Water Policy 22 (2020) 237–251

Systems thinking approach for analysing non-revenue water management reform in Malaysia

Chee Hui Lai[a,*], David T. Tan[b], Ranjan Roy[c], Ngai Weng Chan[d] and Nor Azazi Zakaria[a]

[a]*River Engineering and Urban Drainage Research Centre, Engineering Campus, Universiti Sains Malaysia 14300, Nibong Tebal, Penang, Malaysia*

**Corresponding author. E-mail: cheehui.lai@gmail.com*

[b]*International Institute for Global Health, United Nations University, Kuala Lumpur 56000, Malaysia*

[c]*Department of Agricultural Extension & Information System, Sher-e-Bangla Agricultural University, Dhaka 1207, Bangladesh*

[d]*School of Humanities, Universiti Sains Malaysia 11800, Penang, Malaysia*

Abstract

High volumes of non-revenue water (NRW) threaten water security in many developing countries. The traditional technocentric water management regime largely neglects social and systemic complexities that need to be addressed for successful reform. This paper explores the challenges of water sector reform and NRW reduction in Malaysia to identify possible drivers that can accelerate the NRW management reform. The analysis uses a system thinking approach, with key systemic relationships represented with causal loop diagrams (CLDs). Findings reveal that the NRW management reform is influenced by technical, environmental, economic, social, institutional, and corporate governance factors. Using the CLDs, leverage points that can accelerate NRW management reform are identified. Policies and strategies that can accelerate the NRW management reform in Malaysia are recommended: (1) water supply security and sustainable development must be emphasised as the main concern for water sector reform; (2) understanding of the socio-economic benefits of water tariff adjustment by stakeholders is necessary to build political alliances for water tariff increments; and (3) the newly privatised water services providers in Malaysia require an integrated NRW reduction plan to optimise the time taken for NRW reduction and at the same time, transforming their current human resources that were inherited from the previous public water utilities.

Keywords: Non-revenue water; Reform; Systems thinking; Water policy; Water tariff

1. Introduction

Non-revenue water (NRW) is water produced without generating revenue to water utilities. It comprises the volume of water lost physically such as pipe leakage and overflow of the reservoir, water

doi: 10.2166/wp.2020.165

lost commercially via water theft and unrecorded water consumption, and other forms of unbilled water consumption or loss (Lambert & Hirner, 2000). A low rate of NRW indicates an efficient water supply system, able to sustainably service consumers and generate profit for water utilities. In contrast, high NRW increases the risk of water scarcity and adverse impacts on the well-being of people, economy, and environment (Farley *et al*., 2008). Despite this, an estimated 48.6 billion cubic metres of water is lost annually to NRW; this problem is concentrated in developing countries, which have an average NRW of 35% and loss of 5.8 billion USD compared with 15% and loss of 5.3 billion USD in developed countries (Kingdom *et al*., 2006).

Reducing NRW is a challenging and complex task with multiple components such as pressure management, pipe replacement, and educational programmes that tackle different causes of NRW (Frauendorfer & Liemberger, 2010). As such, it requires not only the involvement of various departments across water utilities and the collaboration of different stakeholders but also changes in institutional, cultural, and governance structures (Biswas & Tortajada, 2010). For instance, reducing water theft requires both changing consumer mindsets and eliminating institutional corruption (Farley & Liemberger, 2005). To solve the complex water issue, countries must move their water regimes towards an integrated framework able to respond to the complex human–technology–environment system (Pahl-Wostl *et al*., 2008).

Malaysia, a developing country in Southeast Asia, has consistently recorded an NRW rate of over 35% in the past decade (MWA, 2017). In 2016, the country lost 5,846 million litres per day (MLD) of treated water because of NRW, an estimated value of 2.56 million USD (exchange rates on 29 December 2017). NRW rates for each Malaysian state ranged from 19% to 60.7%, among which only two states – Melaka and Penang – recorded NRW rates below 25% (Table S1 in the online Supplementary material). These values compare poorly with other cities in Southeast Asia: below 15% for East Manila, Philippines and 7% in Phnom Penh, Cambodia (PPWSA, 2017; MWSS, 2018). In response to persistently high NRW, the Malaysian Government called for a restructuring exercise in 2006, incentivising NRW reduction, and financing mechanisms to reform the water supply sector (Teo, 2014). The Malaysian federal government started national reforms of the water supply sector aimed at standardising policies and addressing financing. However, 11 years later, national NRW was only reduced by 2.5% from 37.7% in 2006 to 35.2% in 2016 (MWA, 2017), much less than expected from these initiatives (Table S2, available online).

A holistic understanding of the dynamic behaviour of the water management system is critical for identifying appropriate and effective means for improvement (Pahl-Wostl, 2007; Ferguson *et al*., 2013; Halbe *et al*., 2013). Particularly, understanding the transition process of water management regimes and its impact on the water management system provides valuable insight into designing the water policy (Wiek & Larson, 2012). Currently, there is a lack of research on the feedback loops and a complex interaction between non-technical (e.g., financial, management, and institutional) elements around NRW management reform in developing countries, including Malaysia. There have been studies that explore non-technical factors that influence NRW management in a country or city (González *et al*., 2011, 2012; Ndirangu *et al*., 2013; Kanakoudis & Tsitsifli, 2016; van den Berg, 2015; See & Ma, 2018; Tabesh *et al*., 2018). Nevertheless, limited attention has been paid to fundamental causes of the non-technical factors identified and the interactions between factors. Furthermore, there is a lack of in-depth understanding about the dynamics of the transition process in NRW management following a nation-wide water sector regulatory reform. Systems thinking can be applied to fill this research gap, as it is an interdisciplinary research tool for understanding the dynamic behaviour of a system

and discovering the relationships between different elements in the system (Arnold & Wade, 2015). This method has been widely used to study complex water systems. For instance, Rehan *et al.* (2011) used it to develop an interconnected water and wastewater asset management framework. Kotir *et al.* (2016) capture the causal non-linear relationships between biophysical and socio-economic drivers of water resource management in a river basin with the systems thinking approach.

Therefore, this study adopts the systems thinking approach to understand the dynamic behaviour and the challenges of NRW management reform in Malaysia. Moreover, this study identifies possible drivers that can accelerate the NRW reduction process and inform other developing nations facing similar challenges. Lessons drawn from the water restructuring exercise in 2006 are essential to this understanding. The findings provide policymakers with valuable insight into the strategies for addressing systemic challenges arising during the process of NRW management reform. Specifically, this paper examines the impetus for the reforms, the mechanisms that the reforms leverage, challenges to adoption of the restructuring, and persistent challenges in operationalising NRW reduction. Finally, water policies based on the systems analysis to further NRW reduction in the Malaysian context are proposed.

2. Methodology

2.1. Data collection and analysis

The study focused on Peninsula Malaysia (West Malaysia), excluding Sabah and Sarawak of East Malaysia as these two states were not covered under the reforms (a map of Peninsular Malaysia is shown in Appendix A1, available online). To investigate factors that influence water service provider (WSP) success in NRW reduction, 19 in-depth qualitative interviews were conducted with key stakeholders: seven federal government officials, 10 senior staff or engineers from WSPs in different Malaysian states, and two non-governmental organisation (NGOs) representatives. Interviews utilised open-ended questions on issues and challenges in reducing NRW in Malaysia, and the drivers and factors that influence WSP's success in reducing NRW (Appendix A2, available online). Interview data were transcribed and analysed by the authors via the content analysis method (Krippendorff, 2013). A literature review was also conducted using government and research reports (EPU, 2006, 2010; Water Services Industry Act, 2006; Chin, 2008, 2016; Chan, 2009; NAD, 2010, 2011; SPAN, 2011; Tan, 2012; Azzis *et al.*, 2014; Teo, 2014; ASM, 2015; Lai *et al.*, 2017; MWA, 2017; PAAB, 2018) to understand past and present efforts for NRW reduction in Malaysia. Secondary data on NRW statistics in Malaysian states were collected from these documents and data reported in the National Water Service Commission's (NWSC) and Pengurusan Asset Air Berhad's (PAAB) websites (www.span.gov.my/ and www.paab.my/).

2.2. Systems thinking approaches

As discussed earlier, this study adopts a systems thinking approach to analyse the NRW management reform. There are varying approaches to systems modelling: problem structuring and casual loop modelling are used to develop qualitative models, whereas dynamic modelling and testing are used for developing quantitative models (Sterman, 2000; Maani & Cavana, 2007). As this study seeks to explore the dynamic behaviour of a complex system and generate hypotheses to explain behaviour rather than create predictive simulation, a qualitative modelling approach with causal loop diagrams (CLDs) was

used. Key contextual elements of the NRW reduction system were identified based on collected information, and the relationships between these elements were mapped in CLDs using Vensim PLE 7.0 (https://vensim.com/vensim-software/), with a focus on identifying key feedback loops that drive system behaviour. In the CLD, there are arrows to show the relationship of the variables in the diagram. Each arrow in a CLD has either positive '+' or negative '−' polarity. The positive and negative arrows in the CLD link the variables to form reinforcing (R) and balancing (B) feedback loops. Reinforcing loops are positive feedbacks that tend to amplify change, whereas balancing loops are negative feedbacks that tend to dampen change and reach equilibriums. A CLD may include many combinations of R and B loops. The interactions of these loops create the dynamic behaviours of complex systems (Sterman, 2000). Details on reading CLDs developed from this study are in the online supplementary note (Appendices A3–A7).

3. Result

3.1. The impetus for water sector reforms

Although water supply efficiency and effectiveness are cited as the impetus for the national water supply reforms (Chin, 2008; Ching, 2012; Teo, 2014), observations strongly suggest that this alone was insufficient to drive structural changes (Figure 1, B1 loop, dotted arrow). Instead, financial pressures on the federal government, together with water security concerns triggered change. Indeed, the efficiency and effectiveness of the water supply system were poor since at least the 1990s – and even before – whereas the significant reform effort did not take place until 2006 (EPU, 2010). State governments were unable to maintain deteriorating water supply systems due to low tariffs and limited state resources. This created demands for federal funding, which was first included in the Sixth Malaysia Plan (Figure 1, B2 loop). However, funding levels were low relative to needs, and achievements in water supply system improvement during this period were limited.

In 1998, a strong El Niño phenomenon caused droughts that overwhelmed water capture and distribution capacities in the highly populated Klang Valley (Kingdom *et al.*, 2006). This unexpected and widely experienced threat to water supply security resulted in significantly increased federal funding for NRW reduction and water supply infrastructure (Figure 1, B3 loop). Despite increased funding, the regulatory-financial environment – especially the low tariff rates and consequent underinvestment in infrastructure – remained a systemic obstacle to achieving water supply infrastructure goals. It became apparent in subsequent years that federal financing was not a sustainable solution to the infrastructure problem, creating the federal impetus for water sector reforms (Figure 1, B4 loop). This, together with increased public exposure to water supply security problems (Figure 1, B5 loop), generated the necessary conditions for reforms to be enacted.

3.2. Regulatory and financing reform

3.2.1. Pre-reform. The pre-reform underinvestment in water supply infrastructure resulted from misaligned structural incentives around finance, which federal funding alone could not resolve. According to Teo (2014), who most interviewees agreed with, a fundamental problem in NRW reduction in Malaysia has been the lack of financial resources to rehabilitate or develop water supply facilities. Indeed, underinvestment in water distribution infrastructure is a well-known problem worldwide (Frauendorfer & Liemberger, 2010). When water distribution infrastructure is properly maintained, NRW rates are kept low, reducing operational costs, and increasing WSP profit, capital, and resources available to continue

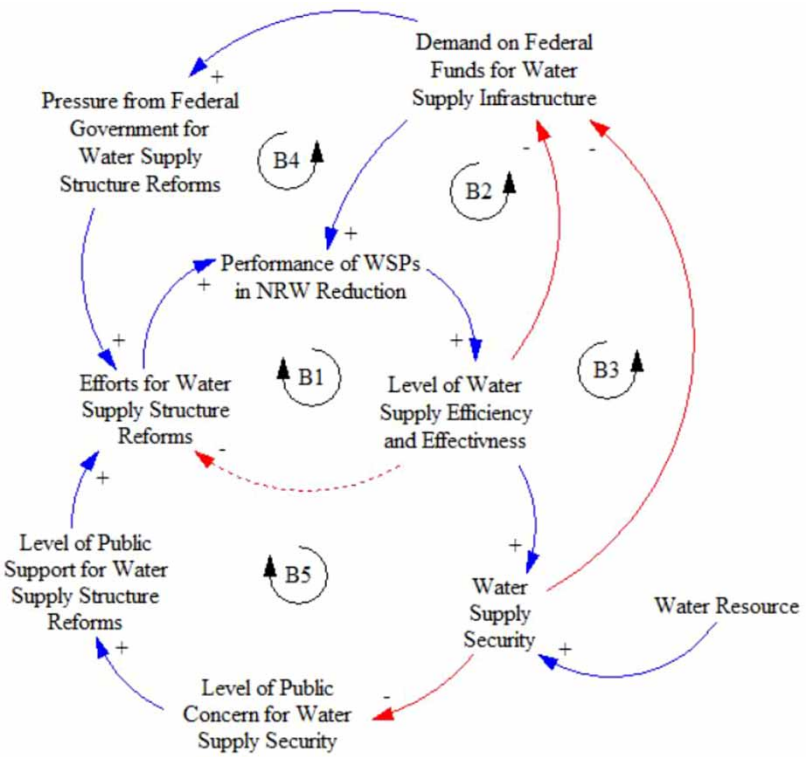

Fig. 1. CLDs illustrating the impetus for reforms of the Malaysian water sector. For a detailed explanation, see text or Appendix A4 in the online supplementary material.

investing in NRW reduction (Figure 2, R1 loop). Conversely, underinvestment in infrastructure undercuts profits in the long term, undermining the ability to invest in infrastructure, turning the R1 loop into a vicious cycle. Unfortunately, NRW reduction is capital-intensive, and financial constraints limit WSPs ability to carry out such work (Figure 2, B6 loop). Furthermore, reduction in NRW rates and savings in operational costs take a long time to be realised (delay symbol ‖ in R1 loop), such that it is often faster and easier to increase water production to make up for NRW – which leads to increased operational costs.

Low water tariffs exacerbate these problems. When WSP profits are low, there is a tendency to increase tariffs to ensure profitability (Figure 2, B7 loop). However, because water tariffs are seen as an essential driver of living costs, which is a major social-economic concern, there is intense political pressure to keep tariffs low (Figure 2, B8 loop). Based on the interviews with NGO representatives and Chan (2009), water tariffs are a socially and politically sensitive issue in Malaysia, especially in state elections, and there has been a lack of political will to openly support the increment of water tariff. In contrast, free water has been a vital manifesto in election campaigns, with the Selangor State Government providing 20 cubic meters per month of free water per household to domestic water consumers since 2008 (Azzis *et al.*, 2014). Most state WSPs are owned by the respective state government and chaired by the Chief Minister or Menteri Besar, which are political positions (Chin, 2016). Consequently, state governments have been reluctant to approve water tariff increases, such that WSPs have usually operated at a loss, adversely impacting capital available for infrastructure.

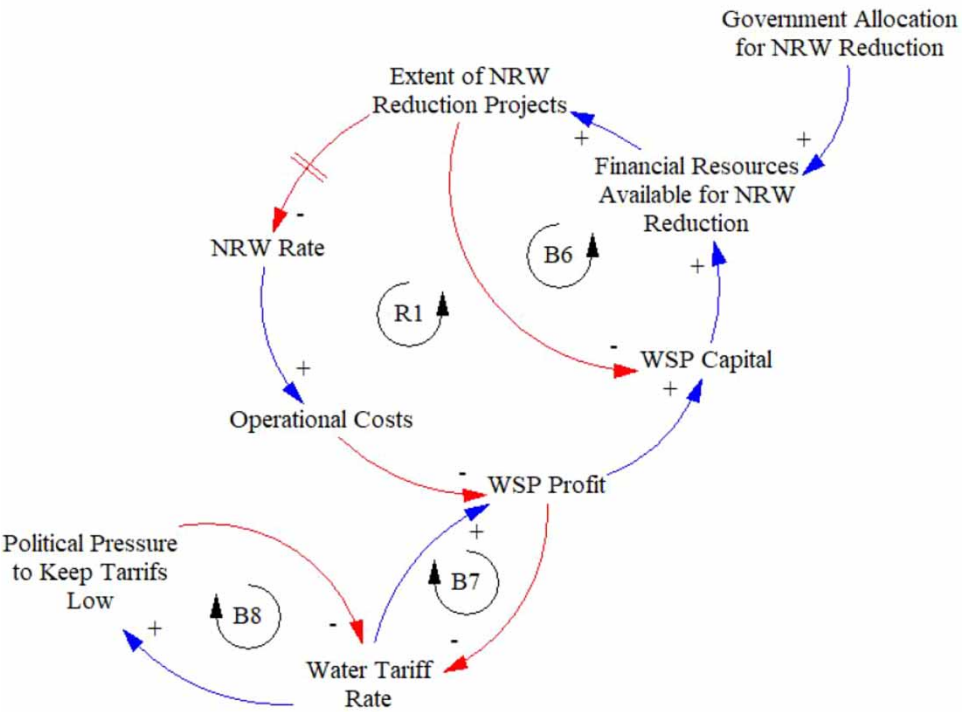

Fig. 2. CLDs show the pre-reform systemic problems in financing NRW reduction and impacts of regulatory and financing reforms. For a detailed explanation, see text or Appendix A5 in the online supplementary material.

Indeed, Malaysian water tariffs are much lower than in comparable South East Asian countries. The average water tariff per thousand litres for the first 35,000 l is USD 0.31 and 0.26 in East Manila, Philippines and Bangkok, Thailand, respectively (source: https://www.manilawater.com, https://www.mwa.co.th), but only USD 0.18 in Malaysia, with WSPs losing USD 0.07 per cubic metre of water sold (MWA, 2017). According to the literature (Tan, 2012; Teo, 2014; ASM, 2015) and most interviewees, these tariffs are unable to achieve cost recovery. Consequently, WSPs were barely able to cover operating expenditure, and thus dependent on federal government allocation for NRW reduction. Such funding, however, is insufficient to address the NRW problem, fails to incentivise investment of profits into infrastructure, and enables WSPs to continue operating on a loss-making basis. Thus, underinvestment persists. With federal funding alone, unable to change the behaviour of the system, structural reforms were carried out to solve financing and incentive obstacles.

3.2.2. Post-reform. These reforms began with the adoption of two new water policy instruments: the Water Services Industry Act (WSIA) 2006 and the National Water Services Industry Act (SPAN Act) 2006. Table 1 describes the major changes instituted in these reforms. Under these Acts, the NWSC was formed in 2007, taking over regulation of the water supply sector previously the purview of state governments, from the treatment of raw water to the discharge of wastewater, in Peninsular Malaysia and the Federal Territory of Labuan. With the Acts, legislation and standards to regulate and monitor the water service sector are made uniform.

The Acts mandated the privatisation of all WSPs previously operated as part of the state government. The privatisation of WSPs is meant to address the problems of indefinite deficits and inefficient operations, thereby incentivising financially sustainable tariffs. Privatisation was accompanied by a shift in authority to set tariffs from state governments to the federal level. By having private companies rather than state governments call for higher tariffs and by moving decisions on tariff rates to a more distant actor, the reforms aim to weaken the link between pressure to reduce tariffs and water tariff rates (Figure 3, the dotted line in B8 loop). While the privatised entities are nonetheless state-owned with one exception, separation of the WSPs from state financing and bureaucracy appears to have achieved the intended effects. Indeed, since 2006, the federal government has approved tariff reviews for seven states to improve the financial position of the WSPs.

Next, WSPs now act as service providers only and do not own water supply assets. Instead, ownership of water supply assets, including pipes, plants, and reservoirs – whether owned by state governments and private WSPs – are handed over to the federal government and placed under the management of PAAB, a water asset management company fully owned by the Ministry of Finance Incorporated. Where private WSPs previously owned these assets, state and federal governments have had to negotiate buy-outs with the owners. Under this 'asset-light model', PAAB serves as the owner of the water supply assets, funding and developing water infrastructure and leasing these assets to licensed WSPs at affordable rates; water resources including catchment areas and river basins remain under state government control. The WSP remains responsible for maintaining and operating the water supply system, including planning and conducting works for reducing NRW.

Table 1. Regulatory, financing, asset management, and water service responsibilities before and after the water sector reform in Malaysia.

Responsibility	Before reform	After reform
Development of water policy for the country	Federal Government through water-related ministry	
Ownership and management of water catchment areas	Respective state governments	
Regulatory of the water supply sector	Decentralised, regulated by the respective state governments with different enactments	Centralised, regulated by the NWSC
WSP	State government water supply department or private water companies	Licensed water companies, state government must corporatise its water service to receive licence from NWSC
Owner of the water supply asset, including pipes, plants, and reservoirs	Respective state government or private water companies	PAAB owns the asset and will lease the asset to NWSC-licensed state WSP
Capital investment of the water supply sector (e.g., the development of the water supply asset)	Interest-free loans provided by the Federal Government to the state governments or private funding sourced by private water companies	Funding sourced from PAAB from capital markets, government grants, subsidies and soft loans, and lease rental of the water asset
Tariff revision approval	Respective state governments	Tariff review approved by the minister based on the recommendation of the NWSC

Sources: Water Services Industry Act (WSIA) 2006; Chin (2008); Teo (2014); interviews with the government officials.

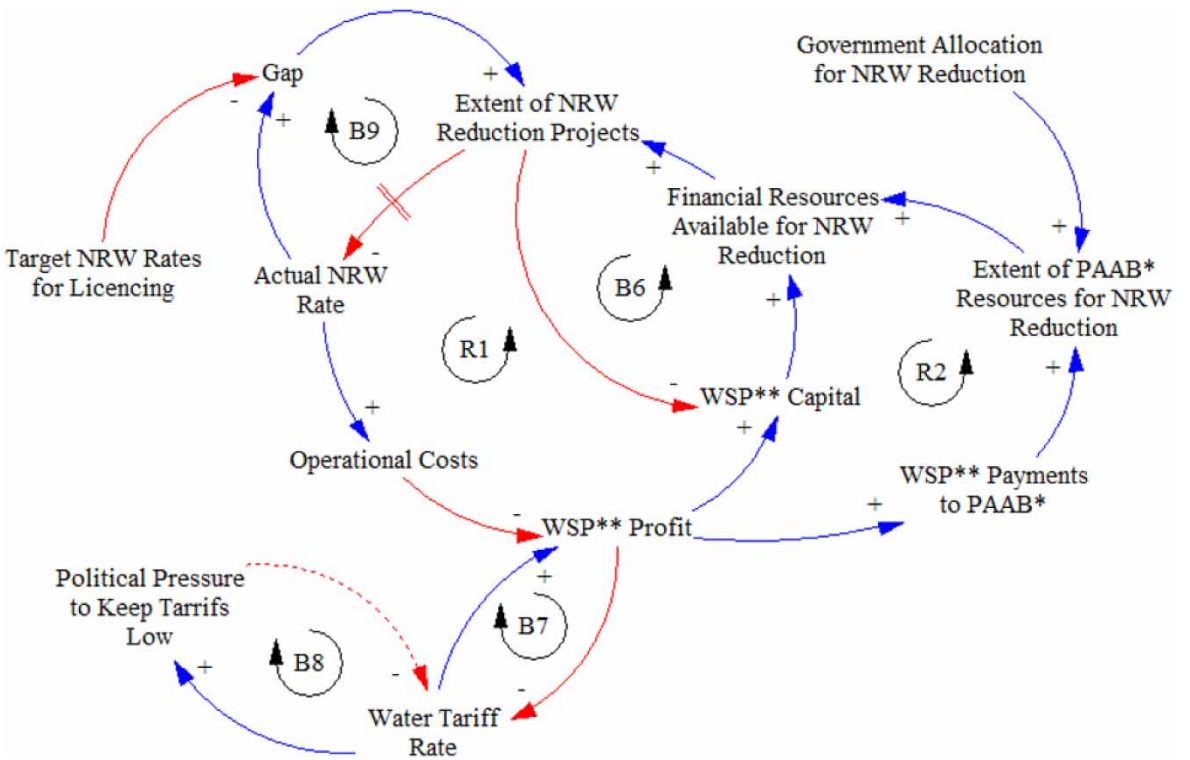

Fig. 3. CLD depicts post-reform systemic incentives of NRW reduction; for a detailed explanation, see text or Appendix A6 in the online supplementary note. *PAAB acts as the custodian for all national water assets. **Post-reform, WSPs play operational roles only (i.e. cannot be asset holders).

This arrangement helps the financing of water supply assets in two ways. First, as a government-backed company with an AAA credit rating, PAAB can raise financing at a much lower cost than WSPs and borrow on longer tenures to match asset life (PAAB, 2008). Second, lease rental from WSPs to PAAB for the use of water assets are channelled back to infrastructure investment. Thus, PAAB effectively pools savings from NRW reduction from across the WSPs and sequesters a source of funds for infrastructure investment (Figure 3, R2 loop). As a WSP moves towards full-cost recovery through increased water tariffs, improved operational efficiency, and reduced NRW, it will be required to pay full values for lease rental, further driving the R2 loop. WSPs will eventually have the option to purchase the water supply asset, and PAAB is expected to dissolve when WSPs have the ability to cover their operational and capital expenditures (Chin, 2008).

Finally, the reforms aim to create a strong incentive for WSPs to pursue NRW reduction by tying licence renewal to NRW rates. The NWSC was formed under the SPAN Act to regulate and govern the water sector in Peninsular Malaysia and the Federal Territory of Labuan. NWSC issues three-year operating licences to state WSPs, with licence renewal dependent on performance evaluation. The NRW rate is one of the key performance indicators in this evaluation (SPAN, 2011), so WSPs must meet targets to continue operation, increasing the urgency of NRW reduction efforts (Figure 3, B9 loop). B9 loop illustrates that WSP's efforts in reducing NRW depend on the gap between actual NRW rates and the target NRW rates. The bigger the gap, the more NRW reduction efforts are expected to reduce the gap.

3.2.3. Reform implementation outcomes. Outcomes of the water supply reforms among early adopter states have been promising, suggesting that the new financing system is well designed to incentivise and enable the investment in water supply infrastructure. By the end of 2016, the first three states to sign and complete the water restructuring exercises – Melaka, Johor, and Negeri Sembilan – achieved substantial reductions in NRW rates (Table S3, available online). However, implementation of the reforms has been difficult, with only 7 out of 11 states in Peninsular Malaysia ratifying and achieving compliance with the reforms by the end of 2016. The later adopters have not yet had time to realise gains from the reforms, with Perlis and Kelantan only completing reforms in 2015 and 2016, respectively, while Perak is yet to corporatize its water service fully. The other later adopter, Penang, had already achieved an NRW rate of below 25% before reforms, as Penang was among the earliest states to corporatize its water service and started the NRW reduction programme even before the reform (Maidinsa, 2011). A further four Peninsular states had yet to complete reforms by the end of 2016. Challenges in-state adoptions of the reforms are beyond the scope of this paper and will be addressed in a separate analysis.

3.3. Towards operational management reform

According to the interviewees from WSPs, inadequate capacity building has been a significant obstacle to improved outcomes in the Malaysian water supply sector. Staff with knowledge and skills such as active leakage control, data management, and pipeline mapping are necessary for implementing advanced leakage management strategies (Sewilam, 2011). Based on the interviews, NRW reduction is relatively new to many of the WSP staff in Malaysia, having only been emphasised in the wake of reforms. The NRW targets set for WSPs ought to provide an incentive to invest in capacity (Figure 4, B10 loop). However, this is a time-consuming process (indicated by delay mark ||, B10 loop). Thus, some WSPs have attempted to address this issue by outsourcing NRW reduction works (Figure 4, B11 loop). The current financial rules, where PAAB provides grants for NRW reduction projects but not for staff capacity building, further incentivises this short-term practice. An example given by an interviewee was of a WSP in Malaysia that hired a private company to install technology for active leakage control. In this case, the investment did not achieve the desired outcome because the WSP lacked staff capable of operating the installed technology.

Outsourcing NRW reduction functions can be a valid strategy, when a particular problem requires highly specialised expertise, or as part of a capacity-building process with WSP staff. However, according to interviewees, some of the outsourcing of NRW reduction works have been on an ad-hoc basis and not part of a coherent, long-term strategy. Continuously outsourcing NRW works can indirectly reduce WSP's investment in capacity building and can be a long-term threat to WSP capacity for NRW reduction (Figure 4, R3 loop). In the long term, however, this can disincentivise investment in WSP capacity, exacerbating the underlying capacity problem. One example is the State of Kelantan, which received a total of 32 million USD under Ninth Malaysian Pan (2006–2010) for reducing NRW (NAD, 2011). The state was supposed to reduce its NRW from 44.4% in 2006 to 36% in 2010 as per the target by the federal government (EPU, 2006); however, Kelantan's NRW rate increased by 8% to 52.4% in 2010. An audit by the National Audit Department of Malaysia pointed out that the lack of expertise in the WSP and the lack of capacity of the local sub-contractors were among the challenges facing the Kelantan's WSP (NAD, 2010). This causal structure in which a short-term solution undermines the necessary long-term solution is a systems archetype known as 'Shifting the Burden'.

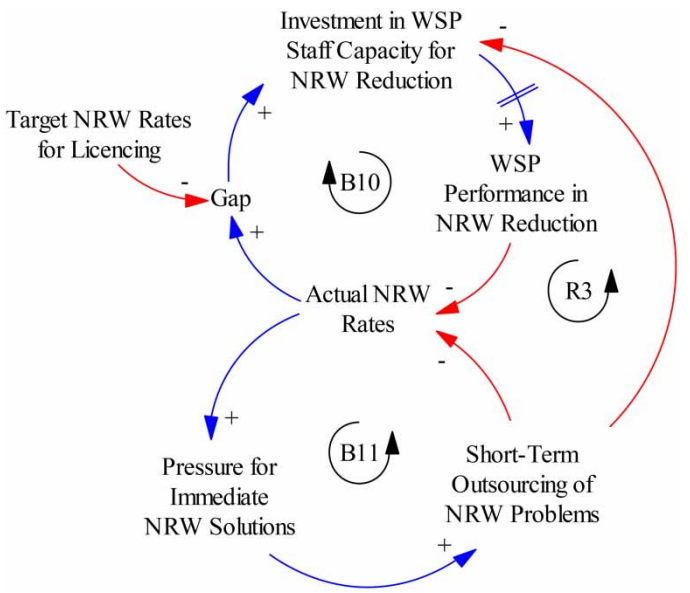

Fig. 4. CLD illustrates the systemic challenges of building WSP staff capacity in operational reform. For a detailed explanation see text or Appendix A7 in the online supplementary material.

4. Discussion and policy implication

The CLDs developed in this paper enhance a holistic understanding of the non-linear feedbacks of water sector reform and provide insights to accelerate NRW reduction in Malaysia. This section discusses the findings and identifies three policy implications to improve NRW management reform in Malaysia based on the leverage points identified.

4.1. Fundamental drivers of water sector reform

The CLD in Figure 1 shows the impetus for the water sector reform. Several reasons have been widely mentioned as the impetus for Malaysia's water sector reform, including efficiency, effectiveness, and financial sustainability of the water sector (Chin, 2008; Ching, 2012; Teo, 2014). According to the analysis of Figure 1, this study suggests that the two fundamental drivers that enabled water sector reform were increasing demand on the federal government for water infrastructure funding (loop B4) and threats to water security that can raise public concern (loop B5). These factors demanded the attention of government actors and the public when more general concerns of water supply effectiveness and efficiency could not (loop B1). This points towards leverage points that can accelerate the progress of water sector reform.

Policy implication 1: *Accelerating water sector reform and NRW reduction by emphasising water security and its contributions to sustainable development.* While experiences of water scarcity were important for generating public support for water sector reform, there were no imminent water crises expected in Malaysia when the 2006 reforms were passed (Teo, 2014). Consequently, the framing and communication around the reforms centred on the ineffectiveness and inefficiency of the water service sector (Chin, 2008), while the visibility of water supply security challenges has receded. However, with increasing the water demand and

changing the climate, the lack of water resources is a future threat (Tan *et al*., 2019). Three (Penang, Melaka, and Selangor) of the 11 states in Peninsular Malaysia are rated as highly vulnerable to water supply risk due to limited and water resource and pollution, with the remaining eight rated as moderately vulnerable (NWRS, 2011). Adoption and implementation of the reforms have stalled in several states, and a renewed emphasis on water scarcity threats supported by rigorous studies could be instrumental in renewing support among policymakers and the public to overcome this obstacle.

In addition, successful water sector reform and NRW reduction also contribute to public health, human rights, environmental protection, and integrity of the water sector in Malaysia (WSIA, 2006). Such contributions are necessary for the Malaysian Government in achieving the United Nation's 2030 Agenda for Sustainable Development, which consists of Sustainable Development Goals (SDGs) that address global sustainability issues (DOS, 2018). Since 2015, the Malaysian Government has committed to implement the 2030 Agenda (EPU, 2017). However, little attention has been paid to explain the contribution of water sector reform in Malaysia towards achieving various aspects of the national sustainability and SDGs. Therefore, in order to increase public support for the reform, efforts should be made to inform the stakeholders involved in the water sector reform about the importance of the reform to sustainable development.

4.2. Systemic incentives arising from regulatory and financing reform

CLDs in Figures 2 and 3 show the systemic incentives for NRW reduction before and after the reform. The results of this study are consistent with findings by van den Berg (2015) and González *et al*. (2012), which point out the significant influence that institutional and regulatory frameworks, water tariffs, and economic incentives of water loss have on NRW reduction. In this study, the CLDs further explain how the change of the regulatory framework and financing mechanism influences WSP's performance in NRW reduction. According to Figure 3, the reform creates the B9 loop by incentivising WSPs towards NRW reduction by making the NRW rate a key performance indicator for licence renewal. The B7 and B8 loops show non-linear feedback across WSP's profit, water tariff, and political influence. Investing in NRW reduction can be an action to increase the service provider's profit by minimising water production cost (loop R1). This is true only if the extra profit generated from the reduction of NRW is enough to cover such investment. Conversely, continuously investing in NRW reduction will put the service provider at the risk of overspending capital (loop B6). This is a key reason why most Malaysian states have been unable to reduce their NRW rates at pre-reform tariff rates effectively. To fix this bottleneck, the political roadblocks to financially sustainable tariff rates must be addressed.

Policy implication 2: *Increasing stakeholders' support and confidence in water tariff adjustment.* Increasing water tariff is a political- and public-sensitive issue. After the water sector reform in Malaysia, political pressure to maintain low water tariffs has been weakened. However, the water sector is yet to be independently managed free from political influence, as most of the states' WSP are/is still owned by the state government (Chin, 2016). To reduce political opposition to tariff increments, WSPs need support from stakeholders, particularly their shareholders and water consumers. For this, stakeholders need to be convinced of the socio-economic benefits that will be delivered through water tariff increment. Confidence in the competence and integrity of the WSPs to make use of the additional revenue to provide better water services is critical.

Manila Water, the WSP in East Manila, Philippines, is an example of success in raising support. The private WSP has been able to provide clean water to poor neighbourhoods that the previous public water utility had

not. As a result, communities in poor neighbourhoods became political allies to Manila Water in support of water tariff adjustment (Wu & Malaluan, 2008). In Malaysia, public perception of WSPs and their knowledge about NRW issues and potential water scarcity threats remains poor, undermining support for water tariff increments (Lai *et al*., 2017). Investment in service delivery and improving the customer experience, even when it may not directly relate to NRW, is vital for gaining stakeholder confidence for tariff agreements. Further means of generating support include consultation in the tariff-setting process and increasing public awareness of how the revenue will be spent and the socio-economic benefits to the public.

4.3. Systemic challenges of operational management reform

The CLD in Figure 4 describes the systemic problems in operational management reform. The findings are consistent with previous studies that have showed the outsourcing of contracts (van den Berg, 2015) and staff capacity (Tabesh *et al*., 2018) significantly influence NRW reduction. However, there was little discussion about the relationship between contracts outsourced and staff capacity in those studies. The CLD developed in this study provides a more complete picture. According to Figure 4, it takes more time to achieve improvements in WSP performance in NRW reduction through improving staff capacity compared with outsourcing the NRW work (loop B10). Therefore, to achieve compliance for licence renewal promptly, WSPs may choose to outsource the NRW reduction work to external experts (loop B11) in lieu of building staff capacity (loop R3). This lack of investment in capacity may be a reason why WSPs have failed to sustain low NRW rates over a long period despite large funding allocations in the past. The leverage point identified here is an investment in building staff capacity and allowance for the time required to do so.

Policy implication 3: *An integrated NRW reduction plan for transforming the human resource.* While the restructuring of the water supply regulatory-financing system is aimed at providing the systemic environment for effective NRW reduction to take place, successful operationalisation at the WSP level remains necessary to realise potential gains. In the Malaysian context, although making licencing renewal contingent on NRW reduction performance should provide WSPs with the necessary incentive to address these issues, other countervailing factors have created barriers to good practice. Since November 2016, all the licenced WSPs in Malaysia must obtain competency certification for all their technical personnel, in compliance with NWSC requirements (PBA, 2019). Beyond this, further efforts to build a high-performing NRW reduction team are necessary, with an emphasis on transforming the current workforce retained from public water utilities during the privatisation processes. In Malaysia, 4 (Perlis, Pahang, Kedah, and Negeri Sembilan) out of 13 states only privatised water service within the past ten years (2008–2018), with another three states (Perak, Sabah, and Sarawak) still being served by state water services. Thus, many of the current WSP staff are former government servants retained during privatisation. In public water utilities, the working culture has been rule-based and procedure-driven, differing from a corporate working culture that is result-based and focused on meeting customers' demand (Wu & Malaluan, 2008).

In light of this, an integrated NRW reduction plan that consists of the human resource transformation plan is required to achieve the necessary work culture transformation. The plan must emphasise ownership of results and the importance of NRW reduction. An example of a successful transformation has been WSP for the state of Melaka, Syarikat Air Melaka Bhd (SAMB). The management of SAMB has prioritised NRW reduction, mainstreaming it among all staff to raise awareness and commitment. As part of this process, an NRW reduction team consisting of both SAMB staff and NRW specialist contractors was created. The team formation allowed SAMB to optimise the time taken for

NRW reduction and transferring skills and knowledge to WSP staff throughout NRW reduction projects at the same time. The service provider also monitors staff efficiency in conducting NRW reduction works. Such holistic human resource transformation strategies have significantly contributed to the sustained success of SAMB, which has reduced the NRW rate from 30.0% in 2008 to 19.3% in 2015.

5. Conclusion

Traditional water management regimes that neglect complexity must be reformed towards a more integrated regime that embraces the complex human–technology–environment system (Pahl-Wostl *et al*., 2008). The NRW rate serves as one of the major indicators for accessing the success of water management reform, as it is a complex task that involves multiple stakeholders to address technical and non-technical issues (González *et al*., 2011). The findings of this study provide insights for the policymakers and water managers to have a better understanding of the dynamic behaviour and challenges of NRW management reform and leverage points that can accelerate the reform. The CLDs developed reveal that the success and progress of water supply and NRW management reforms are influenced by multiple factors such as technical (e.g., water supply efficiency), environmental (e.g., the availability of water resource), economic (e.g., water tariff), social (e.g., public concern and political influence), institutional (e.g., regulatory framework), and corporate governance (e.g., capacity development).

With the findings, leverage points that can accelerate the progress of NRW management reform in Malaysia are identified; three policies are recommended. Firstly, policymakers need to emphasise water security and sustainable development as the main concern when promoting water sector reform. In particular, the worst-case future scenario for not having a successful water sector reform must be disseminated to the public. Secondly, increasing water tariff is a politically sensitive issue, but without a water tariff that is based on full-cost recovery, the WSP does not have the incentive and resource to undertake extensive NRW reduction. To reduce political pressure, the stakeholders must be made to understand the socio-economic benefits of the proposed water tariff adjustment to gain their confidence and support on water tariff adjustment. Finally, the newly privatized WSPs in Malaysia require an integrated NRW reduction plan to optimise the time taken for NRW reduction and at the same time, transforming their current human resources that were inherited from the previous public water utilities.

A limitation of this study is that it has yet to develop an in-depth understanding about the influence of other factors, such as government bureaucracy, corporate culture within the WSP, and conflicts among stakeholders, on NRW management reform. Future research is required to understand the interrelationships of such factors and NRW reduction.

Acknowledgements

The authors acknowledge the funding from the Universiti Sains Malaysia, Account Number: 304/PHUMANITI/650906/W109.

Supplementary material

The Supplementary Material for this paper is available online at https://dx.doi.org/10.2166/wp.2020.165.

References

Arnold, R. D. & Wade, J. P. (2015). A definition of systems thinking: a systems approach. *Procedia Computer Science 44*, 669–678. https://doi.org/10.1016/j.procs.2015.03.050.

ASM (Academy of Sciences, Malaysia) (2015). *Study on the Current Issues and Needs for Water Supply and Wastewater Management in Malaysia*. Available at: http://www.akademisains.gov.my/download/Study%20on%20the%20Current%20Issues%20and%20Needs%20for%20Water%20Supply%20and%20Wastewater%20Management%20in%20Malaysia%20-%20volume%202.pdf.

Azzis, M. S. A., Daud, S., Ibrahim, A., Salleh, H. & Muslat, M. W. (2014). Politics of privatisation: water tariff in water supply distribution in Selangor. *UNISEL Journal of Social Sciences and Humanities 1*(1), 81–89. Available at: http://ojs.journals.unisel.edu.my/index.php/share/article/view/62.

Biswas, A. K. & Tortajada, C. (2010). Water supply of Phnom Penh: an example of good governance. *International Journal of Water Resources Development 26*(2), 157–172. doi:10.1080/07900621003768859.

Chan, N. W. (2009). Issues and challenges in water governance in Malaysia. *Iranian Journal of Environmental Health Science & Engineering 6*(3), 143–152. Available at: http://ijehse.tums.ac.ir/index.php/ijehse/article/view/205.pdf.

Chin, Y. K. (2008). *The Water Tablet: Malaysian Water Reforms*. Ministry of Energy, Water and Communication, Malaysia, Kuala Lumpur.

Chin, Y. K. (2016). Keeping track of the Malaysian water reforms. *Water Malaysia: The Malaysian Water Association Quarterly Bulletin 30*, 6–7.

Ching, T. K. (2012). *Malaysian Water Sector Reform: Policy and Performance*. Wageningen University, Wageningen.

DOS (Department of Statistics, Malaysia) (2018). *The Initial Assessment of the Sustainable Development Goals Indicators for Malaysia 2018*. Department of Statistics, Malaysia, Putrajaya, Malaysia.

EPU (Economic Planning Unit, Malaysia) (2006). *Ninth Malaysia Plan*. Government of Malaysia, Kuala Lumpur.

EPU (Economic Planning Unit, Malaysia) (2010). *Tenth Malaysia Plan*. Government of Malaysia, Kuala Lumpur.

EPU (Economic Planning Unit, Malaysia) (2017). *Malaysia Sustainable Development Goals Voluntary National Review 2017: High-Level Political Forum*. Economic Planning Unit, Prime Minister's Department, Putrajaya.

Farley, M. & Liemberger, R. (2005). Developing a non-revenue water reduction strategy: planning and implementing the strategy. *Water Science & Technology: Water Supply 5*(1), 41–50.

Farley, M., Wyeth, G., Zainuddin, G., Istandar, A. & Singh, S. (2008). *The Manager's Non- Revenue Water Handbook: A Guide to Understanding Water Losses*. Ranhill Utilities & United States Agency for International Development (USAIN).

Ferguson, B. C., Brown, R. R. & Deletic, A. (2013). Diagnosing transformative change in urban water systems: theories and frameworks. *Global Environmental Change 23*(1), 264–280. doi:10.1016/j.gloenvcha.2012.07.008.

Frauendorfer, R. & Liemberger, R. (2010). *The Issues and Challenges of Reducing Non-Revenue Water*. Retrieved from Philippines.

González, F., García, M. A. & Guardiola, J. (2011). Why is non-revenue water so high in so many cities? *International Journal of Water Resources Development 27*(2), 345–360. doi:10.1080/07900627.2010.548317.

González, F., Martínez-Espiñeira, R., García-Valiñas, M. A. & García-Rubio, M. A. (2012). Explanatory factors of urban water leakage rates in Southern Spain. *Utilities Policy 22*(0), 22–30. http://dx.doi.org/10.1016/j.jup.2012.02.002.

Halbe, J., Pahl-Wostl, C., Sendzimir, J. & Adamowski, J. (2013). Towards adaptive and integrated management paradigms to meet the challenges of water governance. *Water Science and Technology 67*(11), 2651–2660. doi:10.2166/wst.2013.146.

Kanakoudis, V. & Tsitsifli, S. (2016). Socially fair domestic water pricing: who is going to pay for the non-revenue water? *Desalination and Water Treatment* 1–11. doi:10.1080/19443994.2015.1067169.

Kingdom, B., Liemberger, R. & Marin, P. (2006). *The Challenge of Reducing Non-Revenue Water (NRW) in Developing Countries. How the Private Sector Can Help: A Look at Performance-Based Service Contracting*. World Bank, Washington DC.

Kotir, J. H., Smith, C., Brown, G., Marshall, N. & Johnstone, R. (2016). A system dynamics simulation model for sustainable water resources management and agricultural development in the Volta River Basin, Ghana. *Science of the Total Environment 573*, 444–457. https://doi.org/10.1016/j.scitotenv.2016.08.081.

Krippendorff, K. (2013). *Content Analysis: An Introduction to Its Methodology*, 3rd edn. SAGE Publications, Los Angeles.

Lai, C. H., Chan, N. W. & Roy, R. (2017). Understanding public perception of and participation in non-revenue water management in Malaysia to support urban water policy. *Water 9*(1), 26. Available at: http://www.mdpi.com/2073-4441/9/1/26.

Lambert, A. & Hirner, W. (2000). *Losses from Water Supply System: Standard Terminology and Recommended Performance Measures*. The Blue Page: The IWA Information Sources on Drinking Water Issues.

Maani, K. E. & Cavana, R. Y. (2007). *Systems Thinking, System Dynamic: Managing Change and Complexity*, 2nd edn. Prentice Hall, Auckland, New Zealand; Pearson Education, New Zealand.
Maidinsa, J. (2011). *Penang: Water, Life & Growth*. Perbadanan Bekalan Air Pulau Pinang, Penang, Malaysia.
MWA (Malaysian Water Association) (2017). *Malaysia Water Industry Guide* 2016. Kuala Lumpur.
MWSS (Metro Manila Water Supply System) (2018). *Non-Revenue Water*. Available at : http://ro.mwss.gov.ph/?page_id=88.
NAD (National Audit Department) (2010). *Auditor General's Report 2009 on the Activities of the Kelantan State Government Departments and Agencies and the Management of State Government Companies*. National Audit Department of Malaysia, Putrajaya.
NAD (National Audit Department) (2011). *Audit Guidelines for Non-Revenue Water*.
Ndirangu, N., Ng'ang'a, J., Chege, A., de Blois, R.-J. & Mels, A. (2013). Local solutions in non-revenue water management through north-south water operator partnerships: the case of Nakuru. *Water Policy 15*, 137–164. doi:10.2166/wp.2013.117.
NWRS (National Water Resources Study) (2011). *Review of the National Water Resources Study and Formulation of National Water Resources Policy*. Kuala Lumpur.
PAAB (Pengurusan Aset Air Berhad) (2008). *Pengurusan Aset Air Berhad Annual Report 2007*. Kuala Lumpur.
PAAB (Pengurusan Aset Air Berhad) (2018). *Pengurusan Aset Air Berhad Annual Report 2017*. Kuala Lumpur.
Pahl-Wostl, C. (2007). Transitions towards adaptive management of water facing climate and global change. *Water Resources Management 21*(1), 49–62. doi:10.1007/s11269-006-9040-4.
Pahl-Wostl, C., Kabat, P. & Moltgen, J. (2008). *Adaptive and Integrated Water Management*. Springer-Verlag, Berlin, Heidelberg.
PBA (Perbadanan Bekalan Air Pulau Pinang) (2019). *Penang Water Service Academy Sets up a Branch Campus in Kuala Lumpur*. Penang Water Supply Corporation (PBAPP), Penang.
PPWSA (Phnom Penh Water Supply Authority) (2017). *Non Revenue Water*. Available at: http://www.ppwsa.com.kh/en/index.php?page=none-revenue-water.
Rehan, R., Knight, M. A., Haas, C. T. & Unger, A. J. A. (2011). Application of system dynamics for developing financially self-sustaining management policies for water and wastewater systems. *Water Research 45*(16), 4737–4750. https://doi.org/10.1016/j.watres.2011.06.001.
See, K. F. & Ma, Z. (2018). Does non-revenue water affect Malaysia's water services industry productivity? *Utilities Policy 54*, 125–131. doi:10.1016/j.jup.2018.04.006.
Sewilam, H. (2011). Capacity development for water loss reduction. In: *Capacity Development for Drinking Water Loss Reduction: Challenges and Experiences*, Sewilam, H. (ed.). UN-Water Decade Programme on Capacity Development, United Nations University, Bonn, Germany, pp. 161–167.
SPAN (National Water Service Commission) (2011). *Water Services Industry Performance Report 2011*.
Sterman, J. D. (2000). *Business Dynamics: Systems Thinking and Modeling for a Complex World*. McGraw-Hill Education, Boston, MA.
Tabesh, M., Roozbahani, A., Roghani, B., Faghihi, N. R. & Heydarzadeh, R. (2018). Risk assessment of factors influencing non-revenue water using Bayesian networks and fuzzy logic. *Water Resources Management 32*(11), 3647–3670. doi:10.1007/s11269-018-2011-8.
Tan, J. (2012). The pitfalls of water privatization: failure and reform in Malaysia. *World Development 40*(12), 2552–2563. http://dx.doi.org/10.1016/j.worlddev.2012.05.012.
Tan, M. L., Samat, N., Chan, N. W., Lee, A. J. & Li, C. (2019). Analysis of precipitation and temperature extremes over the Muda River Basin, Malaysia. *Water 11*(2), 283. Available at: https://www.mdpi.com/2073-4441/11/2/283.
Teo, Y. H. (2014). Water services industry reforms in Malaysia. *International Journal of Water Resources Development 30*(1), 37–46. doi:10.1080/07900627.2013.846719.
van den Berg, C. (2015). Drivers of non-revenue water: a cross-national analysis. *Utilities Policy 36*, 71–78. doi:10.1016/j.jup.2015.07.005.
Water Services Industry Act (WSIA) (2006). Act 655 of Laws of Malaysia.
Wiek, A. & Larson, K. L. (2012). Water, people, and sustainability – a systems framework for analyzing and assessing water governance regimes. *Water Resources Management 26*(11), 3153–3171. doi:10.1007/s11269-012-0065-6.
Wu, X. & Malaluan, N. A. (2008). A tale of two concessionaires: a natural experiment of water privatisation in metro Manila. *Urban Studies 45*(1), 207–229. doi:10.1177/0042098007085108.

Received 19 August 2019; accepted in revised form 9 February 2020. Available online 16 March 2020