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Evaluating Water Consumption Based on Water Hierarchy Structure for Sustainable Development Using Grey Relational Analysis: Case Study in Chongqing, China

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Abstract: With the economic development, the demand for water resources has been increasing dramatically during the last several decades. The sustainable development of water resources has become a major challenge in our society. As the largest economic center in west China, Chongqing was chosen as a typical unit to investigate this issue by using statistical data of fifteen years. In this study, the complexity of the water resource system was simplified through hierarchical structure analysis. Then, grey relational analysis was used to measure hierarchical correlation degree. The correlation between the levels of water consumption was analyzed, especially between water consumption and socio-economic indicators. Based on the result of hierarchical grey evaluation, three conclusions were drawn: (1) from the water consumption-oriented aspect, the correlation rankings, from high to low, are production water use, domestic water use, and eco-environmental water use respectively; (2) from industrial structure aspect, the secondary industry has the highest grey relational degree, which is followed by the primary industry (agriculture); and (3) from the economic and social indicators aspect, many significant factors are highly related to water consumption, such as precipitation, urbanization rate, total population, GDP, the proportion of output value of the three industries and residential water price. In this paper, to achieve the goal of the strictest system of water resource management during the 13th Five-Year Period, the corresponding policy suggestions are proposed for the municipal government of Chongqing.

Keywords: grey relational analysis; water consumption; hierarchy structure; sustainable development; policy suggestion

1. Introduction

With the development of industrialization and urbanization, the demand for water resources has been continuously expanding, and the shortage of water resources and low utilization of water resources have become prominent problems. To solve water resources problems and achieve sustainable development of water resources, a series of policies and regulations have been proposed. The 13th Five-Year Plan for the National Economic and Social Development of the People's Republic of China (13th Five-Year Plan) clearly states that the most stringent water resources management system should be implemented to build a water-saving society [1]. With the basic national conditions and the new normal of economic development, the most stringent water resources management system indicates the determination of Chinese government for the sustainable development of water resources [2].

As the largest heavy industrial and commercial city in southwest China, Chongqing is an important modern manufacturing base in China. It is also a city with water shortages. The economic growth rate of Chongqing has led the country for ten consecutive quarters. The rapid economic development in Chongqing has had a tremendous impact on the environment and resources [3]. Thus, the demand for water resources caused by economic development has become a prominent issue. To achieve the sustainable development of water resources, Chongqing municipal government has also introduced the most stringent water resources management system in Chongqing [4]. The industrial and agricultural water consumption of Chongqing are used in an extensive way and water is used in low efficiency. The solid foundation for heavy industry in Chongqing leads to slower industrial upgrading and excess production capacity. The water consumption amount per unit output value is 71 m^3 per ten thousand Yuan. Due to the topography of Chongqing, the development of modern agriculture is limited, which led to a serious problem in agriculture: the waste of water resource. The effective utilization coefficient of farmland irrigation water is only 0.48. This is what the Chongqing government has been trying to solve. In Chongqing Water Resources Development according to "The 13th Five-Year" Plan, the water use efficiency of industry and agriculture is required to increase [5].

Researchers have analyzed water consumption in various aspects to solve the problem of sustainable development of water resources. Bai et al. provide suggestions for water resources management by predicting water resources [6]. Considering that there are many economic and social factors that affect water use, it is also meaningful to look at the impact of socio-economic indicators on water use. Okadera et al. focused on evaluating the structure of water demand with socio-economic activities [7]. Zhong et al. found that the increase in water prices can increase water use efficiency [8]. Ashoori et al. stated that population and price are the main driving forces for residential water demand. In the future, people must also rely on measures such as catching rainwater and recycling water to meet water demand [9]. Balling et al. found that the sensitivity of different regions to climate is different [10]. House-Peters et al. found that the most important determinants of water demand growth are population growth, climate and urban development [11]. Xu paid considered the relationship between economy and water consumption, and proposed suggestions on sustainable development of water resources without affecting the economic development [12]. Many methods that can be applied to analyze correlations in mathematical statistics, such as the grey relational analysis [13], variance analysis [14], principal component analysis [15,16], and regression analysis [17]. The methods of variance analysis, principal component analysis and regression analysis need many data following a typical probability distribution, and the result of quantization and qualitative analysis may be inconsistent. However, the statistical resources in China are limited, especially local districts and counties. On the contrary, the grey relational model requires fewer data and requires undemanding data distribution [18], which can be employed for this situation.

Based on the above analysis, the complicated water consumption system was analyzed by the analytic hierarchy process (AHP), and the hierarchy structure of water consumption was proposed. The grey relational model was used to calculate the grey relational degree between levels. The rest of the paper is organized as follows. Section 2 proposes propose the hierarchy of water consumption structure. Section 3 introduces the indicators and data. Section 4 describes the grey relational method, and the results of grey relational degree are listed. Section 5 analyzes water consumption and puts forward the corresponding recommendations. Section 6 concludes the paper.

2. Hierarchy Analysis of Water Consumption Structure

The use of water resources exists in various social activities. Water consumption system is a complex system. Through the hierarchical division, a large and complex system can be decomposed into several unidirectional dependent levels [19].

The method of analytic hierarchy process is used to establish the hierarchy structure of water consumption. From the water user-oriented point of view, the total water consumption can be divided into three major sectors: production water use, residential water use and eco-environmental water use. Production water consumption, the largest user of water, according to the division of industry can be divided into three industrial water consumptions. The first three levels of water hierarchy can be obtained. Water resources are closely linked with many social and economic indicators. Therefore, the selection of relevant socio-economic indicators is a challenge. The method of literature statistics is used here to select the relevant factors. For example, May asserted that water price, population, rainfall, etc., are important factors affecting water consumption [20]. Domene et al. believe that urbanization, population, etc., are important factors affecting residential water consumption [21]. To facilitate the analysis of the impact of external factors on water use, socio-economic indicators affecting water use are placed in the water hierarchy. According to the results of the analytic hierarchy process and the literature statistics, the hierarchical structure in Figure 1 can be obtained. Figure 1 shows the hierarchical structure of water consumption and related socio-economic indicators. It can be seen in Figure 1 that there is an interactive relationship between socio-economic indicators and water consumption in various sectors.

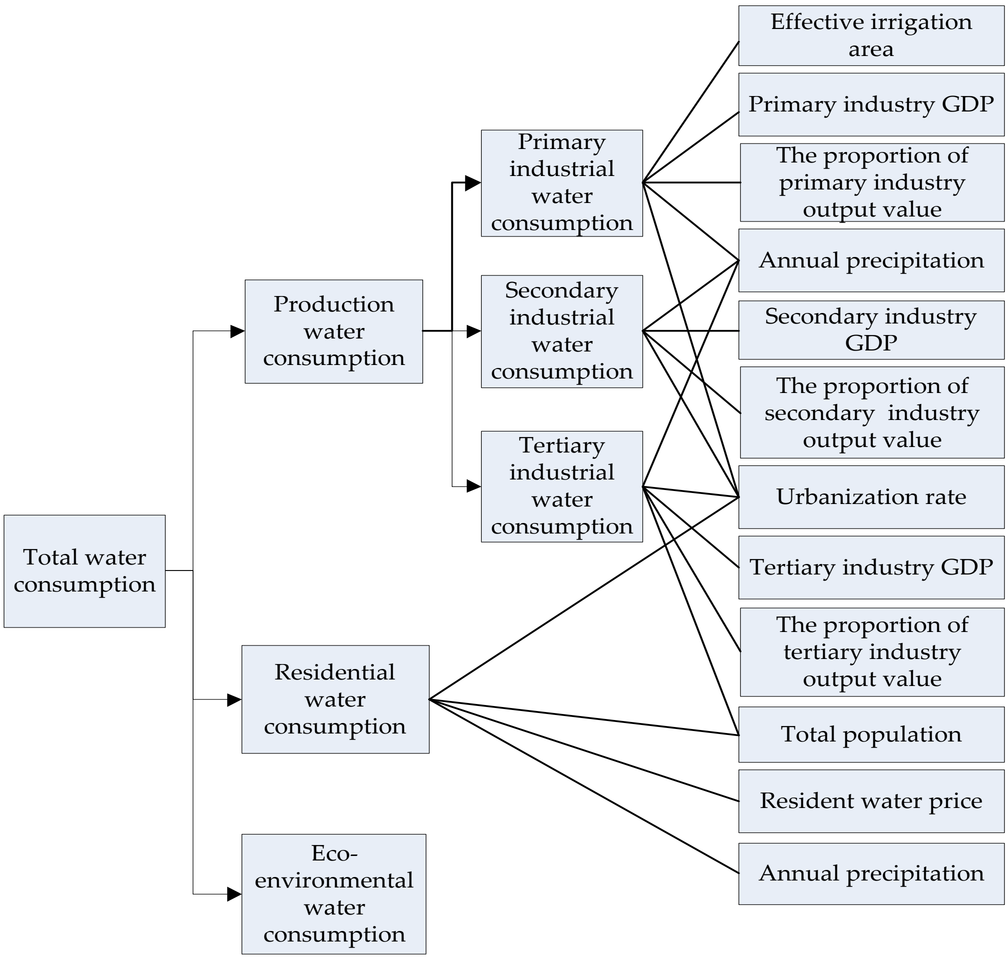

Figure 1. Hierarchical structure of water consumption and related socio-economic indicators.

3. Data Collection and Description

Based on the results of the hierarchical analysis, the data in the previous section were collected. The data of water consumption and related indicators of Chongqing from 2001 to 2015 were collected from Chongqing Water Resources Bulletin (http://www.cqwater.gov.cn/) Water Price Bulletin of Chongqing Price Bureau (http://www.cqpn.gov.cn/), and Statistical Yearbook of Chongqing (http://www.cq.gov.cn/).

Table 1 shows the symbols of indicators and the description of indicators. Table ?? shows the situation of water resources in Chongqing from 2001 to 2015, which is the change in water consumption. Table 3 shows the changes in various social and economic indicators from 2001 to 2015 in Chongqing (only the original data are shown here). Table 4 shows the proportion of output value of the three industries in Chongqing from 2001 to 2015. The proportion of output value of the three industries are calculated based on the ratio of industry GDP to the total GDP, which also represents the contribution of the total GDP.

Table 1. Symbols and description of indicators.

Indicators	Symbols	Description of Each Indicators
Total water consumption	a	The gross quantity of water distributed to users, including water conveyance loss (hundred million m^3).
Production water consumption	b	The water consumption of three major industries.
Residential water consumption	c	Residential daily water consumption.
eco-environmental water consumption	d	The amount of water needed to maintain the stability of the ecosystem.
Primary industrial water consumption	e	Water uses by farmland irrigation, forestry, animal husbandry and fishery, and livestock
Secondary industrial water consumption	f	Industrial water consumption and construction water consumption.
Tertiary industrial water consumption	g	Water used by the service industries of commerce, accommodation and catering, transport and communication, governmental organs, social organizations, etc.
Primary industry GDP Secondary industry GDP Tertiary industry GDP	h i j	The gross domestic product (hundred million RMB) of the three major industries.
Effective irrigation area	k	Land equipped with irrigation engineering facilities, which can be irrigated arable (thousand hectares).
Annual precipitation	l	The amount of precipitation in a region (hundred million m^3).
Urbanization rate	m	The proportion of urban population in the total population.
Residential water price	n	Water price for residents (RMB/Ton).
Total population	o	The resident population (ten thousand).
The proportion of primary industry output value	p	$p = \frac{h}{(h+i+j)}$.
The proportion of secondary industry output value	q	$q = \frac{i}{(h+i+j)}$
The proportion of secondary industry output value	r	$r = \frac{j}{(h+i+j)}$

Table 2. Water resources in Chongqing (2001–2015).

Year	a	b	c	d	e	f	g
2015	78.98	63.21	14.80	0.97	25.87	33.59	3.75
2014	80.47	65.10	14.44	0.93	23.74	37.79	3.57
2013	83.91	69.21	13.86	0.84	24.55	41.47	3.19
2012	82.94	68.73	13.44	0.76	25.18	40.44	3.11
2011	86.80	72.78	13.30	0.72	25.45	44.24	3.08

captionCont.

Year	*a*	*b*	*c*	*d*	*e*	*f*	*g*
2010	86.39	72.57	13.29	0.53	21.63	48.25	2.69
2009	85.30	71.73	13.07	0.50	20.69	48.38	2.66
2008	82.77	69.81	12.50	0.46	20.67	46.73	2.41
2007	77.43	64.80	12.19	0.43	20.78	41.62	2.40
2006	73.20	61.32	11.47	0.41	20.18	39.07	2.27
2005	71.16	59.52	11.25	0.39	24.11	33.56	1.84
2004	67.45	56.11	11.02	0.32	22.87	31.71	1.52
2003	63.17	52.26	10.59	0.32	23.61	27.38	1.27
2002	60.35	46.52	13.53	0.31	20.70	24.80	1.02
2001	57.56	45.54	11.71	0.30	20.32	24.46	0.77

Table 3. Changes in Social and Economic Conditions in Chongqing (2001–2015).

Year	*h*	*i*	*j*	*k*	*l*	*m*	*n*	*o*
2015	687.19	1150.15	863.80	7069.37	60.94	7497.75	3.50	3016.55
2014	677.26	1061.03	1046.52	6529.06	59.60	6672.51	3.50	2991.40
2013	675.18	1002.68	876.43	5812.29	58.34	5968.29	3.50	2970.00
2012	702.97	940.01	890.45	5975.18	56.98	4494.41	3.50	2945.00
2011	692.88	844.52	899.67	5543.04	55.00	3623.81	3.10	2919.00
2010	685.25	685.38	872.07	4359.12	53.00	2881.08	2.90	2884.62
2009	672.02	606.80	848.37	3448.77	51.60	2474.44	2.80	2859.00
2008	658.86	575.40	978.70	3057.78	50.00	2160.48	2.80	2839.00
2007	633.67	482.39	1045.64	2368.53	48.30	1825.21	2.80	2816.00
2006	621.32	386.38	765.87	1871.65	46.70	1649.20	2.66	2808.00
2005	618.09	463.40	932.03	1564.00	45.20	1440.32	2.66	2798.00
2004	616.79	428.05	985.97	1376.91	43.50	1229.62	2.48	2793.32
2003	649.69	339.06	1013.36	1135.31	41.90	1081.35	2.46	2803.19
2002	641.16	317.87	974.93	958.87	39.90	956.12	2.42	2814.83
2001	631.93	294.90	574.07	841.95	37.40	840.01	1.67	2829.21

Table 4. The proportion of output value of three industries of Chongqing (2001–2015).

Year	*p*	*q*	*r*
2016	0.07	0.45	0.48
2015	0.07	0.45	0.48
2014	0.07	0.46	0.47
2013	0.08	0.45	0.47
2012	0.08	0.52	0.39
2011	0.08	0.55	0.36
2010	0.09	0.55	0.36
2009	0.09	0.53	0.38
2008	0.10	0.53	0.37
2007	0.10	0.51	0.39
2006	0.10	0.48	0.42
2005	0.13	0.45	0.42
2004	0.14	0.45	0.41
2003	0.13	0.44	0.42
2002	0.14	0.43	0.43
2001	0.15	0.43	0.42

4. Correlation Analysis Using Grey Theory

Grey relational analysis has obvious advantages for dealing with grey data. Grey Correlation Analysis is an important branch of grey system theory, mainly based on the degree of similarity of the geometric shape of the sequence curve to judge the relationship between different sequences.

Grey relational degree is the mean value of a series of grey relational coefficient, and it is a quantification of the relationship between sequences [22]. The final display result of the grey relational model is the grey relational degree. The higher the grey relational degree is, the closer the relationship is [23]. Of course, the grey relational method also has its disadvantages. The grey relational degree can show the degree of correlation between different sequences, but cannot show the systematic relationship between different sequences, and the causality. Therefore, after getting the grey relational degree, we should focus on the analysis of the causality between different sequences and the process of influence between different sequences.

Generally, the grey relational analysis method can be divided into four steps:

Step 1: Define the behavior time series

Let Xi be the system factor and k be the time sequence number. xi (k) is the observed data at time k (k = 1,2,3, ..., n), then the behavior of time sequence is $X_i = (X_i\ (1), X_i\ (2), \ldots, X_i(n))$. That is, the behavior of time series are X_0, X_1, X_2, ..., X_m (m is the number of relevant factors), and X_0 is the system behavior time series. The grey relational degree is calculated among X_1, X_2, ..., X_m with X_0. Here, production water consumption is taken as an example to calculate the grey relational degree between the production water consumption and the total water consumption. Due to the large number of indicators, symbols are used instead of numbers. Set the original number of total water consumption as X_a.

X_a = (57.56, 60.35, 63.17, 67.45, 71.16, 73.20, 77.43, 82.77, 85.30, 86.39, 86.80, 82.94, 83.91, 80.67, 78.98),

Set the original sequence of production water consumption as X_b.

X_b = (20.32, 20.70, 23.62, 22.87, 24.11, 20.17, 20.78, 20.67, 20.69, 21.63, 25.45, 25.18, 24.55, 23.74, 25.87).

Step 2: Perform dimensionless processing

Dimensionless processing is to remove the unit limits of the data and convert it into a dimensionless pure value, which facilitates the comparison and weighting of different units or orders of magnitude. Using an averaging process, Xi' is divided by $X_i(k)$, then $Y_i(k)$ is used to represent this result. The behavior of time series is obtained Y_0, Y_1, Y_2, ..., Y_m, $Y_i = (Y_i\ (1), Y_i\ (2), \ldots, Y_i\ (n))$:

$$Y_i(k) = \frac{X_i{}'}{X_i(k)} = \frac{\frac{1}{n}\sum\limits_{k=1}^{n} X_i(k)}{X_i(k)} \tag{1}$$

The following results are obtained:

Y_a = (1.32, 1.26, 1.20, 1.12, 1.07, 1.04, 0.98, 0.92, 0.89, 0.88, 0.87, 0.91, 0.90, 0.94, 0.96); and

Y_b = (1.40, 1.38, 1.19, 1.11, 1.04, 1.02, 0.96, 0.89, 0.87, 0.86, 0.86, 0.91, 0.90, 0.95, 0.99).

Step 3: Calculate time-related grey relational degree

The formula is used to calculate the degree of grey relational between X_0 (k) and X_i (k), and the time-dependent correlation coefficient matrix is obtained. p ($p\in(0,1)$) is resolution ratio, which generally take 0.5. The time-related correlation coefficient sequence is $R_{0i} = ((R_{0i}(1), R_{0i}(2), \ldots, R_{0i}(n))$.

$$R_{0i}(k) = \frac{\min\limits_{i}\ \min\limits_{k} \left| Y_0(k) - Y_i(k) \right| + \rho \max\limits_{i}\ \max\limits_{k} \left| Y_0(k) - Y_i(k) \right|}{\left| Y_0(k) - Y_i(k) \right| + \rho \max\limits_{i}\ \max\limits_{k} \left| Y_0(k) - Y_i(k) \right|} \tag{2}$$

The time-related correlation coefficient sequence of industrial water consumption was obtained, that is, the grey relational degree between industrial water consumption and total water consumption per year:

R_{ab} = (0.81, 0.74, 0.99, 0.97, 0.96, 0.95, 0.96, 0.94, 0.95, 0.96, 0.96, 0.99, 0.99, 0.97, 0.94).

Step 4: Calculate the average value r_{0i} ($0 < r_{0i} \leq 1$) of the time-dependent degree of relational is calculated, that is, the grey relational degree between the required X_0 and X_i:

$$r_{0i} = \frac{1}{n}\sum_{k=1}^{n} R_{0i}(k) \tag{3}$$

The grey relational degree between production water consumption and total water consumption can be obtained, r_{ab} = 0.94. The grey relational degree of other related factors are calculated as above. Based on the structure of water use, the grey relational degree of the next level indicator to the upper level indicator is calculated. The results of the grey relational degree (GRD) are shown in Tables 5 and 6.

Table 5. The grey relational degree among water consumption.

	r_{ab}	r_{ac}	r_{ad}	r_{be}	r_{bf}	r_{bg}
Grey relational degree	0.94	0.82	0.51	0.88	0.93	0.78

Table 6. The grey relational degree between water consumption and socio-economic indicators.

	r_{ek}	r_{eh}	r_{el}	r_{em}	r_{ep}	r_{fl}	r_{fi}	r_{fm}	r_{fq}	
GRD	0.90	0.64	0.84	0.85	0.50	0.88	0.67	0.92	0.92	
	r_{gm}	r_{gj}	r_{go}	r_{gl}	r_{gr}	r_{co}	r_{cn}	r_{cl}	r_{cm}	r_{na}
GRD	0.83	0.73	0.78	0.75	0.76	0.84	0.82	0.73	0.87	0.58

5. Discussion and Recommendations

In Table 5, the grey relational degree between production water consumption and total water consumption is 0.94, which is highly relevant. The relationship between eco-environmental water consumption and total water consumption is generally related. Figure 2 shows the proportion of water consumption of various water departments in Chongqing. There is a close and positive relationship between the proportion of water consumption in each sector and the degree of grey relational. The highest degree of grey relational is found between production water consumption and total water consumption, which is mainly due to the highest proportion of production water use to total water use. In the three major water use sectors, the fluctuation of production water consumption has the greatest impact on the total water consumption. Similarly, in the three major water use sectors, the grey relational degree of residential water consumption ranks second, and the ratio of residential water consumption to total water consumption also ranks second. In Figure 2, the proportion of production water is 82%, which is the main source of total water consumption. The production is the main driving force of the total water consumption. In recent years, there has been a decrease in total water consumption, which is most closely related to the reduction of production water consumption. Residential water consumption and eco-environmental water use have been on the rise in recent years, while production water consumption has been declining since 2011, and total water consumption has begun to decline. Therefore, the next section focuses on the analysis of production water consumption.

The total water consumption target of the most stringent water resources management system in Chongqing is introduced as follows: by 2020, the total water consumption will be controlled at 9.7 billion m^3; and, by 2030, the total water consumption will be within 10.5 billion m^3 [3]. Adhering to overall planning and coordinating production, domestic, and ecological environmental water use are the basic principles of the most stringent water resources management system. Under the existing target of total water consumption, to coordinate the water consumption of the three major users, the following sections will analyze the three aspects of production water consumption: residential water consumption, and eco-environmental water consumption.

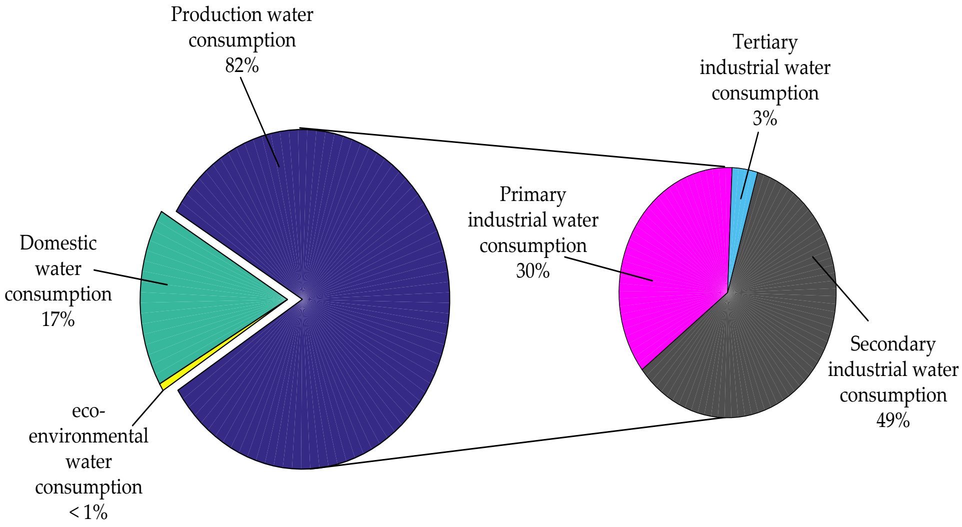

Figure 2. Proportion of water consumption of various water departments in Chongqing.

5.1. Analysis of Production Water Consumption

Production is the basis of economic activity. At the nineteenth National Congress of the Communist Party of China (19th CPC National Congress), President Xi emphasizes that the greatest economic and social benefits should be achieved with the least cost of the resources and environment. The three industries are interconnected, promote each other, and rely on each other. Coordinating the relationship between the three industries is conducive to economic development and social stability. The government should scientifically determine the scale of production water use, coordinate the water consumption of the primary industry, the secondary industry and the tertiary industry, and eliminate backward production capacity. At the same time, the government should encourage companies to develop processes and technologies that use efficient water conservation. Among the three industries, the grey relational degree between the secondary industrial water consumption and the production water consumption is the highest. The primary industrial water consumption ranked second. In Figure 2 that the secondary industry accounts for the largest share of production water consumption, followed by the primary industrial water consumption. There is a positive correlation between the grey relational degree and the proportion of water use. The fluctuation of water consumption in the secondary industry and the tertiary industry has a close impact on the total water consumption. The grey relational degree of tertiary industry water consumption ranks third. Similarly, in the three major industries, the tertiary industry also ranks third in terms of water use. The primary and secondary industrial water consumption is the main driving force for production water. The reduction of production water consumption is closely related to the decrease of water use in the primary and secondary industries. The water consumption of tertiary industry is increasing year by year. The water consumption of primary industry and secondary industry have reduced due to the industrial restructuring policy during the 12th Five-Year Plan period.

5.1.1. Primary Industrial Water Consumption

China is a large agricultural country, and the primary industry (agriculture) is the foundation of the national economy. The primary industry provides important raw materials and a broad market for the secondary and tertiary industries. China has a large population, but the area of arable land is relatively small, and water resources in the north and south do not match. The 19th CPC National Congress proposed to implement the strategy of rejuvenating rural areas and accelerate the pace of agricultural modernization. Chongqing is a mountainous city, and the topography of Chongqing restricts the development of the scale and mechanization of modern agriculture. The Chongqing government should adjust measures to local conditions, encourage the development of modern agriculture with Chongqing characteristics, ensure the amount of water used by the primary industry, and support agricultural development.

The primary industrial water consumption has the highest grey relational degree with the effective irrigated area. Effective irrigated area is an indicator that reflects the drought resistance of arable land. The primary industry should expand the effective irrigation area and improve the irrigation facilities to increase the utilization rate of water resources. The grey relational degree shows that the urbanization rate is also closely related to the water consumption of primary industry. In fact, the development of agricultural modernization has greatly promoted the process of urbanization and provided conditions for the increase of rural surplus labor. Rural areas should speed up agricultural modernization and effectively increase the utilization of water resources. Precipitation is highly correlated with the water consumption of primary industry. It can be imagined that precipitation naturally recharges arable land, forest land, etc., thereby reducing agricultural water consumption. Enterprises in the primary industry should improve the rainwater collection and utilization system, which can improve the recycling rate of water resources.

The grey relational degree between the GDP of the primary industry and the water consumption of the primary industry is 0.64. There is also a correlation between economic development and water use. The increase in GDP of the primary industry means that the expansion of the industrial scale requires the consumption of more water resources. The grey relational degree between the proportion of primary industry output value and primary industrial water consumption is 0.5, and the correlation is weak. The primary industrial water consumption and the proportion of primary industry output value in Chongqing from 2001 to 2015 is shown in Figure 3. In Figure 3, the primary industrial water consumption has been increasing slowly and fluctuating from 2.03 billion m^3 in 2001 to 2.59 billion m^3 in 2015. In recent years, water consumption and GDP of primary industry have been increasing, while the proportion of primary industry output value has been in a downward trend. The primary industry as a whole is in a state of high input and low output. The use of water resources has not played its greatest economic benefits. This is mainly because the mountainous terrain in Chongqing has limited the development of agricultural modernization and the backwardness of water-saving technologies. The excessive proportion of agricultural water is the main reason for the inefficient utilization of water resources in Chongqing.

The government should encourage the development of modern agriculture with Chongqing characteristics. At the same time, the government should rationally adjust the layout of agricultural production, strictly limit the cultivation of high water-consuming crops in severely water-scarce areas, and establish an agricultural water-saving system that matches the distribution of agricultural production. The primary industry should perfect the water-saving projects, and actively promote efficient water-saving irrigation technologies such as sprinkler irrigation and low-pressure pipe irrigation for micro-irrigation.

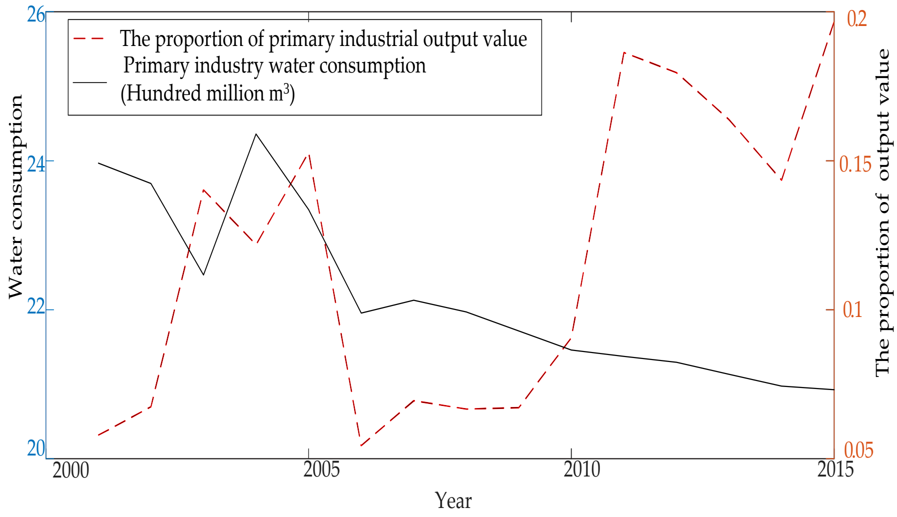

Figure 3. The primary industrial water consumption and the proportion of primary industry output value from 2001 to 2015.

5.1.2. Secondary Industrial Water Consumption

Chongqing is the largest industrial city in southwestern China. It is a major manufacturing center and plays an important role in the country. The secondary industry in Chongqing is unevenly developed. The proportion of heavy industry is still relatively large, and it is difficult to achieve industrial structure from "heavy" to "light" in the short term. During the "Twelfth Five-Year Plan" period, the Chongqing Municipal Government have completed the task of industrial restructuring and eliminating the outdated production capacity. At the same time, it closed down and relocated 256 heavily polluting industries. This is the main reason for the decline of water use in the secondary industry during the period 2010–2015 (the "12th Five-Year Plan" period). Chongqing is China's third largest center for motor vehicle production and the largest for motorcycles. The secondary industry is a dominant local industry in Chongqing and the government should vigorously develop it. At the same time, the government should continue to eliminate outdated industrial capacity and prevent the emergence of new excess capacity.

The degree of grey relational between the urbanization rate and the water consumption of second industry is the highest, and there is a positive correlation between the urbanization rate and the industrial development. With the developments of industry, population and capital accumulate in cities, which promote urbanization. The close relationship between the amount of water used by the secondary industry and the amount of precipitation indicates that the secondary industry has a higher rate of rainwater use and the government should encourage the use of unconventional water.

There is also a correlation between secondary industry GDP and secondary industrial water consumption. The increase in GDP of the secondary industry means to a certain extent the expansion of the secondary industry, and therefore it needs to consume more water. Although the GDP of the secondary industry has been on an upward trend, the proportion of the secondary industry output value has been on a downward trend since the "12th Five-Year Plan" period. The grey relational degree between the proportion of secondary industry output value and the secondary industrial water consumption is 0.92, which is highly correlated. The secondary industrial water consumption and the proportion of secondary industry output value in Chongqing from 2001 to 2015 is shown in Figure 4. It can be seen in Figure 4 that the general trends of these two sequences are the same. The higher the degree of grey correlation, the more similar the geometrical curve between the two sequences. There is a positive correlation between the proportion of output value of the secondary industry and the secondary industry water consumption. The proportion of secondary industry output value is reduced, which represents a reduction in the structure of the secondary industry, thereby reducing the secondary industry water consumption. Chongqing was once one of the six old industrial bases in the country with a good manufacturing foundation. Since 2002, heavy industrialization in Chongqing has deepened. However, due to the low technological content and the high wastage of water resources, the development of secondary industry is slow. Later, heavy industries gradually completed industrial transformation or were replaced. It can be seen in the Figure 5 that both have shown a downward trend. This is related to the policy of implementing industrial restructuring in Chongqing in recent years.

The Chongqing government should continue to eliminate backward production capacity. The production lines with high water resource wastage rates should gradually be replaced. Enterprises should speed up the upgrading and transformation of industrial water-saving technologies, and vigorously promote water-saving technologies such as industrial water recycling and water-saving washing.

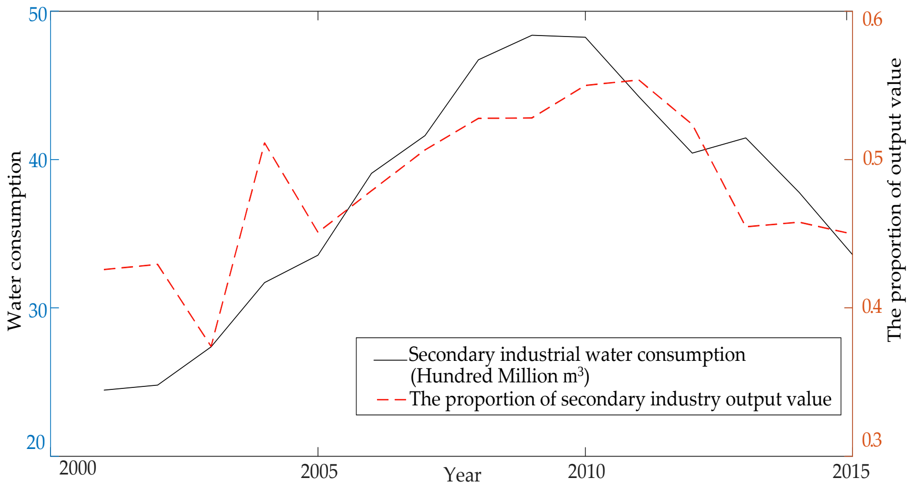

Figure 4. The secondary industrial water consumption and the proportion of secondary industry output value from 2001 to 2015.

5.1.3. Tertiary Industrial Water Consumption

Chongqing is an important modern service industry (tertiary industry) base in China. It is also a comprehensive transportation hub and the largest business center city in southwest China.

The grey relational degree between the tertiary industrial water consumption and urbanization rate is the highest. The economy of Chongqing develops rapidly, urbanization level continues to increase, and many rural citizens flock to the city, prompting the improvement of the tertiary industry. The scale of the tertiary industry gradually expanded, thereby increasing the third industrial water use. The tertiary industry is a service industry related to the population. With the increase of the population, the tertiary industrial water consumption also increases. The grey correlation degree between precipitation and the tertiary industrial water consumption is 0.75, which is lower than that of primary industry and secondary industry. This shows that the utilization rate of rainwater in the tertiary industry is lower than that of the secondary industry and tertiary industry.

The grey related degree of GDP of the tertiary industry is 0.73, indicating that there is a correlation between industrial economic development and water consumption. The grey relational degree between the proportion of tertiary industry output value and tertiary industrial water consumption is 0.76. The expansion of industry scale has led to an increase in the amount of water used. The water consumption of the tertiary industry is on the rise, but the water consumption of the tertiary industry is relatively small, with the average annual proportion about 0.03%. However, the proportion of tertiary industry output value is very large, with the average annual industrial output value ratio of 41%, as shown in Figure 5. This means that the tertiary industries have a small investment in water resources and a large output. Water resources are in a state of low input and high output. This is because the tertiary industry is a service industry that does not produce material products. The primary industry and the secondary industry are the premise and basis for the development of the tertiary industry. The development of the tertiary industry has a positive role in promoting the primary and secondary industries. At the same time, the development of the tertiary industry can promote employment and improve people's living standards and quality of life. The tertiary industry should be vigorously developed, the opening up policy should be implemented to the tertiary industry, and the tertiary industry should be encouraged in economy.

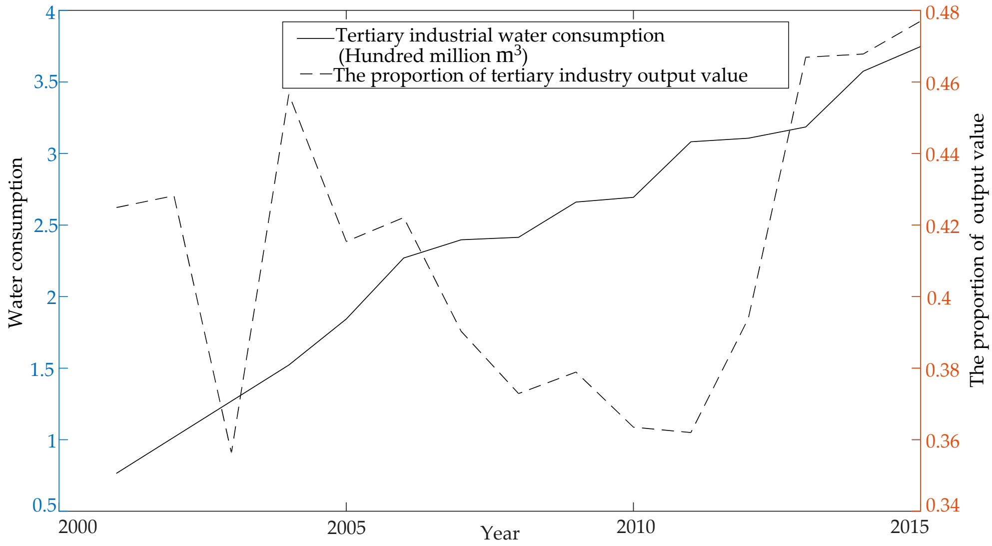

Figure 5. The tertiary industrial water consumption and the proportion of tertiary industry output value from 2001 to 2015.

5.2. Analysis of Residential Water Consumption

The most stringent water resources management system should adhere to the principle of people-oriented. Water as a necessity for people's life, and the government should first guarantee the basic living water of the residents. At the same time, the propaganda of water saving consciousness should be expanded to reduce unnecessary water use. The government should promote the use of highly efficient water-saving household appliances such as taps, showers, washing machines, etc. [24,25].

The higher the grey relational degree, the greater the interaction between the two [26]. The grey relational degree between the total population and the residential water consumption is the largest; of course, the residential water consumption increases with the increase of the population. There is a close correlation between precipitation and residential water consumption. Many residents will collect rainwater for non-food purposes, e.g., to flush toilets, and water plants. Agglomeration areas of residents should improve the rainwater collection and utilization systems, which can be used for irrigation of green areas in the communities, road surface cleaning, or for residents to wash cars, flush toilets, etc., to increase the utilization rate of rainwater resources.

There is a high degree of correlation between residential water prices and residential water consumption. From 2001 to 2015, residential water consumption and the change of residential water price are shown in Figure 6. As can be seen from the chart, from 2002 to 2003, the residential water consumption had a steep declining trend, while there was a big increase in residential water prices in those years, which means the reasonable control of water prices is an effective measure to save water. In addition, we can see in the Figure 6 that the residential water price has not changed since 2012, which is also one of the reasons leading to an increase in residential water consumption. In particular, the grey relational degree between residential water price and the total water consumption was calculated as $r_{na} = 0.58$. The grey relational degree between the residential water consumption and the residential water price is 0.82. This is mainly due to the existence of a hierarchical structure of water consumption. The total water consumption is the highest level of the hierarchy of water consumption. The influence of residential water price on water consumption is transferred to total water consumption through residential water consumption. Residential water price has a more direct impact on residential water consumption, which indirectly affects total water consumption. From the aspect of water consumption, Water price policies can be used to effectively improve water-use efficiency [9]. However, the water price elasticity is small, and the water saving brought by the increase of water price has little effect. Raising the price of water by a large margin would reduce the welfare of the residents but ladder pricing would solve this problem. In 2016, Chongqing started to implement the ladder pricing for water. The Chongqing government should continue to improve the ladder pricing system for water and expand the scope of the implementation. At the same time, the government should organize activities to raise public awareness of water-saving, and promote the recycling of water resources.

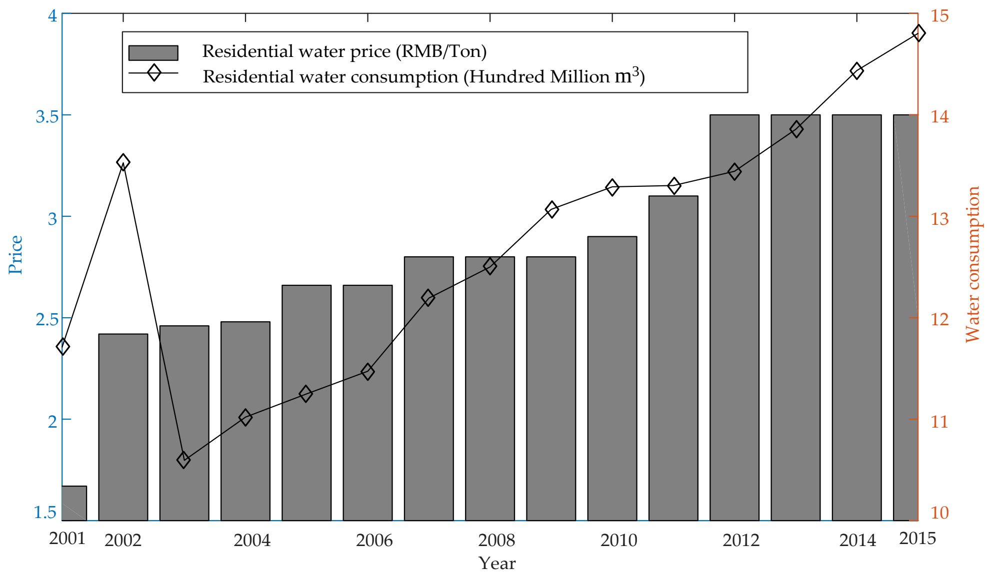

Figure 6. Residential water consumption and residential water price from 2001 to 2015.

5.3. Analysis of Eco-Environmental Water Consumption

The grey relational degree between eco-environmental water consumption and the total water consumption is 0.51, and the correlation is weak. In addition, the annual water consumption is relatively small, with an annual average of approximately 54 million m^3. Therefore, there is no correlation analysis between eco-environmental water consumption and the economic social indicators. The construction of ecological civilization is a long-term plan that concerns the happiness of the people and the future of the nation. The people's longing for a better life has put forward higher requirements for the ecological environment. In the 13th Five-Year Plan, strengthening the construction of ecological civilization was first written into the national five-year plan [2]. This shows the importance of ecological construction nowadays. In the 13th Five-Year Plan for Ecological Civilization of Chongqing City, it was clearly stated that the urban green space coverage should be increased by 1.1%, which highlights the importance of ecological conservation. Therefore, it is necessary to appropriately increase the eco-environmental water consumption and ensure the supply of water for the ecological environment.

6. Conclusions

In this paper, the method of AHP is used to propose a hierarchy of water consumption, and then selects the relevant economic and social indicators to correlate with water consumption. The grey relational model is used to calculate the grey relational degree hierarchically. Then from the three water departments, the water consumption is analyzed in different levels, and proposals for the sustainable development of water resources are put forward. Here they are summarized for three levels:

(1) In the first level of grey relational analysis, the correlation between production water consumption and total water consumption was the highest, while residential water consumption ranked second. Production water and domestic water are the main driving forces of total water consumption. The production water consumption accounts for 82% of the total water consumption. The scale of production water should be scientifically planned and the backward production capacity should be eliminated. Water resources are a necessity for residents' lives. The government should first ensure the residents' basic water use and reduce unnecessary water use. Eco-environmental water consumption is the basis for the conservation of the ecological environment. The government should appropriately increase the eco-environmental water consumption.

(2) In the second level of grey relational analysis, the grey relational degree of the secondary industrial water consumption is the highest. The primary industrial water consumption ranked second. The scale of the industry determines water consumption to a certain extent, and measures for the sustainable development of water resources can be considered from the perspective of industrial structure adjustment. The development among the three major industries restricts each other and promotes each other. The government should promote the comprehensive, coordinated and sustainable development of the three major industries. The topography of Chongqing has led to a slow pace of agricultural modernization. The government should encourage the development of characteristic agriculture and ensure the use of water in the primary industry. The secondary industry is an advantageous local industry in Chongqing. The government should vigorously develop and eliminate backward production capacity. The economic benefits brought by the tertiary industry are large, and the efficiency of water use is high. The government should encourage the development of the tertiary industry.

(3) In the third level of grey relational analysis, precipitation has a high grey relational degree with water consumption. Total population, water prices, urbanization rates, industrial GDP and output ratio of the three industries are all important factors affecting water consumption. The government should vigorously promote awareness of water conservation and the efficient water-saving technologies should be developed. The system of rainwater harvesting and utilization should be improved. At the same time, the ladder pricing system for water should be improved and the scope of implementation should be expanded.

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