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Application of Set Pair Analysis in a Comprehensive Evaluation of Water Resource Assets: A Case Study of Wuhan City, China

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Abstract: With the rapid development of the social economy, China is suffering from severe water scarcity due to improper management. Evaluation of water resource value is a crucial issue for innovative management in regional water resources. In this paper, in consideration of the complexity and uncertainty of water resources, 15 indicators were selected to establish the assessment system for its value in Wuhan City from the following three aspects, namely the environment, resources, and society. The analytic hierarchy process (AHP) and Entropy Weight Method were combined to calculate the comprehensive weight. An improved set pair analysis (SPA) model was applied to evaluate water resource assets in the period of 2013–2017. For the sake of the dependability of these results, the James Pollution Loss model was utilized to compute loss of water resource value caused by the decline of water quality in the water pollution environment. The results show that the amount of water resource through physical quantitative accounting in Wuhan City fluctuates greatly. The initial change is relatively stable, then surges in 2015 and 2016, but slumps in 2017. The total water resource assets for Wuhan City from 2013 to 2017 are 14.221, 14.833, 28.375, 75.558, and 21.315 billion RMB, respectively. Therefore, water resource value accounting plays an indispensable role in the environmental protection and sustainable development of water, as well as provides a support for comprehensive calculation and management of various valuable natural resources.

Keywords: water resources; assets evaluation; water quality; Set Pair Analysis; Wuhan City

1. Introduction

In recent years, China has adopted a series of measures to accelerate the construction of an ecological civilization, as the Third Plenary Session of the 18th Central Committee of the Communist Party of China (CPC) clearly stated in 2013 “to explore the preparation of natural resource balance sheets” [1], which marks the construction of the country’s strategic goal of putting the physical accounting and asset evaluation of natural resources into effect, improving resource conservation and utilization, and building a “beautiful China” [2,3]. Water is the basic natural resource for human beings and all living things to survive and develop [4]. With the rapid development of the social economy, water resources are over-committed [5–7], as well as the massive discharge of industrial, agriculture, and domestic sewage, due to the poor management of water resources, leading to a reduction in water quantity and the decline in water quality [8–10]. Great attention should be paid to the problem of water

resource supply could not meeting water demand, resulting in water scarcity. Almost one-third of the world's population is experiencing a severe water scarcity crisis [11,12]. Therefore, it is indispensable to promote the innovative management of natural resources by grasping the quantity and quality of water resource assets in the region to lessen the contradictions between economic development and environment resources.

Water scarcity occurs when the supply of fresh water cannot meet the demand [13]. It could result from two mechanisms: physical water scarcity, which is due to insufficient natural water resources to meet the needs of a region; and economic water scarcity, caused by poor management [14,15]. It is found that the latter more often leads to water scarcity according to United Nations Development Programme [7]. People tend to turn their attention to water scarcity caused by natural forces rather than to human-induced scarcity, or any other factors [16,17]; the real reasons for water scarcity could be covered up. In fact, water scarcity, linked to water security, is a complex phenomenon that could be solved from social, political, meteorological, economic, and environmental perspectives [18–21]. Most of the research studies have mainly been done with engineering measures, which implies that using economic valuation techniques provides a new perspective for water resource management [22]. Water resources, used for free or at a low price, have been exploited and utilized for a long time without any compensation, leading to increasingly scarce water resources [23,24]. Thus, it is urgent to evaluate the water resource value, establish a balance sheet for water resources, promote the construction of an ecological civilization, and ultimately achieve sustainable development of water resources.

At present, the method to evaluate the value of water resources is mainly carried out through certainty or uncertainty methods. The former is a group of traditional deterministic evaluation methods, including the shadow price method, supply and demand pricing model, income reduction method, marginal opportunity cost method, and computable general equilibrium (CGE) model [25–30]. However, the water resource value system is a complex system. Traditional classical algorithms reflect the economic value of water resources to a certain extent, but they cannot solve the complicity and fuzziness of water resource value systems [31]. The uncertainty evaluation method, which is mainly based on fuzzy theory, might also result in information loss [32,33]. Set pair analysis (SPA), dealing with the interaction between certainty and uncertainty, is suitable for cases with two or more groups from two or more perspectives [34]. To evaluate water resources objectively and truly, we need to recognize the internal structure and take social, economic, and environmental factors into consideration [35]. For this reason, SPA is a systematic method to deal with the uncertainty of complex problems [36,37] and has been gradually utilized for comprehensive evaluation of water quality and water safety [38,39]. In this study, the comprehensive weight, resolved with the combination of AHP and entropy weight, is applied to the set pair analysis model of water resource evaluation. This will be a more practical study and provide a positive reference for the establishment of a water resource asset evaluation system.

Accurate value accounting is a critical part of water resources research. It is of great significance in the rational allocation of water resources, improvement of water environments, and alleviation of water crises. This research focuses on the water resource assets of Wuhan City from 2013 to 2017, covering hundreds of lakes in central China, with the following aims: (1) to establish a balance sheet for physical quantities of water resources; (2) to determine an integrated index of water resource value using a combination of SPA and Triangular Fuzzy Number (TFN) methods; (3) to determine the water resource unit price by applying comprehensive weight to the improved SPA model; (4) to calculate the total value of water resources.

2. Methods and Data

2.1. Study Area

Wuhan City is the political and economic center of Hubei Province, the transportation junction of central China, as well as an important industrial, science, and education base [40]. Wuhan City is located in the east of Hubei Province, from 29°58' N to 31°22' N, 113°41' E to 115°05' E. The maximum

distance from east to west is 132.1 km, and the maximum distance from north to south is 154.0 km. The elevation of Wuhan City ranges from 19.2 m to 873.7 m, but is mostly below 50 m. Elevation is low and terrain is flat in the middle, surrounded by hills and ridges in the north and south, and low mountains in the north, with the Yangtze and Han rivers winding through the city [41]. Wuhan City has a subtropical monsoon climate, with abundant annual rainfall, ranging from 1150 mm to 1450 mm [42]. The precipitation is concentrated from June to August, accounting for about 40% of the annual rainfall [43,44]. Rivers, lakes, and harbors are interwoven, with a total water area of 2217.6 square kilometers, accounting for 26.1% of the city's land area, constituting the water ecological environment of the riversides and lakes (Figure 1). There are 166 lakes in Wuhan City, called “the City of Lakes”, and the total surface area of the lakes ranks first in Chinese cities. Wuhan City, also called “River City”, has abundant freshwater resources. The per capita water resource occupancy reaches more than 40 times the national average level and 10 times the global average level [45].

Figure 1. Water resource distribution map of Wuhan City.

2.2. Principle and Application of Set Pair Analysis

SPA is a scientific theory dealing with the interaction between certainty and uncertainty [46]. The core idea is to construct pairs of related sets of uncertain systems, and then analyze characteristics such as similarity, difference, and opposition of set pairs, and finally to establish the connection degree of similarity, difference, and opposition of a set pair [33]. The application of connection degree transforms the dialectical understanding of uncertainty into a specific mathematical problem, enhancing the reliability and objectivity [47]. First of all, SPA qualitatively analyzes samples according to a certainty and uncertainty analysis between the water resource asset evaluation system and related factors, and then quantitatively calculates the value of water resource assets, so as to better realize the water resource asset evaluation.

2.2.1. The Principle SPA Mathematic Model

The basic unit is composed of two sets with certain connections. Here, we define the connection sets A and B , which then form the set pair $H(A, B)$. The ternary connection is usually used as Equation (1).

$$\mu_{A \sim B} = a + bi + cj \quad (1)$$

where a , b , and c are the degrees of similarity, difference, and opposition under a certain characteristic; i refers to the difference coefficient; j means the opposite coefficient [48]. In this study, A represents the water resource evaluation standard, and B represents the actual index value. The criteria for assessment of value for the water resource value involve comparing the similarity of two sets (A, B). Previous studies regarding fuzzy theory have resulted in excessive information loss to some extent [49,50], making the evaluation results less accurate. In order to assess water resource accounting more accurately, this paper introduces the five-member connection degree [33], as shown in Equation (2).

$$\mu_{A \sim B} = a + b_1 i_1 + b_2 i_2 + b_3 i_3 + cj \quad (2)$$

where a , b_1 , b_2 , b_3 , and c are the connection degrees of the identical component, partial identical component, critical component, partial inverse component, and inverse component of the five-member linkage number, respectively. In the same way, $a + b_1 + b_2 + b_3 + c = 1$, $j = -1$, $i \in (-1, 1)$. The expressions of Equations (1) and (2) are simple, but they reflect the overall structure of the relationship between A and B . Meanwhile, a , b (or b_1 , b_2 , b_3), c reflect the internal structure of the relationship between A and B in detail [51]. The degree of connection breaks through the traditional frame of the relationship between the correlation coefficient, membership degree, and gray correlation degree, offering unique advantages [52].

2.2.2. Factor Data and Weights

The system of water resource value, in fact, is a complex system in which the natural system, social system, and economic system interact with each other [53]. According to China's "13th Five Year Plan of Water Conservancy Reform and Development" [54], "Surface Water Environmental Quality Standards" (GB 3838-2002) [55], as well as some relevant research studies [49,56,57], the water resource value system is formed from a total of 15 indicators from three aspects, namely environment, resources, and society, based on the principle of representative, targeted, and easy to quantify divisions. The environment category include 4 indices (N1–N4) as follows: ammonia nitrogen, chemical oxygen demand (COD), sewage treatment rate, and water functional area compliance rate. The resource indices contain per capita water resources (N5), water resources per unit area (N6), and the amount of water supply (N7). Finally, the society indices include population density (N8), per capita water consumption (N9), per capita gross domestic product (N10), water consumption (N11), water resource development and utilization rate (N12), industrial added value of water consumption (N13), industrial water reuse rate (N14), and agricultural irrigation water utilization factor (N15).

Weight is the representation of the importance of the indicator, and its rationality affects the accuracy of the evaluation results directly [58]. The water resource evaluation system is a multi-level, multi-factor system with uncertainty, randomness, and complexity [56,59]. Therefore, the AHP was selected to calculate the subjective weight with high credibility and accuracy [60,61]. The entropy method was used to consider the objective weight. The entropy weight method can take full advantage of the actual data, and consider the connection between multiple samples comprehensively, which effectively reduces the subjectivity in the calculation process [62]; this means the evaluation results will be more objective and reasonable [35,63]. Finally, a linear weighting method was applied to determine the comprehensive weight. This method of weight calculation avoided the deviation caused by the subjective weighting method and the absolutization caused by the objective weighting method, meaning it would be more general and exact in assessing the value of water resources.

2.2.3. The Comprehensive Assessment Vector of SPA

The connection degree is a map $\mu(A, B)$ from the actual value of the evaluation index B to the evaluation standard A . Equation (3) can be used to calculate the membership degree of each index to the standard value. We can get the combined weight of the evaluation samples by Equation (4).

$$\mu_{mk} = \begin{cases} 1 + 0i_1 + 0i_2 + 0i_3 + 0j & x < s_1 \\ \frac{x-s_2}{s_1-s_2} + \frac{s_1-x}{s_1-s_2}i_1 + 0i_2 + 0i_3 + 0j & s_1 < x \leq s_2 \\ 0 + \frac{x-s_3}{s_2-s_3}i_1 + \frac{s_2-x}{s_2-s_3}i_2 + 0i_3 + 0j & s_2 < x \leq s_3 \\ 0 + 0i_1 + \frac{x-s_4}{s_3-s_4}i_2 + \frac{s_3-x}{s_3-s_4}i_3 + 0j & s_3 < x \leq s_4 \\ 0 + 0i_1 + 0i_2 + \frac{x-s_5}{s_4-s_5}i_3 + \frac{s_4-x}{s_4-s_5}j & s_4 < x \leq s_5 \\ 0 + 0i_1 + 0i_2 + 0i_3 + 1j & x \geq s_5 \end{cases} \quad (3)$$

$$R_i = \omega \times \mu \quad (4)$$

In Equation (3), m represents the evaluation index, k represents the evaluation sample; s_1, s_2, s_3, s_4 , and s_5 represent the evaluation standard values of levels I–V, respectively, μ is the membership degree matrix of each evaluation index, and ω represents the comprehensive weight of each evaluation indicator. R is a comprehensive assessment vector, and x is the actual value of each indicator. Obviously, the degree of connection is the key point of the set pair analysis. It not only reflects the relationship between the set pairs as a whole, but also clearly represents the randomness and ambiguity of the system [64]. Actually, the evaluation of water resource value is a process combining a deterministic evaluation index and evaluation criteria with uncertain evaluation factors and their content changes [47,65]. Set pairs and their connections describe the relationship between these deterministic and uncertain systems extensively and profoundly.

2.2.4. The Comprehensive Evaluation Model of SPA and Triangular Fuzzy Numbers

Triangular fuzzy numbers, dealing with the comprehensive evaluation problem with ambiguity and randomness, contain certain and uncertain information [66]. Set pair analysis can describe the certainty and uncertainty in the process of water resource value assessment, but the difference coefficient i , one of connection numbers, processes the ambiguity between the adjacent standard levels [37]. It is hard to obtain the specific evaluation level of this evaluation system. However, the value of the difference coefficient i is essential to determine the connection degree. In this study, a triangular fuzzy number was used to handle the ambiguity of the difference coefficient. Combining the weights of each indicator, a coupling model with a combination of TFN and SPA was established [67–69], as shown in Equations (5) and (6).

$$\mu_{mk} = \begin{cases} 1 & x < s_1 \\ \frac{x-s_2}{s_1-s_2} + \frac{(s_1-x)^2}{2(s_1-s_2)^2} & s_1 < x \leq s_2 \\ \frac{(x-s_3)^2}{2(s_2-s_3)^2} + \frac{(x-s_3)(s_2-x)}{2(s_2-s_3)^2} & s_2 < x \leq s_3 \\ -\frac{(x-s_4)(s_3-x)}{2(s_3-s_4)^2} - \frac{(s_3-x)^2}{2(s_3-s_4)^2} & s_3 < x \leq s_4 \\ -\frac{(x-s_5)^2}{2(s_4-s_5)^2} - \frac{s_4-x}{s_4-s_5} & s_4 < x \leq s_5 \\ -1 & x \geq s_5 \end{cases} \quad (5)$$

$$Y = 3 - 2\mu \quad (6)$$

where μ is the comprehensive connection degree and Y is the calculation level eigenvalue. The larger the value of Y is, the lower the water resource value is.

2.3. Price Calculation Model of Water Resource

The comprehensive evaluation vector of water resources is a dimensionless vector. Here, we used the transformation model proposed by Jiang [70] (Equation (7)). The price vector S is related to the water price upper limit P , determined by the equal interval method [35,49], as shown in Equation (8). The water resources price upper limitation represents the water price when the maximum water fee tolerance index is reached, as shown in Equation (9).

$$WLJ = R \times S \quad (7)$$

$$S = (P, 0.75P, 0.5P, 0.25P, 0)^T \quad (8)$$

$$P = EA/C - D \quad (9)$$

where WLJ represents the unit price; R represents the comprehensive assessment vector; S is the price vector. P represents the upper limitation of the water price, RMB; E represents the per capita disposable income of residents, RMB; A represents the maximum tolerance index of water price. According to international standards for developing countries' affordability [71], the water fee for residential use accounts for a maximum of 3% of household income; C refers to annual household water consumption, m^3 , derived from [72]; D is the water supply cost and the normal profit, RMB, referred to in the "China Water Network" [73].

Integrated accounting refers to the comprehensive calculation of water resource value through a certain model. Many existing studies have concluded that water resource value is only related to the unit price and quantity [74], ignoring the impact of water quality. In fact, water resource value is the unification of quality and quantity [35,47]. Therefore, this paper comprehensively takes the loss value caused by water quality damage into consideration and establishes a water resource value accounting model according to the relationship between water quantity, price, and quality, as shown in Equation (10).

$$V = D \times WLJ - Q \quad (10)$$

where V represents the total value (million RMB); D is the quantity of water resources, million m^3 ; WLJ represents the unit price, RMB; Q is the water loss value, in million RMB.

2.4. Model of Pollution Loss for Water Resources

The original water structure is damaged by water pollutants, such as Chemical Oxygen Demand (COD) and NH_3-N caused by human life or industrial and agricultural production. When the discharge of sewage exceeds the self-purification capacity of water, the water quality deteriorates severely and the water environmental carrying capacity decreases, resulting in a huge economic loss [75]. According to the James Pollution Loss model [76], the economic loss caused by pollutants in water is not linear with the concentration of pollution [56]. When the concentration of pollutants is low, the damage to the water body will be not obvious. As the concentration increases, the damage to the water body rises sharply. When the concentration of the pollutants rapidly increase, to a certain extent, the damage to the water environment increases slowly until reaching the limitation of loss. This study introduces the water resource economic loss accounting model, as shown in Equations (11)–(13).

$$Q = rqp \quad (11)$$

$$r_i = 1 / (1 + A \times \exp(-B \times C)) \quad (12)$$

$$r_i^n = r_i^{n-1} + (1 - r_i^{n-1})r_{in} \quad (13)$$

where Q is water resources loss caused by water pollution, in million RMB; q represents the discharge of wastewater, 10^8 m^3 , p for water price, RMB. A , B represent the pollution loss parameters of each pollutant; C means the concentration of each pollutant; r_i is the pollution loss rate of each pollutant, and r refers to the comprehensive water resource loss rate.

3. Results

3.1. Physical Accounting for Water Resources in Wuhan City

Physical accounting is a basis for water resource accounting. Table 1 demonstrates the water resource stock as well as its changes in Wuhan City from 2013 to 2017, the data for which came from “Wuhan City Water Resources Bulletin 2013–2017” [72]. Factors influencing water resource increases are water resources from precipitation, inflows, and water return of society. Factors influencing the decrease of water resources are water intake, evaporation, outflows, and ecological consumption for water resources, such as lakes and rivers.

Table 1. Water resource stock for Wuhan in the period of 2013–2017 (10^8 m^3).

Item	Year					
	2013	2014	2015	2016	2017	
Year-beginning stock	47.92	41.03	39.29	57.46	99.79	
Increase in stock	Water resources from precipitation	100.25	98.27	119.02	154.03	98.32
	Inflows	6387	7237	6811	7598	7437
	Water return of society	0.62	1.2	0.68	0.44	0.36
Decrease in stock	Water intake	40.13	39.52	37.59	34.02	34.61
	Evaporation	96.46	98.51	122.69	188.71	188.36
	Outflows	6358	7200	6752	7487	7373
	Ecological water consumption of rivers and lakes	0.17	0.18	0.25	0.41	0.39
Year-end stock	41.03	39.29	57.46	99.79	39.11	

The main factors resulting in the water stock changes in Wuhan City are inflows and outflows. The Yangtze River and Hanshui River run through the city with large transit flows. In 2013, water resources from precipitation were more than evaporation, while from 2014 to 2017, water resources from precipitation were less than evaporation. In the past five years, the evaporation of water resources increased annually to almost twice the amount of precipitation until 2017. The largest stock of water resources appeared in 2016, mainly owing to the largest inflows and precipitation during that year. Interestingly, the stock of water resources declined sharply in 2017, even lower than the year-beginning stock in 2013.

3.2. SPA and Calculation of the Comprehensive Evaluation Vector

Table 2 reflects the assessment system of water resource value and its comprehensive weight. According to GB3838-2002 and some related researches [49,55–57], the water resource value evaluation standard system was established, as shown in Table 3, namely set A. The corresponding actual values for the indicators of the water resource value evaluation index system of Wuhan City from 2013 to 2017 are shown in Table 4, namely set B. All data sources were derived from official statistics, such as “Wuhan Statistical Yearbook 2013–2017”, “Wuhan City Water Resources Bulletin 2013–2017”, and “Wuhan Environmental Quality Bulletin 2013–2017” [72,73,77,78].

Table 2. The assessment system for water resource assets and the corresponding weights.

Criterion	Abbreviation	Index Layer	Subjective Weight	Objective Weight	Comprehensive Weight
M1: Environment	N1	Ammonia nitrogen (mg/L)	0.069	0.03422	0.0516
	N2	Chemical oxygen demand (COD; mg/L)	0.071	0.00045	0.0357
	N3	Sewage treatment rate (%)	0.069	0.00035	0.0347
	N4	Water functional area compliance rate (%)	0.074	0.60344	0.3385
M2: Resources	N5	Per capita water resources (m ³ /people)	0.081	0.10291	0.0919
	N6	Water resources per unit area (10,000 m ³ /km ²)	0.068	0.10886	0.0884
	N7	The amount of water supply(10 ⁸ m ³)	0.062	0.00313	0.0325
M3: Society	N8	Population density (people/hm ²)	0.059	0.00031	0.0296
	N9	Per capita water consumption(m ³ /person)	0.079	0.00565	0.0423
	N10	Per capita gross domestic product (GDP; 10 ⁴ RMB/person)	0.05	0.00851	0.0292
	N11	GDP water consumption (m ³ /10 ⁴ RMB)	0.061	0.02508	0.0430
	N12	Water resource development and utilization rate (%)	0.068	0.08233	0.0751
	N13	Industrial added value of water consumption (m ³ /10 ⁴ RMB)	0.063	0.02444	0.0437
	N14	Industrial water reuse rate (%)	0.058	0.00003	0.0290
	N15	Agricultural irrigation water utilization factor	0.069	0.0003	0.0346

Table 3. The standards for the water resource value assessment system.

Index	Standards for Water Resource Assessment				
	I High	II Relatively High	III Medium	IV Relatively Low	V Low
N1	10	15	20	30	40
N2	90	80	70	60	40
N3	90	80	70	60	50
N4	3000	2000	1200	800	400
N5	200	100	75	50	25
N6	60	50	40	30	20
N7	5	10	50	150	300
N8	300	500	600	700	800
N9	5000	3000	2000	1000	500
N10	50	100	500	1000	3000
N11	10	20	30	40	50
N12	10	20	100	200	500
N13	85	70	60	40	30
N14	0.78	0.71	0.64	0.57	0.5
N15	0.15	0.5	1	1.5	2

Table 4. The indicators of the water resource value assessment system.

Index	2013	2014	2015	2016	2017
N1	26	25	25	24	25
N2	91	91	92	95	96
N3	51.1	45.4	48.1	50.9	46.3
N4	401.47	380.05	542.08	926.88	359.04
N5	48.3	45.85	67.05	116.45	45.51
N6	40.13	39.52	37.59	34.02	34.61
N7	12.03	12.06	12.38	12.56	12.67
N8	393	382	354	316	318
N9	89,000	105,900	120,600	110,700	122,000
N10	44	39	34	29	26
N11	97.8	101	65.41	34.09	88.49
N12	51	49	43	37	30
N13	88.51	88.6	88.7	89.2	90
N14	0.49	0.48	0.49	0.49	0.51
N15	1.324	1.031	0.751	0.791	0.813

According to the water resource value accounting index system, the AHP and entropy weight were used to calculate their subjective and objective weights, respectively. Finally, the comprehensive weight was obtained, as shown in Table 2. Then, combined with Tables 3 and 4, through Equations (3) and (4) the comprehensive evaluation matrix of water resources for Wuhan City in 2017 was calculated. Likewise, the evaluation matrix in the period of 2013–2016 was calculated. The specific comprehensive evaluation results of set pair analyses (SPA) are shown in Table 5.

Table 5. Comprehensive evaluation vector of water resources.

Year	Comprehensive Evaluation Vector (R)
2013	(0.1585, 0.0750, 0.0830, 0.1745, 0.5090)
2014	(0.1609, 0.0733, 0.1146, 0.0963, 0.5845)
2015	(0.1668, 0.0961, 0.1430, 0.0865, 0.5499)
2016	(0.1894, 0.1609, 0.1493, 0.1353, 0.3427)
2017	(0.1744, 0.0890, 0.0726, 0.1129, 0.5511)

According to the results in Table 5, the fifth level has a large proportion of the water resource value assessment levels, at about 34.27% in 2016, and even over 50% in other years.

3.3. Evaluation of Water Resource Quality

According to the comprehensive evaluation results, the specific integrated fuzzy index was evaluated by the coupling evaluation model with triangular fuzzy number method and set pair analysis. According to Equations (2)–(6), the specific integrated fuzzy index of the water resources for 2013–2017 were calculated, with values of about 3.48, 3.59, 3.49, 3.33 and 3.55, which belonged to III, IV, III, III, and IV, respectively. The water quality evaluation grades were level IV both in 2014 and 2017, although the water quality in 2017 was better than that in 2014 according to the evaluation index. It could be seen that the coupling model based on set pair analysis and triangular fuzzy numbers had high sensitivity, meaning it could reflect the degree of water pollution more comprehensively and accurately. The lowest value in 2016, 3.33, indicated that the water quality was relatively better than in other years. It could be seen that the water resource value level fluctuated less, with all values between III and IV, which means that the value evaluation grades of water resources in Wuhan City are at a level of medium to relatively low.

As seen from the results above, in general, the water quality of Wuhan City was relatively low. Although there was a significant quantity of water resources, the water quality outlook was not as optimistic. This needs to be taken seriously by relevant departments to promote sustainable water management.

3.4. Calculation of Unit Price for Stock Value of Water Resources

According to Equation (9), for 2017, the per person disposable income for inhabitants E was 38,642 RMB [78], the yearly household water consumption C was 51.1073 m^3 [72], the max-value for A was 3% [35,71], and D , the costs and normal profits for water resources, was 3.285 RMB. Thus, the upper limit for water price in 2017 was obtained, at 19.3979 RMB. According to the principle of isometric intervals, the water resource price vector results for S in 2017 were 19.3979, 14.5484, 9.6989, 4.8495, and 0. The unit price of water resources (WLJ) in Wuhan City in 2017 was 5.9293 RMB/m^3 according to the results of Table 5 and Equation (7). In a similar way, the unit price for water resources was 3.9405, 4.2865, 5.3049, and 7.7587 RMB/m^3 for 2013, 2014, 2015, and 2016, respectively. The results indicated that the unit water price in Wuhan City fluctuated to some extent, with a stable growth from 2013 to 2016, at almost the highest level in 2016, probably owing to the relatively high quality of water resources in that year, but declined in 2017. It could be seen that the unit price of water resources largely depends on the unity of quantity and quality.

3.5. Pollution Loss of Water Resource Assets

On the basis of previous investigations, the factors seriously impacting the quality of water resources in Wuhan City were Chemical Oxygen Demand (COD) and $\text{NH}_3\text{-N}$ [72]. As we can see, the actual contents of these two pollutants are shown in Table 4, namely N_1 and N_2 . The pollution loss parameters A and B for COD are 2799.02 and 0.83548, respectively, while they are 2118.65 and 6.1268 for $\text{NH}_3\text{-N}$, respectively [79]. Thus, the pollution loss rates r_1 and r_2 of COD and $\text{NH}_3\text{-N}$ in 2017 could be calculated as 0.99997923 and 0.064318681, respectively. According to Equation (13), the comprehensive loss rate r of water pollution was 0.9999778. The discharge of wastewater in Wuhan city in 2017 was 915 million m^3 [77]. The water price in that year was 2.05 RMB/m^3 [73]. Finally, the actual pollution loss could be calculated as 1.875 billion RMB for Wuhan City in 2017 according to Equation (11). In the same way, the amounts of pollution loss from 2013 to 2016 were 1.947, 2.009, 2.107, and 1.866 billion RMB, respectively.

3.6. Calculation of Value of Water Resource Assets

In 2017, based on the physical accounting presented in Table 1, the stock of water assets D was obtained, calculated as 3911 million m^3 . The unit price for the stock value of water resource WLJ was 5.9293 RMB/m^3 . The pollution loss of water resource assets was 1.875 billion RMB. Thus, according

to Equation (10), the total value of water resource assets was calculated, which was 21.315 billion RMB. Similarly, we could also calculate the total asset values for the years 2013–2016 at 14.221, 14.833, 28.375, and 75.558 billion RMB, respectively; details are shown in Table 6. The annual assets of water resources in Wuhan City fluctuate greatly. The initial change is relatively stable, and then surges in 2015 and 2016, reaching the maximum in 2016, mainly due to the large amount of rainfall, at about 75.558 billion RMB, but it slumps in 2017. The water resources assets in Wuhan were 14.221 billion RMB at the beginning of 2013, rising nearly 50% to 21.315 billion RMB at the end of 2017; the assets increased by 7.094 billion RMB.

Table 6. Annual water resources value in Wuhan City from 2013 to 2017.

Item	2013	2014	2015	2016	2017
Unit price (RMB/m ³)	3.9405	4.2865	5.3048	7.7593	5.929
Year-end stock (100 million m ³)	41.03	39.29	57.46	99.79	39.11
Pollution loss Q (billion RMB)	1.947	2.009	2.107	1.866	1.875
Assets of water resource stocks (billion RMB)	14.221	14.833	28.375	75.558	21.315

4. Discussion

This study established the balance sheet of the stock and changes of water resource assets in Wuhan City from 2013 to 2017. Year-end stock was between 3911 and 9979 million m³. Interestingly, the stock of water resources in Jinan ranged from 61 to 128 million m³ from 2011 to 2015 [56], and that of Nanjing was between 2372 and 4615 million m³ from 2011 to 2015 [35], which suggested that Wuhan had more abundant water resources.

From a global perspective, in order to alleviate the scarcity of water, Sustainable Development Goal 6 (SDG 6), set by the United Nations in 2015, focuses on water security and sanitation for all people [80,81]. The goal contains eight targets, with one or more indicators for each of them, to be achieved by 2030 [82]. It provides support for the implementation of integrated water resource management [83], however there is still a need for improvement [84], for example, the gap between targets in SDG 6 and corresponding indicators [80], as well as inequitable water agreements [85]. Utilizing economic valuation techniques could provide a new perspective for water resource management [22]. As there is an absence of a reasonable water price mechanism, the utilization of water resources has been seriously wasted and improperly exploited for a long time, inhibiting the sustainable development of water. Accordingly, it is necessary to study the value accounting of water resources in Wuhan City.

Fifteen indicators were selected from the three aspects, namely environment, resource, and society aspects, to establish the water resource evaluation index system. Then, we combined AHP with entropy weight to compute the integrated weight for each index, effectively solving the problem of the traditional weighting evaluation bring too subjective or absolute, which improved the stability and reliability of evaluation results and provided a reference for a water resource value accounting system. A water resource value assessment system is a complex and blurry system with integrated certainty and uncertainty. Set pair analysis, a new uncertainty theory, is different from traditional probability and fuzzy set theories. This method take full advantage of the information of the water resource evaluation system so that we can calculate the price of water resources more objectively and comprehensively. Meanwhile, the coupling model with set pair analysis and triangular fuzzy number method was used to obtain the fuzzy comprehensive index of water resources value. The results showed that the overall level of water resource value in Wuhan City was medium to low. Differing from previous studies [35,47], this paper demonstrates that the value of water resources is not only related to water price and water volume, but also to the water quality, leading the final total value of water resources obtained being more reliable.

Obviously, in the process of water resource accounting, the lack of uniform standards become the main obstruction. That is why the results obtained by different methods are quite different. Thus, on the basis of a deep understanding of the value connotation for water resources, as well as various

value theories, the issue of how to establish a resource value theory that adapts to the requirements of modernization in order to make it suitable for environmentally sustainable management is the next crucial issue to be solved. Additionally, the total amount of water resources and related factors that are chosen to evaluate the value of water resources should be improved. A previous study has shown that groundwater is seriously polluted in the densely populated industrial and commercial areas of Wuhan City [86]. In the future, it is of great significance to conduct more detailed and accurate research studies in order to provide practical support to decision-makers and regional managers, for example, taking groundwater as an independent and significant factor in the model, or even conducting more detailed and in-depth research studies with more agriculture information regarding kind of crops that are cultivated, the weight of surface water, and groundwater consumption as well.

5. Conclusions

To compute the total value for water resources, this research focuses on the water resource assets of Wuhan City, and the results can be outlined as follows. Firstly, this study has created a balance sheet of the stock and changes of water resources in Wuhan from 2013 to 2017. The results indicate that the water resource amounts in Wuhan fluctuated greatly, from 3911 to 9979 million m³. While the initial change was relatively stable, it rose rapidly in 2015–2016 and then fell sharply in 2017. Then, according to the results of the coupling model based on set pair analysis and triangular fuzzy method values, the water quality was optimal, at a level of medium to relatively low. An improved set pair analysis was applied which obtained unit prices from 2013 to 2017 of about 3.94, 4.29, 5.30, 7.76, and 5.93 RMB/m³, respectively, based on the index system with 15 indicators and the comprehensive weight of each index. Lastly, considering the impact of water quality on the value of water resources, the James Pollution Loss model was introduced to compute the water resource loss value, which improved the reliability of accounting results. Based on the relationship between water price, quantity, and quality, the total values of water resources in Wuhan City from 2013 to 2017 were 14.221, 14.833, 28.375, 75.558, and 21.315 billion RMB, respectively. Water resource value accounting is an innovative water resources management method, which is also conducive to the comprehensive evaluation and management of water resources, as well as the sustainable development of water.

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