ENHANCING WATER RESILIENCE: THE IMPACT OF WATER RISK AWARENESS ON RESERVE MARGIN RATIOS IN MALAYSIA

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ABSTRACT

This study investigates the relationship between water risk awareness and the reserve margin ratio within the context of Malaysia's water management practices. Utilizing a mixed-methods approach, the research combines quantitative analysis of secondary data from the Suruhanjaya Perkhidmatan Air Negara (SPAN) with qualitative insights from interviews with SPAN personnel. The study aims to provide a comprehensive understanding of the operational and regulatory challenges faced by water companies in Malaysia and the impact of these challenges on water supply and resilience. The findings reveal that SPAN monitors two main areas: services, encompassing the entire water service chain from intake to end-users, and facilities, including asset ownership, operations, and construction. SPAN conducts quarterly Water Regulatory Meetings to address technical aspects and capital expenditures, ensuring compliance and identifying water shortages that necessitate the construction of new plants. However, several states, such as Kelantan, Kedah, and Perlis, report critically low or zero reserve margin ratios, highlighting significant water supply vulnerabilities. The study further outlines crucial concerns about water utilisation practices and infrastructure. Leakages in pipes, frequently resulting from the deterioration of pipes that are more than 40 years old, have a substantial impact on water loss and inefficiency. The study emphasises the importance of making substantial investments in infrastructure and implementing a more efficient regulatory approach. This is important to maintain an ideal reserve margin and ensure efficient service delivery. The insights gained from this study have crucial implications for policymakers, water service providers, and other stakeholders in the development of sustainable water management policies.

Keywords: Awareness, Margin Ratio, Reserve, Water risk

1.0 INTRODUCTION

Water risk awareness has become an essential element in ensuring the long-term viability and effectiveness of enterprises, particularly those heavily reliant on water resources (Ross et al., 2020). Issues such as water purity, shortages, and regulatory impacts pose significant challenges for many enterprises, affecting their ability to maintain sustainability and achieve financial success (Sekercioglu et al., 2018). With global water resources increasingly strained by climate change, population growth, and industrial demands, companies need to understand and address water-related hazards to ensure environmentally responsible operations (Drechsel et al., 2023; Koroleva & Novak, 2020).

The reserve margin ratio is an essential metric that quantifies the ability of a business or utility to fulfil water demand above its regular operational capacity (Gaur et al., 2014). The reserve margin ratio is a significant metric that quantifies an organization's ability to handle fluctuations in water supply and demand, providing a safeguard against unforeseen disruptions (Das et al., 2024). A greater reserve margin ratio signifies an enhanced ability to manage unexpected changes in water supply, hence reducing susceptibility to water hazards (Lindner et al., 2018).

The relationship between knowledge of water risk and the reserve margin ratio is crucial for the effective management of water resources (Wu et al., 2012). Water providers who possess knowledge of and actively oversee and regulate water hazards are more likely to keep bigger reserve margins. This would guarantee their ability to maintain operations even in times of water scarcity or issues with water quality (Ahmad et al., 2023). This proactive strategy not only encourages the ongoing functioning of corporate activities but also strengthens the ability to withstand future water-related difficulties (Rahman et al., 2023).

In addition, including an understanding of water risk in an organization's efforts and business strategy can provide significant benefits that go beyond immediate operational gains (Merabtene et al., 2002). Organisations that give priority to water sustainability are frequently seen as frontrunners in environmental stewardship. Consequently, this would bolster their standing and fortify connections with stakeholders, such as clients, shareholders, and regulators.

Water service providers that demonstrate a strong commitment to efficiently managing water-related risks have the opportunity to gain a competitive advantage and attract investors that prioritise social responsibility (Abdelrady&Hussien, 2020). Moreover, fostering a culture of water risk awareness inside a corporation has the potential to provide inventive solutions and enhance operational efficiency. Implementing this would enhance the organization's long-term sustainability and financial prosperity (Ahmad et al., 2023; Cai et al., 2003). The significance of incorporating environmental considerations into strategic planning is exemplified by the comprehensive approach to water resource management outlined by Mysiak et al. (2005). Moreover, it highlights the need to maintain a strong reserve margin ratio within a complete risk management framework. This is because maintaining a balance in water reserves while adhering to constraints such as water demand and the capacity of storage reservoirs is important(Akimoto et al., 2024).

This study examines the correlation between water risk awareness and the reserve margin ratio, assessing how water service providers perceive and address water hazards in their operating strategies. This analysis would offer a valuable understanding of the need to maintain adequate reserve margins and the broader consequences for sustainability and risk mitigation. This work contributes to the growing body of literature on water resource management, offering significant insights that might influence policy choices and help

businesses enhance their capacity to manage water-related risks. Additionally, this would also assist in shaping the policy and practices of water management strategies specifically in Malaysia.

The remainder of the paper is organised as follows. The next section explains the research literature review about water management in Malaysia. The paper further explains the theoretical framework shaping this study. It then explains the mixed methodology being applied in this study. Following that, the findings are presented. Finally, the discussions, conclusions, and suggestions for future research are outlined.

2.0 LITERATURE REVIEW

2.2 Water Management in Malaysia

Malaysia's water services business operates under a monopolistic market system, where each state or territory has control over the full water supply process, including abstraction, treatment, and distribution (Raihanet al., 2023). This decentralised system results in each water utility operating in varied locations, employing different systems, and adhering to distinct sets of regulations. Consequently, the water services in Malaysia vary significantly, resulting in a variety of challenges and responses that are specific to each utility's operational structure and regional environment (Farouk et al., 2023).

This scenario calls for a pressing need for greater coordination and standardisation within the industry to ensure equitable access to safe and reliable water services nationwide. Additionally, fostering collaboration and knowledge-sharing among utilities can facilitate the adoption of best practices. It also encourages innovative solutions to address common challenges such as water scarcity, pollution, and infrastructure degradation.

2.3 History of water resource management in Malaysia

The history of water management in Malaysia dates back to ancient times, with various civilisations and indigenous communities implementing their methods of water management. Malaysia became a British territory in the nineteenth century, and water management developed further under British control (Rivil Water, 2023). To increase access to clean water, the British deployed innovative technology including piped water supplies. To conserve water for use in agriculture and urban areas, they also constructed enormous reservoirs, such as the Chenderoh Dam and the Temenggor Dam (Rivil Water, 2023).

The control of water resources was turned over to the government in 1957 when Malaysia attained independence. As a result of rising water demand brought on by urbanisation and industry, the nation was confronted with new problems. During these early years (1950s – 1960s), the government put policies into place aimed at boosting water supply, enhancing water quality, and effectively managing water resources to meet these issues. The establishment of the Public Works Department (PWD) in 1954 marked the beginning of centralised water supply development efforts. Key water infrastructure projects were initiated, including the construction of dams, reservoirs, water treatment plants, and distribution networks. The first major dam, the Temenggor Dam in Perak, was completed in 1968, followed by the Kenyir Dam in Terengganu in 1985 (Rivil Water, 2023).

Following that, the formation of the National Water Authority occurs during the 1970s to 1980s. The Department of Drainage and Irrigation (DID) was established in 1975 to oversee water resource management, flood control, and irrigation development. In 1979, the National Water Authority (now known as the National Water Services Commission or SPAN) was established to regulate the water industry and ensure efficient water service provision (Wahid et al., 2014). The government introduced a series of water-related legislation, including the Water Supply Enactment and the Sewerage Services Act, to improve governance and regulation.

Malaysia experienced rapid urbanisation and industrialisation, necessitating the expansion of water supply infrastructure. Accordingly, the expansion of water supply infrastructure occurs during the 1990s to the year 2000s. Major projects were implemented, such as the Pahang-Selangor Raw Water Transfer Scheme, which transferred water from Pahang to meet the increasing water demand in the Klang Valley. Privatisation of water services began in the late 1990s, with the government entering into concessions and management contracts with private companies for water supply and services (Hall et al., 2004; Saad and Harun, 2017).

The government placed greater emphasis on sustainable water management and conservation in the 21st century. Integrated Water Resources Management (IWRM) principles were adopted to ensure the holistic and sustainable management of water resources (Sukereman&Suratman, 2014). Efforts were made to enhance water efficiency, reduce non-revenue water (NRW) losses, and promote water conservation practices among industries, communities, and individuals. The government also focused on addressing water pollution and protecting water catchment areas through legislation and enforcement measures (Elfithri& Mokhtar 2018).

Malaysia continues to face challenges in water management, including water scarcity, pollution, climate change impacts, and infrastructure maintenance. The government is actively promoting water demand management, rainwater harvesting, and wastewater reuse to ensure long-term water security and sustainability. Collaborative efforts between government agencies, water service providers, communities, and stakeholders are being pursued to address these challenges and achieve the goals of the National Water Resources Policy to provide a comprehensive framework and strategic direction for the sustainable management and utilisation of Malaysia's water resources (National Water Resource Policy, 2012).

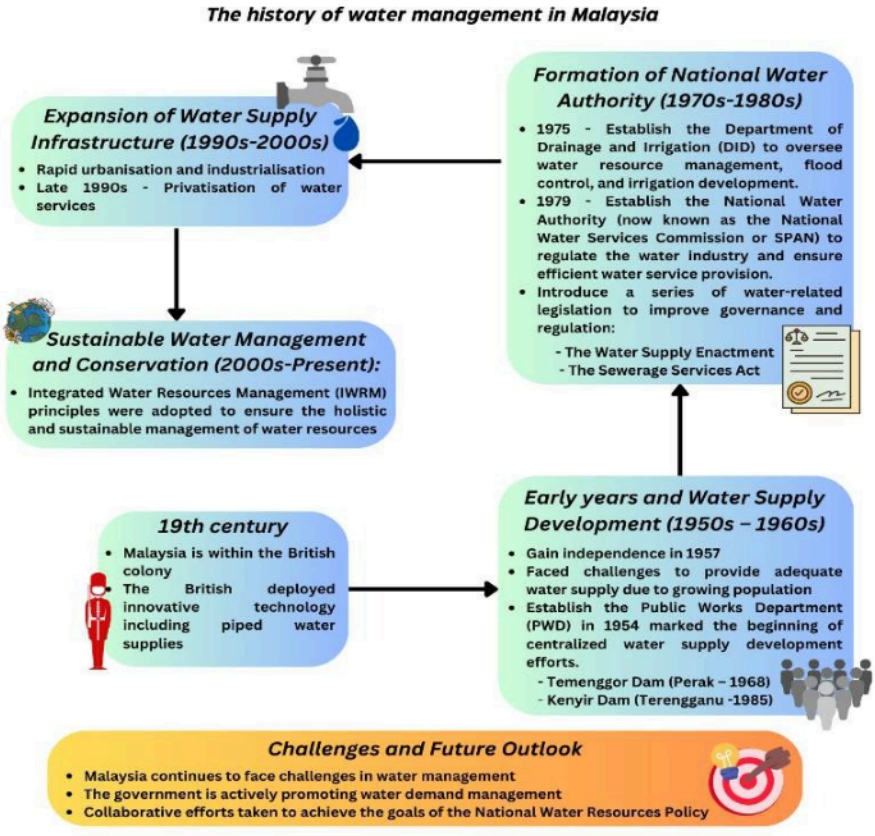


Fig. 1 *The history of water management in Malaysia* (*Source: Self-developed by authors)*

2.4 Resource-Based View (RBV) Theory

RBV theory posits that an organisation's sustainable competitive advantage is derived from its capability to effectively manage and utilise its resources (Freeman et al., 2021). In the context of water risk awareness and reserve margin ratio, RBV theory can be employed to explain how organisations that recognise and proactively manage water risks can develop and leverage their water resources more efficiently (Khan et al., 2023). This awareness leads to the establishment of higher reserve margins, which act as a buffer against potential water-related disruptions (Gaur et al., 2014). By using this strategy, organisations can maintain continuity in operations, reduce vulnerability, and sustain long-term profitability. The RBV theory highlights the strategic importance of water resources as critical assets that need to be managed effectively to achieve sustainable competitive advantage and resilience (Madhani, 2010; Halawiet al., 2005).

By integrating advanced water management practices, investing in water-saving technologies, and fostering a culture of environmental stewardship, companies may establish a strong buffer against water-related disruptions. This strategic resource management not only safeguards operational continuity but also enhances the organisation's reputation and stakeholder trust. As a result, companies that excel in water risk management can distinguish themselves from competitors, achieve cost savings, and attract investment, thereby securing a long-term competitive edge in their industry (Féreset al., 2008). Hence, the RBV framework emphasises the strategic significance of water resource management in improving organisational resilience and promoting sustainable growth.

2.5 Water risk awareness and reserve margin ratio

Water risk awareness refers to the understanding and proactive management of risks associated with water availability, quality, and regulatory constraints of water (Sekercioglu et al., 2018; Hubbard et al., 2013; Ross et al., 2020). As global water resources face increasing pressure due to industrialisation, population growth, and climate change, businesses and governments are placing greater emphasis on identifying and mitigating water-related risks. Preventive measures and risk mitigation should be determined and applied based on the multiple barrier principle. This method employs multiple measures or barriers to manage the risks of various hazards, enhancing the process's overall reliability (Drechsel et al., 2023).

According to Schulte and Morrison (2014), developing a deep understanding of water risk is essential for promoting sustainable water management practices and strengthening organisational resilience. This awareness helps organisations anticipate potential disruptions, plan appropriate responses, and implement strategies to safeguard their water resources.

The reserve margin ratio is a critical metric in water resource management, representing the buffer capacity that allows a business or utility to meet water demand beyond its normal operational capacity (Lindner et al., 2018). A higher reserve margin ratio indicates a greater ability to manage fluctuations in water availability, thereby reducing the vulnerability to water risks (Hall &Borgomeo, 2013). Fisher and Rubio (1997) emphasise the need to maintain a sufficient reserve buffer to ensure the dependability and robustness of water delivery systems, especially in regions with fluctuating water supplies.

Organisations with a strong understanding of water risks are better prepared to maintain higher reserve margins, which helps them mitigate the impacts of water scarcity and maintain stable operations (Pereira et al., 2002). This is in alignment with the Resource-Based View (RBV) theory, which posits that organisations can achieve a competitive advantage by effectively managing and utilizing their resources.

3.0 METHODOLOGY

This study employs a mixed-methods approach, combining quantitative analysis of secondary data with qualitative insights from interviews. The research aims to investigate the relationship between water risk awareness and the reserve margin ratio within the context of Malaysia's water management practices. The integration of both quantitative and qualitative methods provides a comprehensive understanding of the issues at hand(Cadena-Iñiguez et al., 2017).

The secondary data for this study were obtained from the SuruhanjayaPerkhidmatan Air Negara (SPAN), the National Water Services Commission of Malaysia. SPAN provides extensive data on water companies, including information on water supply, demand, reserve margins, and performance metrics. The data covered a period of five years, providing a robust dataset for analysis.

To complement the secondary data, qualitative data were collected through semi-structured interviews with personnel from SPAN. These interviews aimed to gather in-depth insights into the operational challenges, regulatory frameworks, and water risk management practices The interview questions focused on:

1. SPAN's monitoring practices: "Does SPAN monitor all water companies in Malaysia?"
2. Operational issues: "What are the issues related to water and supply chain operations for each state water company?"
3. Water use patterns: "What is the pattern of water use in Malaysia?"

Participants were selected based on their expertise and roles within SPAN, ensuring that the information gathered was relevant and comprehensive.

The qualitative data from interviews were analysed using thematic analysis. The process involved transcribing the interviews, coding the data, and identifying common themes and patterns. This analysis provided contextual understanding and deeper insights into the quantitative findings (Joffe, 2011). Key themes explored included:

- Regulatory challenges and effectiveness
- Strategies for improving water risk management
- Variability in water use patterns across different states

3.4 Validity and Reliability

To ensure the validity and reliability of the findings, several measures were undertaken. By combining secondary data analysis with qualitative interviews, the study ensured a more comprehensive and corroborative approach. Additionally, secondary data were obtained from SPAN, a credible and authoritative source, ensuring the accuracy and reliability of the data. Regarding the interview Protocols, semi-structured interview guides were used to maintain consistency across interviews, and participants were selected based on their expertise to ensure the relevance of the information collected.

4.0 Results and Discussion

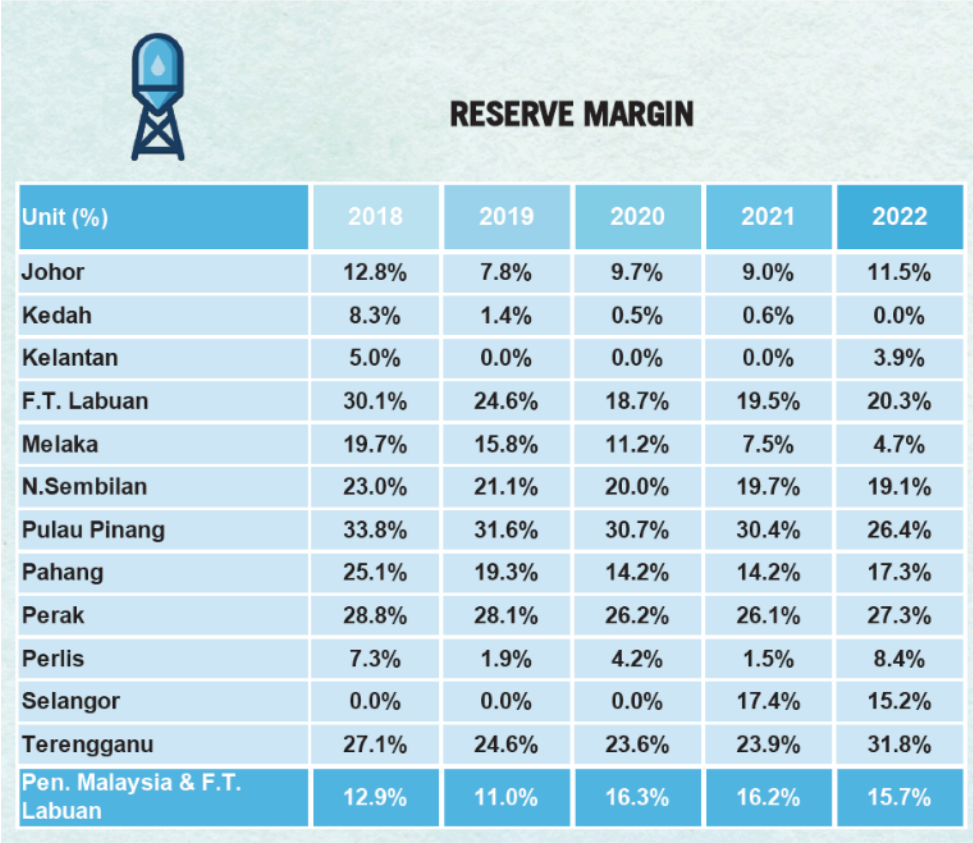
The results are categorised into two distinct sections: quantitative and qualitative. The quantitative component examines secondary data collected from SPAN to offer numerical analysis on reserve margins and the stability of water supply in different states. The qualitative portion provides insights from interviews conducted with SPAN people, including detailed perspectives on operational difficulties, regulatory frameworks, and techniques for managing water risks. This dual methodology enables a thorough comprehension of water resource

management in Malaysia by integrating empirical data with expert perspectives to develop a complete assessment of the present state and possible remedies.

4.1. Quantitative findings

This section highlights the findings derived from the secondary data obtained from SPAN, focusing on the reserve margin for states in Peninsular Malaysia and F.T. Labuan over the period from 2018 to 2022.

The reserve margin data provides critical insights into the water supply stability and risk management capabilities of various states. The table illustrates fluctuations and trends in water reserve margins, highlighting areas of concern and improvement. This information is essential for understanding the current state of water resource management and identifying areas that require targeted interventions to ensure a sustainable and reliable water supply.



RESERVE MARGIN

Unit (%)	2018	2019	2020	2021	2022
Johor	12.8%	7.8%	9.7%	9.0%	11.5%
Kedah	8.3%	1.4%	0.5%	0.6%	0.0%
Kelantan	5.0%	0.0%	0.0%	0.0%	3.9%
F.T. Labuan	30.1%	24.6%	18.7%	19.5%	20.3%
Melaka	19.7%	15.8%	11.2%	7.5%	4.7%
N.Sembilan	23.0%	21.1%	20.0%	19.7%	19.1%
Pulau Pinang	33.8%	31.6%	30.7%	30.4%	26.4%
Pahang	25.1%	19.3%	14.2%	14.2%	17.3%
Perak	28.8%	28.1%	26.2%	26.1%	27.3%
Perlis	7.3%	1.9%	4.2%	1.5%	8.4%
Selangor	0.0%	0.0%	0.0%	17.4%	15.2%
Terengganu	27.1%	24.6%	23.6%	23.9%	31.8%
Pen. Malaysia & F.T. Labuan	12.9%	11.0%	16.3%	16.2%	15.7%

Fig. 2 *Reserve Margin for States in Peninsular Malaysia and F.T. Labuan (Source: Water and Sewerage Fact Book 2022, SPAN page 46)*

Based on Table 1, the overall reserve margin for Peninsular Malaysia and F.T. Labuan fluctuated over the five years. It started at 12.9% in 2018, dropped to 11.0% in 2019, increased significantly to 16.3% in 2020, remained stable at 16.2% in 2021, and slightly decreased to 15.7% in 2022.

Kedah shows a critical decline from 8.3% in 2018 to 0.0% in 2022, indicating severe water reserve issues. Similarly, Kelantan maintained critical reserve margins at 0.0% from 2019 to 2021, with a slight recovery to 3.9% in 2022. On the other hand, Selangor demonstrates significant improvement, rising from 0.0% in 2018 to 15.2% in 2022, reflecting effective water management efforts. Perak shows stable and high reserve margins, slightly fluctuating but remaining strong from 28.8% in 2018 to 27.3% in 2022. Meanwhile, Pulau Pinang indicates high but declining reserves, from 33.8% in 2018 to 26.4% in 2022.

Critical observations from Table 1 highlight that both Kedah and Kelantan consistently show critical reserve margin levels, with Kedah reaching 0.0% in 2022 and Kelantan maintaining 0.0% from 2019 to 2021 before a slight increase. In contrast, Selangor demonstrates significant improvement, especially from a critical level of 0.0% in 2018 to a robust 15.2% in 2022.

These findings indicate varied performance in water reserve management across different states, with some regions showing significant improvements while others face critical shortages. The data highlights the need for targeted interventions to ensure sustainable water management and mitigate the risk of water shortages.

4.2 Qualitative findings

4.2.1 SPAN's monitoring practices

According to the interview with Respondent 1, SPAN monitors two main areas: services and facilities. Service monitoring encompasses the entire water service chain from intake to end-users and sewerage management from users to sewage plants. Facilities monitoring includes asset ownership, operations, and asset construction, overseen through a licensing fee mechanism.

As indicated by Respondent 1: *"SPAN monitors by holding Water Regulatory Meetings every quarter, focusing on the technical side as well as CapEx."* Additionally, if there is a water shortage, *"the construction of the water treatment plant will be made,"* though this process involves high costs.

This highlights that SPAN conducts Water Regulatory Meetings every quarter, focusing on technical aspects and capital expenditures (CapEx). These meetings ensure that water companies adhere to regulatory standards and address any emerging issues. If a water shortage is identified, SPAN facilitates the construction of new plants, although this involves significant costs. Plant control and construction fall under the jurisdiction of PengurusanAset Air Berhad (PAAB).

4.2.2 Operational issues

In the interview, we aimed to uncover the specific challenges faced by state water companies in their operations and supply chains. The primary question posed was: "*What are the issues related to water operations and the supply chain for each state water company?*"

In response, Respondent 1 highlighted several critical issues. Firstly, the set reserve margin rate is 15%, but many states struggle to meet this standard. Notably, Kelantan and Kedah, have recorded a Reserve Margin Ratio of 0%, indicating severe deficiencies. According to Respondent 1, *"The set reserve rate is 15%. Some states record zero and there are also negative ones. Kelantan and Kedah once recorded a Reserve Margin Ratio of 0%."*

Another key point made was that while maintaining a reserve margin that is too high can lead to increased costs, a margin that is too low results in service inefficiencies. This is reflected in Respondent 1's statement: *"Reserve margin cannot be too high because it will involve costs. It should also not be too low because it will lead to service inefficiency."*This indicates that maintaining an optimal reserve margin is crucial; a margin that is too high results in excessive costs, while one that is too low leads to inadequate service provision. The data analysis revealed significant variability in reserve margins across different states, reflecting regional disparities in water supply and management practices.

Additionally, Respondent 2 pointed out significant problems with pipe leaks. *"Many pipe failures occur due to the old age of the pipe. Some are over 40 years old,"* explained Respondent 2. This situation highlights the urgent need for infrastructure upgrades to prevent service disruptions and ensure a reliable water supply.

4.2.3 Water use patterns and infrastructure issues

The interview also shed light on water use patterns and infrastructure challenges in Malaysia. Generally, Malaysia exhibits very high domestic water usage, with some regions exceeding 300 litres per day per capita. For instance, Penang demonstrates particularly high water consumption. According to Respondent 1, *"This excessive usage is attributed to a lack of investment and insufficient funds to build new water treatment plants."*

In Kelantan, numerous small plants are constructed to serve local areas. However, as Respondent 2 explained, *"This approach results in high operational costs due to the need to regulate many small plants."*In contrast, states like Selangor have large, centralized plants that are more efficient in terms of operation and regulation.

A significant issue in Malaysia's water management is water loss, often referred to as non-revenue water (NRW). Respondent 2 further elaborated that *"NRW can be divided into three categories: commercial loss, operational loss, and physical loss."* Commercial loss includes water used for purposes such as firefighting that does not generate revenue. Operational loss includes activities like flushing or plant washing, which account for about 1-2%. The largest category is physical loss, which comprises about 40% of total water loss and includes leaks and other losses in the physical distribution system.

These patterns and issues highlight the critical need for investment in water infrastructure and more efficient water management practices to address high consumption and significant water losses. The insights from the interview emphasize the urgency of upgrading infrastructure and implementing more effective water management strategies to ensure sustainable water supply across Malaysia.

5. DISCUSSIONS

Based on the findings from the quantitative analysis and the insights gathered from the three main interview questions, several key conclusions can be drawn regarding water management in Malaysia.

Firstly, SPAN's monitoring practices reveal that the commission actively oversees all water companies in Malaysia through regular Water Regulatory Meetings held every quarter. These meetings focus on technical aspects and capital expenditures, ensuring that water companies adhere to regulatory standards and address emerging issues promptly. However, the data indicates variability in the effectiveness of these practices across different states, with some regions still struggling to maintain adequate reserve margins.

Secondly, the operational issues related to water and supply chain operations vary significantly across states. Critical challenges include maintaining an optimal reserve margin, which is crucial for balancing cost and service efficiency. States like Kelantan and Kedah have recorded zero reserve margins, indicating severe deficiencies and highlighting the need for targeted interventions. Additionally, the high operational costs associated with regulating numerous small plants, particularly in Kelantan, contrast with the efficiency of larger, centralised plants in states like Selangor.

Thirdly, the pattern of water use in Malaysia demonstrates very high domestic consumption, with some regions, such as Penang, exceeding 300 litres per day per capita.

This excessive usage is primarily attributed to a lack of investment and insufficient funds for building new water treatment plants. Moreover, water loss, categorised as NRW, poses a significant challenge. NRW includes commercial losses (water used for firefighting), operational losses (activities like plant flushing), and physical losses (leaks and distribution system inefficiencies), with physical losses accounting for about 40% of the total water loss.

It can be highlighted that findings bring to light the need for enhanced investment in water infrastructure and more efficient management practices to address the high water consumption and significant water losses. It is critical to address these issues. Ageing water infrastructure could lead to leaks and inefficiencies that would result in the wastage of huge amounts of water, which could hamper the existing limited resources. By modernising water distribution systems and implementing smart technologies, the government can reduce waste and ensure a more sustainable water supply. Additionally, adopting more efficient water management practices, such as promoting the use of water-saving appliances can help lessen the pressure on water resources and reduce overall consumption. These steps are crucial to meeting future demand while preserving water for future generations.

In addition, the variability in reserve margins and the operational challenges faced by different states highlight the importance of targeted interventions and strategic planning to ensure a sustainable and reliable water supply across Malaysia. The allocation of the appropriate amount of financial resources to repair and improve the ageing water systems could prevent water losses via leakages and finally would enhance overall efficiency.

One important aspect of water resilience to be able to compare between countries is to ensure the implementation of the major components such as infrastructure, policy frameworks, and climate adaptability. The latest study results imply that those countries which have strong water management systems, for example, the Netherlands and Singapore, will likely exhibit to a great extent better water resilience than countries that have inferior technologies. For example, floods in the Netherlands are now prevented due to the implementation of the most detailed water management plan in the country, and the use of controlled inundation techniques and pump and tide management strategies which will be able to adapt to flood-related climate changes advantageous (Bakker &Morinville, 2013). The country demonstrating its exceptional achievement in terms of water security by implementing innovative recycling and desalination projects is also Singapore (Chew et al., 2010). These two countries can be compared in this light that water resilience, modern infrastructure and technology are the two significant pieces of the puzzle.

On the other hand, less developed countries with poorer water infrastructures like India and some African countries have a harder time dealing with this issue. The discovery of how some regions lack the necessary infrastructure, have leaky water use procedures, as well as are exposed to the risk of changing climate that prevents them from being water-resilient (Bharti et al., 2020; Onu et al., 2023). For instance, in India, inconsistent water distribution and high dependence on monsoon rains underscore the need for more resilient water management approaches (Bharti et al., 2020). Similarly, the continent of sub-Saharan Africa is in a bad state because it cannot access any advanced water technologies and infrastructural help and therefore, it is more prone to water problems (Onu et al., 2023). The current analysis of similarities and differences in using technology and infrastructure to the enhancement of the world's water security is quite obvious.

6.0 CONCLUSIONS AND SUGGESTIONS FOR FUTURE RESEARCH

In conclusion, although the study provides valuable insights, it is not without limitations. The reliance on secondary data means the study’s accuracy is dependent upon the records provided by SPAN. Additionally, the qualitative findings are based on interviews with a limited

number of SPAN personnel, which may not fully capture the perspectives of all stakeholders involved in water management.

Despite these limitations, the use of a mixed-methods approach in this study enables a thorough investigation of water risk awareness and reserve margin ratios in Malaysia. The research provides a comprehensive framework for understanding the intricacies of water risk management and its impact on reserve margins by combining quantitative data from SPAN with qualitative insights from expert interviews. The purpose of the research is to provide information that may be used to shape policy and practice, to improve the resilience and effectiveness of water management techniques.

The findings highlight that several states, such as Kelantan, Kedah, and Perlis, report critically low or zero reserve margin ratios. This highlights significant challenges in the water supply system, revealing the potential risk regarding the limited resources and outdated infrastructure. These vulnerabilities could lead to reduced access to clean water, and water shortages and could potentially affect sustainability in the long run. Addressing these challenges requires proactive intervention from the management and high investment in infrastructure improvements. This in turn would promote water conservation practices to ensure a stable and resilient water supply in the long run.

The study further outlines crucial concerns about water utilisation practices and infrastructure. Leakages in pipes, frequently resulting from the deterioration of pipes that are more than 40 years old, have a substantial impact on water loss and inefficiency. The study emphasises the importance of making substantial investments in infrastructure and implementing a more efficient regulatory approach. This would ensure reliable access to clean and safe water and reduce the risk of water shortages.

Future research should examine the effectiveness of different investment strategies in water infrastructure, particularly in states with critical reserve margins. Comparative analyses of centralised and decentralised water treatment facilities can offer valuable insights into cost-effectiveness and operational efficiency.

Additionally, examining societal and behavioural factors contributing to excessive domestic water consumption would be beneficial as it would assist in planning water usage. An analysis of consumer behaviour, public knowledge, and the impact of water conservation programmes can provide valuable insights for developing policies that target the reduction of individual water use. This multifaceted approach can help develop more targeted and effective water management strategies, ensuring a sustainable water supply for Malaysia.

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RESEARCH ETHICS

This research has received ethical approval from the Research Ethics Committee of UiTM: REC/02/2023 (ST/MR/27).

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