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Risk Assessment of Dam Management: A Case Study on the Semantok Dam Management Unit

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Abstract:
This study aims to assess the risks associated with the operation and maintenance activities of the Semantok Dam Management Unit (*Unit Pengelola Bendungan*, UPB) to support sustainable management. The method employed is a qualitative case study approach using *Risk Failure Mode and Effects Analysis* (RFMEA), which prioritizes risks based on *Risk Score* and *Risk Priority Number* (RPN). The results identified five main risks: (1) suboptimal irrigation services due to limitations in the water distribution network; (2) a mismatch between *AKNOP* values and actual needs and budget; (3) illegal structures along the dam embankment that interfere with monitoring functions; (4) inaccuracies in monitoring analysis due to insufficient human resource competence; and (5) the presence of wild plants that can interfere with visual inspections and potentially damage the dam structure, exacerbated by insufficient maintenance personnel. This study addresses a gap in the literature, which has primarily focused on technical risks or risks during the construction phase. The application of RFMEA in the context of dam management expands the scope of this method, which has been widely used in the industrial sector and project management. The findings provide important considerations for risk-informed budget planning, particularly in the formulation of the *Operational and Maintenance Actual Need Value* (*AKNOP*), ensuring that allocations reflect real-world, on-site requirements. Furthermore, policies are needed to strengthen the capacity of dam management units through targeted training, certification, increased personnel, and improved analysis of monitoring data. Lastly, policies to protect reservoir buffer zones should be reinforced, both through enhanced physical surveillance and legal approaches, to prevent illegal occupation and associated risks.
Keywords: Risk, UPB, Dam, Operation, Maintenance, RFMEA

INTRODUCTION

Dams are earth, stone, concrete, or stone pairs buildings built to accommodate water, mining waste, or mud so as to form reservoirs (Ministry of Public Works and Housing, 2015). Dams have a strategic role in flood control, drought resilience (which *et al*., 2024), as well as providing benefits such as irrigation, clean water, hydropower, fisheries, tourism, and water sports. The construction of the dam is aimed at achieving better conditions than before (Bravikawati, *et al* 2022). Since 2015, the government has targeted the construction of 61 dams, with 47 already completed and six to be inaugurated by early 2025 (Natural Resources Composite, 2025). The dam is expected to provide benefits such as increasing water holding capacity and potential electrical energy up to 4.06 MW (Natural Resources Composite, 2024). After construction, dam management becomes an important stage that includes operation and maintenance, rehabilitation, and removal, where the operation and maintenance stages play a crucial role in maintaining the safety and sustainability of the dam's benefits (Satrio, 2024). Good dam management can encourage food self-sufficiency.

Safe operations management and infrastructure maintenance are critical given the increasing number of aging dams and the increasing intensity and frequency of extreme climate events (Michalis & Sentenac, 2021). One of the main reasons for delays and increased costs of dam projects is inadequate and weak management, especially risk management. Failure mode analysis is an important factor in identifying potential risks *(Coccon et al*, 2017). Risk rating and assessment are an important part of risk management (Shaffiee Haghshenas *et al*, 2016). For dams that are in the planning process, the risk assessment aims to improve the design and minimize potential hazards that occur due to dam failure. Risk assessment on dams that are already in operation and have been built aims to assess whether the risk of existing hazards can be tolerated or not so that actions are needed to minimize the risk (Conclusion *et al.*, 2023).

Risk assessments assist dam managers in identifying potential risks so that appropriate mitigation measures can be implemented. In addition to the economic aspect, risk assessment at the operational stage is also important to prevent dam failures that cause disasters and cause large losses and can cause fatalities (Juaniza *et al,* 2022). Regular operation, maintenance, and inspection of dams are essential for early detection and prevention of dam failures. Most of the incidents of dam failure occur due to a lack of comprehensive risk management during the operational phase (ICOLD, 2018). One of the incidents in Indonesia was the failure of the Situ Gintung dam in Indonesia in 2009 resulting in around 100 fatalities (Kompas, 2011). According to the community around Situ Gintung, the leak has actually been reported by the surrounding community to the government through the local village officials, but unfortunately this did not immediately receive a serious response (Harsoyo, 2018). Therefore, it is necessary to have risk management in dam management so that if conditions occur that interfere with the organization's goals, risk mitigation has been prepared.

To ensure the safety and function of the dam is maintained, good management is required, including early detection of damage or deviant behavior of the dam. The Ministry of Public Works and Public Housing starting in 2022 will establish a Dam Management Unit (UPB) in accordance with the Decree of the Minister of PUPR Number 1332/KPTS/M/2022 dated October 20, 2022. Previously, this responsibility was with the Head of the Center/River Area Center through the Technical Implementation Unit (UPT). The establishment of UPB aims to strengthen supervision and maintenance so that the functions, benefits, and service life of the dam can be optimally maintained (Rosytha & Suryana, 2023). UPB has an important role in maintaining the function and service life of the dam, through monitoring, operation, maintenance, and securing the area. Each of these activities contains risks, so risk-based control is crucial in dam management.

Management control is a process that directs organizations in achieving short-term and long-term goals amidst the dynamics of the operational environment (Adib & Zhang, 2019). In the context of dam management, the management control system plays an important role in resource allocation, budget oversight, and performance improvement and accountability to stakeholders (Arms *et al*, 2022). The system is also an integral part of organizational management that directs all activities, from planning to evaluation and reporting. The integration of risk management in this system helps organizations identify and mitigate significant risks to support the effective achievement of objectives (Rana *et al* , 2019). Given that UPB's organization for the newly formed dams has not yet been revealed in detail, therefore UPB needs to conduct a thorough analysis to ensure sustainable and efficient dam management.

Risk assessment using the FMEA method is generally adopted in industrial sectors such as sectors, for example in the field of supply chain (Zhu, Golrizgashti, & Sarkis, 2021), manufacturing industry sector (Pangestuti et al., 2022; Wu *et al*., 2021; Shahin *et al*., 2020), food industry (Frinaldi, Putri, Embi, & Afdalisma, 2023), Aviation Industry (Snooke & Price, 2012). In addition, FMEA is also used in healthcare/hospitals (Dadashi *et al*., 2024), and electricity (Kowal & Torabi, 2021), risk of work accidents (Sutapa) *et al*., 2021). Research related to risk assessment of dam management in Indonesia is still limited. Existing studies generally focus on the technical aspects of dam safety structures, such as mains, spills, and intake buildings, and use the ICOLD method (Firmansyah & Sriyana, 2022; Popescu-Busan *et al*, 2019 ;Suprapto, *et al*, 2021), Andersen method (Riando et al , 2023), FMEA (Fernandes *et al* , 2022). Until now, there has been no research that specifically assesses the risk of dam management activities by the Dam Management Unit (UPB) at the operation and maintenance stage of the business process of its activities, not only in terms of dam structure safety. On the other hand, the application of the FMEA method in Indonesia is still limited to the development stage (Khamim & Nur, 2022; Kambey et al., 2022; Pratama et al., 2023). This research was conducted at the Semantok Dam, which is the longest dam in Indonesia with a capacity of 32.67 million m³, a 3100 m long main dam and was inaugurated in 2022 (BBWS Brantas, 2023). The Semantok Dam plays an important role in reducing flood risk in the downstream area of the Semantok River (Kompas, 2022). Considering the importance of the role of the newly formed dam management unit and the limitations of previous studies, this study offers a novel contribution in the form of risk assessment of dam management activities by UPB using the RFMEA method at the operation and maintenance stages. *Risk Failure Mode and Effects Analysis (RFMEA)* is a development or modification of the FMEA format to be more focused on finding critical risks (Nugroho) *et al*, 2021). Research using the RFMEA method is still within the scope of projects and industries (Chavan, 2019; Paul & Basu, 2016; Leite *et al*, 2021; Dytha & Taufik, 2024; Firdaus & Irawan, 2024). There has been no risk assessment using RFMEA in dam management activities at the dam operation and maintenance stage.

This study aims to identify potential risks and determine priority risks in the management of the Semantok Dam at the operation and maintenance stage, using the RFMEA method from the business process of Operation, Maintenance, Monitoring and Security Area activities. In addition, the Semantok dam is one of the national strategic projects and is the longest dam in Indonesia. This leads to the importance of risk-based control in managing dams. With this risk-based control approach, it can be a reference for the Head of the Dam Management Unit to make the right decisions, optimize reservoir operations, and mitigate risks related to various scenarios, which ultimately contributes to a more sustainable and efficient management of water resources so as to support food self-sufficiency and can encourage the achievement of the Government's Asta Cita program.

RESEARCH METHODS

The research method uses a qualitative approach with a descriptive case study method to reveal how to assess and control the risk management of the Semantok Dam at the operation and maintenance stage (Yin, 2020). The focus of the research includes risk identification and risk assessment to obtain risk priorities in the operation, monitoring, maintenance, and security activities of the area using the RFMEA method. The research flow is in Figure 1.

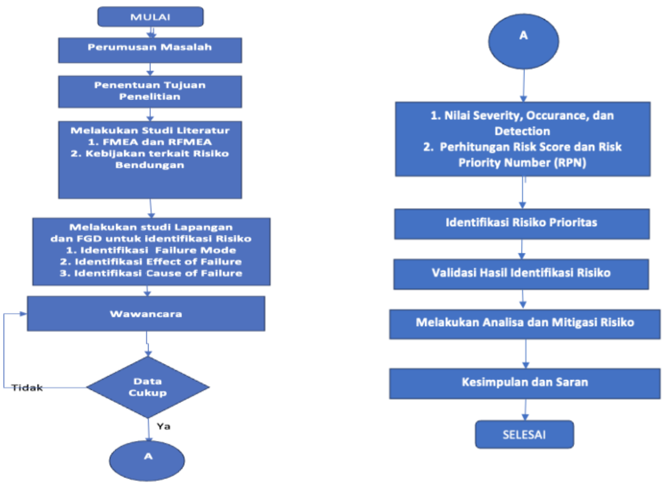

Figure 1. Research Flow

Data collection in this study was carried out in two ways, namely:

(i) Secondary data: which includes Policy or Regulation Documents related to Dams at the Operation and Maintenance stage, risks related to operation and maintenance based on literature, SOP for UPB Dam Management activities, Monthly Report on UPB Management Activities, Dam Management Plan Document, Dam Design, Layout and Construction Data, Dam Emergency Response Plan (RTD), Monthly Report on UPB Management Activities.

(ii) Primary Data was obtained through Focus Group Discussion, semi-structured interviews with informants from various levels of dam managers according to table 1.

Table 1. Informant

No	Position	Description	Informant Code	Interview Topics
1	Head of UPB Semantok Dam	Head in charge of the Dam Management Unit	UPB1	IR, C, PR
2	Head of Operations Unit	The Head of UPB is assisted by the Head of the Operations Unit with a focus on dam operations and monitoring	UPB2	IR, C, PR
3	Head of Maintenance Unit	The Head of UPB is assisted by the Head of the Maintenance Unit with a focus on dam maintenance and security	UPB3	IR, C, PR
4	Head of Operations and Maintenance	The Direct Supervisor of the Head of UPB who is in charge of carrying out guidance on implementation. management of dams and their reservoirs in accordance with applicable provisions and guidelines;	OP1	IR, C, PR
5	Head of SNVT O&P	The Head of the Work Unit who carries out duties and functions related to work in the field of operations and maintenance and budget management.	OP2	IR, C, PR
6	Representative of the Operations Officer	Carrying out dam operations	P1	IR
7	Representative of the Monitoring Officer	Carry out dam monitoring	P2	IR
8	Maintenance Attendant Representative	Carry out maintenance	P3	IR
9	Representative of the Area Security Officer	Carry out area security	P4	IR
10	Head of PJSA	Trustee of the Dam Development Work Unit	BEND	IR
11	Directorate of Operation and Maintenance Development of the Directorate General of Natural Resources	Supervisor of the Directorate of OP Development related to dam management	OPSDA1	IR, C
12	Representative of HIPPA (Water Utilization Farmers Association)	As a stakeholder of water beneficiaries	PA	IR

Note: Risk Identification = IR, Risk Management = C, Risk Assessment = PR

Data validation is carried out through triangulation and member checking (Noble & Heale, 2019). Qualitative data analysis was carried out using *the Interactive Model* (Miles et al., 2014). Risk assessment data analysis is carried out through the stages of risk identification, risk analysis (measuring Likelihood, Impact, and Detection) and evaluation (using Risk Score and RPN) so that priority risks are obtained.

RESULTS AND DISCUSSION

Identify Risks

That based on Circular Letter No. 12 of 2024 concerning Risk Management at the Ministry of PUPR, the Risk Categories are (i) Financial Risk; (ii)reputational risk; (iii) Risk of Corruption; (iv) Legal Risks; (iv) Risk of Work Accidents; (v) Service Risks; (vi) Performance

Risk and SPBE Risk (This risk exists only applied to Echelon I) so it is not discussed in this study.

Dam management activities at the Dam Management Unit in accordance with the Circular Letter of the Directorate General of Natural Resources No. 02 of 2023 concerning Organizational Guidelines and Work Procedures of the Dam Management Unit are divided into 4 (four) activities, namely Operation, Monitoring, Maintenance and Area Security Activities. Based on the SOP of the Semantok Dam, each activity of the Semantok Dam Management Unit is as follows:

(i) Operation Activities consist of Operation Planning (Preparation of RTOW, preparation of SOPs), Implementation of Operations (Collection of TMA and hydrology data as the basis for operation under normal operating conditions, floods and emergencies; Hydromechanical Operations) and Reporting.
(ii) Monitoring activities consist of Operation Planning (Determination of Monitoring Schedule, Preparation of SOPs), Implementation of Operations (Visual Monitoring, Instrumentation Monitoring and Operation Test) and Reporting.
(iii) Maintenance activities consist of Maintenance Planning (Preparation of schedules, preparation of SOPs), Implementation of Maintenance (Routine and Periodic Maintenance) and Reporting.
(iv) Area Security Activities consist of Area Security Planning (Preparation of schedules, preparation of SOPs), Implementation of Area Security and Reporting.

Based on the results of the FGD and interviews from informants, 35 risks were obtained with the details of table 2 as follows:

Table 2. Details of Dam Management Risks

No	Risk Type	Activities	Risk Code	Risk Name	Impact	Cause	Control
1	Financial Risks	All Activities	R1	The AKNOP value is not met	OP performance is not optimal	Government budget limitations	OP activity priorities
2	Reputational Risk	Operation Execution	R2	Bad news related to dam management	Lack of public trust in Organizational Units	Public perception is not understood regarding the dam management process, community expectations are too high beyond the reservoir capacity, the dam RTOW has not been fully conveyed to water users, there are irrigation channels that are not optimal	Intensive coordination with HIPPA
3	Corruption Risk	Operation Execution	R3	The officer opened the door not in accordance with the Operation Plan	Affects reservoir reservoirs	Officers receive rewards from residents to increase the water discharge that has been planned / not according to schedule	discharge reports, CCTV monitoring, Reports from HIPPA
4	Legal Risks	Implementation of Area Security	R4.1	The existence of a semi-permanent/permanent building on the border of the reservoir	Interfering with boundary function	Sub-optimal supervision	Installation of prohibition boards
			R4.2	Unauthorized access to the dam's restricted zone	There is a possibility of damage to existing	Bordering protected forest areas and residential areas, security personnel are	CCTV, Improved physical security, reduced access

No	Risk Type	Activities	Risk Code	Risk Name	Impact	Cause	Control
					instrumentation or equipment at the dam	less sensitive to potential threats/suspicious activities,	and regular access
			R4.3	Vandalism (Destruction of fences, weir bodies etc.)	Cost of repairing physical damage to fences, paint, or monitoring equipment.	Amping access, public indifference to the importance of maintaining infrastructure	CCTV, Improved physical security, reduced access and regular access
5	Occupational Accident Risk	Operation Execution	R5.1	Work accidents during the implementation of operational activities	Worker injury to death	(i) Negligence in turning on the blower so that the air circulation in the Valve is less(ii) Being electrocuted when turning on the panel (iii) The officer slips down to operate the valve (iv) Negligence in opening the door by pass (causing high air pressure to break the pipe). Working not in accordance with SOP	using PPE, conducting daily evaluations
		Maintenance Implementation	R5.2	Work accidents during the implementation of maintenance activities	Worker injuries	1) Slipped during cleaning in the dam area 2) Threat of savages/snakes3) Hit by cutting tools, nails. Working not in accordance with SOP	using PPE, conducting daily evaluations
		Monitoring Implementation	R5.3	Work accidents during the implementation of monitoring activities	Worker injuries	1) Falling of the measuring instrument 2) Slipping 3) Drowning during sediment check	using PPE, conducting daily evaluations
		Implementation of Area Security	R5.4	Work accidents during the implementation of area security activities	Worker injuries	When the water sinks	using PPE, conducting daily evaluations
6	Service Risk	Execution of operations	R6.1	Less than optimal service	Not all of the irrigated land has been irrigated according to the target	Disruption to the water distribution network (drinking canal)	Communication with Service Users
			R6.2	Operation implementation error	Affects services and flood risk	Weather Prediction is not in accordance with conditions, Monitoring and analysis of daily rain forecasts is not carried out	Perform daily operation monitoring
			R6.3	Valve capacity opening inconsistencies	If it is too big, it can reduce the container, if it is too small, the	Less conscientious officers	Evaluation to Beneficiaries

No	Risk Type	Activities	Risk Code	Risk Name	Impact	Cause	Control
					service target is reduced		
			R.6.4	RTOW is inaccurate	Service not as expected	No evaluation of the previous year's RTOW	RTOW evaluation per basis
7	Performance Risk	Operations Planning	R7.1	Hydrological data collected is inaccurate	Improperly stacked RTOW	Data collection is still manual for 2 years, so it is necessary to have valid ECMWF data.	Using valid ECMWF satellite data from the Dam Monitoring Center data.
			R7.2	Hydrological data processing errors	Hydrological data as the basis for calculating RTOW is unreliable	Imperfect modelling in HEC-HMS applications	Calibrate model parameters with existing variables, such as land use conditions
			R7.3	Water Availability Data Analyst Error	Improperly stacked RTOW	The data used does not meet the statistical data	provide assistance with the Dam Monitoring Center in the processing of Hydrological Data.
		Execution of operations	R7.4	TMA Data Retrieval Error	Data analysis errors on daily reservoir operations	Officers lack detail in recording TMA	3x recording, using AWLR data
			R7.5	Valve jams when to be used, especially electrical door panels (cannot close perfectly)	The door cannot be opened, so it cannot serve	Equipment is not maintained (late lubrication), interference with the amping/hydraulics, the seal is damaged, there is debris to the pipe	Perform lubrication and maintenance of mechanical components on a more scheduled basis, placing trash racks or garbage filters upstream to prevent the entry of large materials concerned
			R7.6	Errors in Responding to Emergencies	Increased risk of dam damage and the impact of dams on communities downstream	no RTD simulation	Learn RTD documents
		Monitoring Planning	R7.7	Monitoring plan not implemented as scheduled	Delay in detecting dam behavior	Field conditions	Monitor daily reports
		Monitoring Implementation	R7.8	Equipment Instruments Damaged and Damaged Monitoring	The data is not accurate; the behavior of the dam cannot be detected	Instrument use and lifespan, unlocked (OW), weather, lack of periodic calibration of the tool	Verification

No	Risk Type	Activities	Risk Code	Risk Name	Impact	Cause	Control
				Equipment (reading)			
			R7.9	Inaccuracies in instrumentation measurement	Data Clamping and Inaccurate Data	The method used is not appropriate	update of related SOPs and use of appropriate methods (training)
			R7.10	Inaccuracies in Monitoring Monitoring Nts	Dangerous conditions are not reported quickly	There is no training related to further data analysis related to the instrument	Verification
			R7.11	Errors in data reporting/writing of instrument measurement results	Invalid reporting	Too many that cause officers to be less careful	Verification
			R7.12	Visual Monitoring is not comprehensive	Damage is not reported so that maintenance activities are incomplete The damage is getting bigger	Officers are not careful in conducting inspections that are difficult to reach	Checklist and condition check report
		Monitoring Reporting	R7.13	Reporting delays if there is a data gap	The risk of failure is not addressed quickly and appropriately	lack of integrity from officers and not understanding the risk of dam failure	Regular reporting via GDRIVE
		Maintenance implementation	R7.14	Maintenance OP Guidelines & SOP Documents are not updated according to the conditions in the field	Inefficient and effective work, errors in procedures	The OP Guidelines are not updated; the OP Guidelines do not give rise to procedures in the maintenance of each type of instrumentation	Creation of Repair History
			R7.15	The implementation of the maintenance schedule is not according to plan	Component damage is worse if the component damage is not repaired immediately	Lack of Worker Discipline, Weather Conditions	checklist, daily report monitoring
			R7.16	Lack of competence in performing maintenance	Ineffective maintenance	Lack of training in maintenance activities	checklist, daily report monitoring
			R7.17	Maintenance materials not up to specification	If the tool is damaged by the tool, the concrete structure of the concrete does not last long	OP's guidelines lack of detail, Limited funds	Checkup materials regularly
			R7.18	Maintenance method/procedure error	Deterioration in the quality of work and equipment used in dam management	not in accordance with SOP	Evaluate every day

No	Risk Type	Activities	Risk Code	Risk Name	Impact	Cause	Control
			R7.19	Lack of fulfillment of maintenance materials	Maintenance activities are not optimal	Failure to meet material needs	Optimizing existing
			R7.20	High sediment rate	Dam dams are decreasing	The absence of sediment retaining buildings upstream, the transfer of land functions upstream	Flush sediment every month
			R7.21	The presence of wild plants on the dam body (riprap)	Visual inspection cannot be thorough (Some problems are not detected) can threaten the safety of the dam due to the roots of the plant	less than optimal in plant cleaning due to the area of the weir body, the number of employees is less	Regular cleaning

Source: Processed Data (2025)

Risk Analysis

In risk analysis, a team is needed to conduct a risk assessment. The ideal team size is typically four to six people (Mikulak, McDermott, & Beauregard, 2017). The team that conducted an assessment of the risk of managing the Semantok Dam was the Head of Operations and Maintenance, the Head of SNVT O&P SDA, Head of UPB, Head of the Operations Unit and Head of the Maintenance Unit. This team was chosen because it is the owner and internal stakeholder in the management process of the Semantok dam. The scale chosen is a scale of 1-5 which considers the conditions of convenience and adjusts to the Circular Letter of the Minister of Public Works on Risk Management. The scale of the assessment is according to table 3 below.

Table 3. Occurrence/Likelihood of Dam Management

Level of Possibility	Value	Probability Criteria		
		More tolerated risks		Risks with low tolerance
		Percentage	Number of Frequencies	
Almost nothing happens	1	$x \leq 1\%$;	$x < 2$ times in 1 year	≤ 1 incident in the last 5 years
Rare	2	$1\% < x \leq 10\%$;	$2 < x \leq 5$ times in 1 year	1 incident in the last 5 years
Sometimes it happens	3	$10\% < x \leq 20\%$;	$6 < x \leq 9$ times in 1 year	1 incident in the last 3 years
Frequent	4	$20\% < x \leq 50\%$;	$10 < x \leq 12$ times in 1 year	1 event in the last 2 years
Almost Sure to happen	5	$x > 50\%$	$x > 12$ times in 1 year	≥ 1 incident in the last 1 year

Source: Data Processed based on the SE of the Minister of Public Works No. 12 of 2024 (2025)

Table 4. Detection Dam Management

Score	Detection Description
5	There are no detection methods available or known that can provide early enough warning to respond to the risk.
4	The controls are unproven or unreliable.
3	The control has moderate effectiveness.
2	Control is quite effective.
1	Control is very effective.

Source: Carbone & Tippet (2004)

Table 5. Severity/Impact of Dam Management

Impact	Score	Financial	Reputation	Legal	Work Accident	Service	Performance
Insignificant	1	x ≤ 0.1% of managed revenue/expenditure, or x ≤ 0.05% of managed spending/assets/activities	Number of oral complaints (documented/written) to organization ≤ 3, User satisfaction level 4.25 ≤ x ≤ 5 (scale 5)	No legal consequences or only administrative	Threats to physical and/or psychological safety	x < 5%	x < 5% of performance target
Minor	2	0.1% < x ≤ 0.5% of managed revenue/expenditure, or 0.05% < x ≤ 0.25% of managed spending/assets/activities	Number of oral complaints (documented/written) to organization ≤ 3, User satisfaction level 4 ≤ x ≤ 4.25 (scale 5)	No significant legal consequences	Minor physical and/or mental health issues	5% ≤ x ≤ 15%	5% ≤ x ≤ 10% of performance target
Moderate	3	0.5% < x ≤ 1% of managed revenue/expenditure, or 0.25% < x ≤ 0.5% of managed spending/assets/activities	Number of oral complaints (documented/written) to organization > 5, User satisfaction level 3.75 ≤ x < 4 (scale 5)	Moderate legal violation	Moderate physical (non-permanent injury) and/or mental health issues	15% < x ≤ 35%	10% < x ≤ 20% of performance target
Significant	4	1% < x ≤ 2% of managed revenue/expenditure, or 0.5% < x ≤ 1% of managed spending/assets/activities	Negative coverage in local mass media or viral on social media, User satisfaction 3.5 ≤ x < 3.75 (scale 5)	Serious legal violation, results in major fines	Serious physical health impact (disability/permanent injury) and/or mental	35% < x ≤ 50%	20% < x ≤ 25% of performance target
Very Significant	5	x > 2% of managed revenue/expenditure, or x > 1% of managed spending/assets/activities	Negative coverage in national/international mass media, User satisfaction < 3.5 (scale 5)	Severe legal violation causing major loss	Death	> 50%	> 25% of performance target

Source: Data Processed based on the SE of the Minister of Public Works No. 12 of 2024 (2025)

Furthermore, based on the results of interviews with the five informants through the form that has been provided, the results of the risk assessment are produced. The results of the risk assessment are then calculated with a geometric average before calculating the risk value. The geometric average was chosen because the scoring numbers in the FMEA are a range and have different properties (Forman & Selly, 2001).

Risk Evaluation

Based on the results of the risk assessment, the Risk Score and Risk Priority Number (RPN) values can be calculated. Risk Score is calculated by multiplying Severity and Occurrence (Dytha & Taufik, 2024) and RPN is calculated from the multiplication of Severity, Occurrence and Detection. The results of the Risk Score and RPN are as follows according to table 6.

Table 6. Risk Score and RPN Table

Risk Code	Risk Name	Impact Type	S	O	D	Risk Score	RPN
R1	The AKNOP value is not met	Performance	3,57	4,37	2,55	15,59	39,773
R2	Bad news related to dam management	Reputation	1,89	3,95	2,93	7,46	21,85
R3	The officer opened the door not in accordance with the Operation Plan	Service	1,89	1,89	1,52	3,57	5,40
R4.1	The existence of a semi-permanent/permanent building on the border of the reservoir	Law	3,37	3,95	2,70	13,29	35,91
R4.2	Unauthorized access to the dam's restricted zone	Law	2,30	4,18	2,35	9,07	21,34
R4.3	Vandalism (Destruction of fences, weir bodies etc.)	Law	2,86	2,64	2,49	7,55	18,82
R5.1	Work accidents during the implementation of operational activities	Work Accidents	2,83	1,89	1,52	5,33	8,09
R5.2	Work accidents during the implementation of maintenance activities	Work Accidents	2,40	2,35	1,32	5,65	7,46
R5.3	Work accidents during the implementation of monitoring activities	Work Accidents	2,05	2,35	1,15	4,82	5,53

Risk Code	Risk Name	Impact Type	S	O	D	Risk Score	RPN
R5.4	Work accidents during the implementation of area security activities	Work Accidents	2,09	2,05	1,32	4,28	5,65
R6.1	Less than optimal service	Service	3,57	3,59	3,57	12,81	45,69
R6.2	Error in the implementation of the operation (inappropriate early release due to inaccuracy of the rain forecast)	Service	3,78	2,17	1,15	8,19	9,41
R6.3	Valve capacity opening inconsistencies	Service	3,57	2,49	1,15	8,88	10,20
R.6.4	RTOW is inaccurate	Service	3,57	2,30	1,15	8,19	9,41
R7.1	Hydrological data collected is inaccurate	Performance	3,18	2,00	1,15	6,36	7,30
R7.2	Hydrological data processing errors	Performance	3,37	2,70	1	9,09	9,09
R7.3	Water Availability Data Analyst Error	Performance	3,18	2,55	1,52	8,11	12,29
R7.4	TMA Data Retrieval Error	Performance	2,70	2,70	1,32	7,30	9,63
R7.5	Valve jams when to be used, especially electrical door panels (cannot close perfectly)	Performance	2,55	3,25	1,32	8,28	10,92
R7.6	Errors in Responding to Emergencies	Performance	3,32	2,00	2,35	6,65	15,63
R7.7	Monitoring plan not implemented as scheduled	Performance	2,77	2,61	1	7,21	7,21
R7.8	Equipment Damaged Instruments and Damage Instrument monitoring equipment (reading)	Performance	3,25	3,25	1,64	10,53	17,31
R7.9	Inaccuracies in instrumentation measurement	Performance	3,37	2,49	1,52	8,39	12,71
R7.10	Inaccuracies in Instrument monitoring analysis	Performance	3,78	3,18	2,17	12,00	26,03
R7.11	Errors in data reporting/writing of instrument measurement results	Performance	3,18	2,99	2,17	9,51	20,63
R7.12	Visual Monitoring is not comprehensive	Performance	2,93	3,25	1,64	9,51	16,56
R7.13	Reporting delays in case of data anomalies	Performance	2,86	3,32	1,64	9,51	15,63
R7.14	Maintenance OP Guidelines & SOP Documents are not updated according to the conditions in the field	Performance	3,29	3,29	2,35	10,20	17,77
R7.15	The implementation of the maintenance schedule is not according to plan	Performance	2,70	3,06	1,52	8,28	12,55
R7.16	Lack of competence in performing maintenance	Performance	2,55	3,06	1,43	7,82	11,18
R7.17	Maintenance materials not up to specification	Performance	2,17	3,17	1,64	6,88	11,30
R7.18	Maintenance method/procedure error	Performance	2,35	2,83	1,64	6,65	10,92
R7.19	Lack of fulfillment of maintenance materials	Performance	2,17	2,99	1,64	6,49	10,67
R7.20	High sediment rate	Performance	2,17	1,32	2,35	2,86	6,73
R7.21	The presence of wild plants on the dam body (riprap)	Performance	3,95	4,13	1,52	16,30	24,71

Source: data processed (2025)

Based on the data from Table 6, a pareto chart can be made to compile the ranking of RPN and Risk Score as shown in Figure 2 and Figure 3

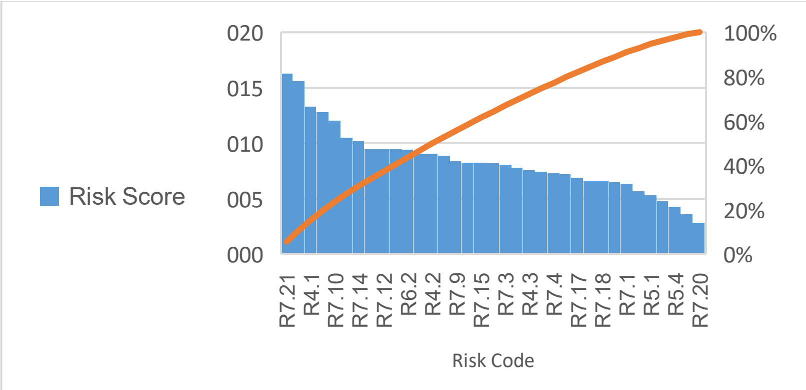

Figure 2. Diagram Pareto Risk Score
Source: data processed (2025)

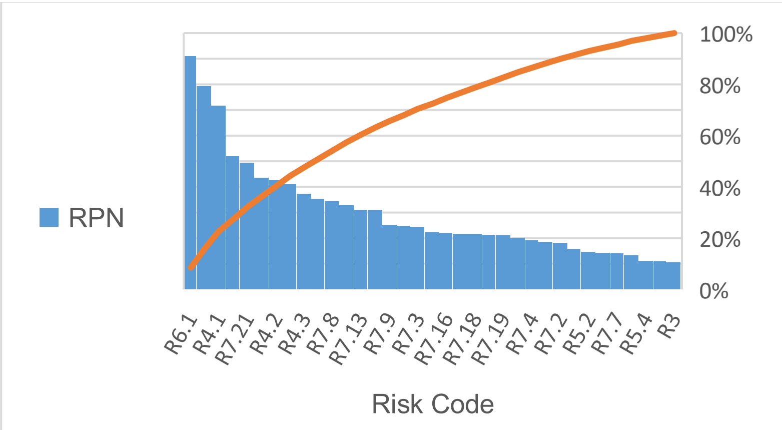

Figure 3. RPN Pareto Diagram
Source: data processed (2025)

Figure 4 shows the risks in order, starting from those with the highest RPN value to the smallest value. Based on the risks that have been registered and the value of each RPN is known, critical risks can be determined. A risk is categorized as critical risk if it has an RPN value above the critical value. The critical value of the RPN is determined from the average RPN value of the entire risk (Firdaus & Irawan, 2024). Meanwhile, the Risk Score limit is taken from Risk Appetite in accordance with the SE of the Ministry of PUPR No. 12 of 2024.

$$\text{RPN Critical Value} = \frac{\text{RPN Total (531,30)}}{\text{Total Risk (35)}} = 15{,}18$$

Next, it is to analyze the critical risk comparison between the Risk Score and RPN using the Scatter Plot Diagram. The critical category value in the RPN based on the calculation of the value is 15.18, while the value that is included in the critical category for the risk score refers to according to the SE of the Ministry of PUPR No. 12 of 2024 is the one with a minimum value of 11. After analysis, a Scatter Plot was made to determine the priority risk, namely the intersection between the Critical Line Risk Score and the Critical Line RPN according to Figure 4.

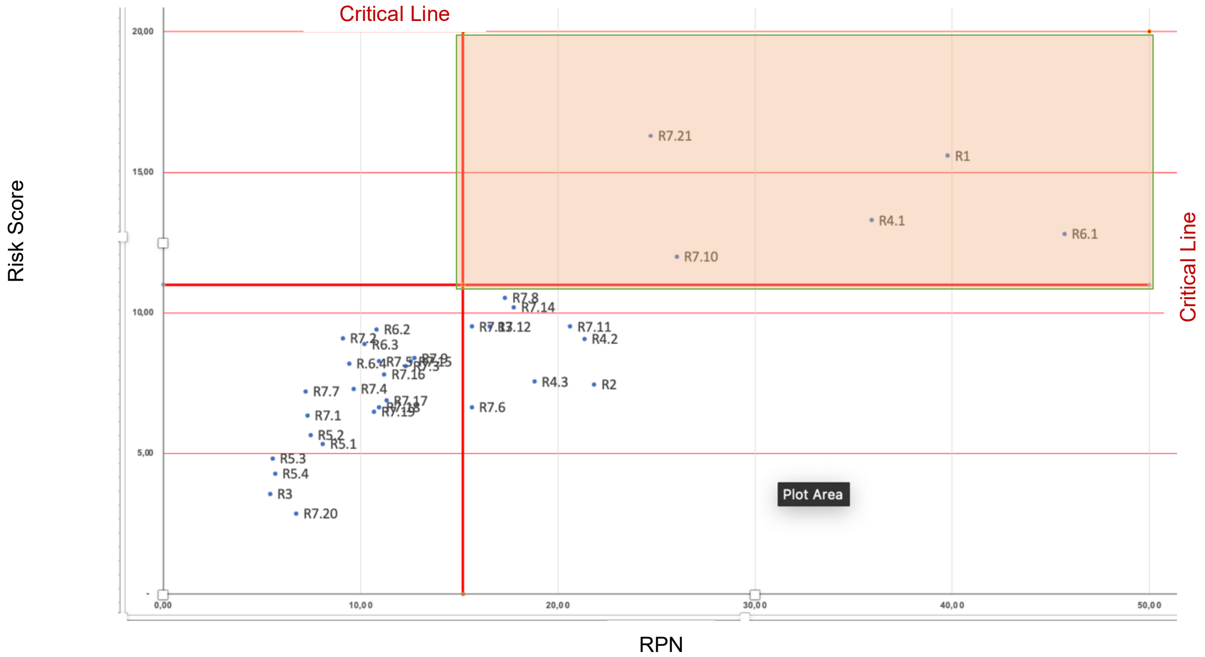

Figure 4 Priority Risk Plot Scatter Chart
Source: data processed (2025)

Based on the results of the risk analysis, the priority use of RFMEA is as follows.

Risk of Suboptimal Irrigation Services

The risk of suboptimal service is one of the risks in the Risk Allocation reference (PT Penjaminan Infrastruktur Indonesia, 2024). Based on BEND informants, the risk of suboptimal services is the suboptimal irrigation service. The Semantok Dam is a multipurpose that apart from being a flood control, this dam has an irrigation service function. The PA informant said that with the Semantok dam, the flood that caused agricultural losses no longer occurred. In addition, agricultural productivity has increased, but not completely. The main cause of the disruption in the water distribution network in the drinking canal is that the water distributed from the dam has not reached the maximum reach of agricultural land with a target of 499 ha. Fulfilled services for drinking channels less than 499 ha.

> *"....If the main intake of 1407 ha is already in accordance with the service, but if the one in the Ngomben channel of 499 ha is not massive, it is indeed due to the limitations of the network or secondary channel, it is still not optimal. This is because the network is faulty, the network is very old from 1970, besides that it may be full of sediment and because the network is closed for approximately 11 kilometers. Yes, if it is taken out in large volumes, the water is a waterbag/back again..."PA*

This shows that to optimize services, steps are needed to rehabilitate channels whose duties are not in the Dam Management Unit. However, UPB needs to coordinate with the stakeholders involved to immediately accelerate channel repairs so that services can be optimized.

Risk of AKNOP Value not being met

Based on the results of brainstorming with the Semantok Dam Management Unit, it was found that the financial risk was not met. AKNOP (Operation and Maintenance Real Needs Figure) refers to the actual need for operating and maintenance costs, particularly in the context of water management infrastructure such as rivers and reservoirs. An unmet AKNOP for a dam can be understood as a gap between the resources needed and the actual resources allocated for operation and maintenance. Funds available for dam operation and maintenance are limited due to the availability of government budgets (Malik Sadat Idris *et al*, 2019). This can have an impact on decreased performance of Operation and Maintenance of dams/OP performance is not optimal. One of the unfulfilled AKNOP values is the government's efficiency policy in 2025. The OPSDA1 informant stated that there is a limited budget of efficiency in 2025.

Risk of the existence of semi-permanent/permanent buildings on the border of the reservoir that are not in accordance with their designation

The reservoir boundary line is a protection limit of 50 meters horizontally from maximum inundation towards the mainland (Ministry of PUPR, 2023). Zoning in the reservoir area is important to maintain the protection and cultivation function of the reservoir. The existence of illegal buildings in this zone can interfere with dam safety, reduce capacity due to sedimentation, damage structures, and hinder access to maintenance. This problem is caused by weak supervision, the extent of the dam so that not all of it is fenced off by the perimeter and low public awareness. Based on OP1 resource persons

"....Because our dam area is quite large and not all of them have been installed security fences thoroughly. We still install safety fences only in the main area of the dam, namely in the main dam, in the main dam building, in the dam support facilities, then in the viewing tower, so that's what we installed the safety building. Such as fences, CCTV, then guards, security, yes, it is limited only to the main dam or main building. Meanwhile, in the inundation area that is quite wide and long, now it has not been installed with a fence. All there is a stake. Now this triggers the risk of illegal occupation or illegal land occupation by the community or irresponsible parties..."

This shows the limitation of supervision due to the size of the dam and not the entire dam area has a safety fence. This risk is also present in reservoirs in Nigeria (Adejumo & Osunwale, 2024) and several reservoirs in Indonesia.

Inaccuracies in Instrument Monitoring Analysis

Inaccuracies in the analysis of instrument monitoring data can lead to anomalies and inaccuracies in data that have an impact on the interpretation of improper dam conditions. This misanalysis has the potential to result in incorrect decision-making in dam management and operation, thereby increasing the risk of damage or functional disruption. The main causes of this inaccuracy are the use of inappropriate or inappropriate analysis methods that are not in accordance with the characteristics of the monitored data and instruments and lack of training related to instrument data analysis. Prasad, et al (2023) mentioning that if there is an error in data analysis, it may be related to the limitation of available data or inaccuracies in data interpretation. This indicates the need to improve competence.

“... In carrying out dam operation and maintenance activities, specific competencies are required. If there is a lack of human resources, the task of the Ministry of Public Works agencies, how do we create competent human beings. I think that's important. It can't just be recorded, if it's just monitoring, taking notes, the graph might be possible. But when doing the analysis, it needs specific competencies and also in the operation and maintenance of dams..." UPB

Based on the informant, it shows that in the operation and maintenance of dams, human resources with special competencies are needed. Simply recording or monitoring can be done by anyone, but for analysis and decision-making, specific skills are required. Therefore, it is important for the Ministry of Public Works to prepare competent personnel. Currently, the one who has a dam expert certification is still the Head of UPB. However, the Head of the Operations and Maintenance Unit who conducted the analysis has not been included in training/certification. Therefore, it is important to have training related to this data analysis.

The presence of wild plants on the dam body (riprap)

The presence of wild plants on the dam body, especially in riprap areas, is a risk that can interfere with the visual inspection process and the safety of the dam itself. Excessive growth of wild vegetation can make it difficult for officials to conduct thorough inspections, so some structural problems or damage to dams may not be detected early. In addition, the roots of such plants can penetrate the dam structure, potentially damaging the protective layer and threatening the stability of the dam (Hadimuljono & Kurniawan, 2022). In addition, with the excessive growth of vegetation can invite rodents that they can create nests and passageways (Escolano-Sánchez & Fernández-Serrano, 2015). The Semantok Dam has a main dam length of 3.1 km and the area of the dam therefore adequate human resources are needed to carry out this maintenance. Wild plants that grow in the body of the dam are not recommended to use herbicides because it is feared that it will contaminate the water in the dam

> *"... The maintenance officers who were riprap were only 4-8 people, even though the length of the dam was 3.1 km. So because it was so long, I pulled out the grass that was rip-rapped, it wasn't finished on the other side. The other side of the wild plant has grown again..." UPB2*

This shows that there is a shortage of maintenance personnel due to the length of the dam body area (3,100 m long). After an analysis using references from Setiawan et al., 2021 and the calculation of the unit price analysis of the number of maintenance officers of the Semantok Dam, there was a shortage. Based on the analysis, a total of 76 people are needed if the work is specifically riprap assuming 40 days (to keep the condition of the dam body safe and tidy, the cutting cycle does not exceed 40 days). Even though maintenance activities on the dam are not only maintenance on the dam body, there are other work such as building maintenance and other facilities. Therefore, there is a shortage of manpower to carry out the maintenance of the Semantok dam.

CONCLUSION

This study identifies 35 potential risks in the Semantok Dam Management Unit (*Unit Pengelola Bendungan*, UPB) across operation, monitoring, maintenance, and security activities, categorizing them into seven main risk types such as financial, reputational, and work accidents. Using the RFMEA method, five priority risks were highlighted as critical, underscoring the need for risk management strategies that address not only technical factors but also institutional, resource, and human capacity aspects. The research contributes to infrastructure risk management theory and demonstrates the value of RFMEA in the dam sector, recommending improved budget planning, enhanced human resource capacity through targeted training, and policies to protect reservoir buffer zones. For future research, it is suggested to broaden risk identification by involving informants from other Dam Management Units to increase the comprehensiveness and effectiveness of risk analysis.

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