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Application of the House of Risk for Operational Risk Mitigation in Regional Public Water Utilities

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Abstract

Clean water is a fundamental public service, and rising customer demand often coincides with increasing operational disturbances at water treatment plants. Current risk management practices remain reactive and are not yet fully aligned with ISO 31000:2018, with no structured method to map relationships between risk events and their causes or to prioritize preventive actions based on effectiveness and implementation difficulty. This study aims to systematically identify, analyze, and mitigate water treatment plant operational risks using the house of risk framework integrated with ISO 31000:2018. A qualitative case study was through in-depth interviews and field observations supported by triangulation. HOR Phase I applied aggregate risk potential analysis to rank risk agents, while Phase II used effectiveness-to-difficulty ratios to prioritize mitigation measures. The study identified fourteen risk events and twelve risk agents, with key contributors including inadequate maintenance scheduling, river landslides or floods, and distribution pipe leakage. Ten mitigation actions were proposed, such as pump performance monitoring, development of technical SOPs, network inspection and flushing, technical training, coordination with dam operators, provision of PPE, and safety enforcement.

Keywords

House of Risk, Operational Risk, Risk Management, Water Utilities.

1. Introduction

Clean water is an essential basic need for human life, making its provision a vital public service that greatly affects societal well-being (Kannan & Anandhi, 2020). The processes of water treatment and distribution aim to ensure that the water supplied is safe for consumption, meets quality standards, and is available sustainably (Ma et al., 2022; Vedrin, 2023). The Regional Drinking Water Company (*Perusahaan Daerah Air Minum*/PDAM) plays a crucial role in providing clean water to the public, operating as a business entity while simultaneously carrying out a public service function.

As a service provider, regional drinking water company faces significant challenges, particularly those triggered by customer growth. Data from 2019 to 2024 indicate an increase in customers from 85,257 to 91,346. This rise in customer numbers is directly correlated with an upward trend in the volume of complaints, with a total of 12,556 cases recorded in 2024. The most frequent complaint categories consistently involve disruptions in water distribution due to interruptions in water production, indicating potential systemic risks within operational and network aspects.

Actual operational risks that have occurred include various incidents, such as the cessation of water production caused by tree branches obstructing the pump and a drastic decline in production source capacity. These operational failures not only disrupt water supply but also result in substantial financial losses and potentially trigger public health issues (He et al., 2021). This complexity demands a proactive approach to mitigating the potential negative impacts posed by these risks.

Currently, risk management at the regional drinking water company is considered suboptimal and tends to be reactive. The absence of standard references such as ISO 31000:2018 has resulted in risk management practices that are less structured and not fully integrated into operational activities (ISO 31000, 2018). Limited understanding of integrated risk management concepts among management and operational staff, along with resistance to change, further constitutes a key barrier to the adoption of a comprehensive approach (Radiansyah et al., 2023).

Therefore, the design of an effective and structured risk management framework is needed. This study adopts the ISO 31000:2018 risk management framework and the House of Risk (HOR) method in the stages of identification, analysis, and evaluation. HOR, a modification of the Failure Modes and Effects Analysis (FMEA), is selected because it focuses on preventive actions by prioritizing the most influential risk agents (Pujawan & Geraldin, 2009). This approach has been shown to be effective in previous studies, such as those applying HOR to address risks at the regional drinking water company Gowa and research implementing ISO 31000 to improve service quality (Febiyanti et al., 2024; Malik et al., 2024).

Although previous studies have applied either ISO 31000 or the house of risk method within water utility contexts, the integration of both approaches into a unified framework for systematically identifying, analyzing, and mitigating operational risks remains limited, particularly amid rising customer numbers, increasing complaint volumes, and actual operational disruptions experienced by the regional drinking water company Denpasar. The scarcity of research that specifically examines operational risks using field-based data and prioritizes them through quantitative indicators such as Aggregate Risk Potential (ARP) and Effectiveness-to-Difficulty (ETD) highlights a research gap that warrants further investigation.

This study aims to identify the operational risks faced by the regional drinking water company and to design a structured risk management system using the House of Risk (HOR) method grounded in ISO 31000:2018 to support risk mitigation within the regional drinking water company's operational scope. The study contributes academically by offering an integrative ISO 31000-HOR model that can

be replicated in other public service sectors; methodologically by presenting a measurable risk-analysis pathway through aggregate risk potential and effectiveness-to-difficulty; and practically by providing regional drinking water companies with data-driven mitigation recommendations aimed at enhancing operational reliability, reducing customer complaints, and strengthening long-term risk governance.

2. Literature Review

2.1. Risk and Classification

Risk represents an inherent aspect of future uncertainty, referring to the likelihood that an event may occur and influence the attainment of planned objectives. Within an organizational setting, risk is understood as the interaction between the probability of an event and the magnitude of its potential impact (Frame, 2003; Sutton, 2015). It encompasses two key dimensions: the consequences affecting essential elements and the uncertainty associated with both the likelihood and the severity of those consequences (Daya et al., 2019).

Operational risk refers to losses that stem from weaknesses or failures in internal processes, human performance, systems, or external conditions that could interrupt an organization's operations (Majka, 2024). For regional drinking water companies, operational risks manifest in various forms, including equipment malfunctions, fluctuations in raw water quality, and the presence of inadequately skilled personnel. Because water services are critical for society, operational failures in water treatment facilities can easily disrupt service delivery and undermine public confidence. Risk is therefore commonly described as a function of event probability and impact severity and its assessment considers both the consequences for valued outcomes and the uncertainty surrounding the occurrence and effects of such events (ISO 31000, 2018; Hubbard, 2020).

2.2. Risk Management ISO 31000:2018

Risk Management is a systematic and structured approach to identifying, analyzing, assessing, and managing the risks faced by an organization. Its purpose is to minimize negative impacts that may arise from uncertainty while maximizing existing opportunities (ISO 31000, 2018). ISO 31000:2018 is an international standard that provides general principles and a framework for risk management. This standard is generic and can be applied to all types of organizations and activities (Natalie & Manuputty, 2022).

In ISO 31000:2018, risk management is carried out through a structured set of processes that begins with establishing the context, in which the organization defines its internal and external environment, clarifies its objectives, and determines the criteria that will be used to assess risks. Once this foundation is set, the organization proceeds to the risk assessment stage, which involves systematically identifying potential risks, analyzing their likelihood and potential impact, and evaluating them to determine which risks require priority attention. After the assessment, the process continues with risk treatment, where the organization selects and implements the most appropriate strategies to modify or reduce the identified risks. Together, these stages form an integrated cycle that supports informed decision-making and promotes consistent, proactive risk management in alignment with organizational goals.

2.3. House of Risk Model

The House of Risk (HOR) is a risk management model developed with a primary focus on preventive action. This model is designed to identify and prioritize risk agents that require mitigation measures (Pujawan & Geraldin, 2009). HOR is an integrated model that combines principles from Failure Mode and Effect Analysis

(FMEA) and the House of Quality (HOQ). HOR consists of two main phases: risk identification and prioritization, and risk treatment.

The first phase is risk identification. This phase aims to identify risk events and risk agents, analyze them, and determine their priority levels. Prioritization is conducted by calculating the aggregate risk potential, obtained from multiplying the probability of a risk agent by the severity level of its associated risk events. Risk agents with the highest ARP values are carried forward to the next phase.

The second phase is risk treatment. This phase focuses on designing appropriate preventive actions to avoid the occurrence of risks. Each action is evaluated based on its total effectiveness (TEAk) and the level of difficulty in implementation. Actions with the highest TEAk/ETD ratios are prioritized, as they are considered the most effective while requiring relatively lower effort (Pujawan & Geraldin, 2009).

3. Methods

This study employs a descriptive qualitative research design using a case study method. A qualitative approach was selected to obtain an in-depth understanding of operational risk management, which requires non-numerical analysis of the perceptions and experiences of field informants (Oranga & Matere, 2023). The research was conducted at the regional drinking water company Denpasar. The research object focuses on operational risks, ranging from clean water treatment to water distribution to consumers. Primary data were obtained through in-depth interviews with informants directly involved in operations. Observations and interviews were conducted from June to July 2025. Informants consisted of the head of the production division, the head of the production subdivision, and production operators, all of whom are involved in the operations of the Water Treatment Plant (*Instalasi Pengolahan Air/IPA*). Secondary data were obtained from literature reviews, internal company documents (operational reports and complaint data), and references to risk management standards, particularly ISO 31000:2018. The primary instruments used were interview guidelines and question lists. The questions were developed based on risk events identified through literature studies and preliminary observations. Data analysis was carried out in stages, referring to the ISO 31000:2018 risk management framework and the House of Risk (HOR) method, which is divided into two main phases.

The House of Risk Phase I (risk identification and prioritization) aims to identify and prioritize risk events and risk agents. Risk assessment is conducted by evaluating the severity and likelihood of risk events using a Likert scale converted into numerical values. Next, aggregate risk potential is calculated by multiplying the probability of the risk agent, the severity of the associated risk event, and the correlation weight (Rij). Risk agents with the highest ARP values are designated as top priority. And then, the House of Risk Phase II (risk treatment) aims to determine the most effective mitigation actions (preventive actions). The total effectiveness of preventive actions (TEAk) is calculated by multiplying ARP with the effectiveness relation value (Bjk). The prioritization of actions considers the level of implementation difficulty Ease of Technical Difficulty (ETD). Actions with the highest TEAk/ETD ratio are selected as the most optimal. Data validity is ensured through source triangulation, namely by comparing interview results among informants and cross-checking them with relevant secondary data. All analytical processes contribute to formulating a structured risk management framework for the regional drinking water company Denpasar. The following is the research flow diagram illustrated in Figure 1.

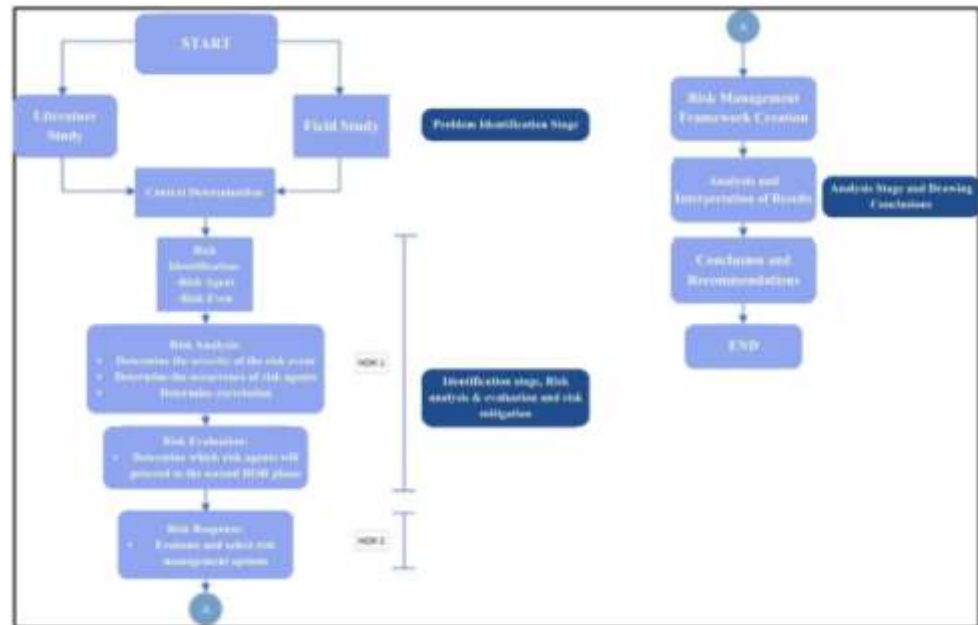


Figure 1. Research Framework

4. Results

4.1. Operational Risks in the Regional Drinking Water Company

Risk data were obtained from literature sources and field studies and needed to be confirmed with informants in the water treatment plant operational division through interviews to ensure that the identified risk events had indeed occurred within the company. After the interviews, source triangulation was conducted to ensure the validity of data obtained from multiple sources or informants by comparing the information across informants. Through the interview findings, 14 operational risk events at the water treatment plant were identified. The next stage was to identify the risk agents. Based on the interview results and informant confirmation, 12 risk agents related to water treatment plant operations were identified.

HOR Phase I involves risk identification and analysis to map the relationship between risk events and risk agents and to calculate the Aggregate Risk Potential. The measurement of a risk event’s impact on an operational process indicates the extent to which the event disrupts the process. Based on the analysis, 14 risk events that have the potential to disrupt water treatment plant operations were identified, as presented in Table 1.

Table 1. Severity Assessment

Risk Code	Risk Event	Informant			Severity (Effect)
		1	2	3	
RE1	Operational disruptions at production wells due to power outages	5	5	5	5
RE2	Decline in Water Treatment Plant (IPA) performance caused by high turbidity of raw water	2	3	3	3
RE3	Water quality received by customers not meeting standards (odor, taste, color)	4	4	4	4
RE4	Decrease in raw water intake, resulting in insufficient supply for water treatment plant operations	3	4	4	4

Risk Code	Risk Event	Informant			Severity (Effect)
		1	2	3	
RE5	Pollution of raw water sources by waste, disrupting the treatment process	2	2	3	2
RE6	Excessive use of chemicals and electrical energy during operations	2	2	2	2
RE7	Decline in production capacity due to damage or inadequate maintenance	4	4	4	4
RE8	Production facilities that are not representative and do not meet operational standards	3	3	3	3
RE9	Falsification of water quality testing results	4	4	4	4
RE10	Inaccurate reporting of chemical usage	2	2	2	2
RE11	Incorrect submission of maintenance budget proposals for production equipment	2	2	2	2
RE12	Use of damaged or uncalibrated production equipment	5	5	5	5
RE13	Workplace accidents involving staff during technical activities, such as hand injuries, slipping, or falling.	3	3	3	3
RE14	Limited availability of spare parts, causing delays in machine or equipment repairs when needed	5	5	5	5

Based on Table 1, there are 4 risk events with an impact level score of two, indicating that the risks have a minor influence on the continuity of water treatment plant operations; 3 risk events with an impact level score of three, indicating that the risks have a moderate influence on the continuity of water treatment plant operations; 4 risk events with an impact level score of four, indicating that the risks have a major influence on the continuity of water treatment plant operations; and 3 risk events with an impact level score of five, indicating that the risks have a very significant influence on the continuity of water treatment plant operations.

Table 2. Occurrence Assessment

Risk Code	Risk Agent	Informant			Triangulation Result (occurrence)
		1	2	3	
RA1	Disruptions in the electricity supply from the state power utility	1	1	1	1
RA2	Landslides or flash floods in the river	2	3	3	3
RA3	Leakage in the distribution pipeline network	2	3	3	3
RA4	Contamination from residents' well water	2	3	2	2
RA5	Dry season conditions	3	4	4	4
RA6	Rainy season conditions	2	3	2	2
RA7	Poorly scheduled maintenance	1	2	2	2
RA8	Insufficient evaluation and maintenance	1	1	1	1
RA9	Lack of layered (multi-level) supervision	1	1	1	1
RA10	Insufficient employee competency	1	1	1	1
RA11	Lack of attention to occupational health and safety	2	2	2	2
RA12	Delays in the arrival of spare parts	1	1	1	1

The measurement of the probability value of risk agents will be carried out to determine the likelihood of risk agents occurring, which may trigger one or more

risk events that could disrupt water treatment plant operational processes to a certain level of impact, as presented in Table 2.

Based on Table 2, there are 12 risk agents that have the potential to trigger risk events in water treatment plant operations. According to the established probability scale, there are 5 risk agents with a probability value of 1, indicating that the risk agent is likely to occur only once a year; 4 risk agents with a probability value of 2, indicating that the agent may occur around five times a year; 2 risk agents with a probability value of 3, indicating that the agent may occur one to two times per month; and 1 risk agent with a probability value of 4, indicating that the agent may occur three to five times per month.

The correlation value (R_{ij}) between each risk agent and risk event describes the causal relationship between them. Source triangulation data based on interview results from informants is presented in Table 3

Table 3. Correlation Values Between Risk Agents and Risk Events

No. RE	Risk Event	No. RA	Risk Agent	Correlation (R_{ij})
RE1	Operational disruptions at production wells due to power outages	RA1	Disruptions in electricity supply from the state power utility (PLN)	9
RE2	Decline in Water Treatment Plant (IPA) performance caused by high turbidity of raw water	RA2	Landslides or flash floods in the river	9
RE3	Water quality received by customers not meeting standards (odor, taste, color) Decrease in raw water intake, resulting in insufficient supply for IPA operations	RA3	Leakage in the distribution pipeline network	9
		RA4	Contamination from residents' well water	6
RE4	Pollution of raw water sources by waste, disrupting the treatment process	RA5	Dry season conditions	9
RE5	Excessive use of chemicals and electrical energy during operations	RA2	Landslides or flash floods in the river	6
RE6	Decline in production capacity due to damage or inadequate maintenance	RA6	Rainy season conditions	9
RE7	Production facilities that are not representative and do not meet operational standards	RA7	Poorly scheduled maintenance	9
RE8	Falsification of water quality testing results	RA8	Insufficient evaluation and maintenance	9
RE9	Inaccurate reporting of chemical usage Incorrect submission of maintenance budget proposals for production equipment	RA9	Lack of layered (multi-level) supervision	6
		RA10	Insufficient employee competency	9
RE10	Use of damaged or uncalibrated production equipment Workplace accidents involving staff during technical activities, such as hand injuries, slipping, or falling.	RA10	Lack of layered (multi-level) supervision	9
		RA9	Insufficient employee competency	6
RE11	Limited availability of spare parts, causing delays in machine or equipment repairs when needed Operational disruptions at production wells due to power outages	RA10	Lack of layered (multi-level) supervision	9
		RA9	Insufficient employee competency	6
RE12		RA7	Poorly scheduled maintenance	9

No. RE	Risk Event	No. RA	Risk Agent	Correlation (R _i)
	Decline in Water Treatment Plant (IPA) performance caused by high turbidity of raw water	RA10	Lack of layered (multi-level) supervision	6
	Water quality received by customers not meeting standards (odor, taste, color)			
RE13	Decrease in raw water intake, resulting in insufficient supply for IPA operations	RE11	Lack of attention to occupational health and safety (OHS)	9
RE14	Pollution of raw water sources by waste, disrupting the treatment process	RE12	Delays in the arrival of spare parts	9

The calculation of the Aggregate Risk Potential (ARP) index is conducted to determine the strength of the relationship between each risk event and the risk agents that contribute to it, with all assessments derived from interview findings. In this process, respondents evaluate the correlation between risk agents and risk events using a three-level scale: a score of 9 represents a strong correlation where the agent plays a significant role in triggering the event; a score of 3 reflects a moderate relationship; and a score of 1 indicates a weak connection. After the correlation values are established, the ARP index, also referred to as the Risk Priority Index, is computed using a specific formula, allowing the analysis to quantify the relative importance of each risk agent and identify which ones require prioritized mitigation.

$$ARP = O_j \sum_i S_i R_{ij}$$

where:

O_j = The likelihood of occurrence of the j-th risk agent.

S_i = The severity level of the impact of the i-th risk event.

R_{ij} = The relationship between risk agent j and risk event i, indicating the extent to which the risk agent contributes to the occurrence of the risk event.

$$ARP_{RA2} = 3 \times ((3 \times 9) + (2 \times 6)) = 117$$

The ARP value for risk agent RA2 is 117. The same calculation method is then applied to determine the ARP values for the remaining risk agents.

4.2. Risk Management System for Regional Drinking Water Company

The risk evaluation stage applies the Pareto principle (80:20), which means that not all risk agents receive treatment. The purpose is to identify the most critical problems that need to be resolved immediately (highest ranking) and those that do not require urgent action (lowest ranking). Therefore, the company does not address every risk agent, but only those considered priorities (Radistya & Handayani, 2024). To determine which risk agents are prioritized, the cumulative percentage value of ARP_j must first be calculated using the following formula.

$$\% \text{ Cumulative ARP}_j = \frac{\text{Cumulative ARP}_j}{\sum ARP} \times 100\%$$

$$\% \text{ Cumulative ARP}_7 = \frac{162}{864} \times 100\% = 18,75\%$$

The ARP percentage value in the first rank is 18.75%. The recapitulation of ARP percentage values will be presented in Table 4 and Figure 1.

Table 4. Recapitulation of Aggregate Risk Potentials (ARP)

RA	Risk Agent	ARP	Percentage (%)	Cumulative (%)
RA 7	Unscheduled pump maintenance	162	18.75	18.75%
RA 2	Landslides/flash floods in the river	117	13.54	32.3%
RA 3	Leakage in the distribution pipeline network	108	12.5	44.8%
RA 10	Insufficient employee competence	102	11.8	56.6%
RA 5	Dry-season conditions	72	8.33	65%
RA11	Lack of attention to occupational health and safety	54	6.25%	71.18%
RA4	Contamination of residents' well water	48	5.56%	76.74%
RA9	Inadequate layered supervision	48	5.56%	82.29%
RA1	Disruptions to the electricity supply from the national grid	45	5.21%	87.50%
RA12	Delay in the arrival of spare parts	45	5.21%	92.71%
RA6	Rainy-season conditions	36	4.17%	96.88%
RA8	Insufficient evaluation and maintenance	27	3.13%	100.00%

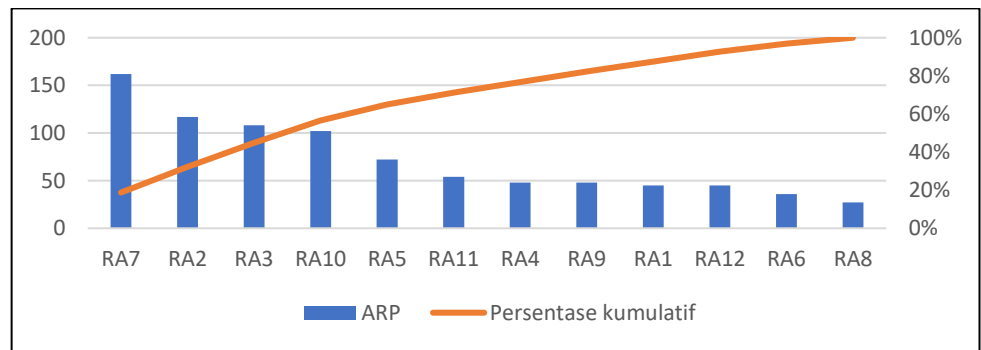


Figure 2. Pareto Diagram of Risk Agents

Based on Figure 2, there are five risk agents that contribute to 80% of the risks, namely RA7, RA2, RA3, RA10, RA5, RA11, and RA4. These risk agents will be addressed through preventive measures in the next phase. The proposed preventive actions fall under HOR Phase II, in which the selected preventive action proposals are prioritized based on their ETDk values.

The proposed preventive actions fall under HOR Phase II, where the selected preventive action proposals are prioritized based on their ETDk values. These risk agents are then incorporated into the HOR Phase II model for designing mitigation actions. The mitigation actions refer to measures intended to reduce the impact of risk agents before the risks occur. The alternative mitigation actions were obtained from interviews and a review of the literature. The design of these mitigation actions focuses on the selected risk agents. The alternative mitigation actions that can be implemented are presented in Table 5.

Table 5. Correlation Values Between Risk Agents and Preventive Actions Along with Their Difficulty Levels

Risk Agent (RA)	Preventive Action (PA)	Source	Correlation	Difficulty Level (DF _k)
Unscheduled pump maintenance	Monitoring pump performance and maintenance SOPs	Informant	9	3
Landslides/flash floods in the river	Flushing sand traps and canals, reducing the number of operating pumps, adding <i>decavlok</i> chemicals	Informant	3	3
	Installing screening at the WTP intake	Author	3	4
Leakage in the distribution pipeline network	Inspection and flushing of the distribution network	Informant	9	4
Insufficient employee competence	Conducting technical training	Informant	9	3
	Developing SOPs for performing technical work	Author	9	3
	Establishing punishment policies for employees who do not perform their work according to SOP	Author	9	4
	Reassigning employees to other divisions according to their field of expertise	Author	3	4
Dry season conditions	Coordinating with dam personnel for water supply management	Informant	3	2
Lack of attention to occupational health and safety (OHS)	providing and using complete PPE and implementing occupational health and safety (OHS) K3	Informant	9	3
	Developing SOPs for	Author	3	3

Risk Agent (RA)	Preventive Action (PA)	Source	Correlation	Difficulty Level (DF _k)
	performing technical work			
Contamination of residents' well water	Inspection and flushing of the distribution network	Informant	9	4

The higher the difficulty value, the more challenging the action is to implement; conversely, a lower difficulty value indicates that the action is easier to implement. Mapping mitigation actions is carried out to determine the influence of each mitigation action on the risk agents by aligning the mitigation options with the selected risk agents. The first step is to measure the correlation values between each mitigation action and the selected risk agents. The second step is to measure the difficulty level (DF_k), which aims to determine how difficult it is to implement each mitigation action. The third step is to calculate the total effectiveness by multiplying the correlation value between the risk agent (j) and the preventive action (k), represented as B_{jk}. The total effectiveness calculation is used to assess how effective each mitigation action is.

The fourth step is to measure the effectiveness-to-difficulty ratio by dividing the total effectiveness value (TEA_k) by the difficulty level of implementing the action. The calculation of the effectiveness-to-difficulty ratio aims to determine the priority ranking of all actions. The total effectiveness (TEA_k) is obtained by calculating the total effectiveness value for each risk agent using the following equation.

$$TEA_k = \sum_j ARP_j B_{jk}$$

$$TEA_4 = (108 \times 9) + (48 \times 9) = 1404$$

The total effectiveness value for the risk agent or PA₄ is 1404. The calculation of the total effectiveness value for implementing mitigation measures relative to the difficulty ratio (ETD_k) is carried out using the following equation.

$$ETD_k = \frac{TEA_k}{DF_k}$$

$$ETD_4 = \frac{1404}{4} = 351$$

The effectiveness-to-difficulty ratio value (ETD_k) for the mitigation action on the risk agent with PA₄ is 351.

Table 6. ETD_k Calculation

Risk Agent (RA)	PA 1	PA 2	PA 3	PA 4	PA 5	PA 6	PA 7	PA 8	PA 9	PA 10	AR P _j
Poorly scheduled maintenance activities	9										162
Landslides or flash floods in the river		3	3								117
Leaks in the distribution pipeline network				9							108
Insufficient employee competence					9	9	9	3			102
Dry season conditions									3		72

Risk Agent (RA)	PA 1	PA 2	PA 3	PA 4	PA 5	PA 6	PA 7	PA 8	PA 9	PA 10	AR Pj
Lack of attention to occupational health and safety (OHS)						3				9	54
Contamination of residents' well water				9							48
Total effectiveness of action k	1458	351	468	1404	918	1161	408	306	405	486	
Degree of difficulty performing action k	3	3	4	4	3	3	4	4	2	3	
Effectiveness to difficulty ratio	486	117	117	351	306	387	102	76.5	202.5	162	
Rank of priority	1	7	8	3	4	2	9	10	5	6	

Table 7 shows that the ranking of preventive actions shows that monitoring pump performance and establishing maintenance SOPs (PA1) is the top priority with the highest ETD value, indicating its strong effectiveness in reducing operational risks. This is followed by developing SOPs for technical tasks (PA6) and conducting inspections and flushing of the distribution network (PA4), both of which play critical roles in strengthening technical reliability. Technical training (PA5) and coordination with dam guards (PA9) also rank highly, reflecting their importance in ensuring operational consistency and water supply stability. Meanwhile, actions such as providing complete PPE and enforcing OHS practices (PA10), operational adjustments involving flushing sand traps and adding chemicals (PA2), and installing intake screening (PA3) hold mid-level priority. The lowest-ranked actions involve implementing disciplinary policies for non-compliance (PA7) and transferring employees based on expertise (PA8), suggesting that while beneficial, they offer comparatively lower effectiveness relative to the effort required.

Table 7. Ranking of Preventive Action

Rank	PA	Preventive Action	ETD
1	PA1	Monitoring pump performance and maintenance SOP	486
2	PA6	Developing SOPs for conducting technical tasks	387
3	PA4	Inspection and flushing of the distribution network	351
4	PA5	Providing technical training	306
5	PA9	Coordination with dam guards for water supply management	202.5
6	PA10	Provision and use of complete PPE and implementation of OHS	162
7	PA2	Flushing sand traps and canals, reducing the number of pumps operated, adding decavlok chemicals	117
8	PA3	Installing screening at the WTP intake	117
9	PA7	Establishing punishment policies for employees who do not perform their duties according to SOPs	102
10	PA8	Transferring employees to other departments according to their field of expertise	76.5

5. Discussion

Based on the ranking table of mitigation actions above, it is shown that PA1 (Monitoring pump performance and maintenance SOPs) occupies the highest priority in reducing the risk of RA7 (Poorly scheduled maintenance activities). Pump performance monitoring using various methods, such as vibration analysis, temperature monitoring, flow and pressure measurement, and thermodynamic testing has been shown to improve pump performance by up to 8% after

maintenance, indicating the importance of monitoring performance parameters such as flow rate and pressure. Clear and structured maintenance SOPs help technicians carry out tasks consistently and safely. Good SOP documentation also supports training and onboarding for new workers and ensures compliance with occupational safety standards such as ISO 45001 (Manghani, 2011).

The second priority action is PA6 (Developing SOPs for technical work). Implementing clear and measurable SOPs directly reduces technical errors and increases compliance with safety procedures, addressing risk agent RA11 (lack of attention to occupational health and safety). The effectiveness of SOPs depends on employee involvement in development, repeated communication of procedures, and internal audits to ensure consistent implementation (Resdiana & Widyastuti, 2019). This also helps reduce risks associated with RA10 (Inadequate employee competency). SOPs without periodic retraining may lose effectiveness over time as personnel or technologies change (Hollmann et al., 2020). Therefore, the success of PA6 lies not only in creating the SOP document but also in ensuring ongoing evaluation, dissemination, and continuous revision to keep up with operational dynamics in water utility companies.

The third priority action is PA4 (inspection and flushing of the distribution network). According to studies on water distribution systems, flushing is an effective operational technique for reducing deposits, maintaining water quality, and mitigating hidden leaks in pipelines thereby reducing risk agent RA4 (contamination from residents' well water) (Vedrin, 2023). Scheduled inspections and flushing allow operators to detect potential pipeline weaknesses early and prevent larger failures such as RA3 (Distribution pipeline leaks). This strategy aligns with leakage management principles, integrating assessment, detection, and prevention to reduce water loss and infrastructure damage (Javed et al., 2025).

The fourth priority action is PA5 (conducting technical training). Many technical competencies are required in water treatment operations, and various risks necessitate specific training, such as: RE9 (falsification of water quality test results), addressed through training in water sampling and laboratory equipment operation (Lane et al., 2003). RE10 (incorrect reporting of chemical usage), addressed through chemical safety management training, including proper storage, handling, and regulatory reporting (Fatemi et al., 2022). RE11 (incorrect budgeting for equipment maintenance), supported by strategic approaches in maintenance budgeting to ensure value for money (Al-Shariyah, 2019). RE12 (use of damaged or uncalibrated equipment), addressed through training in pump repair and calibration, from daily maintenance to overhauls, to ensure reliability and valid testing procedures (Januarsyah & Kirono, 2024).

The fifth priority action is PA9 (coordination with reservoir gatekeepers for water supply management). Water resource management institutions that coordinate across actors, such as dam authorities and water utilities, have been shown to improve allocation efficiency and reduce usage conflicts during droughts (RA5) (Heikkila, 2003). Multi-purpose reservoir management requires intensive operational communication between upstream and downstream operators to balance water supply, irrigation, and flood control needs (Abdelrahim & Al-Malkawi, 2022).

The sixth priority action is PA10 (provision and use of complete PPE and enforcement of occupational safety protocols). Meta-analysis studies show that consistent use of complete PPE significantly reduces the risk of workplace accidents and exposure to physical, chemical, and biological hazards, addressing RA11 (lack of attention to occupational safety) (Malta et al., 2024). However, effectiveness depends heavily on availability, training, and organizational safety culture: workers who understand PPE functions and proper usage are more likely to comply (Tanjung & Susilawati, 2024).

The seventh priority action is PA2 (Flushing sand basins and canals, reducing the number of operating pumps, adding *decaflor* chemicals). According to hydrological system and flood mitigation literature, sediment flushing, pump capacity adjustments, and the use of flocculants (such as *decaflor*) have been shown to reduce sediment loads and increase channel flow capacity (Chen & Tsai, 2017). Although these measures cannot reduce the intensity of river landslides or flash floods (RA2), they can reduce the sediment carried by the water.

The eighth priority action is PA3 (installing intake screening at the water treatment intake). Proper intake screen design must consider flow velocity, mesh opening size, and corrosion-resistant materials because “improperly sized or maintained screens can result in clogging, headloss, and frequent mechanical failures” (Lai et al., 2024). This is supported by experimental studies showing that fouling and wire abrasion from sediment and organic matter “significantly decrease screening efficiency and increase maintenance frequency, particularly under high flow conditions” (Chenari et al., 2024). Thus, while it may not reduce RA2 (River landslides or flash floods), sediment can still be filtered to avoid operational disruptions at the water treatment plant (Dianti, 2023).

The ninth priority action is PA7 (Implementing a punishment policy for workers who do not follow SOPs). Designing a punishment system requires careful consideration because it affects worker psychology and can influence performance. Steps may include a warning-letter system, demotion procedures, or even termination programs (Ishiaka, 2025). Such policies can reduce the likelihood of RA10 (Inadequate employee competency). The tenth priority action is PA8 (Transferring employees to other departments in accordance with their area of expertise). Employee placement must be based on accurate information and appropriate skill specifications. Transferring employees based on relevant certifications ensures they are positioned in roles matching their competencies. This increases operational effectiveness and productivity and reduces the probability of RA10 (Inadequate employee competency) (Bhanu & Silvakalyankumar, 2022).

6. Conclusion

The House of Risk (HOR) framework effectively mapped operational risks and prioritized mitigation strategies using objective, data-driven analysis. The study identified 15 risk events and 26 risk agents, with several, such as unscheduled pump maintenance (RA7), river landslides or flash floods (RA2), and pipeline leakages (RA3) showing the highest Aggregate Risk Potential (ARP). Based on ARP results and Pareto analysis, seven risk agents were designated as the main contributors to nearly 80% of operational issues at the regional drinking water company Denpasar’s water treatment facility. In Phase II, ten preventive actions were formulated and ranked using the Effectiveness to Difficulty (ETD) ratio, ensuring that priorities addressed all high-ARP agents. Key recommended actions include pump performance monitoring and maintenance SOPs (PA1), development of technical SOPs (PA6), and routine inspection and flushing of the distribution network (PA4), all of which are proposed for immediate implementation to significantly reduce operational risks.

As a recommendation, the regional drinking water company is encouraged to establish a dedicated risk management team/unit to ensure effective monitoring and control. Furthermore, the integration of ISO 31000:2018 as the main framework together with HOR (House of Risk) as the analytical method can be applied in other sectors, such as manufacturing, logistics, healthcare, energy, and food and beverage, by adjusting the risk taxonomy, assessment scales, and performance indicators to suit each industry. This study has several limitations that should be acknowledged. The research relies heavily on qualitative data obtained from a limited number of informants directly involved in operational activities, which may restrict the

variability of perspectives and reduce the generalizability of the findings. The analysis is also bounded by the context of a single water treatment installation, meaning that risk characteristics and mitigation priorities may differ across other regional drinking water company units with different environmental, technical, or organizational conditions. In addition, the effectiveness of mitigation actions was assessed conceptually rather than through long-term implementation, so their actual impact on reducing operational risks could not be empirically validated. Future studies are encouraged to incorporate a larger and more diverse set of informants, apply mixed-methods approaches to integrate quantitative operational data, and conduct longitudinal evaluations of implemented mitigation actions to assess real-world performance. Comparative studies across multiple regional drinking water company or water utilities in different regions would also provide broader insights into how contextual factors influence risk patterns and the suitability of the House of Risk framework.

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The data that support the findings of this study are available from the corresponding author upon reasonable request.



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