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Improving Resilience in Water Distribution Systems: An Application of the House of Risk Method at PDAM Gowa Unit Tompobulu

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ABSTRACT

PDAM Gowa, a local government-owned company, plays a vital role in supplying clean water to the Tompobulu community in Gowa District. However, ensuring efficient and reliable water distribution poses challenges at the local and regional levels. This research focuses on enhancing the resilience of the water distribution system to mitigate various risks. The study utilizes the House of Risk (HOR) method for effective risk management and developing suitable mitigation strategies within PDAM's framework. The research identifies 10 risk events and 17 risk factors that affect water distribution in PDAM. Key risks include pipe leakage and supply disruptions. To mitigate these risks, the study proposes nine actionable recommendations for PDAM Gowa Unit Tompobulu. These recommendations involve regular maintenance of distribution infrastructure and equipment to ensure system quality and reliability. Additionally, improving pipe network condition monitoring, implementing leakage control policies, and fostering collaboration with stakeholders to address water supply disruptions are crucial mitigation measures. This research significantly contributes to understanding the risk management associated with water distribution in PDAM. By implementing the recommended mitigation strategies, PDAM Gowa Unit Tompobulu can reduce water distribution risks, enhance system efficiency, and provide improved clean water services to consumers. Moreover, the study has the potential to drive scientific progress and promote the development of best practices and technologies in the drinking water industry.

Keyword: House of Risk, Mitigation Strategies, Resilience, Risk Management, Water Distribution

ABSTRAK

PDAM Gowa, sebuah perusahaan milik pemerintah daerah, memiliki peran penting dalam menyediakan air bersih kepada masyarakat Tompobulu di Kabupaten Gowa. Namun, memastikan distribusi air yang efisien dan dapat diandalkan memiliki tantangan pada tingkat lokal maupun regional. Penelitian ini berfokus pada meningkatkan ketahanan sistem distribusi air untuk mengurangi berbagai risiko. Studi ini menggunakan metode *House of Risk* (HOR) untuk manajemen risiko yang efektif dan pengembangan strategi mitigasi yang sesuai dalam kerangka PDAM. Penelitian ini mengidentifikasi 10 peristiwa risiko dan 17 faktor risiko yang mempengaruhi distribusi air di PDAM. Risiko utamanya meliputi kebocoran pipa dan gangguan pasokan. Untuk mengurangi risiko ini, penelitian ini mengusulkan sembilan rekomendasi tindakan yang dapat dilakukan oleh PDAM Gowa Unit Tompobulu. Rekomendasi tersebut meliputi pemeliharaan rutin terhadap infrastruktur distribusi dan peralatan untuk memastikan kualitas dan kehandalan sistem. Selain itu, meningkatkan pemantauan kondisi jaringan pipa, menerapkan kebijakan pengendalian kebocoran, dan meningkatkan kerjasama dengan pemangku kepentingan untuk mengatasi gangguan pasokan air merupakan langkah mitigasi yang penting. Penelitian ini memberikan kontribusi yang signifikan dalam memahami manajemen risiko yang terkait dengan distribusi air di PDAM. Dengan menerapkan strategi mitigasi yang direkomendasikan, PDAM Gowa Unit Tompobulu dapat mengurangi risiko distribusi air, meningkatkan efisiensi sistem,

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dan menyediakan layanan air bersih yang lebih baik kepada konsumen. Selain itu, penelitian ini memiliki potensi untuk mendorong kemajuan ilmiah dan mempromosikan pengembangan praktik terbaik dan teknologi di industri air minum.
Kata Kunci: Distribusi Air, *House of Risk*, Ketahanan, Manajemen Risiko, Strategi Mitigasi

1. Introduction

Drinking water is a fundamental necessity for humans [1]. We heavily rely on water for daily activities such as washing, cleaning, and bathing [2]. According to the World Health Organization (WHO), in developed countries, each person requires 60-120 liters of water per day, while in developing countries like Indonesia, the requirement is around 30-60 liters per day [3]. Additionally, water has other benefits such as power generation, irrigation, and transportation [4]. As a society progresses, the demand for water also increases. It is crucial for us to ensure that the water we use is not harmful to our health and is free from contamination and hazardous substances [5].

In the provision of clean water, water distribution plays a vital role [6]. In Regional Water Companies (PDAM), the water distribution system must be robust and reliable to ensure that the community receives an adequate and high-quality water supply [7]. However, the water distribution system often faces issues and risks such as supply disruptions, leaks, infrastructure damage, and natural disaster threats [8], [9]. Therefore, it is important to effectively address these risks to ensure smooth and reliable water distribution in PDAM [10].

PDAM Gowa is a local government-owned company that provides clean water to the community of Tompobulu in Gowa District. They utilize water resources and have a Water Treatment Plant (IPA) in Malakaji, Tompobulu. PDAM Gowa Unit Tompobulu serves as an interesting case study in water distribution risk management. Efficient and reliable water distribution is crucial in providing clean water services [11]. PDAM plays a key role in managing and providing safe and adequate water supply to consumers. Challenges in PDAM water distribution often arises at the local and regional levels. Therefore, it is important to understand and address issues related to water distribution [12].

PDAM water distribution involves various complex activities such as collection, treatment, storage, and distribution of water to consumers [13], [14]. Pipe networks, storage tanks, pumps, and other infrastructure play a vital role in ensuring water reaches households and businesses smoothly [15]. However, there are factors that affect the efficiency and reliability of PDAM water distribution [16]. One of them is pipe leakage, which leads to water wastage, decreased water pressure, and reduced service quality [17]. Supply disruption risks can also occur due to operational issues or natural disasters. Water quality is also a primary concern, and damaged or poorly maintained infrastructure can affect the quality of water produced and distributed by PDAM [18]. In-depth analysis of the PDAM water distribution system is necessary to identify and address emerging issues. Research in this field is important to enhance the effectiveness of PDAM water distribution and improve risk management strategies [19].

Previous studies conducted on this topic have provided initial understanding of water distribution risks in PDAM and the mitigation efforts undertaken [20], [21]. However, there is still a need for further research that is more in-depth and comprehensive. Some previous studies may have focused on specific aspects, such as technical risks or environmental risks, but have not fully engaged the House of Risk (HOR) framework in analyzing risks comprehensively. This research aims to highlight the importance of enhancing the resilience of the water distribution system in facing various risks. By applying the House of Risk method [22], this research aims to contribute to more effective risk management and the development of mitigation strategies that are suitable for the specific environment of PDAM Gowa Unit Tompobulu.

2. Research Method

This study utilizes a qualitative research approach by applying the House of Risk method to evaluate and manage risks in water distribution. Data collection involves document analysis, interviews with PDAM Gowa personnel, field observations at the water treatment facility in Malakaji, Tompobulu, and the distribution of questionnaires to 4 respondents, namely the Head of IKK, Technical Supervisor, and General Supervisor. The identified risks and risk factors are analyzed to develop appropriate risk mitigation strategies. The steps in the House of Risk method are as follows:

1. House of Risk Phase 1
   - Identifying risk events (Ei) and risk agents (Aj).
   - Identifying risk events (Ei) and risk agents (Aj).
   - Assigning correlation values between risk events and risk agents, ranging from 0: no correlation, 1: weak correlation, 3: moderate correlation, and 9: strong correlation.
   - Calculating the ARP (Agent Risk Profile) value for the risk agent.

     $ARP_j = O_j \sum S_i R_{ij}$ (1)

     ARP_j is defined as Aggregate Risk Potential, O_j is defined ad Occurrence level of risk, S_i is defined as Severity level of risk, and R_{ij} is defined as Correlation value between risk and risk agent
   - Providing rankings for the ARP (Agent Risk Profile) of each risk agent.
2. House of Risk Phase 2:
   - Creating a design for mitigation actions or preventive actions based on the priorities of Aj.
   - Establishing correlations between Aj and PAP (Preventive Action Plan) with values of 0, 1, 3, and 9, according to predetermined criteria.
   - Calculating the total effectiveness value for each preventive action.

     $TE_k = \sum ARP_j E_{jk}$ (2)

     TE_k is defined as Total effectiveness of each action, ARP_j is defined as Aggregate risk potential, and E_{jk} is defined as Correlation between each preventive action and each risk agent
   - Measuring the degree of difficulty in implementing the preventive action using a scale of 3: easy, 4: moderately difficult, and 5: difficult.
   - Calculating the Effectiveness to Difficulty ratio.

     $ETD_k = TE_k/D_k$ (3)

     ETD_k is defined as Total effectiveness of difficulty ratio, TE_k is defined as Total effectiveness of each action, and D_k is defined as Degree of difficulty
   - Ranking the top priority of preventive actions based on the ETDk value.

3. Result and Discussion

3.1. Results of risk event identification and assessment

The results of risk event identification and the assessment of severity values in the process of distributing clean water at PDAM Gowa Unit Tompobulu can be seen in the following table 1:

Table 1. List of Risk Events

No	Risk Event	Code	Severity
1	Raw water crisis	E1	8
2	Main pipes often experience leaks	E2	7
3	Leakage occurs in distribution pipes	E3	7
4	Malfunctioning or damaged stop valves	E4	6
5	Water loss during the distribution process	E5	7
6	Damage to distribution equipment	E6	6
7	Theft or illegal connections occur	E7	6
8	Suboptimal water distribution to customers	E8	6
9	Changes in water quality occur	E9	4
10	Blockage in distribution pipes	E10	7

3.2. Results of Risk Agent Identification and Occurrence Value Assessment

The results of risk agent identification and occurrence value assessment in the process of distributing clean water at PDAM Gowa Unit Tompobulu can be seen in Table 2.

Table 2. List of Risk Agents

No	Risk Agent	Code	Occurrence
1	High external pressure on pipes	A1	6
2	Damaged or aging water meters	A2	5
3	Erosion of pipe walls	A3	5
4	Non-systematic inspections	A4	6
5	Project work being conducted	A5	5

No	Risk Agent	Code	Occurrence
6	Errors in water meter installation	A6	6
7	Pipes exceeding their service life	A7	4
8	Impact from external objects	A8	7
9	Pipe joints coming loose	A9	7
10	Disruptions in water treatment facilities	A10	8
11	Undetected leaks	A11	8
12	Lack of internal company supervision	A12	6
13	Excessive water billing	A13	6
14	Irregular maintenance schedules	A14	6
15	Inability to pay for water	A15	5
16	Lack of equipment maintenance	A16	6
17	Environmental conditions	A17	2

3.3. House of Risk Phase 1

The objective of House of Risk Phase 1 is to determine which risk sources should be prioritized in order to implement preventive measures against emerging risk agents. The recapitulation of calculations in House of Risk Phase 1 is done through the calculation of Aggregate Risk Potential (ARP), which aims to identify the priority risks that require handling or mitigation. The calculation of ARP values in House of Risk Phase 1 can be seen in Table 3.

Table 3. House of Risk Phase 1

Risk Event	Risk Agent																	Severity of risk
	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17	
E1																	9	8
E2	3		3	1			9	9	3		9	1		3		3		7
E3	3		1	1	9		9	9			9					3		7
E4	1	9		1		3		3						3		9		6
E5										9	9	1				3	9	7
E6	3	9		3				3				1		3		9		6
E7												9	9		9			6
E8				1						9	9	3		1				6
E9									3								9	4
E10				1					3							1		7
Occ of agent	6	5	5	6	5	6	4	7	7	8	8	6	6	6	5	6	2	
ARP	396	540	140	306	315	108	504	1134	378	936	1944	552	324	378	270	1068	342	
Rank	8	6	16	14	13	17	7	2	9	4	1	5	12	10	15	3	11	

Based on the obtained values of Aggregate Risk Potential (ARP), the next step is to evaluate them using the Pareto approach. The prioritization of risk factors in the Pareto diagram is achieved with an 80:20 ratio [23]. This indicates that approximately 80% of the consequences are caused by 20% of the causes, with the main cause being operational disruptions as determined by the risk agents, accounting for 20%. This can be seen in Figure 1.

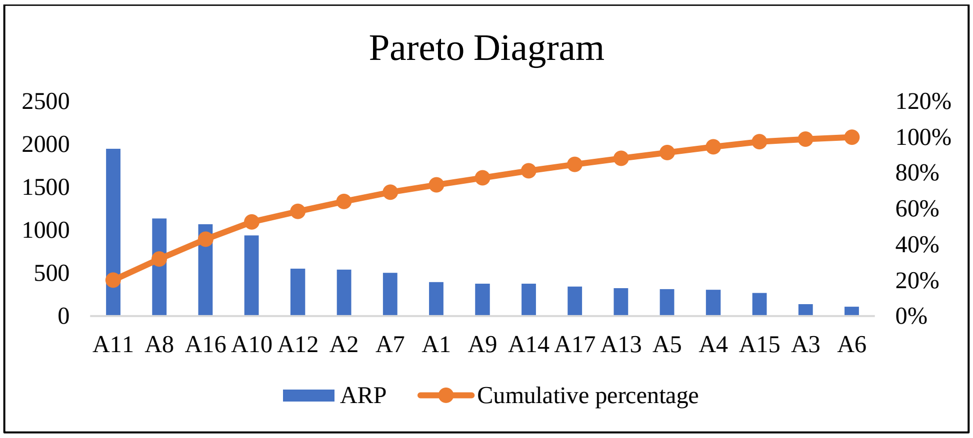

Figure 1. Pareto Diagram

The Pareto diagram is used to determine and identify the priority risk agents that need to be addressed. Here are the results of the Pareto diagram calculation, as shown in Table 4.

Table 4. Results of Pareto Diagram Calculation

Risk Agent	ARP	Occurrence Percentage	Cumulative Percentage	Category
A11	1944	20%	20%	Priority
A8	1134	12%	32%	
A16	1068	11%	43%	
A10	936	10%	53%	
A12	552	6%	58%	
A2	540	6%	64%	
A7	504	5%	69%	
A1	396	4%	73%	
A9	378	4%	77%	
A14	378	4%	81%	Non-Priority
A17	342	4%	85%	
A13	324	3%	88%	
A5	315	3%	91%	
A4	306	3%	94%	
A15	270	3%	97%	
A3	140	1%	99%	
A6	108	1%	100%	
Total	9635	100%		

After identifying the list of dominant or priority risk sources, the next step is to perform the mapping of dominant risks. This mapping aims to assess the risk conditions before any mitigation measures are implemented. Here are the results of the initial risk mapping of the dominant risk agents obtained from the priority data in Table 4, as shown in Table 5.

Table 5. Results of Risk Map Determination Before Risk Mitigation

Occurrence Level		Severity Level				
		1	2	3	4	5
		Very Low	Low	Medium	High	Very High
5	Veri High		A7			
4	High			A10,A8	A9,A11	
3	Medium			A16, A12 A1		
2	Low					
1	Very Low					

From the mapping of risk sources, it is observed that there are 4 risk agents in the red or critical area, indicating that these risks require immediate handling. Additionally, 5 risk agents are in the yellow area, indicating moderate risks. There are no risk agents in the green area, indicating that they do not require regular management and effective control measures. It is crucial to prioritize and address the risks in the red and yellow areas to ensure the effective mitigation of potential negative consequences. Regular monitoring and control measures should be implemented for the identified risk agents to maintain a proactive risk management approach.

3.4. House of Risk Phase 2

The next step after identifying the priority risk agents is House of Risk Phase 2. The most important process in risk management is designing mitigation actions, assessing the correlation level between mitigation strategies and each risk agent, calculating the Total Effectiveness (TEk), Degree of Difficulty (Dk), and Effectiveness to Difficulty (ETDk), and ranking the main priority of preventive actions based on the ETDk values. Assessing the level of difficulty is based on the company's estimation or perception of implementing the mitigation strategies. The scale indicating the degree of difficulty can be seen in Table 6.

Table 6. Risk Mitigation Strategy Plan

No	Strategy Code	Mitigation Strategy	Dk
1	PA1	Implementation of remote distance monitoring system or regular preventive maintenance	4
2	PA2	Regular planning of inspections for pipeline networks.	3
3	PA3	Scheduling regular maintenance and equipment checks to ensure the implementation of a robust system.	3
4	PA4	Regular scheduling of inspections and maintenance for water treatment facilities.	3
5	PA5	Routine scheduling of employee evaluations.	3
6	PA6	Regular planning of meter inspections to detect any anomalies.	3
7	PA7	Planning the creation of a pipeline age database for early warnings.	3
8	PA8	Utilizing or involving pipe materials, implementing early detection systems, and conducting regular maintenance to monitor system constraints periodically.	4
9	PA9	Conducting periodic maintenance or checks, utilizing early detection technology, and selecting high-quality materials.	4

After obtaining the mitigation actions and degree of difficulty values, the next step is to perform the calculation for House of Risk Phase 2. In this table, HOR Phase 2, various variables are combined, including the strategy planning data, dominant risk agent data, calculation of aggregate risk potential (ARP) from dominant risk agents, degree of difficulty (Dk) data, as well as the calculation of total effectiveness (TE_k) and effectiveness to difficulty (ETD_k) to determine the priority order of mitigations. Here is the Table 7 for HOR Phase 2:

Table 7. House of Risk Phase 2

Risk Agent (Ai)	Preventive Action (PA)									ARP
	PA1	PA2	PA3	PA4	PA5	PA6	PA7	PA8	PA9	
A11	9	3	1				3	3	3	1944
A8	1	3								1134
A16			9		3				1	1068
A10		1	3	3					3	936
A12				3	3					552
A2			3			9			1	540
A7	1	1	3				9		1	504
A1								3		396
A9		3	1						9	378
TEk	19134	11808	17874	4464	6012	4860	10368	7020	14154	
Dk	4	3	3	3	3	3	3	4	4	
ETD	4784	3936	5958	1488	2004	1620	3456	1755	3539	
Rank	2	3	1	9	6	8	5	7	4	

From the results of Table 7, here are the ETDk values of risk mitigation strategies for water distribution, ranked in order of priority. Based on the calculations in HOR Phase 2, the sequence of handling strategies that can be implemented according to priority order can be seen in Table 8.

Table 8. Prioritized Risk Mitigation Strategies

Rank	Code	Proposed Mitigation	ETDk Value
1	PA3	Scheduling regular maintenance and equipment checks to ensure the implementation of a robust system.	5958

Rank	Code	Proposed Mitigation	ETDk Value
2	PA1	Implementation of remote distance monitoring system or regular preventive maintenance	4784
3	PA2	Regular planning of inspections for pipeline networks.	3936
4	PA9	Conducting periodic maintenance or checks, utilizing early detection technology, and selecting high-quality materials.	3539
5	PA7	Planning the creation of a pipeline age database for early warnings.	3456
6	PA5	Routine scheduling of employee evaluations.	2004
7	PA8	Utilizing or involving pipe materials, implementing early detection systems, and conducting regular maintenance to monitor system constraints periodically.	1755
8	PA6	Regular planning of meter inspections to detect any anomalies.	1620
9	PA4	Regular scheduling of inspections and maintenance for water treatment facilities.	1488

It is expected that after implementing the above preventive maintenance mitigation design, the risk agents previously categorized in the red or yellow areas will experience a decrease in risk values. This change is anticipated to bring about positive improvements in addressing potential risk sources. Table 9, illustrates the expected outcomes after prioritizing the handling strategies.

Table 9. Expected Risk Map After Prioritizing Handling Strategies

Occurrence Level		Severity Level				
		1	2	3	4	5
		Very Low	Low	Medium	High	Very High
5	Veri High					
4	High		A11			
3	Medium	A10	A8, A9			
2	Low		A16, A1			
1	Very Low	A7, A12	A2			

3.5. *Discussion on Risk Identification*

In the process of risk identification, data on risk events and risk agents were obtained through direct interviews with the Head of IKK (Water Supply Division), the Technical Section Head, and two General Section Heads of the company. A total of 10 risk events and 17 risk agents were identified based on these interviews. These risks are either historical incidents or have the potential to occur during the water distribution process, such as water loss (E5) and distribution pipe leakage (E3). According to the research conducted by Dinda Rita and Winardi Dwi Nugroho, both of these risks have also been observed in the PDAM (Regional Water Supply Company) of Magelang City, where the percentage of water loss due to pipe leakage in their study area was reported to be 45.25%. After obtaining the identified risk events and risk agents, the severity values were calculated to determine the impact or intensity of the events on the water distribution process. Additionally, occurrence values were calculated to assess the likelihood of these risks occurring and resulting in failures during water distribution. The severity and occurrence values were provided by the relevant company stakeholders.

3.6. *Discussion on House of Risk Phase 1*

HOR Phase 1 is the initial stage of the House of Risk method, where risk identification takes place to prioritize preventive actions. The steps in HOR Phase 1 are carried out after identifying and assessing risks, which includes evaluating the severity level, occurrence level, and correlation assessment. Then, the Aggregate Risk Potential (ARP) value is calculated to determine the risk agents that require preventive measures by ranking the ARP values. The obtained ARP values are then inputted into a Pareto diagram to identify dominant risks based on the Pareto principle. From the previous table, it is known that there are 9 dominant risk agents identified from the results of HOR Phase 1 in the Pareto diagram. The descriptions of these 9 dominant risks are as follows:

Risk agent A11, "Undetected leakage occurrence," has the highest ARP value of 1944 according to the calculations in HOR Phase 1, making it the top priority risk. This risk agent occurs due to the absence of a remote distance monitoring system or regular preventive maintenance program. Based on the risk map in Table 5, A11 falls within the red zone, indicating a critical risk. Risk agent A8, "External object collision," has an ARP value of 1134 and poses a critical risk as well. This risk occurs due to foreign objects causing damage to the pipes, disrupting water supply, and the lack of regular inspections on the distribution pipe network. It is also identified within the red zone on the risk map. Similarly, risk agent A16, "Insufficient equipment maintenance," has an ARP value of 1068. It occurs due to equipment malfunction or damage, leading to disruptions in distribution. Establishing a regular equipment maintenance schedule is crucial to mitigate this moderate risk. According to the risk map, A16 is categorized in the yellow zone. Moving on to risk agent A10, "Disruption in water treatment facilities," it has an ARP value of 936 and is considered a critical risk. Regular checking and maintenance of water treatment facilities are essential to prevent any potential disruptions. The risk map also places A10 within the critical risk area [24].

Risk agent A12, "Lack of internal company supervision," has an ARP value of 552, categorizing it as a moderate risk in the yellow zone. This risk occurs due to insufficient monitoring and regular evaluation of employees. Similarly, risk agent A2, "Old or damaged water meters," has an ARP value of 540, also falling within the yellow zone on the risk map. The risk arises from the lack of routine checks to ensure the meters' suitability. Moving on to risk agent A7, "Exceeding pipe lifespan," it carries an ARP value of 504, categorizing it as a moderate risk in the yellow zone. This risk occurs when pipes used by the water utility company surpass their recommended lifespan, resulting in damage to the distribution pipes. Risk agent A1, "High external pressure on the pipes," has an ARP value of 396, placing it in the moderate risk category within the yellow zone. This risk stems from construction or development activities, blockages or damage to water channels, material usage or selection, and the need for early detection systems and regular maintenance to monitor system constraints periodically. Lastly, risk agent A9, "Pipe disconnection," has an ARP value of 378, indicating a critical risk in the red zone. This risk can be mitigated through regular maintenance checks, the use of early detection technology, and the selection of high-quality materials [25].

3.7. Discussion on House of Risk Phase 2

The next step after identifying the priority risk agents is to proceed with House of Risk Phase 2. The most crucial process in addressing risks is to design mitigation actions, evaluate the correlation level between mitigation strategies and each risk agent, calculate the Total Effectiveness (TEk), Degree of Difficulty (Dk), and Effectiveness to Difficulty (ETDk) values, and prioritize preventive actions based on the ETDk scores. Once the dominant risk agents that require immediate attention are identified, risk management strategies and calculations will be implemented. The results obtained from House of Risk Phase 1 will serve as input for the subsequent phase, House of Risk Phase 2. The ETD values will be used as parameters for determining the feasibility of mitigation actions. Higher ETD values indicate more ideal mitigation actions to be implemented. The following is a description of the prioritized risk management strategies based on the priority risk agents, starting with:

The risk mitigation strategies start with PA3, "Scheduling regular maintenance and equipment checks to ensure the implementation of a robust system." This strategy emphasizes the importance of establishing a regular maintenance schedule to preserve assets and maintain discipline in adhering to the schedule, reducing the potential for damages. It has an ETD value of 5958. Moving on to PA1, "Implementation of remote distance monitoring system or regular preventive maintenance." This strategy involves the use of remote monitoring systems or preventive maintenance programs to swiftly and efficiently detect undetected leaks in the water distribution pipes. By utilizing appropriate technology, problems can be identified early, minimizing losses caused by leaks. The ETD value for this strategy is 4782. Next, we have PA2, "Regular planning of inspections for pipeline networks." This strategy underscores the importance of conducting regular inspections to assess the physical condition of the pipelines and prevent damage in the distribution system. It has an ETD value of 3936. Lastly, PA9 focuses on "Conducting periodic maintenance or checks, utilizing early detection technology, and selecting high-quality materials." This strategy involves scheduling regular maintenance and checks, utilizing early detection technology, and using high-quality materials in the distribution system to preserve assets and ensure the quality of service, reducing the potential for disruptions in clean water distribution. Its ETD value is 3539 this risk mitigation has been implemented [26].

Risk mitigation PA7 involves "Planning the creation of a pipeline age database for early warnings." This strategy entails collecting data on pipe replacement, installation, and repairs to create a database that facilitates the PDAM's knowledge of the technical lifespan of pipes. It has an Effectiveness to Difficulty Ratio (ETD) value of 3456. Next is PA5, "Routine scheduling of employee evaluations." It is essential to conduct regular evaluations of employees to assess their performance while carrying out their duties and responsibilities. This strategy has an ETD value of 2004. Moving on to PA8, "Utilizing or involving pipe materials, implementing early detection systems, and conducting regular maintenance to monitor system constraints periodically." To handle external high-pressure situations, selecting strong and pressure-resistant pipe materials is crucial. Commonly used materials for such situations include stainless steel, high-carbon steel, or high-density polyethylene (HDPE). Material selection should consider environmental conditions. This strategy has an ETD value of 1755. Then we have PA6, "Regular planning of meter inspections to detect any anomalies." This strategy involves regularly checking customer water meters to ensure their proper functioning. It has an ETD value of 1620. Lastly, the risk mitigation strategy involves "Regular scheduling of inspections and maintenance for water treatment facilities." Scheduling regular checks and maintenance for the PDAM's water treatment facilities is crucial to ensure optimal performance and avoid disruptions in water supply. This includes routine equipment inspections, replacement of worn-out parts, and preventive maintenance to prevent future issues. By implementing these measures, the company can ensure efficient system operation. This strategy has an ETD value of 1488 this risk mitigation has been implemented [27].

4. Conclusion

This research emphasizes the importance of enhancing the resilience of water distribution systems in facing various risks. By implementing the House of Risk method, this study significantly contributes to the risk management of water distribution in PDAM Gowa Unit Tompobulu. The research findings reveal the existence of 10 risk events and 17 risk factors that need to be considered. Through the House of Risk analysis, 9 prioritized risk factors are identified, with 4 factors categorized as high risk and 5 factors as medium risk. This study recommends a mitigation strategy consisting of 9 preventive actions with appropriate handling plans to address the identified risk factors. By implementing this strategy, PDAM Gowa Unit Tompobulu can reduce risks in water distribution, improve system efficiency, and provide better clean water services to consumers. Furthermore, this research has the potential to drive scientific progress and the development of best practices and technologies in the drinking water industry. Recommendations for further research involve incorporating the following aspects to enhance understanding and effectiveness in the risk management of water distribution in PDAM Gowa Unit Tompobulu. Firstly, the research can focus on further identification and analysis of the identified risk factors, including high and medium risks, to understand their root causes and potential impacts. Additionally, exploring external factors that influence the water distribution system, such as environmental factors, regulatory policies, and climate change, can strengthen the overall understanding. Moreover, integrating stakeholder perspectives, including customers, government, and local communities, can provide more comprehensive insights into risks and suitable solutions. Further research can also involve the use of advanced technologies, such as remote monitoring systems and real-time data analysis, to enhance early risk detection and prompt decision-making in problem-solving. With this approach, further research can make a more substantial contribution to the development of best practices in water distribution risk management, enabling PDAM Gowa Unit Tompobulu to continually improve the quality of clean water services to the community.

References

[1] D. Cannas, E. Loi, M. Serra, D. Firinu, P. Valera, and P. Zavattari, “Relevance of essential trace elements in nutrition and drinking water for human health and autoimmune disease risk,” *Nutrients*, vol. 12, no. 7. MDPI AG, pp. 1–22, Jul. 01, 2020. doi: 10.3390/nu12072074.

[2] A. Wutich, A. Y. Rosinger, J. Stoler, W. Jepson, and A. Brewis, “Measuring Human Water Needs,” *American Journal of Human Biology*, vol. 32, no. 1, pp. 1–17, Jan. 2020, doi: 10.1002/ajhb.23350.

[3] R. Prasetiawati, F. Nasution, and N. Lubis, “Efforts to Increase People’s Knowledge Through Counseling in Realizing Healthy Homes,” *Abdi: Jurnal Pengabdian dan Pemberdayaan Masyarakat*, vol. 4, no. 2, pp. 346–351, Nov. 2022, doi: 10.24036/abdi.v4i2.336.

[4] H. A. Awaad, E. Mansour, M. Akrami, H. E. S. Fath, A. A. Javadi, and A. Negm, “Availability and feasibility ofwater desalination as a non-conventional resource for agricultural irrigation in the MENA region: A review,” *Sustainability (Switzerland)*, vol. 12, no. 18. MDPI, pp. 1–14, Sep. 01, 2020. doi: 10.3390/su12187592.

[5] B. S. Rathi, P. S. Kumar, and D. V. N. Vo, “Critical review on hazardous pollutants in water environment: Occurrence, monitoring, fate, removal technologies and risk assessment,” *Science of the Total Environment*, vol. 797, no. 149134, pp. 1–22, Nov. 2021, doi: 10.1016/j.scitotenv.2021.149134.

[6] R. S. Kookana, P. Drechsel, P. Jamwal, and J. Vanderzalm, “Urbanisation and emerging economies: Issues and potential solutions for water and food security,” *Science of the Total Environment*, vol. 732, no. 139057, pp. 1–14, Aug. 2020, doi: 10.1016/j.scitotenv.2020.139057.

[7] I. Putra, H. Hermawan, and A. F. Wijaya, “Public-Private Partnership (PPP) to Improve the Drinking Water Supply System: A Study on the Regional Government of East Java Province,” 2022. [Online]. Available: http://journalppw.com

[8] H. M. Ramos, A. Carravetta, and A. Mc Nabola, “New challenges in water systems,” *Water (Switzerland)*, vol. 12, no. 9. MDPI AG, pp. 1–13, Sep. 01, 2020. doi: 10.3390/W12092340.

[9] K. B. Adedeji and Y. Hamam, “Cyber-physical systems for water supply network management: Basics, challenges, and roadmap,” *Sustainability (Switzerland)*, vol. 12, no. 22, pp. 1–30, Nov. 2020, doi: 10.3390/su12229555.

[10] K. Ali, R. N. Rizky, and A. Ulayya, “Service Quality Analysis of the Regional Drinking Water Company (PDAM) Tirta Sejuk Against the Need for Clean Water in Blangkejeren,” *PERSPEKTIF*, vol. 13, no. 1, pp. 51–59, Jan. 2024, doi: 10.31289/perspektif.v13i1.10491.

[11] M. Salehi, “Global water shortage and potable water safety; Today’s concern and tomorrow’s crisis,” *Environ Int*, vol. 158, no. 106936, pp. 1–7, Jan. 2022, doi: 10.1016/j.envint.2021.106936.

[12] M. K. Jha, A. Shekhar, and M. A. Jenifer, “Assessing groundwater quality for drinking water supply using hybrid fuzzy-GIS-based water quality index,” *Water Res*, vol. 179, no. 115867, pp. 1–16, Jul. 2020, doi: 10.1016/j.watres.2020.115867.

[13] A. I. Mayrazaka, R. D. Priantana, and S. Sayuthi, “Analysis of Determination of Production Costs and Full Cost Recovery (a Case Study at PDAM XYZ Banda Aceh City),” *Formosa Journal of Applied Sciences*, vol. 3, no. 1, pp. 311–328, Feb. 2024, doi: 10.55927/fjas.v3i1.7636.

[14] E. Kusrini, K. N. Safitri, and A. Fole, “Design Key Performance Indicator for Distribution Sustainable Supply Chain Management,” in *2020 International Conference on Decision Aid Sciences and Application, DASA 2020*, Institute of Electrical and Electronics Engineers Inc., Nov. 2020, pp. 738–744. doi: 10.1109/DASA51403.2020.9317289.

[15] L. M. Dang *et al.*, “Fifth generation district heating and cooling: A comprehensive survey,” *Energy Reports*, vol. 11. Elsevier Ltd, pp. 1723–1741, Jun. 01, 2024. doi: 10.1016/j.egyr.2024.01.037.

[16] M. Haekal and P. Tiningsih, “Performance Evaluation of Water Supply Company (PDAM) in Depok,” *European Journal of Business and Management Research*, vol. 5, no. 2, pp. 1–5, Mar. 2020, doi: 10.24018/ejbmr.2020.5.2.262.

[17] C. A. M. Ávila, F. J. Sánchez-Romero, P. A. López-Jiménez, and M. Pérez-Sánchez, “Leakage management and pipe system efficiency. Its influence in the improvement of the efficiency indexes,” *Water (Switzerland)*, vol. 13, no. 14, pp. 1–25, Jul. 2021, doi: 10.3390/w13141909.

[18] I. Darwis, M. Selintung, B. Bakri, and Y. Arai, “The Infrastructure Performance of Wajo Regency’s Regional Water Company Based on Costumer’s Perceptions,” in *IOP Conference Series: Earth and Environmental Science*, IOP Publishing Ltd, Sep. 2021, pp. 1–11. doi: 10.1088/1755-1315/841/1/012033.

[19] T. M. Kamaludin, A. Rusdin, Nirmalawati, A. Fadjar, and A. Wahab, “Risk Management in the Development of a Regional Drinking Water Supply System,” in *IOP Conference Series: Earth and Environmental Science*, Institute of Physics, 2022, pp. 1–11. doi: 10.1088/1755-1315/1075/1/012038.

[20] W. Spalanzani, U. Ciptomulyono, M. Suef, Asmuddin, and Salwiah, “Fault tree and decision making trial and evaluation laboratory model for formulating risk mitigation strategies at water production process of PDAM Baubau,” in *AIP Conference Proceedings*, American Institute of Physics Inc., Apr. 2020, pp. 1–9. doi: 10.1063/5.0000750.

[21] Y. Herdianzah, “KRI Design and Mitigation Strategy on Water Distribution of Perumda Air Minum Makassar Regional IV: A Case Study,” *Journal of Industrial Engineering Management*, vol. 5, no. 2, pp. 70–79, Nov. 2020, doi: 10.33536/jiem.v5i2.672.

[22] A. Fole, “Designing a Risk Mitigation Strategy for CV. JAT Business Processes Using the House of Risk Method,” 2023. doi: 10.58227/jiei.v1i02.109.

[23] E. Kusrini, K. N. Safitri, and A. Fole, “Risk Mitigation In Distribution Sustainable Supply Chain Management Using The Method Of House Of Risk (HOR),” Yogyakarta, Apr. 2022. doi: 10.32502/js.v7i1.4348.

[24] A. Negm, X. Ma, and G. Aggidis, “Review of leakage detection in water distribution networks,” in *IOP Conference Series: Earth and Environmental Science*, Institute of Physics, 2023, pp. 1–14. doi: 10.1088/1755-1315/1136/1/012052.
[25] N. Mashhadi, I. Shahrour, N. Attoue, J. El Khattabi, and A. Aljer, “Use of machine learning for leak detection and localization in water distribution systems,” *Smart Cities*, vol. 4, no. 4, pp. 1293–1315, Dec. 2021, doi: 10.3390/smartcities4040069.
[26] S. Zhai, B. Gehring, and G. Reinhart, “Enabling predictive maintenance integrated production scheduling by operation-specific health prognostics with generative deep learning,” *J Manuf Syst*, vol. 61, pp. 830–855, Oct. 2021, doi: 10.1016/j.jmsy.2021.02.006.
[27] Q. Deng, B. F. Santos, and R. Curran, “A practical dynamic programming based methodology for aircraft maintenance check scheduling optimization,” *Eur J Oper Res*, vol. 281, no. 2, pp. 256–273, Mar. 2020, doi: 10.1016/j.ejor.2019.08.025.