International Journal of Research Studies in Management
2024 Volume 12 Number 16, 215-226

Drinking water infrastructure, network and risk management: Basis for security framework

Wu, Tang ✉
Graduate School, Lyceum of the Philippines University - Batangas, Philippines

Received: 25 October 2024 **Revised**: 22 November 2024 **Accepted**: 20 December 2024
Available Online: 20 December 2024 **DOI**: 10.5861/ijrsm.2024.1333

ISSN: 2243-7770
Online ISSN: 2243-7789

OPEN ACCESS

Abstract

Access to safe and potable water is a fundamental need of every individual as well as an important factor in stimulating economic growth. Yet the modern drinking water systems are complicated and integrated as well as demanding. This study aimed to examine the water infrastructure, water networks management, and risk management systems in the drinking water industries for improving the sustainability, resilience and efficiency of the water supply systems. In the study, a descriptive design was adopted as it was used to assess the present status of the existing water infrastructure, evaluation of water network management practices currently being applied, and identification of the typical risks and challenges encountered by the water supply sectors. The research utilized a self-designed questionnaire as the study tried to address issues or problems that are very specific to the study area. Self-designed questionnaire allows the researcher to meet these specific needs more effectively. The 400 employees from five drinking water companies in China were used as respondents of the study. They possessed extensive theoretical and practical understanding of the existing systems in place for water infrastructure, network and risk management in the water sector. Based from the results, the water infrastructure are in place as to physical infrastructure, data driven and water quality. The respondents showed agreement on the water network management in terms of asset management, water monitoring and treatment and operational efficiency and optimization. They also generally agreed on the risk management practices utilized as to hazard identification, risk mitigation and control measures and evaluation and verification process. A high significant relationship was found between water infrastructure, water network management and risk management. An integrated drinking water management framework was developed for drinking water industries.

Keywords: water infrastructure, water network management, risk management, integrated drinking water management framework

Drinking water infrastructure, network and risk management: Basis for security framework

1. Introduction

Access to clean, secure drinking water is crucial to human well-being and well-being. In any case, conveying this imperative asset reliably and dependably faces developing challenges. Aging infrastructure, growing water shortages, and the emergence of new contaminants threaten the sustainability and security of the drinking water supply. This study examines three essential pillars of an effective drinking water system which are water infrastructure, water network management and risk management. By integrating these sectors, the researcher aims to develop a comprehensive framework to ensure the safety, reliability and sustainability of drinking water supply.

Water infrastructure refers to the network of physical assets required to deliver drinking water to consumers. According to the American Water Works Association, water infrastructure includes all components from source to tap like water treatment plants, tanks and networks distribution. Understanding the condition and performance of these infrastructures is essential to maintaining water quality and minimizing losses. It is worth noting that water infrastructure includes the physical components that transport water, from the source like in rivers and reservoirs to treatment plant, storage tank, and distribution pipelines. Maintenance and modernization of these infrastructures is critical to water quality and loss reduction (Idrica, 2024). According to Wang et. al.,(2019), more researches are ongoing to develop new materials for pipes and other infrastructure components that are more durable, corrosion-resistant, and have self-healing properties. It was also revealed that there is a growing focus on integrating sensors and monitoring systems into water infrastructure. This allows for real-time data collection, leak detection, and improved decision-making for maintenance and repairs.

Water network management (WNM) refers to the strategies, practices, and technologies used to optimize the performance of water distribution systems. Its primary goal is to ensure an efficient supply of clean water, minimize water loss, and maintain adequate pressure throughout the system. Water network management focuses on efficient water supply throughout the system. This includes monitoring flow patterns, identifying leaks and optimizing pressure to ensure water reaches consumers consistently. Data-driven network management helps optimize resource allocation and reduce operating costs. Moreover, the study of Wu, et al., (2020) disclosed that advanced data modeling and analytics play an increasingly important role in optimizing network performance, forecasting demand, and identifying areas for improvement. Sensor network and real-time monitoring enable leak detection, pressure management, and better overall network visibility. It is interesting to note that artificial intelligence is explored for tasks such as detecting anomalies, optimizing pump operations, and predicting water consumption patterns to improve efficiency of the network (Lee, et al., 2022).

Risk management is an important process in the drinking water industry that identifies, evaluates and mitigates potential threats to the safety and quality of our drinking water. It is a proactive approach that ensures a comprehensive understanding of vulnerabilities and implements strategies to minimize their impact (Bartram et. al.,2019). Risk management involves identifying potential risks of pollution from a variety of sources, the failure of aging infrastructure or natural disasters. Developing mitigation strategies will reduce the risk of contaminated water reaching consumers, thereby protecting public health and the environment. A study by Mallett et al. (2019) found that risk-based management, where resources are allocated based on threat severity and likelihood, is more efficient than traditional compliance-driven methods. The study also emphasized the importance of collaboration between water utilities, public health agencies, and stakeholders in developing and implementing effective risk management strategies. In addition, Wu et. al.,(2021) explored using sensors, data analytics, and AI for real-time water quality and infrastructure monitoring, enabling more proactive risk management.

Water utilities may not have complete data on infrastructure conditions, water flow patterns or past pollution events which can hinder risk analysis and assessment. Water infrastructure, network management and risk management may be managed by separate departments or units, making it difficult to have an integrated approach. The water industry faces a potential knowledge gap as experienced professionals retire. Training and transferring knowledge to the next generation is very important. Developing standardized approaches to risk assessment, infrastructure evaluation, and network performance analysis can be challenging. Effectively translating research findings into practical solutions and implementing them in real water management systems can be challenging. By addressing these challenges, researchers can help develop more robust and sustainable water management practices that ensure clean drinking water for future generations. There are few researches that develop effective public education and engagement strategies to increase public understanding of water infrastructure challenges and build support for needed improvements and investments. Research plays a critical role in developing innovative and sustainable solutions to ensure equitable access to safe and affordable drinking water for all, especially underserved communities. Research can help inform the development of adaptive policy and regulatory frameworks that promote innovation and encourage water utilities to invest in new technologies and best practices.

The researcher aims to establish a framework for drinking water management that will support the development and implementation of best practices throughout the water supply chain and will promote responsible infrastructure planning and water use for future generations. This study will explore how these areas can be seamlessly integrated to achieve the safe and reliable water supply. Effective network management and risk mitigation ensure consistent access to potable water. This research will contribute to an important field by determining the best practices in the development, operation, and maintenance of water infrastructure. This will also promote innovative approaches to water network management for optimal performance and will develop a strong risk management strategies to proactively mitigate threats. Understanding of entire water infrastructure systems, network management strategies and risk mitigation techniques will enable better management decisions, optimize costs and provide efficient services.

Objectives of the Study - The study aimed to examine the water infrastructure, network and risk management in 5 drinking water companies in China that will be the basis in developing an integrated drinking water security framework. Specifically, the study determined the water infrastructure as to physical infrastructure, data driven infrastructure and water quality; assessed the water network in terms of asset management, environmental impact and operational efficiency and optimization; evaluated the risk management as to hazard identification, risk mitigation and control measures and evaluation and verification process; tested the significant relationship among water infrastructure, water network management and risk management; and developed a drinking water security framework.

2. Methods

Research Design - The descriptive design helps researchers gather information about the drinking water industry's existing water infrastructure, network management practices, and current risk management strategies. This creates a basic understanding of the system's strengths and weaknesses. Through descriptive design, the proponent was able to describe the current state allowing researcher to identify infrastructure limitations, network inefficiencies, and potential risks associated with existing risk management activities. Additionally, improvement opportunities can be identified in each of these areas. This type of research also provides a detailed picture of the characteristics and behavior of a particular group of people or a particular phenomenon.

Participants of the Study - The study used 400 employees from drinking water industry in China. Five drinking water companies were used as the research locale of the study. Employees have firsthand knowledge of the water infrastructure and network they manage. They are also involved in water treatment, distribution, and maintenance and can be a valuable source of data for the study. Employees can shed light on how water network management and risk management are actually carried out in practice.

Instrument of the Study - The proponent used a self-made survey questionnaire as the data gathering instrument to assess the variables understudy. Survey questionnaire allowed the researcher to collect information from large numbers of people involved in the drinking water industry. The first part of the questionnaire assessed the water infrastructure as to physical infrastructure, data driven infrastructure and technology infrastructure. The second part evaluated the water network management in terms of asset management, environmental impact and operational efficiency and optimization and the third part described the risk management as to hazard identification, risk mitigation and control measures and evaluation. The instrument undergone content validation by 3 experts in the field and reliability test with the following cronbach's alpha.

Table 1

Reliability Summary Table

Indicators	Cronbach Alpha	Remarks
Water Infrastructure Management, Water Network and Risk Management	.986	Excellent
Per variable		
Water Infrastructure Management	.973	Excellent
Physical infrastructure	.955	Excellent
Data Driven Infrastructure	.958	Excellent
Technology infrastructure	.902	Excellent
Water Network	.979	Excellent
Asset Management	.934	Excellent
Environmental impact	.960	Excellent
Operational efficiency and optimization	.919	Excellent
Risk Management	.970	Excellent
Hazard identification	.902	Excellent
Risk mitigation	.928	Excellent
Control measures and evaluation	.955	Excellent

Data Gathering Procedure - The researcher developed clear and concise indicators for the three variables to assess the desired information. After approval of the adviser, it was sent to panel of experts for content validation. The pilot testing was done to a small group to identify any issues and problems to refine the indicator. The sampling procedure was selected by the proponent and prepared a letter addressed to the HR head of the five companies to allow him for the data gathering. The employees of the five companies were selected using convenience-purposive sampling technique. After approval of the HR head, the questionnaire was administered offline and online to the respondents in the five companies. All the data gathered was collated, tabulated, interpreted and analyzed for the completion of the research study.

Data Analysis - Weighted mean and rank were used to determine the water infrastructure as to physical infrastructure, data driven infrastructure and water quality, assess the network in terms of asset management, water monitoring and treatment and operational efficiency and optimization; evaluate the risk management as to hazard identification, risk mitigation and control measures and evaluation and verification process. The result of Shapiro-Wilk Test showed that p-values of all variables were less than 0.05 which means that the data set was not normally distributed. Therefore, Spearman rho was used as part of the non-parametric tests to determine the significant relationship. All analyses were performed using SPSS version 28.

Ethical Consideration - Water company employees can confidently participate in this research, knowing that their contributions was used responsibly and ultimately lead to a safe and sustainable water management framework. Respondents were clearly informed about the purpose of the research and how their participation will contribute to the development of the water management framework. Employees were encouraged to provide information that is truthful and accurate to the best of their knowledge. Informed consent was obtained from participants, explaining the purpose of the interview and how the data would be used. Ethical considerations are important in any research and researchers must obtain informed consent, protect participant confidentiality, and ensure collection and analysis collect data responsibly.

3. Results and discussion

Table 2

Summary Table on Water Infrastructure

Key Result Areas	Composite Mean	VI	Rank
Physical Infrastructure	3.27	Agree	1
Data Driven Infrastructure	3.19	Agree	2
Water Quality	3.18	Agree	3
Grand Composite Mean	3.21	Agree	

Legend:3.50-4.00=Strongly Agree;2.50-3.49=Agree;1.50-2.49=Disagree;1.00-1.49=Strongly Disagree

Table 2 presents the summary table on water infrastructure in terms of physical infrastructure, data driven infrastructure, and water quality, with a grand composite mean of 3.21 which indicates agree on all indicators. Water infrastructure can be defined as any combination of systems and facilities responsible for delivering water and sanitation services. These three components are thus interlinked and necessary in ensuring that safe, reliable, and sustainable water services are delivered. For example, possession of the necessary physical infrastructure that delivers water to consumers is necessary, but data-driven infrastructure can optimize the use of that infrastructure while improving the quality of water. Among the dimensions, physical infrastructure obtained the highest rank with a composite mean of 3.27 and an agreed verbal interpretation. This proves that the highest rank given to water infrastructure in terms of physical infrastructure likely reflects its critical importance to society and the substantial investment required to maintain and improve it. As they are exposed to continuous interactions with their physical environment, such as scouring and creeping of water, sedimentation of soils, shifting water and air pressures, algae bloom that block or roots of vegetation that punctures pipes, water infrastructures are constantly in a process of change, assuming various forms and materialities when constructed and in-use. Other actors also bring about changes through their actions, perhaps tampering with the infrastructure to get the water flowing in the desired quantities and qualities into desired places at given moments in time. In this regard, water infrastructures and their performances are never fully stable or accomplished but always in-the-making, producing emergent spatial and temporal configurations and relationships (Sanchez et al., 2019).

Table 3

Summary Table on Water Network Management

Key Result Areas	Composite Mean	VI	Rank
Asset Management	3.17	Agree	1
Water Monitoring and Treatment	3.11	Agree	3
Operational Efficiency and Optimization	3.16	Agree	2
Grand Composite Mean	3.15	Agree	

Legend:3.50-4.00=Strongly Agree;2.50-3.49=Agree;1.50-2.49=Disagree;1.00-1.49=Strongly Disagree

Table 3 presents the summary table on network in terms of asset management, water monitoring and treatment, and operational efficiency and optimization, with a grand composite mean of 3.15 which indicates agree on all indicators. Networking has vital functions in the processes of managing water, including asset management, water monitoring and treatment, and operational efficiency and optimization. Through networking technologies, utilities can upgrade asset management, improve their water monitoring and treatment structures, and re-strategize their operations towards efficient and sustainable delivery. Among the dimensions, asset management obtained the highest rank with a composite mean of 3.17 and an agreed verbal interpretation. This indicates that with the deployment of more technologies and equipment for more services to satisfy consumer needs, the field of asset management becomes very interesting to researchers from various disciplines. When different interactions among components and assets in a system are factored in, optimization modelling for maintenance becomes immensely complicated. Such intricate interactions require substantial computational resources in dealing with operations and maintenance problems. But again, these features also bring about the opportunity of designing policies such that compared to the individual optimization strategies, the overall system can be made more efficient (Petchompro et. al.,2019).

Table 4

Summary Table on Risk Management

Key Result Areas	Composite Mean	VI	Rank
Hazard Identification	3.22	Agree	1
Risk Mitigation and Control Measures	3.10	Agree	3
Evaluation and Verification Process	3.21	Agree	2
Grand Composite Mean	3.18	Agree	

Legend:3.50-4.00=Strongly Agree;2.50-3.49=Agree;1.50-2.49=Disagree;1.00-1.49=Strongly Disagree

Table 4 presents the summary table on risk management in terms of hazard identification, risk mitigation and control measures, and evaluation and verification process, with a grand composite mean of 3.18 which indicates agree on all indicators. In managing the operations of an organization, the process or activity of identification, assessment, and minimization of possible risks that would negatively affect its goals and objectives plays a significant role in the management of the company. Thus, through these three stages, the organization can effectively manage risks in order to shield itself from any probable damages.

Among the dimensions, hazard identification obtained the highest rank with a composite mean of 3.22 and an agreed verbal interpretation. This is related to a study by Darifah et al. (2023). MSMEs Cuanki Bakti Mulia is a food business enterprise producing cuanki in Indonesia. There is a high risk because the severity of accidents may lead to major injuries. It aims to identify hazards, analyze and measure risks, and control at MSMEs Cuanki Bakti Mulia in Kasemen District, Serang City. Hazard Identification Risk Assessment and Control (HIRAC) method will be used. The object of study is the work of MSMEs Cuanki Bakti Mulia, namely all potentially hazardous activities. Data from the company, interviews, direct surveys of production equipment, and machines in the production process were collected for this study. The results of the study showed that many risks were identified. The process of making and rolling meatball dough, and fried dumpling dough had a high risk rating compared to others. In dough making, ingredients existing in flour that come into direct contact with breath may irritate the nasal and mouth mucous leading to respiratory problems. In dough rolling, the prolonged exposure to vibration through the hands causes hearing loss due to noise. Several protection and prevention measures have been taken mainly for workers to avoid accidents in the workplace and ensure hygiene in foods produced. The proposed hazard controls include the replacement of firewood with gas stoves when frying to make tofu and fried dumplings, restriction of working hours of the workers, and adequate rest resulting from reduction of the working hours. PPE needs to be provided and equipped.

Table 5

Relationship Between Water Infrastructure and Water Network Management

Variables	rho	p-values	Interpretation
Physical Infrastructure			
Asset Management	0.671**	<.001	Highly Significant
Water Monitoring and Treatment	0.791**	<.001	Highly Significant
Operational Efficiency and Optimization	0.880**	<.001	Highly Significant
Data Driven Infrastructure			
Asset Management	0.751**	<.001	Highly Significant
Water Monitoring and Treatment	0.922**	<.001	Highly Significant
Operational Efficiency and Optimization	0.846**	<.001	Highly Significant
Water Quality			
Asset Management	0.925**	<.001	Highly Significant
Water Monitoring and Treatment	0.842**	<.001	Highly Significant
Operational Efficiency and Optimization	0.920**	<.001	Highly Significant

***. Correlation is significant at the 0.01 level*

Table 5 illustrates the correlation between water infrastructure and network variables. For Physical Infrastructure: Asset Management (rho=0.671, p< .001): There is a moderately strong positive correlation between physical infrastructure and asset management, which is highly significant. This indicates that improvements in physical infrastructure are associated with better asset management practices. For Water

Monitoring and Treatment (rho=0.791, p<.001): A strong positive correlation suggests that robust physical infrastructure is linked with enhanced water monitoring and treatment. For Operational Efficiency and Optimization (rho=0.880, p<.001): There is a very strong positive correlation, indicating that better physical infrastructure is highly associated with improved operational efficiency and optimization. The findings were supported by the study of Singh et. al.,(2019) where they disclosed that the efficient and responsible stewardship of water systems depends on the integration of physical systems, asset management, water quality monitoring, treatment and efficiency in operations. Improving these aspects enables water utilities to increase service level and reduce expenses whilst ensuring a dependable and robust water supply.

For Data-Driven Infrastructure: Asset Management (rho=0.751, p< .001): A strong positive correlation indicates that data-driven infrastructure significantly enhances asset management; Water Monitoring and Treatment (rho=0.922, p< .001): This very strong correlation shows that integrating data-driven infrastructure significantly improves water monitoring and treatment systems and Operational Efficiency and Optimization (rho=0.846, p< .001): A strong positive correlation suggests that data-driven infrastructure supports operational efficiency and optimization effectively. According to Shi (2018), the rising adoption of technology in water infrastructure management brings far-reaching consequences to asset management, water monitoring and treatment, and the optimization of operations. Data-driven systems can collect, process, and apply information on an unprecedented scale to enhance decision-making processes and improve performance. Wherever one turns, one finds the importance of the development of a data-driven infrastructure in the management of water utility assets, the control of water quality, and the efficiency of operations. This helps utilities become more efficient, less expensive, and most importantly, more sustainable water systems.

For Water Quality: Asset Management (rho=0.925, p< .001): There is a very strong positive and highly significant correlation, indicating that higher water quality is closely associated with excellent asset management. For Water Monitoring and Treatment (rho=0.842, p<.001): A strong positive correlation suggests that high water quality is linked to efficient water monitoring and treatment processes. For Operational Efficiency and Optimization (rho=0.920, p< .001): A very strong positive correlation indicates that better water quality is associated with greater operational efficiency and optimization. Wang et. al.,(2019) pointed out that ensuring the quality of water is very important for the management of water systems, as it is also related to asset management, water monitoring and treatment, and improving operational efficiency and effectiveness. Water quality constitutes one of the key determinants of the functioning and sustainability of water systems. By managing water quality properly through asset management, control and treatment of water, and operational efficiency and optimization, water utilities can provide enabled safe water supply to the populations they serve.

All correlations are positive and highly significant (p< .001), with the strongest associations found between Water Quality and all network variables, especially with Asset Management and Operational Efficiency and Optimization. This suggests that improvements in both physical and data-driven infrastructure have a strong impact on asset management, water monitoring, and operational efficiency, ultimately enhancing water quality. The strong correlation between water infrastructure and water network management is a long-standing concept in the water resources sector. This interdependence stems from the fundamental principle that effective water network management depends largely on the quality and adequacy of the underlying infrastructure.Well designed water infrastructure including pipes, reservoirs, treatment plants and any other items of a water infrastructure, if designed and operated well, play a significant role in the efficient and effective supply of water to the consumers. Good infrastructure serves to reduce water wastage, and leakages or any interruptions in service provision (Trowsdale et. al.,2020). As pointed out by Pointet (2022), the condition of water infrastructure affects the quality of water supplied to the consumers. It is possible for water quality to deteriorate owing to corrosion, seepage or intrusion if such factors are not eliminated in time. Certain network management practices, regular inspections and maintenance for instance, are useful in protecting water quality.

Table 6 presents the relationship between different aspects of water infrastructure and risk management variables. For Physical Infrastructure: Hazard Identification (rho=0.584, p<.001): There is a moderately strong and highly significant positive correlation, indicating that better physical infrastructure improves the identification of hazards in water systems.

Table 6

Relationship Between Water Infrastructure and Risk Management

Variables	rho	p-values	Interpretation
Physical Infrastructure			
Hazard Identification	0.584**	<.001	Highly Significant
Risk Mitigation and Control Measures	0.563**	<.001	Highly Significant
Evaluation and Verification Process	0.499**	<.001	Highly Significant
Data Driven Infrastructure			
Hazard Identification	0.503**	<.001	Highly Significant
Risk Mitigation and Control Measures	0.511**	<.001	Highly Significant
Evaluation and Verification Process	0.489**	<.001	Highly Significant
Water Quality			
Hazard Identification	0.669**	<.001	Highly Significant
Risk Mitigation and Control Measures	0.693**	<.001	Highly Significant
Evaluation and Verification Process	0.748**	<.001	Highly Significant
Physical Infrastructure			
Asset Management	0.671**	<.001	Highly Significant
Water Monitoring and Treatment	0.791**	<.001	Highly Significant
Operational Efficiency and Optimization	0.880**	<.001	Highly Significant
Data Driven Infrastructure			
Asset Management	0.751**	<.001	Highly Significant
Water Monitoring and Treatment	0.922**	<.001	Highly Significant
Operational Efficiency and Optimization	0.846**	<.001	Highly Significant
Water Quality			
Asset Management	0.925**	<.001	Highly Significant
Water Monitoring and Treatment	0.842**	<.001	Highly Significant
Operational Efficiency and Optimization	0.920**	<.001	Highly Significant

For Risk Mitigation and Control Measures (rho=0.563, p<.001): A moderately strong positive correlation shows that physical infrastructure is associated with better risk mitigation and control measures. For Evaluation and Verification Process (rho=0.499, p<.001): A moderate positive correlation indicates that physical infrastructure plays a role in improving the evaluation and verification of risk management processes.

For Data-Driven Infrastructure: Hazard Identification (rho=0.503, p<.001): A moderate positive and highly significant correlation suggests that data-driven infrastructure improves hazard identification capabilities. For Risk Mitigation and Control Measures (rho=0.511, p<.001): A moderate positive correlation shows that data-driven infrastructure supports more effective risk mitigation and control measures. For Evaluation and Verification Process (rho=0.489, p<.001): This shows a moderate positive correlation, indicating that data-driven infrastructure has an impact on improving the evaluation and verification processes for risk management, although it is slightly weaker compared to other variables.

For Water Quality: Hazard Identification (rho=0.669, p<.001): A strong and highly significant positive correlation indicates that better water quality is closely related to more effective hazard identification in risk management. For Risk Mitigation and Control Measures (rho=0.693, p<.001): A strong positive correlation suggests that improved water quality is strongly associated with better risk mitigation and control measures. For Evaluation and Verification Process (rho=0.748, p< .001): A very strong positive correlation indicates that water quality has a significant influence on enhancing the evaluation and verification process in risk management.

Physical Infrastructure shows moderate but highly significant positive correlations with all three risk management variables, indicating that it plays a role in effective risk management, especially in hazard identification and risk mitigation. Data-Driven Infrastructure has slightly lower but still highly significant correlations with risk management, suggesting that while it contributes to improved risk management processes, its impact is somewhat weaker compared to physical infrastructure and water quality. Water Quality has the strongest correlations across all risk management variables, especially in Evaluation and Verification Process, indicating that higher water quality is most strongly associated with effective risk management practices, particularly in the final evaluation and verification stages.

All correlations are highly significant (p< .001), underscoring the importance of robust water infrastructure in enhancing risk management efforts. As confirmed by Vishunu et. al.,(2024), there is a close link between water infrastructure and the management of risks, because, on the one hand, there is no doubt that water infrastructure is crucial because it facilitates the delivery of services to communities, and on the other hand, it is also exposed to a number of risks. However, risk management is necessary if the water infrastructure systems are to be resilient and continue to function effectively over time.

Table 7 examines the relationship between water network management and various risk management processes. There is a strong positive correlation between Asset Management and Hazard Identification rho=0.712 with a p-value<0.001. This means that as Asset Management improves, the effectiveness of Hazard Identification also tends to improve. The relationship is highly significant, indicating that this result is not due to random chance.

Table 7

Relationship Between Water Network Management and Risk Management

Variables	rho	p-value	Interpretation
Asset Management			
Hazard Identification	0.712**	<.001	Highly Significant
Risk Mitigation and Control Measures	0.797**	<.001	Highly Significant
Evaluation and Verification Process	0.781**	<.001	Highly Significant
Water Monitoring and Treatment			
Hazard Identification	0.543**	<.001	Highly Significant
Risk Mitigation and Control Measures	0.589**	<.001	Highly Significant
Evaluation and Verification Process	0.602**	<.001	Highly Significant
Operational Efficiency and Optimization			
Hazard Identification	0.742**	<.001	Highly Significant
Risk Mitigation and Control Measures	0.749**	<.001	Highly Significant
Evaluation and Verification Process	0.741**	<.001	Highly Significant

**. Correlation is significant at the 0.01 level

There is a very strong positive correlation between Asset Management and Risk Mitigation and Control Measures rho=0.797 with a p-value < 0.001. This suggests that better management of assets is closely tied to the implementation of effective risk mitigation strategies. The significance level (<.001) reinforces that this is a highly reliable result.

There is another strong positive correlation between Asset Management and the Evaluation and Verification Process rho=0.781 with a p-value<0.001. This implies that improvements in asset management practices are strongly linked with more effective evaluation and verification of risk management processes. The relationship is highly significant.

There is a moderately strong positive correlation between Water Monitoring and Treatment and Hazard Identification rho=0.543 with a p-value< 0.001. This suggests that improvements in water monitoring and treatment are associated with better hazard identification processes. The relationship is highly significant, meaning that this finding is unlikely to be due to random chance.

There is a moderate to strong positive correlation between Water Monitoring and Treatment and Risk Mitigation and Control Measures rho=0.589 with a p-value< 0.001. This indicates that as water monitoring and treatment practices improve, the effectiveness of risk mitigation strategies also tends to improve. The highly significant p-value reinforces the reliability of this result.

There is a moderately strong positive correlation between Water Monitoring and Treatment and the Evaluation and Verification Process rho=0.602 with a p-value<0.001. This suggests that better water monitoring and treatment practices are linked with more effective evaluation and verification of risk management processes.

Again, the relationship is highly significant.

There is a strong positive correlation between Operational Efficiency and Optimization and Hazard Identification rho=0.742 with a p-value<0.001. This suggests that improvements in operational efficiency are strongly associated with enhanced hazard identification processes. The highly significant p-value indicates that this relationship is reliable and not due to chance.

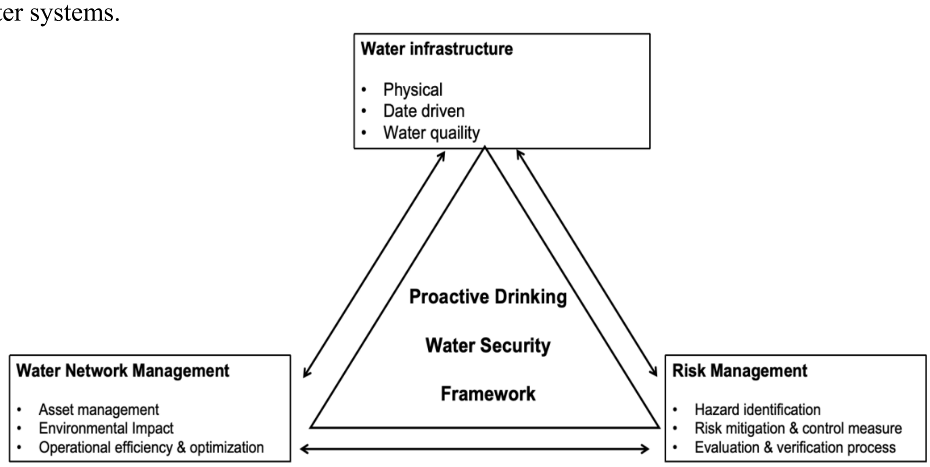
There is a very strong positive correlation between Operational Efficiency and Optimization and Risk Mitigation and Control Measures rho=0.749 with a p-value<0.001. This implies that better operational efficiency is closely linked to more effective implementation of risk mitigation strategies. The relationship is highly significant, confirming that this is a reliable finding.

There is another strong positive correlation between Operational Efficiency and Optimization and the Evaluation and Verification Process rho=0.741 with a p-value<0.001. This suggests that more efficient operations are strongly associated with better evaluation and verification of risk management processes. The highly significant result makes this relationship very reliable.

There is a strong link between water network management and risk management, if water systems are to be made strong and sustainable. Water network management is concerned with the planning, operation, and maintenance of water structures, whereas risk management concentrates on the threats within the system and doing something about those threats. These two are interrelated since a core element of managing a water network is dealing with the risks of doing it and managing the risk management approach informs the design itself of the network and its operations. Risk management strategies may include regular maintenance and inspections of water infrastructure to minimize the failures which lessens the chances of disruptions. In this case, it refers to water utilities that will have crisis management plans risk management and consequently will be able to cope with the situation born out of natural disasters like earthquakes or infrastructural failures. In looking at and appreciating the big picture on the influence of water network management as well as the relationship with risk management, water utility companies can improve the reliability and sustainability of their systems, control risks to public, and provision of water services becomes simpler and more efficient (Molinos-Senante et. al.,2023).

Proactive Drinking Water Security Framework

The Proactive Drinking Water Security Framework is a means of approach in management which aims at improving the functionalities of planning drinking water systems, developing, operating and maintaining them. It evolves as a function of water infrastructures, water networks management and risk management in the area of drinking water systems.



The significant relationship between water infrastructure, network management, and risk management is fundamental to the effective and sustainable operation of drinking water industries. Every component contributes largely in making sure that water is safe, reliable, and affordable to the consumers. The infrastructure for water supply management creates the foundation for water network management . The design, construction, and maintenance of various infrastructure elements such as treatment plants, distribution systems, and storage structures, all influence the effectiveness and reliability of water supply. A well-managed network of water supplies not only provides the consumers with the needed water, but also ensures that there are no wastages of water anywhere in the system. This is considered a distribution system. Such understanding presupposes a comprehensive knowledge of the system's features and provision. Inherent in the water infrastructure, such risk factors as natural disaster, wear and tear of the existing water systems, and pollution, can be found. Risk management is the recognition of these weaknesses and the evaluation of their potential impact, followed by the formulation of appropriate countermeasures. Active risk management enhances the resilience of the water utilities to any disruptions and the quick recovery from any difficulties that may be experienced by the system. To address these risks, effective management practices such as timely maintenance, inspection, or upgrading of the water system can be employed. This segment is important as water networks managers are responsible for preparing and executing strategies to respond to any occurrence that disrupts the normal operations of the water networks as a result of natural disasters or accidents. For the protection of public health, the drinking water has to be of the highest possible quality and purity. Appropriate infrastructure development, its operation, and risk management strategies contribute to the provision of safe and clean water. Affordable and dependable water supplies are vital to the economic growth and development of a nation. At present, most of the businesses, industries, and communities can work comfortably because of the existence of a very good water system. Quite naturally, water resources can be regarded as limited resources. It is important to manage water supply systems and their components due to the nature of water as a resource that can be exhausted within a short period. The three components, water infrastructure, network management, and risk management which all work hand in hand to ensure a safe drinking water industry is developed and maintained. Focusing on these systems enables utilities to support the provision of water to customers who demand it in a safe, reliable and economical way without compromising the safety of people or the environment.

4. Conclusions and recommendations

The study showed agreement that the water infrastructure are in place as to physical infrastructure, data driven and water quality. The respondents moderately agreed on the water network management in terms of asset management, water monitoring and treatment and operational efficiency and optimization. The respondents generally agreed on the risk management practices utilized as to hazard identification, risk mitigation and control measures and evaluation and verification process. A high significant relationship was found between water infrastructure, water network management and risk management. A drinking water security framework was developed for drinking water industries.

To help prevent contamination of water sources, water companies' managers can put in place protective activities like watershed protection, land management, and other pollution control regulations. The operations managers may set up a detailed arrangement of monitoring stations in the water distribution network including source points, treatment plants, reservoirs and important distribution points. The HR managers may implement appropriate measures to minimize risks from occurring, such as security policies, training programs, and maintenance procedures. The integrated drinking water management framework may be used by drinking water industries to address resource management, water quality control and sustainable development. Future researchers may delve into the possibilities of digitalization and artificial intelligence in enhancing the effectiveness and sustainability of water management.

5. References

Bartram, J., & Bain, R. (2019). Drinking water quality: Challenges and solutions. World Health Organization.
Darifah, S., Sugiharto A., Hakim A.F., Rahmawati H., Purbasari A.P., Ramnadhani D., Salsabila R.H.,

Halimatusadiah H., Monique I., Shalih F.A.T., Huwaida N.Z. (2023). Hazard Identification Risk Assessment and Risk Control Measures in Micro, Small, and Medium Enterprises Cuanki in Kasemen District, Serang City. JIKM [Internet]. 14(3):393-407. https://ejournal.fkm.unsri.ac.id/index.php/jikm/article/view/1461

Idrica (2024). Water trends in drinking water network management: Efficiency and sustainability pen_spark, https://www.idrica.com/blog/water-trends-drinking-water-network-management-2024/

Lee, J., Kim, J. H., & Kim, D. (2022). Leak detection in water distribution systems using wireless sensor networks: A review. Water Supply, 22(1), 1893-1910.

Mallett, J. C., Hurley, M., Liu, W., Moy, W. W., Newell, B., & Ademoroti, C. M. (2019). A risk-based decision support system for water safety planning in regional water utilities. Water Science and Technology, 79(8), 1580-1589.

Molinos-Senante, M., Chamorro, A., Contreras, M., & Echaveguren, T. (2023). Natural hazard risk management in the Chilean drinking water industry: Diagnosis and recommendations. Utilities Policy, 82, 101553.

Petchompro, S. & Parlikad, A.K. (2019). A review of asset management literature on multi-asset systems. Reliability Engineering and System Safety. https://doi.org/10.1016/j.ress.2018.09.009

Pointet, T. (2022). The United Nations world water development report 2022 on groundwater, a synthesis. LHB, 108(1), 2090867.

Sanchez, L.M.S.N., Kemerink-Seyoum, J.S., & Zwarteveen, M. (2019). Water Infrastructure Always In-The-Making: Distributing Water and Authority through the Water Supply Network in Moamba, Mozambique. Water 2019, 11(9), 1926. https://doi.org/10.3390/w11091926

Shi, F. (2018). Data-driven predictive analytics for water infrastructure condition assessment and management (Doctoral dissertation, University of British Columbia).

Singh, M. K., & Kekatos, V. (2019). Optimal scheduling of water distribution systems. IEEE Transactions on Control of Network Systems, 7(2), 711-723.

Trowsdale, S., Boyle, K., & Baker, T. (2020). Politics, water management and infrastructure. Philosophical Transactions of the Royal Society A, 378(2168), 20190208.

Vishunu, R. S., Anilkumar, S., & Bimal, P. (2024). Disaster Risk Assessment and Analysis of Physical Infrastructure: A Comprehensive Review of Scientific Methods and Techniques. IDRiM Journal, 14(2).

Wang, Z., Wang, H., & Zhou, Y. (2019). Self-healing polymers for water infrastructure applications. Polymers, 11(12), 2082.

Wang, X., & Yang, W. (2019). Water quality monitoring and evaluation using remote sensing techniques in China: A systematic review. Ecosystem Health and Sustainability, 5(1), 47-56.

Wu, Z., Wang, Y., Liu, S., & Wang, J. (2020). Big data analytics for improving urban water network resilience. Water Resources Management, 34(14), 3733-3747.

Wu, Z., Wang, Y., Liu, S., & Wang, J. (2021). Big data analytics for water distribution system resilience assessment: A case study in China. *Journal of Hydrology*, 599, 126732.