Global J. Environ. Sci. Manage. 9(3): 619-636, Summer 2023, Serial #35

Global Journal of Environmental Science and Management
(GJESM)

Homepage: https://www.gjesm.net/

Podcasts

CASE STUDY

Water security assessment framework for deltas of the transboundary river basins

T.H. Truong*, **L.T.T. Nguyen, D.D. Nguyen, T. Pham, T.M. Vu, P.H. Nguyen, Q.T. Nguyen**

Vietnam National Mekong Committee, 23 Hang Tre street, Hanoi, Vietnam

ARTICLE INFO

Article History:
Received 19 November 2022
Revised 28 December 2022
Accepted 02 February 2023

Keywords:
Ecological system
Hazard risk
River delta
Transboundary
Water security

DOI: 10.22035/gjesm.2023.03.17

ABSTRACT

BACKGROUND AND OBJECTIVES: Water security for food production in the deltas of international river basins has become the top concern of the basin countries. Numerous efforts were made to develop frameworks for the assessment of water security at different scales. However, no framework could be directly applied to the deltas of the transboundary basins because they have not fully addressed the characteristics of the deltas. This study aims to develop a comprehensive framework for the assessment of water security for the international river basin deltas and applied it to the Vietnamese Mekong Delta.
METHODS: The water security assessment framework was developed on the basis of the concept of water security defined by the United Nations Water following the "Driving forces-Pressure-State-Impact-Response" approach. The developed framework is then used to evaluate the water security conditions for 22 subregions of the Mekong Delta.
FINDINGS: The proposed water security assessment framework comprises the following six dimensions: water resources, domestic water supply, water for economic development, water-related disasters, ecological and environmental protection, and water governance, which contain 21 indicators and 5 sub-indicators. The results of applying this framework to the Mekong Delta showed that the overall water security conditions in most subregions in 2018 were only at the medium level. The degree of water security in flood season is higher than that in the dry season. The main reasons that lead to the medium-level water security of the region have been identified, including high dependence on external water resources (more than 90%) and transboundary water cooperation between the basin countries and rather low water productivity in economic sectors. The study suggests that improvement in transboundary water cooperation and water productivity would help enhance future water security in the Mekong Delta.
CONCLUSION: Assessment of the water security for the deltas of the transboundary river basins requires a comprehensive assessment framework. The framework developed in this study was successfully applied to the case of the Vietnamese Mekong Delta. The proposed framework will help policymakers of the Mekong riparian countries to monitor the impact of the basin development plans and policies on water security conditions jointly and determine appropriate solutions to enhance water security for the basin.

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
42	6	2

*Corresponding Author:
Email: *thtien652004@gmail.com*
Phone: +84098 125 7395
ORCID: 0000-0003-1034-6198

Note: Discussion period for this manuscript open until October 1, 2023 on GJESM website at the "Show Article".

INTRODUCTION

Water is essential for life and all human development activities. It is also a renewable resource; however, the world's water resource is finite and is facing the risk of degradation and depletion due to overexploitation and climate change (Kim *et al*., 2018; Kumar, 2018; Arab *et al.,* 2021; Zhu *et al*., 2022). Thus, ensuring water security for human life and ecosystems is the top concern of all countries worldwide (Mekonnen and Hoekstra, 2016; Thang *et al.,* 2019). The world has 276 transboundary river basins, crossing 151 countries and territories, and is home to more than 40 percent (%) of the global population (De Strasser *et al.,* 2016; Dennis and Grady, 2022). The total flow of transboundary rivers accounts for approximately 54% of the total flow of all rivers in the world. Ensuring water security in these river basins is substantially more challenging than those within the territory of a country due to their dependence on the spirit of cooperation of the riparian countries in the basins. Within the river basins, the deltas are the most special areas with common features that are located at the most downstream parts of the basins and generally adjacent to the sea. These deltas receive a considerable amount of water and sediment from the upstream parts yearly and have become the main food production areas of the countries in the basins. The delta regions are currently facing remarkable challenges of climate change and increased water exploitation and utilization in the basin, which markedly affects the water and food security of countries worldwide (Hong, 2020). Policymakers often raise the questions of how to assess and quantify the water security for the deltas of the transboundary river basins, where the water is managed by different countries with various interests and priorities in water use, and what appropriate decisions must be taken to ensure water security for the region. Many studies have been conducted on water security at different scales, including global (Gain *et al.*, 2016), country (Makin *et al*., 2013; Holmatov et al, 2017; Koontanakulvong and Doungmanee, 2015; Marttunen *et al*., 2019), city (Jensen and Wu, 2018; Hoekstra *et al.*, 2018; Aboelnga *et al*., 2019), basin (Dong and Liu, 2014; Babel and Shinde, 2018; Giri *et al.,* 2018; Mui, 2018; Hatmoko *et al*., 2020; Babel *et al*., 2022), and delta scales (Dou *et al*., 2021). These studies developed water security assessment frameworks with their indicators and applied them according to their purposes. For example, Makin *et al*. (2013) proposed a framework of indicators for assessing national water security comprising five dimensions (household water security, productive economy, urban water security, environment water security, and resilience to water-related hazards) but disregarded the governance dimension and transboundary feature of water resources. Jensen and Wu (2018) developed a framework specifically for the assessment of domestic water security, which comprises four dimensions (resources, access, risks, and governance), and applied to the case of Singapore and Hong Kong. Similarly, Aboelnga *et al*. (2019) also worked on an urban water security framework and attempted to incorporate the transboundary–imported water dependency ratio into the framework. Babel and Shinde (2018) proposed a framework for water security assessment at the basin scale comprising five dimensions (water availability, water productivity, water-related disasters, watershed management, and water governance) and applied it to water security assessment in river basins in Thailand (Babel *et al*., 2022). Mui (2018) aimed to develop a framework for the assessment of water security for the Ma river basin in Vietnam. Although applied to transboundary river basins (some river basins in Thailand are transboundary), the frameworks proposed in the studies of Babel *et al.* (2022) and Mui (2018) did not consider the transboundary factors. At the delta scale, Dou *et al*. (2021) developed a method for assessing the water security for the river basin deltas. The framework contains only three dimensions (water resources security, environmental security, and exploitation and utilization potential) and was applied to the case of the national river basin delta (Yangtze River Delta, China). Many attempts have been made to develop frameworks for the assessment of water security at different scales. However, no framework could be directly applied to the deltas of the transboundary basins because they have not fully addressed the characteristics of such delta regions. Some studies focused only on one aspect of the deltas, such as domestic water security (Jensen and Wu, 2018; Aboelnga *et al*., 2019), while others focused on several aspects of the river basin deltas, but still have not fully captured the characteristics of the delta region, especially the transboundary factors in their frameworks (Babel and Shinde, 2018; Mui, 2018; Dou *et al*., 2021; Babel *et al*., 2022). A more comprehensive assessment framework than the previous ones is required due to the special features of the transboundary basin deltas. This study aims to propose a water security assessment framework for the deltas of transboundary river basins by taking the Mekong Delta of Vietnam as the case study. The specific objectives of the study are as follows: i) to measure the water security in the Mekong Delta, ii) to identify the main factors that most affect the water security, and iii) to propose solutions for improvement of the water security in the region. The water security assessment framework developed in this study will help policymakers and managers monitor and evaluate the impact of the development plans and policies on water security conditions, identify factors affecting water security, and determine appropriate solutions to enhance water security for the deltas for the transboundary river basins. This study has been conducted in the Mekong Delta of Vietnam during 2019 to 2022.

MATERIALS AND METHODS

The Mekong river delta is selected as the pilot site for this study because it is the delta of the international river basin and plays a crucial role in food security for Vietnam. This river delta is also one of the deltas in the world that are most vulnerable to sea level rise. The section below will describe the details of the pilot site and the development method of the water security assessment framework for the region.

Description of the pilot site

The Mekong River delta flows through the following six countries: China, Myanmar, Laos, Thailand, Cambodia, and Vietnam, with a total length of 4763 kilometer (km) and a total annual flow of approximately 446 billion cubic meter (m^3). The Mekong River Basin covers an area of approximately 810,000 square kilometer (km^2) and is home to more than 70 million people, who are mainly dependent on agriculture and aquaculture (MRC, 2018). The Mekong Delta of Vietnam is the last part of the Mekong River Basin (Fig. 1). With a total natural area of approximately 3.96 million hectares (ha), this river basin is home to over 22% of the country's total population. The Mekong Delta receives a considerable amount of water (approximately 440 billion m^3/year) and sediment (160–165 million tons/year) from the upper part of the Mekong River Basin yearly (MRC, 2018). With remarkable agricultural potential, the Mekong Delta contributes over 50% of the total food

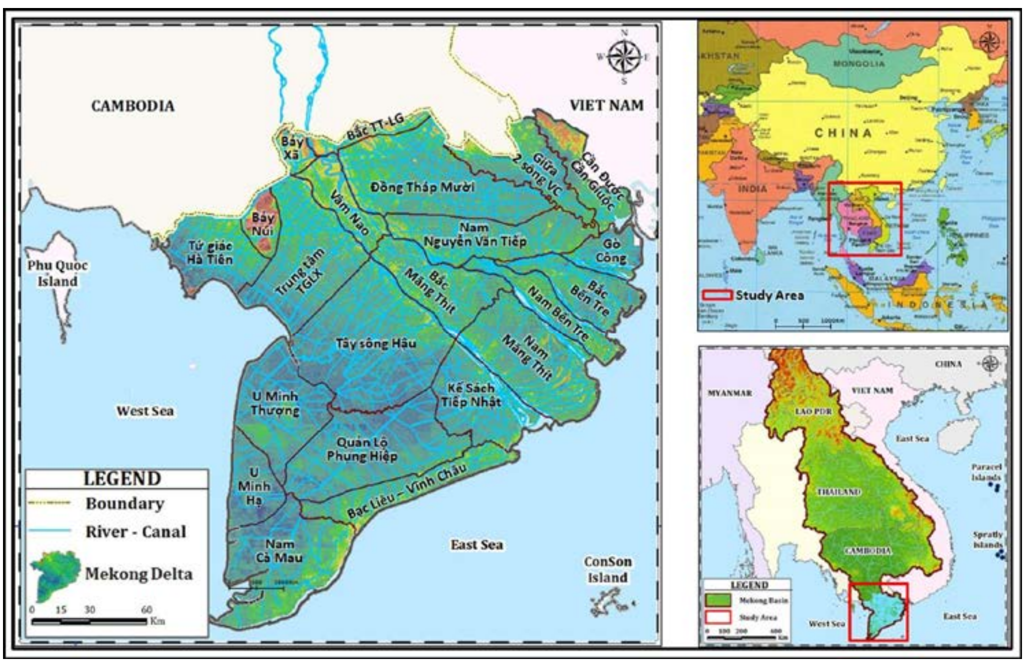

Fig. 1: Geographic location of the study area in the Mekong Delta in Vietnam

products and more than 90% of the country's total rice export (Thang *et al*., 2019). In addition to meeting the domestic demand, the rice product of Vietnam also contributes to feeding approximately 40 million people in Asian and African countries. People living in the delta rely on the Mekong water for water supply, food production, inland transport, and many other services. However, located in the downstream part of the Mekong River Basin, the Vietnamese Mekong Delta increasingly suffers from serious impacts of water-related development activities in the basin and unpredictable effects of faster-than-expected climate change. If these threats are not properly addressed, then the endeavor toward sustainable development and the livelihoods of millions of people living in the area will be severely affected.

Development of water security assessment framework for the Mekong Delta

The development of the framework for the transboundary river basin deltas is based on the frameworks of Mui (2018) and Babel *et al*. (2022) for water security assessment at the basin scale. This approach was conducted by proposing additional indicators and sub-indicators that characterize the special features of the transboundary river basin deltas into their frameworks. The framework built in this study and that of the two other studies rely on the definition of water security (Grey *et al*., 2013; UN-Water, 2013; Loe and Hjornlund, 2008; Wilhelm *et al*., 2022) and follow the "Driving Forces-Pressure-State-Impact-Response" approach, which was widely used in water assessment (Babel and Shinde, 2018; Sun *et al*., 2018; Van Ginkel *et al*., 2018; Lu et *al*., 2022). Following this approach, the degree of water security for the region is characterized by an overall water security index that comprises various water security dimensions. The water security dimensions are selected on the basis of various factors that have impacts on water security and each dimension comprises one or more indicators/sub-indicators, which are selected in accordance with the SMART (Specific, measurable, achievable, relevant, and time-based) criteria (Vachnadze, 2016). Each indicator/sub-indicator is measured by one or more variables.

Calculation of water security indexes/indicators

The parameters are calculated quantitatively or qualitatively based on available data and collected information to compute the water security indexes/indicators for each subregion. These parameters with different units will be normalized on a common scale from 1 to 5 for comparison (Aboelnga *et al*., 2019). The values of each indicator (*I*), dimension (*D*), and overall water security for the delta (*WSI*) are calculated by the weighted method using Eqs. 1, 2, and 3, respectively (Assefa *et al*., 2019).

$$I_{ij} = \sum_{j=1}^{n}\sum_{j}^{m} w_{ijk} S_{ijk} \quad (1)$$

$$D_i = \sum_{j=1}^{n} x_{ij} I_{ij} \quad (2)$$

$$WSI = \sum_{i=1}^{p} y_j D_i \quad (3)$$

Where, *p* is the number of dimensions, *n* is the number of indicators in dimension *i*, *m* is the number of variables for indicator *j*, *w* is the weight given to each variable, *S* is the score of each variable, *x* is the weight given to each indicator, and *y* is the weight given to each dimension. The weight of each variable, indicator, and dimension is determined by logical analysis based on the characteristics and conditions of each delta with close consultation with experts and scientists.

All data and information required for water security assessment were obtained from the General Statistics Office of Vietnam, Provincial People's Committees and their relevant Departments in the Mekong Delta, and relevant research institutes. The data and information on the upstream part of the Mekong River Basin were obtained from the Mekong River Commission Secretariat in Vientiane, Laos. Some secondary data and information were taken from previous studies and other data were obtained from the surveys (questionnaires).

RESULTS AND DISCUSSION

The authors developed the water security assessment framework for the Mekong Delta considering its specific conditions and applied it to calculate the water security indexes for 22 subregions based on the method described above.

The boundaries of the subregions are zoned on the basis of the Mekong Delta Regional Plan in the period 2021–2030 with a vision to 2050 (MPI, 2022). The findings of this study were presented and discussed with the different stakeholders, including the representatives from the relevant government agencies, provincial authorities in the Mekong Delta, research institutes, scientists, and technical experts in various fields, during the course of the study.

Water security assessment framework for the Mekong Delta

The framework is characterized by an overall water security index comprising the following six dimensions (Mui, 2018): water resources, domestic water supply, water for economic development, water-related disasters, ecological and environmental protection, and water governance. Considering the selection of indicators, in addition to those proposed by Mui (2018) and Babel *et al*. (2022), the authors introduced five additional indicators and three sub-indicators to different dimensions to capture the characteristics of the Mekong Delta. The rationales for the selection of these additional indicators are as follows. Water resources in the Mekong Delta are highly dependent on external sources and seasonally varied. Therefore, one indicator reflecting the dependence on the external water source and two sub-indicators reflecting the intra-annual variability of the river flow and the capability to resist the variability were added to the water resources dimension. Under the domestic water supply dimension, two indicators considering the efficiency of the centralized water supply systems and the affordability of water use tariff were supplemented. As inland waterway transport is one of the important modes of transport, one indicator of water use for inland waterway transport was introduced considering the water economic activities dimension. For the agricultural sector, in addition to agricultural use efficiency, the authors proposed one additional sub-indicator to ensure water security and reflect the proportion of irrigated arable land. Under the water governance dimension, one indicator of transboundary water cooperation among the basin countries was finally added. Overall, the proposed framework comprises 21 indicators and 5 sub-indicators. The framework captures the impacts of climate change through various indicators under the dimensions of water resources, water economic activities, water-related disasters, and environmental and ecological system protection. Table 1 presents the detailed water security assessment framework for the Mekong Delta. The ranges and scores for water security indicators were adopted for the Mekong Delta using some selected values that have been established in previous studies (Makin *et al*., 2013; Mui, 2018; Aboelnga *et al*., 2019). For new indicators and sub-indicators that are specific to the Mekong Delta, the ranges and scores were proposed in close consultation with the managers, experts, and scientists. Table 2 shows the results of the ranges and scores adopted for the Mekong Delta.

Considering the weights of the water quality indexes and indicators, similar to approaches adopted by Mui (2018), three dimensions related to water resources, domestic water supply, and economic activities have a direct impact on water security, and the weight of each dimension is chosen to be 0.2. The environmental and ecological system protection dimension has an indirect impact and is of high importance for water security; therefore, the weight is 0.15. Two dimensions related to water-related disasters and water governance have an indirect impact on water security; therefore, the weight is 0.125. The sum of the weights given to 6 dimensions is equal to 1. Similar to Aboelnga *et al*. (2019), the water security index in this study is also divided into the following five levels: (1) poor (index <1.5), (2) low (index score: 1.5–2.5), (3) medium (index score: 2.5–3.5), (4) high (index score: 3.5–4.5), and (5) very high (index score >4.5). Tables 1 and 2 are used to calculate the water security index for each dimension in this study.

Water resources dimension

The calculation results show that the water availability in all subregions is remarkably high, with the annual average water volume per capita in all subregions ranging from 20,000 to 24,000 m^3/person/year. This value is substantially higher than the threshold applied worldwide (1700 m^3/person/year) (Srinivasan *et al*., 2017; Singh, 2018) and also higher than that of other river basins in the regions (Mui, 2018 and Babel *et al*., 2022). Despite a high value of water availability, the overall water security index for the water resources dimension for each subregion ranges only from 2.7–2.9, which indicates a "medium" level of water security (Fig. 2a). The aforementioned

Table 1: Water security assessment framework for the Vietnamese Mekong Delta

No	Dimension/indicator	Sub-indicator	Variable	Methods of calculation
I. Water resources dimension, D_1				
1	Water availability, $I_{(1,1)}$		Per capita water availablity (m^3/person/year)	Annual renewable water resources/population (Aboelnga *et al*., 2019; Oluwasanya *et al*., 2022)
2	Water resilience, $I_{(1,2)}$	Intra-annual variability, $I_{(1,2,1)}$	Intra-annual flow coefficient of variation	$C_v = \frac{\sqrt{\frac{\sum_i^n (Q_i - Q_0)^2}{n-1}}}{Q_0}$,
		Inter-annual variability, $I_{(1,2,2)}$	Inter-annual flow coefficient of variation	where C_v is the intra-and inter-annual flow coefficient of variation, Q_i is the water discharge at month/year *i*, Qo is the monthly/yearly average discharge, and *n* is the number of months in year/number of years for calculation (Makin *et al*., 2013)
		Water storage, $I_{(1,2,3)}$	Duration that water storage can meet the water demand (days)	(Total water amount stored in rivers/canals and exploitable groundwater quantity in Delta)/Daily water demand (Jensen and Wu, 2018, Park et al., 2022)
3	Dependence on external water sources, $I_{(1,3)}$		Proportion of external water sources (%)	(Amount of water originating from foreign countries/Annual renewable water resources) × 100% (Makin *et al*., 2013)
II. Domestic water supply dimension, D_2				
4	Accessibility to clean water, $I_{(2,1)}$		Proportion of clean water accessed by users (%)	(Number of clean water accessed by users/total population) × 100% (Assefa *et al*., 2019)
5	Accessibility to clean water from centralized water supply systems, $I_{(2,2)}$		Proportion of clean water accessed by users from centralized water supply systems (%)	(Clean water accessed by users from centralized water supply systems/total population) × 100% (Assefa *et al*., 2019)
6	Efficiency of the centralized water supply systems, $I_{(2,3)}$		Proportion of water losses from centralized water supply systems (%)	(Total water losses/Total water supply amount from the centralized water supply systems) × 100% (Mui, 2018)
7	Water sanitation, $I_{(2,4)}$		Proportion of households with hygienic latrines (%)	(Number of households with hygienic latrines/Total number of households) × 100% (Mui, 2018)
8	Affordability of water use tariff, $I_{(2,5)}$		Proportion of the cost for domestic water use (%)	(Annual payment for domestic water use/ total annual income of the users) × 100% (Assefa *et al*., 2019)
III. Water economic activities dimension, D_3				
9	Water consumption for economic activities, $I_{(3,1)}$		Proportion of water used for economic sectors (%)	(Total amount of water used by water consumptive economic sectors/total exploitable water amount) × 100% (Mui, 2018)

Continued Table 1: Water security assessment framework for the Vietnamese Mekong Delta

No	Dimension/indicator	Sub-indicator	Variable	Methods of calculation
10	Water use for agriculture, $I_{(3,2)}$	Irrigated area, $I_{(3,2,1)}$	Proportion of irrigated arable land (%)	(Irrigated arable land/Total arable land) × 100% (Makin *et al*., 2013)
		Agricultural use efficiency, $I_{(3,2,2)}$	Agricultural use efficiency, United States dollars per cubic meter (USD/m^3)	Total financial value of the agricultural products/Total amount of water used in agricultural production (Makin *et al*., 2013)
11	Water use for inland waterway transport, $I_{(3,3)}$		Insecure duration for navigation (days)	Determined on the basis of the number of days when the daily average water depth in the river/channel is less than the specific water depth required for each category of the river/channel (Proposed by Authors)
12	Water use for industry, $I_{(3,4)}$		Industrial use efficiency (USD/m^3)	Total financial value of the industrial products/Total amount of water used for the industry (Makin *et al*., 2013)
IV. Water-related disasters dimension, D_4				
13	Capacity to cope with disasters, $I_{(4,1)}$		Gross Domestic Product (USD/person/year)	Method of calculation of the Gross Domestic Product (Mui, 2018)
14	Drought factor, $I_{(4,2)}$		Proportion area of drought (%)	(Drought-affected area/Total arable land) × 100% (Babel and Shinde, 2018)
15	Flood factor, $I_{(4,3)}$		Proportion area of flooding (%)	(Flood-affected area/Total arable land) × 100% (Babel and Shinde, 2018)
16	Saltwater intrusion factor, $I_{(4,4)}$		Proportion area of saltwater intrusion (%)	(Saltwater intrusion affected area/Total arable land) × 100%
V. Environmental and ecological system protection dimension, D_5				
17	River flow for the environment and the ecosystem, $I_{(5,1)}$		Difference of river flow with the acceptable minimum monthly natural flow during each month of the dry season (%)	(Difference of river flow with the acceptable minimum monthly natural flow during each month of the dry season/Acceptable minimum monthly natural flow during each month of the dry season) × 100% (Proposed by Authors)
18	Water quality factor, $I_{(5,2)}$		Water quality index for environment and ecosystem	Water quality index method (Călmuc, 2018; Mui 2018)
19	Upstream development activity, $I_{(5,3)}$		Impacts of upstream development activity	Mathematical models (MRC, 2017)
VI. Water governance dimension, D_6				
20	Water resource management in the deltas, $I_{(6,1)}$		Implementation of integrated water resources and river basin management	Interview and consultation with managers, experts, and scientists (Mui, 2018)
21	Transboundary cooperation on water management, $I_{(6,2)}$		Implementation of transboundary cooperation on water management	Interview and consultation with managers, experts, and scientists (Proposed by Authors)

Table 2: Ranges and scores of water security indicators adopted for the Mekong Delta

No	Indexes/ Indicators	Variables	1	2	3	4	5	References
I. Water resources dimension, D_1								
1	$I_{(1,1)}$	Per capacity water availability (m^3/person/year)	<500	500–800	800–1000	1000–1700	>1700	Aboelnga *et al.*, 2019
2	$I_{(1,2,1)}$	Intra-annual flow coefficient of variation	>0.4	0.4 – 0.31	0.3 – 0.21	0.2 – 0.1	<0.1	Proposed by Authors
3	$I_{(1,2,2)}$	Inter-annual flow coefficient of variation	>0.4	0.4 – 0.31	0.3 – 0.21	0.2 – 0.1	<0.1	Mui, 2018
4	$I_{(1,2,3)}$	Duration that water storage can meet the water demand (days)	<1	1–15	16–30	31–60	>60	Proposed by Authors
5	$I_{(1,3)}$	Proportion of external water sources (%)	>60	60 – 40	40 – 20	20 – 10	<10	Aboelnga *et al.*, 2019
II. Domestic water supply dimension, D_2								
6	$I_{(2,1)}$	Proportion of clean water accessed by users (%)	<40	40–60	61–80	81–90	91–100	Mui, 2018
7	$I_{(2,2)}$	Proportion of clean water accessed by users from centralized water supply systems (%)	<60	60–70	71–80	81–90	91–100	Mui, 2018
8	$I_{(2,3)}$	Proportion of water losses from centralized water supply systems (%)	>40	40 – 31	30 – 21	20 – 5	<5	Proposed by Authors
9	$I_{(2,4)}$	Proportion of households with hygienic latrines (%)	<60	60–70	71–80	81–90	91–100	Mui, 2018
10	$I_{(2,5)}$	Proportion of the cost for domestic water use (%)	>2.1	2.1 – 1.21	1.2 – 0.81	0.8 – 0.5	<0.5	Proposed by Authors
III. Water economic activities dimension, D_3								
11	$I_{(3,1)}$	Proportion of water used for economic sectors (%)	>70	70 – 41	40 – 31	30 – 20	<20	Mui 2018
12	$I_{(3,2,1)}$	Proportion of irrigated arable land (%)	<60	60–75	76–85	86–95	96–100	Proposed by Authors
13	$I_{(3,2,2)}$	Agricultural use efficiency (USD/m^3)	<0.1	0.1–0.2	0.2–0.35	>0.35–1	>1	Mui 2018
14	$I_{(3,3)}$	Insecure duration for navigation (days)	>7	5–7	3–4	1–2	<1	Proposed by Authors

Continued Table 2: Ranges and scores of water security indicators adopted for the Mekong Delta

No	Indexes/ Indicators	Variables	1	2	3	4	5	References
15	$I_{(3,4)}$	Industrial use efficiency (USD/m^3)	<2.0	2–5.5	5.6 – 20	21–50	>50	Makin *et al.*, 2013
IV. Water-related disasters dimension, D_4								
16	$I_{(4,1)}$	Gross Domestic Product (USD/person/year)	<516	516–1035	1035–4085	4085–12,614	>12,614	Mui, 2018
17	$I_{(4,2)}$	Proportion area of drought (%)	>40	40 – 21	20 – 11	10 – 5	<5	Mui, 2018
18	$I_{(4,3)}$	Proportion area of flooding (%)	>40	40 – 21	20 – 11	10 – 5	<5	Proposed by Authors
19	$I_{(4,4)}$	Proportion area of saltwater intrusion (%)	>40	40 – 21	20 – 11	10 – 5	<5	Proposed by Authors
V. Environmental and ecological system protection dimension, D_5								
20	$I_{(5,1)}$	Difference of river flow with the acceptable minimum monthly natural flow during each month of the dry season (%)	<(−20)	(−20) – 0	0–5	6–20	>20	Mui, 2018
21	$I_{(5,2)}$	Water quality index for environment and ecosystem	0–25	26–50	51–75	76–90	91–100	Mui, 2018
22	$I_{(5,3)}$	Impacts of upstream development activity	All mainstream dams and tributary dams, and water diversion works constructed	All mainstream dams (except Kratie and Sambo) and tributary dams constructed	Development at the 2018 level	Only tributary dams	No development	Proposed by Authors
VI. Water governance, D_6								
23	$I_{(6,1)}$	implementation of integrated water resources management (IWRM) and integrated river basin management (IRBM)	Still, traditional water management applied; not yet transferred to the IWRM and	IWRM and IRBM were applied at the initial stage; no significant results were achieved.	IWRM and IRBM comprehensively implemented; River Basin Organization established	RBO has an appropriate structure and good results gained from the IWRM and IRBM implementation	RBO has an appropriate structure and excellent results gained from the IWRM and IRBM	Mui, 2018

Continued Table 2: Ranges and scores of water security indicators adopted for the Mekong Delta

No	Indexes/ Indicators	Variables	1	2	3	4	5	References
			IRBM approaches		and initially operated		implementation	
24	$I_{(6,2)}$	transboundary cooperation on water management	No bilateral and multilateral cooperation mechanisms established	Only multilateral cooperation mechanisms were established, but poor cooperation results were still achieved	Bilateral and multilateral cooperation is established, but not all legal and institutional instruments are in place; some results of cooperation achieved	Bilateral and multilateral cooperation established all legal and institutional instruments are in place; good results of cooperation gained	Bilateral and multilateral cooperation established all legal and institutional instruments are in place; very good results of cooperation gained	Proposed by Authors

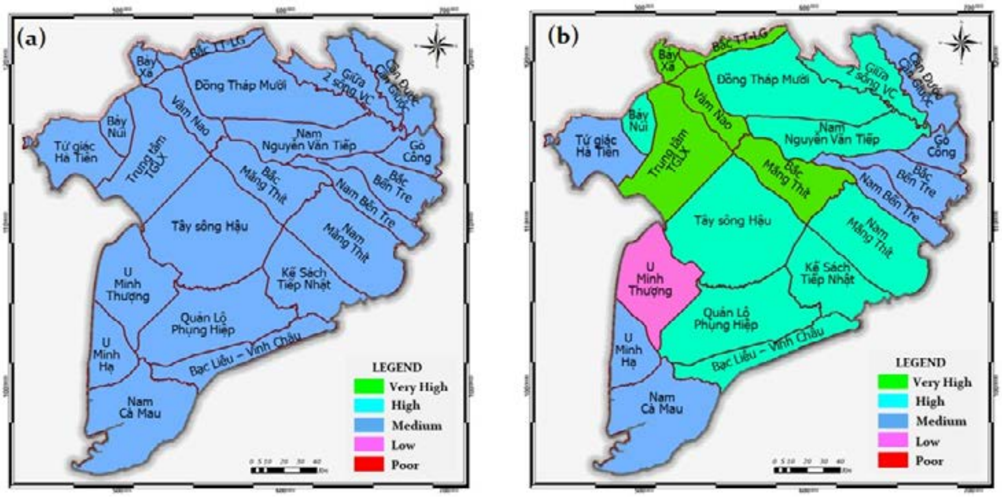

Fig. 2: Maps showing the overall water security index of (a) the water resources dimension and (b) the domestic water supply dimension for each subregion in 2018

results are mainly due to the high dependence of the water resources in the Mekong Delta on external sources (more than 90%), the uneven distribution of the water resources during the year (coefficient of intra-annual variation approximately 0.8), and the relatively smaller water storage in the subregions compared to the total water demand.

Domestic water supply dimension

The overall water security index for the domestic water supply dimension shown in Fig. 2b indicates that 14 of the subregions (more than 60%) located along the Mekong River have a high and very high level of water security. In these subregions, more than 80% of the population can access clean water from state-owned and private water supply systems. The remaining subregions with medium and low domestic water security levels have a substantially limited number of water supply plants because they are located far from the Mekong water. Despite this condition, the water sanitation situation in the region is very good, where 80% of the subregions have a high and very high percentage of households with hygienic latrines. The payment for domestic water use is relatively low (from 0.7–1 USD/person/month), which is equal to approximately 0.5%–1% of the average monthly income. This finding indicates that the water fee is quite affordable for users in all subregions. This phenomenon is also remarkably similar to the case of the Ma river basin in Vietnam (Mui, 2018).

Economic activities dimension

The overall water security index shown in Fig. 3a indicates a medium-level water security for economic activities in most subregions (13/22). Similar to the case of the Ma river basin in Vietnam (Mui, 2018), river basins in Thailand (Babel *et al*., 2022), and Rafsanjan Plain in Iran (Bagheria and Babaeian, 2020), in the Mekong Delta, agriculture is the largest water user among the economic sectors. People living in the Mekong Delta still apply wet rice cultivation, which consumes considerable amounts of water, while the rice price is usually low. This condition leads to low water use efficiency in agricultural production. The condition for the navigation sector varies across the subregions (10/22 subregions) with a low and poor level of water security. The main reason identified is due to the heavy sediment deposition of the rivers and canals in these subregions and lack of the resources for frequent dredging. Regarding the industry, water security is in a better condition than that of the agricultural and navigation sectors.

Water-related disasters dimension

The overall water security index shown in Fig. 3b reveals that only five subregions have low- to medium-level water security and the remaining subregions have a high water security level. This phenomenon is due to the formed system of dikes and embankments of the Mekong Delta with a total length of approximately 13,000 km to prevent saltwater intrusion, high tide, and storm surge for

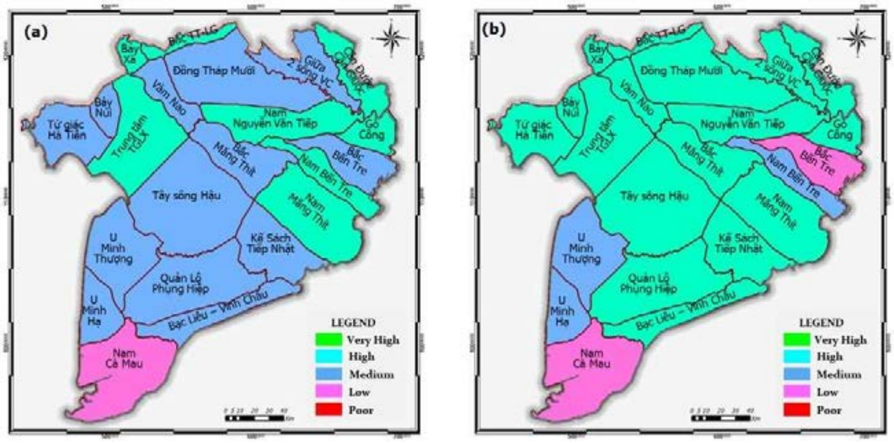

Fig. 3: Maps showing the overall water security index of (a) the economic activities dimension and (b) the water-related disaster dimension for each subregion in 2018

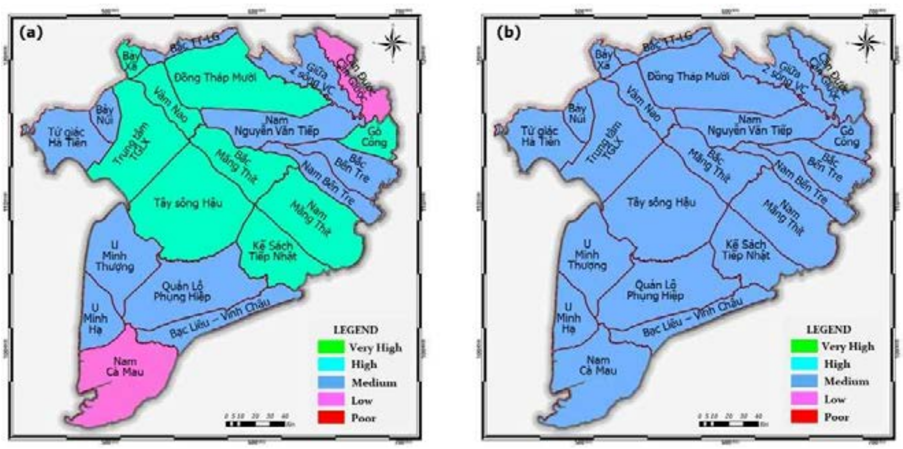

Fig. 4: Maps showing the overall water security index of (a) the environment and ecosystem dimension and (b) the water governance dimension for each subregion in 2018

the coastal areas and avoid August floods to protect summer–autumn rice. Consequently, the damage due to saltwater intrusion and flood is considerably reduced. Those with medium and low water security conditions are the coastal subregions, which are still suffering from saltwater intrusion and drought due to an incomplete dike system and difficulty in accessing the Mekong water.

Environment and ecosystem dimension

The analysis results show that in 2018, the river flow was maintained at high and very high levels in almost all subregions (18/22 subregions) except the coastal subregions. Water quality in most of the subregions is at the medium to the low level. Regarding the development activity in the upper Mekong River Basin, the assessment results show that all subregions of the Mekong Delta are moderately affected at the current level of development (MRC, 2017). Under such circumstances, 9 subregions located along the Mekong River have a high water security level and the remaining (coastal subregions) have medium (11 subregions) and low (2 subregions) levels of water security (Fig. 4a). This phenomenon is due to the tide effects that obstruct the water flow from the canals to the sea and cause the water pollution in the coastal subregions. The condition of the environment and ecosystem in the Mekong Delta was similar to that of most river basins in Thailand (Babel *et al*., 2022) but better than that in the Ma River in Vietnam (Mui, 2018), where the environment and ecosystem were affected by specific water quality and development activities in the local basin.

Water governance dimension

The results of surveys and assessments of the implementation of IWRM and IRBM in the Mekong Delta and of the transboundary water cooperation in the basin revealed that the water security indicators considering water management results in the delta and the transboundary water cooperation are at the medium level. Consequently, the overall water security index for the water governance dimension is also at the medium level at all subregions of the delta (Fig. 4b), which is similar to the situation of other river basins (Mui, 2018; Babel *et al*., 2022).

Overall water security assessment for the Mekong Delta

Fig. 5a shows the overall water security index computed from the water security indexes of all six dimensions for each subregion in 2018. Despite being a large plain with abundant resources, the water security in most subregions in the Mekong Delta is only at the medium level. Moreover, the water security conditions in the Mekong Delta are

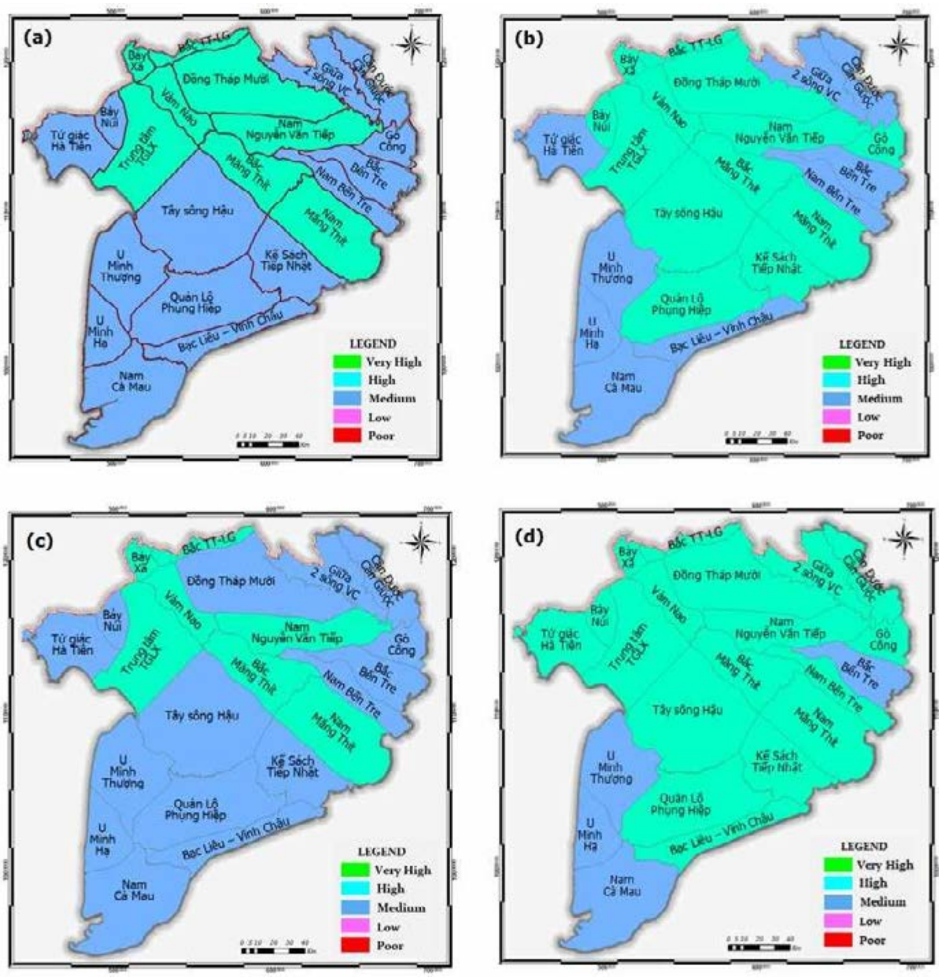

Fig. 5: (a) Overall water security index in 2018; (b) Overall water security index in the 2018 flood season; (c) Overall water security index for the 2018 dry season; (d) Overall water security index in 2018 (based on the methods of Mui, 2018; Babel *et al*., 2022)

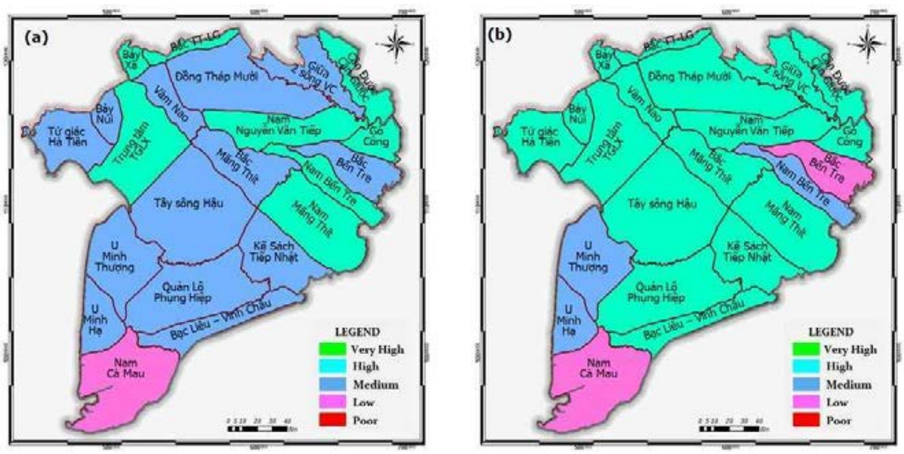

Fig. 6: (a) Overall water security index in 2018; (b) Overall water security index forecasted for 2050

different in the flood and dry seasons due to seasonal variation of the rainfall in the basin and the impact of the upstream reservoir's operation (Figs. 5b and 5c, respectively); the water security in the flood season is better than that in the dry season. This phenomenon is due to the Mekong water serving as the main source for the people, while in addition to the Mekong water, a water source coming from local precipitation is avalaible in the wet season. The water security in the Mekong Delta is governed by external and internal factors. The external factors refer to high dependence on external sources, uneven distribution of water resources, increase in water use by the basin countries, the impact of climate change, and transboundary water cooperation. The internal factors refer to the water use efficiency in the economic sectors, water management, flood, drought, and saltwater intrusion in the Mekong Delta. Similar to the internal factors, external factors also play a crucial role in water security in the Mekong Delta. This phenomenon can be observed by comparing the water security situations of the Mekong Delta obtained by applying the methods of Mui (2018) and Babel *et al.* (2022) (Fig. 5d) and that developed in this study (Fig. 5a). The results indicated that disregarding external factors would lead to inaccurate estimation of the water security condition of the region.

Proposed measures for improvement of water security for the Mekong Delta

Improvement of the water security in the Mekong Delta requires not only a single effort of the Vietnamese government but also joint efforts and cooperation of all basin countries. At the basin-wide level, the riparian countries must strengthen transboundary water cooperation through the existing cooperation frameworks, especially through the Mekong River Commission and the Mekong–Lancang Cooperation. The cooperation should focus on promoting open dialogs among the countries at all levels, strengthening data and information sharing, establishing the basin-wide warning and forecasting system and emergency response mechanisms, and creating the multireservoir operation rules for the entire Mekong mainstream hydropower cascade to regulate the flow between the dry and rainy seasons. At the Mekong Delta level, the solutions should be in a form of combined structural and nonstructural measures. The structural measures would focus on the improvement of the water supply system to the coastal subregions, increase the storage capacity, regular dredging of canals to allow smooth transport of the vessels, and investment in wastewater treatment. The nonstructural measures include application of advanced water technologies for efficient water use and identification of crops that can resist environmental stressors and saline water environment, promoting the implementation of the IWRM and IRBM and roles of the Cuu Long River Basin Committee. The water security conditions forecasted for 2050 would be significantly improved in comparison with that in 2018 based on the Mekong Delta Regional Plan (MPI, 2022), regional development scenarios under the climate change context in the Mekong River Basin (MRC, 2017), and consideration of all the above-proposed measures (Figs. 6a and 6b). The degree of water security for most subregions of the Mekong Delta would be improved from medium to high level in 2018 to 2050.

CONCLUSION

This study contributed to the development of a water security assessment framework for the deltas of transboundary river basins, specifically for the Mekong Delta of Vietnam, by considering its special feature in the framework. The proposed framework in this study relies on 6 dimensions (including water resources, domestic water supply, water for economic development, water-related disasters, ecological and environmental protection, and water governance), 21 indicators, and 5 sub-indicators. The assessment results of the water security for the Mekong Delta showed that the overall water security conditions in most subregions in 2018 were only at the medium level despite their numerous advantages. The degree of water security in flood season is higher than that in the dry season. The medium-level water security of the region can be mainly attributed to its high dependence on external water resources (more than 90%) and transboundary water cooperation between the basin countries and low water productivity in economic sectors. Therefore, the transboundary factor must not be ignored in the assessment framework because disregarding this factor would lead to inaccurate estimation of the water security condition of the region. The study also suggests that the improvement of transboundary water cooperation, water management plan, and water productivity in the Mekong Delta would help enhance future water security in the region. The main challenge in assessing water security for the transboundary river basin is to obtain sufficient data and information on the upper part of the basin, which can be successfully realized through joint efforts and cooperation of all basin countries. The water security assessment framework developed in this study would introduce an opportunity for the policymakers and managers of the Mekong riparian countries to monitor and evaluate the impact of the basin development plans and policies on water security conditions jointly not only for the Mekong Delta but also for the entire basin, identify factors affecting water security, and determine appropriate solutions to enhance water security for the basin.

AUTHOR CONTRIBUTIONS

T.H. Truong, the corresponding author, was responsible for the development of methodology, data analyses, and draft paper preparation. L.T.T. Nguyen was in charge of overall supervision, study conceptualization, and funding acquisition. T. Pham contributed to the study conceptualization and funding acquisition and calculated indicators under the water economic activities dimension. P.H. Nguyen contributed to the study conceptualization and paper editing and calculated indicators under the dimension of the water-related disaster. D.D. Nguyen contributed to the conceptualization of the study and calculated indicators under the water resources and domestic water supply dimensions. T.M. Vu calculated indicators under the environmental and ecological system protection dimension. Q.T. Nguyen was responsible for data collection and analysis of the water governance dimension.

ACKNOWLEDGMENTS

The authors would like to express high acknowledgment to the Vietnam Ministry of Science and Technology for supporting the Research Grant. The authors also thank the Mekong River Commission Secretariat, the General Statistics Office of Vietnam, the People's Committees and relevant departments of the Mekong Delta's provinces, and research institutes for providing the data and information.

CONFLICT OF INTEREST

The author declares that there is no conflict of interest regarding the publication of this manuscript. The ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy, have been completely observed by the authors.

OPEN ACCESS

PUBLISHER'S NOTE

GJESM Publisher remains neutral with regard to jurisdictional claims in published maps and institutional afflictions.

ABBREVIATIONS

%	Percentage
Cv	Intra-and inter-annual flow coefficient of variation
D	Dimension
Đồng Tháp Mười	Name of subregion in the Mekong Delta
GWP	Global water partnership
ha	Hectare
i	Order of dimension
j	Order of indicator
i.e.	That is
IRBM	Integrated River Basin Management
IWRM	Integrated Water Resources Management
km	Kilometer
km^2	Square kilometer
m	Number of variables for an indicator
m	Meter
m^3	Cubic meter
MPI	Ministry of Planning and Investment
MRC	Mekong River Commission
p	Number of dimensions
Q	Water discharge
RBOs	River Basin Organizations
S	Score of each variable
SMART	Specific-Measurable-Achievable-Relevant and Time-based
UN	United Nations
USD	United States dollar
w	Weight for each variable
WQI	Water quality index
WSI	Water security index
x	Weight for each indicator
y	Weight for each dimension

REFERENCES

Aboelnga, H.T.; Ribbe, L.; Frechen, F.B.; Saghir, J., (2019). Urban water security: Definition and assessment Framework. Resources. 8(4): 1-19 (**19 pages**).

Arab, N.U.; Abubakr, A.; Balkhi, M.H.; Bazaz, A.I.; Yousuf, Z.; Hafeez, M.; Mansoor, A.B.; Razak, N.; Ahmad, I., (2021). Water security and its scarcity: A review. Pharma. Innovation J., 10(1): 217-219 (**3 pages**).

Assefa, Y.T.; Babel, M.S.; Susnik, J.; Shinde, V.R., (2019). Development of a generic domestic water security index, and its application in Addis Ababa, Ethiopia. Water. 11(37): 1-23 (**23 pages**).

Babel, M; Shinde, V.R., (2018). A framework for water security assessment at basin scale. APN Sci. Bull., 8(1): 27-32 (**6 pages**).

Babel, M.; Chapagain, K.; Shinde, V.R.; Prajamwong, S.; Apipattanavis, S., (2022). A disaggregated assessment of national water security: An application to the river basins in Thailand. J. Environ. Manage., 321: 1-15 (**15 pages**).

Bagheria, A.; Babaeian, F., (2020). Assessing water security of Rafsanjan Plain, Iran – Adopting the SEEA framework of water accounting. Ecol. Indic., 111: 1-17 (**17 pages**).

Călmuc, V.A.; Călmuc, M.; Ţopa, M.C.; Timofti, M.; Iticescu, C.; Lucian P.; Georgescu, L.P., (2018). Various methods for calculating the water quality index. Annals of "Dunarea De Jos" University of Galati- Fascicle II, Year X (XLI), 2: 171-178 (**8 pages**).

Dennis, L.E.; Grady, C.A., (2022). Watery research boundaries: A bibliometric and network science approach to explore gaps and overlaps in water research. Water Secur., 16(100117): 1-10 (**10 pages**).

De Strasser, L.; Lipponen, A.; Howells, M.; Stec, S.; Bréthaut, C., (2016). A Methodology to assess the water energy food ecosystems nexus in transboundary river basins. Water. 8(59): 1-28 (**28 pages**).

Dong, Q.; Liu, X., (2014). Risk assessment of water security in Haihe River Basin. Water Sci. Eng., 7(2): 119-132 (**14 pages**).

Dou, P.; Zuo, S.; Ren, Y.; Rodriguez, M.J.; Dai, S., (2021). Refined water security assessment for sustainable water

management: A case study of 15 key cities in the Yangtze River Delta, China. J. Environ. Manage., 290: 1-13 (**13 pages**).
Gain, A.K.; Giupponi, C.; Wada, Y., (2016). Measuring global water security towards sustainable development goals. Environ. Res. Lett., 11: 124015, 1-13 (**13 pages**).
Giri, S.; Arbab, N.N.; Lathrop, R.G., (2018). Water security assessment of current and future scenarios through an integrated modeling framework in the Neshanic River Watershed. J. Hydrol., 563: 1025-1041 (**17 pages**).
Grey, D.; Garrick, D.; Blackmore, D.; Kelman, J.; Muller, M.; Sadoff, C., (2013). Water security in one blue planet: Twenty-first century policy challenges for science. Phil. Trans. R. Soc. A, 371: 20120406, 1-10 (**10 pages**).
Hatmoko, W.; Firmansyah, R.R.; Fathony, A., (2020). Water security of river basins in West Java. IOP Conference Series: Earth Environ. Sci., 419: 012140, 1-7 (**7 pages**).
Hoekstra, A.Y.; Buurman, J.; van Ginkel, K.C.H., (2018). Urban water security: A review. Environ. Res. Lett., 13: 053002, 1-14 (**14 pages**).
Holmatov, B.; Lautze, J.; Manthrithilake, H.; Makin, I., (2017). Water security for productive economies: Applying an assessment framework in southern Africa. Phys. Chem. Earth. 100: 258-269 (**12 pages**).
Hong, V.N.H., (2020). Water Security in the Mekong River Basin Challenges, Causes and Solutions. Am. Sci. Res. J. Eng. Technol. Sci., 64(1): 187-199 (**13 pages**).
Jensen, O.; Wu, H., (2018). Urban water security indicators: Development and pilot. Environ. Sci. Policy. 83: 33-45 (**13 pages**).
Kim, Y.; Kong, I.; Park, H.; Kim, H.J.; Kim, I.J.; Um, M.J.; Green, P.A.; Vörösmarty, C.J., (2018). Assessment of regional threats to human water security adopting the global framework: A case study in South Korea. Sci. Total Environ., 637-638: 1413-1422 (**10 pages**).
Koontanakulvong, S.; Doungmanee, P., (2015). Thailand's water security situation in the context of the world and ASEAN. Hydrological Sciences and Water Security: Past, Present and Future (Proceedings of the 11th Kovacs Colloquium, Paris, France. 117-118 (**2 pages**).
Kumar, C.P., (2018). Water security – Challenges and needs. Int. Educ. Sci. Res. J., 4(1): 26-29 (**4 pages**).
Loe, R.C.; Hjornlund, H., (2008). Irrigation and water security: the role of economic instruments and governance. Sustainable Irrigation Manage. Technol. Policies II., 112: 35-42 (**8 pages**).
Lu, M.; Wang, S.; Wang, X.; Liao, W.; Wang, C.; Lei, X.; Wang, H., (2022). An assessment of temporal and spatial dynamics of regional water resources security in the DPSIR framework in Jiangxi Province, China. Int. J. Environ. Res. Public Health. 19(6): 1-21 (**21 pages**).
Makin, I.; Arriens, W.L.; Prudente, N., (2013). Indicators for assessing national water security: Asia Water Development Outlook. Proceedings from the GWP workshop: Assessing water security with appropriate indicators, 53-83 (**31 pages**).
marttunen, m.; mustajoki, j.; sojamo, s.; ahopelto, l.; keskinen, m., (2019). a framework for assessing water security and the water–energy–food nexus—The case of Finland. Sustainability. 11(2900): 1-24 (**24 pages**).
Mekonnen, M.M.; Hoekstra, A.Y., (2016). Four billion people facing severe water scarcity. Sci. Adv., 2: 1-6 (**6 pages**).
MPI, (2022). Mekong Delta Regional Plan in the period 2021 - 2030 with a vision to 2050. Ministry of Planning and Investment (in Vietnamese).
MRC, (2017). Study on sustainable management and development of the Mekong River including impacts of mainstream hydropower projects. Mekong River Commission, Vientiane, Laos.
MRC, (2018). State of the Basin Report. Mekong River Commission, Vientiane, Laos.
Mui, N.T., (2018). Study on water security for sustainable management of the Ma River Basin (in Vietnamese). Doctoral Dissertation in Soil Environment, Serial Number 9.44.03.03 (in Vietnamese).
Oluwasanya, G.; Perera, D.; Qadir, M.; Smakhtin. V., (2022). Water security in Africa: A preliminary assessment. United Nations University Institute for Water, Environment and Health, Report Series 13: 1-43 (**43 pages**).
Park, S.Y.; Kim, J.S.; Lee, S.; Lee, J.H., (2022). Appraisal of water security in asia: the pentagonal framework for efficient water resource management. Appl. Sci., 12(16): 1-14 (**14 pages**).
Singh, A.K., (2018). Water Security – A Reality Check. J. Indian Soc. Soil Sci., 66: 179-192 (**13 pages**).
Srinivasan, V.; Konar, M.; Sivapalan, M., (2017). A dynamic framework for water security. Water Secur., 1: 12-20 (**9 pages**).
Sun, D.; Wu, J.; Zhang, F.; Su, W.; Hui, H., (2018). Evaluating water resource security in Karst Areas Using DPSIRM Modeling, gray correlation, and matter–element analysis. Sustainability. 10: 1-16 (**16 pages**).
Thang, L.V.; Thanh, N.H.; Tuan, N.V., (2019). Security for water source of mekong river and impacts on Vietnam National Security. Resour. Environ., 9(4): 71-79 (**9 pages**).
UN-Water, (2013). Water security and the global water agenda. United Nations – Water. United Nations University Institute for Water, Environment and Health.
Vachnadze, R., (2016). Prioritization of performance meassures using analytic hierachy process. Int. J. Anal. Hierarchy Process. 8(3): 490-501 (**12 pages**).
Van Ginkel, K.C.H.; Hoekstra, A.Y.; Buurman, J.; Hogeboom, R.J., (2018). Urban water security dashboard: Systems approach to characterizing the water security of cities. J. Water Resour. Plann. Manage., 144(12): 1-11 (**11 pages**).
Wilhelm, F.M.; Maldonado, R.S.; Castillo, R.M., (2022). Assessing water security through a set of consistent metrics and application to water funds in Latin America. Cur. Trends Civil. Struct. Eng., 9(1): 1-16 (**16 pages**).
Zhu, Q.; Tran, L.T.; Wang, Y.; Qi, L.; Zhou, W.; Zhou, L.; Yu, D.; Dai, L., (2022). A framework of freshwater services flow model into assessment on water security and quantification of transboundary flow: A case study in northeast China. J. Environ. Manage., 304: 1-12 (**12 pages)**.
Park, S.Y.; Kim, J.S.; Lee, S.; Lee, J.H., (2022). Appraisal of water security in asia: the pentagonal framework for efficient water resource management. Appl. Sci., 12(16): 1-14 (14 pages).

AUTHOR (S) BIOSKETCHES

Truong, T.H., Ph.D., Senior Researcher, Vietnam National Mekong Committee, 23 Hang Tre street, Hanoi, Vietnam.
▪ Email: *thtien652004@gmail.com*
▪ ORCID: 0000-0003-1034-6198
▪ Web of Science ResearcherID: NA
▪ Scopus Author ID: NA
▪ Homepage: https://vnmc.gov.vn/?lang=en

Nguyen, L.T.T., M.Sc., Senior Researcher, Vietnam National Mekong Committee, 23 Hang Tre street, Hanoi, Vietnam.
▪ Email: *thulinhmk@gmail.com*
▪ ORCID: 0000-0002-3055-152X
▪ Web of Science ResearcherID: NA
▪ Scopus Author ID: NA
▪ Homepage: https://vnmc.gov.vn/?lang=en

Nguyen, D.D., M.Sc., Senior Researcher, Vietnam National Mekong Committee, 23 Hang Tre street, Hanoi, Vietnam.
▪ Email: *dinhdat143@gmail.com*
▪ ORCID: 0000-0001-6720-2916
▪ Web of Science ResearcherID: NA
▪ Scopus Author ID: NA
▪ Homepage: https://vnmc.gov.vn/?lang=en

Pham, T., M.Sc., Senior Researcher, Vietnam National Mekong Committee, 23 Hang Tre street, Hanoi, Vietnam.
▪ Email: *phamtuong307@gmail.com*
▪ ORCID: 0000-0002-8606-6769
▪ Web of Science ResearcherID: NA
▪ Scopus Author ID: NA
▪ Homepage: https://vnmc.gov.vn/?lang=en

Vu, T.M., M.Sc., Senior Researcher, Vietnam National Mekong Committee, 23 Hang Tre street, Hanoi, Vietnam.
▪ Email: *vumthien@gmail.com*
▪ ORCID: 0000-0002-0135-0358
▪ Web of Science ResearcherID: NA
▪ Scopus Author ID: NA
▪ Homepage: https://vnmc.gov.vn/?lang=en

Nguyen, P.H., M.Sc., Senior Researcher, Vietnam National Mekong Committee, 23 Hang Tre street, Hanoi, Vietnam.
▪ Email: *huyphuongmk@gmail.com*
▪ ORCID: 0000-0002-0517-7046
▪ Web of Science ResearcherID: NA
▪ Scopus Author ID: NA

Nguyen, Q.T., M.Sc., Senior Researcher, Vietnam National Mekong Committee, 23 Hang Tre street, Hanoi, Vietnam.
▪ Email: *quantnn@gmail.com*
▪ ORCID: 0000-0003-3535-8865
▪ Web of Science ResearcherID: NA
▪ Scopus Author ID: NA
▪ Homepage: https://vnmc.gov.vn/?lang=en

HOW TO CITE THIS ARTICLE

NTruong, T.H.; Nguyen, L.T.T.; Nguyen, D.D.; Pham, T.; Vu, T.M.; Nguyen, P.H.; Nguyen, Q.T., (2023). Water security assessment framework for the deltas of the transboundary river basins. Global J. Environ. Sci. Manage., 9(3): 619-636.

DOI: 10.22035/gjesm.2023.03.17

URL: https://www.gjesm.net/article_701533.html