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NON-REVENUE WATER: IDENTIFYING CHALLENGES AND ANTICIPATING FUTURE SOLUTIONS

Wan Aida Nadia Wan Abdullah[1*], Roshidi Din[2], Nuramalina Mohamad Na'in[3], Nik Fatinah N. Mohd Farid[4]

[1] School of Computing, Universiti Utara Malaysia, Malaysia
Email: w.aida.nadia@uum.edu.my
[2] School of Computing, Universiti Utara Malaysia, Malaysia
Email: roshidi@uum.edu.my
[3] School of Computing, Universiti Utara Malaysia, Malaysia
Email: mn.nuramalina@uum.edu.my
[4] School of Computing, Universiti Utara Malaysia, Malaysia
Email: nikfatinah@uum.edu.my
[*] Corresonding Author

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Abstract:

Water, a vital resource for human survival and societal development, is increasingly threatened by the pervasive issue of Non-Revenue Water (NRW). This paper explores the multifaceted challenges associated with NRW, investigating the technical intricacies, economic implications, and social dimensions that contribute to water losses globally. Aging infrastructure, technical inefficiencies, and varying socio-economic factors are identified as primary challenges impacting the management of water distribution systems. The economic toll of NRW is analyzed, revealing substantial financial losses for water utilities, hindering their ability to invest in critical infrastructure upgrades. Social justice aspects of NRW are unveiled, emphasizing how unequal access to water services perpetuates disparities, particularly in vulnerable communities. Climate change further amplifies the complexity, introducing new challenges to water availability and distribution. Community engagement strategies and adaptive measures in the face of climate change are also investigated. By comprehensively understanding the challenges and proactively seeking solutions, stakeholders can pave the way for sustainable, resilient, and equitable water management systems. This paper serves as a valuable resource that discuss in general Europe, China, Japan, South Korea and specifically in specific states Malaysia regarding NRW systems.

Keywords:

Non-Revenue Water, Water Distribution System, Leakage Model, Sustainable Water Management

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Introduction

Water is an indispensable resource, crucial for sustaining life and fostering the growth of communities worldwide. However, the management of water resources poses a significant challenge, particularly in the face of escalating urbanization, population growth, and the impacts of climate change (Dias, Besner & Prevost, 2017). One critical aspect of water management that demands attention is the phenomenon of Non-Revenue Water (NRW). NRW refers to water that is lost before it reaches the end consumer or generates revenue for water utilities. This issue is a pervasive concern globally, contributing to substantial economic losses and undermining efforts to ensure equitable access to clean water (Lai, Chan & Roy, 2017; Tabesh, Asadiyami Yekta & Burrows, 2009). In this context, this journal aims to delve into the intricate challenges associated with Non-Revenue Water and explore innovative solutions to address this complex issue.

The extent of Non-Revenue Water varies widely across regions, often influenced by factors such as aging infrastructure, technical inefficiencies, inadequate maintenance, and, in some cases, deliberate tampering. Unravelling these challenges is crucial for developing effective strategies to curb water losses (Jones et al., 2021). The main components of NRW is shown in Figure 1.

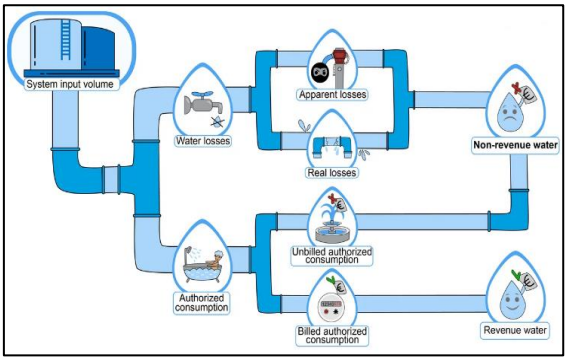

Figure 1: Main Components of NRW

Figure 1 shows the main components to examine the multifaceted nature of NRW challenges, considering both the technical intricacies of water distribution systems and the broader socio-economic factors that contribute to water loss. By understanding the intricate web of issues surrounding NRW, stakeholders can better identify targeted interventions that align with the unique circumstances of each community (Lai et al., 2020; Güngör-Demirci et al., 2018; Al-Washali, Sharma & Kennedy, 2016).

NRW poses a substantial financial burden on water utilities, often resulting in lost revenue that could be redirected toward infrastructure improvements and expanded access to clean water services (Liemberger & Wyatt, 2019). The economic toll of NRW is particularly pronounced in developing regions where resources are scarce, hindering the ability of utilities to invest in much-needed upgrades. In this context, this paper scrutinizes the economic implications of Non-Revenue Water, shedding light on the true cost of water losses and emphasizing the urgent need for investment in resilient water infrastructure (Al-Washali, Sharma & Kennedy, 2016). By quantifying the economic impact, it can make a compelling case for prioritizing NRW reduction as a central pillar of sustainable water management (Lai et al, 2020).

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Furthermore, the social dimensions of Non-Revenue Water cannot be overlooked. Water scarcity and unequal access to water services disproportionately affect vulnerable communities, perpetuating cycles of poverty and disenfranchisement (Muhammetoglu et al, 2018). As the world grapples with the consequences of climate change, Non-Revenue Water takes on new dimensions of urgency. The altered precipitation patterns, increased frequency of extreme weather events, and rising temperatures all pose threats to water availability and distribution systems (Nova, 2023). This paper investigates the intersection of climate change and NRW, exploring adaptive strategies that can enhance the resilience of water utilities in the face of a changing climate. By recognizing the interconnectedness of these challenges, we can develop holistic solutions that address both current and future risks.

The exploration of Non-Revenue Water is a vital undertaking with far-reaching implications for the health, economic prosperity, and social equity of communities worldwide (Dias, Besner & Prevost, 2017). In essence, the challenge of Non-Revenue Water extends beyond mere water loss – it is a complex issue interwoven with economic, environmental, and societal repercussions. As it grapples with an ever-changing world, understanding the nuances of NRW and proactively seeking solutions is paramount to ensuring a water-secure future for generations to come (Jang & Choi. 2017). This paper serves as a platform for identity the pursuit of innovative strategies to minimize Non-Revenue Water and pave the way for a more sustainable water future.

NRW'S Challenges Around The World

Non-Revenue Water (NRW) poses a global challenge that transcends regional boundaries, impacting communities worldwide. One overarching challenge is the sheer scale of water losses occurring throughout the water supply chain, from production and treatment to distribution and consumption (Jabari, 2017). The World Bank estimates that approximately 32 billion cubic meters of water are lost annually due to NRW, representing a staggering economic loss and exacerbating water scarcity concerns (Murugan & Chandran, 2019). This issue is particularly acute in rapidly urbanizing areas where aging infrastructure, insufficient maintenance, and rapid population growth contribute to significant water losses, undermining efforts to provide reliable and equitable access to clean water (Murugan & Chandran, 2019; Gupta et al, 2020).

A second general challenge is the inherent complexity of NRW, involving a myriad of interconnected factors. Technical challenges, such as aging pipes, leaks, and inefficient distribution systems, often coexist with social and economic factors, including inadequate metering, illegal connections, and disparities in water pricing structures (Torkaman, Ahmadi & Aminnejad, 2021). Addressing NRW necessitates a holistic approach that considers not only the physical aspects of water infrastructure but also the socio-economic dynamics within communities. Overcoming these challenges requires innovative solutions, the integration of advanced technologies, and concerted efforts from policymakers, water utilities, and local communities to create sustainable and resilient water management systems worldwide (Tabesh Asadiyami Yekta & Burrows, 2009; Gupta et al., 2020).

NRW in Europe

The issue of NRW in Europe is a pressing concern that demands meticulous attention as the region grapples with the complexities of water resource management. NRW, defined as water lost before reaching end-users or generating revenue for water utilities, poses significant

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challenges across European countries. One primary factor contributing to elevated NRW levels is the aging water infrastructure prevalent in many European cities (Czerwinski et al., 2007). The extensive network of pipes, some dating back decades, is susceptible to leaks and inefficiencies, resulting in substantial water losses before it reaches consumers.

Several factors contribute to the persistence of high NRW rates in Europe. Technical inefficiencies in water distribution systems, inadequate maintenance practices, and suboptimal metering contribute to the overall water loss (Biesheuvel, Weige & Heindel, 2011). As a result, NRW not only represents a loss of a precious resource but also undermines the financial sustainability of water utilities, hindering their ability to invest in infrastructure upgrades and meet the evolving demands of growing populations (Müller & Reutter, 2017).

The challenge of NRW in Europe is further compounded by the diverse socioeconomic landscapes across countries. Economic disparities and differences in governance structures influence the capacity of nations to address NRW effectively (Kanakoudis et al., 2013). While some European countries boast advanced technologies and financial resources for infrastructure improvements, others face constraints that impede their ability to invest in comprehensive solutions. The absence of standardized methods for measuring and reporting NRW hinders accurate comparisons between countries and regions [20]. Establishing common metrics and sharing best practices could streamline efforts to reduce NRW and create a more cohesive strategy for sustainable water management across Europe.

NRW in China

The NRW in China has emerged as a critical issue, posing multifaceted challenges to the country's water resource management. The expansive urbanization and rapid economic growth witnessed in China have placed immense pressure on water supply systems, making NRW a substantial concern. One primary issue contributing to elevated NRW levels in China is the aging water infrastructure, particularly in urban areas. Aging pipelines, inefficient distribution systems, and inadequate maintenance practices collectively contribute to significant water losses, undermining the nation's efforts to achieve water security and sustainability (Ouyang et al., 2017).

Several factors compound the NRW challenge in China, encompassing both technical and non-technical aspects. Technical factors include leakages, pipe corrosion, and inadequate metering, while non-technical factors involve unauthorized abstractions, illegal connections, and insufficient billing systems. These factors vary across regions due to the diverse economic and developmental landscapes within China (Berardi, 2014). For instance, in rapidly developing urban centres, the demand for water outpaces the capacity of aging infrastructure, leading to heightened NRW rates. In contrast, rural areas face distinct challenges, such as inadequate access to modern water infrastructure and limited financial resources for maintenance (Yu et al., 2015).

The economic ramifications of NRW in China are substantial, affecting both water utilities and the broader economy. The financial losses incurred due to water that never reaches paying consumers impede the ability of water utilities to invest in crucial infrastructure upgrades and maintenance (Wu, House & Peri, 2016).

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China's ambitious goals for sustainable development, coupled with the increasing impacts of climate change, add layers of complexity to the NRW challenge. The country's vulnerability to water scarcity and changing precipitation patterns necessitates adaptive strategies that align with its unique environmental context. Innovative solutions, such as advanced sensor technologies, real-time monitoring, and data analytics, are increasingly recognized as integral to addressing NRW and enhancing the resilience of China's water supply systems (Singh et al., 2021).

NRW in Japan

One primary issue contributing to NRW in Japan is the aging water distribution network. Many cities and regions possess pipelines that have been in use for decades, making them susceptible to leaks and inefficiencies. Despite Japan's reputation for technological innovation, the maintenance and renewal of water infrastructure have become crucial focal points to mitigate NRW and ensure a sustainable water supply (Pathirane, Kazama & Takizawa, 2021).

Factors influencing NRW in Japan extend beyond technical aspects to include social and environmental considerations. In urban areas like Tokyo and Osaka, high-density populations and intricate city layouts can result in complexities within the water distribution systems (Isobe, 2011). Additionally, the prevalence of high-rise buildings and underground utilities further complicates the monitoring and maintenance of water pipelines (Lam, Kenway & Lant, 2017). Furthermore, the country's susceptibility to natural disasters, such as earthquakes and typhoons, poses challenges in ensuring the resilience of water infrastructure, potentially contributing to increased NRW during and after such events.

Efforts to address NRW in Japan are also influenced by the commitment to water conservation and environmental sustainability. Balancing economic growth with responsible water use is crucial, requiring continuous investment in advanced technologies, smart metering, and efficient management practices (Kanazawa et al., 2005). While Japan benefits from a well-regulated and organized water sector, the ongoing challenge is to adapt and modernize infrastructure to meet the evolving demands of urbanization and environmental factors. Collaborative initiatives involving government agencies, water utilities, and technology developers play a pivotal role in developing comprehensive strategies to reduce NRW in Japan and ensure a resilient water supply for its citizens (Shirahata, 2012).

NRW in Korea

South Korea, known for its rapid industrialization and technological advancements, faces challenges associated with NRW that necessitate a closer examination. One prominent issue contributing to NRW in South Korea is the aging water infrastructure, particularly in urban areas. As cities have undergone extensive development over the decades, the existing pipeline network may face deterioration, leading to leaks and inefficiencies (Jang & Choi, 2017). The need for comprehensive infrastructure upgrades and maintenance is apparent to curb these losses and ensure the sustainable supply of water.

Several factors contribute to the persistence of high NRW rates in South Korea, encompassing both technical and non-technical dimensions. Technical factors include outdated distribution systems, leakages, and inadequate metering, all of which result in water losses. Additionally, the complexity of urban landscapes, high-density populations, and intricate city layouts further compounds these technical challenges (Jang, Choi & Park, 2019). Non-technical factors such

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as unauthorized abstractions, illegal connections, and disparities in water pricing structures contribute to the overall NRW challenge, necessitating a holistic approach to address these interconnected factors (Choi et al., 2020).

The economic implications of NRW in South Korea are significant, affecting the financial sustainability of water utilities. Moreover, the economic burden may result in increased water tariffs, impacting consumers and potentially exacerbating social disparities in access to clean water (Lim, Savic & Kapelan, 2015). Overcoming these challenges requires a comprehensive strategy that considers the unique characteristics of South Korea's water infrastructure, economic landscape, and urban development patterns. Collaborative efforts among government bodies, water utilities, and local communities are essential to develop effective solutions and ensure a resilient and efficient water supply system for the nation (Moon, 2020).

NRW in Malaysia

Non-Revenue Water (NRW) represents a significant challenge in Malaysia, impacting the sustainability of water resources across its diverse states. The issue is particularly pronounced in urban centres, where rapid population growth and industrialization strain existing water infrastructure (Lai, Chan & Roy, 2017). Aging pipelines, leakages, and inefficient distribution systems contribute to substantial water losses before reaching consumers. Understanding the nuances of NRW in each state is essential for developing targeted solutions that align with the unique challenges faced by different regions (Lai et al., 2020).

In states like Selangor, the economic hub of Malaysia, burgeoning urbanization and industrial activities have led to heightened demand for water, placing stress on existing infrastructure. The state grapples with technical factors such as pipe leakages and inadequate metering systems. Additionally, the rapid pace of development may contribute to unauthorized connections and water theft, further exacerbating NRW challenges (Sakke, Ithnin & Ngah, 2014; Mid Khalid, 2018).

Penang, a state known for its economic dynamism, faces challenges associated with the age of its water distribution infrastructure. The prevalence of older pipes and the need for regular maintenance contribute to water losses. Addressing NRW in Penang requires a delicate balance between sustaining economic growth and ensuring the efficient use of water resources (Ab Rashid, Abd Rahman & Abdul Rashid, 2021).

In contrast, rural states like Kelantan and Sabah encounter unique challenges related to access to modern water infrastructure. Limited financial resources, coupled with geographical constraints, make it difficult to invest in advanced technologies and maintenance practices. These states often grapple with a different set of technical factors, including issues related to water quality and availability (Hafiz Kadar, Syarmila Sameon & Ezanee Rusli, 2018).

Climate variability introduces an additional layer of complexity to the NRW challenge in states like Johor and Terengganu. Adapting water management strategies to mitigate the effects of climate change is crucial for ensuring water resilience in these states (Sia, Fernandez & Chong, 2021; Kurisu et al., 2016).

The complex landscape of Non-Revenue Water in Malaysia requires a nuanced, state-specific approach. Recognizing the diverse factors and challenges faced by each state is crucial for

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implementing targeted interventions that balance economic growth with sustainable water management (Jones et al., 2021). Collaborative efforts among government bodies, water utilities, and local communities are essential to create resilient and efficient water systems that address the unique needs and challenges of each state in Malaysia (Lai et al., 2020).

Expected Future Solution for NRW

Addressing the pervasive challenge of NRW requires innovative and forward-thinking solutions to ensure the sustainable use of this precious resource. The future of NRW mitigation lies in a multifaceted approach that integrates advanced technologies, community engagement, adaptive strategies, and policy reforms (Güngör-Demirci et al., 2018).

The integration of advanced technologies stands at the forefront of future solutions for NRW. Smart metering, sensor networks, and real-time monitoring systems offer unprecedented insights into water distribution systems, enabling rapid detection of leaks, pipe weaknesses, and inefficiencies (Gupta et al., 2020). Artificial intelligence and data analytics play a pivotal role in predictive maintenance, allowing utilities to proactively address potential issues before they escalate. The embrace of these technologies empowers water utilities with the tools needed to optimize water distribution, minimize losses, and enhance overall system efficiency (Ouyang et al., 2017).

As climate change continues to impact global weather patterns, adaptive measures are essential for resilient water management. Future solutions must consider the potential effects of climate variability on water availability and distribution systems. This may involve the development of flexible water supply strategies, improved water storage facilities, and dynamic infrastructure planning to accommodate changing environmental conditions (Liemberger & Wyatt, 2019). Integrating climate resilience into NRW reduction efforts ensures long-term effectiveness and mitigates the risks associated with an unpredictable climate.

A holistic and integrated approach to water management is essential for addressing NRW comprehensively. Future solutions should consider the interconnectedness of water supply, distribution, wastewater management, and environmental conservation. Developing synergies between different components of the water cycle fosters efficiency and sustainability Murugan & Chandran, 2019). The future of NRW reduction lies in a combination of technological innovation, community involvement, climate resilience, policy reforms, and integrated water management strategies. By embracing these forward-thinking solutions, stakeholders can collectively work towards a future where water resources are conserved, distributed efficiently, and made accessible to all (Lai et al., 2020; Jabari, 2017).

Conclusion

In conclusion, the exploration NRW in this paper has underscored the critical need for a concerted and multifaceted approach to address the challenges associated with water loss globally. The intricate web of technical, economic, social, and environmental factors contributing to NRW demands innovative solutions that go beyond conventional approaches. the urgency to tackle NRW is heightened by the escalating impacts of climate change, rapid urbanization, and the imperative to ensure equitable access to clean water for all countries around the world.

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Anticipating the future solutions to NRW involves embracing advanced technologies, fostering community engagement, and implementing adaptive strategies that account for a changing climate. It reviews the challenge in general Europe, China, Japan, and South Korea, then specifically in some states in Malaysia. The path forward entails not only addressing the immediate technical challenges but also navigating the socio-economic complexities and disparities that perpetuate water losses. By anticipating the future landscape of water management and proactively seeking innovative solutions, we can lay the foundation for resilient, sustainable, and inclusive water systems. This paper serves as a call to action, urging policymakers, water utilities, researchers, and communities to collaborate in the pursuit of a water-secure future where the challenges of NRW are met with innovation, adaptability, and a shared commitment to responsible water management.

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