





Article

Enhancing Water Supply Resilience in a Tropical Island via a Socio-Hydrological Approach: A Case Study in Con Dao Island, Vietnam

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Citation: Nguyen, D.C.H.; Nguyen, D.C.; Luu, T.T.; Le, T.C.; Kumar, P.; Dasgupta, R.; Nguyen, H.Q. Enhancing Water Supply Resilience in a Tropical Island via a Socio-Hydrological Approach: A Case Study in Con Dao Island, Vietnam. *Water* **2021**, *13*, 2573. <https://doi.org/10.3390/w13182573>

Academic Editor: Maria Mimikou

Received: 20 August 2021

Accepted: 15 September 2021

Published: 18 September 2021

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Abstract: Socio-hydrological approaches are gaining momentum due to the importance of understanding the dynamics and co-evolution of water and human systems. Various socio-hydrological approaches have been developed to improve the adaptive capacity of local people to deal with water-related issues. In this study, a social-hydrological approach was developed to enhance the water supply resilience in Con Dao Island, Vietnam. We used a water-balance model, involving the Water Evaluation and Planning (WEAP) tool, to conduct a scenario-based evaluation of water demands. In doing so, we assessed the impacts of socio-economic development, such as population growth and climate change, on increasing water demand. The modelling results showed that the existing reservoirs—the main sources to recharge the groundwater (accounting for 56.92% in 2018 and 65.59% in 2030)—play a critical role in enhancing water supply resilience in the island, particularly during the dry season. In addition, future water shortages can be solved by investment in water supply infrastructures in combination with the use of alternative water sources, such as rainwater and desalinated seawater. The findings further indicate that while the local actors have a high awareness of the role of natural resources, they seem to neglect climate change. To meet the future water demands, we argue that upgrading and constructing new reservoirs, mobilizing resources for freshwater alternatives and investing in water supply facilities are among the most suitable roadmaps for the island. In addition, strengthening adaptive capacity, raising awareness and building professional capacity for both local people and officials are strongly recommended. The research concludes with a roadmap that envisages the integration of social capacity to address the complex interaction and co-evolution of the human–water system to foster water-supply resilience in the study area.

Keywords: socio-hydrology; Con Dao Island; water resilience; WEAP

1. Introduction

Swift global changes, frequent extreme weather conditions along with increasing water demand has significantly impacted the socio-economic development through our co-evolution with water [1]. Keeping in mind the limited availability of freshwater resources as

well as the fact that one-third of the global population is living in water stress, sustainable water management is a global challenge of high priority [2]. It is reported that out of this available little freshwater deposit, half of the global population depends on groundwater to meet their potable water demand [3]. For the Asian continent, despite having a significant share of global freshwater resources, the average per capita water availability is much less than that of the rest of the world owing to water pollution, water conflicts, poor governance and management strategies and socio-cultural practices [3–5].

Because the interaction between the hydrological cycle and its interaction with the biophysical environment is very complex, different holistic approaches, such as integrated water resource management (IWRM) models [2], socio-hydrological approaches [6], etc., have been used by both scientific communities as well as decision-makers. Among various IWRM tools, some of the models, such as WEAP (Water Evaluation and Planning), MIKE, RIBASIM (river basin simulation model), and WBalMo (water balance model), have been widely used across the globe [2,7–9].

Socio-hydrological science is gaining interest due to the importance of understanding the dynamics and co-evolution of water and human systems, and hence there is a greater impact on decision making [10]. In practice, the socio-hydrological approach requires participatory models where the community has a great influence at every step of the analysis, and hence the outcome guarantees a result for common good [11]. In the literature, a lot of studies on the relationship between social and hydrological systems have been carried out in the field of socio-hydrological resilience [12], prediction in a socio-hydrological world [13], system understanding [14], risk management [15], and land-use management [16]. These studies generally used socio-hydrological models to support decision-makers analyze the people–water interaction and receive feedback before offering effective decisions [1].

Recently, a socio-hydrological approach has been developed by [6] to improve the adaptive capacity of residents in isolated riverine islands in the context of water scarcity due to rapid global changes and climate change (Figure 1). This approach built a resilient water environment for achieving human wellbeing in three large riverine islands in Asia, namely Fraserganj, South 24 Parganas (Ganges River, India), Dakshin Bedkashi (Padma River, Bangladesh), and Con Dao Island (Mekong River, Vietnam). The authors recommended the key steps to apply the socio-hydrological concept for project management, in which the use of numerical tools considering social aspects was highlighted to assist in the analysis and decision-making process. The study has opened a new way for sustainable water resource management in isolated riverine islands, particularly enhancing water supply resilience for Con Dao Island, based on the social-hydrological approach.

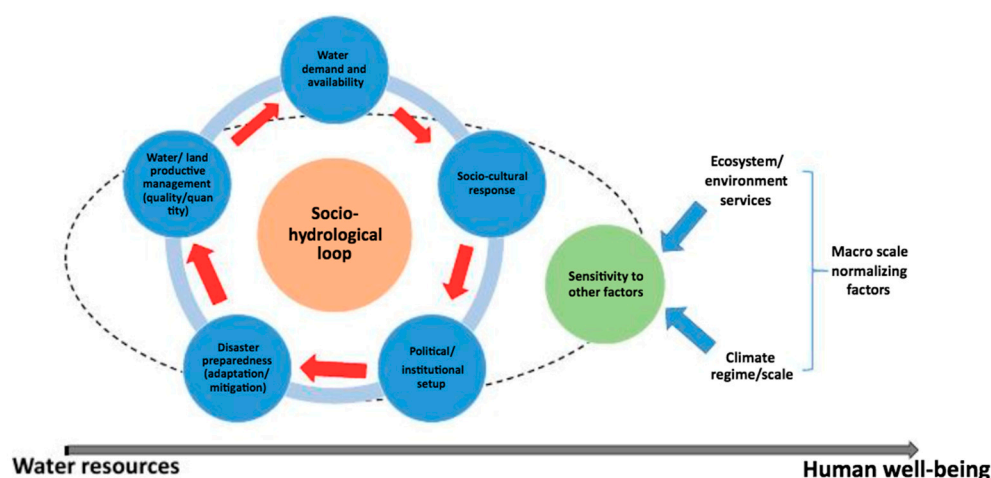


Figure 1. Conceptual diagram of socio-hydrological approach to bridge the gap between water resources and human wellbeing (Source: [6]).

Con Dao is an island in Southern Vietnam, a very popular tourist destination because of its natural sceneries [17]. However, in recent years, this island has been witnessing water scarcity because of various reasons, viz. a sharp increase in water demand because of rapid population growth and a decline in water availability [18].

Regarding numerical tools for water resource management in Con Dao, reference [19] developed a coupled hydrological model of HEC-HMS and MODFLOW to analyze the interaction between surface water and groundwater in Con Dao Island. The study proposed a drought management plan with solutions to improve water availability for coping with the increasing water demand in the future. However, the study did not consider the social/institutional analysis, i.e., water balance and water project implementation which are significant attributes in the socio-hydrological loop.

Several solutions have been proposed to resolve the problems, such as improving the current water supply in Con Dao by upgrading the storage capacity of the existing reservoirs, constructing new reservoirs, and desalinating water [20]. Other alternative water resources such as rainwater can be also a promising solution to resolve water problems in the island since it has plenty of precipitation annually (~2000 mm/year). However, there is no information available on the efficiency assessment of all proposed solutions/countermeasures in the island. To address the above gaps, the objectives of this paper are (i) to identify the interaction between people and water in Con Dao Island, Vietnam through the lens of a socio-hydrological approach, and (ii) to suggest a sustainable water management strategy for enhancing water supply resilience in the context of climate change and socio-economic development in the area.

2. Materials and Methods

2.1. Study Site

The study site is Con Dao, a typical island, located in Ba Ria-Vung Tau (BRVT) province, 230 km from Ho Chi Minh City, Vietnam (located at 8°40'57" N and 106°36'26" E) (Figure 2). It is an isolated historical island consisting of 16 small islands with a total area of 75.2 km². It has a tropical climate and receives approximately 2000 mm/year of precipitation. Despite the high precipitation rate and the relatively low population density (about 112 people/km²), the island is facing a water shortage, with the situation expected to worsen in the future due to the limitations of the current water supply system, and the increasing demand due to the increase of residents and travelers. These rapid changes are casting extreme effects on the communities in the island due to their poor adaptive capacities (limited resources/infrastructure and institutional setup) as they are isolated geographically. Hence, achieving a healthy interaction between human and water systems in the island in the future is a critical concern of sustainability.

2.2. Current Water Supply Status in Con Dao Islands

There are three water resources in the island: surface water, groundwater, and rainwater.

Surface water is the main source of water, even though there is no large river in the island. The island consists of 45 short and small streams with a total length of 37.6 km (about 0.73 km/km²). Most of the streams only have water in the rainy season, but no or little water in the dry season [19]. The rainfall is often not retained in the streams but flows directly into the sea due to the high and steep topography. To date, the Con Dao Islands have three large reservoirs, including two natural lakes (An Hai and Quang Trung 1 (QT1)) and the Quang Trung 2 (QT2) Reservoir, constructed in 2018, which are the main water sources to supply the decentralized water supply plant as intake resources. The storage capacities of the An Hai, QT1, and QT2 reservoirs are 540,000 m³, 518,000 m³, and 645,000 m³, respectively. These reservoirs are linked to each other by the canals, and these are the main sources to recharge water into the aquifer. The decentralized water supply plant then treats the water and the supply for 3 residential sub-areas: Central Town, Co Ong Airport, and Ben Dam Port.

(Shallow) groundwater has been exploited for the water supply plant in Central Town through 25 wells around the QT1 reservoir. This water provides mostly domestic water to the water supply plant (with a capacity of 3440 m³/day). The water not only supplies water to Central Town but also to Co Ong and Ben Dam through two water transfer stations with the capacity of 300 and 800 m³/day, respectively. The shallow groundwater system is recharged from reservoirs seasonally.

Rainwater use is still not under current practice in the island, except in some remote areas where the water distribution system hardly reaches.



Figure 2. Map of Con Dao Islands (Modified from [18]).

2.3. Socio Hydrology Approach

To achieve the research objectives, an integrated socio-hydrological approach has been developed with a combination of quantitative assessment using numerical modeling and qualitative assessment using field surveys, focus group discussions (FGDs), and Key Informant Interviews (KIIs). The detailed methodology is shown in Figure 3.

2.3.1. Quantitative Analysis

The first step of quantitative analysis was to set up a hydrological numerical model. In this study, the Water Evaluation and Planning (WEAP) system, which is an integrated water resource management tool based on the basic principle of water balance accounting, was used as it has been widely applied for water resource problems all over the world [9,21–23].

2.3.2. Qualitative Analysis

Participatory Rural Appraisal (PRA) tools were applied in this study, which includes focus group discussion (FGD), in-depth interviews, and questionnaire surveys. The FGD was first conducted with 10 local government officials and technical staff for about three hours. Participants in the FGD included district officials from the People's Committee and different sectors that are related to water use/management in the island, e.g., the Office of Natural Resources and Environment (DNRE). Originally, criteria for the selection of the FGD participants included (1) working for the local authority at the district level, (2) leaders who were responsible for the development of their sectors such as chairmen or heads. In reality, the participants were selected following the arrangement of the Con Dao authority. Participants in the FGD were queried with open-ended questions related to water management and water use in Con Dao Island (Appendix C).

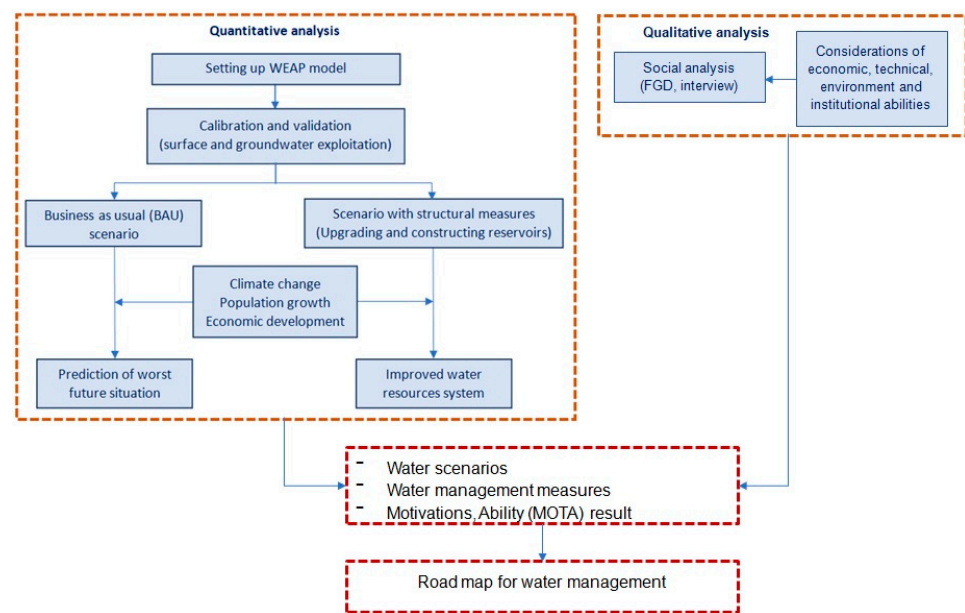


Figure 3. Study framework.

The in-depth interviews were then carried out with four local officials to assess their motivation and ability in water management based on the qualitative assessment aspect of the Motivation and Ability (MOTA) framework (Figure 4). Here, local officials include those who are working for the district authority and local state water companies. The motivation of the local officials is observed based on their perceived existing issues, solutions, and professional roles in solving the issues. The ability of the current governing system is described based on the perceptions of local officials on institutional capacity, financial capacity, and technical capacity [24,25].

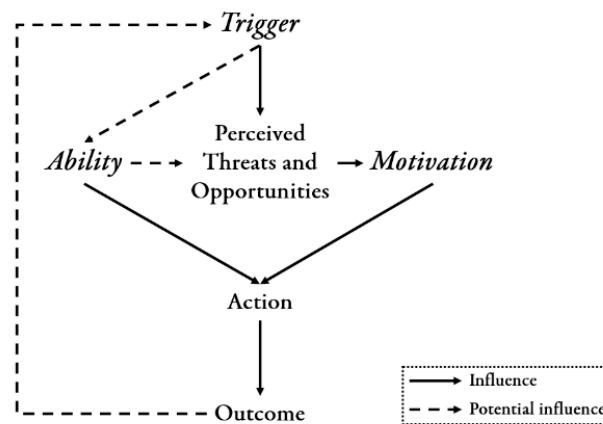


Figure 4. MOTA framework (Source: [25]).

Finally, surveys were conducted with 50 households. The households were selected based on 8 criteria including (1) geographic features; (2) hydrological features; (3) cultural features; (4) ecological features; (5) different administrative boundaries; (6) different sex; (7) different age; and (8) different jobs. The survey questionnaire was developed to cover the most possible factors responsible for water security issues in the study area.

The information obtained from the observations during the survey, FGD, and in-depth interviews was interpreted intersubjectively by the research team to examine the obstacles and enablers of sustainable water management in Con Dao Island.

3. Results

3.1. Hydrological Simulation

3.1.1. Model Setup

This step began with identifying water users and water sources in the study area, as well as developing a schematic (spatial layout) of the water supply and demand system for Con Dao (Figure 5). The main water users on the island are local residents, tourists, and agricultural and industrial activities, while the main water sources are rainwater, reservoirs, and groundwater (Table 1).

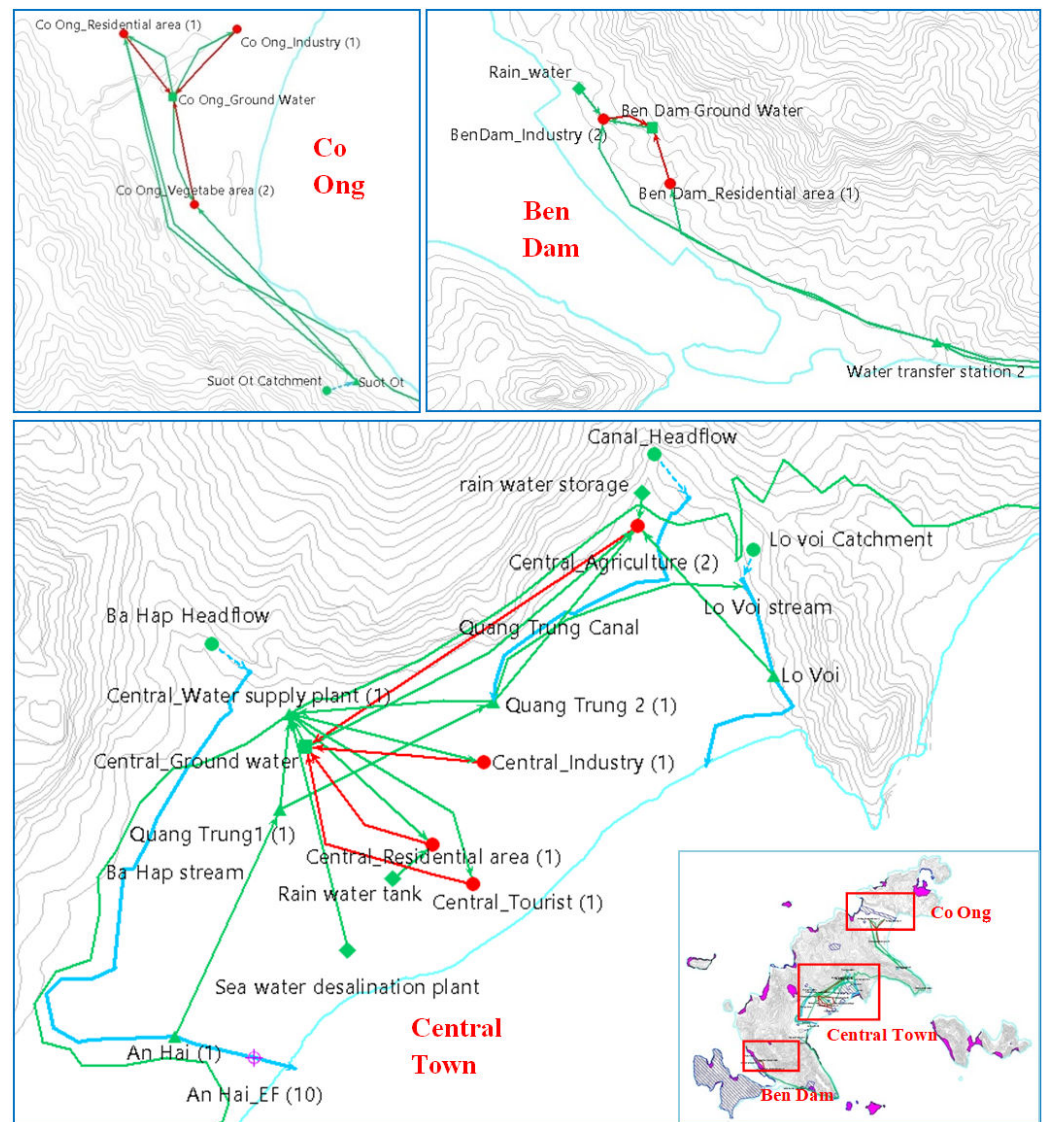


Figure 5. Schematic of the WEAP model for Con Dao Island.

Table 1. Water users and water supply sources for different areas in Con Dao.

Area	Water Users	Water Supply Sources	
		Current	Future
Co Ong	- Local residents	- Groundwater	- Reservoir: Suoi Ot
	- Tourists	- Rainwater	- Groundwater
	- Agriculture	- Water transferred from Central town	- Rainwater
	- Industry (airport)		- Water transferred from Central town
Central town	- Local residents	- Reservoirs: An Hai, Quang Trung 1, and Quang Trung 2	- Reservoirs: An Hai, Quang Trung 1, Quang Trung 2, and Lo Voi
	- Tourists		
	- Agriculture	- Groundwater	- Groundwater
	- Industry	- Rainwater	- Rainwater
Ben Dam	- Local residents	- Rainwater	- Reservoirs: Nui Mot
	- Tourists	- Water transferred from Central town	- Groundwater
	- Industry		- Rainwater
			- Water transferred from Central town

Next, water demand and water supply at present (2018) and in the future (2030) were calculated. For water demand, the input data in WEAP included population, the number of tourists, type of crops (vegetables, annual crop, fruits), crop calendar, livestock (the number of buffaloes, cattle, pigs, chickens, ducks, and goats), industrial area, type of industry (ice production). These data were taken from the 2018 Statistical Yearbook of Con Dao [26] and other related reports, such as the master plan on socio-economic development of Con Dao and the agricultural development planning for Con Dao to 2020, vision to 2030 [20] (as shown in Appendix A). The water demand for agricultural production was calculated by the crop coefficient approach, whereas other demands (i.e., domestic use, tourism, industry, and agriculture) were determined by the following formula:

$$Q_{\text{day}} = N \times q / 1000 \text{ (m}^3\text{/day)} \quad (1)$$

in which:

q is the water use standard regulated in TCXDVN 33:2006 of the Ministry of Construction on the water supply–distribution system and facility–design standard;

N is the number of people or the area of the industrial zone (ha).

Meanwhile, the input data for water supply included meteorological data (monthly rainfall and evaporation), the storage of reservoirs, groundwater storage and recharge, the capacity of the water supply plant, and water transfer stations. These data were provided by the Division for Water Resources Planning and Investigation for the South of Vietnam (DWRPIS), Con Dao Meteorological station, and the Con Dao local government (shown in Appendix B).

In this model, the groundwater–surface water interactions in Con Dao were simulated using the method in WEAP, i.e., the amount of groundwater inflow from or outflow to reservoirs was specified.

In the second step, calibration and validation were carried out to assess the reliability of WEAP for Con Dao. The model was run to simulate monthly surface and ground water exploitation with the input data from step 1, including water demand for different sectors (e.g., domestic use, tourism, agriculture, industry) and water supply sources (e.g., reservoirs and groundwater). The calibration was achieved by the 2014 data when simulated and observed values of water exploitation were matched, i.e., the Nash–Sutcliffe efficiency (NSE) value will reach “1”. The final parameters of the calibration process were then used to validate the model with the 2018 data. The better the validation model was, the closer the NSE value was to “1”.

The third step was to set up scenarios for evaluating the current condition and future development of water resource management (Table 2). A reference scenario (BAU scenario—

S0) was set up to estimate future risks and challenges in water security considering key drivers, namely climate change, population growth, economic development, land-use change, and groundwater extraction rate. According to the master plan on socio-economic development of Con Dao in 2020, with vision to 2030 [20], population and tourists by 2030 were estimated to be about 30,000 and 300,000 people, respectively. Additionally, the industrial area will be expanded by 50 hectares. In this scenario, the forecast of temperature and rainfall in 2030 was based on the Vietnam climate change scenarios by [27].

Table 2. Summary of water resources management scenarios for Con Dao Island.

No.	Scenario	Description
1	Reference—BAU (S0)	<ul style="list-style-type: none"> - Increase in water demand due to socio-economic development and population growth - Climate change impacts (temperature increases 10% while rainfall decreases 10%) - No improvement in water supply capacity
2	Increasing water supply (S1)	Same as S0, but increasing in water supply capacity +Upgrading storage capacity of the existing reservoirs: An Hai ($0.02 \times 10^6 \text{ m}^3$), Quang Trung 1 ($0.02 \times 10^6 \text{ m}^3$) +Constructing new reservoirs: Nui Mot (25,000 ha, in 2020), Suoi Ot (171,000 ha, in 2021), Lo Voi (68,000 ha, in 2022) +Mitigating the loss from the water supply system (from 10% to 5%) +Investing on a surface water supply plant ($3000 \text{ m}^3/\text{day}$)
3	Using low-cost alternative water resources (S2)	S1 + Using rainwater tanks at households in Central Town as a resource for domestic use
4	Using high-cost alternative water resources (S3)	S1 + Constructing a seawater desalination plant (capacity of $3000 \text{ m}^3/\text{day}$)
5	Combining (S4)	S2 + S3

Scenarios with countermeasures were similar to the reference scenario but took into account human intervention to improve water supply capacity. According to the master plan on the socio-economic development of Con Dao, the local government has planned to dredge the existing reservoirs (An Hai and Quang Trung 1), construct new reservoirs (including Nui Mot in 2020, Suoi Ot in 2021, Lo Voi in 2022), mitigate the losses from the water supply system, and invest in a surface-water supply plant (S1). Rainwater is also a promising water resource in such remote islands, which can be a sustainable way to obtain good-quality drinking water at a low cost and with little energy expenditure and was considered in this study (S2). In addition, desalination was considered a high-cost water resource alternative (S3) as proposed in the master plan on the socio-economic development of Con Dao [20]. All countermeasures were incorporated in Scenario S4.

3.1.2. Model Calibration and Validation

Only groundwater exploitation data was available for model calibration and validation. The WEAP model for Con Dao Island was calibrated using the groundwater exploited by the water supply plant in 2014 (Figure 6). This calibrated model was then validated with the data in 2018. The NSE values of the calibration and validation were 0.894 and 0.867, respectively. The results imply that the model was reliable to simulate the water scenarios for the Island.

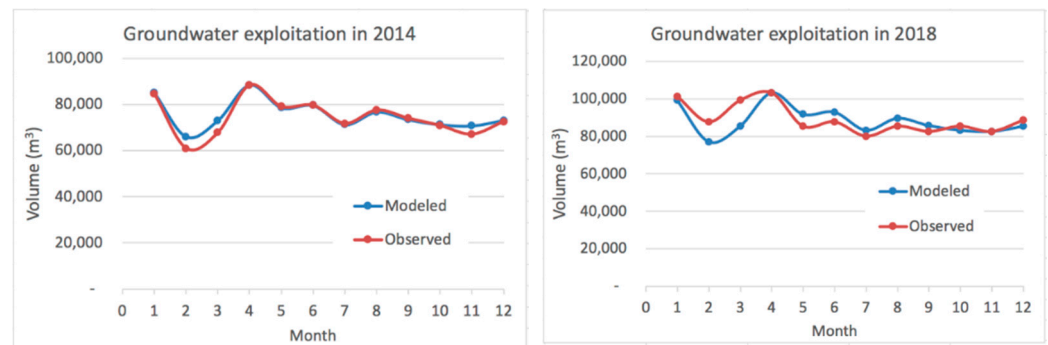


Figure 6. Calibration and validation results of the WEAP model for Con Dao Island.

3.1.3. Interaction between Surface and Ground Water

To simulate the flow from surface water to groundwater, the “Specify GW-SW Flows” method was used in this study. The outputs from the model showed that the volumes of groundwater replenished from the An Hai, QT1, and QT2 reservoirs in 2018 are about 497.7, 496.0, and 548.2 thousand m³, respectively. The corresponding values will increase up to 574.5, 600.1, and 657.2 thousand m³ in 2030. The increased groundwater recharge, in this case, can be explained by the increase in reservoir capacity after dredging. These outputs showed a close relationship between surface water and groundwater in Con Dao Island.

Compared to other sources of groundwater recharge, the rate of inflows from the three reservoirs of An Hai, QT1, and QT2 into an aquifer was 1.5 million m³ (accounting for 56.92% in 2018) and 1.8 million m³ (65.59% by 2030) (Figure 7). The WEAP model also presented that more than 80% of groundwater recharge in the period from January to April will come from these three reservoirs. This demonstrated the importance of the reservoirs on enhancing water supply resilience in Con Dao Island, particularly during the dry season. Therefore, the reservoirs need to be preserved and upgraded in terms of both quantity and quality for the future under the impact of climate change.

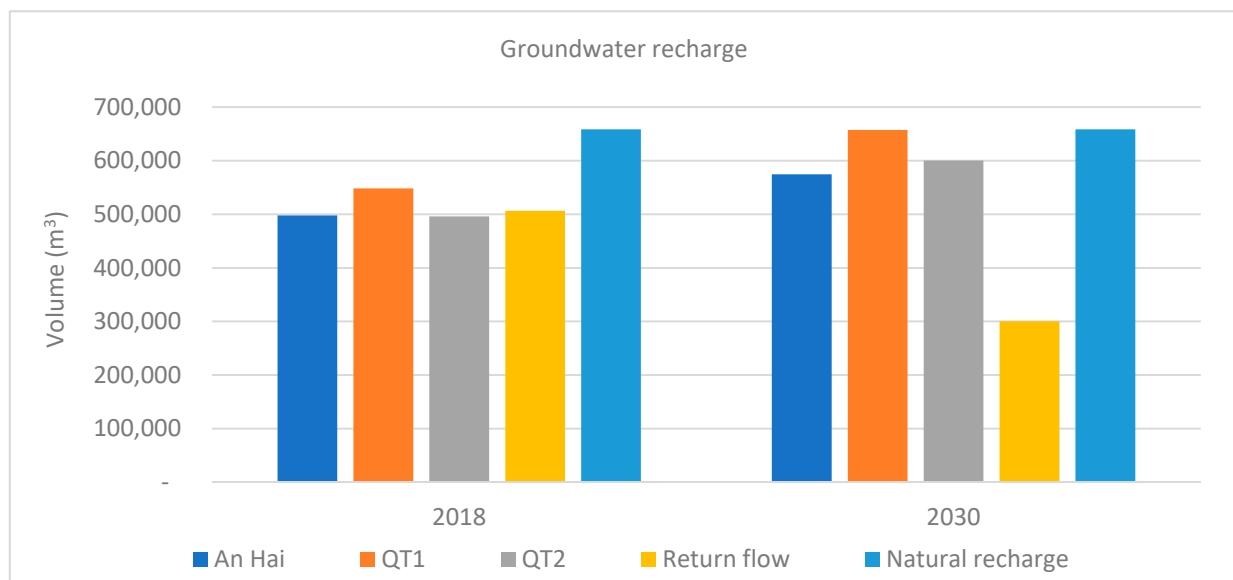


Figure 7. Groundwater recharge in Con Dao Island in 2018 and 2030.

3.1.4. Water Supply and Water Demand in Con Dao Island

As the population increases along with socio-economic development, the water demand will also increase (Appendix A). In 2018, the water demand was about 1.37 million m³, in which industry, domestic use, tourists, and agricultural production occupied about 32.0%, 22.5%, 23.0%, and 18.0%, respectively. The water demand by 2030 will nearly triple to

3.83 million m³, and domestic water use will be the largest, followed by water for tourists and industry. It is worth noting here that the number of tourists often spikes in the summer (peak tourist season), leading to a rapid increase in water demand. On the other hand, the impacts of climate change (i.e., temperature increases 10% while rainfall decreases 10%) could decrease water supply sources. Therefore, the water shortage will be more serious due to limited water supply capacity.

To deal with the increase in water demand, it is necessary to change the water supply. If people do not have any solutions to increase the capacity of water supply, the future demand will not be met, i.e., unmet water demand will be severe (about 2.56 million m³ in 2030) (referring to scenario S0 in Figure 8a). For scenario S1, where the government would invest in the water supply infrastructure, the unmet demand will reduce by only about 0.48 million cubic meters in 2030, which will mainly occur in the dry season (Figure 8b). These results show that the policies proposed by local authorities are appropriate, but do not yet fully meet the water demand for the future.

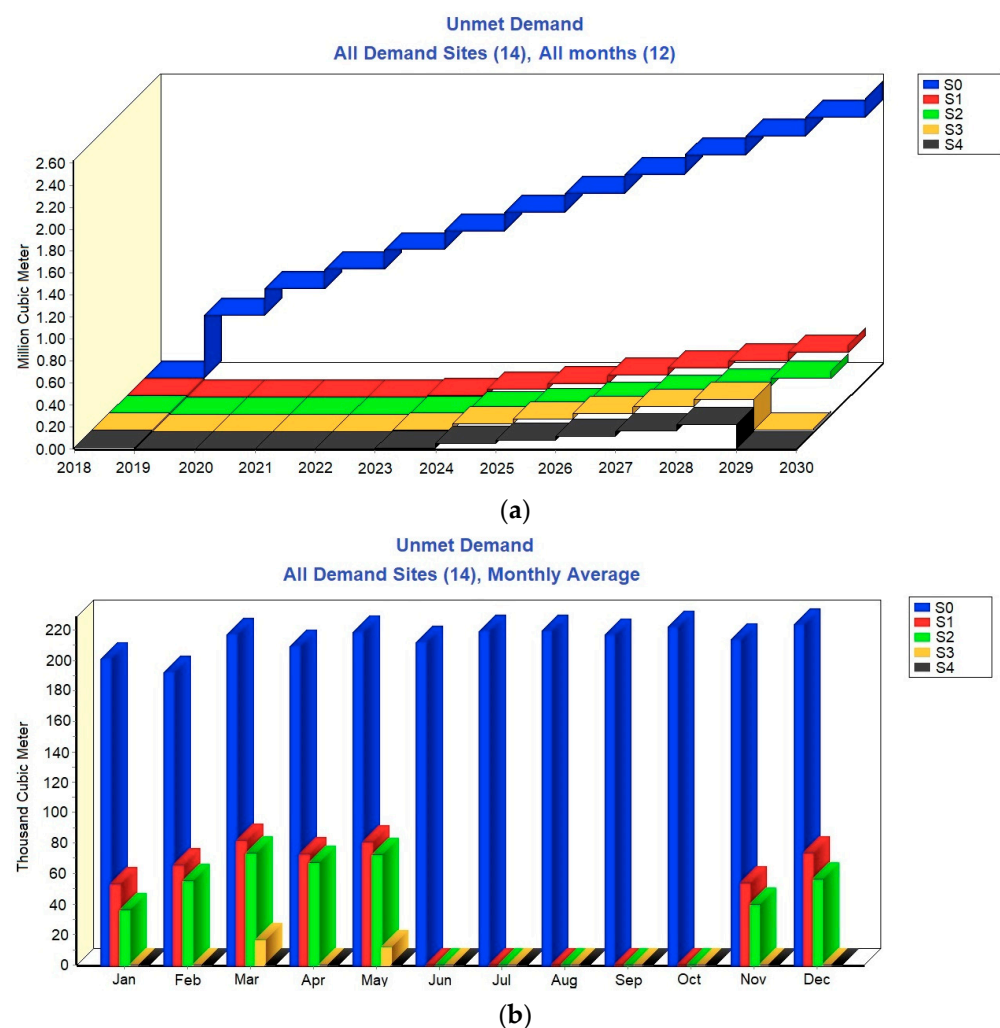


Figure 8. Unmet demand in Con Dao Island under S0, S1, S2, S3, S4 scenarios: (a) by year; (b) by monthly average.

While rainwater was considered as a resource for domestic use in the Central town (S2), the potential of rainwater harvesting quantity was calculated based on the number of households and the roof area of each household (estimated about 100 m²). In this case, the water supply will increase by about 0.08 million m³, resulting in a decrease in the unmet demand to 0.40 million m³.

If a seawater desalination plant is invested in (S3), the water supply can be increased significantly and almost meet the future water demand. The unmet demand for this scenario will be only 0.03 million m³. The future water demand will be fully met if all the methods of increasing the water supply are combined (S4). This can be considered a sustainable solution for the water supply system in the island.

3.2. Social Observation

3.2.1. Obstacles and Enablers in Sustainable Water Management in Con Dao Island Perceptions of Local Actors in Natural Resources Management and Climate Change

Local people have shown a high awareness about the importance of natural resource protection such as the freshwater, ocean, and forest, partly thanks to the propaganda campaigns organized by local governments. However, only a limited number of surveyed households practice water reuse, reduction, and recycling, including collecting rainwater, due to less financial benefits. Most of them are not worried about or have never experienced a water shortage. Regarding climate change, a small portion of local people confirm that they heard about the term before, mostly those who used to work for the government or participated in social associations. Similarly, local officials have a high awareness of the protection of natural resources and the importance of the inclusiveness of locals' participation in the process. They have a good understanding of climate change in general, though raising awareness on this issue for local people is not mentioned properly. In general, both local people and officials might be aware of the importance of the protection of natural resources; nevertheless, they do not know how to apply this awareness in practice. Training organized by local governments is recommended to improve local household knowledge on specific practices.

Perceptions of Local Officials on Problems and Solutions Regarding Water Management

Several perceived risks are stated by local officials on water use and management in the Con Dao Islands. Firstly, the groundwater quantity is limited, especially during the dry season (April and May) when the number of tourists reaches a peak. Secondly, annual monitoring shows that the groundwater quality is decreasing due to pollution. A possible solution is dredging the existing reservoirs (interview of technical staff of DNRE).

3.2.2. Abilities to Implement Water Infrastructure Projects Institutional Abilities

There are different institutions involved in the water management in the Con Dao Islands, including (1) the Department of Finance, which provides financial resources for relevant activities; (2) various associations such as the women's association, veteran association, etc., which play an important role in promoting and raising awareness of the local people; (3) the Economic Department, which is in charge of operating the dam systems; and (4) residential areas which play a supporting role in the local water management. The cooperation between the different institutions is reported to be effective and smooth.

Nevertheless, multiple institutional bottlenecks were raised by the respondents. Firstly, laws and policies on monitoring and controlling pollution for small-scale businesses or households are limited, especially in wastewater management for livestock. There are neither regulations nor mechanisms on the sanctions for causing environmental pollution that are applied to the smallholders. Secondly, some organizations are public non-business units; therefore, all the expenses need to be approved at higher managing levels through long and complicated procedures. Unclear and overlapping roles limit the effectiveness of the working process. An unclear position in the formal system also makes it difficult to coordinate with higher managing levels. Another bottleneck is the limited capacity of the officials. Not only is there a need for improving their professional skills, but the officials also expressed a need for additional training in other fields. Finally, there is a lack of information, especially on the groundwater capacity of the area; thus, it is difficult to expand the current capacity of the water supply.

Financial Abilities

Respondents stated that the financial capacity of the relevant agencies in water management is sufficient to carry out their tasks. Their budgets are provided by the central government following the current financial regulations of Vietnam. Priorities of the budget include paying tax to the government, paying salary to the staff, and contributing to a common fund for awarding and other social benefits. However, they do not have a financial budget for capacity building.

Technical Abilities

The technical abilities are varied in different agencies. In the case of the Water Supply Station, though most of the technicians have been working for a long time, since after the American War (1975), their capacity is nevertheless limited in operating the old water supply system. These technicians have lots of experience and they work manually very well; however, this might be a disadvantage if the Station wants to upgrade the water system using state-of-the-art technologies. This agency, therefore, has a high demand for capacity building. By contrast, the technical officials of the DNRE are confident in their professional skills. However, they raise concerns on concurrent tasks that they were not trained to work on. Local officials follow assigned tasks from higher managing levels. Besides working in their professional field, they are concurrently responsible for other tasks due to a lack of human resources. For example, the technical staff of the DNRE has the main responsibilities of checking the results and writing reports on the monitoring of water quality. They are additionally in charge of working on raising awareness of the local people on water protection.

4. Discussion

4.1. The Roadmaps for Sustainable Water Management in Con Dao Island

Assumptions on the socio-economic conditions as input for different scenarios are summarized in Table 3. This section elaborates on the possibility of the different scenarios in light of the enablers and obstacles analyzed from the previous section.

Table 3. Input socio-economic scenarios and output from the model.

Input of the Model: Scenarios	Output from the Model
S0 (current water supply)	Does not meet future demand
S1 (increasing centralized water supply capacity by upgrading and constructing new reservoirs and a surface water supply plant)	Reduces but still does not meet future demand
S2 (find a low-cost alternative water resource, e.g., rainwater)	Reduces but still does not meet future demand
S3 (find high-cost alternative water resources, e.g., seawater)	Almost meets future demand (99%)
S4 (combine S2 and S3)	Fully meet future demand, reduce risky if any part does not work well

The current awareness of officials on the possible increasing demand and the shortage of water supply due to, e.g., population increase and tourism, is an enabler to motivate them to achieve alternatives described in scenarios S1, S2, S3, and S4. Given the current dominance of the hierarchical management system and existing plans of the leading water suppliers, increasing centralized water supply capacity by upgrading and constructing new reservoirs seems to be the most foreseen scenario (S1) on the island [20]. Nevertheless, meeting S1 would require extra technical training for the employed technical staff and recruiting new ones. This is possible with reasonable budget allocation available as mentioned above.

Alternatives for low-cost freshwater resources such as rainwater (S2) or high-cost resources such as seawater treatment (S3) are well recognized by the top officials in Con Dao. However, these alternatives would require affordable and workable technologies (for seawater) [28–30] and raising awareness in local people’s perceptions on saving freshwater (for rainwater and other facilities) [31–33]. While a considerable amount of finance and technical training to apply the new technologies is of concern, raising awareness is doable for local officials given their experience in campaigning and propaganda. Combining these measures would result in the most desirable scenario S4. With the current socio-economic and political situation of Con Dao, as well as enablers and obstacles as analyzed above, continuing on S1 at present while mobilizing resources for S2 and S3 would be the most suitable roadmap to achieve water demand of the island. Modelling well in advance and along the way to carefully assess the feasibility of each roadmap, considering possible changes will help to tackle uncertainties and support the Con Dao Island on the roadmap.

4.2. Further Recommendations for Water Management in the Con Dao Island

Due to the limits of water, land, and human resources, as well as the vulnerability to climate change, when it comes to water management in the island, an integrated approach should be considered. In integrated planning, all the different water resources and the uses and users of water resources must be considered together. Firstly, the available water resources and their sustainable yields should be assessed in the planning of water resource developments. The better-quality and cheaper water resources (rainwater, groundwater, surface water) need to be assessed initially. Other options, including desalination, may be required if the other sources are over-utilized or where the economy can afford them.

Conjunctive uses of different water should be considered. Better-quality water resources (i.e., rainwater) may be a suitable option for most basic demands that require high-quality standards, such as drinking and cooking with little or no treatment. While lower-quality water resources (surface water and seawater) require high treatment to supply high-quality standards, they can be suitable for meeting the non-drinking demands, such as toilet flushing and washing, with lower treatment. These approaches, which can enhance the sustainability of the water supply system and reduce the energy as well as the costs for treatment have also been widely proposed and practiced successfully in other studies [34–36].

While most of the large, centralized water developments (upgrading water reservoirs, water treatment and seawater treatment plants) consume a lot of time and resources, these methods only rely on human and economic resources from the government and do not involve the residents. A decentralized system, such as rooftop rainwater harvesting, can be much easier to implement. To promote a decentralized water supply system, the following strategies are recommended: first, more local pilot projects need to be implemented. Because water problems are site-specific, so should be the solutions. Technical criteria from other regions should be used only as a reference and should be customized to local conditions. Locally available materials and workers should be used where possible to minimize costs and increase the workmanship, as well as to enhance the awareness of residents. Operation and maintenance requirements should be minimized to enable the residents’ operation and maintenance. Second, the promotion and education of water preservation and use should be carried out at all levels. Lastly, an innovative micro-funding system should be created in cooperation with Corporate Social Responsibility (CSR) or Environmental, Social, and Governance (ESG) activities of the public sector enterprises as a win–win tool. Together with seed money from the public sector, small islands can develop a localized business via spinoff effects.

4.3. Socio-Hydrological Approach from This Study

The new-science socio-hydrology has been promoted recently as a promising tool for water management to cope with contemporary challenges, including the uncertainty from climate change. Socio-hydrology has been attempting to build predictive models on the

co-evolution of the coupled human–water system by integrating social aspects into existing hydrological models [10]. Despite the ongoing efforts, accommodating different social aspects into socio-hydrological models remains a challenge due to insufficient empirical data [37,38]. Attempting to overcome this challenge, social aspects, however, have been hardly integrated as inputs into our model due to several constraints including the limitations of the existing hydrological models and limited capacity of obtaining appropriate data for quantifying the social aspects for use in the selected models. Nevertheless, different attributes, such as the *socio-cultural responses*, *political/institutional setup*, and *water demand and availability*, in the socio-hydrological approach [6] have been addressed as inputs for the scenario development to identify the feasible roadmaps of Con Dao Island.

In this study, the importance of the protection of natural resources has been emphasized by local governments and well perceived by local people as a result of awareness-raising propaganda and campaigning. However, understanding climate change and its consequences has been neglected. Though having a good awareness of natural resources, local people are highly dependent on local governments for water use and management. The link between climate change and environmental issues, especially in the water sector, are not well perceived by local people, leading to a gap in perceptions of the existing issues. This is perceived as a consequence of the unclear and overlapping of the hierarchical management system in Vietnam, as well as a limited capacity of local officials. This research encounters several limitations, such as the small survey sample size and non-randomly selected samples. Better research design to adapt the questionnaires to local contexts and model preparation is recommended to continue the efforts in future research.

5. Conclusions

The proposed social-hydrological approach combining modeling and social methods such as focus group discussion, in-depth interviews, and a survey was applied to address water resource management in Con Dao Island. The analysis of the interaction between surface water and groundwater showed that the An Hai, QT1, and QT2 reservoirs play an important role in enhancing water supply resilience in the island, particularly during the dry season, as they are the main sources to recharge into the groundwater. The WEAP results also showed that the water demand in the island tends to increase in the context of socio-economic development, population growth, and climate change, making the water shortage more serious due to the limited water supply capacity. Although the water supply capacity in the island has been improved by the investment of the local government in water supply infrastructures, the water demand may not be fully met in the near future. The sustainable solution for the water supply system in Con Dao needs to be combined with the use of alternative water sources, such as rainwater and desalinated seawater.

Despite having a high awareness of the role of natural resources, local actors seem to neglect climate change and its consequences due to the hierarchical management system and the dependence of local people on the government. Given these enablers and obstacles, upgrading and constructing new reservoirs while mobilizing resources for freshwater alternatives and saving facilities is the most desirable roadmap for the island. To achieve the roadmap, strengthening adaptive capacity, raising awareness, and building a professional capacity for both local people and officials are important to address existing issues in water and relevant sectors in Con Dao Islands.

Further research could explore the possibility of integrating the information on social aspects into the existing models to understand better the interaction and co-evolution of the human–water system in the case of islands.

Author Contributions: Conceptualization and methodology, H.Q.N. and D.C.H.N.; data collection, H.Q.N., D.C.H.N., T.C.L. and T.T.L.; model set-up, D.C.H.N.; social analysis, T.T.L. and H.Q.N.; writing—original draft preparation, D.C.H.N., T.T.L. and H.Q.N.; writing—review and editing, D.C.H.N., T.T.L., H.Q.N., P.K., D.C.N. and R.D. All authors have read and agreed to the published version of the manuscript.

Funding: This work is supported by Asia Pacific Network for Global Change Research (APN) under the Collaborative Regional Research Programme (CRRP) with project reference number CRRP2019-01MY-Kumar.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data developed in this study will be made available on request to the corresponding authors.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Water demand in Con Dao (Con Dao Statistical Yearbook 2018).

Area	Water users	Quantity		Water Use Standard (m ³ /day)		Water Demand (m ³ /year)	
		2018	2030	2018	2030	2018	2030
Central Town	Local residents	5625	13,500	0.1	0.2	205,313	985,500
	Tourists	4000	6500	0.2	0.3	292,000	711,750
	Annual crop (ha)	12	5			58,696	24,457
	Vegetables (ha)	6	33	Crop coefficient		29,348	161,415
	Fruit trees (ha)	14	11			111,992	87,994
	Cattles (head)	207	500	0.05	0.05	3778	9125
	Pigs (head)	1072	2000	0.03	0.03	11,738	21,900
	Chickens, ducks (head)	11,000	20,000	0.01	0.01	20,075	36,500
	Goat (head)	157	300	0.03	0.03	1433	2738
	Industry (ha)	7	11	22.0	22.0	54,750	91,250
Ben Dam	Local residents	1300	3000	0.1	0.2	47,450	19,000
	Tourists	-	500	0.2	0.3	-	54,750
	Industry (ha)	45	62	22.0	22.0	361,350	97,860
Co Ong	Local residents	1500	4000	0.1	0.2	54,750	292,000
	Tourists	300	2500	0.2	0.3	21,900	273,750
	Vegetables(ha)	2		Crop coefficient		9783	24,457
	Industry (ha)	3	5	22.0	100.0	21,900	36,500

Appendix B

Table A2. The meteorological data—monthly rainfall and evaporation in Con Dao (unit: mm).

2018												
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Rainfall	7.8	4.6	3.2	4.8	32.2	301.9	526.8	436.5	223.2	256.4	102.1	66.6
Evaporation	117.1	101.3	103.1	97.6	93.1	88.5	92.9	97.2	86	75.9	95.1	113.3
2014												
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Rainfall	3.5	0	0	1.5	72.6	163.1	415.9	153.2	174.2	282.4	126.6	61.7
Evaporation	105.5	108.5	112.2	101.8	83.8	91	93.4	102	80	87.2	87.4	94.8

Appendix C. Questions for the Focus Group Discussion

1. What kind of activities do you need to use water for? For example, agriculture, aquaculture, industry, etc.
2. What kind of issues related to water use are you currently facing in your area?
3. Do you experience any water shortages for domestic use?
4. Do you think the water quality has an effect on your mental and physical health?
5. Do you think water shortage has an effect on your social relationships?
6. Do you feel annoyed when you experience water shortages or low water quality?
7. Are you discriminated against due to water shortages or low water quality?
8. Do you know about policies that are related to water in your area? If yes, please specify.

References

1. Blair, P.; Buytaert, W. Socio-hydrological modelling: A review asking "why, what and how?". *Hydrol. Earth Syst. Sci.* **2016**, *20*, 443–478. [\[CrossRef\]](#)
2. Kumar, P. Numerical quantification of current status quo and future prediction of water quality in eight Asian megacities: Challenges and opportunities for sustainable water management. *Environ. Monit. Assess.* **2019**, *191*, 319. [\[CrossRef\]](#) [\[PubMed\]](#)
3. United Nations World Water Assessment Programme (WWAP). *The United Nations World Water Development Report 2017; Wastewater: The Untapped Resource*; UNESCO: Paris, France, 2017; p. 198.
4. Jalilov, S.-M.; Kefi, M.; Kumar, P.; Masago, Y.; Mishra, B.K. Sustainable Urban Water Management: Application for Integrated Assessment in Southeast Asia. *Sustainability* **2018**, *10*, 122. [\[CrossRef\]](#)
5. Peña-Ramos, J.; Bagus, P.; Fursova, D. Water Conflicts in Central Asia: Some Recommendations on the Non-Conflictual Use of Water. *Sustainability* **2021**, *13*, 3479. [\[CrossRef\]](#)
6. Kumar, P.; Avtar, R.; Dasgupta, R.; Johnson, B.A.; Mukherjee, A.; Ahsan, N.; Nguyen, D.C.H.; Nguyen, H.Q.; Shaw, R.; Mishra, B.K. Socio-hydrology: A key approach for adaptation to water scarcity and achieving human well-being in large riverine islands. *Prog. Disaster Sci.* **2020**, *8*, 100134. [\[CrossRef\]](#)
7. Ingol-Blanco, E.; McKinney, D.C. Development of a Hydrological Model for the Rio Conchos Basin. *J. Hydrol. Eng.* **2013**, *18*, 340–351. [\[CrossRef\]](#)
8. Slaughter, A.R.; Mantel, S.K.; Hughes, D.A. Investigating possible climate change and development effects on water quality within an arid catchment in South Africa: A comparison of two models. In Proceedings of the 7th International Congress on Environmental Modelling and Software, San Diego, CA, USA, 15–19 June 2014; Volume 3, pp. 1568–1575.
9. Yang, L.; Bai, X.; Khanna, N.Z.; Yi, S.; Hu, Y.; Deng, J.; Gao, H.; Tuo, L.; Xiang, S.; Zhou, N. Water evaluation and planning (WEAP) model application for exploring the water deficit at catchment level in Beijing. *Desalination Water Treat.* **2018**, *118*, 12–25. [\[CrossRef\]](#)
10. Sivapalan, M.; Savenije, H.H.G.; Blöschl, G. Socio-hydrology: A new science of people and water. *Hydrol. Process.* **2011**, *26*, 1270–1276. [\[CrossRef\]](#)
11. Herrera-Franco, G.; Montalván-Burbano, N.; Carrión-Mero, P.; Bravo-Montero, L. Worldwide Research on Socio-Hydrology: A Bibliometric Analysis. *Water* **2021**, *13*, 1283. [\[CrossRef\]](#)
12. Eslamian, S.; Reyhani, M.N.; Syme, G. Building socio-hydrological resilience: From theory to practice. *J. Hydrol.* **2019**, *575*, 930–932. [\[CrossRef\]](#)
13. Srinivasan, V.; Sanderson, M.; Garcia, M.; Konar, M.; Blöschl, G.; Sivapalan, M. Prediction in a socio-hydrological world. *Hydrol. Sci. J.* **2017**, *62*, 338–345. [\[CrossRef\]](#)
14. Viglione, A.; Di Baldassarre, G.; Brandimarte, L.; Kuil, L.; Carr, G.; Salinas, J.L.; Scolobig, A.; Blöschl, G. Insights from socio-hydrology modelling on dealing with flood risk—Roles of collective memory, risk-taking attitude and trust. *J. Hydrol.* **2014**, *518*, 71–82. [\[CrossRef\]](#)
15. Falter, D.; Schröter, K.; Dung, N.V.; Vorogushyn, S.; Kreibich, H.; Hundecha, Y.; Apel, H.; Merz, B. Spatially coherent flood risk assessment based on long-term continuous simulation with a coupled model chain. *J. Hydrol.* **2015**, *524*, 182–193. [\[CrossRef\]](#)
16. Fish, R.D.; Ioris, A.A.; Watson, N.M. Integrating water and agricultural management: Collaborative governance for a complex policy problem. *Sci. Total. Environ.* **2010**, *408*, 5623–5630. [\[CrossRef\]](#)
17. Dang, T.K.P. Tourism imaginaries and the selective perception of visitors: Postcolonial heritage in Con Dao Islands, Vietnam. *Isl. Stud. J.* **2021**, *16*, 249–270. [\[CrossRef\]](#)
18. National Institute of Agricultural Planning and Projection (NIAPP). *Agricultural Development Planning of Con Dao District to 2020, Vision to 2030*; National Institute of Agricultural Planning and Projection (NIAPP): Hanoi, Vietnam, 2017.
19. Long, T.T.; Koontanakulvong, S. SW-GW Interaction Analysis for Drought Management in Con Son Valley, Con Dao Island, Ba Ria-Vung Tau Province, Vietnam. In Proceedings of the 1st AUN/SEED-Net Regional Conference on Natural Disaster, Yogyakarta, Indonesia, 22–23 January 2014; Volume 22, p. 23.
20. Minister of Planning and Investment (MPI). *Decision No. 1742/QĐ-BKHDT of the on Approving the Master Plan on Socio-economic Development of Con Dao District, Ba Ria-Vung Tau Province, Up to 2020, with a Vision toward 2030*; Minister of Planning and Investment (MPI): Hanoi, Vietnam, 2011.
21. Mounir, Z.M.; Ma, C.M.; Amadou, I. Application of Water Evaluation and Planning (WEAP): A Model to Assess Future Water Demands in the Niger River (In Niger Republic). *Mod. Appl. Sci.* **2011**, *5*, 38. [\[CrossRef\]](#)
22. Dang, D.K.; Tran, N.A.; Mai, T.N. Application of WEAP model for integrated water balance in Lam River Basin. *Vietnam J. Sci. Technol.* **2015**, *31*, 186–194.
23. Agarwal, S.; Patil, J.P.; Goyal, V.C.; Singh, A. Assessment of Water Supply–Demand Using Water Evaluation and Planning (WEAP) Model for Ur River Watershed, Madhya Pradesh, India. *J. Inst. Eng. Ser. A* **2019**, *100*, 21–32. [\[CrossRef\]](#)
24. Nguyen, H.Q.; Korbee, D.; Ho, L.; Weger, J.; Hoa, P.T.T.; Duyen, N.T.T.; Luan, P.D.M.H.; Luu, T.T.; Thao, D.H.P.; Trang, N.T.T.; et al. Farmer adoptability for livelihood transformations in the Mekong Delta: A case in Ben Tre province. *J. Environ. Plan. Manag.* **2019**, *62*, 1603–1618. [\[CrossRef\]](#)
25. Phi, H.L.; Hermans, L.M.; Douven, W.J.; Van Halsema, G.E.; Khan, M.F. A framework to assess plan implementation maturity with an application to flood management in Vietnam. *Water Int.* **2015**, *40*, 984–1003. [\[CrossRef\]](#)

26. Ba Ria—Vung Tau (BRVT) Statistics Office. *BRVT Statistical Yearbook 2018*; Statistical Publishing House of BRVT: BRVT, Vietnam, 2019.
27. Minister of Natural Resources and Environment (MONRE). *Climate Change and Sea Level Rise Scenarios for Vietnam*. 2016. Available online: https://vihema.gov.vn/wp-content/uploads/2015/12/02.-Tom-tat-Kich-ban-BDKH-va-NBD-cho-VN_2016-Tieng-Anh.pdf (accessed on 25 September 2020).
28. Urrea, S.A.; Reyes, F.D.; Suárez, B.P.; Bencomo, J.A.D.L.F. Technical review, evaluation and efficiency of energy recovery devices installed in the Canary Islands desalination plants. *Desalination* **2018**, *450*, 54–63. [[CrossRef](#)]
29. Borge-Diez, D.; Garcia-Moya, F.J.; Cabrera-Santana, P.; Rosales-Asensio, E. Feasibility analysis of wind and solar powered desalination plants: An application to islands. *Sci. Total. Environ.* **2020**, *764*, 142878. [[CrossRef](#)]
30. Duong, H.C.; Tran, L.T.T.; Truong, H.T.; Nelemans, B. Seawater membrane distillation desalination for potable water provision on remote islands – A case study in Vietnam. *Case Stud. Chem. Environ. Eng.* **2021**, *4*, 100110. [[CrossRef](#)]
31. Thuy, B.T.; Dao, A.D.; Han, M.; Nguyen, D.C.; Nguyen, V.-A.; Park, H.; Luan, P.D.M.H.; Duyen, N.T.T.; Nguyen, H.Q. Rainwater for drinking in Vietnam: Barriers and strategies. *J. Water Supply Res. Technol.* **2019**, *68*, 585–594. [[CrossRef](#)]
32. Kim, Y.; Han, M.; Kabubi, J.; Sohn, H.-G.; Nguyen, D.-C. Community-based rainwater harvesting (CB-RWH) to supply drinking water in developing countries: Lessons learned from case studies in Africa and Asia. *Water Supply* **2016**, *16*, 1110–1121. [[CrossRef](#)]
33. Temesgen, T.; Han, M.; Park, H.; Kim, T.-I. Policies and Strategies to Overcome Barriers to Rainwater Harvesting for Urban Use in Ethiopia. *Water Resour. Manag.* **2016**, *30*, 5205–5215. [[CrossRef](#)]
34. Nguyen, D.C.; Han, M.Y. Design of dual water supply system using rainwater and groundwater at arsenic contaminated area in Vietnam. *J. Water Supply Res. Technol.* **2014**, *63*, 578–585. [[CrossRef](#)]
35. Kourtis, I.M.; Kotsifakis, K.G.; Feloni, E.G.; Baltas, E.A. Sustainable Water Resources Management in Small Greek Islands under Changing Climate. *Water* **2019**, *11*, 1694. [[CrossRef](#)]
36. Lautze, J.; Holmatov, B.; Saruchera, D.; Villholth, K.G. Conjunctive management of surface and groundwater in transboundary watercourses: A first assessment. *Hydrol. Res.* **2018**, *20*, 1–20. [[CrossRef](#)]
37. Aerts, J.C.J.H. Integrating agent-based approaches with flood risk models: A review and perspective Integrating agent-based approaches with flood risk models: A review and perspective. *J. Water Secur.* **2020**, *11*, 100076. [[CrossRef](#)]
38. Baldassarre, G.D.; Sivapalan, M.; Rusca, M.; Cudennec, C. Socio-hydrology: Scientific Challenges in Addressing a Societal Grand Challenge. *Water Resour. Res.* **2019**, *55*, 6327–6355. [[PubMed](#)]