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Exploring the Environmental Cost of Water Resources: A Case Study

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Abstract In recent years, the effects of climate change have become more significant, and extreme climate events such as super storms, droughts, and heatwaves have occurred frequently around the world. While we are cognizant of the limitations and uncertainties associated with water resources, management agencies seek the effective use of water resources to support national economic development. This study adopts multiple approaches with cases study to demonstrate the measurement of environmental costs of water resources and to provide a sound framework for water accounting information system. The paper would contribute to the field of the management and sustainable development of water resources.

Keywords: *environmental cost, sustainable development, water resources*

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1. Introduction

While environmental pollution has become increasingly worsened with the development of society and economy, environmental protection issues have received more attention across countries. The World Economic Forum (WEF) released the Global Risks Report in 2019, estimating the top ten risks that will significantly affect global development in the next decade. In particular, "Water crisis" ranks fourth in terms of the degree of the impact and ninth in the likelihood of occurrence. Hence, water resource issues will pose a great challenge to all countries around the world in the future.

As the source of life, water is not only the main material necessary to grow food, generate energy, and produce industrial products but also the key element to ensure integrated ecosystems [1]. It is the basic resource that supports country socioeconomic development. Although the exploitation and utilization of water resources have promoted national economic development, they have seriously endangered the sustainability of water resources. In recent years, Taiwan has been repeatedly hit by extreme climates, such as droughts in dry seasons and floods in wet seasons. The environmental issue associated water resources management has become one of main concerns of policy-makers in Taiwan.

Drought, waterlogging, and water pollution are generally caused by ineffective water resources management. An integrated information system is needed to provide effective water resources management. Using accounting information systems, recognized as management control systems, could integrate accounting, statistics, environment, and economic development to maximize water resource utilization. However, traditional accounting methods could only measure economic benefits from the perspective of enterprises. Considering the complexity of the driving factors of water environmental cost, valuation models with various prospects of social responsibility would integrate social, environmental, and governance factors with sustainable development goal. No research on the measurement of environmental cost of water resources in Taiwan has provided the guidelines for managing sustainable development of water resources. This paper presents first attempts to construct an integrated accounting information system in measuring environmental cost of water resources and to provide a more complete picture of water resource management. An analytical framework for coordinating information sources of different systems can fill the current gap in the knowledge regarding water resource management [2].

A financial information system built on social responsibility accounting could timely reflect the interaction between enterprises and environments and strengthen enterprises' social responsibilities for environmental protection [3,4]. Managing scarce water resources with integrated information system would be a promising research direction for academics and policy makers [5,6,7,8].

2. Literature Review

The global water crisis in the 21st century is caused by not only the diminishing of available freshwater resources but also poor water management systems [9]. The lack of systematic water resource data in most countries prevents regular reporting of water utilization and treatment efficiency. Furthermore, water resources management agents at all levels fail to supervise the implementation of water resource policies, impeding the formulation and implementation of water resources management policies [10]. The demands for superior water resources accounting, which could provide better quality of water resource data, increase gradually [11].

Most countries carry out only individual statistics on water resource quantity (including surface water resources, groundwater resources, and total water resources) and utilization (including water supply and consumption). They fail to consider the overall water balance of certain regions so that the changes in the current water resources are not well presented and reflected upon. In the present water resource statistics, there is no detailed data on water evaporation, loss, and leakage, making it neither possible to accurately estimate the changes, utilization, and loss of water resources nor to reflect the intrinsic relationship between causes and results of these changes [1]. Therefore, it is necessary to integrate environmental and economic data of water resources under the framework of the environmental management accounting system.

2.1. Theoretical Framework of Environmental Accounting

The American Accounting Association (AAA) defined environmental accounting in 1973 as "the process of recording, analyzing, and reporting financial and ecological effects on corporate organizations to address environmental issues". The environment management accounting system refers to the information system that combines environmental protection and accounting through management mechanisms. The environmental management system can provide enterprises with an organized and systematic approach to improve their operation mechanisms, save operation costs, and enhance environmental performance [12]. According to the Guidelines on Environmental Management Accounting of the International Federation of Accountants (IFAC), the main goals of corporate environmental accounting are: (1) to assess and disclose environment-related financial information using financial statements; (2) to assess and disclose environment-related financial and practical information employing environmental management accounting; and (3) to link to national environmental statistics systems.

Environmental accounting is an accounting or statistical system that records economic, social, and environmental information, with the basic goal of achieving multi-objective coordination of economic, environmental, and social benefits [13]. In the traditional accounting theory, environmental resources are excluded from accounting statements. Most of economic growth indices cannot accurately reflect the intrinsic level of economic development by exaggerating economic benefits and ignoring environmental costs. Considerable research has been made on the measurement of environmental accounting and some research conclusions have been supported by the establishment of laws and standards [2].

2.2. Water Resources Management

Water resources management in the 20th century was widely discussed with the construction of large water conservancy facilities, such as dams, ditches, and dikes-called the hard path approach [14]. These projects are mainly used for water resource scheduling in dry and wet seasons. By constructing water conservancy facilities or developing water resources systems, water can be stored in dry seasons and drained in wet seasons. However, this approach fails to follow the sustainable development model of nature. With the economic development of human society, such as agricultural capacity, urbanization, and industrialization, the sustainable development of water resources is imperiled.

The construction of water conservancy facilities could meet the various needs of mankind [14]. However, the effectiveness of water resources management is challenged by adding new hard paths. For instance, it is widely recognized that the continuously heightened dikes and dams will cause ecological damages and is ultimately not sustainable [15]. In addition, if hard path-oriented water resources management measures are adopted, the maintenance costs of water conservancy facilities will be heightened with the risks of disrepair and performance degradation. Therefore, policy makers gradually shift towards a soft path approach of institutional reforms on water resource management [1]. This approach can tackle uncertainty in water resources management by providing more useful information for policy-makers in revising management systems and taking complementary measures (such as water price reform, water resources protection, and water rights distribution).

2.3. Water Resources Accounting

In economic production and life, human beings need to constantly acquire water resources from nature and discharge the final waste into nature after consumption. Water resources are commodities and can be exchanged in the market depends on their scarcity and utility [16]. The System of Environmental-Economic Accounting Water (SEEA-Water) Handbook, published by the United Nations Statistics Division (UNSD) in 2012, provides a conceptual framework for hydrological and economic information, which is compiled in a cohesive and coherent manner. The System can provide water flow information to establish the system architecture criteria of the interaction between economy and environment [17]. SEEA-Water has been implemented in 44 countries, with different agencies responsible for preparing SEEA-Water accounts [18]. SEEA-Water reports mainly provide data for policy-making and water resources management in national water policy development, water pricing, water distribution, and water resources analysis [19].

General Purpose Water Accounting (GPWA) reports, originated from the Australian water policy reform in the early 21st century, are prepared based on accounting standards to meet the information needs of external users, internal decision-makers, and stakeholders. In addition, these reports can be audited or reviewed according to uniform standards, which can be regarded as standardized water resources accounting reporting [6,20]. The water reporting entities specified in the GPWA standards should regularly prepare water accounting reports with a compact structure based on recognized GPWA standards. After GPWA was promoted and implemented in Australia, pilot programs were run in some countries, such as Spain and South Africa, to examine the effectiveness of GPWA [21,22].

2.4. Environmental Cost Accounting of Water Resources

Environmental costs refer to the costs of steps necessary to manage the environmental impacts of enterprises in an environmentally responsible manner. Environmental accounting is constructed by establishing measurement models and methods, based on theories of labor value, marginal utility value, and environmental economics, to measure environmental costs [2].

Environmental costs refer to the internal and external costs of steps necessary to manage the environmental impacts of enterprises in an environmentally responsible manner, as well as other costs incurred in meeting environmental objectives and regulations. Internal environmental costs are the expenditures that can be accurately measured in monetary terms and need to be borne by enterprises due to the effects of their economic activities on the environment. On the other hand, external environmental costs are those that cannot be accurately measured in monetary terms and assumed by enterprises due to the effects of the external economy [2]. The World Bank considers environmental cost as the reflection of currency reduction and the embodiment of environmental loss caused by natural resource depletion and environmental quality degradation during production and operation [23]. Recognized environmental costs of water resources are not only limited to monetary items but also include information useful to decision makers and can be measured in various ways, including water volume units or other descriptive ways [6]. Studies on environmental costs of water resources could provide more complete information on water resource costs to policy-makers, investors, and consumers [24].

3. Research Models

Due to the complexity of the key elements of water resources environment, various valuation methods are adopted on environmental cost measurement. Water Resources Agency (WRA) (2001) in Taiwan has studied the reservoir evaluation of water resources and adopts the Delphi expert questionnaire to define the main influence areas of the reservoir development plan and select key environmental factors [25]. The advantage of this method is to comprehensively consider the major environmental factors in the reservoir catchment area. The disadvantage, however, is that some environmental factors cannot be queried from any statistical or survey data.

Kramer and Eisen-Hecht [26] use contingent valuation method (CVM) via telephone and email to perform cost-benefit analysis of water quality to reflect the intrinsic value of water in the Catawba River basin of North and South Carolina. Dumas et al. [27] apply the travel cost method, hedonic pricing method, and contingent valuation method to evaluate the changes in the economic benefits due to the point source pollution[1] on water quality of Cape Fear River in North Carolina. Salvano et al. [28] evaluate non-point source water pollution[2] of agricultural production through a case study on the Chaudiere River. They adopt benefit transfer method to perform economic benefit evaluation on the restoration of water quality. Ho [29] proposes that an ecological compensation mechanism is a measure by charging the behaviors that damage the environment.

The United Nations Statistics Division [17] proposes several external environmental cost evaluation methods in the System of Environmental-Economic Accounting Water (SEEA-Water) for economic value analysis on water resources. And, other evaluation methods suggested by previous research mainly consider the fair value of environmental resources as the basic requirement. Due to the complexity of the diving factors of water environment cost, this study adopts multiple evaluation methods which are popularly discussed in the literature and described as follows:

(1) Shadow Price Approach: Shadow price is also known as the optimum planned price or calculated price. It refers to the price in economic analysis, which can reflect the real economic values of inputs and outputs, market supply and demand, and resource scarcity according to certain principles so that resources can be reasonably allocated and expressed in currency [17]. Shadow price reflects the resource scarcity and the demands for finished products in a certain optimal socioeconomic state conducive to the optimal allocation of resources. A shadow price is used to evaluate environmental impacts and represents the opportunity cost intended to pay for environmental resources.

(2) Restoration Cost Approach: Restoration cost is also known as replacement cost or virtual treatment cost. The measurement is the cost of restoring the ecological damage caused by environmental pollution includes at least the treatment cost before the discharge of pollutants. The restoration cost approach is widely applied in environmental public interest litigation to stop environmental pollutions and restore the ecological environment losses caused.

(3) Contingent Valuation Method: The method is also known as hypothetical market approach. It is a popular method for evaluating the value of public goods with intangible benefits, such as the environment. The method measures the values of goods or services (or the compensation price people are willing to accept) mainly by directly examining the economic behaviors of interviewees in hypothetical markets by a questionnaire survey to obtain consumers' willingness to pay.

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[1] Point source pollution means that the geographical locations where pollutants are emitted can be clearly identified. For example, emissions from sewage treatment plants, power plants, and other industrial facilities [17].

[2] Non-point source water pollution refers to emissions without specific pollution sources or geographical locations. For example, rainfall runoff pollutants, agricultural non-point sources, and emissions from urban areas [17].

(4) Ecological Compensation Method: The approach balances the negative environmental effects caused by development behaviors, which can be applied to various development behaviors. The concept of ecological compensation refers to the compensation for the damages to ecological functions or values caused by engineering development and construction through habitat creation, restoration, improvement, or conservation to ensure the overall ecological quality and maintain the original or even higher level. The compensation for the ecological environment refers to the "no net loss" of "resource acreage" and the "biological function" of ecological resources [29].

Environmental costs may be incurred during the development and operation of water resources. Regarding the environmental costs of reservoir catchment area, various environmental expenditures incurred during reservoir operations. In addition, before the reservoir operation, various expenditures incurred due to environmental damages as well as the expenditures spent in minimizing the environmental impairment during planning and construction periods. The environmental expenditures during construction period are capitalized and amortized annually over reservoir operation period by regulations[3]. Therefore, we construct an equation for calculating the annual total environmental costs of water resources as follows:

$$\mathbf{WEC} = (\mathbf{BWEC})/\mathbf{50} + (\mathbf{OWEC}) \quad (1)$$

Where **WEC** is water resources environmental cost; **BWEC** and **OWEC** are the water resources environmental cost during construction and operation periods. The environment costs consist of the natural resource depletion cost and environmental quality degradation cost [30]. Therefore, the calculations of environmental costs during construction and operation periods are defined as follows:

$$\begin{aligned}\mathbf{BWEC} &= \textbf{natural resource depletionduring construction}\\ &+\textbf{environmental quality degradationduring construction}\end{aligned} \quad (2)$$

$$\begin{aligned}\mathbf{OWEC} &= \textbf{natural resource depletionduring operation}\\ &+\textbf{environmental quality degradation during operation}\end{aligned} \quad (3)$$

Based on the argument of environmental factors analysis for water resources in WRA [25], we employ multiple approaches to measure the environmental costs of water resources during the different phases of reservoir development. Regarding natural resource depletion during construction, the restoration cost method is suggested to be employed to measure the effects of permanent detriments on plants removal. This method measures the cost of restoring the ecological damage caused by reservoir construction. For the historic relics, we apply the contingent valuation approach to measure the cost of removing or damaging these relics during construction. And the ecological compensation method is adopted to evaluate the compensation for the damages to ecological functions or the cost of habitat restoration caused by reservoir construction. The costs of environmental quality degradation during construction are normally included in the budget of reservoirs and are not needed to estimate for avoiding overstatement.

During the operation stage of reservoirs, we use the contingent valuation method to estimate the natural resource depletion during operation through the expenditures of maintaining cultural exhibition parks for relic sites. And, the restoration cost and ecological compensation methods are applied to measure the costs of environmental quality degradation during operation by collecting the expenditures of silt cleaning and pollution treatment.

4. Case Study

4.1. Accounting for the Environmental Cost of Two Reservoirs

Since no study has quantified natural resource depletion and environmental quality degradation, this study analyzes and quantifies the key factors, sources of influence, and consideration scope of the water resources development plan, identified by the Water Source Development Planning of WRA [25], by using the cases of two reservoirs of Taiwan during construction and operation phases.

The basin-based water resources management measures have not been adopted in Taiwan. The water resources management units are dispersed among different agencies and organizations without common management objectives. This study uses the cases of Liyutan and Hushan Reservoirs in Taiwan to estimate and compare the classified environmental costs of reservoirs development over the past two decades for showing the importance of environmental costs in water resources policy making and management.

The Liyutan and Hushan Reservoirs are under the jurisdiction of the Central Region Water Resources Office, Water Resources Agency, Ministry of Economic Affairs, Taiwan. We selected them as the cases in this study for the following reasons. Although there are around a hundred reservoirs in Taiwan, the data of water resources management of the two reservoirs are more complete than those of others. Due to the characteristics of reservoir operation and safety considerations[4], newly completed reservoirs are need to be tested for a period before being operated at full capacity. Liyutan Reservoir was completely constructed over twenty years and Hushan Reservoir was built five years ago but is more representative than other planned reservoirs. The two cases could be the representatives of the new and old reservoirs while we compare the environmental costs of water resources.

Liyutan Reservoir is an off-channel reservoir with the main purpose of public and industrial waters supply for Miaoli County and Taichung areas in Taiwan. The catchment area is 53.45 km^2, the submerged area is 4.32 km^2, and the

[3] The service life of a reservoir is 50 years according to the classification of property issued by the Directorate General of Budget, Accounting and Statistics (DGBAS) of Taiwan.

[4] Concerning the water storage of reservoirs in the preliminary stage after construction, the water level should be raised gradually by years and stages in order to ensure the safety of reservoir dams according to the regulations of the initial operation.

total water storage capacity is 126 million m^3. The Liyutan Reservoir project is divided into two phases: the first phase is the reservoir project, mainly including dams, spillway, extraction, and after bay weir. The first stage of construction began in 1985 and was completed in 1992 with total construction cost of NTD 8.59 billion. The second phase is the trans-basin water transfer project with the catchment area of 447.12 km^2 and completed in 2002 with total construction cost of NTD 13.84 billion (Source: Liyutan Reservoir website: https://www.wracb.gov.tw/47847/47848/47851/50249/) [31].

Liyutan Reservoir was planned before 1985 with a simple environmental impact report required for reservoir development. No historic sites were found in the submerged area and no detailed investigation report given on habitat effects of animals, plants, and fishes. In 2017, the RealWorld Surveying and Geomatics Corp. (RealWorld) was commissioned to do the reservoir siltation survey. The results showed that the reservoir silt had increased year by year. In particular, the silting in 2017 increased by 0.56 million m^3 compared with that in 2016 [32]. In 2018, the annual water supply of Liyutan Reservoir was 333.06 million m^3, including 84.20 million m^3 for agriculture and 248.85 million m^3 for domestic use (Source: Official statistics report website of Water Resources Department of the Ministry of Economic Affairs [33]).

Hushan Reservoir is located at the upper reach of Meilin River, Taiwan and is an off-channel reservoir with a catchment area of 6.58 km^2, a submerged area of 2.02 km^2, and its total water storage is 51.39 million m^3. The Hushan Reservoir project commenced in 2003 and the water storage was completed in 2016 with a total cost of NTD 20.48 billion (Source: Hushan Reservoir website: https://www.wracb.gov.tw/47906/47907/47908/50941/) [34].

The building of Hushan Reservoir was planned before 2001, when many environmental impact assessments and restoration projects (e.g., habitat transfers or habitat compensations) were made during the reservoir development to reproduce endangered animals. These costs are included in the construction costs of the reservoir. Hushan Reservoir, located in Douliu Hills, is a key archaeological area in Yunlin County. A number of prehistoric sites were found and have various cultural layers of different ages or connotations [35]. In order to maintain the effects of historic sites and cultural history, the reservoir development unit entrusted Yunlin County Government and Li Ambi Studio to construct a cultural ecology exhibition park. The cost is estimated to be NTD 106.78 million [36].

The annual water supply of Hushan Reservoir in 2018 was 37.37 million m^3 for domestic use (Source: Official statistics report website of Water Resources Agency [33]). Hushan Reservoir was completed in 2016 and the effective water storage in 2017 increased to 12.8 million m^3, accounting for about 25% of the total water storage [37]. In order to compare the two reservoirs, the environmental cost accounting of Hushan Reservoir is performed based on the expected full load of water.

There is no investigation report on the silting of Hushan Reservoir because it is still in the trial operation. According to the data of Liyutan Reservoir in 2017, the silting accounts for 0.44% (0.56 million m^3/126 million m^3) of the total water storage of the reservoir. Therefore, the annual silting of Hushan Reservoir was estimated to be 0.23 million m^3 during the normal operation (51.39 million m^3* 0.44%).

According to the data collected and measured by the environmental cost models we suggest, the water resources environmental cost during construction (BWEC) for Liyutan Reservoir is NTD 1.39 billion, accounting for 6.18% of the total construction cost. The annual environmental cost during operation (OWEC) is NTD 0.78 billion, accounting for 3.48% of the total construction cost. And the annual water resource environmental cost (WEC) of Liyutan Reservoir is NTD 0.81 billion, accounting for 3.61% of the total construction cost. As for Hushan Reservoir, the water resources environmental cost during construction (BWEC) is NTD 0.74 billion, accounting for 3.63% of the total construction cost. The annual environmental cost during operation (OWEC) is NTD 0.34 billion, accounting for 1.67% of the total construction cost. And the annual water resources environmental cost (WEC) is NTD 0.36 billion, accounting for 1.75% of the total construction cost.

Table 1. Environmental costs of Liyutan Reservoir and Hushan Reservoir (Unit: NTD thousand)

Items	Liyutan Reservoir		Hushan Reservoir	
	Amount	Percentage	Amount	Percentage
Total construction cost	22,430,000	100.00%	20,475,000	100.00%
Environmental cost during construction (BWEC)	**1,385,725**	**6.18%**	**742,570**	**3.63%**
Forest restoration expense in submerged areas	864,000	3.85%	404,000	1.98%
Water conservation loss	205,835	0.92%	160,411	0.78%
Carbon sequestration reduction loss	91,590	0.41%	71,378	0.35%
Cost of damage to historic sites	-	-	106,781	0.52%
Habitat compensation cost	224,300	1.00%	-	-
Environmental cost during operation(OWEC)	**781,219**	**3.48%**	**342,565**	**1.67%**
Cultural environment compensation expense	16,018	0.07%	8,505	0.04%
Silt cleaning cost	222,320	0.99%	90,440	0.44%
Pollution treatment cost	542,881	2.42%	243,620	1.19%
Annual environmental cost (WEC) (note)	**808,934**	**3.61%**	**357,416**	**1.75%**

Source: Compiled by this study
Note: Annual WEC = (BWEC /50 years)+ OWEC.

The BWEC and OWEC of two reservoirs are shown in Table 1. The difference in environmental costs between the two reservoirs is mainly caused by the different price indexes of construction costs spanning 23 years. If the construction price index for 2016 is adjusted to 61.44% [38] of the base period of 1992 according to the Directorate General of Budget, Accounting and Statistics (DGBAS), the annual WEC of Liyutan Reservoir will account for 2.22% of the total construction cost. Subsequently, the annual WEC difference between Liyutan Reservoir and Hushan Reservoir will be significantly narrowed.

4.2. Cost-Value Analysis of Water Resources

This study further to perform the cost-value analysis on the environmental costs of the reservoirs. The unit prices of water come from the 2018 Subordinate Agency Budget of Water Resources Operation Fund by the Central Region Water Resources Office of Taiwan. The unit prices of public water supply are NTD 0.93/m^3 for Liyutan Reservoir and NTD 1.43/m^3 for Hushan Reservoir [39]. Both Liyutan Reservoir and Hushan Reservoir are under the jurisdiction of the Central Region Water Resources Office. Therefore, the operation and management cost per unit for both reservoirs is NTD 1.04/m^3, calculated by dividing the water supply cost of NTD 0.76 billion by annual operation volume of 0.73 billion m^3 obtained from the 2018 Financial Statement of the Central Region Water Resources Office [40].

Table 2 shows the results of cost-value analysis of Liyutan Reservoir and Hushan Reservoir. The current unit prices of public water supply are remarkably low, which are close to the operation and management cost per unit of the reservoirs, without considering construction and environmental costs. The losses of water sales per cubic meter is NTD 3.89 for Liyutan Reservoir and NTD 4.74 for Hushan Reservoir, which are 3 to 4 times higher than the unit prices of raw water. The findings show that the government provides subsidies to make up for construction costs and environmental losses. However, such subsidies would mislead consumers and policy-makers of water resources and jeopardize the sustainability of nature resources.

Table 2. Cost-value analysis of Liyutan Reservoir and Hushan Reservoir (Unit: NTD/ m^3)

Items	Liyutan Reservoir	Hushan Reservoir
Unit selling price of raw water (note 1)	**0.928**	**1.428**
Total unit cost of raw water	**4.814**	**6.169**
Environmental cost (note 2)	2.429	2.391
Construction cost (note 3)	1.347	2.740
Operation management cost (note 4)	1.038	1.038
Profits (losses) from the sales of water	**(3.886)**	**(4.741)**

Source: Compiled by this study
Note 1: Data from the 2018 Subordinate Agency Budget of Water Resources Operation Fund
2: Environmental cost per m^3 = annual environmental cost / annual operation volume
3: Construction cost per m^3 = (total construction cost /50 years)/ annual operation volume
4: Data from the 2018 financial statement of the Central Region Water Resources Office.

5. Conclusion

In the era of severe climate change and sustainable resource use, exploring the environmental cost of water resources is one of the most important global environmental challenges. This study aims to assist national water resources agencies in developing an effective accounting information system of water resources. By combining theoretical analysis with the study of cases, this research provides an environmental cost measurement framework for water resources in Taiwan. The comprehensive use of multiple valuation methods of environmental costs in this study helps improve the robustness and generalization of our findings.

With Liyutan Reservoir and Hushan Reservoir of Taiwan as the cases, we explore the characteristics of environmental costs of water resources by analyzing the effects and connotations of environmental factors of water resources. The environmental accounting system constructed in this paper would provide useful information in effectively promoting environmental governance and water resources conservation. According to the unique characteristics of renewability and liquidity of water resources, an effective environmental cost accounting of water resources could solve the problems of water quality deterioration and water environment destruction.

Due to the complexity of the driving factors of water resources environmental cost, the results of cost estimation may vary largely due to the data availability, collection expenses, and geographic differences. It is expected that additional environmental cost factors could be considered in future studies so that the accounting information system of water resources would provide more comprehensive environmental information for users.

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