

A Model of the Relationship Between Policy, Organizational Structure, and Risk-Based Financing Patterns to Improve Dam Maintenance Performance

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ABSTRACT

Dams are critical infrastructure that play a vital role in water resource management, flood control, and water supply for irrigation and domestic needs. However, dam maintenance in Indonesia still faces major challenges, mainly due to less adaptive policies, suboptimal organizational structures, and unsustainable financing patterns. This study aims to analyze the relationship between policy (X1), organizational structure (X2), and risk-based financing patterns (X3) in improving dam maintenance performance (Y). The research methods included a literature study, a survey of 75 respondents, and statistical analysis using multiple regression. The results showed that the three variables had a positive and significant effect on maintenance performance, with policy as the most dominant factor (coefficient of 0.487), followed by organizational structure (0.203) and financing pattern (0.114). These findings indicate that a risk-based approach can improve the effectiveness of maintenance through adaptive policies, clear organizational coordination, and appropriate financing strategies. The implications of the study emphasize the need to improve policies, strengthen organizational structures, and develop sustainable financing patterns to support more optimal dam maintenance performance in the future.

Keywords: Dam, Maintenance, Policy, Organizational Structure, Financing Pattern, Risk.

INTRODUCTION

Dams have long been recognized as one of the critical infrastructures that support the sustainable management of water resources. Their diverse functions, ranging from flood control and water supply for irrigation and domestic consumption to serving as an energy source through hydroelectric power, make them a vital component in economic and social development (Ngo et al., 2023; Tadese et al., 2020; Tanksali & Soraganvi, 2021). In recent decades, the need for dams has increased as population growth and climate change have led to erratic rainfall patterns (Smith & Brown, 2019). However, the construction of dams also poses various challenges, both from technical and social perspectives. For example, the ecological impacts resulting from changes in river flows are often a crucial issue that needs to be managed properly to maintain the

sustainability of local ecosystems (Johnson et al., 2021). In addition, social challenges such as population relocation and changing livelihoods often arise in dam construction projects, which require a participatory and inclusive approach in their planning (Lee & Kim, 2022).

Although dams provide many benefits, the phenomenon of dam damage has become a major concern in various parts of the world. Damage to dams can be caused by a variety of factors, including lack of maintenance, inadequate building materials, climate change that causes extreme weather phenomena, as well as the age of infrastructure that has exceeded design limits (Alvarez et al., 2021). A clear example of dam damage that has had a major impact is the incident that occurred at the *Brumadinho Dam*, Brazil, in 2019, which resulted in thousands of fatalities and enormous economic losses (Santos & Pereira, 2020). Climate change plays a significant role in worsening the condition of dams. Increased frequency and intensity of rainfall, extreme flooding, and drastic temperature fluctuations can cause tremendous stress on dam structures. Research by Brown and Taylor (2022) shows that some old dams that were not designed to withstand today's extreme climatic conditions are at a higher risk of being damaged or even completely failing.

In addition, the age factor cannot be ignored. Many of the world's dams today were built more than 50 years ago and have exceeded their expected lifespan. This aging process, if not accompanied by proper maintenance and rejuvenation programs, can lead to significant structural degradation, increasing the risk of damage that could harm the surrounding communities (Nguyen et al., 2023). Damaged or failed dams not only cause great material losses but also have a serious impact on the environment and people's lives. Damage to dams can result in flash floods that destroy settlements, agricultural land, and other infrastructure. In addition, disturbed river ecosystems and surrounding areas can cause ecological losses that are difficult to recover (Jackson & Lee, 2021).

Based on the literature study conducted on previous research, the classification of the causes of dam damage is as follows: *Secretary Factors* (Obead, I. H.; Fattah, M. Y. 2022), *Structural Failure Factors* (Duffaut, P.; Larouzeé, J. 2019; Margaret Armstrong et al., 2019; Tahmina Tasnim Nahar et al., 2024; Bin Xu et al., 2024; Nour Chahrour et al., 2024), *Slope Deformation Factors* (Dwitya, R.; Pratomo, A. H.; Cahyadi, T. A. 2024), *Environmental and Geological Factors* (Duffaut, P.; Larouzeé, J. 2019; Qian Yong et al., 2019), *Technological Factors* (Quader, M. T. U.; Kabir, G. 2024; Zhuo Rong et al., 2024), *Operational and Maintenance Factors* (Lane, N. 2008; Marini Bravikawatia et al., 2022; Anna Rosytha, Wiel Mushawiry Suryana, 2023; Ayodele Salami Lawal et al., 2023), and *Risk Management Factors* (André Carlos Silva et al., 2023).

Table 1. Dams – Damaged Dams

Dam	Country	Causes of Damage	Reference Source
Brumadinho Dam	Brazil	Structural failure due to inadequate materials and lack of maintenance	Santos & Pereira (2020)

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Edenville Dam	United States	Overtopping and structural failure due to changes in water flow	Landers (2022)
Bangiao Dam	Chinese	Overtopping due to extreme rainfall that exceeds the design capacity	ASDSO (2022)
Fukushima Fujinuma Dam	Japan	Failure due to a strong earthquake	ASDSO (2022)
St. Francis Dam	United States	Foundation failure and inadequate design	ASDSO (2022)
Situ Gintung	Indonesia	Embankment failure due to heavy rain and structural damage	Stuart (2009)
A Long Way From Hell	Indonesia	A longspring that causes damage to the dam body	Kompas Daily (2013)
Cipamingkis Dam	Indonesia	Structural damage due to erosion caused by heavy water flow	Media Indonesia (2019)

Based on this data, it is known that one of the causes of dam damage is the lack of maintenance and care of the dam. Dam maintenance and care include a wide range of activities aimed at maintaining the structural integrity, functionality, and safety of dams. This process involves periodic inspections, repairs, and updates of dam components to prevent damage that could result in structural failure. Without adequate maintenance, dams can become vulnerable to various threats such as erosion, cracks, foundation failure, and even environmental disasters.

According to Froehlich (2016), "regular maintenance and regular inspections are important steps for early detection of structural problems that can develop into serious damage if not addressed promptly." By conducting regular inspections, potential damage to critical components of the dam, such as spillways, sluices, and retaining walls, can be identified and repaired before they cause major failures.

In addition, dam maintenance must consider social and environmental impacts. Lee and Kim (2022) emphasize the importance of "involving local communities in the maintenance planning process, especially in developing countries, to ensure that maintenance activities not only protect dam structures, but also maintain ecosystem balance and minimize social impacts." This approach helps to improve the sustainability and long-term effectiveness of maintenance efforts.

The lack of dam maintenance performance in Indonesia is caused by two main variables: organizational structure policies and financing patterns. According to Sari (2021), unclear organizational policies governing dam maintenance often result in confusion in the implementation of maintenance programs. In addition, inconsistent financing patterns worsen maintenance conditions because dams do not receive sufficient financial support to carry out maintenance on a regular basis (Junaidi, 2020). The combination of these two factors worsens maintenance efficiency and increases the risk of deteriorating the quality of dam infrastructure.

In Indonesia, the maintenance and care of dams is based on the Regulation of the Minister of Public Works and Public Housing No. 27 of 2015 concerning Dams, which explains that dam maintenance is as follows: preventive maintenance is aimed at preventing damage and deterioration of the quality of dams and their complementary buildings, as well as extending the useful life. Extraordinary maintenance, carried out based on needs outside of the predetermined maintenance schedule, is aimed at repairing damage caused by deterioration in quality, floods, earthquakes, equipment congestion, failures (structural, hydrolyzed, seepage, operation, etc.), vandalism, and so on.

Based on the Regulation of the Minister of Public Works and Public Housing (*Permen PUPR*) No. 27 of 2015 concerning Dams, dam maintenance and care is a responsibility that must be carried out by dam owners or managers to ensure the safety and sustainability of dam functions. Maintenance includes periodic inspections, testing, repairs, and monitoring of the physical and operational condition of the dam to prevent potential damage that can endanger public safety and the environment. The regulation emphasizes the importance of integrated management, including the preparation of operations and maintenance plans, as well as the implementation of regular technical audits to ensure that all technical and administrative aspects of the dam are met according to the standards that have been set. However, in its implementation in Indonesia itself, it is still ineffective in its implementation.

Dams are vital infrastructure that play an important role in water resource management, flood mitigation, irrigation provision, and hydropower generation. However, recent studies show that many dams in the world, including in Indonesia, face serious challenges related to structural maintenance and safety (Wang et al., 2020; Nguyen et al., 2023). Previous research by Santos & Pereira (2020) and ASDSO (2022) revealed that dam damage is often caused by factors such as lack of routine maintenance, inadequate design, and the impacts of climate change. Furthermore, a study by Lee & Kim (2022) emphasizes the importance of a participatory approach in dam maintenance to minimize social and environmental impacts. However, these studies have not comprehensively integrated policy aspects, organizational structures, and risk-based financing patterns as key factors in dam maintenance performance.

The gap in this research lies in the lack of a holistic analysis of how the interaction between policies, organizational structures, and risk-based financing can affect the effectiveness of dam maintenance, particularly in developing countries such as Indonesia. While studies by Brown & Taylor (2022) and Alvarez et al. (2021) have highlighted the impacts of climate change and infrastructure aging, research on risk management approaches in policy and institutional contexts is still limited. In addition, findings from Junaidi (2020) and Sari (2021) show that policy ambiguity and financing inconsistencies are the main obstacles to dam maintenance in Indonesia, but the solutions offered have not been empirically tested. Therefore, this study aims to fill the gap by analyzing the relationship between the three variables in an integrated manner.

The urgency of this study is based on the high risk of dam failures that can cause major disasters, such as those that occurred at the *Brumadinho Dam* in Brazil and *Situ Gintung* in Indonesia (Santos & Pereira, 2020; Scott, 2009). Climate change exacerbating the frequency of extreme weather is also increasing pressure on old dam infrastructure (Brown & Taylor, 2022). In Indonesia, ineffective dam maintenance has caused structural and operational damage, such as in the *Way Ela* and *Cipamingkis Dams* (Kompas Daily, 2013; Media Indonesia, 2019). Thus, this research is urgent to provide policy recommendations and management strategies that can improve the resilience of dams to multidimensional risks.

The novelty of this research lies in its risk-based approach that integrates three main variables—policy, organizational structure, and financing patterns—in a single analysis model. In contrast to previous studies that focused on technical or financial aspects separately (Froehlich, 2016; Lane, 2008), this study developed an integrated framework to assess the contribution of each factor to maintenance performance. In addition, the study used mixed methods (surveys, archival analysis, and case studies) to strengthen the validity of the findings. The resulting regression model also provides empirical evidence of policy dominance as the most influential factor, which has not been widely revealed in the previous literature.

The objectives of this study are to: (1) analyze the influence of policies, organizational structures, and risk-based financing patterns on dam maintenance performance, (2) identify the interactions between these variables, and (3) formulate recommendations for improving management policies and practices. Research contributions include the provision of empirical models that can serve as a reference for stakeholders in decision-making, as well as the enrichment of the literature on high-risk infrastructure management. The implications of the study include the need for a more adaptive revision of national policies, strengthening institutional coordination, and the development of sustainable financing mechanisms to support long-term dam maintenance. These findings are also relevant for countries with similar challenges in water infrastructure management.

METHOD

This study used a quantitative approach with a survey method to analyze the relationship between policy variables (X1), organizational structure (X2), and risk-based financing patterns (X3) on dam maintenance performance (Y). The research population included all stakeholders involved in dam management in Indonesia, including government officials, engineers, and project managers from the Ministry of PUPR and local governments. The research sample amounted to 75 respondents who were selected using purposive sampling techniques with the following criteria: (1) having at least 3 years of experience in dam management, and (2) being directly involved in the process of planning, financing, or maintaining dams.

The research instrument in the form of a closed questionnaire used a Likert scale of 1-5 to measure respondents' perception of the variables X1, X2, X3, and Y. Before use, the questionnaire

was tested for validity through Pearson Correlation analysis ($r > 0.3$) and reliability with Cronbach's Alpha ($\alpha > 0.7$). Data collection was carried out through online surveys (Google Forms) and structured interviews with a team of dam experts to deepen the quantitative findings. The research procedure began with a literature study to develop a theoretical framework, followed by instrument tests, questionnaire distribution, and data analysis. Secondary data were obtained from policy documents (Permen PUPR No. 27/2015), dam maintenance reports, and archives of dam failure cases in Indonesia.

Data analysis used SPSS 25 software with the following techniques: (1) descriptive statistics to profile respondents, (2) classical assumption tests (normality, multicollinearity, heteroscedasticity), (3) multiple linear regression analysis to test the influence of X1, X2, and X3 on Y, and (4) Spearman correlation to test the relationship between independent variables. The regression model was formulated as $Y = 0.907 + 0.487X1 + 0.203X2 + 0.114X3$, with significance tests using t-test ($p < 0.05$) and determination coefficient (R^2) to measure the model's predictive strength. The results of the analysis were complemented by qualitative interpretations of the interviews to provide in-depth context to the statistical findings.

RESULT AND DISCUSSION

Research Question 3

This study aims to model the relationship between Policy (X1), Organizational Structure (X2), Financing Pattern (X3), and Dam Maintenance Performance (Y). The analysis was carried out through literature studies, archives, and discussions with a team of dam experts to compile relevant variables and indicators. A questionnaire was distributed to 75 respondents to assess the influence of variables and indicators on improving dam maintenance performance. The collected data were statistically analyzed to test the relationship model between X1, X2, X3, and Y, to understand how much of an impact they had on improving dam maintenance performance. Based on the results of multiple regression analysis, the following model was obtained:

$$Y = 0.907 + (0.487) X1 + (0.203) X2 + (0.114) X3$$

Based on multiple regression analysis, the equation model obtained is:

The value of constant (a) has a positive value of 0.907. This positive sign indicates that if all independent variables, namely Policy (X1), Organizational Structure (X2), and Financing Pattern (X3), are valued at 0 (unchanged), then the value of Dam Maintenance Performance Improvement (Y) is estimated to be 0.907. Policy (X1) has a coefficient of 0.487, and has a significance value (Sig.) of < 0.001 (< 0.05), so its effect on (Y) is significant. In contrast, the Organizational Structure (X2) has a coefficient of 0.203 with a significance value of 0.009 (< 0.05), which shows a significant positive influence on (Y). The Financing Pattern (X3) has a coefficient of 0.114 with a significance value of 0.007 (< 0.05), which means that the Financing Pattern has a positive and significant influence on (Y). Thus, the largest contribution to Dam Maintenance

Performance Improvement (Y) comes from Policy (X1), followed by Organizational Structure (X2), and Financing Pattern (X3).

Overall, these results show that Policy (X1), Organizational Structure (X2) and Financing Pattern (X3) have a positive and significant influence on Dam Maintenance Performance Improvement (Y). Policy (X1) had the strongest and most significant positive influence with a coefficient value of 0.487 and a significance value of < 0.001 (< 0.05), while Organizational Structure (X2) had a significant positive influence with a coefficient value of 0.203 and a significance value of 0.009 (< 0.05), then Financing Pattern (X3) had a significant positive influence with a coefficient value of 0.114 and a significance value of 0.007 (< 0.05).

After statistical analysis was carried out, it was known that:

1. Hypothesis H1: Policy (X1) Affects Organizational Structure (X2)

a. Correlation Test

Based on the analysis using Spearman's rho correlation, it was found that the relationship between X1 and X2 was significant with a correlation coefficient value of 0.638 ($p < 0.01$). This shows a positive correlation that is quite relevant. The better the implementation of the Policy (X1), the better the quality of the Organizational Structure (X2).

b. Statistical Significance

Since the $p <$ value is 0.01, the hypothesis that X1 affects X2 is accepted. H1 was proven to be statistically valid, with a positive correlation between the variables.

2. Hypothesis H2: Policy (X1) Influences Financing Patterns (X3)

a. Correlation Test

Based on the analysis using Spearman's rho correlation, it was found that the relationship between X1 and X3 was significant with a correlation coefficient value of 0.356 ($p < 0.01$). This shows a positive correlation that is quite relevant. The better the implementation of the Policy (X1), the better the quality of the Financing Pattern (X2) will be.

b. Statistical Significance

Since the $p <$ value is 0.01, the hypothesis that X1 affects X3 is accepted. H2 was proven to be statistically valid, with a positive correlation between the variables.

3. Hypothesis H3: Policy (X1) Affects Dam Maintenance Performance Improvement (Y)

a. Correlation Test

The results of Spearman's correlation showed a value of 0.631 ($p < 0.01$). The relationship between X1 and Y is significant, with a strong correlation.

b. Regression Analysis

In the regression model, the regression coefficient for X1 is 0.487 with a t-value of 5.304 ($p < 0.01$). This value shows a statistically significant positive influence. Each increase of 1 unit on X1 increases the Y value by 0.487.

c. Since the correlation and regression results showed a significant relationship, the hypothesis that Policy (X1) affects Dam Maintenance Performance Improvement (Y) is accepted.

4. Hypothesis H4: Organizational Structure (X2) Influences Financing Patterns (X3)

a. Correlation Test

Based on the analysis using Spearman's rho correlation, it was found that the relationship between X2 and X3 was significant with a correlation coefficient value of 0.431 ($p < 0.01$). This shows a positive correlation that is quite relevant. The better the implementation of the Policy (X1), the better the quality of the Financing Pattern (X2) will be.

b. Statistical Significance

Since the $p <$ value is 0.01, the hypothesis that X2 affects X3 is accepted. H4 was proven to be statistically valid, with a positive correlation between the variables.

5. Hypothesis H5: Organizational Structure (X2) Affects Dam Maintenance Performance Improvement (Y)

a. Correlation Test

The results of Spearman's correlation showed a value of 0.619 ($p < 0.01$). The relationship between X2 and Y is significant, with a strong correlation.

b. Regression Analysis

In the regression model, the regression coefficient for X2 is 0.203 with a t-value of 2.681 ($p < 0.01$). This value shows a statistically significant positive influence. Every 1-unit increase on X2 increases the Y value by 0.203.

c. Conclusion

Since the correlation and regression results show a significant relationship, the hypothesis that Organizational Structure (X2) affects Dam Maintenance Performance Improvement (Y) is accepted.

6. Hypothesis H6: Financing Pattern (X3) Affects Improvement in Dam Maintenance Performance (Y)

a. Correlation Test

The results of Spearman's correlation showed a value of 0.513 ($p < 0.01$). The relationship between X3 and Y is significant, with a strong correlation.

b. Regression Analysis

In the regression model, the regression coefficient for X3 is 0.114 with a t-value of 2.767 ($p < 0.01$). This value shows a statistically significant positive influence. Every 1-unit increase on X3 increases the Y value by 0.114.

c. Conclusion

Since the correlation and regression results show a significant relationship, the hypothesis that the Financing Pattern (X3) affects the Improvement of Dam Maintenance Performance (Y) is accepted.

Overall, these results demonstrate the importance of the role of policies, organizational structures, and risk-based financing patterns in supporting improved dam maintenance performance. The combination of the three creates a robust framework for effectively identifying, managing, and mitigating risks in dam maintenance. With a risk-based approach, the policies implemented can be more adaptive to operational challenges, organizational structures can be optimized to support responsive decision-making, and financing patterns can be adjusted to the level of risk faced.

Research Discussion

Research Question 3

This study identifies the relationship between Policy (X1), Organizational Structure (X2), and Risk-Based Financing Pattern (X3) in improving Dam Maintenance Performance (Y). The results of the regression analysis showed that the three independent variables had a positive and significant influence on the Dam Maintenance Performance, with Policy as the most dominant factor, followed by Organizational Structure and Financing Pattern.

In addition, there is a positive relationship between these variables, where Policies contribute to strengthening Organizational Structures and Financing Patterns, while Organizational Structures also play a role in supporting more effective Financing Patterns. As such, an integrated approach between strong policies, clear organizational structures, and appropriate financing patterns is essential to improve the sustainability and effectiveness of dam maintenance. The results of this study support the findings of various previous studies that emphasized the importance of risk-based policies, organizational coordination, and adaptive financing strategies in the management of dam infrastructure.

CONCLUSION

This study confirmed that policies, organizational structures, and risk-based financing patterns had a positive and significant influence on dam maintenance performance, with policy identified as the most dominant factor. Lack of routine maintenance and unclear policies were the main challenges in dam management in Indonesia. While most dams performed well to adequately, there were still some that underperformed and required continuous improvement in maintenance management. The results of this study contributed to highlighting the importance of a risk-based approach in dam maintenance policies to improve the reliability and sustainability of infrastructure. The practical implications of these findings suggested that improved policies, strengthened organizational structures, and more effective financing strategies could significantly enhance dam maintenance performance. For further research, it was recommended that the scope of analysis be expanded by considering additional variables and assessing positive risks to gain a more comprehensive understanding of dam management.

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