SUSTAINING ISLAND PARADISES: BALANCING FRESHWATER RESOURCES AFFECTED BY OVERTOURISM IN SOUTHERN THAILAND

ELSE WINTERMANS

Faculty of Architecture & the Built Environment, Delft University of Technology
Julianalaan 134, 2628BL Delft

ABSTRACT

This paper examines the critical challenges of water scarcity and overtourism, focusing on their impact on islands in southern Thailand. The expansion of the tourism sector exacerbates water scarcity during low rainfall, causing groundwater depletion, saltwater intrusion, and wastewater issues. Urgent revisions to water strategies are emphasized, prioritizing the optimization of current freshwater resources. The proposed approach is guided by a literature-based Excel tool, with Koh Samui as a case study. The tool's spider diagram highlights key investment areas, including Active Leakage Control (ALC), groundwater recharge, and wastewater treatment. Despite dry periods, the island can leverage its high precipitation through Rainwater Harvesting (RWH), with considerations for alternatives like desalination and Atmospheric Water Harvesting (AWH). The (re)-use of non-potable water sources further alleviates pressure on the freshwater system. In conclusion, the tool provides a clear roadmap for water strategy development, establishing essential priorities.

KEYWORDS: *Water Scarcity, Water Strategy, Overtourism, Sustainable Tourism, Islands, Thailand, Koh Samui*

I. INTRODUCTION

1.1. Global Problem of Water Scarcity and Overtourism

Global water scarcity is currently a focal point of discussions about environmental sustainability and the safety of future water supply systems. Globally, population expansion and economic growth have significantly increased the demand for adequate, clean, and safe water sources (Tzanakakis et al., 2020). As a result, the world is facing an increasing challenge of water scarcity. This critical challenge impacts approximately 2.3 billion people residing in water-stressed areas, with projections indicating the potential displacement of around 700 million people by 2030 due to widespread water scarcity (Tashtoush & Alshoubaki, 2023).

Simultaneously, the tourism industry has undergone significant growth as an economic activity. This growth has been accompanied by the concentration of tourist flows to specific areas, causing crowding and problems with carrying capacity, a phenomenon commonly referred to as overtourism (Butowski, 2019). Tourism is increasingly contributing to local and seasonal pressures on water supply systems of tourist destinations worldwide (Becken, 2014). The rise in tourism imposes an additional burden on local water reserves, especially in areas already sensitive to water scarcity such as (semi-)arid and remote regions (Fathy et al., 2021). Considering climate change, it is anticipated that this situation will deteriorate in the future.

1.2. Water Scarcity on Islands

Islands have been considered popular tourist destinations for a long time. Yet their remoteness, size, dependency on imports, and limited waste absorption capacity have also often contributed to a lack of control over many sustainability challenges that affect them (Butler & Dodds, 2022). Numerous islands, reliant on tourism as their main industry, encounter challenges associated with water scarcity primarily due to the overwhelming expansion of the tourism sector. Water problems on islands are mainly related to the limited water resources. This results in a water scarcity or shortage, characterized by uneven distribution across both time and space. Consequently, there is a tendency to excessively exploit the available freshwater reservoirs, impacting their long-term quality and sustainability (Hophmayer-Tokich & Kadiman, 2006).

1.3. Water Scarcity on Thai Islands

Numerous islands located in the southern region of Thailand experience the issue of water scarcity caused by overtourism (Beutick & Breure, 2016; Board, 2023; Changklom et al., 2021). The problem arises during a period of low rainfall coinciding with the peak tourist season and is worsened by improper wastewater management. The limited freshwater supply drives up the cost of piped water, urging businesses to drill wells to access groundwater. This leads to a decline in the water table. As aquifer water levels decrease, seawater begins to intrude into the groundwater, causing saltwater contamination. Furthermore, the local water treatment plants on these islands are incapable of managing the volume of wastewater generated. As a result, excessive untreated wastewater is discharged into the sea, contributing to the pollution of both seawater and groundwater (Beutick & Breure, 2016; Board, 2023).

Anticipated growth of tourist numbers on Thai islands exceeds the capacity of the current water system. Consequently, it is imperative to revise and enhance existing water strategies to encourage water conservation practices and increase water availability. This paper examines potential strategies to improve and ensure the sustainability of water systems on islands to meet future demands. The current water system on five selected Thai islands is analyzed, and one island is selected to serve as an illustrative example to elaborate on potential water strategy improvements.

1.4. Definitions of Water

In this study, various types of water are discussed. The primary focus of the research lies in tap water, aiming to achieve a balance between supply and demand. On the selected Thai islands tap water primarily serves personal hygiene, cleaning, pool maintenance and irrigation (Beutick & Breure, 2016).

Table 1. Definitions of Water (Author, 2023).

Term	Definition
Fresh Water	Contains no or an unnoticeable concentration of sea salt (e.g. rainwater)
Brackish Water	Contains a noticeable concentration of salt which is less than the concentration in salt/sea water
Salt/Sea Water	Water with a high concentration of salt
Drinking Water	Water of drinking quality
Tap Water	Water from the tap, this type of water is equal to (filtered) fresh water

Wastewater	The consumed tap or drinking water collected in a drainage system, incorporating the effluent from activities such as flushing toilets, showers, emptying pools, and similar sources
Rainwater	Equal to precipitation
Groundwater	Water available in the subsurface, this water can be either fresh or brackish

II. METHODOLOGY

2.1. Methods of Water Extraction

The initial step involves examining various strategies to address water scarcity on islands. Addressing water scarcity includes considering three primary actions:

- reducing water consumption
- temporarily storing water
- increasing water supply

Challenges associated with water scarcity can be tackled at different levels, including island-wide, within local municipalities or cities, and at the level of individual units such as hotels, resorts, or individual users. Through literature review, a set of methods is established to identify the most effective and feasible measures given a specific situation. This set of methods is translated into an Excel tool (referred to as water strategy tool) that can be used for any island. Based on the parameter values per island the water strategy tool will result in a spider diagram that provides an overview of the most effective methods and where the best investments can be made to alleviate pressure on existing freshwater sources. Subsequently, the water strategy tool is used to formulate a water strategy to address water scarcity on Thai islands.

2.2. Selected Island

To visualize the current water system on Thai islands, an analysis has been conducted on a chosen set of five Thai islands: Phuket, Koh Phi Phi Don, Koh Samui, Koh Pha-Ngan, and Koh Tao. The selection of these islands is based on the overarching issue of water scarcity mainly caused by overtourism. Besides, the islands were chosen to represent two distinct precipitation patterns observed between the eastern and western coasts within the southern region of Thailand. Additionally, an effort was made to select islands with variations in factors such as size, population, and number of tourists (see Appendix C: Climate and Selected Islands). Data of these islands regarding tap water supply, tap water demand, climate and tourist arrivals is collected and analyzed to draw conclusions about the current and future water balance. Koh Samui is used as an example to visualize the existing water system and apply the water strategy tool.

2.2.1 Current Water System

To differentiate between various sources of tap water, the current water system of Koh Samui is initially examined (Figure 1). An analysis of existing water sources has been performed and mapped out (see Appendix E: Data Selected Island Koh Samui; Figure 1). Given that tourism is the main operating industry, the focus of water usage will be on households and tourists. There is no exact data available on the sector distribution of Koh Samui. Nevertheless, it is known that a small percentage is associated with agriculture, particularly coconut plantations. This category will be classified as "other," encompassing the remaining industries. The distribution of tap water mainly relies on pickup trucks carrying various quantities, collected by residents in private or shared water tanks.

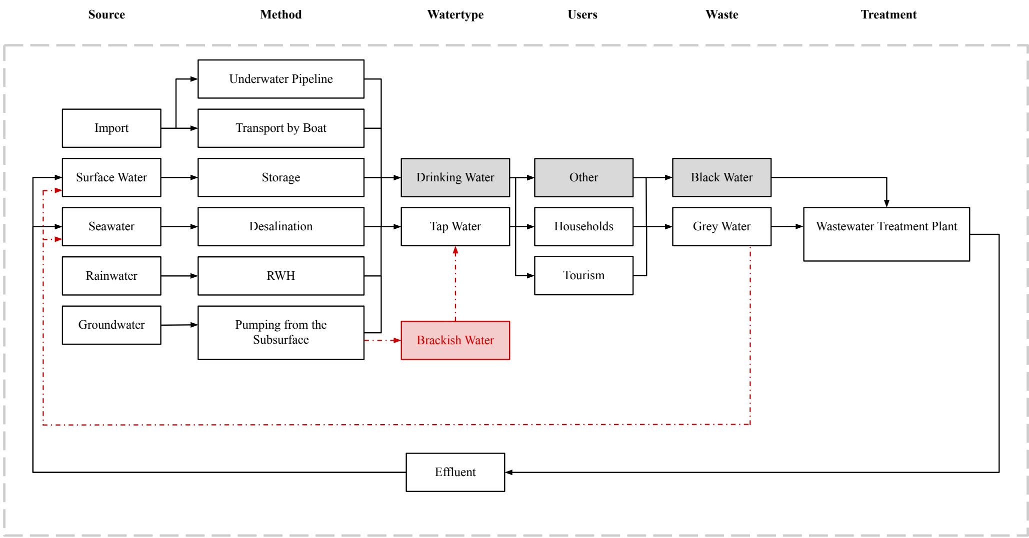

Figure 1. Current Tap Water System flow diagram of Koh Samui, highlighting in red the damaging water flows caused by overloading of the water system due to overtourism (Author, 2023)

2.2.1.1 Tap Water Supply

Historically, rainwater was the only source of tap water before the island became a tourist hotspot. This occurred through direct catchment or extraction from the subsurface after infiltration. The surge in tourism has strained the water supply system, resulting in intermittent availability of freshwater from natural sources. To cope, water is brought in by boat daily and an underwater pipeline was constructed from the mainland to Koh Samui as an additional water source, completed in 2019 (Board, 2023). In addition to imported water, there is a small percentage of saltwater converted into tap water through desalination. Data regarding to factors established for the water strategy tool, which influences the water supply system (e.g. topography, monthly precipitation pattern) is collected and analyzed.

2.2.1.2 Tap Water Demand

In a study conducted by Becken (2014), an analysis of water usage associated with tourism was performed across 21 countries, comparing it to municipal use. The findings indicate that the most significant disparities are evident in countries with low or moderate incomes. In Thailand, the average water consumption by tourists is more than six times higher than that of the local population. This highlights a substantial imbalance in the water supply between tourists and residents. In Excel, a calculation is included to estimate the monthly water consumption. The calculation is based on the study of Beutick and Breure (2016), that aims to advise the local government of Koh Tao on improving its water system to meet future tap water demand. The calculation considers the disparity between the water usage of tourists and that of the local population, established through literature review. Additionally, it incorporates the monthly variations in tourist numbers (see Appendix D: Calculation Tap Water Demand). Data regarding tap water demand will be collected and analyzed to draw conclusions about the water system.

2.2.1.3 Wastewater

Pollution of water resources is a major problem that affects water quality and thus availability. Since tourism is the main industry of Koh Samui, wastewater is mainly produced by tourist accommodations. There is no exact data available on wastewater treatment plants on Koh Samui, but it is known that the volume of wastewater exceeds the island's capacity. This information will be considered in determining the improvement strategy.

2.2.2 Improvement Strategy

After collecting all data, the water strategy tool can be applied to identify opportunities for Koh Samui to enhance its current water system and meet future demand. The outcome of the water strategy tool, combined with the analysis of the current water system, leads to a new flow diagram that integrates improvement methods. Conclusions regarding the improvement strategy and applicability of the tool can be derived from this diagram.

III. RESULTS

3.1 Methods of Water Extraction

The strain on available freshwater reserves emphasizes the urgent need for sustainable management of water resources. Several solutions to improve water management on islands are outlined in this section. However, there is no singular action that can address the challenge of sustainable water management on islands. Instead, an integrated approach that includes a range of measures is required at all levels (island-wide, within local municipalities or cities, and at the level of individual units). These include both introduction of appropriate technology as well as improvement of management issues. Besides, it is important to note that raising awareness of water issues by locals and tourists at all levels is critical in the successful implementation of water conservation programs and activities.

The suggested solutions primarily involve the preservation of existing water resources, and the development of alternative ones. Studies indicate that merely augmenting water supply cannot solely resolve issues of water scarcity (Hophmayer-Tokich & Kadiman, 2006). The more water is produced, the more it tends to be consumed. It seems to be more advisable to enhance the utilization of the current freshwater resources (e.g., by minimizing wastage and pollution) before introducing alternative options, or at least parallel to them. Therefore, the approach to address water scarcity on islands is divided into two steps: preserve the current water system and introduce alternative water sources.

3.1.1 Preserve Existing Water System

3.1.1.1 Reduce Water Loss

Reducing water losses is one of the most important methods of saving water and should be addressed on the island-wide scale to conserve the existing freshwater resources, before investing in alternative and expensive solutions (Hophmayer-Tokich & Kadiman, 2006). Water loss is characterized by the discrepancy between water pumped into a system and the water billed to users. The volume of water lost depends largely on the quality, maintenance, and approach to active leakage control (ALC) of the water distribution network. Non-revenue water (NRW) refers to the water lost before it reaches consumers. High NRW rates result from the loss of large quantities of water through leakages in water distribution networks, which encompass both physical losses and apparent losses (Ong et al., 2023). Apparent losses include water that is consumed but not paid, directly impacting the utility's revenue. Physical losses include leaks in network, transmission, water tanks and service connections.

To minimize water loss, the development of an Apparent Loss Control (ALC) strategy is essential. ALC comprises diverse methods for managing and preventing leaks within water distribution systems. Approaches to reduce apparent losses include customer management and water meter management, while methods to minimize physical losses involve pressure management, District Metered Areas (DMA), speed and quality of repairs, and leak detection technologies (see Appendix A: Methods of Water Extraction; Figure 1; Table 1). These strategies aim at reaching a level of water loss reduction that is economically, environmentally, and socially acceptable. It is important to note that complete elimination of physical water losses is not feasible. Hence, the minimum technically achievable annual volume of water losses in well-maintained and well-managed systems is referred to as unavoidable water loss. The most beneficial method of ALC often depends on the specific characteristics of the water distribution system. However, a comprehensive approach that combines multiple techniques tends to be most effective. ALC not only contributes to delivering less water to the system but also delays the necessity for new resources, reducing energy costs, efficient use of energy and water, and reducing the number of maintenance and repairs/costs (Bozkurt et al., 2022).

3.1.1.2 Improve Water Quality

The decline in water quality not only poses health risks but also reduces water availability if wells are compromised, exacerbating the issue of water scarcity on islands (Hophmayer-Tokich & Kadiman, 2006). Therefore, it is crucial to adopt approaches aimed at enhancing water quality. These approaches should be addressed on the island-wide scale but can also be supported on the local- and individual unit level.

On islands, two main types of pollution exist: saltwater contamination and wastewater pollution. Strategies to enhance wastewater treatment plants encompass methods such as integrating natural systems, climate-adaptive infrastructure, process control systems, energy efficiency improvement, decentralized treatment units, and nutrient recovery. Addressing saltwater contamination involves methods to improve the natural renewal of groundwater in aquifers, including infiltration galleries, groundwater recharge systems, aquifer monitoring, and zoning regulations (see Appendix A: Methods of Water Extraction; Figure 2; Table 2). Through a combination of these strategies, islands can work towards improving water quality.

3.1.1.3 (Re)Use of Non-Potable Water Sources

Wastewater treatment not only contributes to pollution prevention but also creates opportunities for water recycling. Non-potable water sources include seawater, brackish water and treated wastewater. Using these types of water for non-potable purposes alleviates the demand on natural aquifers (Hophmayer-Tokich & Kadiman, 2006). Non-potable purposes include toilet flushing, washing, firefighting, agricultural/landscape irrigation, cooling systems, swimming pools, industrial processes, and groundwater recharge - depending on the level of treatment and effluent quality. The utilization of non-potable water sources can be implemented on all scales: island-wide, local, and individual units.

(Re)Use of non-potable water sources strategies could be effectively implemented through a combination of strategic planning and infrastructure development. Greywater recycling schemes, agricultural water management and dual pipe systems in tourist venues and resorts can reduce the pressure of tourist related water problems (see Appendix A: Methods of Water Extraction; Figure 3; Table 3).

3.1.1.4 Use of Water Saving Technologies

The use of water-saving technologies is aimed at reducing water consumption and promoting efficient water management practices. This not only results in financial savings for households and businesses but also improves resilience during droughts. Methods include efficient irrigation systems, low-flow fixtures, and smart water meters (see Appendix A: Methods of Water Extraction; Table 4). However, initial installation costs can be a barrier, particularly for smaller communities with limited budgets. Additionally, some advanced technologies may require specialized knowledge for proper implementation and maintenance, posing technical challenges. Retrofitting existing infrastructure to accommodate these technologies may also be logistically complex and costly. Therefore, successfully navigating these challenges involves a comprehensive approach, considering local conditions and the adoption of technologies to the specific needs of the island.

3.1.1.5 Increasing Water Storage

Increasing water storage refers to the deliberate effort to enhance the capacity to store and retain water for various purposes. This is crucial for managing water resources, especially in the face of growing populations, climate change, and increasing water demand. There are various methods for enhancing water storage, ranging from traditional approaches like reservoirs, dams and water storage tanks to more innovative and sustainable solutions like stormwater management systems and green infrastructure (see Appendix A: Methods of Water Extraction; Table 5). However, the feasibility of these methods is dependent on the availability of adequate space and precipitation. The size, geography and community dynamics of an island directly impacts the availability of space, which becomes a critical factor, especially in coastal areas where most of the local population and tourist activities are concentrated (Hophmayer-Tokich & Kadiman, 2006). Thus, while increasing water storage is crucial for addressing water-related challenges, it is important to recognize that the effectiveness of such measures is closely tied to the spatial considerations inherent to the island's unique context.

3.1.2 Introduce Alternative Water Sources

3.1.2.1 Water Importation

Water importation involves transporting water from external sources to an island to meet rising demand, typically implemented on the island-wide scale. The management of water on islands is heavily influenced by their isolation, requiring a dependency on local water resources (Hophmayer-Tokich & Kadiman, 2006). Water importation methods include underwater pipelines, seawater transport or air transport (most uncommon) (see Appendix A: Methods of Water Extraction; Table 6). The feasibility of water importation depends on the island's geographical context. Islands near continents or part of an archipelago can leverage their proximity to overcome logistical challenges in water transportation. Conversely, more isolated islands face greater obstacles, making water importation less viable due to significant distances.

Islands face a nuanced situation when contemplating water importation. While it offers a practical solution for water shortages, especially in less remote islands, it brings disadvantages. The process heightens dependence on external water sources, challenging the island's self-sufficiency and resilience. Therefore, the decision to import water involves careful consideration of the island's isolation, logistical constraints, and the potential impact on its autonomy in water resource management.

3.1.2.2 Rainwater Harvesting

Rainwater harvesting (RWH) involves the utilization of technology to collect and store rainwater sourced from rooftops, land surfaces, or rock catchments. This practice employs various methods, ranging from simple approaches like barrels to more intricate techniques such as underground check dams (see Appendix A: Methods of Water Extraction; Table 7) (Hophmayer-Tokich & Kadiman, 2006). Rainwater collected from roof catchments is typically suitable for the individual unit use and has minimal adverse environmental effects. Moreover, technologies are simple to install and operate, local people can be easily trained to implement them, and construction materials are also readily available. Nevertheless, rainwater harvesting should not be considered as a primary or sole water source, mainly due to its limited supply and the uncertainty of rainfall.

3.1.2.3 Desalination

Desalination refers to the process of extracting the excess salt and other minerals from seawater or brackish water to obtain freshwater. In some cases, desalination processes can also be used to produce electricity (Trinh et al., 2022). Despite providing a reliable water source that is not subjected to the seasonal changes, desalinated water is costlier than traditional freshwater for many countries. Factors affecting desalination costs include capacity and type of facility, location, feed water, labor, energy and concentrate disposal. Seawater desalination is generally more expensive than treating brackish water. Moreover, the complexity of desalination systems requires high maintenance and expertise, as well as materials and equipment of very high standard, not usually available locally, resulting in high importation costs (Hophmayer-Tokich & Kadiman, 2006). Thus, although desalination can effectively address domestic water demands, its high cost requires the implementation of other measures. Many regard desalination as a final option, suitable only when conventional water resources are depleted. It should not replace a more cost-effective, long-term water supply strategy but rather act as a supplementary source.

Desalination technologies can be classified based on their separation mechanisms into two categories: phase-change (thermal) processes and membrane-based separation processes. In the phase-change method, salts are removed through continuous evaporation and condensation processes. This includes techniques like multi-effect distillation (MED), multi-stage flash (MSF) and vapor compression distillation (MVC). The membrane-based desalination utilizes membranes - such as reverse osmosis (RO), nanofiltration (NF) and electrodialysis (ED) - acting as filters to allow water to pass through while retaining salt and other minerals (see Appendix A: Methods of Water Extraction; Table 8). Currently the desalination industry is dominated by reverse osmosis (RO), because of its simplicity, energy efficiency and relatively low operational cost (Hailemariam et al., 2020). Additionally, desalination can be classified as active or passive. Active desalination uses external power sources and mechanical systems and may have higher energy requirements. In contrast, passive desalination relies on natural energy sources like solar radiation and osmotic pressure without requiring external power, making it energy-efficient and environmentally sustainable. Examples include solar desalination, pressure retarded osmosis (PRO) and forward osmosis (FO) (Pourkiaei et al., 2021). The choice between active and passive methods depends on factors like energy availability, scale, and environmental considerations.

3.1.2.4 Atmospheric Water Harvesting

Atmospheric water harvesting (AWH) is the process of collecting water from air by condensing moisture present in the atmosphere. It involves the use of specialized systems to capture water vapor, which is then condensed into liquid water. This process typically requires cooling air to a point where the moisture condenses, and the condensed water droplets are collected on surfaces designed for this purpose. The effectiveness of AWH is subject to factors such as humidity and temperature (Tashtoush & Alshoubaki, 2023). Although Atmospheric Water Harvesting (AWH) presents a promising solution for regions struggling with water scarcity, the initial installation of such systems can incur substantial upfront costs. This financial burden may pose a challenge for communities with restricted financial resources. Additionally, high expertise is required for proper operation and maintenance of these systems. Furthermore, the water yield from AWH systems is relatively low in comparison to alternative water sources. Particularly in regions with low humidity, the water output may decrease, restricting the viability of AWH in arid climates. These limitations emphasize that AWH may be better suited as a supplementary water source rather than a primary one.

Fog and dew are the two types of atmospheric water that can be harvested using specialized systems. In some regions, fog harvesting is a beneficial source of water, but it is limited by the occurrence of fog. In contrast, dew-gathering technology can be used wherever a cooled surface is available. Natural factors such as temperature, relative humidity, wind speed, cloudiness and material properties influence the process of dew formation. Regions with high humidity, low wind, and sunny days are ideal. Dew water harvesting can be divided into three main categories:

passive or radiative cooling condensers approach, water generation via a solar-regenerated desiccant system, and water collection via an active cooling condensation method (see Appendix A: Methods of Water Extraction; Table 9). Active water harvesting technologies are based on the use of energy to operate specific prototypes or devices, which can be powered by sorbent materials or cooling the air below its dew point temperature. The amount of harvested water in active water collecting devices is directly proportional to the amount of input energy. These technologies are capable of collecting significantly more water compared to passive methods (Tashtoush & Alshoubaki, 2023).

3.1.3 Assessment Factors with Corresponding Methods

The applicability of the above-mentioned measures depends on various factors (e.g. precipitation rate, temperature, prosperity, relative humidity) that are implemented to the water strategy tool. These factors are plotted in an entry sheet in Excel (see Appendix B: Water Strategy Tool; Table 1). This entry sheet is linked to the spider diagram where a score of 0 to 4 is plotted for each factor, with higher scores indicating better applicability. The diagram should be viewed clockwise, with reducing water loss and improving water quality taking priority, and alternative water sources such as import, desalination, and AWH considered as the least possible options. Subsequently, the applicable solutions sheet outlines the effectiveness of each method as illustrated in table 2, with green signifying the most effective methods, yellow being a viable choice in the absence of other solutions, and red indicating ineffectiveness.

Table 2. Example of applicable solutions sheet Koh Samui (Author, 2023).

Assessment Factor	Method Group	Method
Distance to Mainland	Importation	Pipelines
Prosperity	Desalination	Reverse Osmosis (RO)
Fog	Atmospheric Water Harvesting	Fog Harvesting

3.2. Selected Island

3.2.1 Water Strategy Tool

Figure 2 illustrates the spider diagram obtained for Koh Samui. The diagram highlights Koh Samui's notable scores in ALC, groundwater recharge, and wastewater treatment, attributed to substantial water loss and issues with water quality due to saltwater intrusion and wastewater pollution. To enhance the water system, it is imperative to prioritize investment in these key areas. Despite facing dry periods, the island benefits from a relatively high precipitation pattern, offering significant potential for RWH. During periods of rainfall, rainwater can be collected and temporarily stored for effective utilization during dry spells. In case these strategies prove insufficient, desalination and AWH emerge as viable options, considering the consistently high temperatures and relative humidity prevalent throughout the year. The specific methods associated with these strategies are detailed in Appendix F: Water Strategy Tool. In summary, the island's distinctive characteristics present broad opportunities to enhance and sustainably manage its water system.

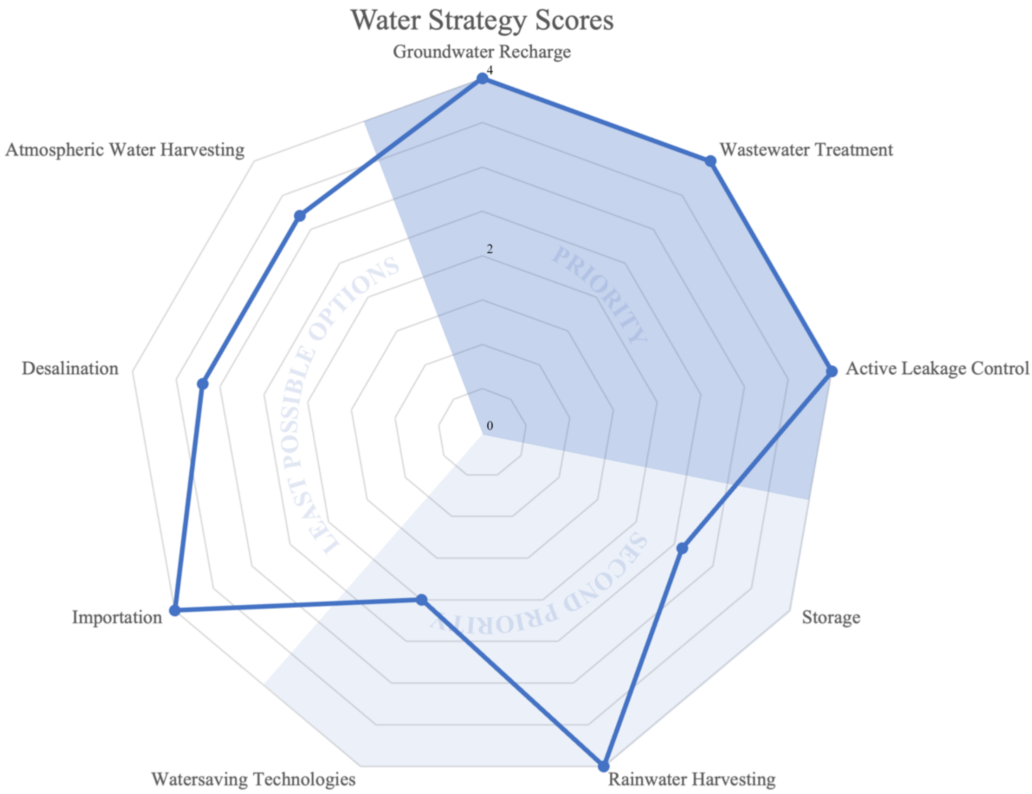

Figure 2. Result of Potential Water Strategies for Koh Samui (Author, 2023)

3.2.2 Improvement Strategy Koh Samui

With the obtained spider diagram, a suggestion can be made to integrate potential methods into the current water system, as illustrated in Figure 3. Due to the existing water pollution from saltwater intrusion and untreated wastewater, it is crucial to prioritize investment in addressing these issues. This involves incorporating groundwater recharge systems, investing in wastewater plants, and reusing both grey water and treated wastewater to alleviate the strain on wastewater processing. Due to significant water loss, it is crucial to implement ALC methods for the identification and resolution of water leaks. Additionally, brackish water is introduced as a new water type for non-potable purposes, including toilet flushing, washing, firefighting, agricultural/landscape irrigation, cooling systems, and swimming pools. Due to a relatively high annual precipitation rate, initial investment in RWH is advised. Despite the relatively high rainfall, issues arise during dry periods due to insufficient water retention, with most of the rainfall occurring in October and November, making December to April the driest period. The highest water demand is also from February to April and August (see Appendix E: Data Selected Island Koh Samui). At the individual unit level, a significant contribution can be made by installing rooftop catchment systems, potentially locally filtered for non-potable use during droughts. Only as a final step alternative water sources like desalination and AWH should be considered. Due to high temperatures and relative humidity, desalination and AWH methods can be passively applied on Koh Samui, nevertheless careful consideration of costs and expertise is required. These methods might be considered as additional water sources during extreme periods (February to April and August). In conclusion, emphasis remains on improving existing strategies, and the flow diagram highlights that non-potable water reuse effectively alleviates pressure on the island's existing freshwater system.

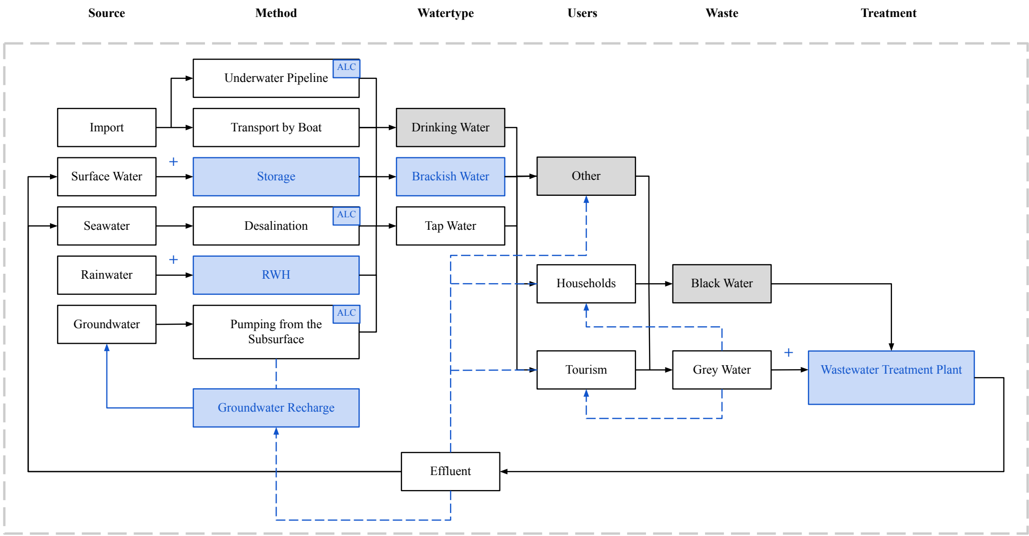

Figure 3. Tap Water System flow diagram of Koh Samui with improvement strategies, highlighting in blue the changes. (Author, 2023)

IV. CONCLUSIONS

This paper examines the occurring global issues of water scarcity and overtourism, focusing on their intersection and impact on islands, particularly in the southern region of Thailand. These islands, already vulnerable due to their size and isolation, face difficulties in managing local freshwater resources. The overwhelming expansion of the tourism sector during low rainfall periods intensifies water scarcity on these islands, leading to groundwater depletion, saltwater contamination, and inadequate wastewater management. The paper emphasizes the urgency of revising water strategies to sustainably manage water resources on islands and proposing potential strategies, with a specific focus on Koh Samui. The suggested approach advocates prioritizing the optimization of current freshwater resources before introducing alternatives. Strategies are formulated at various levels, utilizing a literature-based water strategy tool that assesses feasibility through a spider diagram, guiding effective method selection. Koh Samui serves as a case study for the application of the water strategy tool, aiding in the identification of effective measures tailored to the island's unique characteristics and challenges. The outcome spider diagram for Koh Samui emphasizes methods like Active Leakage Control (ALC), groundwater recharge, and wastewater treatment that require priority investment. Despite facing dry periods, the island can benefit from its yearly high precipitation pattern through Rainwater Harvesting (RWH), with additional considerations for alternative sources like desalination and Atmospheric Water Harvesting (AWH) during extreme periods. Besides, (re)-use of non-potable water sources like grey water, treated wastewater and brackish water (e.g. toilet flushing and irrigation) significantly releases pressure on the existing freshwater system. In conclusion, it can be stated that the tool provides a clear direction for the development of a water strategy, serving as a foundation for determining priorities.

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APPENDIX

A: Methods of Water Extraction

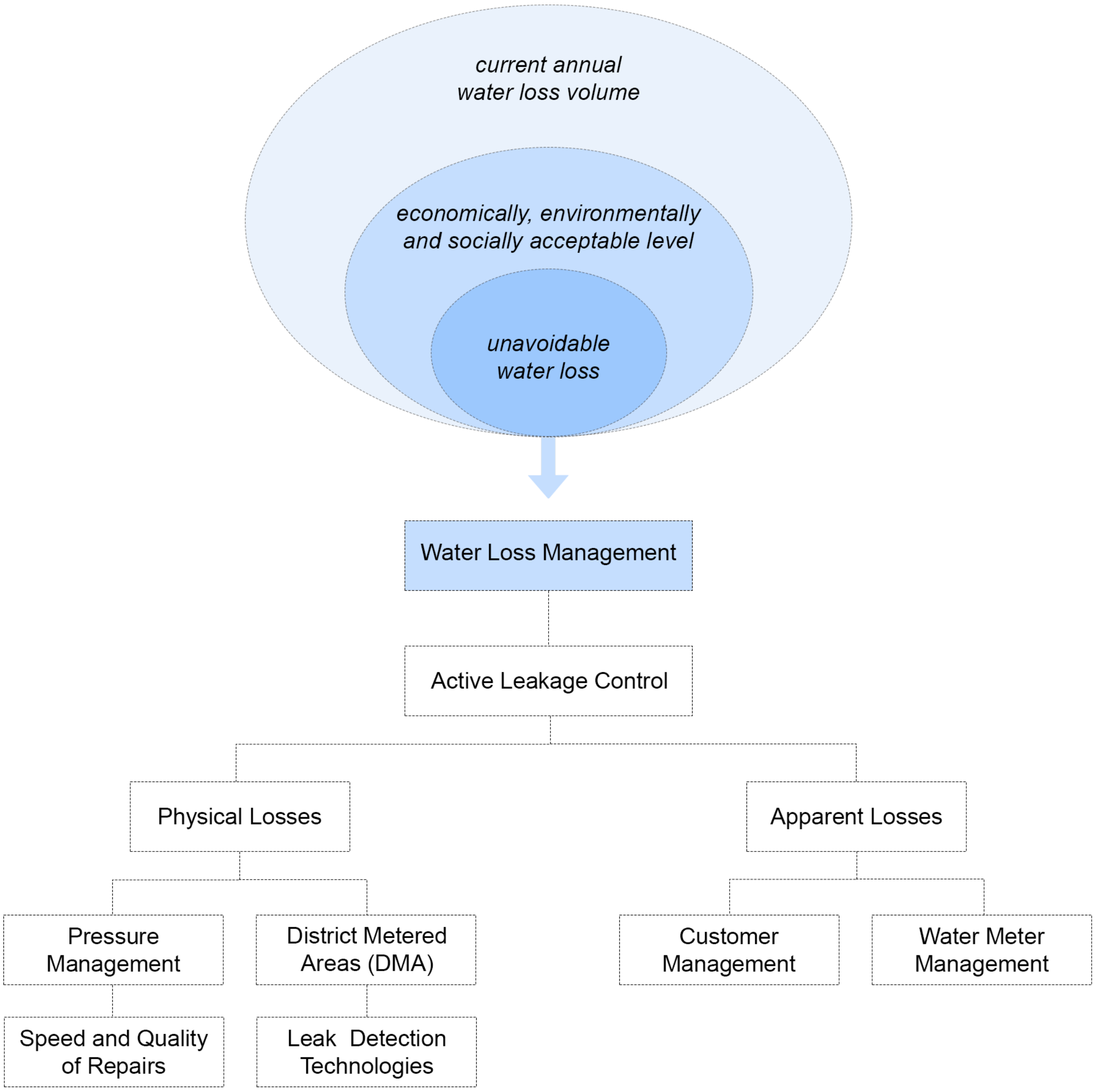

Figure 1: Water Loss Management Strategies (Author, 2023)

Table 1. Reduce Water Losses: Definitions of ALC Methods (Author, 2023).

Methods	**Physical Losses**
Pressure Management	Pressure management is one of the most influential and cost-effective activities of reducing leakage. It can be defined as the practice of managing water distribution system pressures to the optimum levels of service ensuring sufficient and efficient supply to consumers (Charalambous et al., 2014).
District Metered Areas (DMA)	A division of the water distribution network into smaller sections or zones with defined boundaries. It is a systematic approach to operational

	management that allows water service providers to analyze water-flow profiles, identify potential problem areas with greater ease, and, thus, reduce leakage detection time (Ong. et al., 2023).
Speed and Quality of Repairs	Aims to ensure timely and lasting repair and is regarded as critical to the success of the overall physical water loss control program. The length of time a leak is allowed to run affects the volume of physical losses, so repairs should be completed as soon as possible once a leak is detected. Repair quality also has an effect on whether the repair is sustained (Charalambous et al., 2014).
Leak Detection Technologies	Modern leak detection technologies include both hardware and software-based tools. Such devices can quickly identify problem areas and leakages in the distribution network, better evaluate their impacts on water loss volumes, and improve the ability of service providers to respond rapidly and repair leaks (Ong. et al., 2023).
Methods	**Apparent Losses**
Customer Management	Apparent losses from water theft (e.g. illegal connections and meter tampering) can be reduced through a combination of customer reporting and monetary instruments (e.g. fines). Implementing a customer reporting programme encourages water users to have a greater awareness of their consumption and report illegal connections (Ong. et al., 2023).
Water Meter Management	Mechanical and/or smart water meters which monitor customer consumption patterns apparent losses by tracking the volume of water distributed from the storage locations to the distributor mains and supply service lines (Ong. et al., 2023).

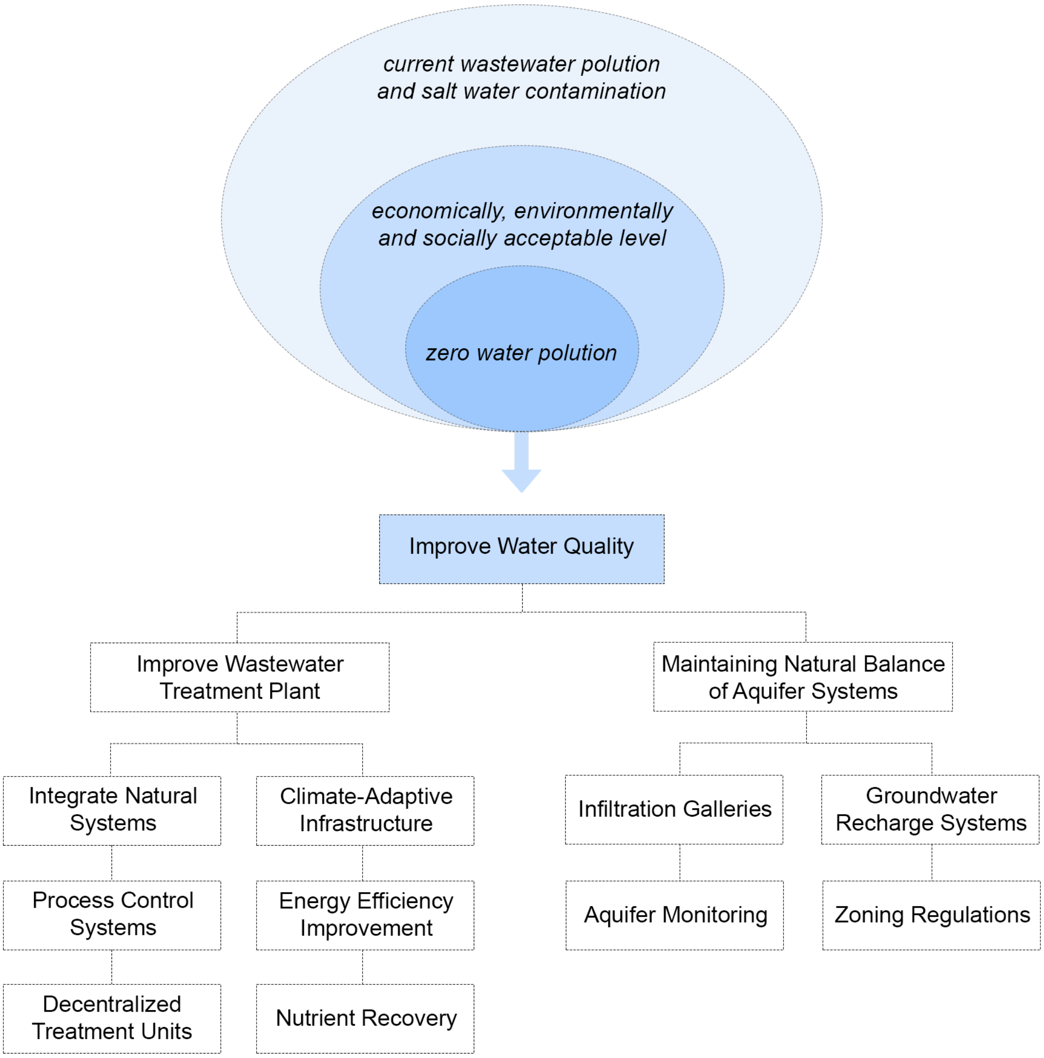

Figure 2: Improve Water Quality Methods (Author, 2023)

Table 2. Improve Water Quality: Definitions of Methods (Author, 2023).

Methods	Improve Wastewater Treatment Plant
Integrate Natural Systems	Incorporating ecological and natural processes to enhance the overall efficiency and sustainability of wastewater treatment facilities. This approach recognizes the capacity of natural systems to treat and purify water through biological, physical, and chemical processes. Examples are systems like constructed wetlands for additional treatment and green roofs to manage stormwater and reduce the volume of water entering the treatment plant during rain events.
Climate-Adaptive Infrastructure	Design and upgrade infrastructure to be resilient to the impacts of climate change, such as increased stormwater flows and extreme weather events.
Process Control Systems	The use of automation and technology to monitor, regulate and optimize various processes within a wastewater treatment plant. These systems play a

	crucial role in improving the efficiency, reliability, and overall performance of wastewater treatment.
Energy Efficiency Improvement	Implementing measures to optimize the energy consumption of treatment processes, thereby reducing operational costs and environmental impacts. For example this could be done by upgrading pumps, blowers, and other equipment to more energy-efficient models and/or implementing technologies like anaerobic digestion with biogas recovery to generate energy from organic sludge.
Decentralized Treatment Units	Integrate decentralized treatment units, such as compact package plants or constructed wetlands, to treat specific types of wastewater or address localized issues.
Nutrient Recovery	Involves the extraction and recycling of valuable nutrients, such as nitrogen and phosphorus, from wastewater before it is discharged or reused. This approach addresses environmental concerns associated with nutrient discharges into water bodies, such as eutrophication, while also providing opportunities for resource reuse.
Methods	**Maintaining Natural Balance of Aquifer Systems**
Infiltration Galleries	Infiltration galleries, also known as horizontal wells, use submerged horizontal conduit systems, typically PVC slotted pipes, to allow water permeation. Buried near sea level, these structures collect groundwater, mitigating saline intrusion and facilitating centralized extraction for various purposes.
Groundwater Recharge System	A groundwater recharge system comprises methods and practices intended to replenish or enhance the natural renewal of groundwater in an aquifer. The aim of a groundwater recharge system is to enhance the natural process by which water infiltrates the subsurface and reaches the groundwater table. Groundwater recharge systems play a crucial role in maintaining the balance of aquifer systems and mitigating the impacts of over-extraction. They are particularly important in areas facing challenges such as declining groundwater levels, increased water demand, and the potential effects of climate change on water availability.
Aquifer Monitoring	Establish a comprehensive aquifer monitoring program to regularly assess groundwater levels, quality and trends.
Zoning Regulations	Implement land use planning measures that consider groundwater protection, including restrictions on activities that could contaminate or deplete aquifers.

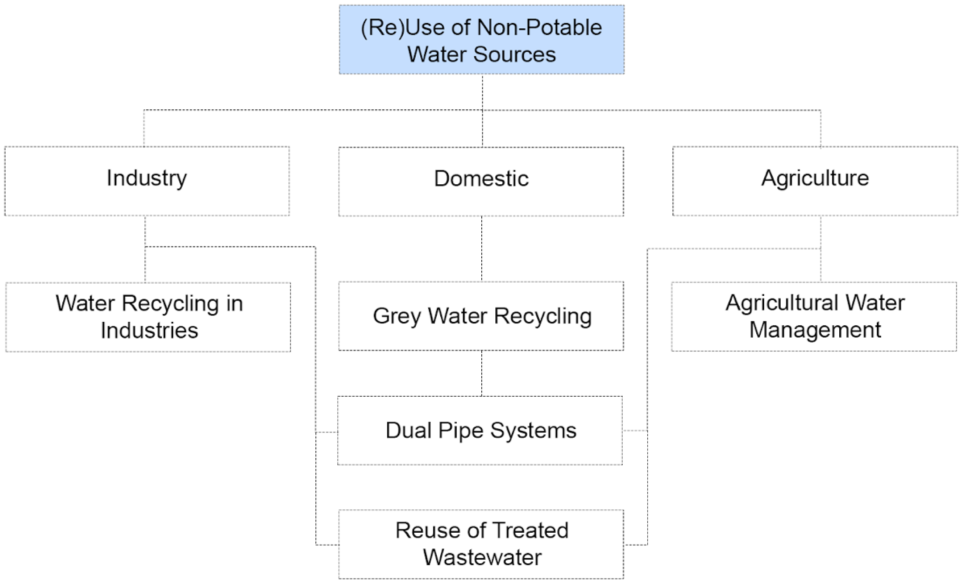

Figure 3: (Re)Use of Non-Potable Water Sources Methods (Author, 2023)

Table 3. (Re)Use of Non-Potable Water Sources: Definitions of Methods (Author, 2023).

Methods	**(Re)Use of Non-Potable Water Sources**
Reuse of Treated Wastewater	The reuse of treated wastewater involves the application of treated or reclaimed wastewater for various beneficial purposes instead of discharging it directly into the environment. Treated wastewater is subjected to advanced purification processes to meet specific water quality standards, making it suitable for non-potable uses like agricultural/landscape irrigation, industrial processes, cooling systems, groundwater recharge, etc. Reusing treated wastewater is an important practice for sustainable water management and contributes to water conservation.
Greywater Recycling	Greywater recycling involves the collection, treatment, and reuse of wastewater generated from domestic activities such as bathing, showering, handwashing and laundry. Unlike blackwater, greywater is relatively clean and can be treated for reuse in non-potable applications like landscape irrigation, toilet flushing, laundry, car washing, cooling systems, etc. Proper design, treatment and adherence to regulatory standards are essential for the safe and effective implementation of greywater recycling systems.
Agricultural Water Management	Agricultural water management involves the planning, distribution, and efficient use of water resources in agricultural practices to achieve optimal crop production while considering sustainability, water conservation, and environmental impact. This field addresses the challenges of providing adequate water to crops, managing irrigation systems, and minimizing water-related risks in agriculture. This includes employing diverse irrigation methods like drip, sprinkler, and surface irrigation tailored to meet specific crop water needs. Additionally, it involves cultivating crops with greater tolerance to saline water, enabling the use of brackish water for irrigation.
Dual Pipe Systems	Dual pipe systems, also known as dual plumbing systems or dual distribution systems, involve the installation of two separate sets of pipes within a building — one for potable water and the other for non-potable water. This

	approach is designed to distinguish between water used for different purposes, optimizing resource use and promoting water conservation.
Water Recycling in Industries	Water recycling in industries involves the collection, treatment and reuse of water in closed-loop systems within industrial processes. This practice helps industries become more efficient and responsible in managing water usage. Recycled water could be used in manufacturing processes, cooling systems and other industrial operations.

Table 4. Use of Water Saving Technologies: Definitions of Methods (Author, 2023).

Methods	**Water Saving**
Efficient Irrigation Systems	Drip irrigation and precision irrigation technologies deliver water directly to plant roots, minimizing wastage and optimizing water use in agriculture. Soil moisture sensors and smart irrigation controllers further enhance efficiency by tailoring irrigation schedules based on actual plant needs.
Low-Flow Fixtures	Low-flow fixtures, including low-flow toilets, faucets and showerheads, reduce water consumption in households and commercial buildings. These fixtures maintain functionality while significantly decreasing water usage, contributing to water conservation efforts.
Smart Water Meters	Smart water meters provide real-time data on water consumption, allowing consumers and utilities to monitor usage patterns. This technology enables more informed decision-making, identities leaks promptly and promotes water conservation by encouraging responsible water use.

Table 5. Increase Water Storage: Definitions of Methods (Author, 2023).

Methods	**Water Storage**
Reservoirs and Dams	Building reservoirs and dams is a traditional method to increase water storage capacity. These large artificial lakes store freshwater from other sources, serving as a reliable supply during periods of low rainfall. Reservoirs can be strategically located to maximize water availability.
Green Infrastructure	Green infrastructure increases water storage by incorporating natural or nature-based elements that promote water retention, infiltration and absorption. Permeable surfaces, rain gardens, urban forests, wetlands and other features contribute to enhanced water storage capacity. These practices reduce surface runoff, promote groundwater recharge and mitigate the impact of stormwater.
Stormwater Management Systems	Developing stormwater management systems helps capture and store excess rainwater during heavy rainfall events. This can involve the construction of retention ponds, permeable surfaces and green infrastructure to reduce runoff and enhance water storage.
Water Storage Tanks	Installing water storage tanks provides a direct and accessible way to store treated water. These tanks can be located at various points in the distribution network, ensuring a steady supply of water. Storage tanks can also be

	implemented at the local- and individual unit level by community tanks and individual tanks.

Table 6. Water Importation: Definitions of Methods (Author, 2023).

Methods	**Water Importation**
Seawater Transport	Water can be transported in large tanker ships that carry significant volumes of freshwater. These ships load water from a source and transport it to the destination island, where it is unloaded and distributed.
Air Transport	Water can be transported via air using cargo planes equipped with water storage containers. While this method is less common and more expensive, it may be considered for urgent or emergency situations.
Pipelines	Pipelines can be constructed underwater or over long distances to transport water from a mainland source to an island. This method is feasible when there is a relatively short distance between the island and the mainland.

Table 7. Rain Water Harvesting: Definitions of Methods (Author, 2023).

Methods	**RWH**
Rooftop Catchment Systems	Roof-based rainwater harvesting involves collecting rainwater runoff from building roofs using gutters and downspouts. The water is directed to storage systems, such as rain barrels or cisterns, after passing through leaf screens and first flush diverters to improve its quality. Filtration and optional purification methods further enhance water quality. This practice provides a local and cost-effective water source for non-potable uses like irrigation and flushing toilets.
Underground Checkdams	An underground check dam is a water conservation structure designed to capture and store rainwater underground. These structures are typically implemented in regions with intermittent or seasonal water flow.

Table 8. Desalination: Definitions of Methods (Author, 2023).

Methods	**Desalination**
Reverse Osmosis (RO)	RO is the most widely used desalination method worldwide. It involves forcing water through a semipermeable membrane to separate salts and impurities from the water, producing freshwater (Ahmed et al., 2021).
Nanofiltration (NF)	NF is a membrane-based water treatment process that have a larger semi-permeable membrane pore size than RO. While it is effective in removing salts and certain contaminants, it also permits the passage of some smaller ions and molecules. This selectivity is advantageous in applications where partial desalination or specific ion removal is desired (Ahmed et al., 2021).
Electrodialysis (ED)	ED uses an electric field to drive ions through ion-exchange membranes, separating salt ions from freshwater. This method is particularly used for brackish water desalination, because the energy required for ED increases

	with increasing concentration of ions in the feed solution (Ahmed et al., 2021).
Multi-Stage Flash Distillation (MSF)	In this method seawater is heated under low pressure to produce stream. The steam is then condensed into freshwater, leaving the salts behind. The process is repeated in multiple stages to enhance efficiency (Ahmed et al., 2021).
Multi-Effect Distillation (MED)	Similar to MSF, MED involves heating seawater to produce steam. However, in MED the steam is generated in multiple chambers (effects) at different temperatures, allowing for more energy-efficient freshwater production (Ahmed et al., 2021).
Vapor Compression Distillation (MVC)	MVC is a thermal desalination process that involves the evaporation and condensation of water to separate it from salts and impurities. This method utilizes the principle of vapor compression to enhance the efficiency of the desalination process. MVC is known for its relatively higher energy efficiency compared to traditional thermal desalination methods like MED and MSF (Ahmed et al., 2021).
Solar Desalination	Solar desalination refers to the process of using solar energy to convert saline or brackish water into freshwater. It includes methods like solar stills, where sunlight evaporates water, leaving salts behind, and solar-assisted desalination systems that integrate solar energy with other desalination technologies. Challenges include addressing efficiency, scalability and the intermittent nature of solar energy for large-scale and continuous water production (Ahmed et al., 2021).
Pressure Retarded Osmosis (PRO)	PRO is a process that harnesses the osmotic pressure difference between freshwater and saline water to generate energy. It involves placing a semi-permeable membrane between freshwater and saline water sources. As water molecules move from the freshwater to the saline side through the membrane, they create pressure on the saline side. This pressure is used to drive turbines or generators, converting osmotic pressure into mechanical or electrical energy. PRO is a renewable energy method with potential for low environmental impact, but challenges include optimizing membrane efficiency and addressing scale-up issues (Ahmed et al., 2021).
Forward Osmosis (FO)	FO is a water treatment method leveraging osmotic pressure to separate water from dissolved solutes. In FO, a draw solution with lower osmotic pressure is placed alongside a more concentrated feed solution, separated by a semipermeable membrane. Water naturally moves from the feed solution to the draw solution through the membrane, leaving behind contaminants. The draw solution, enriched with separated water, can be regenerated for reuse. Challenges include draw solution regeneration and the selection of efficient membranes (Ahmed et al., 2021).

Table 9. Atmospheric Water Harvesting: Definitions of Methods (Author, 2023).

Methods	**AWH**
Fog Harvesting	Fog harvesting is a method of collecting water from suspended droplets in the air. The principle of the fog collector is based on a conventional idea: mesh is installed in a fog-prone area, exposed to the wind. When fog interacts with

	the mesh, water molecules within the fog start to trickle down into a collector tank under the influence of gravity. Two main types of fog collectors exist: standard fog collectors and large fog collectors. Large fog collectors are designed for substantial water yields, while standard fog collectors are suitable for smaller-scale applications. Fog harvesting is particularly effective in areas with high humidity and frequent fog (Tashtoush & Alshoubaki, 2023).
Radiative Cooling	Radiative cooling is a method that uses the natural cooling capacity of the Earth's surface to collect atmospheric water. This process involves exposing specific materials to the sky, enabling them to cool below the surrounding temperature and condense water vapor from the atmosphere. The Earth's surface cools through the emission of thermal radiation, which is absorbed by the atmosphere and then radiated back into space. Radiative cooling has the potential to reduce surface temperatures below the dew point, causing atmospheric water vapor to condense and form collectible water. This technique exhibits promise for water harvesting in arid and semi-arid regions, where conventional methods may be less efficient. It is a simple process relying on the temperature difference between sky radiation and the outgoing radiation power of the condenser (Tashtoush & Alshoubaki, 2023).
Solar-Regenerated Desiccant Systems	This method produces water through desiccant materials such as zeolites and hygroscopic silica-gel, which absorb atmospheric moisture during the night and undergo a desorption process to regenerate water during the daytime. This desorption process involves releasing water molecules from the desiccant materials through heating induced by solar radiation. However, a significant drawback of this method is its limited water yield (Tashtoush & Alshoubaki, 2023).
Active Cooling Condensation Method	Active cooling in atmospheric water harvesting requires electrical power to run a compressor or vacuum pump, resulting in a high-water yield when the active harvesting device is consistently employed. Dew water harvesting technology, being unaffected by climatic conditions, serves as an alternative technology available to supply water to environmentally sensitive areas. Additionally, the quantity of water harvested by active water-collecting devices is directly proportional to the input energy amount, indicating that the energy it can provide determines the duration for obtaining atmospheric harvested water. Many systems operate based on the evaporation-condensation principle, and active water harvesting systems are commonly designed utilizing a vapor compression cycle. However, desiccant wheels can also be employed in the design of active water harvesting devices (Tashtoush & Alshoubaki, 2023).

B: Water Strategy Tool

The water strategy tool is based on assessment factors as displayed in Table 1. Islands' size and population density are classified by the Asian Development Bank (Hophmayer-Tokich & Kadiman, 2006). The other numerical factors are based on global averages.

Table 1. Assessment Factors for Water Management Methods (Author, 2023).

Assessment Factors				Corresponding Methods
Size	very small *< 100 km²*	small *100 km² - 2000 km²*	large *> 2000 km²*	Storage - AWH
Population Density	low < 50 inhabitant/km2	moderate 50 - 500 inhabitant/km2	high > 500 inhabitant/km2	Storage
Topography	gently sloping *the land surface displays mild slopes and is generally not very steep*	moderately sloping *the landscape has significant slopes, but they are still manageable*	steep *the area is characterized by steep slopes, indicating pronounced relief*	Storage - AWH
Distance to Mainland	very close *< 25 km*	close *25 km - 100 km*	far *> 100 km*	Importation
Annual Precipitation Rate	low *< 500 mm*	moderate *500 mm - 1000 mm*	high *> 1000 mm*	RWH - Storage
Average Relative Humidity	low *< 30%*	moderate *30% - 70%*	high *>70%*	AWH
Temperature	low *< 10℃*	moderate *10℃ - 25℃*	high *> 25℃*	Desalination - AWH
Prosperity	low *limited economic resources, low income levels and restricted access to essential amenities*	moderate *moderate economic resources and incomes, where access to basic needs and services is reasonable*	high *abundant economic resources, high income levels and extensive access to high-quality amenities and services*	Water Saving Technologies - Desalination - AWH
Water Loss	low *islands with minimal water loss, indicating efficient water*	moderate *islands experiencing a moderate level of water loss,*	high *islands characterized by a significant level of water loss,*	ALC

	management practices and infrastructure	*suggesting a need for improved water conservation measures and infrastructure maintenance*	*signifying potential inefficiencies in water distribution systems and infrastructure*	
Water Quality	low *islands experiencing challenges with limited water quality due to saltwater contamination and wastewater pollution*	moderate *islands experiencing a moderate level of water quality concerns, including issues related to saltwater contamination and wastewater pollution*	high *islands characterized by a high level of water quality, with minimal impact from saltwater contamination and wastewater pollution*	Wastewater Treatment - Groundwater Recharge

C: Climate and Selected Islands

Thailand features a tropical climate influenced by seasonal monsoon winds, with the southern region manifesting unique climatic patterns compared to the mainland. Figure 1 provides a map of Thailand, with the selected islands and different climate zones. The east coast (4), facing the Gulf of Thailand, experiences heavy rainfall between October and mid-December. Contrastingly, the west coast (5), along the Andaman Sea, encounters a rainy season from May to October, characterized by less intense rainfall.

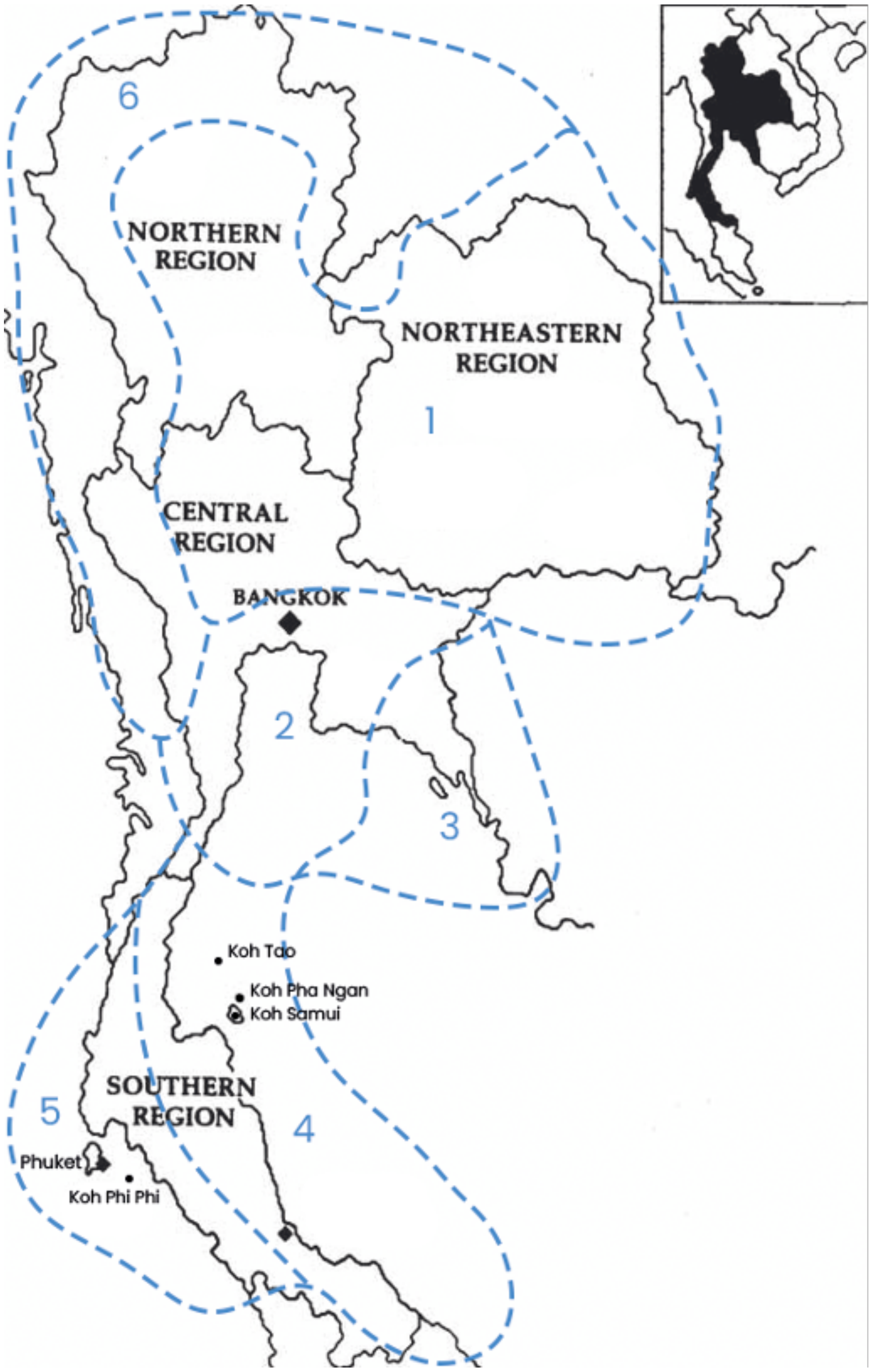

Figure 1. Climate Zones of Thailand with Selected Islands (Author, 2023)

Table 1. Characteristics of Selected Islands (Author, 2023).

Island	Surface (m^2)	Location	Permanent Residents	Yearly Amount of Tourists	Precipitation ≥ 150 mm
Phuket	1.406	Southern region - west coast	400.000	14.000.000	May – Oct
Koh Phi Phi Don	10	Southern region - west coast	2.500	?	May - Oct
Koh Samui	229	Southern region - east coast	70.000	2.700.000	Oct - Nov
Koh Pha-Ngan	125	Southern region - east coast	14.000	1.000.000	Oct - Nov
Koh Tao	21	Southern region - east coast	10.000	500.000	Oct - Nov

D: Calculation Tap Water Demand

The generated spreadsheet calculates values by integrating both present and anticipated future demand with the following formulas:

$$Yearly\ Water\ Demand\ (m^3) = \left(N_{tourist} * V_{water} * t_{tourist} + N_{permanent} * V_{water,l} * 365\right) * F_r * F_{s,l}$$

$$Monthly\ Water\ Demand\ (m^3) = \left(N_{tourist,month} * V_{water,t} * t_{tourist} + N_{permanent} * V_{water,l} * d_{month}\right) * F_r * F_{s,l}$$

With:

$$N_{tourist,month} = \%_{total\ tourist,month} * N_{tourist}$$

Subsequently, the average daily water demand is calculated as follows:

$$Daily\ Water\ Demand\ (m^3) = \frac{Monthly\ Water\ Demand}{d_{month}}$$

Table 1. Definition parameters, highlighting in blue the parameters that have a fixed value equal for each selected island (Author, 2023).

Parameter	Characteristic	Value	Unit
$N_{tourist, current}$	Tourists per year (current)	*variable*	People
$N_{tourist, future}$	Tourists per year (future)	*variable*	People
$N_{permanent}$	Permanent residents	*variable*	People
$V_{water,t}$	Average water demand tourists	0,5	m^3 per tourist per day
$V_{water,cl}$	Average water demand locals (current)	0,008	m^3 per inhabitant per day
$V_{water,fl}$	Average water demand locals (future)	0,12	m^3 per inhabitant per day
$t_{tourist}$	Average tourist stay	*variable*	days
d	Days per year / per month	365 / *variable*	days
F_r	Rest demand factor	*variable*	-
$F_{s,l}$	Spillage and leakage factor	*variable*	-

In table 1, the definitions of the parameters are presented. Parameters highlighted in blue have a predetermined value that remains the same for each island. The water demand for tourists and inhabitants has been established through literature review. It is assumed that this usage will be similar for each island.

Tourist Water Demand

The water usage of tourists varies based on their activities and accommodation types. Studies show a wide global range from 84 to 2000 liters per person per day (Gossling et al., 2012). For instance, resorts often require more water for irrigation of green spaces, whereas direct water use in guestrooms dominates in hotels. Additionally, facilities like spas, swimming pools, and sports amenities contribute significantly to daily water consumption. Water demands also vary with the tourist accommodation occupancy rates and the season, particularly concerning garden irrigation during dry periods.

According to research by Becken (2014), the average water consumption in hotels of tourists is 716 liters per person per day in Thailand. The study of Beutick and Breure (2016) suggests an approximate average daily water consumption of 500 liters per tourist on Koh Tao, based on accommodation types, tourist activities and literature insights. The selected islands share similar types of accommodations and tourist activities; therefore, a tourist water consumption rate of 500 liters per person per day is chosen. Tourists currently do not experience any water shortages on the islands; hence, it is assumed that their water usage will not change in the future.

Local Water Demand

As mentioned before, the average water consumption of tourists in Thailand exceeds the consumption of the local population by more than 6 times. The average water consumption of the local population of Thailand is 120 liters per person per day (Becken, 2014). However, on the selected islands, it is estimated that locals tend to consume less water on average due to existing water scarcity and high water costs, leading to efforts to conserve water. Despite some enhancements in living conditions, many residents still adopt basic water-saving methods, like manual toilet flushing and handwashing dishes. The study of Beutick and Breure (2016) estimated a current water demand of 80 liters per resident per day, based on interviews with local residents on Koh Tao. Besides, the water consumption of the local population of Phuket in

January 2020 was 932.180 m3/month (Changklom et al., 2021). With a population of approximately 400.000 individuals, this also results in a water demand of 0,08 m3 per person per day. Therefore it is assumed that this value applies to all selected islands. With anticipated economic advancements and potential reductions in water costs through sustainable solutions, the usage is expected to increase, reaching an average of 120L/day in the future.

Rest Water Demand

Beyond the dominant tourism sector and households, a minor fraction of water is utilized by other industries on the selected islands. Sector-specific data for these islands is only available for Koh Tao and Phuket. On Koh Tao, there is little to no industry and a small percentage of agricultural activity related to coconut plantations (Beutick & Breure, 2016). Conversely, on Phuket, the proportion of other industries is larger due to differences in size and population. Therefore, a distinction is made between the smaller islands with a relatively low population (Koh Phi Phi Don, Koh Tao, and Koh Pha-Ngan) and the larger ones with a relatively high population (Phuket and Koh Samui). It is anticipated that the proportion of water consumption by other industries will be highest on the largest island Phuket and lowest on the smallest island Koh Phi Phi Don, fluctuating between 10 to 50 percent.

E: Data Selected Island Koh Samui

Figure 1. Existing Water Sources Koh Samui - Scale 1:200.000 (Author, 2023)

Table 1. Total Yearly Demand Koh Samui (Author, 2023).

Characteristic	Parameter	Enter value	Unit
Tourists per year (current)	$N_{tourists, current}$	2.700.000	people
Tourists per year (future)	$N_{tourists, future}$	3.000.000	people
Permanent residents	$N_{permanent}$	70.000	people
Average water demand tourists	$V_{water, t}$	0,5	m3 per tourist per day
Average water demand locals (current)	$V_{water, cl}$	0,08	m3 per inhabitant per day
Average water demand locals (future)	$V_{water, fl}$	0,12	m3 per inhabitant per day
Average tourist stay	$t_{tourist}$	8,0	days
Days per year	d	365	days
Rest demand factor	F_r	1,4	-
Spillage and leakage factor	$F_{s, l}$	1,3	-
Current Yearly Demand	D_c	23.376.000	m3 per year
Future Yearly Demand	D_f	27.420.000	m3 per year

Table 2. Total Monthly and Daily Demand Koh Samui (Author, 2023).

Characteristic	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Unit
Percentage of Total Tourists	9,8%	10,3%	10,4%	9,8%	7,2%	7,0%	8,7%	12,0%	7,0%	6,0%	5,5%	6,3%	percentage
Tourists per month (Current)	264.600	278.100	280.800	264.600	194.400	189.000	234.900	324.000	189.000	162.000	148.500	170.100	people
Tourists per month (Future)	294.000	309.000	312.000	294.000	216.000	210.000	261.000	360.000	210.000	180.000	165.000	189.000	people
Days per month	31	28	31	30	31	30	31	31	30	31	30	31	days
Monthly Water Demand (Current)	2.242.240	2.309.944	2.360.176	2.232.048	1.731.184	1.681.680	2.026.024	2.674.672	1.681.680	1.495.312	1.386.840	1.554.280	m3 per month
Monthly Water Demand (Future)	2.614.248	2.677.584	2.745.288	2.598.960	2.046.408	1.987.440	2.374.008	3.094.728	1.987.440	1.784.328	1.659.840	1.849.848	m3 per month
Daily Water Demand (Current)	72.300	82.500	76.100	74.400	55.800	56.100	65.400	86.300	56.100	48.200	46.200	50.100	m3 per day
Daily Water Demand (Future)	84.300	95.600	88.600	86.600	66.000								

66.200	76.600	99.800	66.200	57.600	55.300	59.700	m3 per day

Table 3. Climate Koh Samui - Meteoblue 2006-2023 (Author, 2023).

Characteristic	Jan	Feb	Mrt	Apr	Mei	Jun	Jul	Aug	Sep	Okt	Nov	Dec	Total (mm)
Hot days (˚C)	32	33	35	35	34	34	33	33	32	32	31	31	
Mean daily maximum (˚C)	29	31	32	32	31	31	30	31	30	29	29	29	
Mean daily minimum (˚C)	22	22	23	24	25	25	24	24	24	24	24	23	
Precipitation (mm)	26	20	53	68	114	99	108	105	131	221	233	85	1263
Humidity (%)	76	76	77	77	78	77	77	77	79	82	81	77	
Rainy days (d)	7,0	6,2	9,4	14,9	25,6	25,4	26,6	25,6	25,2	25,7	20,1	11,7	

F: Water Strategy Tool

Table 1. Entry Sheet Values Koh Samui (Author, 2023).

Assessment Factor	Select Option		
Size	○ Very Small	◉ Small	○ Large
	< 100 km2	100 km2 - 2000 km2	> 2000 km2
Population Density	○ Low	○ Moderate	◉ High
	< 50 inhabitant/km2	50 - 500 inhabitant/km2	> 500 inhabitant/km2
Topography	○ Gently sloping	◉ Moderately sloping	○ Steep
	the land surface displays mild slopes and is generally not very steep	the landscape has significant slopes, but they are still manageable	the area is characterized by steep slopes, indicating pronounced relief
Distance to Mainland	◉ Very close	○ Close	○ Far
	< 25 km2	25 km2 - 100 km2	> 100 km2
Annual Precipitation Rate	○ Low	○ Moderate	◉ High
	< 500 mm	500 mm - 1000 mm	> 1000 mm
Average Relative Humidity	○ Low	○ Moderate	◉ High
	< 30%	30% - 70%	> 70%
Temperature	○ Low	○ Moderate	◉ High
	< 10°C	10°C - 25°C	> 25°C
Fog	◉ Low	○ Moderate	○ High
	fog is not present or only lightly	fog is present, leading to a noticeable reduction in visibility but still allowing for some activities	dense fog is prevalent, causing a substantial reduction in visibility and potentially disrupting various daily activities
Prosperity	○ Low	◉ Moderate	○ High
	limited economic resources, low income levels and restricted access to essential amenities	moderate economic resources and incomes, where access to basic needs and services is reasonable	abundant economic resources, high income levels and extensive access to high-quality amenities and services
Water Quality	◉ Low	○ Moderate	○ High
	islands experiencing challenges with limited water quality due to saltwater contamination and wastewater pollution	islands experiencing a moderate level of water quality concerns, including issues related to saltwater contamination and wastewater pollution	islands characterized by a high level of water quality, with minimal impact from saltwater contamination and wastewater pollution
Water Loss	○ Low	○ Moderate	◉ High
	islands with minimal water loss, indicating efficient water management practices and infrastructure	islands experiencing a moderate level of water loss, suggesting a need for improved water conservation measures and infrastructure	islands characterized by a significant level of water loss, signifying potential inefficiencies in water distribution systems and infrastructure

Table 2. Applicable Solutions Koh Samui (Author, 2023).

Assessment Factor	Method Group	Method
Water Loss	Physical Losses	Pressure Management
Water Loss	Physical Losses	District Metered Areas (DMA)
Water Loss	Physical Losses	Speed and Quality of Repairs
Water Loss	Physical Losses	Leak Detection Technologies
Water Loss	Apparent Losses	Customer Management
Water Loss	Apparent Losses	Water Meter Management
Water Quality	Improve Wastewater Treatment Plant	Integrate Natural Systems
Water Quality	Improve Wastewater Treatment Plant	Climate-Adaptive Infrastructure
Water Quality	Improve Wastewater Treatment Plant	Process Control Systems
Prosperity	Improve Wastewater Treatment Plant	Process Control Systems
Water Quality	Improve Wastewater Treatment Plant	Energy Efficiency Improvement
Prosperity	Improve Wastewater Treatment Plant	Energy Efficiency Improvement
Water Quality	Improve Wastewater Treatment Plant	Decentralized Treatment Units
Water Quality	Improve Wastewater Treatment Plant	Nutrient Recovery
Water Quality	Maintaining Natural Balance of Aquifer Systems	Infiltration Galleries
Water Quality	Maintaining Natural Balance of Aquifer Systems	Groundwater Recharge System
Water Quality	Maintaining Natural Balance of Aquifer Systems	Aquifer Monitoring
Water Quality	Maintaining Natural Balance of Aquifer Systems	Zoning Regulations
Prosperity	Watersaving Technologies	Efficient Irrigation Systems
Prosperity	Watersaving Technologies	Low-Flow Fixtures
Prosperity	Watersaving Technologies	Smart Water Meters
Size	Storage	Reservoirs and Dams
Population Density	Storage	Reservoirs and Dams
Topography	Storage	Reservoirs and Dams
Annual Precipitation Rate	Storage	Reservoirs and Dams
Topography	Storage	Green Infrastructure
Annual Precipitation Rate	Storage	Green Infrastructure
Annual Precipitation Rate	Storage	Stormwater Management Systems
Size	Storage	Water Storage Tanks
Population Density	Storage	Water Storage Tanks
Topography	Storage	Water Storage Tanks
Annual Precipitation Rate	Storage	Water Storage Tanks
Distance to Mainland	Importation	Seawater Transport
Distance to Mainland	Importation	Air Transport
Distance to Mainland	Importation	Pipelines
Annual Precipitation Rate	Rainwater Harvesting	Rooftop Catchment Systems
Annual Precipitation Rate	Rainwater Harvesting	Underground Check Dam
Prosperity	Desalination	Reverse Osmosis (RO)
Prosperity	Desalination	Nanofiltration (NF)
Prosperity	Desalination	Electrodialysis (ED)
Prosperity	Desalination	Multi-Stage Flash Distillation (MSF)
Prosperity	Desalination	Multi-Effect Distillation (MED)
Temperature	Desalination	Multi-Effect Distillation (MED)
Prosperity	Desalination	Vapor Compression Distillation (MVC)
Prosperity	Desalination	Solar Desalination
Temperature	Desalination	Solar Desalination
Prosperity	Desalination	Pressure Retarded Osmosis (PRO)
Prosperity	Desalination	Forward Osmosis (FO)
Fog	Atmospheric Water Harvesting	Fog Harvesting
Temperature	Atmospheric Water Harvesting	Radiative Cooling
Average Relative Humidity	Atmospheric Water Harvesting	Radiative Cooling
Prosperity	Atmospheric Water Harvesting	Radiative Cooling
Temperature	Atmospheric Water Harvesting	Solar-Regenerated Desiccant Systems
Average Relative Humidity	Atmospheric Water Harvesting	Solar-Regenerated Desiccant Systems
Prosperity	Atmospheric Water Harvesting	Solar-Regenerated Desiccant Systems
Temperature	Atmospheric Water Harvesting	Active Cooling Condensation Method
Average Relative Humidity	Atmospheric Water Harvesting	Active Cooling Condensation Method
Prosperity	Atmospheric Water Harvesting	Active Cooling Condensation Method