SEMARAK ILMU PUBLISHING
202103268166(003316878-P)

Semarak International Journal of Machine Learning

Journal homepage: *https://semarakilmu.com.my/journals/index.php/sijml/index*
ISSN: 3030-5241

Innovative Machine Learning Applications in Non-Revenue Water Management: Challenges and Future Solution

Roshidi Din[1,*], Amalina Mohammad Na'in[1], Sunariya Utama[1], Muhaimen Hadi[1], Alaa Jabbar Qasim Almaliki[1]

[1] School of Computing UUM College Arts and Sciences, Universiti Utara Malaysia, 06010, Sintok, Kedah, Malaysia

ARTICLE INFO

Article history:
Received 15 February 2024
Received in revised form 17 March 2024
Accepted 20 March 2024
Available online 18 April 2024

Keywords:
Non-revenue water; machine learning; water infrastructure; technological innovation

ABSTRACT

The escalating global concerns surrounding Non-Revenue Water (NRW) necessitate a paradigm shift in water management strategies, and innovative machine learning (ML) applications emerge as a transformative solution. This paper investigates the intersection of ML and NRW management, recognizing the pressing need to curb water losses due to leaks, theft, and inaccuracies. As water utilities grapple with the economic and environmental repercussions of NRW, this paper explores the potential of ML algorithms, such as predictive analytics to revolutionize traditional approaches. The discussion encompasses the intricate landscape of challenges, including data quality issues, model interpretability, and the inherent complexity of implementation. Recognizing the multidisciplinary nature of these challenges, the journal emphasizes the collaborative efforts required to harmonize technological innovation with practical implementation. As the world confronts the imperative to optimize water resources, this paper posits that innovative ML applications present a pivotal opportunity to not only enhance the accuracy and efficiency of NRW management but also to foster a more sustainable and resilient water infrastructure. Through a comprehensive grasp of challenges and a proactive pursuit of remedies, stakeholders can establish sustainable, resilient, and equitable water management systems. This paper acts as a valuable reference, providing a detailed discussion encompassing Europe, China, Japan, South Korea, and specific states within Malaysia, with a specific focus on non-revenue water (NRW) systems.

1. Introduction

The 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 [1]. 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,

* *Corresponding author.*
E-mail address: roshidi@gmail.com

contributing to substantial economic losses and undermining efforts to ensure equitable access to clean water [2,3]. 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. Unraveling these challenges is crucial for developing effective strategies to curb water losses [4]. The component on NRW in general shows in Figure 1.

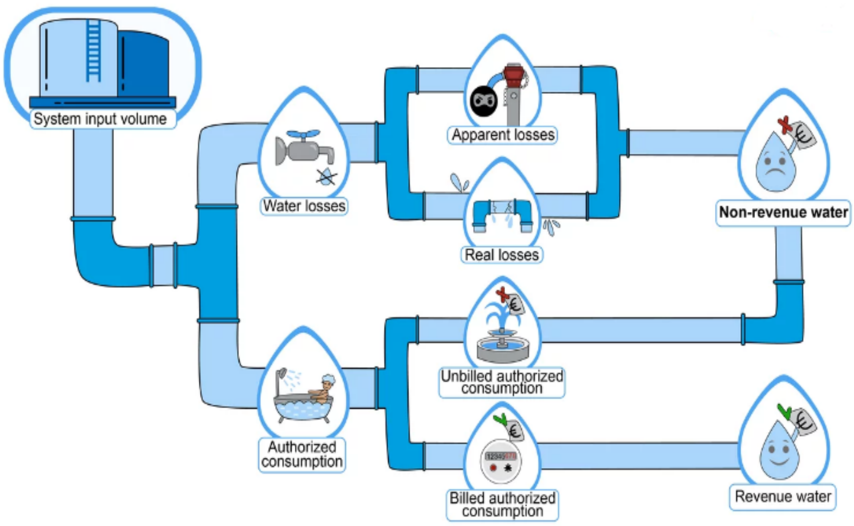

Fig. 1. Major component of NRW

Figure 1 shows the component of 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 [2,5,6].

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 service [7]. 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 [8]. By quantifying the economic impact, it can make a compelling case for prioritizing NRW reduction as a central pillar of sustainable water management [9] .

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 [10]. 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 [11]. 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 [1]. 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 grapple 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 [12] . 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.

2. Machine Learning in NRW

The role of machine learning in addressing non-revenue water (NRW) is becoming increasingly vital for water utilities seeking efficient and sustainable water management practices. Machine learning algorithms can analyze large datasets generated by water distribution systems, including information from sensors, meters, and historical records [13]. By leveraging these algorithms, utilities can detect and identify patterns indicative of leaks, unauthorized water usage, or inaccuracies in metering. The ability of machine learning models to process and interpret such complex data sets allows for quicker and more accurate identification of areas with high NRW, enabling utilities to respond promptly and address issues before they escalate [14].

Furthermore, machine learning contributes significantly to the predictive maintenance of water infrastructure. By continuously learning from historical data, these algorithms can anticipate potential leaks or failures in the system. This proactive approach allows utilities to schedule maintenance activities strategically, reducing downtime and minimizing water losses [15]. The integration of machine learning in NRW management enhances the overall resilience and reliability of water distribution systems, optimizing resource utilization and ensuring the sustainable delivery of water services [16].

In addition to addressing physical losses, machine learning also plays a role in managing apparent losses, such as inaccurate meter readings. Advanced analytics can identify irregularities in meter data, flagging potential issues for further investigation [17]. By improving the accuracy of metering and billing processes, machine learning contributes to the reduction of revenue losses associated with inaccuracies in measuring water consumption. As water utilities worldwide face increasing challenges related to water scarcity and infrastructure resilience, the adoption of machine learning in NRW management stands as a critical step toward building more sustainable and effective water systems [18].

2. General Challenge NRW 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 [12]. 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 [19]. 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 [20].

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 [21]. 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 [22].

2.1 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 challenges across European countries. One primary factor contributing to elevated NRW levels is the aging water infrastructure prevalent in many European cities [22]. 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 [23]. 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 [24].

Furthermore, machine learning has gained substantial traction in Europe, with widespread adoption across various sectors such as healthcare, finance, and manufacturing. European countries are actively investing in research and development, fostering collaboration between academia and industry to harness the potential of machine learning for innovation and economic growth [25].

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 [26]. 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.

3. 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 [27].

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 [28]. For instance, in rapidly developing urban centers, 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 [23].

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 [29]. 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 [30].

3. 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 [31].

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 [32]. Additionally, the prevalence of high-rise buildings and underground utilities further complicates the monitoring and maintenance of water pipelines [28]. 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 [29]. 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 [30].

4. NRW in South 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 [33]. 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 [34]. Non-technical factors such 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 [35].

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 [36]. Overcoming these challenges requires a comprehensive strategy that considers the unique characteristics of South Korea's water infrastructure, economic landscape, and urban development patterns using machine learning application detection [37]. 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 [38].

3. Condition 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 centers, where rapid population growth and industrialization strain existing water infrastructure [2]. 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 [5].

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 [39,40].

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 [41].

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 [42].

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 [39,40]. 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 implementing targeted interventions that balance economic growth with sustainable water management [4]. 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 [2].

4. Expected Future Solution 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 [6].

The integration of advanced technologies stands at the forefront of future solutions for NRW. With machine learning as fundamental to develop, smart metering and real-time monitoring systems offer unprecedented insights into water distribution systems, enabling rapid detection of leaks, pipe weaknesses, and inefficiencies [4,10]. 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 [21].

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 that monitoring by application of machine learning [43]. This may involve the development of flexible water supply strategies, improved water storage facilities, and dynamic infrastructure planning to accommodate changing environmental conditions. 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 [44]. 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 [12].

4. Conclusions

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. It also suggest to develop the application based on machine learning to enhance efficiency and sustainable water management.

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.

References

[1] Dias, Vanessa CF, Marie-Claude Besner, and Michèle Prévost. "Predicting water quality impact after district metered area implementation in a full-scale drinking water distribution system." *Journal-American Water Works Association* 109, no. 9 (2017): E363-E380. https://doi.org/10.5942/jawwa.2017.109.0099.

[2] Lai, Chee Hui, David T. Tan, Ranjan Roy, Ngai Weng Chan, and Nor Azazi Zakaria. "Systems thinking approach for analysing non-revenue water management reform in Malaysia." *Water Policy* 22, no. 2 (2020): 237-251. https://doi.org/10.2166/wp.2020.165.

[3] T Tabesh, M., AH Asadiyani Yekta, and R. Burrows. "An integrated model to evaluate losses in water distribution systems." *Water Resources Management* 23 (2009): 477-492. https://doi.org/10.1007/s11269-008-9284-2.

[4] Jones, Lim Jen Nee, Daniel Kong, Boon Thong Tan, and Puspavathy Rassiah. "Non-revenue water in Malaysia: Influence of water distribution pipe types." *Sustainability* 13, no. 4 (2021): 2310. https://doi.org/10.3390/su13042310.

[5] Güngör-Demirci, Gamze, Juneseok Lee, Jonathan Keck, Robert Guzzetta, and Paul Yang. "Determinants of non-revenue water for a water utility in California." *Journal of Water Supply: Research and Technology—AQUA* 67, no. 3 (2018): 270-278. https://doi.org/10.2166/aqua.2018.152.

[6] Al-washali, Taha, Saroj Sharma, and Maria Kennedy. "Methods of assessment of water losses in water supply systems: a review." *Water Resources Management* 30 (2016): 4985-5001. doi: 10.1007/s11269-016-1503-7.

[7] Liemberger, Roland, and Alan Wyatt. "Quantifying the global non-revenue water problem." *Water Supply* 19, no. 3 (2019): 831-837. doi: 10.2166/ws.2018.129.

[8] AL-Washali, Taha M., Mohamed E. Elkhider, Saroj K. Sharma, and Maria D. Kennedy. "A review of nonrevenue water assessment software tools." *Wiley Interdisciplinary Reviews: Water* 7, no. 2 (2020): e1413. https://doi.org/10.1002/WAT2.1413.

[9] Muhammetoglu, Ayse, Cezmi Nursen, I. Ethem Karadirek, and Habib Muhammetoglu. "Evaluation of performance and environmental benefits of a full-scale pump as turbine system in Antalya water distribution network." *Water Science and Technology: Water Supply* 18, no. 1 (2018): 130-141. https://doi.org/10.2166/ws.2017.087

[10] Nova, Kannan. "AI-enabled water management systems: an analysis of system components and interdependencies for water conservation." *Eigenpub Review of Science and Technology* 7, no. 1 (2023): 105-124. https://studies.eigenpub.com/index.php/erst/article/view/12.

[11] Ouyang, Hailong, Shubin Lan, Haijian Yang, and Chunxiang Hu. "Mechanism of biocrusts boosting and utilizing non-rainfall water in Hobq Desert of China." *Applied soil ecology* 120 (2017): 70-80.https://doi.org/10.1016/j.apsoil.2017.07.024

[12] Pathirane, Ashan, Shinobu Kazama, and Satoshi Takizawa. "Dynamic analysis of non-revenue water in district metered areas under varying water consumption conditions owing to COVID-19." *Heliyon* 10, no. 1 (2024). https://doi.org/10.1016/j.heliyon.2023.e23516.

[13] M Mashhadi, Neda, Isam Shahrour, Nivine Attoue, Jamal El Khattabi, and Ammar Aljer. "Use of machine learning for leak detection and localization in water distribution systems." *Smart Cities* 4, no. 4 (2021): 1293-1315.https://doi.org/10.3390/smartcities4040069.

[14] Farouk, Abdelrahman M., Rahimi A. Rahman, and Noor Suraya Romali. "Economic analysis of rehabilitation approaches for water distribution networks: Comparative study between Egypt and Malaysia." *Journal of Engineering, Design and Technology* 21, no. 1 (2023): 130-149. https://doi.org/10.1108/JEDT-03-2021-0174.

[15] Khrais, Laith T. "Role of Artificial Intelligence in Shaping Consumer Demand in E-Commerce." Mdpi Journal 12 (2020): 1–14.

[16] Y Yussof, Nurfarah Anisah Mohd, and Hann Woei Ho. "Review of water leak detection methods in smart building applications." *Buildings* 12, no. 10 (2022): 1535. https://doi.org/10.3390/buildings12101535.

[17] Van der Walt, J. C., Philippus Stephanus Heyns, and Daniel Nicolas Wilke. "Pipe network leak detection: comparison between statistical and machine learning techniques." *Urban Water Journal* 15, no. 10 (2018): 953-960.

[18] C Chebrolu, Shankar Babu. "How do cloud capabilities impact various aspects of IT effectiveness?." In *2012 IEEE Fifth International Conference on Cloud Computing*, pp. 932-940. IEEE, 2012. https://doi.org/10.1109/CLOUD.2012.117.

[19] Murugan, S. Sakthi, and S. Chandran. "Assessment of Non-revenue water in a water distribution system and strategies to manage the water supply." *Assessment* 6, no. 04 (2019).

[20] Gupta, Aditya Dinesh, Prerna Pandey, Andrés Feijóo, Zaher Mundher Yaseen, and Neeraj Dhanraj Bokde. "Smart Water Technology for Efficient Water Resource Management: A Review." Energies 13, no. 23 (2020): 1–23.

https://doi.org/10.3390/en13236268.

[21] Torkaman, Nader, Hassan Ahmadi, and Babak Aminnejad. "Calibration of the continuous water model based on the NRW patterns." *Journal of Applied Water Engineering and Research* 9, no. 3 (2021): 194-202. https://doi.org/10.1080/23249676.2020.1844603.

[22] Czerwinski, Alexandra, Stefan Sandmann, Elke Stöcker-Meier, and Lutz Plümer. "Sustainable SDI for EU noise mapping in NRW-best practice for INSPIRE." *International Journal of Spatial Data Infrastructures Research* 2, no. 2 (2007): 90-111.

[23] B Biesheuvel, Cornelis, Stefanie Weige, and Walter Heindel. "Mammography screening: evidence, history and current practice in Germany and other European countries." *Breast Care* 6, no. 2 (2011): 104-109. https://doi.org/10.1159/000327493.

[24] Müller, Miriam, and Oscar Reutter. "Vision development towards a sustainable North Rhine-Westphalia 2030 in a science-practice-dialogue." *Sustainability* 9, no. 7 (2017): 1111. https://doi.org/10.3390/su9071111

[25] Valerio, Carlotta, Lucia De Stefano, Gonzalo Martínez-Muñoz, and Alberto Garrido. "A machine learning model to assess the ecosystem response to water policy measures in the Tagus River Basin (Spain)." *Science of the Total Environment* 750 (2021): 141252. https://doi.org/10.1016/j.scitotenv.2020.141252.

[26] Kanakoudis, V., S. Tsitsifli, P. Samaras, and A. Zouboulis. "Assessing the performance of urban water networks across the EU Mediterranean area: the paradox of high NRW levels and absence of respective reduction measures." *Water Science and Technology: Water Supply* 13, no. 4 (2013): 939-950. https://doi.org/10.2166/ws.2013.044.

[27] OOuyang, Hailong, Shubin Lan, Haijian Yang, and Chunxiang Hu. "Mechanism of biocrusts boosting and utilizing non-rainfall water in Hobq Desert of China." *Applied soil ecology* 120 (2017): 70-80.https://doi.org/10.1016/j.apsoil.2017.07.024.

[28] B Berardi, L., S. Liu, D. Laucelli, S. Xu, P. Xu, W. Zeng, and O. Giustolisi. "Energy saving and leakage control in Water Distribution Networks: A joint research project between Italy And China." *Procedia Engineering* 70 (2014): 152-161. https://doi.org/10.1016/j.proeng.2014.02.018.

[29] Wu, Xun, R. Schuyler House, and Ravi Peri. "Public-private partnerships (PPPs) in water and sanitation in India: lessons from China." *Water Policy* 18, no. S1 (2016): 153-176. https://doi.org/10.2166/wp.2016.010.

[30] Wu, Xun, R. Schuyler House, and Ravi Peri. "Public-private partnerships (PPPs) in water and sanitation in India: lessons from China." *Water Policy* 18, no. S1 (2016): 153-176. https://doi.org/10.1016/j.cosust.2021.02.006.

[31] Pathirane, Ashan, Shinobu Kazama, and Satoshi Takizawa. "Dynamic analysis of non-revenue water in district metered areas under varying water consumption conditions owing to COVID-19." *Heliyon* 10, no. 1 (2024). https://doi.org/10.1016/j.heliyon.2023.e23516.

[32] Isobe, Yoh, Atsushi Nashimoto, Kohei Akazawa, Ichiro Oda, Kenichi Hayashi, Isao Miyashiro, Hitoshi Katai et al. "Gastric cancer treatment in Japan: 2008 annual report of the JGCA nationwide registry." *Gastric Cancer* 14 (2011): 301-316. https://doi.org/10.1007/s10120-011-0085-6.

[33] Lam, Ka Leung, Steven J. Kenway, and Paul A. Lant. "Energy use for water provision in cities." *Journal of cleaner production* 143 (2017): 699-709. https://doi.org/10.1016/j.jclepro.2016.12.056.

[34] Jang, Dongwoo, Gyewoon Choi, and Hyoseon Park. "Adaptation of multiple regression analysis to identify effective factors of water losses in water distribution systems." *Smart Water* 4, no. 1 (2019): 1. https://doi.org/10.1186/s40713-018-0013-6.

[35] Choi, Gye Woon, Hyoung Geun Jo, Hyo Seon Park, and Dong Woo Jang. "Application of decision making model for leakage reduction to economic project in water distribution systems." *Journal of Ambient Intelligence and Humanized Computing* (2020): 1-10. https://doi.org/10.1007/s12652-019-01634-2.

[36] Lim, Euijeong, Dragan Savic, and Zoran Kapelan. "Development of a leakage target setting approach for South Korea based on economic level of leakage." *Procedia Engineering* 119 (2015): 120-129.https://doi.org/10.1016/j.proeng.2015.08.862.

[37] Lee, Jae Min, Kyung-Seok Ko, and Keunje Yoo. "A machine learning-based approach to predict groundwater nitrate susceptibility using field measurements and hydrogeological variables in the Nonsan Stream Watershed, South Korea." *Applied Water Science* 13, no. 12 (2023): 242. https://doi.org/10.1007/s13201-023-02043-9.

[38] MOON, Hee-Keun. "A Study on improving the approaches to set the economic level of water losses in water distribution system." PhD diss., KDI School, 2020. https://211.253.42.153/handle/11125/34424.

[39] N Sakke, Nordin, Hamirdin Ithnin, and M. Suhaily Yusri Che Ngah. "Pengaruh Air Tidak Berhasil (NRW) ke Atas Kemapanan Bekalan Air di Selangor, Malaysia: Influence of Non-Revenue Water (NRW) on the Sustainability of Water Supply in Selangor, Malaysia." *Perspektif Jurnal Sains Sosial dan Kemanusiaan* 6, no. 2 (2014): 66-81. https://ejournal.upsi.edu.my/index.php/PERS/article/view/1664.

[40] Khalid, Rasyikah Md. "Review of the water supply management and reforms needed to ensure water security in Malaysia." *International Journal of Business and Society* 19, no. S3 (2018): 472-483.

[41] Ab Rashid, Muhammad Fakruhayat, Azimah Abd Rahman, and Siti Masayu Rosliah Abdul Rashid. "Analyzing the factors and effects of water supply disruption in Penang Island, Malaysia." *Malays. J. Soc. Sci* 17 (2021): 62-75. https://doi.org/10.17576/geo-2021-1703-05.

[42] Kadar, Haikal Hafiz, Sera Syarmila Sameon, and Mohd Ezanee Rusli. "SMART2L: Smart Water Level and Leakage Detection." *International Journal of Engineering and Technology (UAE)* 7, no. 4.36 Special Issue 36 (2018): 448-452. https://doi.org/10.14419/ijet.v7i4.36.23914.

[43] Zamri, Nurnadiah, Wan Nur Amira Wan Azman, Mohamad Ammar Pairan, Siti Sabariah Abas, and Miaomiao Gao. "An analysis of finding the best strategies of water security for water source areas using an integrated IT2FVIKOR with machine learning." *Frontiers in Environmental Science* 10 (2023): 971129. https://doi.org/10.3389/fenvs.2022.971129.

[44] Kanakoudis, V., S. Tsitsifli, P. Samaras, and A. Zouboulis. "Assessing the performance of urban water networks across the EU Mediterranean area: the paradox of high NRW levels and absence of respective reduction measures." *Water Science and Technology: Water Supply* 13, no. 4 (2013): 939-950. https://doi.org/10.2166/ws.2013.044.