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Stakeholder-based decision support model for selection of alternative water sources - A path towards sustainable industrial future in Vietnam

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ABSTRACT

The combined effect of climate change, rapid industrialisation and traditional water use has created freshwater stress situations in industrial delta regions. Alternative Water Sources (AWSs) offer opportunities to mitigate the freshwater stress issue and, thus, contribute to a sustainable industrial future. This study developed a Decision Support Model (DSM) to assist the decision-makers in selecting the most feasible AWS. In the study location, Tan Thuan Export and Processing Zone (TTZ) of Ho Chi Minh City, rainwater, industrial effluent and brackish water were selected as AWS options and evaluated for technical, environmental, economic, social and institutional criteria. The stakeholder organisations representing government organisations, industrial-zone management organisations and enterprises were selected as decision-makers based on their willingness to explore AWSs. Four DSM scenarios were derived from the varying decision-making power of the selected stakeholder organisations. The results obtained from applying DSM in TTZ showed rainwater as the most feasible AWS for all the scenarios, while the rank of other AWSs fluctuated for different scenarios. To implement the result of DSM in practice, the government should not only focus on formulating clear technological guidelines on AWS quality but also on providing subsidies and creating an environment of social acceptance of AWSs. The DSM allows the decision-makers to determine the most capable AWS in mitigating freshwater stress issues and the changes required to shift towards these AWSs.

1. Introduction

The high rate of urbanisation and industrialisation imposes pressure on water resources creating freshwater stress (Prieto et al., 2016; World Bank Group, 2019). With the global expansion of industry and corporate value chains, freshwater scarcity is increasingly creating new business challenges worldwide (Mueller et al., 2015). The stress on freshwater is further exacerbated by climate change effects and saltwater intrusion, especially in the delta regions (Beckman, 2011). Vietnam is one such country that has been facing severe water-related challenges, especially in the industrial sector (Mueller et al., 2015). Vietnam's low-lying coastal lines and the topography create a hub for import and export, favouring industrial development (Kuenzer and Renaud, 2012). However, along with socioeconomic development, rapid industrialisation has put pressure on the natural resources of Vietnam (Kim and Poensgen, 2019), e.g., depletion and contamination of freshwater resources (Moglia et al., 2012). Additionally, most industries in Vietnam use a linear system of freshwater resources through a centralised system, i.e., single-use and disposal of water resources (Merli et al., 2018).

Alternative water sources (AWSs) can play a vital role in reducing freshwater stress in the IZs/EPZs of Vietnam (Ngo et al., 2015). AWSs are non-conventional water sources, such as rainwater, brackish water (Jones et al., 2019), industrial effluent and (Qadir et al., 2020) that, after adequate treatment, can supplement or replace traditional water sources (Dan, 2007). These AWSs have been explored in the Urban harvest Approach (UHA) (Agudelo-Vera et al., 2012) to improve urban water metabolism. However, UHA did not indicate feasibility assessments or tools for the decision-makers to evaluate the AWSs. The current study realises the multi-sourcing measure and contributes to UHA by providing a tool that supports the decision-makers in selecting the most suitable AWS. To our knowledge, worldwide studies have been restricted in providing information (Bint et al., 2018), a tool (dos Santos

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Amorim et al., 2020), or a method (Zamani et al., 2022) for AWSs. However, to understand the feasibility of using AWSs in fulfilling the industrial water demand, it is important to evaluate these sources according to multiple criteria relating to the environment, economy, social, regulatory and technical performances, and their trade-offs (Kamali et al., 2019; Newman et al., 2014).

A multi-criteria decision-making (MCDM) method can resolve the decision-making challenge of selecting the most suitable AWS from several potential AWS options (Haji Vahabzadeh et al., 2015). MCDM allows decision-makers to evaluate AWSs for different criteria within a framework of mutual agreement (Cristobal and Ramon, 2012). A decision support model (DSM) is a common tool in decision-making that uses mathematical models of MCDM to support decision-making (Power and Heavin, 2017). Different stakeholders are involved in the industrial sectors of Vietnam, including enterprises, industrial authorities, and government bodies. They have a stake in the decision-making process for selecting AWS (Reddy et al., 2015). Hence, the involvement of all relevant stakeholders as decision-makers in the DSM is necessary to get the most realistic and accepted solution and to develop sustainable and climate-robust industrial water provision.

Several studies have explored and compared the use of AWSs (Cooley et al., 2019; Dan, 2007; McNabb, 2019). However, these studies neglected stakeholders in the active decision-making process. The earlier research by Tran (2013) and Kim and Poensgen (2019) have repeatedly emphasised the necessity of stakeholders' participation in decision-making processes to create new reforms for sustainable industrial development in Vietnam. Stakeholder involvement includes sharing information, consulting, dialoguing on decisions, and providing value in formulating and implementing policy (OECD, 2015). It brings together a range of stakeholders with different interests and enables them to identify their position and that of others, leading to a deeper understanding of the issues (Ricart Casadevall, 2016). A DSM with stakeholders as decision-makers provides a transparent evaluation of the available alternatives for the relevant criteria (Cristobal and Ramon, 2012).

This paper aims to suggest the most suitable alternative water source in the industrial zones of Vietnam by actively involving the stakeholders in the decision-making process. A DSM is developed to achieve this aim by applying the MCDM method to provide decision support. Further, DSM scenarios are developed based on stakeholders' decision-making power to find their stances' effect on the analysis. The result from the DSM aims to point out the most feasible AWS and changes required to shift towards AWSs to deal with climate change impacts.

2. Materials and methods

2.1. Description of the study area

This study is based on the Tan Thuan Export and Processing Zone (TTZ). TTZ lies on a peninsula surrounded by the Saigon River in Ho Chi Minh City (HCMC) with an area of 3,000,000 m^2 (Tuong P. V., 2011), as shown in Fig. 1. TTZ has 173 industries operating under the service management of HCMC export processing and industrial zones authority (HEPZA) (Tan Thuan Corporation, 2016–2021). TTZ primarily relies on water supplied by the Saigon Water Supply Company (SAWACO), which is responsible for the extraction, purification, and distribution of surface water in the HCMC (Dan, 2007). The organisations willing to explore AWSs within TTZ are taken for the active stakeholder participation-based DSM. Even though this study focuses primarily on TTZ, it shares the issues such as saltwater intrusion, depletion of freshwater, and lack of clear AWSs use guidelines, across all the IZs of Vietnam.

2.2. Current and alternative water sources

Most HCMC industries depend only on hinterland water extracted from surface water sources (Wilbers et al., 2014). Vietnam receives adequate rainwater averaging 1800 mm per year (Khoi and Trang, 2016; Vo, 2008), has brackish water being a delta country, and has abundant industrial effluent (Dan et al., 2011). These three AWSs were pre-selected based on (i) their locational accessibility to the IZ, (ii) infrastructure, and (iii) an opportunity for a self-sufficient water supply on a local scale. This preselection was further confirmed by participatory workshops and brainstorming sessions where the stakeholders expressed a keen interest in these sources.

2.3. Stakeholder-organisations

Vietnam has a mix of hierarchical policy systems and horizontal governance, with the dominance of government agencies (Fischer et al., 2019; Phuong et al., 2018). For a sustainable water management system, a coordinated response across multiple levels of government (national,

Source: Encyclopædia Britannica, Inc. and TTZ website

Fig. 1. Location layout of TTZ and Ho Chi Minh City.

regional, and local) is necessary for clear actions (Phuong et al., 2018).

In Vietnam, Provincial People's Committees (PPC) are responsible for water supply services in their respective provinces. The major decisions related to investment, tariffs, regulations, and policy settings are influenced by the PPC via the Department of Natural Resources and Environment of HCMC (DONRE). DONRE is one stakeholder organisation in this study (World Bank, 2010). Another stakeholder organisation is the Industrial Zone Authority (IZA) in HCMC, which is called HCMC Export Processing and Industrial Zones Authority (HEPZA) which is managed and financed by PPC (World Bank, 2010). It works with the 'one-stop service' principle in IZ, i.e., in this service, all industries in the IZ can get information and service related to government contracts, which includes water supply and treatment and groundwater exploitation.

Industrial zone infrastructure companies (IZICs) and industrial enterprises (IEs) are the other two stakeholders in this study. IZICs are responsible for investigating, operating, and maintaining the infrastructure of the IZs, including water supply and wastewater discharge infrastructure. IZICs are on the frontline regarding environmental compliance in the IZs (World Bank, 2010). IEs are the individual industries in IZs. They are private entities with varying demands of water quality and quantity. They are the stakeholders and end-users who directly influence and are influenced by the water management system in the IZs.

2.4. Decision criteria

The decision criteria are based on the workshop in TTZ and broadly relate to the environmental, economic, social, and institutional aspects of the decision-making process (Garrido-Baserba et al., 2015). The decision criteria are a mix of qualitative and quantitative measures. The important criteria that have implications on the overall results of the research were therefore grouped into technical, environmental, economic, corporate, and institutional criteria. Each criterion was further divided into sub-criteria and measured by indicators. Table 1 shows the criteria, sub-criteria, and performance indicators used to assess AWSs in this study. For the environmental criterion, energy intensity was identified since lowering energy intensity is prioritised by the Vietnamese Government aimed at its 2050 vision ("Decision, 1855/QD-TTg," 2007).

Table 1
List of criteria, sub-criteria, and description of indicators; L = Literature Review & Q = Questionnaire.

Criteria	Sub-criteria	Description of performance indicator	Data source
Technical	Quality and Quantity	Quality of a specific AWS based on treatment parameters, and maximum exploitation capacity of the source (million m^3/month), its availability and stability throughout the year ('x' months available/year)	L
Environmental	Energy Intensity	Energy used per cubic meter (KWh/m^3) of water for treatment and distribution of AWSs to determine its carbon footprint	L
	Output stream	Production of additional environmental waste due to the use of the AWSs, e.g., brine	L
Economic	Avg. water cost	Cost of water in (VND/m^3) for initial investment, O&M and employees	L + Q
Corporate	Willingness of IE	Percentage of stakeholders willing to shift to AWSs	Q
Institutional	Regulations	The role of national and local regulations in using AWSs	Q
	Incentives	Availability of incentives in the form of tax exemption or subsidy to encourage using AWSs	Q

For economic, corporate, and institutional criteria, sub-criteria were identified during the workshops in TTZ aimed at identifying the drivers and barriers to circular water supply in IZs in Vietnam (Firoozyar et al., 'Unpublished Work').

2.5. Data collection

The data in the research were collected through literature review, participatory workshops, and brainstorming sessions. A set of questionnaires was explicitly developed to collect data on the experts' understanding and perspective on AWSs. A total of 16 stakeholder experts, Government-DONRE (4), IZA-HEPZA (3), IZIC (4), and IEs (5), were invited to fill in the online questionnaire. The questionnaire was a mix of multiple-choice, ranking, and open questions, with room for additional comments under each question. The study initially targeted a small group of five enterprises as a feasibility study. The study hypothesised that the emergence of AWSs, based on exploiting a win-win situation among enterprises, could lead to a new form of enterprise embracing sustainable industrial development (Boons and Berends, 2001). The questionnaire was used to evaluate the AWSs for the corporate and institutional policy criteria. The remaining technical, environmental, and economic criteria were assessed through a literature review. Expert's perceptions, preferences, and concerns on AWS's technical, environmental, and economic aspects were documented through open interviews for a complete understanding of the scope and feasibility of AWSs in IZ of HCMC, Vietnam.

2.6. Model construction

The DSM is a spreadsheet-based decision support model built in the Visual Basic for Applications (VBA) language of Microsoft Excel®. It uses the MCDM method for analytical processing. The MCDM applied to the DSM is 'Vlse Kriterijumska Opti mizacija I Kompromisno Resenje' (VIKOR) (Opricovic, 1990). VIKOR has been used in numerous water management-related research (Cristobal and Ramon, 2012; Golfam et al., 2019). VIKOR-MCDM works well with conflicting and non-commensurable decision criteria (Opricovic and Tzeng, 2007). It uses a linear normalisation process to eliminate the units of a given criterion (Opricovic and Tzeng, 2007). The VIKOR methodology is applied in line with Cristobal and Ramon (2012)'s research (detailed in the supplementary material). The AWS options and their selection criteria were implemented through the multi-criteria decision functionality to allow decision-makers to model their preference of considered AWS options about the decision criteria.

2.6.1. Criteria and stakeholder organisation's weight

In the VIKOR method, it is necessary to give each criterion a weight based on its relative importance to other criteria. In this study, the experts representing the decision-making organisations decide on the importance of the decision criteria. Each expert assigns the criteria's importance in linguistic terms, translated into numeric terms via a 5-point Likert scale (Table 2).

The DSM calculates the weights of the decision criteria for each stakeholder organisation using the normalising formula:

$$C_{j,k}\ (\%) = \frac{i_j}{\sum_{j=1}^{n} i_j} \times 100\% \qquad \text{Equation 1}$$

Table 2
Linguistic evaluation of criteria importance on a 5-point Likert scale.

Linguistic evaluation	Extremely important	Very important	Moderately important	Somewhat important	Least important
Likert scale	5	4	3	2	1

where, n = total number of criteria; j = nth = number of criteria (1,2 … n); k = number of stakeholder organisations; i = aggregate importance of each criterion per stakeholder organisation.

The DSM employs weights for decision-making organisations based on their decision-making power. The final weights of criteria, including stakeholder's weight, are calculated by DSM using:

$$C_j(\%) = \sum_{j=1}^{n} \left(\sum_{k=1}^{m} C_{j,k} \times w_k \ \% \right) \qquad \text{Equation 2}$$

where, m = total number of decision-making organisations; k = number of decision-making organisations (1,2 …,m); w_k = importance of each decision-making organisation expressed in percentage.

2.6.2. DSM matrices

The DSM model contains three types of matrices; (i) evaluation matrix; (ii) analysis matrix, and (iii) normalisation matrix. The evaluation matrix of the DSM is centred on the input information decided by the experts, such as (i) AWS options; (ii) decision criteria; (iii) stakeholder organisations; (iv) number of experts participating from each organisation; and (v) weight of the stakeholder organisation, based on the power to make a decision. These data can be adjusted at any point during the decision-making process.

The analysis matrix converts the linguistic evaluation matrix into numeric form by the three-point and five-point Likert scales. Next, it incorporates the weight of criteria and stakeholder organisations obtained from Equations (1) and (2). For further calculation, the converted numeric values of the experts are averaged to represent their organisations. A complete numeric evaluation of AWSs derived from its linguistic evaluation is provided in the supplementary material. The analysis matrix leads to a normalisation matrix based on the VIKOR methodology that provides ranks of alternatives. The output with rank one indicates the most feasible option. A complete framework of DSM is shown in Fig. 2.

2.7. DSM scenario

DSM scenarios allow exploring the change in outcome when the decision-influencing capacity of decision-makers is changed. In Vietnam, the influence of stakeholder organisations varies in the decision-making process (Fischer et al., 2019; Phuong et al., 2018). Hence, to understand the influence of decision-making power on the ranking of AWS, four scenarios were developed with varying weights of stakeholder organisations and fed into DSM. The scenarios are (*i*) top-down approach, (*ii*) bottom-up approach, (*iii*) organisational exchange approach, and (*iv*) power dependency approach.

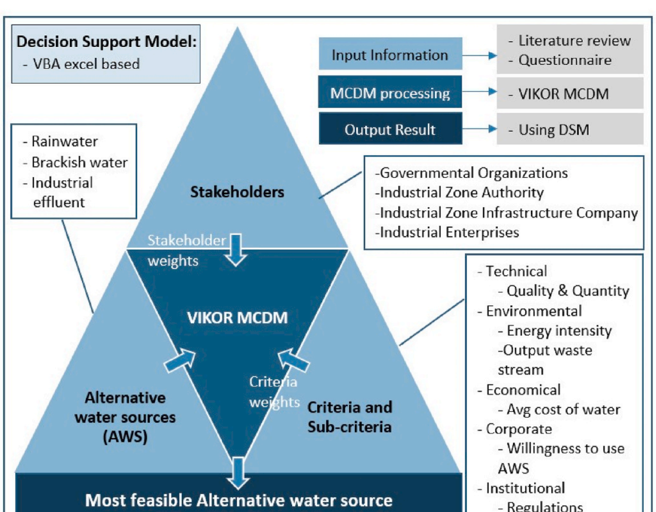

Fig. 2. Framework of DSM applied for the study.

The top-down approach hypothesises that the central government makes decisions with the decision of authority as a starting point (Seraw and Lu, 2020). This approach, synonymously 'forward mapping', makes policies and decisions at a high level and traces them through the lowest level of the implementers (Birkland, 2019). The bottom-up approach, also known as the 'backward mapping' (Birkland, 2019; Seraw and Lu, 2020), takes the lowest level of implementers, their capabilities, and motivations as the starting point. Then the decisions are mapped backwards from the end-users to the topmost policymakers (Seraw and Lu, 2020). Both organisational exchange and power dependency approaches fall under the inter-organisational interaction approach (Seraw and Lu, 2020). The power dependency approach involves power relationships between organisations based on dominance and dependence, whereas the organisational exchange approach takes all involved organisations equally for mutual benefit (Seraw and Lu, 2020). The weightage given to each stakeholder organisation for these scenarios is shown in Table 3.

3. Result and discussion

3.1. Evaluation of AWS

The results show that 15 out of 16 participating experts identify the necessity of using AWSs to sustain growth in the future. For selecting the most feasible AWS for TTZ, AWSs were evaluated against the decision criteria based on literature review and experts' opinions. They are summarised in Table 4 and discussed below.

3.1.1. Technical evaluation

The technical criterion for evaluating AWSs is based on their availability, stability, level of treatment, and quality parameters. TTZ has a water demand of 450,000 m^3/month, fully supplied by SAWACO. With an estimated maximum potential of 4 million m^3/year, rainwater can be harvested from the area of the TTZ, i.e., 75% of the current yearly demand (calculations shown in supplementary material). Brackish water is another AWS that is abundant in the proximity of TTZ (Dan, 2007). The upgraded industrial effluent is available at the site. With a flow rate of 360,000 m^3/month, industrial effluent is a consistent source throughout the year (World Bank, 2010).

Rainwater is usually clean and free from human pathogens. Therefore, it requires only basic treatment steps of sedimentation, filtration, and disinfection (Bui et al., 2019). The brackish water should be desalinated to a useable quality. Many mature advanced technologies are available for desalination, such as phase-change thermal processes, membrane processes like reverse osmosis (RO), electrodialysis, and hybrid processes (Honarparvar et al., 2019). Industrial wastewater effluent quality is low due to organic matter, heavy metals, etc. (Dan, 2007); however, its quality is stable as all industries must meet the environmental regulations for discharge. As a result, the water treatment train needed to treat industrial effluent to useable quality is advanced but reliable (Hoover, 2009; Lazarova et al., 2012; Raucher and Tchobanoglous, 2014).

Table 3
Scenarios developed in DSM based on stakeholder organisation's decision-making power.

Scenarios	Approaches	Stakeholder organisation and weightage			
		Government	IZA	IZIC	IE
	Top-down	70%	10%	10%	10%
	Bottom-up	10%	10%	10%	70%
	Organisational exchange	25%	25%	25%	25%
	Power dependency	40%	20%	20%	20%

Table 4
Evaluation matrix of Alternative Water Sources in IZs of HCMC; where (E) is based on experts' opinion and (L) is literature; (Q) is Quantitative data and (q) is qualitative data; and ++, +, +/−, -, – represent the best to worst evaluation respectively.

Criteria (C)		Industrial effluent	Rainwater	Brackish water
C1: Technical (L)	Availability (Q)	+ Available from industries or centralised water treatment in the IZs (Dan, 2007) *80% supply capacity*	+/− Available directly only for six months of rainy seasons, 1800 mm/yr (Dan, 2007) *75% supply capacity*	++ Always available in the coastal regions, but salinity is increasing due to sea-water intrusion (Ngo et al., 2015) *100% supply capacity*
	Stability (Q)	++ Good consistency throughout the year (Dan, 2007) 12 months	+/− Weak to medium depending on the rainfall *Directly for* 6 months	++ Good for coastal areas (Dan, 2007) 12 months
	Treatment (q)	– Advanced water treatment required	+ Conventional treatment system (Dan, 2007)	– Advanced Desalination treatment technology
	Quality parameters (q)	– Depending on the composition of raw wastewater- heavy metals, non-biodegradables, COD, pathogens, colour, etc.	++ A relatively clean source with stable quality (Dan, 2007)	– Dissolved solids, high salinity (Mavukkandy et al., 2019)
C2: Environmental (L)	Energy (Q)	– Very high energy is required for the treatment (Hoover, 2009; Lazarova et al., 2012; Raucher and Tchobanoglous, 2014) *Average:* 1.74 kW h/m^3	++ Not very energy-intensive treatment process (Lazarova et al., 2012) *Average:* 0.42 kW h/m^3	– High energy requirement for the treatment *Average:* 1.29 kW h/m^3
	By-products (residues) (q)	++ Wastewater is treated and used as a resource minimising the waste output (Cooley et al., 2019)	+/− No additional environmental problems due to shifting RWH as AWS	– Environmental problem of chemically contaminated reject brine stream (Mavukkandy et al., 2019)
C3: Economic (L)	Avg. cost (Q)	– High capital cost, very high O&M costs but reduced wastewater tariff (Cooley et al., 2019) *1.21 to 2.17 USD/m^3*	+ Medium capital cost (storage tanks), low O&M costs Cooley et al. (2019) *0.46 to 1.0 USD/m^3*	– High capital cost, high O&M costs (Cooley et al., 2019) *0.83 to 1.49 USD/m^3*
C4: Corporate (E)	Stakeholder's willingness (q)	+/− Medium acceptance	+ Highly accepted	+/− Medium acceptance
C5: Policy (E)	Regulations (q)	+/- Few regulations concerning wastewater reuse within the IZ but not clear to follow and conflicting	– No clear guidelines concerning using rainwater as a water source	– Some regulations concerning brackish water but not in terms of decentralised water supply
	Subsidy (q)	– No direct subsidy	– No subsidy	– No subsidy

(Details of qualitative data and extensive evaluation matrix in supplementary paper).

3.1.2. *Environmental evaluation*

The environmental criterion consists of evaluating energy intensity and residues of using AWSs. The energy intensity is the total energy required to pump, treat and distribute per cubic meter of AWSs (Hoover, 2009). From the environmental point of view, the energy consumption of technologies and the type of fuel are highly relevant. Higher energy intensity produces higher greenhouse gas emissions (Lee et al., 2017). Industrial effluent and brackish water require advanced water treatment technologies with high energy intensity (Hoover, 2009; Lazarova et al., 2012; Raucher and Tchobanoglous, 2014). However, rainwater harvesting requires relatively low energy intensity. Details of the environmental evaluation are provided in the supplementary material. Another environmental factor, residues of the treatment process that causes environmental pollution, is presented in Table 4.

3.1.3. *Economic evaluation*

For the economic evaluation of the AWSs, the average annual capital and operating costs of using the water source over its lifetime are considered (Cooley et al., 2019). Examples of capital costs are installing technologies, laying out infrastructure, and constructing storage tanks. O&M costs include regularly occurring costs, such as purchasing the chemicals required for treatment or reinstalling filters. Variability in project design, location, and the size of the treatment plant results in a wide range of costs for using AWSs (Cooley et al., 2019). This paper compares the average cost of all three AWSs at an industrial scale from different locations and maps it to the TTZ. Industrial effluent and brackish water is associated with high capital and O&M cost, while rainwater has medium to high capital costs but low O&M cost (Dan, 2007). Details of the economic evaluation are provided in the supplementary material.

3.1.4. *Corporate evaluation*

The corporate criterion of AWSs is evaluated by participating experts. Based on the questionnaire, more than 70% of experts (DONRE, HEPZA, and IZIC) were willing to use upgraded industrial effluent compared to only 20% of experts from IEs. A distaste of industrial effluent among the end-users was observed. Rainwater was the most accepted AWS, with over 80% of all experts willing to use treated rainwater for industrial use. The end-user stakeholder, IEs, preferred brackish water over upgraded industrial effluent.

3.1.5. *Policy evaluation*

This criterion evaluated the existing institutional regulations and subsidy policies for each AWS. Theoretically, the Vietnamese Law of Water Resources encourages AWSs (Bui et al., 2019). The policy on water resources points out freshwater conservation measures using recycled water, water reuse, and storing rainwater. It also supports water reuse, recycling, and rainwater harvesting by creating incentives such as soft loans, tax exemptions, and tax reductions to put such water management techniques into practice (The Vietnamese Law of Water Resources, 2012). Still, in the questionnaire with experts, it was observed that most stakeholders either have no knowledge of the policies on AWSs or find these resources unfeasible for practical use for unrevealed reasons. The subsidies stakeholders often seek to shift to use

AWSs are currently non-existent.

Table 4 gives the general overview of the evaluation matrix, which is applied in the DSM together with criteria (section 2.4) and criteria-weights (section 2.6.1) for all four scenarios discussed (Table 3). The evaluation of some criteria, such as water quality and quantity, is based on local conditions. But, as Vietnam or countries in Southeast Asia have no experience using AWSs discussed in the paper as a primary water source, it was not possible to get the real site data. Hence, a nuanced approach of data transfer was applied for the transfer of unavailable data (Elahi, 2008). For instance, economic criteria were referenced from Cooley et al. (2019)'s California-based standard, which was normalised so that the range of data is not distorted (Team, 2019) and used for comparative analysis of AWS feasibility. The normalised costs give TTZ a good base for starting a discussion with relevant stakeholders to ask for a further investigation into the implementation of AWSs.

3.2. Ranking of AWSs decision criteria for four scenarios

DSM analysis showed the treated rainwater as the highest-ranked AWS for four scenarios, making it the most feasible AWS in TTZ (Table 5). Rainwater was evaluated more positively for all criteria than other AWSs. In the top-down, organisational exchange and power dependency approaches, the upgraded industrial effluent ranked second, and brackish water was the last. Since the use of upgraded industrial water reduces the discharge of untreated wastewater effluent into the environment and simultaneously decreases the water demand, it is highly favoured by stakeholder organisations responsible for environmental management. However, treated brackish water ranks second for the bottom-up approach, followed by upgraded industrial effluent. As the end-user of the water source, the 'health risks fear' and 'yuck factor' related to the use of upgraded industrial water (Ricart Casadevall et al., 2019) appears to be valid among the IEs. This health-related hesitation could be the reason for arriving at the lowest ranking of industrial effluent in the bottom-up approach.

3.2.1. Rainwater as AWS

Rainwater harvesting is a traditional technique adopted in many countries on a small scale. In recent years, rainwater has been successfully implemented on a larger scale in many countries, e.g., Australia and Jordan (Wurthmann, 2019). The DSM evaluation ranks rainwater as the most feasible AWS for TTZ in Vietnam, which has great potential for large to medium-scale rainwater harvesting systems. In a hierarchical multilevel government setting country like Vietnam, regulations play an important role in deploying alternative sources such as rainwater for mainstream use (Phuong et al., 2018). During the study, more than 80% of the participating IEs and 100% of IZIC experts indicated that the existing regulations do not facilitate rainwater harvesting for actual use. The lack of proper guidelines prevents end-users from truly making use of rainwater. Hence, if the Vietnamese government makes clear guidelines and firm regulations on rainwater collection, storage, and use, the willing end-users will be able to use rainwater.

3.2.2. Industrial effluent as AWS

The willingness to use industrial effluent in TTZ varied at different levels of decision-making. The experts from DONRE, HEPZA, and IZIC are inclined towards industrial effluent, as it minimises waste and takes a step towards circularity by closing the water resource loop at the local level. However, IEs seem to distrust the quality of upgraded industrial effluent. Nevertheless, experts believe that businesses will be motivated to use industrial effluent as AWS, given the right conditions of government support for upgraded industrial effluent through clear quality guidelines and economic stimulus.

Table 5
Ranking of AWSs for varying decision-making power of stakeholders.

Scenarios	Industrial effluent	Rainwater	Brackish water
Top-down (**70–10–10–10**)	2	1	3
Bottom-up (**10–10–10–70**)	3	1	2
Organisational exchange (**25–25–25–25**)	2	1	3
Power dependency (**40–20–20–20**)	2	1	3

There are examples of upgraded wastewater already being used in water-stressed regions worldwide. Industrial effluent is used as a water source in the cities such as Singapore and Windhoek after an advanced treatment train. Singapore uses recycled water for industrial purposes, while Windhoek uses it for drinking water (Lafforgue and Lenouvel, 2015). The government of Singapore educated the public about the safety and purity of treated wastewater and the importance of long-term water management. The name '*NEWwater*', implicating that the water is a new source and not just recycled, helped to overcome psychological barriers (Guan and Toh, 2011). The California wastewater recycling system feeds high-quality treated water into environmental systems such as aquifers and reservoirs and mixes it with raw treated water. Subsequently, the mix is treated to drinking water standards (Cooley et al., 2019). Vietnam needs to seek a water-resilient future by reusing upgraded effluent from the industries as a circular and self-reliant way of supplying water. This will be possible only with the support of end-users and clear regulations on the quality of upgraded wastewater. Furthermore, on-site energy recovery (e.g., biogas) in wastewater treatment offers an excellent opportunity to reduce the overall energy demand (Lee et al., 2017).

A lack of effluent separation may also limit the possibility of industrial effluent reuse (Huang et al., 2006). However, since the existing IZs in Vietnam use a combined-sewer system, waste separation in existing IZs may cause huge investment reconstruction of the sewer system. Therefore, implementing wastewater separation is more appropriate for planning new industrial zones. Moreover, the current conventional treatment processes may not effectively remove specific pollutants from a particular industry (Kharat, 2015). To truly consider the effects of wastewater separation on the effluent reuse feasibility, a thorough study under different industrial categories, such as food and pulp and paper, rubber, and heavy metals, is required.

3.2.3. Brackish water as AWS

Brackish surface water was the least feasible source in three of the four scenarios. The experts from DONRE, HEPZA, and IZIC consider the environmental uncertainties of using brackish water (brine issues and land subsidence due to brackish extraction). Nevertheless, brackish surface water is a reliable source and is abundantly available in Vietnam. The technologies required for brackish water treatment are relatively mature and evolving to become cost and energy efficient. With increasing industrialisation and urbanisation, brackish water can be a long-term plan as it has (*i*) high acceptance from the end-users and (ii) become the major source of alternative water in many dry areas (Mavukkandy et al., 2019).

3.3. AWSs for sustainable future of industrial development

3.3.1. Current water management in Vietnam and other water-stressed regions

There is growing attention to climate change adaptation in Vietnam. In 2021, the HCMC launched a program on clean water supply. They obtain water from further upstream of the Sai Gon and Dong Nai rivers since the water quality there is less polluted and has a lower saltwater intrusion (Vietnam News Agency, 2021). The water management programs still favour conventional water sources with no concrete plans facilitating the shift toward AWSs. Even though government encourages using AWS, the guideline on their application is not clear and requires extensive study to prove the feasibility of the source. This discourages the end-users from actually utilising AWS. Moreover, overlaps, contradictions, and gaps in the authority of different agencies responsible for regulating conventional and alternative water sources hamper the regulatory effectiveness of using AWSs (World Bank, 2010).

Similar to IZs in Vietnam, many industrial areas in other water-stressed regions still rely on conventional water sources only. For many countries, replacing freshwater sources with AWSs is a drastic transformation. Therefore, they tend to be reluctant toward such shifts (Sharma et al., 2012). Nevertheless, to sustain further economic growth without becoming constrained by limited water resources, it is important to shift towards using AWSs now (Lafforgue and Lenouvel, 2015). Various technical, economic, social, and institutional changes are imperative to attain such a shift for long-term sustainable development. Thus, AWSs should be dealt with in a broader framework than a strict regulatory approach (Lafforgue and Lenouvel, 2015). Changes should be realised at all levels, from the government to end-users. TTZ has the potential to become one of the early adopters of AWSs, gaining long-term benefits of resilient water management and setting an example for other IZs around the world.

3.3.2. Changes required to put AWSs in practice in IZs and the role of the DSM in future changes

The DSM's result showed rainwater as the most feasible AWS for TTZ. However, the Vietnamese Government has no guidance or regulation on rainwater harvesting and reuse. No IE in TTZ harvests rainwater (Bui et al., 2019) even though it has wide acceptance among stakeholders. To implement the DSM's result, i.e., application of rainwater, the TTZ should investigate rainwater harvesting systems for collecting, treating, and storing rainwater during the rainy season.[1] Treatment of harvested rainwater before delivering it to end users, and maintaining its quality during storage is necessary since industries may require high-quality water.

To implement AWSs in practice, the government should focus on formulating clear guidelines on technologies and water quality for different purposes. Additionally, it should provide attractive subsidies or tax exemptions and implement ways to break the existing stigma related to AWS. All the cities and countries that have successfully implemented AWSs have their local or regional government facilitating the use of alternative sources through technologies, regulations, economic incentives, and public acceptance (Lafforgue and Lenouvel, 2015; Mavukkandy et al., 2019; Wurthmann, 2019). Furthermore, these governments have worked systematically to win end-users' trust and break the psychological barrier to (re)using wastewater treatment plant effluents and brackish water. Learning from the examples of such cities, policymakers in Vietnam should couple the technical and social approaches by working with social scientists and engineers.

Through participatory workshops within the framework of this study, this is revealed that the decision-making process in Vietnam follows the top-down approach. The decision-making process for issues related to the environment starts with the Ministry of Natural Resources and Environment and follows Law No. 80/2015/QH13 issued by the National Assembly in 2015. The DSM's results on various scenarios will give TTZ, and other IZs in the region a good base for starting a discussion with the DONRE and HEPZA.

The DSM's feasibility ranking is based on AWS's current conditions. With uncertainty in the future, the current evaluation of AWSs can broadly alter. For instance, as technologies are improved, costly AWS can become cheaper or attain higher energy efficiency, making them more suitable for the case location (Lazarova et al., 2012). Likewise, with increasing water-stress situations, the acceptance of AWSs can increase among the stakeholders and end-users (Ricart Casadevall et al., 2019). In addition to technological and behavioural changes, variations in the quality and quantity of AWSs are relevant. For instance, rainwater patterns may shift due to climate change (Dan, 2007). Such changes that alter the evaluation can generate a new rank for AWS. The DSM can easily adjust the changes in the evaluation of AWS, making it relevant and essential for future use. If required, adjustments in the participating experts and the relevant stakeholder organisations can be made through the DSM.

[1] HCMC has two main seasons: dry (December to April) and wet (the rest months).

4. Conclusion

The DSM developed in this study has shown to be a useful tool for selecting feasible AWS. The DSM ranks the AWSs, e.g., rainwater, industrial effluent, and brackish water, based on the relevant stakeholders' evaluation in the decision-making process. The feasibility of these AWSs was evaluated for their technical, environmental, economic, social, and institutional aspects. In this study, while some of these criteria were evaluated based on local conditions (water quality and quantity), others were based on the data transfer approach from other locations (e.g., normalised costs of AWSs), which provide a good base for further investigation into AWSs implementation.

Four scenarios were developed with varying weights of stakeholder organisations, where rainwater ranked as the most feasible AWS in all scenarios. Rainwater can supplement up to 75% of TTZ's existing water demand. Industrial end-users seem reluctant to reuse industrial effluents, while governmental organisations appear more favourable. In contrast, governments fear adverse environmental effects from brackish water resources due to brine generation and land subsidence when extracting brackish water. In both cases, demonstrations of good practices at sites of early-adopting Vietnamese industries and industrial zone management authorities would offer a way to overcome these barriers. For all AWSs (re)use, novel regulations on application and quality for different uses are needed to make large-scale applications feasible. However, the study hypothesises that implementing AWSs in TTZ would proceed in phases, beginning with the testing phase. Thus, the representation of organisations in decision-making scenarios is restricted to only those willing to explore AWSs.

The result of the DSM is based on the current case-specific evaluation of AWS. In the future, evaluation of AWSs variations can be expected due to advanced technological innovations improving treatment quality or making treatment more cost and energy efficient. Changes in the quality and quantity of water sources could arise, e.g., scarcity of alternative sources due to drought. Acceptance from stakeholders is another factor that might alter the outcome. The DSM allows adjusting the stakeholders, their influence, and criteria in evaluating AWS, making it relevant for future use. As the water stress increases, the shift to AWSs becomes crucial. Tools like the DSM are needed to identify which AWS can most mitigate freshwater stress situations in a given location. The subsequent development of the DSM should further expand the model to analyse the applicability of combined AWSs further to enhance resilience to freshwater stress.

CRediT authorship contribution statement

Astha Bhatta: Conceptualization, Methodology, Formal analysis, Data curation, Writing – original draft, Visualization. **Truong Minh Le:** Investigation, Writing – review & editing. **Koen Wetser:** Conceptualization, Supervision, Writing – review & editing. **Katarzyna Kujawa-Roeleveld:** Conceptualization, Supervision, Writing – review & editing. **Huub H.M. Rijnaarts:** Funding acquisition, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

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Appendix A. Supplementary data

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