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A Method of Evaluating Water Resource Assets and Liabilities: A Case Study of Jinan City, Shandong Province

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Abstract: The traditional concepts of water resource development and utilization have caused serious hydrological and environmental issues in some regions. In addition, policy issues in China have led to a severe water crisis. The quantitative accounting of water resources is a theoretical approach to solving these problems. In this paper, 13 indicators were selected from four classes, including resources, the environment, society, and efficiency, and a case study of Jinan, Shandong Province, was performed using a set pair analysis model to calculate the water resource assets from 2011–2015. In previous methods of water resource accounting, the water quality was not considered; therefore, the loss coefficient of water resource assets was proposed to improve the reliability of accounting. According to the relationships among the unit price of water, water quantity, and water quality, physical and quantitative accounting methods were used to create water balance sheets from 2011–2015. The calculation results showed that the physical change in water resource assets in Jinan City was −30 million m^3, and water resource assets initially increased and then decreased. In 2011, 2012, 2013, 2014, and 2015, water resource assets totalled 36.5 million USD, 45.9 million USD, 66.7 million USD, 35.5 million USD, and 37.5 million USD, respectively (at 6.4588, 6.3125, 6.1932, 6.2166, 6.2284 USRMB, respectively). This initial accounting provides quantitative and physical support for the improved management of water resources.

Keywords: water resources; balance sheet; set pair analysis; loss coefficient of water resource assets; Jinan City

1. Introduction

Water is the source of life, a key to production, and the basis of ecology [1]. In recent decades, humankind has not realized the importance of water resources [2] and has underestimated their role [3], and overexploitation and pollution have seriously threatened and hindered human survival and development. In addition, people have underestimated the calculated value of a portion of water resources. For example, the reduction in the value of resources caused by resource consumption in socio-economic activities has not been reflected in national economic accounting; thus, the external costs of socio-economic activities are underestimated, and this fails to completely reflect the comprehensive achievements of human society in its development [4]. In this context, the concept of "the sustainable development of water resources" was proposed. Determining how to evaluate the development and sustainability of regional water resources has become an issue that scientists around the world have relentlessly explored [5,6].

To scientifically evaluate water resources, it is necessary to assess and quantify actual water resource scenarios [7]. Allan [8] and Hoekstra [9] proposed the concepts of "virtual water" and "water footprint", respectively, and introduced a series of indicators to evaluate the sustainability of water resources used in national or regional production or services [10]. Although the quantitative evaluation index of the water footprint comprehensively and intuitively reflects the overall sustainable development in a study area, it is still insufficient for the task of identifying the comparative advantages and disadvantages in regional development and water resource accounting [11].

Analyzing the water resource carrying capacity (WRCC) is another effective method of scientifically evaluating water resources. Since the 1990s, many studies of the WRCC have been performed [12–14]. Notably, many scholars have proposed various definitions, research methods, and index systems with good and generally accepted results [15]. Another popular research topic is the complex relationships among water resources, socioeconomics, and the environment in the evaluation of the regional WRCC and measurements of the effectiveness of sustainable development. Such studies use the same approach as water resource accounting. Therefore, future studies must quantify the value of water based on water analysis [16]. Traditional economic accounting systems often ignore water resources and environmental factors; thus, major improvements can be made to improve scientific methods of water resource evaluation.

The Third Plenary Session of the 18th Central Committee of the Communist Party of China (CPC) made a major decision to "explore the preparation of the natural resource balance sheet, audit the implementation of natural resource assets, and establish a system of lifelong accountability for ecological and environmental damage" [17]. Currently, no international precedent exists regarding the creation of water resource balance sheets. Water resources are also characterized by renewability, randomness, and liquidity. Therefore, different issues exist in the creation of water resource balance sheets, especially in the treatment of other natural resources and the use of different theories, methods, and research contexts [18]. A balance sheet can be used to assess the quality of regional development, and directly links the population, resources, and environment. Only through analyses of regional developmental quality can we comprehensively evaluate and regulate regional development [19].

In summary, the innovative management of water resource assets is important for resource utilization and environmental stability, and must be emphasized. Water resource balance sheets can be used to determine the properties of water resource assets, to identify these assets and the associated liabilities and changes, to reflect the development and utilization of water resources in a given period, as well as the subsequent impact on the environment [20]. This approach provides a reliable method of water evaluation. In addition, the government can implement targeted water use compensation or a compensation system, thus promoting stable socioeconomic and environmental development in China.

In this study, Jinan City, Shandong Province, was chosen to construct an evaluation system for water resource assets. We calculated the regional water resources, assets, and liabilities, and quantitatively analyzed and evaluated the sustainable development capacity of water resources in the area. The results of this study provide a framework for the objective understanding of the sustainable development of water resources and a basis for resource and environmental audits when the current cadre leaves office.

2. Case Study: Physical Accounting of Water Resources in Jinan City

2.1. Case Study

Jinan City is not only the provincial capital city of Shandong Province, but also a pilot city of water resource balance sheet accounting in China. The city is located in the central and western parts of Shandong Province (Figure 1). It can be divided into three major watersheds: the Yellow River Basin, the Xiaoqing River Basin, and the Tuhai-Majia River Basin. At present, several water resource problems exist in Jinan [21].

- Resource shortages and supply and demand gaps have led to obvious constraints on economic development. The existing water supply capacity can only meet the anthropogenic and industrial water demands, and the agricultural water gap is completely supplemented with sewage water.

In 2015, the effective irrigation area of Jinan was 239,922 hm^2, accounting for only 72.32% of the area of agricultural arable land. Additionally, the area of harvested farmland due to drought and water shortages was only 15,000 hm^2.

- Jinan is facing a grim groundwater situation. With the large-scale exploitation of karst groundwater and rapid urbanization, continuous lowering of groundwater levels, groundwater quality deterioration, and a large area of karst collapse have occurred in these karst groundwater systems. Correspondingly, the springs have notable groundwater flowing into a below-ground fissure, which decreased the springs' output for long periods, and some springs have even dried up [22].
- Since the 1990s, water pollution in Jinan has become increasingly prominent. Due to the rapid development of townships and enterprises and inefficient production processes, the amount of industrial wastewater discharge that does not meet the local standards is high, and the sewage treatment rate is low. These issues have caused serious pollution issues in surface waters and have seriously deteriorated water quality. Harmful substances such as arsenic, mercury, lead, chromium, and fluoride have been detected in surface waters, and their concentrations have increased over time. Additionally, water pollution has shifted from point-based pollution to regional pollution. Many heavily-polluted rivers and lakes have lost their ecological functions.

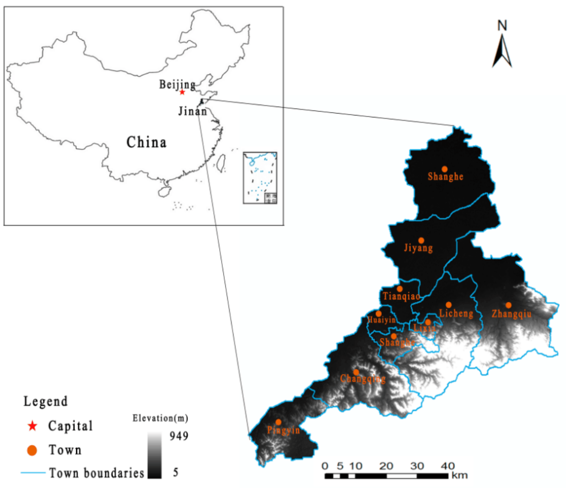

Figure 1. Location and administrative divisions of Jinan City.

2.2. Physical Accounting

The physical accounting of water resources provides data for calculating the values of water resource assets. The first step in this process is the creation of a water resource balance sheet. Physical accounting is based on water resource statistics, and reflects regional water resource information based on the physical units of different resources [23]. The statistical factors associated with water resource assets and accounting in Jinan City are as follows: an increase or decrease in stock caused by natural factors (such as inflow, outflow, and precipitation) and human activities (such as the water intake and water return). From the point of view of data availability, the accounting of water resources in Jinan is mainly based on water resource quantities that vary over the course of a year, and some assets of water resources or reserves are not considered. In Jinan City, reservoirs are a major source of surface water and an important form of precipitation storage. According to the initial estimate of Jinan City, at the beginning of 2011, the physical stock of water resources was 0.091 billion m^3, and at the end of 2015, the stock was 0.061 billion m^3. The change in water resources from 2011 to 2015 was a loss of 0.03 billion m^3. he physical accounting of water resources in Jinan City from 2011 to 2015 is shown in Table 1. The increase in stock caused by precipitation is the factor that leads to the largest change in water resource assets in Jinan City. Additionally, actual evaporation is the main cause of the decrease in the water resource stock.

Table 1. Stock accounting of the water resources of Jinan City from 2011–2015 (100 million m^3).

Item		Year				
		2011	**2012**	**2013**	**2014**	**2015**
Year-beginning stock		1.04	0.91	1.16	1.28	0.64
Increase in stock	Water resources from precipitation	54.55	46.54	60.18	42.64	58.37
	Inflows	16.09	15.61	20.86	7.91	11.14
	Water return of society	1.91	1.87	1.94	1.86	1.52
Decrease in stock	Water intake	17.36	17.53	17.15	16.91	16.05
	Evaporation	51.37	42.71	61.27	33.88	52.91
	Outflows	2.83	2.65	3.59	1.47	1.96
	Ecological water consumption of rivers and lakes	1.12	0.88	0.85	0.79	0.14
Year-end stock		0.91	1.16	1.28	0.64	0.61

3. Methodology

In previous papers, the value of water resources was based on the product of the unit price and the quantity of water resources [24,25], but this ignores the role of water quality in the value of water resources. Therefore, we propose a loss coefficient of water resource assets and define water resource assets based on the water quality, water quantity, and water price:

$$V = D \cdot WLJ \cdot r_i \quad (1)$$

where V is the value of water resource assets in million USD (United States dollar); D is the water quantity, million m^3; WLJ is the unit price of water resources, USD; and r_i is the loss coefficient of water resources.

3.1. Determination of the Unit Price of Water Resources

3.1.1. Comprehensive Evaluation Vector Based on Set Pair Analysis (SPA)

(1) SPA mathematic model:

Algorithms based on fuzzy set theory may lead to the loss of too much information, and the subsequent results can be homogeneous and difficult to understand. SPA theory was introduced to solve such problems. SPA is a new method of systematic analysis proposed by Zhao in 1989 [26]. This method has been widely used in the comprehensive evaluation of water quality, the prediction of hydrological properties, and the evaluation of water safety [27]. The original connection degree is calculated as follows: $\mu(A, B) = a + bi + cj$. However, the method encounters problems in the refinement of values (e.g., (b, c), which can lead to contradictory results [28]. In this paper, we refined (b, c) in the original theory and extended the degree of association to the fifth level. The method was then applied to calculate the unit price of water resources [29].

The value of water resources can be divided into four categories: resource, environmental, societal, and efficiency factors. This value is based on a total of n indicators and is recorded as $x_j (j = 1, 2, ..., n)$. The water value can be divided into five grades: high, relatively high, medium, relatively low, low. The grade of water resources comprises Set A, and the index value that affects the value of water resources is Set B. Thus, they form a set pair, which can be used to compare the corresponding items in the two sets:

$$\mu(A, B) = a + bi^{+} + ci^{-} + dj^{+} + ej^{-} \quad (2)$$

where a is the matching degree, b is the positive difference degree, c is the negative difference degree, d is the positive correspondence degree, and e is the negative correspondence degree. Therefore, $a + b + c + d + e = 1$.

(2) Calculation of the SPA connection degree:

The value evaluation vectors of different regions will differ according to the difference in the index value, even if they are of the same grade. Therefore, the connection degree should be established to describe the quantitative relationship between the evaluation index and the grade. The grade was selected as the evaluation criterion. If the index value matches the evaluation grade, then $a = 1$, and other coefficients are zero. If the index value is of an adjacent evaluation grade, the closer to the evaluation standard the value is, the larger a is. Conversely, the farther away from the evaluation standard the value is, the greater b, c, d, and e are. If the index is of an adjacent and superior evaluation grade, the closer to the adjacent evaluation criterion the value is, the larger a is, and the smaller b is; otherwise, a is smaller, and b is larger. If the index is of an adjacent and inferior evaluation grade, the closer to the standard the value is, the larger a is, and the smaller c is; otherwise, a is smaller and c is larger. If the index does not match the grade or the adjacent grades, but is associated with a superior grade, the closer to the standard the value it is, the larger a and b are, and the smaller d is. Conversely, if the grade is inferior, the closer to the standard the value is, the larger a and c are, and the smaller e is. An indicator evaluation model was constructed according to these principles. According to the above model principle, taking the first-grade connection degree as an example, the calculation model of the positive index is as follows. We can calculate the second-level to fifth-level connection degree by analogy.

$$\mu_1(s_{1j}, x_j) = a + bi^+ + ci^- + dj^+ + ej^-$$
$$= \begin{cases} 1 + 0i^+ + 0i^- + 0j^+ + 0j^- & x_j \in [0, s_{1j}) \\ \frac{s_{1j}}{x_{ij}} + \frac{x_{ij} - s_{1j}}{x_{ij}} i^+ + 0i^- + 0j^+ + 0j^- & x_j \in [s_{1j}, s_{2j}) \\ \frac{s_{1j}}{x_{ij}} + \frac{s_{2j} - s_{1j}}{x_{ij}} i^+ + 0i^- + \frac{x_{ij} - s_{2j}}{x_{ij}} j^+ + 0j^- & x_j \in [s_{2j}, +\infty) \end{cases} \tag{3}$$

where s_{kj} is the threshold value of k and $k + 1$ for the j^{th} index. a, b, c, d, and e are calculated for each index in each region according to the above model. Similarly, we can construct the formulas for the reverse degrees relative to the different ranks.

By calculating the comprehensive weight of the index $W = \omega_j$ and the connection degree matrix $N = a_{jk} + b_{jk}i^+ + c_{jk}i^- + d_{jk}j^+ + e_{jk}j^-$, we can select a fuzzy operator pair (W and N) to calculate the integrated connection degree $\bar{\mu}_k$ in region i relative to the grade k.

$$\bar{\mu}_k = W \circ N = a_k + b_k i^+ + c_k i^- + d_k j^+ + e_k j^- \tag{4}$$

(3) Calculation of the comprehensive evaluation vector of SPA:

The set pair potential is the ratio of the matching degree to the opposite degree in this study. The set pair potential reflects the trend or convergence degree of the two sets in the specific research context. In comprehensive evaluations of water resources, the price of the asset is calculated. The degree of convergence in the region can be obtained for different levels of set pair potentials in region i. The larger the set pair potential is, the stronger the matching trend is. The corresponding grade of the largest set pair potential is the result of the sample judgment. The improvement of the SPA based on set pair potential is calculated using Equation (5).

$$shi(\bar{\mu}_k) = a_k / (d_k + e_k) \tag{5}$$

The pessimistic potential is the translation of differences based on the opposite degree from a pessimistic point of view. The definition of the pessimistic potential is given by Equation (6).

$$shi_p(\bar{\mu}_k) = a_k/(b_k + c_k + d_k + e_k) \quad (6)$$

The optimistic potential is the translation of differences based on the matching degree from an optimistic point of view. The definition of the optimistic potential is given by Equation (7).

$$shi_o(\bar{\mu}_k) = (a_k + b_k + c_k)/(d_k + e_k) \quad (7)$$

The value of the set pair potential is determined based on the interval of the pessimistic potential. Thus, the position of the set pair potential can be calculated according to Equation (8) to determine the closeness degree of the set pair potential in the interval relative to the optimistic potential. This relationship reflects the accuracy of the optimistic potential determined based on the set pair potential:

$$s_k = \frac{shi(\bar{\mu}_k) - shi_p(\bar{\mu}_k)}{shi_o(\bar{\mu}_k) - shi_p(\bar{\mu}_k)} \quad (8)$$

where s_k is normalized. The comprehensive evaluation vector V_k of SPA can be obtained using Equation (9).

$$V_k = \frac{s_k}{\sum_{k=1}^{5} s_k} \quad (9)$$

3.1.2. Index Data and Weight Calculation

We chose four criteria—resources, the environment, society, and efficiency—which are representative and easy to quantify. So, the feature set of the value of water resources is as follows: V = resources, environment, society, efficiency. The resource indices include per capita water resources and water resources per unit area. The environment indices include chemical oxygen demand, ammonia nitrogen, sewage treatment rate, and water functional area compliance rate. The society indices include per capita gross domestic product (GDP), water consumption, industrial added value of water consumption, and population density. Finally, the efficiency indices consist of three parts: water resource development and utilization rate, agricultural irrigation water utilization factor, and industrial and water reuse rate. They are chosen in the accounting and price evaluation of water resources in Jinan [30–33]. We evaluated these indexes based on different attributes. The analytic hierarchy process (AHP) and entropy weight methods [34,35] were combined to assign combined weights to each index based on subjective preference and objective correlation (Table 2).

The water quality grading standard was formulated according to the pollution level classification table of the "National Surface Water Environmental Quality Standard (GB3838-2002)". In addition, based on the relevant research results [36–40] and according to the water resource development and control program proposed in the "13th Five-Year Plan of Water Conservancy Reform and Development" [41], the scope of the analysis was established. Combined with the detailed data from 31 provinces and cities between 2011 and 2015, each evaluation level was standardized, and the safety standards were adjusted according to expert advice (Table 3). Table 4 shows the indicator system of the sustainable development of water conservation in jinan from 2011 to 2015.

Table 2. Determination of subjective and objective weights.

Criterion layer	Weight	Attribute	Abbreviation	Index Layer	Subjective Weight	Objective Weight	Comprehensive Weight
A1: Resources	0.333	+	B1	Per capita water resources (m^3/ people)	0.077	0.1805	0.129
		+	B2	Water resources per unit area (10,000 m^3/km^2)	0.077	0.1727	0.125
A2: Environment	0.333	-	B3	Chemical oxygen demand (COD; mg/L)	0.077	0.0181	0.048
		-	B4	Ammonia nitrogen (mg/L)	0.09	0.1403	0.115
		-	B5	Sewage treatment rate (%)	0.064	0.0018	0.033
		+	B6	Water functional area compliance rate (%)	0.077	0.1682	0.123
A3: Society	0.167	+	B7	Per capita gross domestic product (GDP; 10,000 USD/people)	0.09	0.021	0.055
		+	B8	GDP water consumption (m^3/10,000 USD)	0.09	0.0341	0.062
		-	B9	Industrial added value of water consumption (m^3/10,000 USD)	0.077	0.0176	0.047
		-	B10	Population density (people/hm^2)	0.077	0.0002	0.039
A4: Efficiency	0.167	-	B11	Water resource development and utilization rate (%)	0.077	0.2434	0.16
		+	B12	Agricultural irrigation water utilization factor	0.038	0.002	0.02
		+	B13	Industrial water reuse rate (%)	0.09	0.0002	0.045

Table 3. Indicator system and scope of the sustainable development of water conservation.

Index Layer	Scoring Criteria for the Quantitative Accounting of Water Resources				
	I Low	*II* Relatively Low	*III* Medium	*IV* Relatively High	*V* High
B1	≤500	(500, 1000]	(1000, 1350]	(1350, 1700]	>1700
B2	≤7	(7, 16]	(16, 44]	(44, 78]	>78
B3	≥30	[20, 30)	[15, 20)	[10, 15)	<10
B4	≥1.5	[1.0, 1.5)	[0.5, 1.0)	[0.15, 0.5)	<0.15
B5	≤80	(80, 85]	(85, 90]	(90, 95]	>95
B6	≤60	(60, 70]	(70, 80]	(80, 90]	>90
B7	≤2	(2, 7]	(7, 14]	(14, 22]	>22
B8	≥130	[100, 130)	[70, 100)	[50, 70)	<50
B9	≥60	[45, 60)	[30, 45)	[15, 30)	<15
B10	≥2000	[1200, 2000)	[800, 1200)	[150, 600)	<150
B11	≥50	[40, 50)	[30, 40)	[20, 30)	<20
B12	≤0.5	(0.50, 0.57]	(0.57, 0.64]	(0.64, 0.71]	>0.71
B13	≤80	(80, 85]	(85, 90]	(90, 95]	>95

Table 4. Indicator system of the sustainable development of water conservation.

Index Layer	2011	2012	2013	2014	2015
B1	266.4	343.9	256.2	129	190.43
B2	19.7	25.5	19.1	9.7	14.5
B3	30.8	25.3	24.5	24.2	23.7
B4	1.7	1.1	1	0.8	0.9
B5	89.6	86.6	89.8	90.2	95.3
B6	27.3	21.4	26.7	50	36
B7	6.43	6.94	7.5	8.21	8.63
B8	39.8	36.5	32.8	29.3	27.5
B9	16.4	15.5	14.7	13.8	12.3
B10	738.7	741.9	745	750	760.2
B11	83.2	107.6	78.6	204.1	132.5
B12	59	57	63	59	60
B13	85	86	86	87	87

3.1.3. Unit Price of the Stock Value of Water Resources

The evaluation model of water resources' value was proposed by Wenlai in 1995 [42,43]. The results of this model provide a comprehensive evaluation of the value of water resources. To convert the dimensionless evaluation vector of the fuzzy comprehensive evaluation into the corresponding scalar price value, the price vector (WLJ) is established based on the conversion formula proposed in Wenlai's value theory of water resources:

$$WLJ = V \times S \tag{10}$$

where V is the evaluation vector of SPA and S is the price vector based on the water price [44] using the difference interval method. Therefore, the price of water resources is within [P, 0], and $S = (P,\ 0.75P,\ 0.5P,\ 0.25P,\ 0)^T$.

The upper limit of the price of water resources is the price when the maximum water price is reached. This relationship can be expressed by the following formula:

$$P = EA/C - D \tag{11}$$

where P is the upper limit of the water price, USD; A is the maximum water price, %; E is the per capita disposable income of residents, USD; C is the yearly household water consumption, m^3; and D is the water supply cost and the normalized profit, USD.

3.2. Loss Coefficient of Water Resource Assets

The value of water resources is affected by water pollution. When water pollution is severe, the value of water resources is low. Based on a hyperbolic function, the influence of water quality-based economic loss can be determined using the method proposed by Jinxiu [45,46]. In this approach, water quality is the abscissa, and the relative water quality coefficient (the ratio of the actual water quality to the optimal water quality) is the ordinate. A plotted line denotes the relationship between water quality and the asset quality coefficient, as shown in Figure 2. When the water quality is optimal, the asset quality coefficient is 1.0; when the water quality is inferior in the five classes of water, the asset quality coefficient is zero; and when the water quality varies from the best to the worst as the water quality class increases, the asset quality coefficient varies from 1.0 to 0.

$$r_i = 0.5 - \frac{e^{\alpha(C-C_a)} - 1}{e^{\alpha(C_a-C)} + 1} \tag{12}$$

where a is a parameter that characterizes the hyperbolic morphology and reflects the sensitivity of the water quality condition to its function. The larger a is, the steeper the functional curve is; i.e., the use function is extremely sensitive to the water quality condition. A small value of a indicates that the use function is not sensitive to the water quality condition. Additionally, C is the water quality scenario, and water quality is classified according to the "National Surface Water Environmental Quality Standard (GB-3838-2002)". C_α is the intersection of the asset coefficient and debt quality coefficient (i.e., the point at which these coefficients are equal).

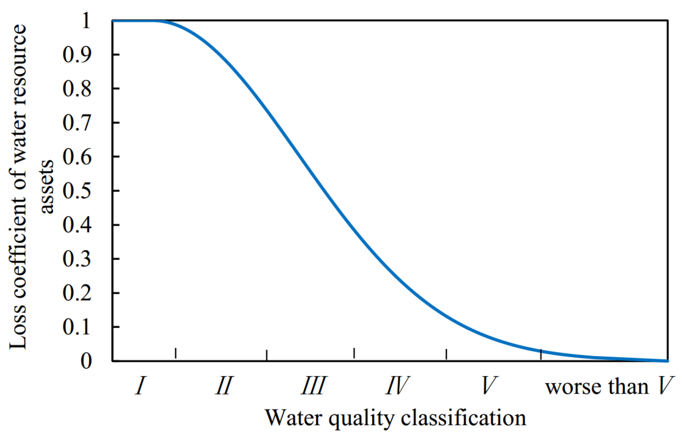

Figure 2. Loss coefficient of water resource assets and water quality classification.

4. Results

4.1. Calculation of the Comprehensive Evaluation Vector

According to the data in Table 5 and Equations (2) and (3), we calculated the SPA connection degree matrix of water resources in Jinan in 2015. We chose the fuzzy operator and used MATLAB software and the "sumproduct" function in Excel to compute the weight vector W and the connection degree matrix R_{2015}. Based on this approach, the comprehensive connection degree of different grades in Jinan in 2015 was obtained (Equation (13)). Similarly, we can obtain the SPA connection degree of Jinan from 2011 to 2014.

$$\begin{aligned}\mu_{2015} = W \circ R_{2011} = [&0.69 + 0.10i^{+} + 0.11i^{-} + 0.02j^{+} + 0.08j^{-}; 0.56 + 0.19i^{+} + 0.20i^{-} + 0.01j^{+} + 0.04j^{-};\\ &0.56 + 0.05i^{+} + 0.13i^{-} + 0.13j^{+} + 0.12j^{-}; 0.41 + 0.11i^{+} + 0.19i^{-} + 0.14j^{+} + 0.15j^{-};\\ &0.34 + 0.09i^{+} + 0.14i^{-} + 0.20j^{+} + 0.23j^{-}]\end{aligned} \quad (13)$$

According to Equations (4)–(9), we can calculate the set pair potential, pessimistic potential, optimistic potential, and position of the set pair potential for different grades in Jinan in 2015. Comprehensive evaluation vector is a dimensionless number, and its value is between 0 and 1. The greater the value is, the greater the probability of belonging to the rating level. According to the calculation results in Table 5, the water resources value in Jinan City in 2015 was between I, II, and III, indicating that the water resources value in Jinan City was low.

Table 5. Set pair analysis (SPA) comprehensive evaluation results of Jinan water resource assets (2015).

Grade Standard	*I*	*II*	*III*	*IV*	*V*
Set pair potential	7.32	10.22	2.22	1.38	0.78
Pessimistic potential	2.22	1.26	1.30	0.69	0.51
Optimistic potential	9.62	17.32	2.93	2.40	1.30
Position of the set pair potential	0.69	0.56	0.56	0.41	0.34
Comprehensive evaluation vector V	0.27	0.22	0.22	0.16	0.13

4.2. Loss Coefficient of Water Resource Assets

Loss coefficient is a comprehensive coefficient affected by water quality, so this coefficient can also reflect the local manager's water management level and local weather journals. When the local management level is high and rainfall is large, loss coefficient will be larger; otherwise, it will become smaller. According to the relevant literature [45,46], this paper argues that when the comprehensive water quality is inferior to V, r_i is close to the minimum value and is assumed to be 0.01. When the comprehensive water quality is Grade I, the water quality is high, and ecological function is not lost—namely, r_i is equal to one. When the comprehensive water quality is Grade II, the water quality is good, and its impact on socioeconomic production is small. Specifically, it is assumed to equal 0.99. Entering actual data into the Equation (12) yields a value of parameter $\alpha = 0.53606$. Based on this value, the average water quality of the functional area and the loss coefficient of water resource assets in Jinan from 2011 to 2015 can be calculated. The calculation of asset coefficients results in Figure 3.

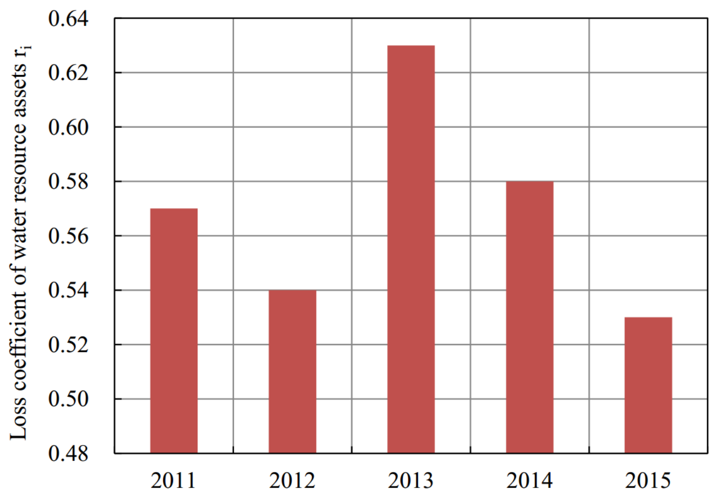

Figure 3. Asset coefficients of water resources for different water qualities.

4.3. Calculation of the Value of Water Resources

The water price is the link between physical accounting and quantitative accounting. The scarcity of water resources in Jinan makes it difficult to determine the rational use of water resource assets. In Equations (10)–(11), the maximum value of Index A was 2% [33]; monthly per capita disposable income E was 3328.78 USD; the annual water demand of residents C was 41.34 m^3; and the value of water supply costs and normalized profits D was 0.446 USD. Using the equidistant interval method, the price of water resources is in the interval [P, 0]. In 2015, the value of the vector was [12.37, 9.28, 6.19, 3.09, 0]. Thus, at the end of 2015, the unit price of water resources in Jinan was 1.159 USD/m^3. Using the same method, the unit price of water resources was 0.703 USD/m^3, 0.733 USD/m^3, 0.827 USD/m^3, and 0.956 USD/m^3 in 2011, 2012, 2013, and 2014, respectively. Based on the physical accounting, the value of water assets was obtained to determine the corresponding aggregate indicators through comprehensive calculations. Based on the annual stock changes presented in Table 1, the annual assets of water resources in Jinan from 2011–2015 were obtained, as shown in Table 6. The value of water resources in Jinan was 36.5 million USD at the beginning of 2011, and the change in water resource assets from 2011–2015 was −30 million m^3. The value of water resource assets at the end of 2015 was 37.5 million USD. Therefore, the value of water resource assets in Jinan initially increased and then decreased. The value of water resource assets in 2013 was the highest, and the most important reason was that the amount of rainfall was large in 2013. Thus, water resources at the end of the year were larger than that of normal years. Besides, the large rainfall led to a better water environment. Compared with 2014, although 2015 was a dry year, the final value of the water resource assets was higher than that of 2014 because economic condition and water management level in 2015 were better than that of 2014.

Table 6. Annual assets of water resources in Jinan from 2011 to 2015.

Item	2011	2012	2013	2014	2015
Unit price (USD/m^3)	0.703	0.733	0.827	0.956	1.159
Water resources at the end of the year (million m^3)	91	116	128	64	61
Decay rate of environmental function r_i	0.57	0.54	0.63	0.58	0.53
Assets of water resource stocks (million USD)	36.5	45.9	66.7	35.5	37.5

5. Discussion

5.1. Advantages and Applicability of the Method

International special research on natural resource balance sheets are rare. Most studies were carried out in conjunction with the preparation of national balance sheet based on SNA2008 and SEEA 2012. In the rare studies and practices at home and abroad, Australia's achievements are outstanding. The Australian Water Accounting Standard (AWAS) formulated and implemented by Australian Bureau Of Meteorology (BOM) has given the definition and interpretation of the content and role of water resources balance sheets in the water resources statistics system. After years of practical application, it has become standardized and institutionalized [47]. However, the water resources balance sheet of the Australian BOM is mainly enterprises' calculation of water revenue and expenditure. The sheet uses the amount of water resources to represent the water assets (similar to Table 1). In this paper, the application of the SPA evaluation method and an evaluation model can take full account of the development status of relevant indicators in the country's rank and evaluation regions. The degree of social, economic, and ecological development is consistent with the theory of physical potential. Loss coefficient of water resource assets can make the calculation process more fully consider the water quality factors so that the calculation results are more accurate. The method is simple and adaptable, and its result is intuitive and clear, which provides a good reference.

5.2. Calculation of the Value of Water Resources

Xia [48] proposed the concepts of the functional capacity and functional deficit of water resources to describe the conditions of the sustainable use of water resources. These concepts have the same connotation as the concepts of water resource assets and liabilities. Water resource assets and liabilities describe the sustainability of water resources in terms of the magnitudes of resources. The functional capacity and deficit of water resources describes the sustainability of regional water resources in terms of physical quantities. To verify the accuracy and feasibility of the calculation method, we used the research methods of Xia and others to calculate the water resource capacity of Jinan City from 2011 to 2015. Although the results calculated using the two methods differed in dimension, we can verify our computational method by comparing the results of the two methods. We found that the trend in the water resources of Jinan was the same based on the two methods. This result (shown in Figure 4) suggests that the evaluation results in this paper exhibit good agreement with the actual situation in Jinan.

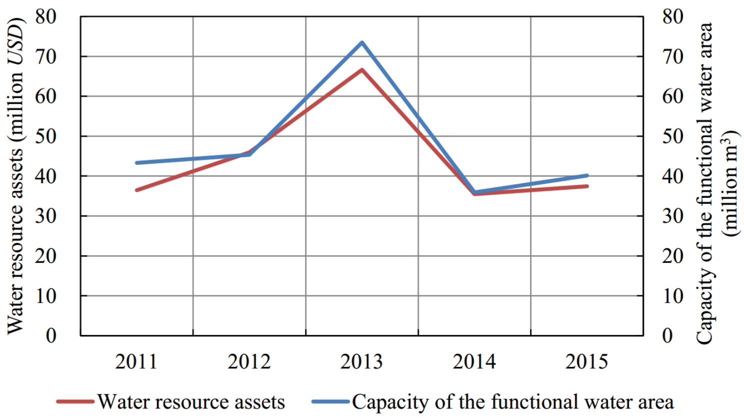

Figure 4. Comparison of the two calculation methods.

The balance sheet of water resource assets and liabilities not only shows the quantity of the end stock of regional water resources, but also the regional water quality based on the loss coefficient of water resource assets. Moreover, it quantitatively reflects the trends in regional water resource assets and liabilities based on different water qualities and quantities. Compared to the water resource assets and liabilities, the functional capacity of water resources can only reflect the condition when the water quality reaches a given standard, and it cannot reflect the condition when the water quality is better than a given standard. Calculating the water resource assets and liabilities can overcome this issue and provide diverse quantitative information regarding the regional water resources, water quality, and water quantity. Additionally, it can reflect fluctuations in regional water resource assets and liabilities and provide useful information for the planning, development, management, and protection of water resources.

5.3. Deficiencies and Prospects

There is room for improvement in our research. First, on the spatial scale, the research problems mainly focus on the selection of indicators because of the differing importance of different indicators which affect the evaluation results. To select a more reliable indicator, one which accounts for the availability of the indicator and which is representative of the city's evaluation must be selected. Evaluation indicators in different cities are likely to be different, so there may be controversy in contrast to the results of different cities. Second, on the time scale, the monitoring time of some of the indicators (B5, B6, B12, B13) are not long. Therefore, we cannot get a long-term water resources asset value. Longer time series can further help us to explore the relevance of water resources value to local policies and climate change. Third, are there other aspects of the water resources assets and liabilities (ecological compensation value, water resources depletion liabilities, water environmental liabilities, etc.)? Is it possible to link water resources service value with water resource assets calculation?

6. Conclusions

At present, China has not had a mature economic measure to measure the level of regional water resources development. Exploring the preparation of water resources balance sheet can make up for this gap well, and it is convenient to compare the water resources value, water resources development, and protection degree of different cities in the province. Although methods have been proposed to create water resource balance sheets, an advanced and unified method does not currently exist. Physical and quantitative accounting of the water resource assets in Jinan City was performed based on the availability of data and the actual needs of local water resource management. Notably, the calculation of the water price linked the physical accounting and quantitative accounting.

In this paper, 13 indicators were selected based on the categories of resources, the environment, society, and efficiency. In addition, we used SPA and an evaluation model which accounted for user affordability to calculate the unit price of water resources in Jinan from 2011 to 2015. In addition, we considered the impact of pollution on water resources and proposed the concept of the loss coefficient of water resource assets to improve the reliability of accounting by combining water quantity and water metrics. In this paper, Jinan City was studied based on a pilot project of valued-based changes in the physical accounting of water resource assets. The next step is to focus on the accounting of water and environmental degradation costs caused by water depletion and environmental pollution. Such a study could provide a basis for the calculation of liability values in water resource balance sheets.

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Abbreviations

The following abbreviations are used in this manuscript:

USD	United States dollar
USRMB	the exchange rate of RMB to USD
WRCC	water resource carrying capacity
CPC	the Communist Party of China
SPA	set pair analysis
COD	chemical oxygen demand
GDP	gross domestic product
AHP	the analytic hierarchy process
AWAS	Australian Water Accounting Standard
BOM	Australian Bureau Of Meteorology

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