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An Assessment of Water Resources in the Taiwan Strait Island Using the Water Poverty Index

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Abstract: Water resources are a very important issue in the Global Risk 2015 published by the World Economic Forum. The research objective of this study was to construct a Water Poverty Index (WPI) for islands. The empirical scope of this study was based on Kinmen Island in the Taiwan Strait, which has very scarce water resources. Kinmen has a dry climate with low rainfall and high evaporation. Therefore, the Kinmen area is long-term dependent on groundwater resources and faces serious water resource problems. This study used the WPI to examine various issues related to water resources. In addition, this study selected several main indicators and performed time series calculations to examine the future trends of water resources in Kinmen. The results show that the overall water resources of Kinmen are scarce. To ensure sustainable development of water resources in Kinmen, policies to improve water scarcity, such as water resource development, water storage improvement, and groundwater control, should be researched. The research results of this study can be used as a reference for government agencies in formulating and revising water resources to achieve the sustainable development of island-type water resources.

Keywords: Water Poverty Index; Delphi method; water scarcity; time series

1. Introduction

In the last few decades, the increases in the world's population, living standards, consumption patterns, and irrigated agriculture have driven a rising global demand for water [1–4]. Climate change and anthropogenic activities increase the risk of water quantity and quality deterioration [5,6]. To implement the "Agenda 21" of the Rio Summit, the United Nations convened the Sustainable Development Earth Summit in Johannesburg in 2002. In this meeting, the United Nations presented water resources, energy, health, agriculture, and biodiversity as the five major issues that 21st-century humans must face, with water resources considered to be the main issue. The key results from this meeting were that sustainable development goals were drafted for the future, and a target and a schedule for those goals were clearly set [7]. According to the estimates provided by international agencies such as the World Health Organization, the global population facing water shortages will increase from 20% in 2000 to 30% in 2025, and the number of countries facing water shortages will increase from 30 in 2000 to 50 in 2025. Statistical data reveal that the countries and people suffering from water shortages mostly have a high correlation with poverty [8]. In many countries, especially those located in arid to semi-arid regions, precautions are being taken against water scarcity [9–11]. The optimization of wellfield management practices and water quality protection has received significant attention in different regions around the world [11–16]. One of the effects of water scarcity is a lack of sufficient drinking water for the population. This issue can be worsened by improper wellfield management.

In the past decade, especially within environmental politics, there has been a growing interest in, and concern for, the ways in which discourses are constructed, used, and misinterpreted in public political debates about shared water resources [17–19]. Because of the aforementioned issues, the Centre for Ecology and Hydrology (CEH) in the UK began to develop the Water Poverty Index (WPI) in 2002 [20]. The main purpose of the WPI is to provide a numerical value that can be used to calculate how much national welfare is represented by water and to denote the extent of water poverty's effects on humans. The main considerations in this index system are water availability, water accessibility, the ability for people to acquire water, and the background environmental quality of water conservation for a country or a region. The development of this index makes the ranking and comparison of countries or communities possible and can consider various physical and socioeconomic factors of water scarcity [20].

The WPI uses the local scale as its starting point for development. A WPI has been developed and applied to various countries, such as South Africa, Sri Lanka, and Tanzania. In 2002, the WPI team considered the commonality and accessibility of national data in the WPI architecture for the three aforementioned countries to develop a WPI suitable for the nation, based on the use in [21]. Water is a vital resource for natural ecosystems and for sustainable human life [22], especially in arid and semiarid regions [23]. Water bodies are the focus of the interactions among various components of the terrestrial system, and, in many areas, they are the most important freshwater resources [24]. This comprehensive indicator will guide the improvement of various issues related to water resources and enable policy makers to implement correct water management measures. A shortage of water resources is every outlying island's fate. Policy makers' decisions on water shortages are important. A set of indicators related to water poverty enables policy makers to obtain key information about water resources in a simplified form. These indicators can indicate whether a region can provide sufficient water and sanitation services under economic development and population growth [25], thereby enhancing the sustainability of policies. The Water Poverty Index (WPI) is a mathematical data-driven tool for gauging the degree of water-related poverty in a community, region, or country. Several approaches to the development of such an index have been tested; the five-component WPI developed by Sullivan and associates is now widely accepted, although refinements for more cost-effective applications continue [26].

Kinmen is located on the coast of China, 15 kilometers away from Xiamen. It is 259 kilometers away from Taiwan's nearest Hsinchu, relatively far from Taiwan's main island. Taiwan is densely populated, the topography fluctuates greatly, and the source of the river is short and rapid, so occasionally there will be water shortage when the rainfall is uneven. The stratum of Kinmen Island is dominated by granite gneiss. Due to the sparse annual rainfall, it is a dry climate with strong evaporation, and the water resources are extremely insufficient. A literature review was conducted to establish a primary calculation method for a WPI for Kinmen. The main research purpose of this article is to develop a WPI in different regions, especially to estimate the developmental trends of the relationship between water resources and socioeconomics in small islands. The results will propose countermeasures for regional water resource management and establish an assessment system as a reference for island-type water resource management.

2. Development and Application of the WPI

2.1. Framework of the WPI

The national attention paid to water resource issues differs globally because the issues different areas face are not the same. A previous study discussed the water resource issues of Tanzania, South Africa, and Sri Lanka from several perspectives, such as water resources, water use, water quality and change, the water used for production or food, the ability to manage water resources, and environmental and spatial scale [27]. Their definitions are as follows:

(1) Water resources: Based on economic and calculated considerations, available water resources are usually estimated using post rainfall runoff and groundwater recharge (blue water);

(2) Measure of access: In areas where access to water is difficult, the time it takes to fetch water is very important. During the dry season, rich or influential people can obtain sufficient water resources, while the poor can only find the water that is naturally available. People who have insufficient income often must choose between food or water, making their lives very difficult.
(3) Water quality and change: Water quality is an indicator used to define environmental improvements. Changes in the water supply are often overlooked indicators, and, in developing countries, this impact factor can determine the uncertainty of the water supply in the region.
(4) Water used for production or food: The United Nations only focuses on the water required for people's livelihoods; however, the food manufacturing sector also uses a large amount of water (industries such as animal husbandry, agriculture, and manufacturing), which should be included in the calculation of the WPI.
(5) Ability to manage water resources: the effective management of water resources is closely related to education and income levels and affects whether water resources can be effectively used and whether relevant units can properly resolve issues.
(6) Environment: The improvement of water resources must not cause environmental damage, and environmental sustainability must be a priority. The areas of nature reserves, the popularizing rate of environmental information, and the special environmental features of each region should be discussed from this perspective.
(7) Spatial scale: The state of water resources often changes with space. Sometimes, areas less than a few kilometers apart have different socio–economic features that affect their use of water resources. Therefore, spatial scale requires careful consideration to reflect the degree of discrepancy in regional water use.

After the CEH integrated the above aspects (while drafting their WPI indicators), mainly the poor were targeted, as the poor do not have appropriate pathways of water intake. The initial WPI combined physical, social, economic, and environmental data to reflect water poverty, water use, the ability to manage water resources, etc. The credibility, availability, and representation of these indicators have been discussed by international scholars through a wide range of consultations [20,28,29]. The WPI has been applied nationally. The WPI was developed into a cross-national indicator that uses the human development index (HDI) to measure a nation's position (1 is the highest, and 0 is the lowest). The WPI includes five components with several subcomponents: resources, access, capacity, use, and the environment. The details are provided in Table 1 [30].

Table 1. Basic framework of the Water Poverty Index (WPI).

Component	Subcomponent
Resources	Internal volume of fresh water sources, foreign water, population.
Access	Percentage of the population that can get clean water; percentage of the population that can use sanitary equipment, percentage of the population for whom irrigation is acceptable.
Capacity	GDP Per Capita, under-five infant mortality, the proportion of education, Gini index (income distribution).
Use	Daily water consumption, the proportion of industrial water and agricultural water.
Environment	Standard (Z) value of the water quality, water pressure, environmental laws and management, biodiversity, information technology capacity indicators in the environmental sustainability index architecture.

2.2. Application of the WPI

After the international ranking of the WPI was released, scholars from all over the world began research on the WPI. The WPI can be applied to agriculture, irrigation, integrated water resource management, and rural water availability [29,31,32]. To combine the WPI and geographic information system, the WPI distribution can be mapped, and a spatial analysis can be conducted [33]. The WPI was applied to analyze water conflicts in poor areas [34]. Many indicators are available for assessing water resources in the world, and at least 34 agricultural indicators and 50 socioeconomic indicators have been recorded. However, the WPI is still the most effective assessment tool [8,20,27,34]. This tool is easy to calculate and implement, is based mostly on existing data, and assists in prioritizing water requirements [32]. However, many scholars still have doubts about the WPI, such as whether the sources of various data should be trusted, as well as the use of a simple function, balanced weighting, and redundant variables when calculating the WPI [35–37].

Based on the above shortcomings, some scholars have proposed amendments. In 2010, Garriga and Foguet proposed ways to correct the following two problems [38]: The inadequate techniques used to combine available data and the poor statistical properties of the resulting composites [38]. To this end, several combinations have been considered to create the WPI; these combinations are based on the indicators' selection criteria, simple aggregation functions, and multivariate analyses. In 2013, van der Vyver compared the differences between the multiplication and addition functions in the WPI [39]. In 2017, Juran et al. improved the WPI to make it more suitable for locals and to solve more complex problems [40]. In 2017, Jemmali associated human economic welfare with physical water availability. In summary, although the WPI is a complete set for the comprehensive evaluation index [37], it is still necessary to make some slight adjustments to the WPI when it is applied to different regions because of the differences in localities.

2.3. Development of the WPI in Taiwan

To establish the native WPI value for Taiwan, which was a responsibility entrusted by the Water Resources Agency (WRA, MOEA) to the Environmental Quality Protection Foundation in mid-November 2003, Dr. Caroline Sullivan and Dr. Jeremy Meigh, the main researchers of the WPI team in the UK CEH, were invited to visit Taiwan to describe the methods for WPI calculations and construct a regional WPI [27]. The research team "Taiwan WPI Scholars Expert Committee" was comprised of experts in relevant fields and stakeholders in order to increase the applicability of the WPI for localization in Taiwan [30]. This project was based on dividing Taiwan's water resources into four units (north, middle, south, and east), thereby drafting a local WPI for the partition scale to determine the differences between water resources. The research team referred to the local indicator structure of other countries and compared the connotations of the WPI architecture with the international draft candidate indicators for Taiwan's native WPI. The Delphi method was applied to decide whether to admit the indicator project, and the individual weights were used to integrate a set of calculations as the foundation for a Taiwanese WPI; Figure 1 presents the overall the architecture of water poverty in Taiwan [41].

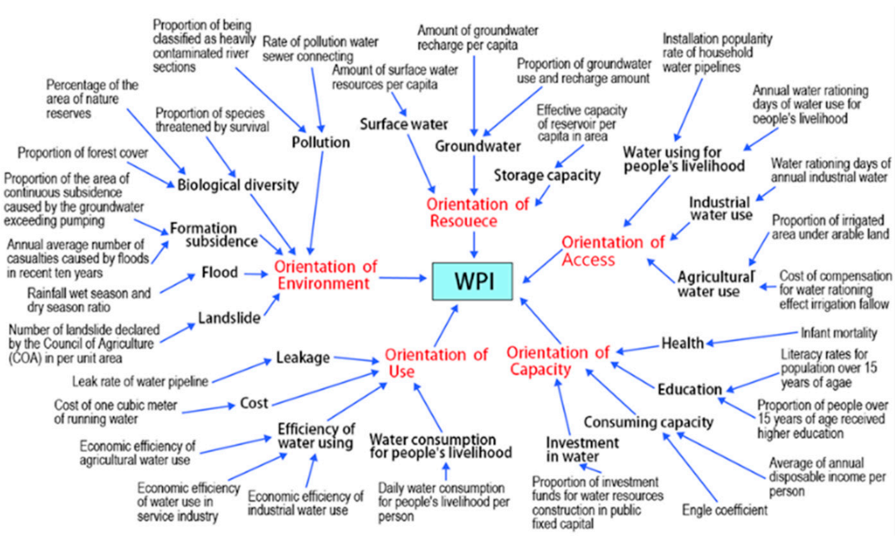

Figure 1. The framework of the Vensim model of Taiwan's WPI [41].

However, this research project did not include offshore islands, and water shortages have always been a major issue in offshore islands. The WPI can be used as a reference by decision-makers in offshore islands when formulating and revising policies and help offshore islands effectively develop their water resources sustainability.

2.4. Study area

Kinmen, a unique geographical island in the Taiwan Strait, has been selected as the target in this study. Kinmen is one of the counties and cities in Taiwan, with a population of approximately 130,000 in 2018. Kinmen is located at Xiamen Bay, between China and Taiwan (Figure 2). Kinmen includes 12 islands of different shapes (Kinmen Island, Lishou, Dadan Islet, Erdan Islet, etc.), with a total area of approximately 151 km^2 [42].

The annual average temperature in Kinmen is 22.1 °C. Because of the influence of northeast monsoons, the temperature difference between winter and summer in Kinmen is extremely large. The typhoons invading Kinmen are concentrated between May and October. The 12 reservoirs in Kinmen are the area's main water sources. The annual average rainfall of Kinmen is 1047 mm, which is only 41.63% of the annual average rainfall of 2515 mm in Taiwan; however, the annual average evaporation of the dish is 1653 mm in Kinmen [42]. As the tourist population increases, the area's dry climate with low rainfall and strong evaporation results in extreme water shortages. The main purpose of the 12 artificial reservoirs in Kinmen is to store surface water, reduce the excessive withdrawal of groundwater, and prevent the groundwater level from declining.

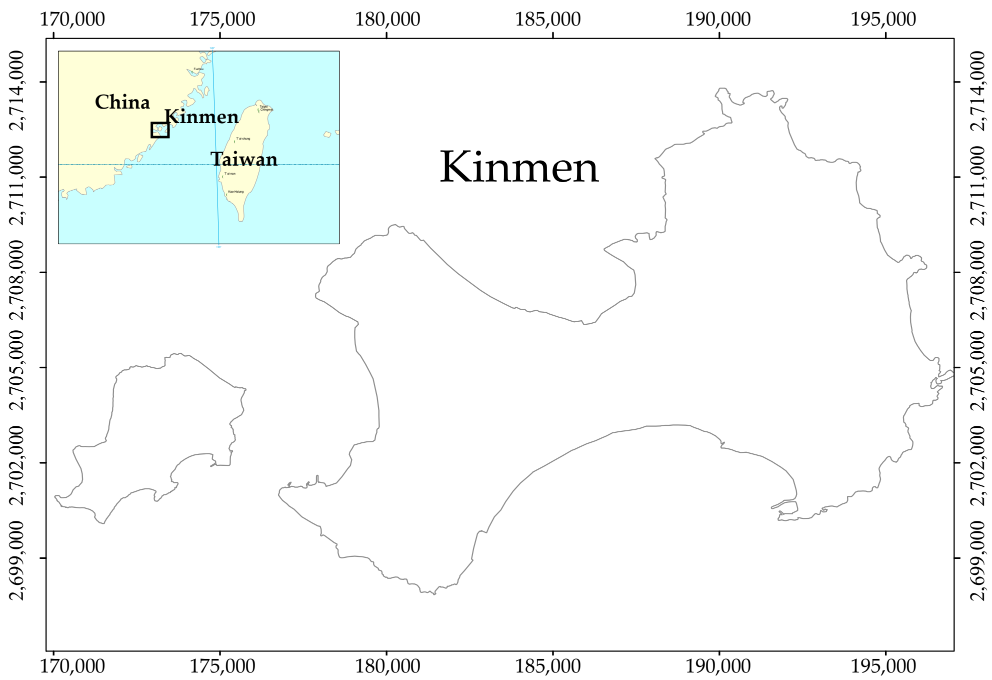

Figure 2. Kinmen island location.

The distribution of water resources in the Kinmen District is displayed in Figure 3. The Huwei River channel, the upstream channel of the Wujiang River, Zhushan, and Shuitou, are the main potential infiltration area in Western Kinmen. Western Kinmen generally has a higher infiltration rate than Eastern Kinmen and is thus more suitable for surface water infiltration to recharge the groundwater. The granite structure of Taiwu Mountain in Eastern Kinmen has low permeability and renders surface water infiltration difficult (with the exception of the water in Xiahu Village). The management and application of groundwater resources and potential surface water infiltration areas in Kinmen are presented in Figure 4.

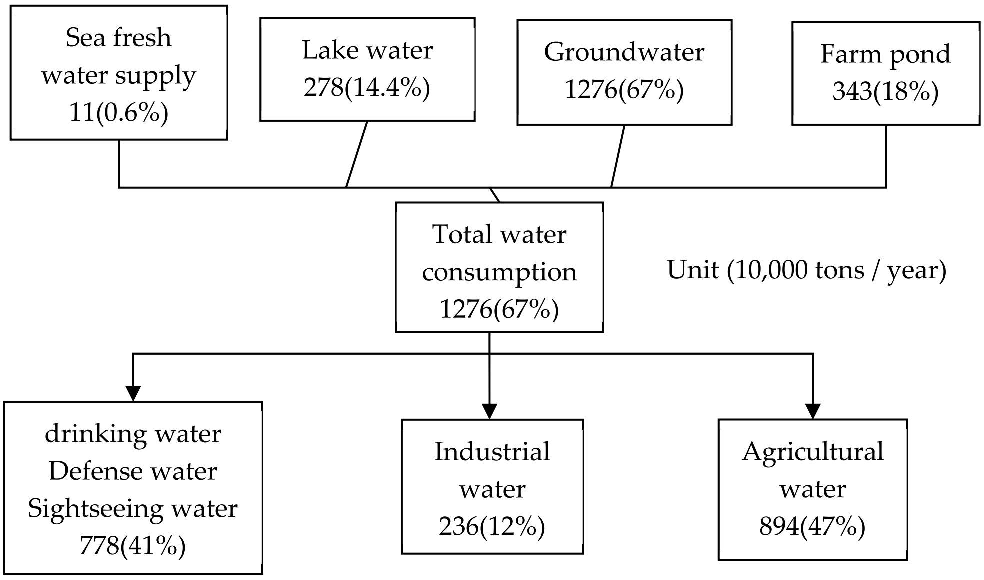

Figure 3. Distribution of the water resources in Kinmen island.

Data source: 2014 Utilization of water resources in Kinmen obtained from the Master Plan of Water Resource management for Eastern Taiwan and Offshore Islands (ratified version), published in 2017 [43].

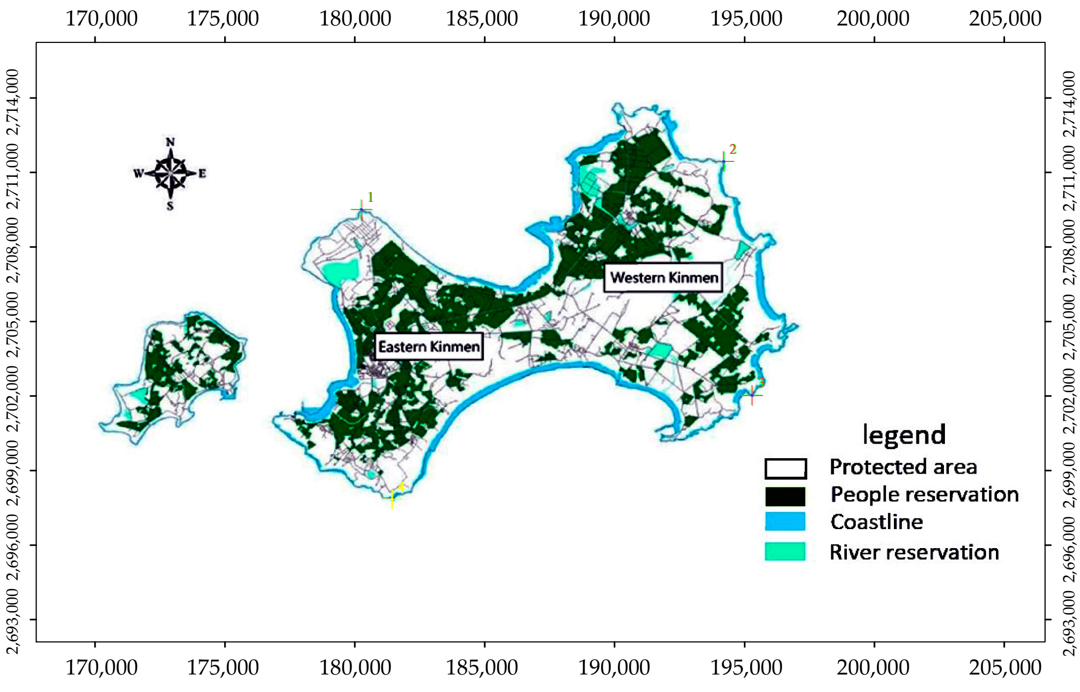

Figure 4. Potential surface water infiltration areas in Kinmen [44].

The lack of a water supply is a severe problem in Kinmen. Although Kinmen actively has developed various ways to store water, the tourism industry on Kinmen Island has created a greater demand for tap water after the opening of the Mini-Three-Links in Taiwan in 2000 (from Kinmen to China). The increasing population has created a demand for water resources in Kinmen Island which have increased year by year; moreover, the evaporation is greater than rainfall in the area, and the catchment area is small. Thus, water shortages frequently occur in the dry season.

In 2002, Taiwan developed a framework for the local WPI and calculated the WPI of the counties and cities in Taiwan. However, this calculation did not include Taiwan's outlying islands, such as Kinmen, and the WPI of Taiwan has not been updated since then. Therefore, based on the WPI calculated for Taiwan in 2013, this study calculated the WPI of Kinmen based on the information regarding Kinmen water resources and compared that information with the WPIs of Taiwan's counties and cities. A time-series forecast for Kinmen water resources-related indicators was made to determine the changes in the indicators between now and 2030 and to provide a reference for formulating policies. The aims of this paper are as follows:

(1) Based on the framework of the WPI in Taiwan, to calculate the WPI in Kinmen;
(2) Based on the calculation results of the WPI in Kinmen, compare the ranking with the WPI in Taiwan;
(3) For influential indicators, use a time-series forecast by year to understand the changes in the WPI in Kinmen until 2030.

The calculation results of the indicator structure can provide a policy reference for solving water resources problems, but the calculation process requires the assistance of experts to provide relevant calculation methods and selections of indicator scales. The research design and data sources of this article are as follows:

(1) In the WPI, every component, second component, and indicator project can illustrate the water resource problems in Kinmen.
(2) Different indicators have different calculation scales so that the differences between the indicators can be identified.
(3) The indicator calculation results reflect the conditions of water resources in Kinmen.

Each source for the indicator calculation information comes from a statistical yearbook issued by the government.

2.5. Development of Water Resources in Kinmen

Water shortage has been a critical issue in the development of Kinmen, especially after the rapid development of tourism. Artificial lake dams have been used to store water for a long time; however, due to drought and human activities in the catchment area, controlling water and its quality has become difficult. Due to the uneven distribution of rainfall and small catchment areas, most of the runoff water flows into oceans, thereby decreasing the availability of surface water sources.

In Kinmen, water sources cannot be easily obtained, and the region has adopted various ways to develop water resources, the types of which are divided into three categories: surface water, groundwater, and desalination. Because eastern geology is made of granite, the dam's water is the only reliable water source. Moreover, western geology has favorable permeability geology and groundwater, which is relatively rich and has high water quality compared to other parts of the island. Accordingly, groundwater is used as a source of running water. Figure 5 illustrates the distribution of major water resources in Kinmen. Figure 6 illustrates the estimated water consumption for people's livelihoods in the Jinmen area in 2018: Jincheg 12000 CMD (Cubic Meter per Day) (50%), Ronghu 3000 CMD (13%), Taihu 7000 CMD (29%), and Hongshan 2000 CMD (8%). Overall, the tap water in Western Kinmen is comprised of lake water (50%) and groundwater (50%), whereas the tap water in Eastern Kinmen is comprised of water diverted from China (50%), lake water (40%), and desalinated water (10%).

In 2017, the number of visitors to Kinmen reached 780,000 and will possibly increase in the coming years. However, most of the hotel industry has arranged their own groundwater and running water supplies, so these businesses cannot truly reflect the tourism water demand and supply situation.

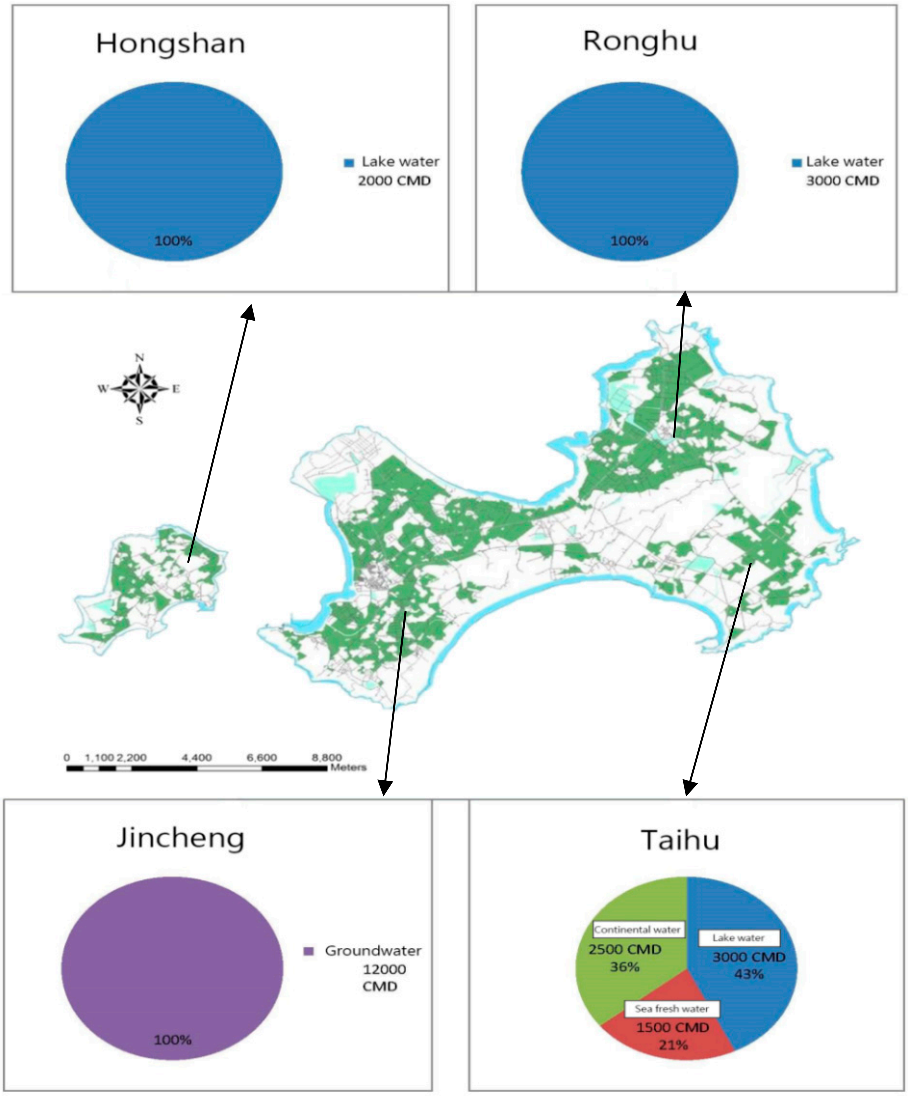

Figure 5. Distribution of the water resources in Kinmen.

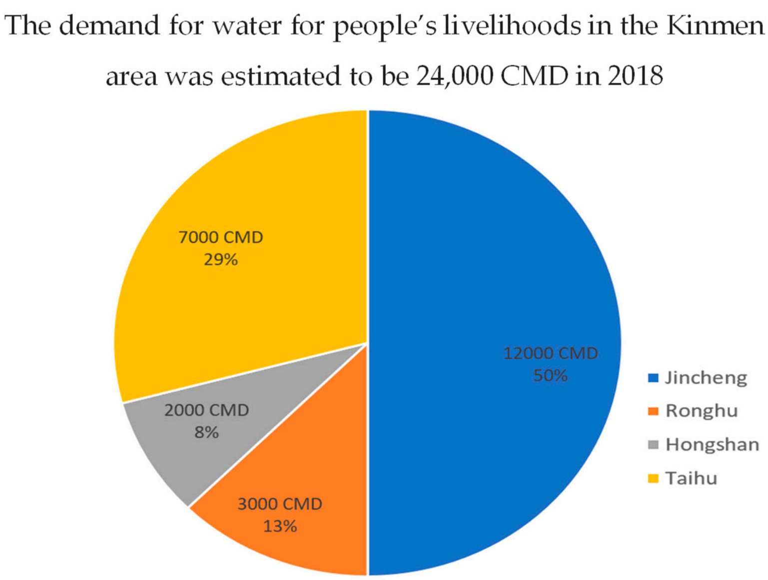

Figure 6. Estimated residential water demand in Kinmen in 2018.

3. Research Method

3.1. The WPI Calculation Method

3.1.1. Transnational Application of the WPI

After nation-based development and application, the WPI was developed into a transnational index system that features international assessments. Its application is similar to that of the human development index of the United Nations in that it measures a nation's relative position among other countries (1 being the highest score and 0 the lowest). The basic framework of the WPI is listed in Table 1.

The WPI consists of five components, each of which consists of several subcomponents. The indicators of each component have their own specific representativeness and significance. Except for the indicators that should be calculated using specific methods, the WPI can be calculated using the following three steps [27]:

(1) For a certain country's WPI index, calculate its relative position among all countries around the world (1 is the highest, and 0 is the lowest).

$$y_j = \left(x_j - x_{min}\right) / \left(x_{max} - x_{min}\right) \tag{1}$$

where x_j is the actual value of item j in a certain country. x_{max} and x_{min} are the maximum and minimum values of an item in all countries. The highest and lowest range of a variable is from 100 to 0. y_j is the index value of a country corresponding to item j.

(2) Next, the score of the index is averaged and multiplied by 100; the total score of the dimension is then obtained. The highest score is 100.

$$c_i = 100 \times \sum_{k=1}^{n} Y_k / n \tag{2}$$

The variable i is the score of one specific dimension, and this component is assumed to have n indicators. With five components, 100 is the highest score. The total score of each component is averaged, and the total score of the WPI is obtained.

(3) The total score of each component is multiplied by its weighting and then summed up. The WPI is the nation's total score, with 100 being the highest score. A higher score indicates superior water resources.

A total of 147 countries around the world were evaluated. The comparison results revealed that, among them, the top five are Finland, Canada, Iceland, Norway, and Guyana; the bottom five are Haiti, Niger, Ethiopia, Eritrea, and Malawi [45].

3.1.2. Development of Taiwan's WPI

The candidate indicators for determining Taiwan's regional WPI were developed as illustrated in Table 2. The framework adjusted the indicator items to genuinely reflect the actual situation of each region in Taiwan and was more suitable for quantification. Subcomponents were added under each component to categorize similar indicators, thus enabling the indicator system to form a three-level pyramid structure. The calculation of resource components is detailed as follows.

The formulae for calculating the indicator values of resources are as follows:

(1) Surface water resources per capita

Surface water resources = precipitation × area × runoff ratio

Surface water resources per capita = surface water resources/population (100 million metric ton/million people).

The data are normalized at this stage; the formula is as follows:

x_i = *ln* (the surface water resources per capita)
$y_i = \frac{x_i}{x_{max}}$ where x_i is the actual value, x_{max} is the maximum regional value over the years in Taiwan, and y_i denotes the regional indicator value.

(2) Safe yield of groundwater per capita (recharge volume)
Formulae:
x_i = the safe yield of groundwater per capita (million metric tons)
$y_i = \frac{x_i}{x_{max}}$
x_{max} is the maximum regional value, and y_i denotes the regional indicator value.

(3) Groundwater use and recharge ratio
Reduce the scale and normalize the values for comparison. The formula is as follows:
Formulae:
x_i = Groundwater use and recharge ratio, where y_i denotes the indicator value.
$Y_i = 1$ *if* $x_i < 1$
$y_i = 1 - (x_i - 1)/0.2$ *if* $1 \leq x_i \leq 1.2$
$y_i = 0$ *if* $x_i > 1.2$.

(4) Effective capacity of the regional reservoir per capita
Formulae:
x_i = *ln* (effective capacity of regional reservoir/regional population) (10,000 m^3/million people)
$y_i = \frac{x_i}{x_{max}}$
x_{max} denotes the maximum regional value, and y_i denotes the regional indicator value.

In this study, there are two situations for the weightings. Situation 1 features equilibrium weighting, and situation 2 entails the weighting of each component and subcomponent of Taiwan. The weightings are calculated using the Delphi method [46–48]. The Delphi technique (subsequently referred to as the Delphi) is, in essence, a series of sequential questionnaires or 'rounds', interspersed with controlled feedback, that seeks to obtain the most reliable consensus of opinion from a group of experts [49–51]. The Delphi method is a structured decision-making tool.

When collecting information, multiple experts on a subject are requested to give their independent and subjective judgements repeatedly to eventually determine objective information, opinions, and viewpoints [52–54]. Researchers anonymously obtain the opinions of experts (from a designated group) over iterative rounds. The expert opinions from each round are compiled, organized, and sent to every expert for analysis and judgment. The experts then put forward new arguments based on the organized materials. After multiple iterations, the experts' opinions gradually converge, and a more consistent and reliable conclusion or program is obtained [47,52].The Delphi has been shown to be a widely used and flexible method that is particularly useful in achieving consensus in a given area of uncertainty or lacking empirical evidence [55,56]. This study addresses the weights of the WPI using the following means:

Situation 1 (S1): Adopt a method similar to the environmental sustainability index (ESI) and determine individual weights using the indicator framework. Each of the five components accounts for 20% of the weight, and the weight is equally divided by the number of subcomponents under each component. Each subcomponent is composed of multiple indicators, each of which is assigned an equal weight.

Situation 2 (S2): Establish indicators, subcomponents, and components according to the expert consensus obtained through the Delphi method [57]. This step can further understand the difference between the calculated results from different weights. The detailed weightings are provided in Table 2.

Table 2. Weightings of the Taiwan WPI in situations 1 and 2.

Component	S1/S2	Subcomponent	S1/S2	Indicator	S1/S2
Resources	0.200/0.213	Surface water	0.066/0.072	Amount of surface water resources per capita	0.066/0.072
		Groundwater	0.066/0.072	Amount of groundwater recharge per capita	0.033/0.037
			0.066/0.067	Proportion of groundwater use and recharge amount	0.066/0.035
		Storage capacity	0.066/0.067	Effective capacity of reservoir per capita in area	0.066/0.067
Access	0.200/0.188	Water used for people's livelihoods	0.066/0.072	Installation popularity rate of household water pipelines	0.033/0.037
				Annual water rationing days of water use for people's livelihood	0.033/0.035
		industrial water	0.066/0.059	Water rationing, days of annual industrial water	0.066/0.059
		agricultural water	0.066/0.057	Proportion of irrigated area under arable land	0.033/0.029
				Cost of compensation for water rationing effect irrigation fallow	0.033/0.028
Capacity	0.200/0.178	Health	0.050/0.050	Infant mortality	0.050/0.050
		Education	0.050/0.045	Literacy rates for population over 15 years of age	0.025/0.023
				Proportion of people over 15 years of age received higher education	0.025/0.022
		Consumption capacity	0.050/0.040	Average annual disposable income per person	0.025/0.020
				Engle coefficient	0.025/0.019
		Investment in water	0.050/0.045	Proportion of investment funds for water resource construction in public fixed capital	0.050/0.045
Use	0.200/0.213	Amount of water used for people's livelihoods	0.050/0.056	Daily water consumption for people's livelihoods per person	0.050/0.056
		Efficiency of water use	0.050/0.057	Economic efficiency of industrial water use	0.017/0.020
				Economic efficiency of water used in the service industry	0.017/0.019
				Economic efficiency of agricultural water use	0.017/0.019
		Cost	0.050/0.049	Cost of one cubic meter of running water	0.050/0.049
		Leakage	0.050/0.051	Leakage rate of water pipeline	0.050/0.051
Environment	0.200/0.213	Landslide	0.040/0.043	Number of landslides declared per unit area	0.040/0.043
		Flood	0.040/0.041	Annual average number of casualties caused by floods in recent ten years	0.020/0.020
				Rainfall wet season and dry season ratio	0.020/0.021
		Formation subsidence	0.040/0.044	Proportion of the area of continuous subsidence caused by the groundwater exceeding pumping	0.040/0.044
		Biological diversity	0.040/0.037	Proportion of forest cover	0.013/0.013
				Percentage of area of nature reserves	0.013/0.012
				Proportion of species threatened by survival	0.013/0.012
		Pollution	0.040/0.048	Proportion of being classified as heavily contaminated river sections	0.020/0.023
				Sewage sewer takeover rate	0.020/0.025

3.2. Time-Series Analysis

The WPI is calculated using a single year of water resource data. This study uses a regression analysis to estimate the changes in water resources over time. Seven indicators that are highly accurate and close to the values of the indicators in Kinmen are used to conduct a time-series forecast using the linear regression method. Through these forecast results, policy makers can adopt an appropriate water policy.

4. Research Results

4.1. Comparisons with Other Counties and Cities

The framework of the WPI in Taiwan has five components (resources, access, capacity, use, and environment) and 30 indicators. After calculating the WPI in Kinmen and comparing it with other counties and cities, we determined the following (Table 3):

(1) The resource score: In situation 1, the total score of the Kinmen region was 0.621; thus, Kinmen was ranked 13th among all counties and cities. In situation 2, the total score of the Kinmen region was 0.619, ranking it 13th among all counties and cities. In both situations, Kinmen had the same rank.

(2) The access score: In situation 1, the total score of the Kinmen region was 0.828, which ranked Kinmen 11th among all counties and cities. In situation 2, the total score of the Kinmen region was 0.838, ranking Kinmen 9th among all counties and cities. Kinmen's ranking in situation 2 was more than that in situation 1.

(3) The capacity score: In situation 1, the total score of the Kinmen region was 0.523, which ranked Kinmen 17th among all counties and cities. In situation 2, the total score of the Kinmen region was 0.522, ranking Kinmen 17th among all counties and cities. In these two situations, Kinmen had the same rank.

(4) The use score: In situation 1, the total score of the Kinmen region was 0.532, ranking Kinmen 16th among all counties and cities. In situation 2, the total score of the Kinmen region was 0.547, which ranked Kinmen 15th among all counties and cities. Kinmen's ranking in situation 2 was greater than that in situation 1.

(5) The environment score: In situation 1, the total score of the Kinmen region was 0.809, ranking Kinmen first among all counties and cities. In situation 2, the total score of the Kinmen region was 0.799, which ranked Kinmen first among all counties and cities. In these two situations, Kinmen had the same rank.

(6) An analysis of the overall scores and county and city rankings showed that, in situation 1, the total score of Kinmen was 0.663, which ranked Kinmen 10th among the 23 counties and cities, and, in situation 2, the total score of Kinmen was 0.664, which ranked Kinmen 9th among the 23 counties and cities.

Table 3 presents the WPI calculation results of Kinmen and the other administrative divisions of Taiwan regarding the five components. This table provides a comparison between Kinmen and the other administrative divisions of Taiwan. The unique geographical location of Kinmen—being very close to China—differentiates itself from the other administrative divisions in Taiwan.

Table 3. The total scores for the WPI of Kinmen and comparisons with other Taiwanese counties and cities in situations 1 and 2.

Component County/City	Resources S1/S2	Access S1/S2	Capacity S1/S2	Use S1/S2	Environment S1/S2	WPI Total Score S1/S2	Total Rank S1/S2
Keelung City	0.589/0.585	0.782/0.786	0.505/0.506	0.274/0.283	0.533/0.531	0.537/0.533	23/23
Taipei County	0.633/0.628	0.810/0.813	0.624/0.628	0.535/0.523	0.755/0.749	0.671/0.666	7/8
Taipei City	0.614/0.610	0.825/0.828	0.762/0.758	0.506/0.495	0.644/0.634	0.670/0.658	9/12

Table 3. *Cont.*

Component County/City	Resources S1/S2	Access S1/S2	Capacity S1/S2	Use S1/S2	Environment S1/S2	WPI Total Score S1/S2	Total Rank S1/S2
Taoyuan County	0.637/0.633	0.736/0.749	0.510/0.504	0.663/0.652	0.760/0.755	0.661/0.662	12/10
Hsinchu County	0.691/0.688	0.629/0.614	0.614/0.620	0.634/0.626	0.786/0.779	0.671/0.669	7/7
Hsinchu City	0.612/0.608	0.759/0.744	0.610/0.609	0.777/0.777	0.780/0.777	0.708/0.705	2/3
Miaoli County	0.830/0.828	0.732/0.717	0.749/0.756	0.679/0.673	0.778/0.767	0.754/0.749	1/1
Taichung County	0.741/0.737	0.842/0.837	0.499/0.497	0.459/0.455	0.777/0.769	0.663/0.660	10/11
Taichung City	0.432/0.428	0.925/0.921	0.580/0.578	0.400/0.394	0.719/0.716	0.611/0.601	21/21
Nantou County	0.790/0.786	0.778/0.776	0.533/0.538	0.571/0.573	0.782/0.770	0.691/0.692	4/4
Changhua County	0.588/0.589	0.886/0.881	0.507/0.513	0.662/0.667	0.490/0.487	0.627/0.625	18/17
Yunlin County	0.666/0.671	0.890/0.886	0.602/0.610	0.623/0.621	0.364/0.355	0.629/0.623	17/18
Chiayi County	0.730/0.734	0.841/0.839	0.584/0.586	0.658/0.658	0.573/0.562	0.677/0.675	6/6
Chiayi City	0.392/0.392	0.829/0.832	0.631/0.638	0.653/0.653	0.700/0.698	0.641/0.638	16/15
Tainan County	0.584/0.586	0.853/0.853	0.565/0.568	0.742/0.736	0.530/0.519	0.655/0.650	13/13
Tainan City	0.500/0.500	0.875/0.875	0.610/0.616	0.749/0.744	0.533/0.534	0.653/0.650	14/14
Kaohsiung County	0.572/0.573	0.828/0.826	0.477/0.476	0.527/0.520	0.718/0.707	0.624/0.620	19/19
Kaohsiung County	0.278/0.279	0.945/0.939	0.574/0.575	0.607/0.604	0.688/0.701	0.618/0.613	20/20
Pingtung County	0.688/0.691	0.744/0.729	0.563/0.564	0.651/0.650	0.744/0.735	0.678/0.676	5/5
Taitung County	0.647/0.644	0.790/0.786	0.500/0.492	0.251/0.262	0.728/0.720	0.583/0.579	22/22
Hualien County	0.760/0.759	0.793/0.786	0.623/0.615	0.239/0.245	0.749/0.740	0.633/0.626	15/16
Yilan County	0.826/0.825	0.882/0.874	0.555/0.557	0.594/0.596	0.684/0.681	0.708/0.708	2/2
Kinmen County	0.621/0.619	0.828/0.838	0.523/0.522	0.532/0.547	0.809/0.799	0.663/0.664	10/9

Source: Environmental Quality Culture and Education Foundation: Research on the Application and International Cooperation of the WPI in Taiwan (The study organizers).

4.2. Comparisons with Other Regions

(1) In situation 1, Kinmen ranked last among the regions, including southern Taiwan, central Taiwan, northern Taiwan, eastern Taiwan, and Kinmen. In situation 2, Kinmen ranked the same. Figures 7 and 8 compare Kinmen and the other regions of Taiwan in situations 1 and 2, respectively. In both figures, Taiwan is divided into four regions, namely north, central, south, and east, to facilitate its comparison with Kinmen.

(2) Comparing the differences between each component of Kinmen in situations 1 and 2. Except for the capacity component in situation 2 (0.01), which was higher than that in situation 1, the other components in situation 1 were all higher than those in situation 2 by 0.01–0.03. Overall, no significant differences were observed in the WPI between situations 1 and 2.

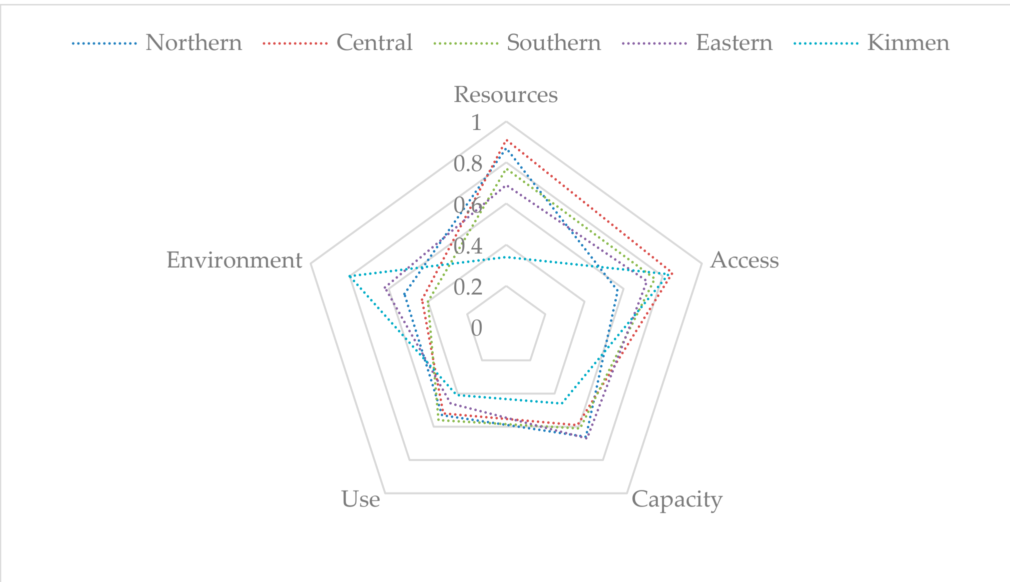

Figure 7. Comparisons with the other 4 regions in situation 1.

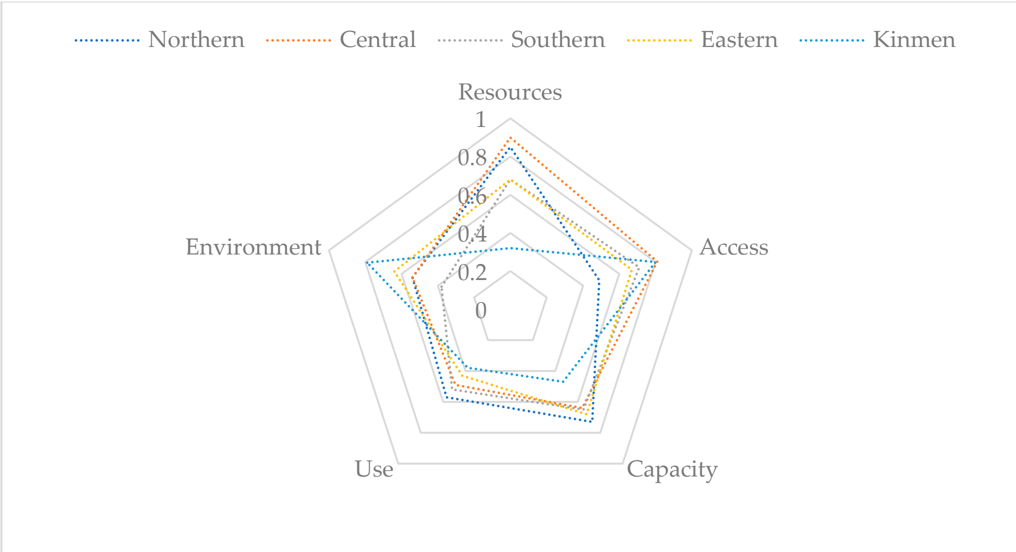

Figure 8. Comparisons with the other 4 regions in situation 2.

4.3. The Future Development of the WPI of Kinmen

Since the publication of the results for each administrative division, the Environmental Quality Protection Foundation and Water Resources Agency have not updated the trial calculation data despite the highly changeable nature of most indices in the WPI framework. Kinmen is subject to the following conditions: lake reservoir development without new water resources; excessive and long-term groundwater pumping; a long-standing lack of annual statistical reports on data such as water usage and the output value of each industry (agriculture, manufacturing, and services), Engel's coefficient, forest area, and threatened fish species; poor-quality raw water, which results in high treatment costs; and a lack of change in geological conditions within a short period of time. Under the premise that the baseline, use components, and environmental components remain the same (unimproved), this study selected seven types of data—the amount of surface water resources per capita, the percentage of the population served tap water, the proportion of people 15 years or older having received higher education, the average annual disposable income per person, the daily water consumption per person, the water pipeline leakage rate, and the sewerage connection rate—from the WPI framework that were the most accessible, accurate, and subject to human-induced changes. This research limitation was implemented to predict the trends of the time series. The formula and criteria created in 2002 were then used to conduct trial calculations of the time series changes in Kinmen.

(1) Per capita surface water resources: According to estimations based on the WPI data [58,59], the per capita surface water resources in Kinmen will be reduced to approximately 5.346 m^3/person by 2030 (Figure 9).
(2) Water popularization rate: According to estimations based on the WPI data, the water popularization rate in Kinmen will be reduced to approximately 95.3% because of the increase in the immigrant population by 2030 (Figure 10).
(3) People over 15 years old according to their proportion of higher education: According to estimations based on the WPI data, the proportion of people over 15 years old with higher education in Kinmen will increase to approximately 56% by 2030 (Figure 11).
(4) The average annual income per person: According to estimations based on the WPI data, the average annual income per person in Kinmen will increase to approximately 291,000 yuan/person by 2030 (Figure 12).
(5) Daily livelihood water consumption per person: According to estimations based on the WPI data, the daily livelihood water consumption per person in Kinmen will be reduced to approximately 88.71 L/person by 2030 (Figure 13).

(6) Water pipeline leakage rate: According to estimations based on the WPI data, the water pipeline leakage rate in Kinmen will be reduced to approximately 10.42% by 2030 (Figure 14).
(7) Sewage sewer takeover rate: According to estimations based on the WPI data, the sewage sewer takeover rate in Kinmen will be approximately 63.9% by 2030 (Figure 15).

This study estimates the per capita surface water resources based on the time-series changes of the seven index items. Compared with 2017, the reduction rate is 87.78% in 2030. Daily water consumption per person, compared with 2017, will decrease by 81.83% in 2030. Government agencies should have appropriate contingency measures to address the dilemma of water resource reduction.

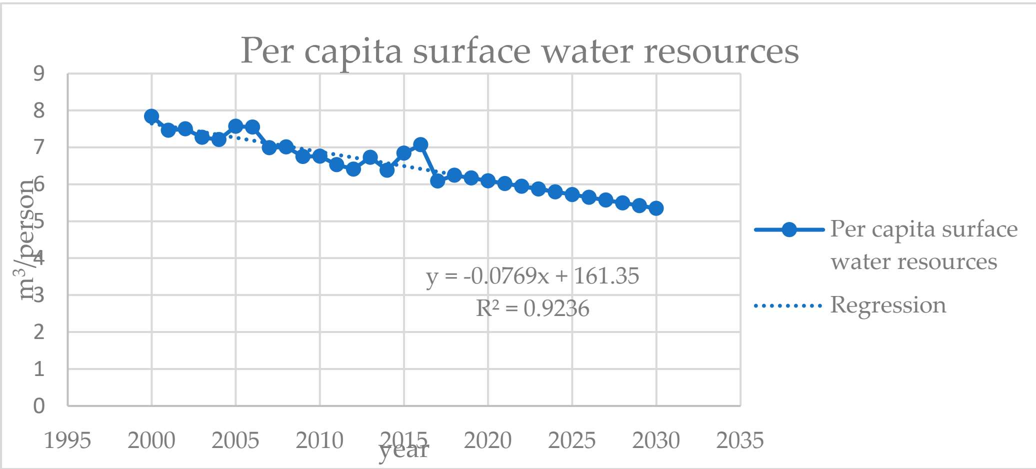

Figure 9. Estimated trend of the per capita surface water resources from 2000 to 2030 [58,59].

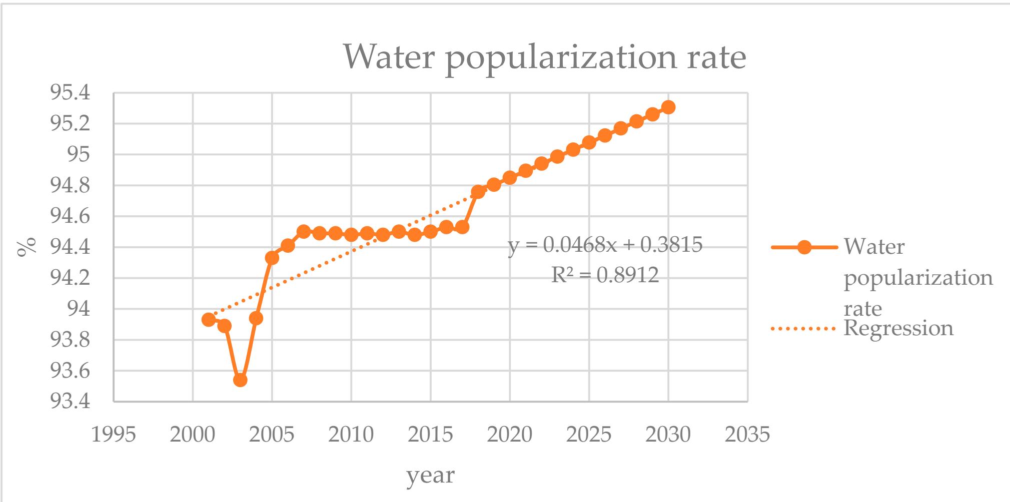

Figure 10. Estimated trend of the water popularization rate from 2000 to 2030 [58].

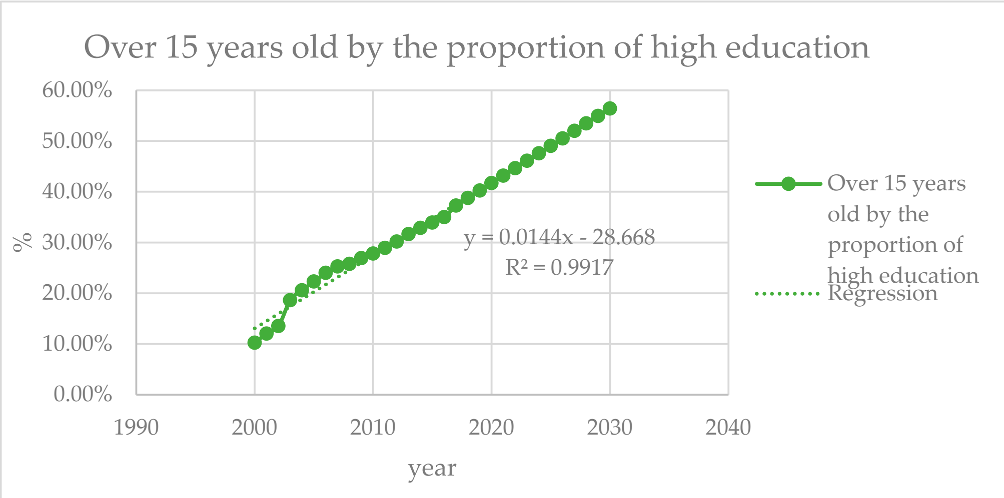

Figure 11. Estimated trend of people over 15 years old by their proportion of higher education from 2000 to 2030 [58].

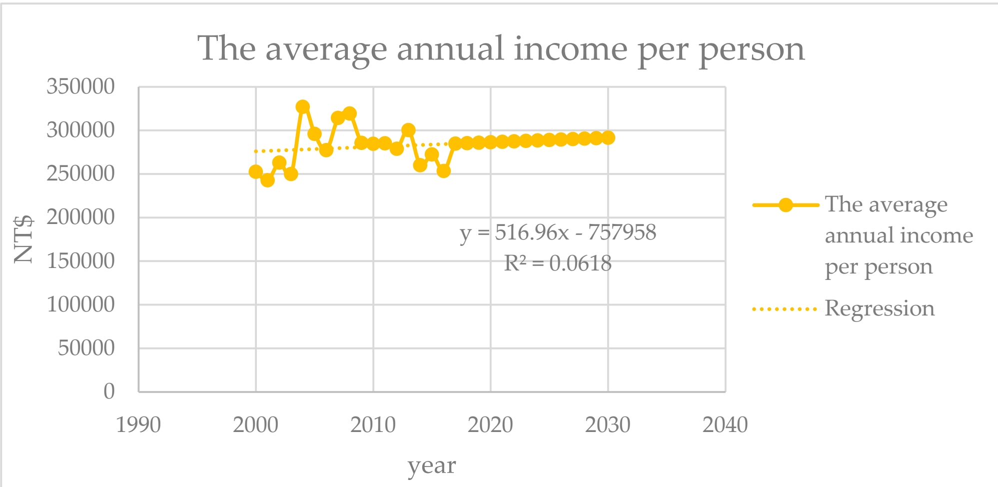

Figure 12. Estimated trend of the average annual income per person from 2000 to 2030 [58].

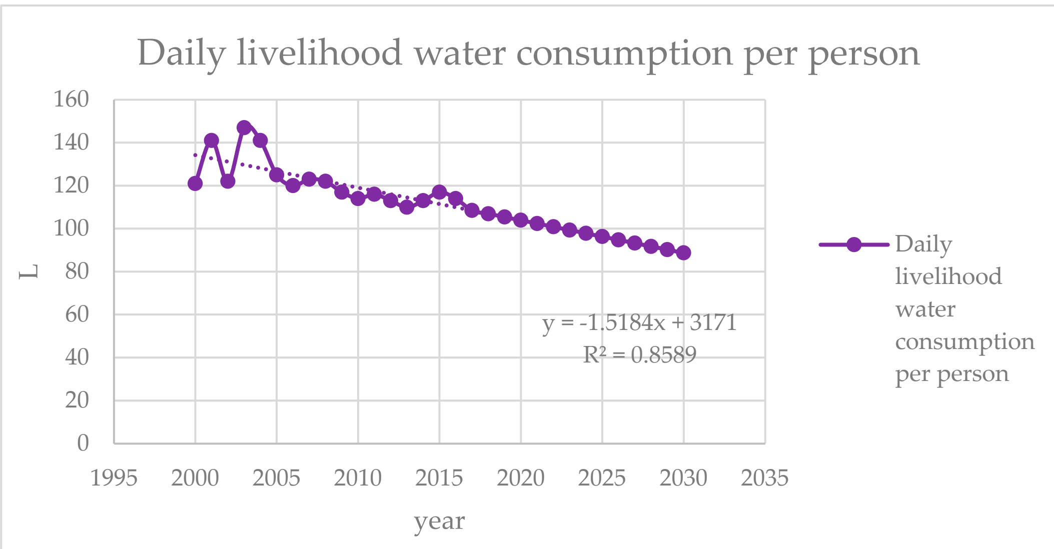

Figure 13. Estimated trend of the daily livelihood water consumption per person from 2000 to 2030 [58].

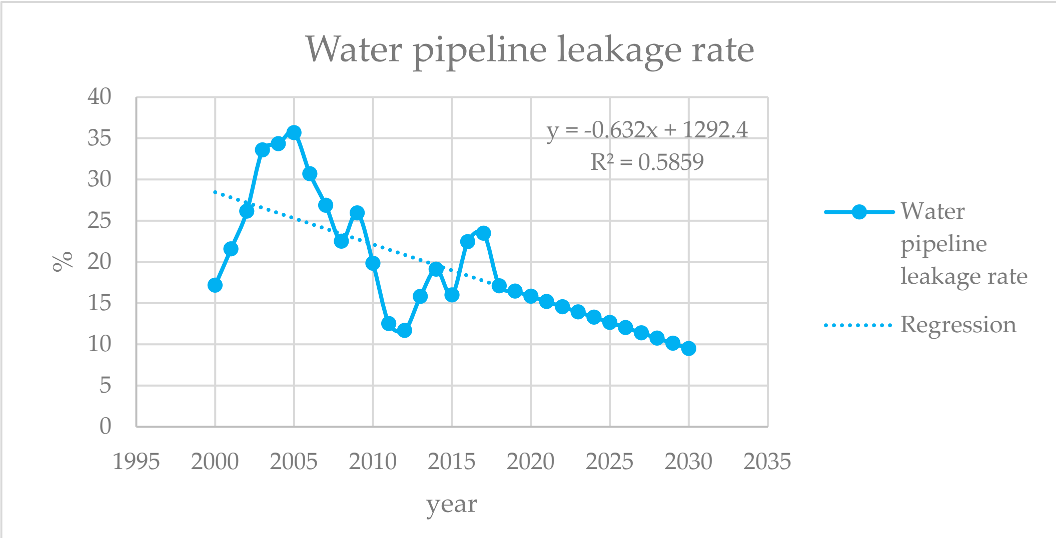

Figure 14. Estimated trend of the water pipeline leakage rate from 2000 to 2030 [58].

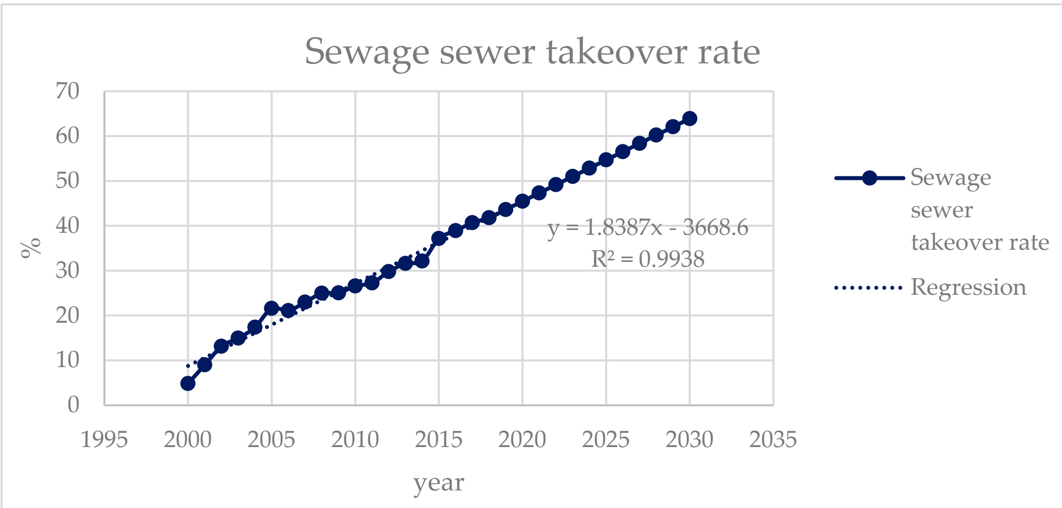

Figure 15. Estimated trend of the sewage sewer takeover rate from 2000 to 2030 [58].

5. Conclusions and Suggestions

5.1. Conclusions

This study summarizes the recent development and application of WPI through literature review and uses the Delphi method to analyze the island type water resource management. The construction of WPI projects is divided into five components, including Resources, Access, Capacity, Use, Environment, etc., and an evaluation system including 30 subcomponent projects. The scope of the empirical study selects the very special Kinmen Island in Taiwan for water resource management and utilization. Correspond to the local data from counties in Taiwan, carry out trial scores for each index item. The empirical results prove that the island-type WPI constructed in this study is effective.

(1). In terms of "resources", Kinmen has a score of 0.621, ranking 13th in 23 counties. This result is calculated based on the experience values of the Water Resources Survey and Planning Report of the Kinmen Region in March 1995. According to a report from the Kinmen Waterworks to the Administrative Committee of the Executive Yuan on 28 August 2012, the groundwater in Kinmen Island was pumped by about 8000 tons per day. At that time, it was expected that in 2016, the amount of groundwater pumped would increase to 20,000 tons per day. This indicates that there is a gap between the data calculated from the empirical value and the actual observed data.

(2). From the perspective of the "path", the Kinmen area scored 0.828, ranking 11th in 23 counties and cities. This is because the tap water penetration rate in Kinmen is nearly 95%, and the rest of the people 's livelihood uses groundwater. In addition, most of the main industrial water and agricultural water use groundwater or farm ponds, which are not included in the calculation of relevant indicators, so they score higher.

(3). From the perspective of "ability", the Kinmen area scored 0.523, ranking 17th in 23 counties and cities. This indicates that the control of water resources and the level of efforts to protect water resources in the Kinmen area still need to be strengthened.

(4). From the perspective of "use", Kinmen has a score of 0.532, ranking 17th in 23 counties and cities. It seems that the water consumption in Kinmen is very low, but in fact, it is very common for people to dig wells for water. The amount of non-tap water is not included. If the actual groundwater and farm pond water are added, the score of this item will be lower. This indicates that there is still room for improvement in water use efficiency in the Kinmen area.

(5) From the "environmental" perspective, the Kinmen area scored 0.809, ranking first in 23 counties and cities. This is because Kinmen has a good geological environment and is relatively free of natural disasters, making the Kinmen area less problematic of water resources and the environment.

(6) In the overall evaluation of WPI, in terms of county and city evaluation, the Kinmen area is above the middle level. However, in terms of district evaluation, the rankings of Kinmen are at the bottom. This indicates that the overall water resources of the Kinmen region are relatively scarce in the region.

(7) The results of the estimated trend change show that if the water use capacity is not increased and the ways of improving water use are not improved, the water resources in the Kinmen area will be even more scarce in the future than now.

Based on to the indicators established in this research, the conclusions are as follows. Compared with other cities and counties, Kinmen was above average (S1:10/23, S2:9/23). However, Kinmen was ranked last when compared with other four regions. The results showed that Kinmen has a lack of water resources compared with other regions. Therefore, if Kinmen's government is incapable of increasing water access and improving the economic viability of water resources, the entire Kinmen region will face severe water shortage. This research showed that Kinmen's scores regarding access to water and use of water and resource are comparatively low, and therefore, it is strongly recommended that corresponding policies should be implemented to solve the problem of water poverty in Kinmen. The results of this research and development of a special island type WPI evaluation system have achieved good results in the application of water resource management in Kinmen Island, Taiwan. The assessment of other ocean island types can be very important reference basis.

5.2. Policies and Suggestions

The recommendations of this study are as follows:

(1). The "capacity to obtain water" and "use of water" in the Kinmen area have low scores in comparison with other counties and cities in Taiwan. If relevant policies can be formulated, the WPI score of Kinmen will be significantly improved.

(2). In terms of the "capacity to obtain water", when developing major water resources projects, we should adopt transparent operation methods, combined with public education, and avoid the pollution of water resources so that sufficient water can be used. It is also necessary to educate the public to cherish water resources and save water so that water resources can be used continuously.

(3). In terms of "water use", groundwater has been excessively used in the Kinmen area based on actual observations, causing seawater to invade the groundwater layer. In terms of water resource management, in-depth investigations should be conducted to control the use of groundwater within safe water discharge to ensure that sufficient groundwater sources can be used in the future.

(4). Considering the "water-related environment", environmental pollution is an urgently important issue for water resource management. It is necessary to accelerate the sewage takeover rate and reduce pollution to lakes and reservoir catchment areas and their watersheds in order to reduce the complexity and cost of water purification treatment.

Only a few improvement policies could increase the WPI score, such as China guiding water to Kinmen in 2018, developing surface water resources, storing water, recycling sewage, desalinizing seawater, and creating a linked passage for water from other countries. Regarding access to water, an important plan for using water resources should feature a principle of transparency, which could not only combine with universal education but could also avoid water pollution in the case of no water, to provide people knowledge for the sustainable use of water. Moreover, many people continue to dig underground water without permission, which makes the control of water use more difficult. Therefore, to control the use of water, records should be maintained, investigations of wells should be conducted, and facilities should be supervised. Administrating pollution, accelerating and increasing the takeover rate, and decreasing the pollution around lakes and dams could reduce the costs and complications involved in purifying water. Kinmen's long-term military administration has restricted development in the area to proactively protecting forests to retain the natural environment (compared to Taiwan's other regions). However, with the elimination of military affairs and the introduction of tours and mini links, many relevant structures are beginning to be developed. Moreover, to clean up the bombs set around the beach during the military age, the surface has been uncovered. Although forests have benefited from prompt planting initiatives, the quality of the area's water resources have been severely affected. A policy should be established to limit ongoing damage to the area's water resources. Each WPI datum is very extensive, which requires researchers to collect information in different areas. However, there is insufficient information depending on the applied calculation systems. This requires that every agency increase its investigatory and time-based projects to produce a more accurate score. A possible future research direction is to develop an API that can automatically update the WPI. Another possible research direction is to make predictions on the seven variables in Section 4.3 by considering all of the factors that influence each variable.

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