Policy-Based Water Management Challenges at the Local Level Under Non-traditional Security Perspective: The Case of Hanoi City, Vietnam

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Abstract

This study identifies water security (WS) management challenges at the local level with the case study of Hanoi, Vietnam, in 2020 - 2022. We apply an interdisciplinary approach of "Management of Non-traditional Security" and "systems thinking". Particularly, it is inspired by the concept of Cost and Benefit Analysis and integrates the concept of WS (UN-Water), integrated water resources management (Global Water Partnership), and UN Sustainable Development Goal 6 on water. On this basis, the methodological framework is elaborated by an equation reflecting a cause-and-effect relationship between variables of WS state ($\sum_{i=1}^{3} S_i$ including safety, stability, sustainability) and WS management costs ($\sum_{i=1}^{3} C_i$ including risk, crisis, post-crisis recovery). These variables are assessed semi-quantitatively through six dimensions (technical, policy & legislation, social, economic, awareness & behavior, projects & programs) and measured by interval scale based on a 5-point Likert scale ranging from lowest (0-1.5) to highest (4.6-5) levels. The results show that WS management in Hanoi is ineffective with a very low level of WS state ($\sum_{i=1}^{3} S_i$ = 1.86), characterized by water ecosystem degradation, insecure domestic water supply, and an overloading drainage system. If Hanoi's

https://doi.org/10.32388/CJB3VP

authorities do not increase investment in WS risk management, its WS state will be worse, and the city will not be able to achieve its sustainable development goals for 2030 and beyond. This approach offers a better understanding of assessing the effectiveness of policy-based WS management under multidimensional aspects of non-traditional security issues, particularly at the local level of emerging countries like Vietnam. The findings contribute to a new way of thinking and a novel philosophy of the WS management system for data-driven policy-making and interdisciplinary water management research.

Keywords: Hanoi, Non-traditional security management, Policy-based water security management, Systems thinking, Water security management.

I. Introduction

1.1 Study on water security management

1.1.1 Concept of water security and non-traditional security

Water has long been considered an essential public product and a factor determining the living environment and human life. Because of its importance, environmental security, which includes water security (WS), has been recognized by the United Nations (UN) in 1994 as one of the seven new dimensions of human security. WS is classified into the category of non-traditional security (NTS) by many scholars (Caballero-Anthony, 2016; c.f., El-Sayed & Mansour, 2017; P. D. Hoang et al., 2022), particularly in Asia. Accordingly, the UN defines WS as ‘‘all aspects of human security related to water use and management’’. Furthermore, access to sufficient and safe water is regarded as a human right and is included in the Sustainable Development Goal 6 on water by the UN in 2010 and 2015, respectively.

This can be considered as an extension of the WS concept defined by UN-Water (2013). There are different WS concepts, and they evolve over time, reflecting the cognitive development in this field (Gerlak et al., 2018) and diverse fields of interest.

In Vietnam, WS is not officially defined by law. However, the Government emphasized the importance of water as NTS in the document of the 8th National Congress of the Communist Party in 2021. Additionally, WS has been integrated into some important governmental documents, e.g., the latest conclusions 36-KL/TW 2022 on WS and dam safety of the Politburo’s in 2022. The concept of WS is expected to be stipulated in the revised Law on Water Resources, supposedly in 2023.

Overall, WS indicates sustainable and equitable access to water in both quantity and quality, at a reasonable cost to meet the needs of daily life, socio-economic development, maintenance of ecosystem functions, and socio-political stability. Additionally, because of its importance, WS has been categorized as a subject of non-traditional security.

1.1.2 Research into WS assessment and management

WS is a very broad field due to its multidimensional and interdisciplinary nature. Here, we discuss only major aspects related to the methodology of this paper. In a comprehensive literature review, Gerlak et al. (2018) conclude that nearly 60% of WS research topics focus on human security (i.e., human demand is more important). The remainder concentrates on combined security for both humans and the environment, and this tendency is on the rise. In another aspect of WS methodologies, an intensive synthesis of Octavianti & Staddon (2021) indicates two emerging research clusters. The first group is the WS assessment, which relied on household-based experiences in accessing water sources, often using interview data. The second is the WS assessment based on water resources, often using secondary data.

In addition, WS assessment and management tend to approach the principle of integrated water resource management (IWRM). The most widely accepted IWRM concept is the one developed by the Global Water Partnership (GWP) in 2000, which emphasizes the concerted management of water in relation to land and related resources and the balance of economic, social, and environmental sustainability. This is one of the systematic, holistic, and interdisciplinary approaches to WS management (WSM) and is also mentioned in the Law on Water Resources 1998 in Vietnam.

From a methodological perspective, there are qualitative, quantitative, and mixed methods of WS assessment. The combination of qualitative and quantitative measures is on-trend (Octavianti & Staddon, 2021).

In Vietnam, several studies on WS have been conducted recently by international development organizations, e.g., the national water resilience system (WBG, 2019), national WS index (ADB, 2020) or scholars, e.g., regional WS index of Red River Delta (c.f., Dang et al., 2017) (a simplification of ADB's methodology), and transboundary WS of Mekong River Delta (c.f., Truong et al., 2023). These studies provide an overview of WS at a wider scale at the national and regional levels. However, a holistic and comprehensive assessment of the relationship between the root causes and consequential WS state under policy-based management perspectives is poorly understood. Particularly, aspects of social sustainability, awareness and behavior change have not been integrated into WS's assessment. Additionally, nature-based technical aspects (e.g., green infrastructure) and solid waste management systems are missing from the WS assessment system. Most importantly, no studies assess the effectiveness level of WSM, which can contribute to an evidence-based policy-making process in a more straightforward and effective manner. For Hanoi, as a case study (details in section 1.2), there are several research studies on water, mainly focusing on one or few technical aspects or environmental parameters, e.g., arsenic pollution (Glodowska et al., 2021; Winkel et al., 2011), water quality in schools (Hung et al., 2020), and domestic water services (Bui et al., 2022), or water pollution and flooding (WBG, 2020).

Non-traditional security issues and WS

As WS is multidimensional and interdisciplinary in nature, incomplete understanding and poor management decisions and practice, especially at the policy-making level, may arise without applying an inclusive assessment approach. In this regard, research on the assessment of WSM effectiveness is poorly understood, particularly at the local level and in the context of developing countries like Vietnam, where non-traditional threats, including water security, emerge.

Management of Non-traditional Security (MNS)

Generally, management of non-traditional security (MNS) refers to transnational or international cooperation in the management of transboundary threats, particularly in Asia (Caballero-Anthony, 2016). MNS focuses on people as the center of security rather than the military security of a nation. Currently, the majority of MNS concentrate on international or transnational approaches in addressing NTS issues. At the local level (e.g., a community or city), there is no management framework that is streamlined and can support authorities or policy-making institutions to make general but proper decisions in addressing NTS, including WS. Therefore, it is necessary to facilitate the decision-making process, particularly for local authorities, who often do not have all subject matter expert knowledge but wish to make effective decisions based on integrated and interdisciplinary data in a non-traditional manner. In this context, an MNS concept developed by Hoang et al. (2022) is considered, where MNS refers to "*the process through which responsible organizations and/or authorized people make decisions to ensure the safety, stability, and sustainable development of subjects/actors and/or referent objects*".

1.2 Water issues in Hanoi

Hanoi is the capital and is located in the North of Vietnam. With an official population of over 8.3 million inhabitants (GSO, 2022), it is the largest city by area and the second most populous and economically developed city in Vietnam. However, the pressure of population growth, rapid urbanization, and economic development are challenging the existing infrastructure and WS management capability, leading to significant environmental and water crises. Specifically, Hanoi's inner-city rivers are almost "dead" with black water and stinking smells, especially in the dry and warm season (c.f., laodong.vn, 2021; D. D. Nguyen & Zheltenkov, 2019). The World Bank (2020) estimated that about 50% of Hanoi's population lives in severely polluted areas. Additionally, flooding events in Hanoi are getting worse concerning intensity and consequences (suckhoedoisong.vn, 2022). Surface water and groundwater resources are degraded in both quantity and quality (M. Nguyen et al., 2022). Hanoi announced clean water access of 100% and 84% in the urban and rural areas (hanoimoi.com.vn, 2022), respectively (clean water is defined as domestic piped water meeting requirements of national technical regulations QCVN 01-1:2018/BYT). Nevertheless, domestic water supply faces problems of water quality and partial water shortage in the inner city and is more critical in rural areas (c.f., kinhtedothi.vn, 2022; vovgiaothong.vn, 2020). In conclusion, without proper WSM measures, Hanoi will continue confronting increasing multidimensional losses and will not be able to achieve its sustainable development goals by 2030 and beyond.

1.3 Objectives

This study details the interdisciplinary and integrated MNS approaches initiated by Hoang et al. (2022) and applies systems thinking to assess the effectiveness of WSM at the local level with the case study of Hanoi city from 2020 to 2022. Specifically, we assess the overall effectiveness of WSM based on its performance as WS state and WSM cost. Subsequently, we identify WSM challenges and propose policy-based management solutions to improve the WS state towards sustainable development of Hanoi by 2030 and beyond. Academically, we aim to contribute a multidimensional assessment approach and a straightforward and non-traditional way of thinking for data-driven policy-making and the development of interdisciplinary research in the field of WSM. This aims particularly to serve the policy-making process at the local level in the context of developing countries like Vietnam, which are confronting non-traditional emerging issues like water security coupled with environmental crisis.

II. Assessment of WSM challenges by systems thinking and MNS approach

2.1 Definition of WSM system

The effectiveness of WSM is analyzed by applying the concept of systems thinking (Jackson, 2005), which views problems of a referent object to be solved as part of an overall system. Particularly, the WSM system includes processes illustrating generation, treatment, supply and usage, and functional services. The referent object of WS is the water system, which serves the function of not only human and economic activities but also the resilience of ecosystems. More specifically, the WSM effectiveness is assessed based on the interdisciplinary MNS approach initiated by Hoang et al. (2022), representing a cause-and-effect relationship between levels of security state and cost invested or lost in security management (details in Section 2.2). More specifically, we assess the WS state and WSM cost by integrating concepts of WS from UN-Water (2023), IWRM from GWP (200), and UN SDG 6 on the water into six dimensions, including (1) technical, (2) policy & legislation, (3) social, (4) economic, awareness & behavior

(5), and projects & programs (6). Figure 1 illustrates the WSM system within the methodological framework of this study.

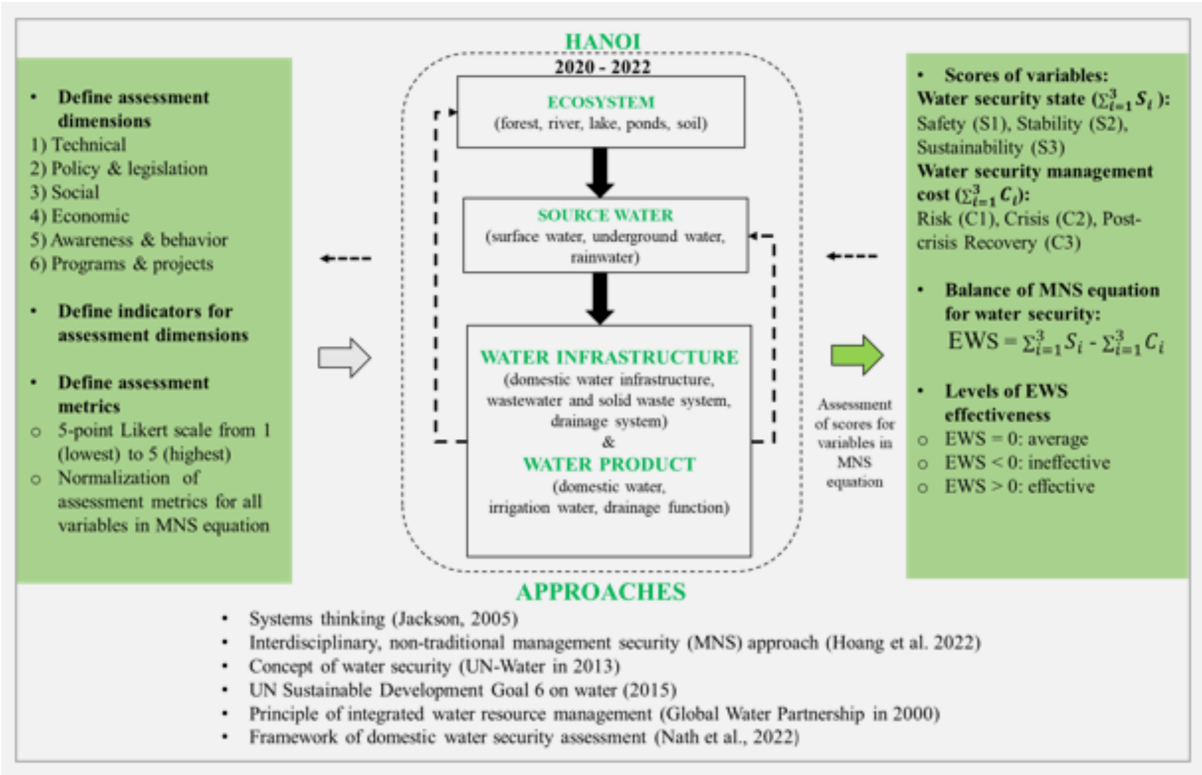

Figure 1. Assessment system of water security management of Hanoi in 2020 – 2022

As shown in Figure 1, elements of the WSM system include:

- Temporal boundary: from 2020 to 2022.
- Spatial boundary: administrative border of Hanoi.
- Processes (details in Table 4) which are defined based on their contributions to the overall system, including three groups:
    - Water-related ecosystems: river, pond/lake, forest;
    - Water and waste management infrastructure: domestic water infrastructure (water treatment plant/station, pipeline network, storage facilities); drainage system (sewer

network, urban tree/green space, regulating ponds/lakes); wastewater and solid waste management infrastructure from collection, treatment to disposal);

- Water products: domestic water, irrigation water, drainage function.

See Supplementary Material 1 for how processes are defined and assigned weights.

2.2 Concept of WSM under MNS perspective

2.2.1 MNS equation

The MNS approach was developed by Hoang et al. (2022) as an equation reflecting the relationship between variables of MNS cost and MNS effectiveness that contribute to the overall NTS of a referent object. This equation, called the "MNS equation", is applied to assess the MNS effectiveness. It is inspired and based on the principle of Cost-Benefit Analysis (CBA). Although controversial, the CBA is widely exploited to assess the effectiveness of an environmental policy and investment project (OECD, 2018). The CBA usually applies monetary units for ease of comparison. However, in reality, there are cases in which it is difficult to use money as a measure of value, e.g., the value or loss of human life or of an ecosystem, or benefits/impacts of the natural environment on human health and well-being. In other words, there are things that are priceless but invisible, especially the intangible benefits of nature. We, therefore, suppose that everything has a "price", which represents both measurable and immeasurable value. Additionally, we consider the NTS state of a referent object as a value and a result of specific MNS measures. Consequently, this NTS state should be assessed in relation to the investment costs for corresponding management measures (MNS cost). The management measure is considered to be only effective if the desired NTS state is achieved and the MNS cost is reasonable. Based on this argument, the MNS effectiveness can be expressed as a cause-and-effect relationship as follows:

MNS effectiveness = NTS state – MNS cost

Equation 1

- **NTS and WS state**

NTS has a dynamic concept and is still evolving. However, it is often mentioned as threats that originate from non-military sources, which shift away the security of the referent object from state or military-centric to individual and human-centric (Caballero-Anthony, 2016). Addressing these dangers requires comprehensive responses, including political, economic, social, and humanitarian use of military force, as these issues are transboundary in nature (NTS Centre, 2023). Successful securitization of these threats emphasizes the attention and resources needed to tackle them and, more importantly, not in a traditional manner (Caballero-Anthony, 2016). In this regard, the NTS of a referent object in this study has a wider sense than the literal meaning of security, indicating "the state of being free of danger or threat" (Oxford Dictionary) or simply being safe. We suppose that the NTS concept refers to the highest level or broadest sense of security, which includes **safety** (S1), **stability (S2)**, and **sustainability (S3)**. This security concept finally aims for the sustainable development of a referent object, which includes economic, social, and environmental aspects as interdisciplinary assessment dimensions. We consider that S1 must be the highest priority of any referent object. Therefore, we define S2 as the predictable and consistent state of a referent object on the condition of an achieved S1 state. Likewise, we consider S3 the ability to maintain the achieved S1 and S2 states at a certain level not only for the current but also for future generations (Oxford Dictionary and modifications from UN's definition of sustainable development). The mathematical relationship between S1, S1, and S3 is flexible depending on the NTS issues of concern, study context, and author's justification.

- **Characterization of WS state**

In this study, for simplification, we suppose WS state ($\sum_{\mathrm{i}=1}^{3} \mathrm{S_i}$) is the sum of S1, S2, and S3 or $\sum_{\mathrm{i}=1}^{3} \mathrm{S_i} = S1 + S2 + S3$. The characterization of S1, S2 and S3 is presented in Table 1.

- **MNS and WSM cost**

As mentioned earlier, any NTS state of a referent object is a result of MNS measures. The degree of MNS measures is illustrated in the form of MNS cost. However, in this study, MNS cost ($\sum_{\mathrm{i}=1}^{3} \mathrm{C_i}$) refers to a broader sense of cost *invested* or *lost* corresponding to a certain level of security. Particularly, this MNS cost can be in the form of resources invested, such as money, time, activities, human capacity, or intangible values (natural capital), such as ecosystem services, human health and well-being, etc. We suppose that sound management of risk is the prerequisite to preventing crisis from occurring and subsequently achieving the desired NTS state of a referent object. Although risk has both a negative and positive nature, in this study, we focus on its negative aspects, which demand priority and resources to handle. In this regard, we consider a risk of the possibility of something bad happening (Cambridge Dictionary), which can prevent a referent object from achieving its desired NTS state.

When a risk occurs, it becomes a crisis (Coombs, 2019), which indicates "a time of intense difficulty, trouble, or danger" (Oxford Dictionary). When the worst of the crisis is over, the post-crisis recovery takes place to get back to the normal state of a referent object. This definition is inspired by the stage "recovery" in the disaster management cycle of the UNDRR (UN-SPIDER, 2023). We, therefore, suppose that MNS cost includes the cost invested for risk management (C1) and the cost lost for crisis (C2) and post-crisis recovery (C3) management.

Similar to the security state, the mathematical relationship between C1, C2, and C3 is flexible depending on the non-traditional issues of concern and the author's justification.

- **Characterization of WSM cost**

For simplification, in this study, we suppose WSM cost ($\sum_{i=1}^{3} C_i$) is the sum of C1, C2, and C3 or $\sum_{i=1}^{3} C_i = C1 + C2 + C3$. The characterization of C1, C2 and C3 is presented in Table 1.

Table 1. Characterization of variables in water security management (WSM) equation [Equation 2**]**

Variables		Descriptions	Sources of justification
S1	**Safety state**	• Functional state of processes in WSM system compared to technical regulations or requirements, e.g., pollution state of surface water (river, lake, pond), drinking water quality / scarcity, presence of urban flood	WS concept (UN-Water (2013), IWRM (GWP, 2008), SDG 6 (UN, 2015)
S2	**Stability state**	• Consistency and predictability of achieved safety state • The stable state of social and economic activities / conditions in relation to water demand (quality, quantity) for human health and well-being, ecosystems, and economic and political stability	Definition of stability (Cambridge Dictionary) and author's perception
S3	**Sustainability state**	• The ability to maintain a certain level of the achieved safety and stability state not only for the current but also future generations.	Definition of sustainability definition (Oxford Dictionary), sustainable development (UN, 1987) and SDG (UN, 2015)
C1	**Cost invested for risk management**	• WS risks are potential water-related issues or future WS crisis (see description of C2 below) • Investment in all dimensions (see Table 2)) to prevent or mitigate WS risks (e.g., water pollution, scarcity, flooding)	WS concept (UN-Water, 2013), IWRM (GWP, 2008), SDG 6 (UN, 2015)
C2	**Cost lost (losses) for crisis management**	• When WS risks occur, they become WS crises Examples: surface/groundwater pollution, drinking water pollution, water scarcity, flooding, solid waste pollution, and water-related ecosystem degradation. • Cost lost (losses) in the form of economic, human well-being, ecosystem degradation/loss for WS crisis management	Relationship between risk and crisis (Coombs, 2019)
C3	**Cost lost (losses) for post-crisis recovery management**	• Cost lost in the form of economic, human well-being, and ecosystem degradation/loss to recover to the previous (normal) security state after the WS crisis is over.	Relationship between risk and crisis (Coombs, 2019), disaster management cycle of UNDRR (UN-SPIDER, 2023)

2.2.2 WSM equation

On the basis of the above argument, applying Equation 1 for the case of WSM effectiveness (EWS), we have the flowing equation (WSM equation):

$$\text{WSM effectiveness} = \text{WS state} - \text{WSM cost or EWS} = \sum_{i=1}^{3} \mathbf{S_i} - \sum_{i=1}^{3} \mathbf{C_i} \quad \text{Equation 2}$$

2.3 Determination of variable values in the WSM equation

2.3.1 Characterization of assessment dimensions

The determination of variable values in the MNS equation (Equation 1) depends on the NTS of concern, scope of study, and author's justification. In this study, we determine variable values for the WSM equation (Equation 2) via assessment of dimensions. Table 2 justifies the selection of assessment dimensions concerning the WSM concept.

Table 2. Characterization of assessment dimensions for the water security management (WSM) system of Hanoi in 2020 – 2022

	Dimension	Descriptions	Sources of justification
D1	**Technical**	• D1 refers to the technical capacity of the community represented by: ○ water-related infrastructure, operation and maintenance to ensure the functions of processes within the WSM system ○ technical requirements or regulations of water products and services (quality, quantity)	• WS concept (UN-Water, 2013): basic need for drinking and sanitation, socio-economic activities • SDG 6 (UN, 2015): safe drinking water for all (6.1); improve water quality by reducing pollution (6.3), increase water-use efficiency, address water scarcity (6.4); protect and restore water-related ecosystems (6.6) • IWRM (GWP, 2008): "maximize economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems"
D2	**Policy & legislation**	• D2 refers to the coordinated management of water, land and related resources in terms of policy & legislation and institutional mechanisms, specifically: ○ high-level policy and law and under-law regulations or guidance documents related to processes with the WSM system. ○ content / quality and enforcement of policy & legislation	• WS concept (UN-Water, 2013): good governance, transboundary cooperation • IWRM (GWP, 2008): coordinated development and management of water, land and related resources • IWRM (GWP, 2008): "water resources are an integral component of the ecosystem" • SDG 6 (UN, 2015): transboundary cooperation (6.5), (protection and

	Dimension	Descriptions	Sources of justification
			restoration of water-related ecosystems (6.6), capacity building (6A)
D3	**Social**	• D3 refers to the **universal, fair, and equal access** to water-related services across rural and urban areas, different groups in society (e.g., marginal groups, low-income groups, gender)	• WS concept (UN-Water, 2013): safe, sufficient, affordable water for populations, fulfills human rights • SDG (UN, 2015): universal and equitable access to water (6.1) • IWRM (GWP, 2008): "maximize economic and social welfare in an equitable manner", "water resource is … a social and economic good" • Human rights to clean and affordable water and a clean environment (UN 2010, 2022)
D4	**Economic**	• D4 **refers** to: ○ financial investment or losses in water-related processes and other dimensions ○ affordable water-related services ○ financial tools / innovations	• IWRM (GWP, 2008): "water resources are an integral component of the ecosystem, a natural resource, and a social and economic good." • IWRM (GWP, 2008): "maximize economic and social welfare." • WS concept (UN-Water, 2013): "Financing – innovative sources of financing complement funding…"
D5	**Awareness & behavior change**	• D5 refers to: ○ awareness of water security issues, environmental / water rights ○ behavior or practical activities toward ensuring water / environmental security	• SDG (UN, 2015): capacity building (6A) • Human rights to clean and affordable water and a clean environment (UN 2010, 2022) • WS concept (UN-Water, 2013): transboundary cooperation for mutual benefit
D6	**Projects & programs**	• D6 refers to specific investment, implementation and operation aspects of policy & legislation, particularly in the form of projects & programs: ○ financial investment in individual projects & programs ○ overall financial investment in projects & programs ○ operation of projects & programs	• See D2, D4

2.3.2 Relationships between assessment dimensions and variables in the WSM equation

Table 3 describes the relationship between assessment dimensions, their corresponding indicators, and variables in the WSM equation (Equation 2). In some cases, an indicator can characterize several dimensions.

For WS state, S1 is generally assessed based on compliance with technical regulations or perceived standards. S2 refers to the positive stability and consistency of considered dimensions. S3 often refers to the social, economic, awareness & behavior dimensions.

For WSM cost, in many cases, there are no distinct differences between C2 and C3 as they may occur simultaneously. For example, the constant discharge of untreated wastewater into a river causes a pollution crisis. The stage of post-crisis recovery (self-regulating and self-sustaining) to the initial state of the healthy river ecosystem takes place at the same time as the pollution crisis. However, this post-crisis recovery has hardly been successful due to the continuous pollution and, therefore, is unnoticeable. We consider this situation a vicious cycle of crisis and post-crisis recovery. In this circumstance, we consider the values of C1 and C2 the same.

Table 3: Relationship between assessment dimensions, indicators, and variables in WSM equation (Equation 2).

Dimensions		**Indicators**	**Sub-indicators**	**S1**	**S2**	**S3**	**C1**	**C2**	**C3**
D1	**Technical**								
	[D4]	• Investment in water-related infrastructure (e.g., collection system, treatment plant, equipment etc.)	○ Existing infrastructure: quantity, capacities, coverage ○ Rate of treatment and access to water-related services				x		
	[D4]	• Investment in water-related technologies (e.g., protection of water resources, treatment, monitoring etc.)	○ Existing technologies (via quality of products, services) ○ State of products, services, related ecosystem health				x		
	[D4]	• Investment in operation and maintenance (O&M) (e.g., monitoring and controlling, human resources)	○ Existing state of O&M ○ Existing state of water-related products and services				x		
		• Compliance or comparison with technical regulations to ensure quality and quantity of water-related services and products (e.g., treatment rate of wastewater, access to clean water, collection rate of solid waste etc.)	○ Status of aquatic ecosystems (rivers, ponds, lakes, canals): quality and quantity ○ Status of water-related services (domestic water, function of sewer system) ○ Crisis events: pollution violation cases, water scarcity, flooding,	x	x	x		x	x
	[D4]	• Cost lost for water-related crisis management (e.g., water pollution, water scarcity, limitations in access to water-related services)						x	
	[D4]	• Cost lost for water-related after the crisis event to recover to normal condition	○ Cost lost for recovery to the normal state of human health, ecosystems, economic benefits						x
D2	**Policy & legislation, institution**								
		• At the general level: ○ Investment in policy and laws on WS: existing or not ○ Investment in the quality of the framework of policy and laws on WS	○ Existing policy and laws: Environmental protection law (2020), Law on Water Resources (2012) and other laws ○ Content: Water security concept, Integrated water resources management, integrated solid waste management				x		

Dimensions		Indicators	Sub-indicators	S1	S2	S3	C1	C2	C3
		• At the implementation / enforcement level: ◦ Investment in the feasibility of under-law guidance documents (decree, circular, dispatch, etc.)	◦ Quality: consistency, transparency, clarity ◦ Feasibility: pathway to implement, feasible requirements of compliance ◦ Punishment for violation			x	x		
	[D3]		◦ Inclusion of human rights to clean and affordable water and the environment and mechanism to implement				x		
	[D4]	• Investment of resources in implementing policy and laws	◦ Institutional capacities: equipment, human resources, capacity building ◦ Institutional mechanisms			x	x		
		• Enforcement of laws and regulations	◦ Existing violations ◦ Implementation reports			x			
D3	**Social**								
	[D4]	• Investment in closing social gaps between urban and rural in access to water-related services	◦ Comparison of water-related infrastructure between urban and rural areas: presence of services, access to services, quantity, capacities, product/service quality, affordable price ◦ Equal access to services ◦ Fair price for all ◦ Affordable price				x		
	[D4]	• Investment in closing social gaps between marginal groups (i.e., low-income groups, migrants) in access to water-related services					x		
		• Social gaps between urban and rural in access to water-related services				x			
		• Social gaps between marginal groups (i.e., low-income groups, migrants) in access to water-related services				x			
	[D2]	• Investment in access and openness to information from water-related services and management (e.g., water quality, claims resolution)	◦ Information accessibility (e.g., website, channel and mechanism to claim customer rights) ◦ Information availability, transparency, reliability				x		
	[D2]	• Pubic accessibility to information on water-related services (e.g., from the water treatment plant, water institution and authority): data quality, transparency, reliability				x			
D4	**Economic**					x			

Dimensions		Indicators	Sub-indicators	S1	S2	S3	C1	C2	C3
		• Investment in other dimensions					x		
	[D3, D5]	• Investment in financial and economic tools to promote sustainable WS practice (e.g., water saving, energy saving; reuse, recycling of water; water use efficiency)	○ Current price / fee of water-related service ○ Price subsidization				x		
	[D2]	• Investment in financial and economic tools to promote investment in water-related projects					x		
	[D3]	• Affordable price of water-related services				x			
D5	**Awareness & Behavior**								
	[D1]	• Investment in raising awareness of WS	○ Water-related projects on awareness raising toward positive behavior change				x		
	[D2, D4, D6]	• Investment in changing to positive behavior/practice of WS	○ Legal regulation and enforcement ○ Long-term communication projects ○ Education and practice ○ Waste collection infrastructure in public areas: waste bin, monitoring, and inspection equipment/activities				x		
	[D3]	• Awareness of water-related issues	○ Aware of the issues			x			
	[D3]	• Behavior toward WS practice	○ Practice water saving, reuse of water ○ Discharge of solid waste in public area			x			
	[D3]	• Awareness and claim to have human rights to clean, affordable water and a clean environment							
D6	**Projects & Programs**								
	[D4]	• Overall investment in projects & programs related to water	○ Overall financial investment				x		
	[D4]	• Investment in individual projects & programs related to water	○ Financial investment in individual projects & programs				x		

Dimensions		Indicators	Sub-indicators	S1	S2	S3	C1	C2	C3
		• Investment in implementation and maintenance	○ Institutional mechanism				x		
	[D2]	• Effectiveness of implementation of programs and projects	○ Operation of projects & programs			x			

2.3.3 Assessment metrics and normalization of variable values

- **Assigning metric scale for S1, S3, S3, C1, C2, C3**

Variable values of S1, S2, S3, C1, C2, C3 in **Equation 2** are measured through an **interval scale,** which is modified based on a 5-point Likert scale, including: very low (0 – 1.5), low (1.6 – 2.5), average (2.6 – 3.5), high (3.6 – 4.5), and very high (4.6 – 5).

For most of the cases, dimensions of technical (D1), policy & legislation (D2), awareness & behavior (D5), and projects & programs (D6) can be **generalized** as follows:

- **Dimension D1**

As mentioned in Section 2.2.1 (NTS and WS state), S1 must be the highest priority of any referent object. If a referent object is not in a sufficiently safe state, it cannot reach an S2 state and, subsequently, an S3 state. Therefore, we define stability as the predictable and consistent state of a subject on the condition of an achieved safety state. Likewise, we consider sustainability to be the ability to be maintained at a certain level of the achieved S1 and S2 states. In this regard, we suppose that if S1 is equal to or less than average (S1 = < 3), levels of S2 and S3 will be lower. In this case, we base on the moderate level of data uncertainty of around 20% (c.f., Tran & Weichgrebe, 2020) for environmental processes / parameters and assign lower levels of S2 and S3 as follows: $S2 = S1 - 20\% * S1$ and $S3 = S2 - 20\% * S2$.

- **Dimensions D2, D5, D6**

Due to the research scope and data limitations, we generalize levels of C1 and S3 based on the common situation and characteristics of dimensions D2, D5 and D6 (see details in Supplementary Material 2 and Section 3.1) as follows:

  - D2 - policy & legislation: C1 = 2.5, S3 = 2
  - D5 - awareness & behavior: C1 = 2, S3 = 2.5

- D6 – projects & programs: C1 = 2.25, S3 = 2

- **Normalizing values for $\sum_{i=1}^{3} S_i$, $\sum_{i=1}^{3} C_i$ and EWS**

To standardize the unit and assessment scale, values of WS state ($\sum_{i=1}^{3} S_i$) and WSM cost ($\sum_{i=1}^{3} C_i$) are then normalized to a similar five-interval scale, by dividing their sum total by 3. The relationship between levels of $\sum_{i=1}^{3} S_i$, $\sum_{i=1}^{3} C_i$ and EWS is illustrated in Figure 2.

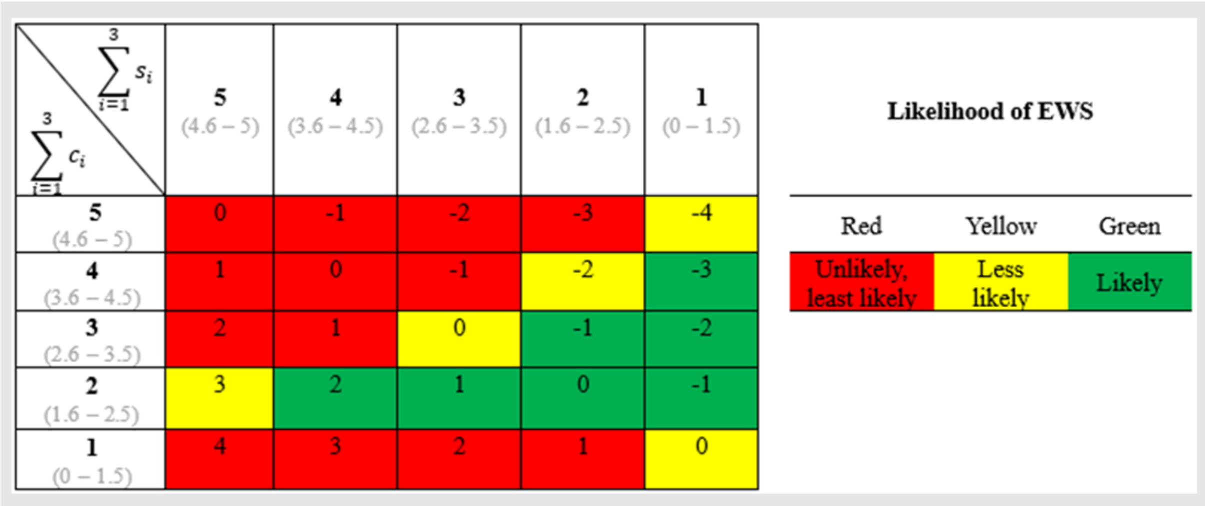

Figure 2. Relationship between levels of effectiveness of water security management (EWS), water security state ($\sum_{i=1}^{3} S_i$) and water security management cost ($\sum_{i=1}^{3} C_i$)

Our argument for this relationship is that the higher the level of $\sum_{i=1}^{3} C_i$, the lower the level of $\sum_{i=1}^{3} S_i$. Therefore, it is impossible to have simultaneously high levels of $\sum_{i=1}^{3} S_i$ and $\sum_{i=1}^{3} C_i$. Based on this, we specify the level of EWS, as shown in Figure 3. Particularly, EWS is measured through a **ratio scale** and level of $\sum_{i=1}^{3} S_i$. Specifically, the ratio scale represents the difference (%) of EWS's absolute values against the true zero (0) (indicating the average level of EWS) within five interval scales: EWS (%) $= \frac{EWS - 0}{5} * 100$. This normalization process is applied because of the similarity of the ratios in both cases of normalization (five-interval scales) and original absolute values (fifteen-interval scale).

$\sum_{i=1}^{3} S_i$	**1** (0 – 1.5)	**1; 2** (0 – 1.5) (1.6 – 2)	**2** (1.6 – 2.5)	**3** (2.6 – 3.5)	**3** (2.6 – 3.5)	**4** (3.6 – 4.5)	**5** (4.6 – 5)
EWS	**-3**	**-2**	**-1**	**0**	**1**	**2**	**3**
EWS [%]	**- 60%**	**- 40%**	**- 20%**	**0%**	**20%**	**40%**	**60%**
EWS level	**Crisis**	**Very low ($\sum_{i=1}^{3} S_i = 2$); crisis**	**Low**	**Average**	**Good**	**Very good**	**Perfect**
	Ineffective WSM				**Effective WSM**		

Figure 3. Levels of effectiveness of water security management (WSM) (EWS = $\sum_{i=1}^{3} S_i$ - $\sum_{i=1}^{3} C_i$, $EWS\ (\%) = \frac{S-0}{5} * 100$)

2.4 Balance of WSM system

For simplicity's sake, we consider the overall WSM system in Hanoi equal to the sum of WSM of eleven individual processes (Table 4). However, processes are assigned weights in percentage (%) based on the difference in their contributions to the overall WSM system (100%) at the time of study. Accordingly, there are three groups of processes including:

- **highest weight** (15%) with one process: wastewater;
- **average weight** (10%) with seven processes: river, groundwater, lake/pond, sewer system, solid waste, domestic water infrastructure, domestic water;
- **lowest weight** (5%) with three processes: irrigation water, green space, forest

A detailed explanation for the assignment of process weight is provided in Supplementary Material 1. The WSM of each process is balanced separately before integrating into the WSM system (Table 4).

2.5 Data collection and processing

- **Study area**

Hanoi has an area of over 330,000 m^2 and 30 administrative units, including 17 rural districts and 13 urban districts. Approximately 50% of the city population lives in rural areas (GSO, 2022). The city has a monsoon-influenced humid subtropical climate pattern with an annual precipitation level of about 1,700 mm. Hanoi has a dense network of seven rivers and hundreds of lakes and ponds (Figure 4). Delta, midland, and mountainous areas are three main types of terrain in Hanoi (Hanoi Portal, 2015).

Location of Hanoi, Vietnam

(Source: snapshot from google.com/map on 12/06/2023)

River network in Hanoi

(Source: map published in a World Bank Group's report (WBG, 2020))

Figure 4: Location of Hanoi Capital in Vietnam and its dense river network

- **Data collection**

Data were collected for all processes representing the state of the WSM system in Hanoi from 2020 to 2022. The majority of data are from secondary sources. However, **primary data** were additionally collected from interviews, site observations, and personal communications with experts. **Interviews** were conducted in person, via questionnaire online, and by telephone. Interviews and personal communications with experts were mainly conducted for processes related to *domestic water* and water-related *ecosystems*. **Site observations** were applied for most of the process. It is based on visual or sensuous observation of the site directly without the assistance of the monitoring equipment. This observation method was inherited from technical experiences and secondary data from previous empirical studies conducted in Hanoi by the author (c.f., Tran & Weichgrebe, 2020). **Secondary data** were collected and synthesized from various sources, including participating in technical workshops and training courses, updated research studies, national thematic reports (e.g., MONRE 2018), technical assistance reports from international development organizations, e.g., the World Bank Group (2019, 2020), Asian Development Bank and authorities' statements and expert opinions from technical magazines and public media (television, YouTube, local and national websites). Further details about data collection are provided in Supplementary Material 3.

- **Data processing**

Values of variables in the WSM equation [**Equation 2**] were determined using a combination of qualitative and quantitative data assessment based on the structure presented in Table 3. A list of dimensions and indicators used for assessing each process is presented in Supplementary Material 4. In case of data uncertainty, "educated guess" or information-based inference was applied (c.f., Tran & Weichgrebe, 2020). An example of data processing for process *wastewater* is provided in Supplementary Material 3.

III. WSM challenges in Hanoi

The findings show a very low level of WSM effectiveness in Hanoi (EWS = -1.32 or – 26%), due to insufficient and ineffective investment in risk management (C1 = 2.24) and subsequently higher costs of crisis and post-crisis recovery management (C2 = 3.63, C3 = 3.73) and a low level of WS state ($\sum_{i=1}^{3} S_i$ = 1.86). Table 4 illustrates assessment results for all processes in the WSM system (see details in Supplementary Material 5).

Table 4: Assessment results of water security management (WSM) in Hanoi in 2020 – 2022. EW*S = WSM effectiveness,* $\sum_{i=1}^{3} \boldsymbol{S_i}$ *= WS state,* $\sum_{i=1}^{3} \boldsymbol{C_i}$ *= WSM cost*

Process	**Weight [%]**	**EWS [%]**	**EWS**	$\sum_{i=1}^{3} \boldsymbol{S_i}$	$\sum_{i=1}^{3} \boldsymbol{C_i}$
Forest	5%	-20%	-0.97	2.22	3.19
River	10%	-28%	-1.41	1.90	3.31
Groundwater	10%	-13%	-0.66	2.02	2.69
Ponds & lakes	10%	-23%	-1.13	2.00	3.13
Green space	5%	-20%	-1.00	1.81	2.81
Sewer system	10%	-27%	-1.34	1.87	3.21
Wastewater	15%	-45%	-2.25	1.26	3.51
Solid waste	10%	-48%	-2.41	1.30	3.71
Irrigation water	5%	-18%	-0.89	2.06	2.94
Domestic water infrastructure	10%	-18%	-0.88	2.05	2.93
Domestic water	10%	-11%	-0.57	2.56	3.12
Overall water security	100%	**-26%**	**-1.32**	**1.86**	**3.18**

With EWS ranging from -11% to -49%, no process achieves an average level of WSM effectiveness. Of these, *domestic water* has the most effective WSM. Conversely, *solid waste* and *wastewater* show the least effective WSM.

The following discusses specific challenges in WSM in Hanoi.

3.1 Inadequate and ineffective investment in WS risk management

- **Water and waste management infrastructure**

According to UNICEF (2020), the total investment in *clean water* and sanitation in Vietnam decreased from 1% of the GDP in 2016 to 0.56% in 2018. For Hanoi, investment in *wastewater* and *solid waste* management, *clean water* production, and urban *drainage systems* is inadequate. The majority is Capital Expenditure investment (i.e., Capex, expense for physical infrastructure). The Operation Expenditure (Opex, e.g., expense for operation and maintenance) is insignificant (WBG, 2019, 2020).

  - **Wastewater**

Domestic wastewater is the major contributor (approx. 80%) to the total wastewater (load, volume) in Hanoi (WBG, 2020). There are eight ongoing municipal wastewater treatment plants (WWTP) with a total capacity of approx. 300.000 m^3/day (Plan 312/KH-UBND of Hanoi People's Committee in 2013), responding to only 30% of urban-generated wastewater. However, the actual treatment rate is only 17 – 20% because of the water losses in the sewer connection to WWTP. *Industrial wastewater* (16% of total load) from industrial parks & clusters (12%) and craft villages (4%) is not properly treated (WBG, 2020). Nationwide, most industrial parks are equipped with WWTP (approx. 90%), with design capacities meeting about 70% of total wastewater effluent. Under the current wastewater crisis, we suppose a not higher treatment rate for Hanoi. For industrial clusters, only 36% are equipped with WWTP, with a total treatment capacity of less than 30%. Many industrial WWTPs do not operate fully to save costs, resulting in much lower actual treatment rates (MONRE, 2018; WBG, 2019, 2020). Investment in WWTP for craft villages is significantly deficient, leading to almost no wastewater treatment (MONRE, 2018; Tran & Weichgrebe, 2020; WBG, 2020).

For ***agriculture***, there are no measures to handle wastewater generated from the overfertilization and overuse of pesticides (Tran & Weichgrebe, 2020; WBG, 2019, 2020). About 50% of the animal waste is treated, mainly in small-scale biogas plants (hanoi.dangcongsan.vn, 2020). However, simple treatment technologies often lead to a vast amount of liquid waste (i.e., digestate) discharged directly into the environment (Tran & Weichgrebe, 2020).

- **Domestic water**

The clean water access in Hanoi is about 90%. Investment in water treatment plants/stations, pipeline networks, and operation and maintenance (O&P) in rural areas is significantly inadequate and ineffective, leading to lower clean water access of 84% compared to urban areas (100%) (hanoimoi.com.vn, 2022). Additionally, insufficient investment *in appropriate treatment technologies and O&P* of the entire supply system results in unqualified clean water quality or even abandoned treatment facilities. As an example, over 24% of 119 rural water stations have stopped working, and less than 50% can function properly (Hanoi DONRE, 2019). Furthermore, investment in *controlling source water quality* (i.e., input for water plants) is inadequate, e.g., for maintaining water source protection corridors, domestic water safeguard zones and automatic, virtual monitoring systems.

- **Drainage system**

Sewer drainage network

In Hanoi, only a quarter of the city in the Tô Lịch River catchment is equipped with an appropriate sewer system, and the connection rate is only over 60% (vovgiaothong.vn, 2022). The remainder lacks a synchronic investment, especially in the western districts (Plan 312/KH-UBND of Hanoi People's Committee in 2013; WBG, 2020). Conventional sewer capacity and current technologies are insufficient to adapt to the increasing impacts of climate change. Most sewer networks are combined systems for wastewater and rainwater, naturally gravitational, and critically lack maintenance; therefore, they often underperform, become obsolete, patchy, messy, and overloaded (WBG, 2019, 2020).

Nature-based drainage

There is an insignificant investment in nature-based solutions (e.g., rivers, ponds & lakes, urban trees) to facilitate drainage capacity. Specifically, river beds thicken due to the sedimentation from untreated wastewater discharge, leading to a decrease in water storage volume (c.f., WBG, 2020). Furthermore, the number and area of *ponds and lakes* have reduced dramatically due to rapid urbanization. Between 2010 and 2015, 17 lakes (corresponding to 72,540 m^2) in Hanoi were filled (CECR, 2015). In 2015 – 2020, the city lost over 2,000,000 m^2 of natural surface water (tienphong.vn, 2022a). Unfortunately, these phenomena continue. Hanoi has a green space of only 11.7% (nguoidothi.net.vn, 2020), with very low forest coverage of 5.67% and urban trees of less than 2 m^2/person (nld.com.vn, 2021). Compared to recommendations and technical regulations (e.g., green space of 30% (Van Den Bosch et al., 2016), urban tree of 7 m^2/person (national technical regulation QCVN 01:2021/BXD) and 9 m^2/person (WHO, 2012), and 15 m^2/person from UN's Habitat (Data-Driven EnviroLab, 2022), Hanoi critically lacks green infrastructure.

- **Solid waste**

Insufficient and ineffective investment in solid waste management infrastructure negatively impacts surface water and groundwater quality in Hanoi (WBG, 2019, 2020). Infrastructure and technologies from collection to disposal are mainly outdated and resource-intensive (c.f., N. H. Hoang & Fogarassy, 2020; vietnamnews.vn, 2023). Waste separation at the source is not a common practice due to the absence of necessary infrastructure. The *waste collection system* is mainly manual, labor-intensive, and ineffective. Hanoi announced the waste collection of 100% and approx. 90% for urban and rural areas, respectively (tienphong.vn, 2022b). However, actual rates are possibly much lower. Particularly, waste appears almost ubiquitous in public areas and open water bodies(c.f., nghenghiepcuocsong.vn, 2021). Polluting waste transfer stations and illegal dumpsites are not rare. Landfilling is the major treatment technology for most collected waste (89%); the remainder (11%) is incinerated (vietnamnet.vn, 2020). The current landfill technologies are polluting and severely degrading groundwater and surface water quality. With a daily waste generation of 7,000 metric tons, Hanoi often faces waste disposal crises as all landfills are overloaded (c.f., vietnamnet.vn, 2021) and waste generation per capita is increasing.

- **Implementation of policy, legal regulations, and institutional mechanism**

The water management framework is relatively sound at the level of policy and laws. However, the under-law documents are fragmented and sometimes overlapping, conflicting, unstable, infeasible, and insufficiently updated (T. P. L. Nguyen, 2010; WBG, 2019). The Ministry of Agriculture and Rural Development and the Ministry of Natural Resources and Environment is mainly responsible for the implementation of two major water-related laws: Water Resources 2012 and Environmental Protection 2020. At the local level of Hanoi city, water management is additionally in charge by people's committees, sectoral departments (Natural Resources and Environment, Agriculture and Rural Development, Construction, Health, Finance, etc.) and authorities (Police Department for Environment, Project Management Unit, Drainage and Sewerage Company, etc.). This legislative system creates overlapping and conflicting responsibilities among state ministries and Hanoi's authorities and agencies. Furthermore, there is a critical lack of investment in both infrastructure and capacity building for the implementation of water regulation (e.g., inspection and monitoring) (WBG, 2020). Therefore, it results in a complex and fragmented institutional mechanism and often requires huge coordination across ministries and Hanoi's inter-agencies and leads to the situation that *"everybody's business is nobody's business*". Consequently, enforcement of legal regulations is weak, and implementation of water programs and projects is highly ineffective (c.f., WBG, 2019, 2020). This is the major reason hindering investment in water-related projects, particularly from the private sector.

- **Closing social gaps in access to water services**

There are investment differences in water and waste services between urban and rural areas. They are represented by lower clean water access of 84% (compared to 100% in urban areas) (hanoimoi.com.vn, 2022), almost no wastewater treatment facilities, inadequate solid waste management system and illegal dumpsites in rural areas. Limited economic benefits are the main drivers that investors are not interested in rural water-related projects (c.f., VIR, 2021).

- **Awareness raising and proper behavior**

In Hanoi, most residents are aware of the WS issues. However, investment in raising awareness is inadequate to transform awareness into good behaviors (WBG, 2020). More specifically, many education and communication programs are short-term (project-based), fragmented, and superficial. Besides, weak enforcement of legal regulations (e.g., sanctioning of violations, economic incentives), lack of transparency (e.g., data openness and sharing), and infrastructure investment (e.g., waste bins in public areas, dedicated water conservation zones) result in a low level of residents' trust in the WSM system and negative behaviors in water and environmental protection, e.g., illegal discharge of solid waste in public areas, sewers, and open water bodies (c.f., WBG, 2020). Additionally, the lack of economic tools is one of the major reasons hindering sustainable practices in water use. Fees for clean water, wastewater treatment, and waste collection are too low that they are insufficient to cover the O&P (c.f., WBG, 2019, 2020). Excessive subsidies make customers take water-related services for granted (c.f., UN Environment, 2018; WBG, 2019, 2020). For example, for the majority of residents (90%) in Hanoi, especially urban households, the clean water price of 6,000 VND/m^3 (i.e., 2.5 US$ cent/m^3 for the first 10 m^3) is acceptable or relatively cheap (since July 2023 the price has increased 25% after ten years of no change). Therefore, sustainable practice, e.g., saving water, is not a present concern or strong economic motivation. Although human rights to water and the environment were recognized by the United Nations in 2010 and 2022, respectively, the awareness and behaviors toward water security justice are inadequate. The lack of a specific legal mechanism to support residents claiming these rights is the main reason for this (WBG, 2019).

3.2 High costs of WS crisis management and very low WS state

Insufficient and ineffective investment in WS risk management (C1 = 2.24) has resulted in high costs or losses for crisis and post-crisis management (C2 = 3.7, C3 = 3.8) and a very low WS state ($\sum_{i=1}^{3} S_i = 1.8$) (see details in Supplementary Materials 6). More than 80% of processes have C2 and C3 costs at above-average levels. The most "expensive" costs are associated with the ineffective management of *solid waste (C2 = C3 = 4.49)*, *wastewater (C2 = C3 = 4.37)*, *river (C2 = 3.93, C3 = 3.98)*, and *sewer (C2 = 3.58, C3 = 3.7).* Dominant WS crises include severe water pollution and depletion of water resources, degradation of drainage systems and intensification of flooding events, and existing and potential risks of domestic water. The WS state of ***surface water*** is at low levels (*river*: C2 = 3.93, C3 = 3.98; $\sum_{i=1}^{3} S_i = 1.9$; *ponds and lakes*: C2 = C3 = 3.63; $\sum_{i=1}^{3} S_i = 2$), represented by the heavy pollution of rivers and many lakes and ponds, especially in the inner city. Furthermore, *river water* suffers from increasing riverbank subsidence as a result of uncontrolled sand-mining activities, particularly on the Red River. Additionally, damaging upstream flashfloods and fluvial floods still occur in some rural districts (e.g., Chương Mỹ). ***Groundwater*** (C2 = C3 = 3, $\sum_{i=1}^{3} S_i = 1.96$) has a low WS state with higher costs associated with the critically decreasing water levels and contamination of Arsenic, Amoni, Mangan, Ferrous, and organic substances, particularly in the South of Hanoi (c.f., Vu et al., 2022; Winkel et al., 2011). Although ***domestic water*** (C2 = 3.27, C3 = 3.28, $\sum_{i=1}^{3} S_i = 2.56$) has the second highest WS state level in the system, it faces major challenges of the inconsistent quality of source water and clean water, particularly from rural small-scale groundwater stations (CDC Hanoi, 2023). About 10% of the rural residents have to use rainwater and groundwater due to the lack of clean water access. Most importantly, residents largely lack trust in domestic water quality; the majority of households (>80%) are equipped with domestic water filtration facilities. Domestic water scarcity occurs in some urban and rural areas where there are clean water quality crises and water cuts due to pipeline breaks or water incidents. Degradation of the ***irrigation system*** (C2 = C3 = 3.31, $\sum_{i=1}^{3} S_i = 2.06$) is represented by irrigation water pollution and unproductive water use. Particularly, the major irrigation system Bắc Hưng Hải and many canals are severely contaminated (vietnamnews.vn, 2022). ***Drainage system*** (*sewer*: *C2 = 3.58, C3 = 3.7*, $\sum_{i=1}^{3} S_i = 1.84$; *green space:* C2 = C4 = 3.5, $\sum_{i=1}^{3} S_i = 1.53$; *lakes and ponds*: C2 = C3 = 3.63, $\sum_{i=1}^{3} S_i = 2$) is poor-equipped, polluted, seriously degraded and overloading, leading to increased urban *flooding events* and considerable economic losses. Currently, there are 11 flooding hotspots. The western districts and suburban districts of Long Biên and Gia Lâm are the most affected areas (WBG, 2020).

3.3 Outlook of WS-related programs in Hanoi by 2030

The WSM challenges in Hanoi in 2020 – 2023 are not new. They emerged after the economic renovation in Vietnam in 1986 and, unfortunately, still exist. The upcoming regulatory reformation of WSM is expected in the revised Law on Water Resources and the new Law on Water Supply and Drainage, expected to be approved in 2023 and 2025, respectively. These laws are supposed to create a synchronic legal corridor for state water management, including domestic water supply. At the local level, Hanoi is implementing water-related programs with the following objectives: wastewater treatment rates of 50 - 55% by 2025 and 90% by 2030 and gradual reduction of urban flooding for a precipitation cycle of 10 years (Decision 725/QĐ-TTg of the Prime Minister in 2013, Plan 312/KH-UBND of Hanoi People's

Committee in 2013); clean water access of 100% by 2025, reduction of groundwater use to 25% by 2025 and 16% by 2030 (Decision 554/QĐ-TTg of the Prime Minister in 2021); urban tree coverage of 18 m^2/capita by 2030 (Decision 1259/QĐ-TTg of the Prime Minister in 2011, Decision 1495/QĐ-UBND of Hanoi People's Committee in 2021) and forest coverage of 6.2% by 2025 (Plan 57/KH-UBND of Hanoi People's Committee in 2022); waste collection of 80 - 100% (Decision 609/QĐ-TTg of the Prime Minister in 2014), incineration up to 85% (Decision 1259/QĐ-TTg of the Prime Minister in 2021). However, the majority of water and waste projects and programs are currently significantly behind schedule. Additionally, if the above-analyzed challenges remain unsolved, Hanoi definitely cannot achieve these objectives and its sustainable development goals by 2030 and beyond (see Supplementary Material 7 for further details of water-related programs and projects).

IV. Recommendations

The existing challenges in infective WS and outlooks state that it would be overly optimistic that Hanoi can achieve even an average level of WS state by 2030. However, for long-term WS policy-based management, we recommend viewing the WSM system as a whole and controlling decisive variables of the WSM equation to achieve an improved level of WSM. In the short term, Hanoi should promote investment in risk management of significant processes, i.e., *wastewater*, *solid waste*, *drainage system*, and *domestic water.* The focus should be as follows:

(1) Investment and implementation of water-related projects & programs with equal attention to Capex and Opex and more sustainable technologies;

(2) Investment in enforcement and implementation of legal regulations, particularly resources for inspection and controlling of WS violation cases, and mechanisms to control clean water quality;

(3) Investment in capacity building for relevant management institutions toward international standards and reforming administrative procedures to avoid irresponsibility and complexity;

(4) Investment in public awareness raising toward good behaviors, urgently in the domain of solid waste collection and treatment technologies, household connection to sewer and clean water pipeline, environment and water justice, and

(5) Closing gaps in access to water-related services by increasing investment in water infrastructure and applying financial mechanisms to support rural households.

V. Conclusions

The WSM of Hanoi in 2020 – 2022 is highly ineffective (EWS = - 29%), represented by challenges of inadequate and ineffective investment in risk management (C1 = 2.3) and subsequently high costs of crisis and post-crisis recovery management (C2 = 3.67, C3= 3.76), and a very low WS state ($\sum_{i=1}^{3} S_i = 1.8$). The city is suffering severe water pollution and depletion of water resources, degradation of drainage systems and intensification of flooding events and damages, and existing and potential risks to domestic water supply. The outlook shows this situation will not be improved by 2030 in the business-as-usual scenario. However, Hanoi can improve the current situation by increasing investment in WS risk management of "high cost" processes, i.e., *wastewater*, *solid waste*, *drainage system*, and *domestic water*. Thereby, the investment should focus on infrastructure, effective implementation of water-related projects, enforcement of legal regulations and reformation of institutional mechanisms, awareness raising toward good behavioral change, and closing gaps in access to water-related services in rural areas.

This is the first study applying the approach of MNS and systems thinking in assessing WSM challenges, which integrates interdisciplinary data and inclusive water-related processes in a semi-quantitative assessment. Although there are several limitations, e.g., data unavailability and majorly qualitative assessment of dimensions, our study offers a multilateral view and subsequently supports the evidence-based policy and decision-making process in WSM, particularly at the local level. Finally, this method contributes to a better understanding and provides materials for interdisciplinary research development in WSM and sustainability management. Further studies should investigate the interrelationship and measurement metrics for variables of the MNS equation more quantitatively and comprehensively.

Author contribution

Phi Dinh Hoang developed the concept of non-traditional security management and research topics. Nguyet Thi Tran developed the concept of systems thinking for the water security assessment system. Nguyet Thi Tran and Phi Dinh Hoang detailed the research concept, collected and processed data, and compiled the manuscript. Ky Xuan Nguyen participated in the development of the paper topic, research concept, and data collection.

Acknowledgment

The authors acknowledge the support of Vietnam National University under the project "Study on solutions to ensure water security for sustainable development of Hanoi city" and grant numbers: QG.19.60. The authors thank Ute Arnold, University of Bonn, for revising the manuscript. The authors thank all interviewees in Hanoi. The authors thank the editor and reviewers for their valuable comments.

Funding

This work is funded by the project "Study on solutions to ensure water security for sustainable development of Hanoi City" and grant number QG.19.60 of the Vietnam National University, Hanoi.

Conflicts of interest

The authors declare no conflicts of interest.

Ethical responsibilities of authors

All authors have read, understood, and have complied as applicable with the statement on 'Ethical responsibilities of Authors' as found in the Instructions for Authors.

Data availability statement

All relevant data are included in the paper or its Supplementary Information.

References

ADB. (2020). *Asian Water Development Outlook 2020: Advancing Water Security across Asia and the Pacific* (Issue 2020). Asian Development Bank. https://www.adb.org/publications/asian-water-development-outlook-2020

Bui, N. T., Darby, S., Vu, T. Q., Mercado, J. M. R., Bui, T. T. P., Kantamaneni, K., Nguyen, T. T. H., Truong, T. N., Hoang, H. T., & Bui, D. D. (2022). *Willingness to Pay for Improved Urban Domestic Water Supply System: The Case of Hanoi, Vietnam*. https://www.mdpi.com/2073-4441/14/14/2161/htm

Caballero-Anthony, M. (2016). *An Introduction to Non-Traditional Security Studies: A Transnational Approach*. https://doi.org/10.4135/9781473972308

CDC Hanoi. (2023). *External inspection results of clean water in Hanoi*. http://hanoicdc.gov.vn/823/suc-khoe-moi-truong--y-te-truong-hoc-.html

CECR. (2015). *The premiere of "Hanoi Lakes Report 2015" – Center for Environment and Community Research*. https://cecr.vn/en/the-premiere-of-hanoi-lakes-report-2015/

Coombs, W. T. (2019). *Ongoing Crisis Communication*. SAGE Publications Inc. https://us.sagepub.com/en-us/nam/ongoing-crisis-communication/book270207

Dang, N. M., Tu, V. T., Babel, M., Shinde, V., & Sharma, D. (2017). *Water Security Assessment for the Red River Basin, Vietnam*. Springerprofessional.De. https://www.springerprofessional.de/en/water-security-assessment-for-the-red-river-basin-vietnam/19577384

Data-Driven EnviroLab. (2022). *Urban Tree Cover*. https://datadrivenlab.org/urban/issue-profiles/urban-tree-cover/

El-Sayed, M. K., & Mansour, R. S. (2017). Water Scarcity as a Non-traditional Threat to Security in the Middle East. *India Quarterly*, *73*(2), 227–240. https://doi.org/10.1177/0974928417699916

Gerlak, A. K., House-Peters, L., Varady, R. G., Albrecht, T., Zúñiga-Terán, A., de Grenade, R. R., Cook, C., & Scott, C. A. (2018). Water security: A review of place-based research. *Environmental Science & Policy*, *82*, 79–89. https://doi.org/10.1016/j.envsci.2018.01.009

Glodowska, M., Stopelli, E., Straub, D., Vu Thi, D., Trang, P. T. K., Viet, P. H., AdvectAs team members, Berg, M., Kappler, A., & Kleindienst, S. (2021). Arsenic behavior in groundwater in Hanoi (Vietnam) influenced by a complex biogeochemical network of iron, methane, and sulfur cycling. *Journal of Hazardous Materials*, *407*, 124398. https://doi.org/10.1016/j.jhazmat.2020.124398

GSO. (2022). *Statistical Yearbook of Vietnam 2021*. General Statistics Office of Vietnam. https://www.gso.gov.vn/du-lieu-va-so-lieu-thong-ke/2022/08/nien-giam-thong-ke-2021-2/

Hanoi DONRE. (2019). *Hà Nội: 90 công trình cấp nước sạch tập trung hoạt động ổn định [Hanoi: 90 clean water supply stations operate stably]*. https://moc.gov.vn/vn/tin-tuc/1184/38818/ha-noi--90-cong-trinh-cap-nuoc-sach-tap-trung-hoat-dong-on-dinh.aspx

Hanoi Portal. (2015). *Overview of Hanoi*. https://english.hanoi.gov.vn/overview?p_p_id=Cms_WAR_Cmsportlet_INSTANCE_OdEiAOXb1f1R&p_p_lifecycle=0&p_p_state=normal&p_p_mode=view&p_p_col_id=column-1&p_p_col_pos=1&p_p_col_count=2&_Cms_WAR_Cmsportlet_INSTANCE_OdEiAOXb1f1R_jspPage=%2Fhtml%2Fcms%2Fportlet%2Ffrontend%2Fview.jsp&p_p_id=OdEiAOXb1f1R&_Cms_WAR_Cmsportlet_INSTANCE_OdEiAOXb1f1R_categoryId=2002&_Cms_WAR_Cmsportlet_INSTANCE_OdEiAOXb1f1R_articleId=23231&_Cms_WAR_Cmsportlet_INSTANCE_OdEiAOXb1f1R_title=overview-of-ha-noi&_Cms_WAR_Cmsportlet_INSTANCE_OdEiAOXb1f1R_command=details&_Cms_WAR_Cmsportlet_INSTANCE_OdEiAOXb1f1R_counter=1

hanoi.dangcongsan.vn. (2020). *Hà Nội: Xử lý ô nhiễm môi trường chăn nuôi - định hướng phát triển [Hanoi: Treatment of livestock environmental pollution - development orientation]*. https://hanoi.dangcongsan.vn/dang-trong-cuoc-song/ha-noi-xu-ly-o-nhiem-moi-truong-chan-nuoi-dinh-huong-phat-trien-nong-nghiep-ben-vung-566537.html

hanoimoi.com.vn. (2022). *Phấn đấu tỷ lệ cấp nước sạch nông thôn đạt 90% [Striving to achieve rural clean water access of 90%]*. http://www.hanoimoi.com.vn/tin-tuc/Doi-song/1050620/phan-dau-ty-le-cap-nuoc-sach-nong-thon-dat-90

Hoang, N. H., & Fogarassy, C. (2020). Sustainability Evaluation of Municipal Solid Waste Management System for Hanoi (Vietnam)—Why to Choose the ‘Waste-to-Energy’ Concept. *Sustainability*, *12*(3), Article 3. https://doi.org/10.3390/su12031085

Hoang, P. D., Nguyen, H. Q., Nguyen, K. X., & Hoang, T. A. (2022). Management of nontraditional security for Vietnam's sustainable development: An integrated approach. *Sustainability: Science, Practice and Policy*, *18*(1), 696–709. https://doi.org/10.1080/15487733.2022.2111066

Hung, D. T., Thi Cuc, V., Thi Bich Phuong, V., Thi Thanh Diu, D., Thi Huyen Trang, N., Phuong Thoa, N., Thi Tuyet Chinh, D., Manh Hung, T., Manh Linh, C., & Van Long, N. (2020). Evaluation of Drinking Water Quality in Schools in a District Area in Hanoi, Vietnam. *Environmental Health Insights*, *14*, 1178630220959672. https://doi.org/10.1177/1178630220959672

Jackson, M. C. (2005). Systems Thinking: Creative Holism for Managers. *European Journal of Operational Research*, *161*(3), Article 3. https://doi.org/10.1016/j.ejor.2004.03.005

kinhtedothi.vn. (2022). *Nhiều khu vực nông thôn ở Hà Nội đang khát nước sạch [Many rural areas in Hanoi lack clean water]*. https://kinhtedothi.vn/nhieu-khu-vuc-nong-thon-o-ha-noi-dang-khat-nuoc-sach.html

laodong.vn. (2021). *Hà Nội: Hệ thống sông nội đô đang "chết" dần vì ô nhiễm [Hanoi: The inner city's river system is gradually "dead" due to pollution]*. https://laodong.vn/ban-doc/ha-noi-he-thong-song-noi-do-dang-chet-dan-vi-o-nhiem-892524.ldo

MONRE. (2018). *Báo cáo hiện trạng môi trường quốc gia năm 2018—Chuyên đề: Môi trường nước lưu vực sông [National State of Environment Report 2018 -Topic: River basin environment]*. Ministry of Natural Resources and Environment. http://dwrm.gov.vn/index.php?language=vi&nv=download&op=Sa-ch-Ta-i-lieu-tham-kha-o/Bao-cao-hien-trang-moi-truong-quoc-gia-nam-2018-Chuyen-de-Moi-truong-nuoc-luu-vuc-song

nghenghiepcuocsong.vn. (2021). *Thủ đô XANH sống chung với rác [GREEN capital living with garbage]*. https://nghenghiepcuocsong.vn/thu-do-xanh-song-chung-voi-rac/

nguoidothi.net.vn. (2020). *Độ che phủ cây xanh Hà Nội gấp đôi hay bằng một nửa TP.HCM? [Is the tree cover in Hanoi double or half of HCMC?]*. https://nguoidothi.net.vn/do-che-phu-cay-xanh-ha-noi-gap-doi-hay-bang-mot-nua-tp-hcm-25716.html

Nguyen, D. D., & Zheltenkov, A. (2019). Impacts of waste water from main factories on water quality of Tolich river, Hanoi. *E3S Web of Conferences*, *91*, 04001. https://doi.org/10.1051/e3sconf/20199104001

Nguyen, M., Lin, Y. N., Tran, Q. C., Ni, C.-F., Chan, Y.-C., Tseng, K.-H., & Chang, C.-P. (2022). Assessment of long-term ground subsidence and groundwater depletion in Hanoi, Vietnam. *Engineering Geology*, *299*, 106555. https://doi.org/10.1016/j.enggeo.2022.106555

Nguyen, T. P. L. (2010). *Legal framework of the water sector in Vietnam: Achievements and challenges | Journal of Vietnamese Environment*. https://journals.qucosa.de/jve/article/view/18

nld.com.vn. (2021, May 10). *Đô thị thiếu không gian xanh nghiêm trọng [Urban areas seriously lack green space]*. https://nld.com.vn. https://nld.com.vn/news-20210509210609935.htm

NTS Centre. (2023). *What are NTS issues?* https://www.rsis.edu.sg/research/nts-centre/about-us/

Octavianti, T., & Staddon, C. (2021). *A review of 80 assessment tools measuring water security*. https://wires.onlinelibrary.wiley.com/doi/full/10.1002/wat2.1516

OECD. (2018). *Cost-Benefit Analysis and the Environment: Further Developments and Policy Use*. https://www.oecd.org/publications/cost-benefit-analysis-and-the-environment-9789264085169-en.htm

suckhoedoisong.vn. (2022). *Tình trạng ngập của Hà Nội sẽ ngày càng tội tệ hơn [Hanoi's flood situation will get worse]*. https://suckhoedoisong.vn/tinh-trang-ngap-cua-ha-noi-se-ngay-cang-toi-te-hon-169220706115234538.htm

tienphong.vn. (2022a). *Ao hồ bị san lấp, nước thoát đi đâu? [Ponds are leveled; where does water go?]*. https://tienphong.vn/post-1442402.tpo

tienphong.vn. (2022b). *Hà Nội xử lý chất thải nguy hại đạt tỷ lệ 99% [Hanoi achieves domestic hazardous waste treatment rate of 99%]*. https://tienphong.vn/post-1437603.tpo

Tran, N. T., & Weichgrebe, D. (2020). Regional material flow behaviors of agro-food processing craft villages in Red River Delta, Vietnam. *Journal of Industrial Ecology*, *24*(3), Article 3. https://doi.org/10.1111/jiec.12966

Truong, T. H., L.T.T. Nguyen, D.D. Nguyen, T. Pham, T.M. Vu, P.H. Nguyen, & Q.T. Nguyen. (2023). *Water security assessment framework for deltas of the transboundary river basins*. https://www.gjesm.net/article_701533_bb0d43ce01d071677900c2c4da39715b.pdf

UN Environment. (2018). *Pricing Reforms for Sustainable Water Use and Management in Vietnam*. https://publications.iwmi.org/pdf/H048608.pdf

UNICEF. (2020). *Policy brief—Water, Sanitation and Hygiene in Vietnam*. https://www.unicef.org/vietnam/media/5551/file/Water,%20sanitation%20and%20hygiene%20in%20Viet%20Nam.pdf

UN-SPIDER. (2023). *Risks and Disasters | UN-SPIDER Knowledge Portal*. https://www.un-spider.org/risks-and-disasters

Van Den Bosch, M. A., Mudu, P., Uscila, V., Barrdahl, M., Kulinkina, A., Staatsen, B., Swart, W., Kruize, H., Zurlyte, I., & Egorov, A. I. (2016). Development of an urban green space indicator and the public health rationale. *Scandinavian Journal of Public Health*, *44*(2), 159–167.

vietnamnet.vn. (2020). *Hanoi's landfills overloaded*. https://vietnamnet.vn/en/hanois-landfills-overloaded-685456.html

vietnamnet.vn. (2021). *Hanoi faces waste storage crisis*. https://vietnamnet.vn/en/hanoi-faces-waste-storage-crisis-785070.html

vietnamnews.vn. (2022). *Major irrigation system suffering serious pollution*. https://vietnamnews.vn/environment/1311052/major-irrigation-system-suffering-serious-pollution.html

vietnamnews.vn. (2023). *Hà Nội needs urgent, optimal solution for waste treatment capacity*. Vietnamnews.Vn. https://vietnamnews.vn/environment/1494175/ha-noi-needs-urgent-optimal-solution-for-waste-treatment-capacity.html

VIR. (2021, June 28). *Necessary reforms to boost investment into Vietnam's burgeoning water sector*. Vietnam Investment Review - VIR. https://vir.com.vn/necessary-reforms-to-boost-investment-into-vietnams-burgeoning-water-sector-85184.html

vovgiaothong.vn. (2020). *Chất lượng nước sạch ở đô thị đang được giám sát thế nào?* https://vovgiaothong.vn/newsaudio/chat-luong-nuoc-sach-o-do-thi-dang-duoc-giam-sat-the-nao-d28765.html

vovgiaothong.vn. (2022). *Hà Nội: Tỷ lệ đấu nối mạng lưới nước thải sinh hoạt chỉ đạt trên 60% [Hanoi: Connection rate to domestic wastewater collection network is only* *over 60%]*. https://vovgiaothong.vn/ha-noi-ty-le-dau-noi-mang-luoi-nuoc-thai-sinh-hoat-chi-dat-tren-60-d16892.html

Vu, H., Merkel, B., & Wiche, O. (2022). Major ions, trace elements and evidence of groundwater contamination in Hanoi, Vietnam. *Environmental Earth Sciences*, *81*(11), 305. https://doi.org/10.1007/s12665-022-10402-z

WBG. (2019). *Vietnam: Toward a Safe, Clean, and Resilient Water System*. World Bank. https://doi.org/10.1596/31770

WBG. (2020). *Hanoi—Toward A Water Pollution and Flood Free City*. World Bank. https://doi.org/10.1596/34151

Winkel, L. H. E., Trang, P. T. K., Lan, V. M., & Berg, M. (2011). *Arsenic pollution of groundwater in Vietnam exacerbated by deep aquifer exploitation for more than a century | PNAS*. https://www.pnas.org/doi/abs/10.1073/pnas.1011915108