionals in the field of dam maintenance to evaluate their frequency and impact. Data analysis was carried out through Kendall Tau correlation test, factor analysis, linear regression, and multicollinearity test to determine the significant influence of risk factors on maintenance performance. The results showed that of the 38 risk variables identified, 31 were categorized as high risk, with 19 main categories having a significant impact on dam maintenance. The most influential risk factors are work method errors, labor limitations, and environmental factors such as sedimentation and erosion. Regression analysis shows that these risk factors explain 53.9% of the variability in dam maintenance performance. The implications of this study emphasize the need for the implementation of data-based risk mitigation systems, increased supervision, and strengthening of labor capacity to ensure the effectiveness of dam maintenance on an ongoing basis.

Keywords: Dam Maintenance, Infrastructure Management, Risk, Statistical Analysis.

INTRODUCTION

Water infrastructure plays a crucial role in sustainable development and disaster risk reduction globally (Rahma, 2018). With climate change intensifying extreme weather events, the resilience and maintenance of water infrastructure, including dams, have become increasingly critical (Alfin et al., 2022). Many countries face challenges in ensuring dam safety due to aging infrastructure, inadequate maintenance, and evolving environmental risks. Addressing these issues is essential to prevent catastrophic failures that could lead to loss of life, economic disruption, and environmental degradation (Perera et al., 2021). In the Indonesian context, the government has undertaken extensive dam development projects to enhance water resource management and energy production, necessitating a strong focus on dam maintenance and risk management (Jaya et al., 2024).

Based on data from the Ministry of Public Works and Housing (PUPR), the number of dams in Indonesia currently exceeds 213 large dams, 182 of which are owned by the Ministry of PUPR. Through the Ministry of PUPR, the government is completing the construction of 61 new dams during the 2014–2024 period across various regions in Indonesia (Malik Sadat Idris et al., 2019). By 2021, 29 dams had been completed, while 32 were still under construction.

Adding new dams ready for operation will inevitably bring maintenance responsibilities to these dams. The risk of dam failure can occur and potentially result in property and life losses if all aspects of dam maintenance are not adequately managed (Augusto et al., 2020). The potential for dam failure is not only caused by natural disasters. However, it can also result from various factors, including the deteriorating physical condition of the dam, internal damage, non-functional infrastructure, sedimentation issues, and other factors affecting dam management (Rosytha & Suryana, 2023). Aside from extraordinary natural events, dam failures can also be attributed to structural deterioration, internal damage, non-functional infrastructure, sedimentation issues, and management-related challenges.

One notable case of dam failure occurred on March 27, 2009, at Situ Gintung Dam in South Tangerang. The collapse of Situ Gintung Dam caused hundreds of residential homes to be damaged and resulted in the loss of 100 lives. The cause of this collapse, based on slope stability analysis, revealed that the dam's safety factor was below the standard safety factor (1.19 < 1.5). This indicated weakened dam conditions, such as erosion, scouring, and cracks (Nabilah et al., 2020). Another case occurred in 2023 at the Cisadane River Dam, where damage to the dam's floodgate disrupted the clean water supply in Tangerang City. The deteriorating structural condition of the dams caused both cases. The underlying causes of these cases were the lack of a comprehensive strategy for dam maintenance planning and the identification of potential risk factors impacting dam maintenance performance.

This study offers a novel approach by integrating risk assessment methodologies with maintenance performance evaluation, providing a comprehensive framework for proactive dam management. Unlike previous studies that primarily focus on structural integrity or hydrological impacts in isolation, this research incorporates a multi-dimensional risk analysis to identify critical vulnerabilities in dam maintenance. By leveraging advanced data-driven techniques, this study aims to bridge the gap between theoretical risk assessment and practical maintenance strategies, ensuring a more resilient and sustainable dam management system.

Based on the above background, the purpose of this study is to analyze the relationship between dam maintenance risk factors and dam maintenance performance. The risk factors used in this study are high-level risks based on data analysis. So that the benefits in this study are to provide insights into effective dam maintenance strategies and enhance dam management practices to ensure long-term structural integrity and operational reliability. This study aims to identify and evaluate key risk factors that influence dam maintenance performance, allowing for the development of mitigation measures to address potential threats proactively. By examining the correlation between these risk factors and maintenance performance, the study seeks to contribute to more efficient resource allocation and improved decision-making in dam management.

Furthermore, the findings of this research are expected to serve as a reference for policymakers, engineers, and maintenance teams involved in dam management. The study also aims to emphasize the importance of adopting a risk-based approach to dam maintenance, enabling stakeholders to prioritize high-risk areas and allocate resources effectively. In the broader context, this research aims to support the government's efforts in maintaining the safety and sustainability of critical water infrastructure, ultimately reducing the likelihood of catastrophic dam failures and safeguarding communities and ecosystems downstream.

RESEARCH METHOD

This study uses a mixed-method approach, which combines archive analysis and surveys as the main strategy. Based on Yin (2003) classification, there are five main research strategies, namely experiments, surveys, archive analysis, history, and case studies. In this study, archival analysis was used to identify risk factors in dam maintenance work by categorizing them into five main aspects, namely work methods, workers, equipment, materials, and the environment or public facilities. The identified risk factors were then validated by experts using the Delphi Method to ensure their relevance to maintenance performance.

After the validation process, the research continued with a survey involving 30 respondents, consisting of professionals in the field of dam maintenance, such as engineers, technicians, project managers, and safety officers. This survey aims to measure the frequency and impact of each previously identified risk factor. The data obtained will be analyzed using the risk matrix framework of the 6th edition of PMBOK, which will help categorize the level of risk into low, medium, and high. Risks that fall into the high category will be analyzed further to understand the relationship between these risk factors and maintenance performance.

The data analysis in this study was carried out using a quantitative and qualitative approach. Qualitative analysis was used to categorize risks based on expert validation results, while quantitative analysis was carried out by applying various statistical techniques. Correlation tests were used to identify the relationship between risk factors and maintenance performance, while factor analysis was used to find patterns of relationships between risk variables. In addition, this study also applies regression analysis, t-test, Durbin-Watson test, and multicollinearity test to ensure the validity and reliability of the resulting model. With this approach, the study aims to identify the most significant risk factors that affect dam maintenance performance and provide more effective mitigation recommendations.

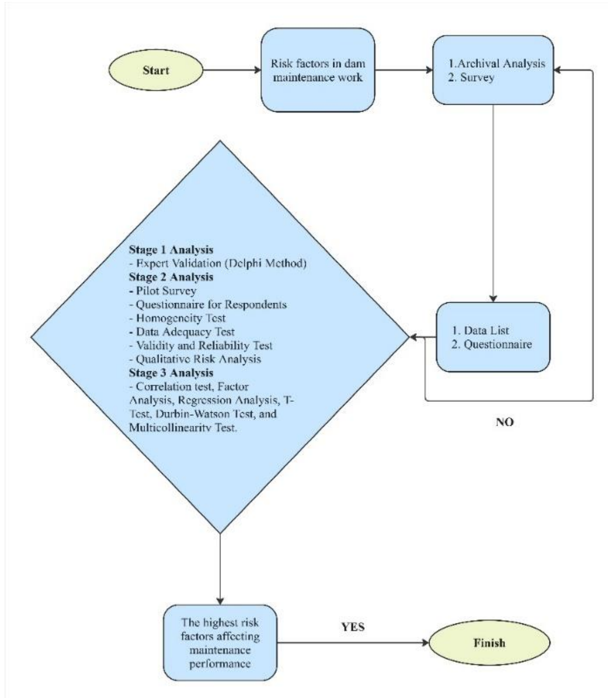


Figure 1. Research Flow Diagram

Source: Data Processed, 2024

RESULT AND DISCUSSION

Risk Identification

Based on archival analysis and expert validation, 38 risk variables influencing dam maintenance performance were identified.

Table 1. Risk Variables

Activities	Hazard Type	Hazard Description	Risk Type	Code	Risk Description
Routine maintenance	Method	Work standard inadequate	Method	X.1	Execution of work method does not follow the plan
			Method	X.2	Work cannot be applied as planned and is hazardous
	Worker	Inexperienced workers	Worker	X.3	Operational procedure mistakes made by workers
			Worker	X.4	Worker injured during work
			Worker	X.5	Work results pose a safety hazard

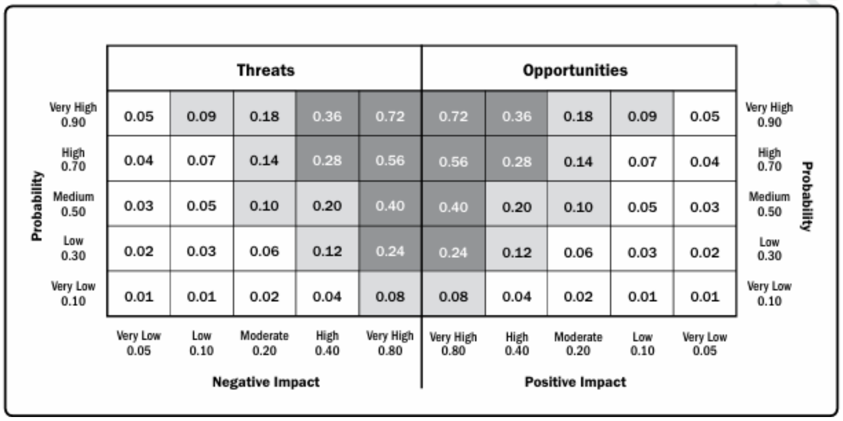
Activities	Hazard Type	Hazard Description	Risk Type	Code	Risk Description
	Worker	Insufficient supervision	Public	X.6	Vandalism
	Equipment	Failure to account for equipment availability during project execution	Equipment	X.7	Insufficient availability of equipment
	Material	Material volume delivered is not as expected	Material	X.8	Insufficient material on-site
	Environment	Accumulation of waste and debris	Environment	X.9	Environmental pollution
	Environment	Sedimentation	Environment	X.10	Reduced dam capacity
Periodic maintenance	Method	Work standard inadequate	Method	X.11	Execution of work method does not follow the plan
			Method	X.12	Work cannot be applied as planned and is hazardous
	Worker	Pekerja yang tidak berpengalaman	Worker	X.13	Operational procedure mistakes made by workers
			Worker	X.14	Worker injured during work
			Worker	X.15	Work results pose a safety hazard
	Worker	Insufficient supervision	Public	X.16	Vandalism
	Equipment	Equipment falls from height	Equipment	X.17	Equipment damage
	Material	Failure to schedule material availability	Material	X.18	Late material delivery
	Environment	Accumulation of waste and debris	Environment	X.19	Environmental pollution
	Environment	Sedimentation	Environment	X.20	Reduced dam capacity
Repair work	Method	Work standard inadequate	Method	X.21	Execution of work method does not follow the plan
	Worker	Mistakes in structural repair methods	Worker	X.22	Work results pose a safety hazard
	Worker	Material falling during movement	Worker	X.23	Worker injuries

Activities	Hazard Type	Hazard Description	Risk Type	Code	Risk Description
			Worker	X.24	Fatalities
	Equipment	Equipment not meeting specifications	Peralatan	X.25	Equipment not optimal, lowering quality
	Environment	Erosion at the dam	Environment	X.26	Property damage leading to collapse
Strengthening work	Method	Mistakes in planning work method analysis	Method	X.27	Work method errors
	Worker	Lack of understanding of failure causes	Worker	X.28	Work results pose a safety hazard
	Equipment	Equipment not meeting specifications	Equipment	X.29	Equipment not optimal, lowering quality
	Material	Material does not meet specifications	Material	X.30	Increased work costs
	Environment	Flooding and runoff at the dam	Environment	X.31	Damage to public facilities/buildings
	Environment	Natural disasters	Environment	X.32	Property damage leading to collapse
Rehabilitation	Method	Mistakes in planning work method analysis	Method	X.33	Work method errors
	Worker	Mistakes in demolition methods	Worker	X.34	Work results pose a safety hazard
	Equipment	Equipment not meeting specifications	Equipment	X.35	Equipment not optimal, lowering quality
	Material	Changes in specifications and material typesl	Material	X.36	Increased work costs
	Environment	Flooding and runoff at the dam	Environment	X.37	Damage to public facilities/buildings
	Environment	Natural disasters	Environment	X.38	Property damage leading to collapse

Source: Data Processed, 2024

Qualitative Risk Analysis

Risk analysis is conducted to determine the risk factor value by multiplying the risk's frequency value with the risk's impact value for each risk factor, resulting in a risk ranking. The risk analysis uses the probability and impact matrix guideline according to PMBOK 6th edition.



Probability	Threats					Opportunities					Probability
Very High 0.90	0.05	0.09	0.18	0.36	0.72	0.72	0.36	0.18	0.09	0.05	Very High 0.90
High 0.70	0.04	0.07	0.14	0.28	0.56	0.56	0.28	0.14	0.07	0.04	High 0.70
Medium 0.50	0.03	0.05	0.10	0.20	0.40	0.40	0.20	0.10	0.05	0.03	Medium 0.50
Low 0.30	0.02	0.03	0.06	0.12	0.24	0.24	0.12	0.06	0.03	0.02	Low 0.30
Very Low 0.10	0.01	0.01	0.02	0.04	0.08	0.08	0.04	0.02	0.01	0.01	Very Low 0.10
	Very Low 0.05	Low 0.10	Moderate 0.20	High 0.40	Very High 0.80	Very High 0.80	High 0.40	Moderate 0.20	Low 0.10	Very Low 0.05	
	Negative Impact					Positive Impact					

Figure 1. Probability and Impact Matrix

Source: Project Management Institute, 2017

Based on Figure 1, the risk levels can be defined as follows:

a. Low risk with a risk value of 0.01 – 0.07

b. Medium risk with a risk value of 0.08 – 0.20

c. High risk with a risk value of 0.21 – 0.72

Based on the qualitative risk analysis, 31 of the 38 variables found in routine maintenance, periodic maintenance, repair work, reinforcement work, and rehabilitation activities were identified as high risk. Next, the descriptions of similar hazards and risks were clustered, resulting in 19 high-risk categories.

Table 2 High-Risk Categories

Risk Code	Risk Type	Variable	Risk Description	Score	Category
R1	Environment	X.31 X.37	Damage to public facilities/buildings	0.30	High
R2	Workers	X.4 X.14	Worker injured during work	0.30	High
R3	Environment	X.10 X.20	Reduced dam capacity	0.28	High
R4	Methods	X.1 X.11 X.21	Execution of work method does not follow the plan	0.28	High

Risk Code	Risk Type	Variable	Risk Description	Score	Category
R5	Workers	X.3 X.13	Operational procedure mistakes made by workers	0.27	High
R6	Environment	X.26	Property damage leading to collapse	0.27	High
R7	Workers	X.5 X.15	Work results pose a safety hazard	0.27	High
R8	Environment	X.9 X.19	Environmental pollution	0.26	High
R9	Environment	X.32 X.38	Property damage leading to collapse	0.26	High
R10	Materials	X.8	Insufficient material on-site	0.26	High
R11	Methods	X.27 X.33	Work method errors	0.26	High
R12	Equipment	X.17	Equipment damage	0.26	High
R13	Materials	X.18	Late material delivery	0.25	High
R14	Workers	X.34	Work results pose a safety hazard	0.24	High
R15	Workers	X.24	Fatalities	0.23	High
R16	Methods	X.2 X.12	Work cannot be applied as planned and is hazardous	0.23	High
R17	Public	X.6 X.16	Vandalism	0.22	High
R18	Workers	X.22	Work results pose a safety hazard	0.22	High
R19	Workers	X.23	Worker injuries	0.21	High

Source: Data Processed, 2024

Analysis of the Relationship Between Risks and Dam Maintenance Performance

Correlation Test

Correlation analysis was conducted to determine the relationship between the independent variable (X), the risk, and the dependent variable (Y), the dam maintenance performance. The correlation test used is the Kendall Tau correlation test, which is a non-parametric correlation test. The decision-making process follows these steps:

a. The correlation coefficient is compared with the r table value (correlation table). If the correlation coefficient > r table, there is a significant correlation (Ha is accepted). If the correlation coefficient < r table, then there is no significant correlation (H0 is accepted).

b. The significance level in this study is 0.05%, so the r table value is 0.361.
c. At the significance level, if the Sig. Value < 0.05, there is a significant correlation (Ha is accepted). If the Sig. There is no significant correlation for a value> 0.05 (Ho is accepted).
d. Accepted Ha is marked with a star (** or *). Table 3 shows the results of the correlation test between variables X and Y.

Table 3. Correlation Test

Risk Code	Correlation Coefficient	Sig. (2-tailed)
R1	.569**	0.000
R2	.368*	0.019
R4	.386*	0.013
R6	.490**	0.001
R7	.438**	0.005
R8	.505**	0.001
R9	.592**	0.000
R11	.390*	0.011
R14	.411**	0.008
R15	.435**	0.005
R16	.399*	0.013
R19	.423**	0.006

Source: Data Processed, 2024

Factor Analysis

The central aspect of conducting factor analysis is determining the Kaiser-Meyer-Olkin Measure (KMO) value and the significance (sig.) value. The requirements before proceeding with factor analysis are that the KMO value should be > 0.5, and the significance value should be < 0.5. The results of the KMO and Bartlett's test can be seen in Table 4.

Table 4. KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.754
Bartlett's Test of Sphericity	**Approx. Chi-Square**	624.778
	df	171
	Sig.	0.000

Source: Data Processed, 2024

Based on the KMO and Bartlett's test results, 0.754 > 0.5 and a significance value of 0.000 < 0.05 were obtained, indicating that variables X and Y have sufficient data and can proceed to factor analysis. Subsequently, factor analysis was performed to group them into new components.

Table 5. Component Matrix (Factors X)

	Component
	1
R1	0.839

	Component
	1
R2	0.855
R4	0.824
R6	0.859
R7	0.819
R8	0.796
R9	0.810
R11	0.901
R14	0.840
R15	0.780
R16	0.873
R19	0.766

Source: Data Processed, 2024

Regression Analysis

Table 6 shows the model summary of variables X and Y obtained from the regression analysis using SPSS software.

Table 6. Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.745[a]	0.555	0.539	0.643	2.249

Source: Data Processed, 2024

Based on the results in the table above, the adjusted R^2 value represents the confidence level of the model, which is obtained at 0.539. The adjusted R^2 value of 0.539 exceeds the required threshold for further regression analysis, which is 0.5. This indicates that 53.9% of dam maintenance performance can be explained by the factors (X), while other causes outside the model explain the remaining 46.1%. The following is the ANOVA result from the regression analysis of variables X and Y.

Table 7. ANOVA Result

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	14.430	1	14.430	34.923	.000[b]
	Residual	11.570	28	0.413		
	Total	26.000	29			

Source: Data Processed, 2024

The table above shows the significance value of the influence of the independent variable (X) on the dependent variable (Y). Based on the table, a significance value of 0.000 < 0.05 is obtained, indicating that the factor (X) is valid as an input in the regression analysis as it affects the performance of dam maintenance. Below are the coefficient values from the regression analysis of variables X and Y.

Table 8 Coefficient Values

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	4.000	0.117		34.083	0.000
	REGR factor score 1 for analysis 1	0.705	0.119	0.745	5.910	0.000

Multicollinearity Test

A regression model should have low or no correlation between independent variables, indicating no multicollinearity. The multicollinearity test examines the collinearity statistics, which consist of the tolerance value and the variance inflation factor (VIF). The criteria are as follows:

a. The tolerance value should be between 0.0 and 1.
b. VIF value should be less than 10.

The results of the multicollinearity test can be seen in Table 9.

Table 9. Multicollinearity Test

Model		Collinearity Statistics	
		Tolerance	VIF
1	REGR factor score 1 for analysis 1	1.000	1.000

Source: Data Processed, 2024

Based on Table 9, the tolerance value is 1.000, which meets the criteria of being between 0.0 and 1. The variance inflation factor (VIF) is 1, less than 10. This indicates that the regression model does not experience multicollinearity and is acceptable.

Discussion

This study identified 38 risk variables that affect dam maintenance performance through archival analysis and expert validation. These findings are in line with research conducted by (Juwono & Subagiyo, 2018), which states that infrastructure maintenance work, especially dams, has a high risk due to substandard work methods, limited experienced labor, and environmental factors such as sedimentation and pollution. A qualitative analysis using the PMBOK 6th edition risk matrix framework shows that 31 of the 38 risk variables are categorized as high risk, with the main classifications covering work methods, workers, equipment, materials, and the environment. This is reinforced by research (Fadilah, 2023), which found that failures in work methods and lack of labor supervision are the main risk factors that can cause work accidents and reduce the effectiveness of dam maintenance.

Furthermore, the Kendall Tau correlation test shows that several risk factors have a significant relationship with dam maintenance performance, especially those related to the environment and workers. These results are in line with the findings of the study (Qi et al., 2020), which states that environmental factors such as sedimentation and pollution can reduce dam capacity and accelerate infrastructure degradation. In addition, inexperienced workers and lack of supervision can increase the potential for procedural errors, as also found in research (Latorella & Prabhu, 2017), which shows that errors in work procedures have a direct impact on the safety and efficiency of public facility maintenance. Further analysis factors show that the main risk factors that most affect dam maintenance performance include equipment damage, errors in work methods, and risks posed by natural disasters and floods, which is also supported by a study (Smith et al., 2014) that highlights the importance of risk mitigation in large infrastructure projects.

Regression analysis produces an Adjusted R^2 value of 0.539, which indicates that 53.9% of the variability in dam maintenance performance can be explained by the identified risk factors. These results reinforce the theory of risk management in infrastructure maintenance proposed by (Yudhaningsih et al., 2022), which emphasizes that risks in civil engineering projects can be controlled with systematic risk factor analysis and the application of data-based mitigation strategies. In addition, the multicollinearity test shows that there is no high correlation between the independent variables, so the regression model used can be considered valid and reliable in evaluating the effect of risk on dam maintenance performance. Taking into account the results of this study, it is important for dam managers to implement a data-based risk mitigation system and increase worker capacity through more comprehensive training to reduce the impact of risk on dam infrastructure.

CONCLUSION

The relationship between risks namely works methods, workers, materials, equipment, and environment/public and maintenance performance has been analysed using a series of statistical tests. The correlation test demonstrated a significant correlation between risks and maintenance performance. Based on the correlation test results, 12 high-risk factors were found to have a significant correlation with maintenance performance. Through the t-test, the relationship between risks and maintenance performance yielded H1 being accepted, indicating that risks significantly influence maintenance performance. Regression analysis further confirmed that the regression equation indicates the influence of risks on maintenance performance. Based on the findings from the statistical analysis, the research hypothesis is proven maintenance work risks significantly affect dam maintenance performance. This research can assist dam managers in identifying risks that may affect dam maintenance performance. It also serves as a reference for dam managers in developing operational and maintenance guidelines.

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