Coupling Coordination between Water System Management and Socio-economic Development in Xi'an

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Abstract: Promoting the coupling coordination of water system management and socio-economic development is the driving force for regional sustainable development. In this paper, the evaluation index system of water system management and socio-economic development is constructed, and the comprehensive development coefficients are calculated by using the combination of entropic weight method and variation coefficient method, then the coupling coordination degree (CCD) model and scissor difference method are applied to analyse the differences between water system management and socio-economic development, as well as the coupling coordination level and the evolution speed in Xi'an, from 2009 to 2019. The results showed that: (1) The comprehensive development coefficient of Xi'an water system management showed a fluctuating upward trend, and the socio-economic development increased steadily yearly. (2) The CCD increased from 0.440 to 0.830, and it evolved from slightly unbalanced development with socio-economy lagged in 2009 to favourably balanced development with water system management lagged in 2019. (3) The scissors difference in inverted "U" shape, indicating that the gaps between the two systems are gradually decreasing. Subsequently, based on the results of the above analysis, policy suggestions are made to ensure a balanced development in Xi'an and to provide experience for other water-scarce cities to set up water system management strategies.

1 INTRODUCTION

Water is the source of life and the vitality of cities. The urban water system provides a basic material guarantee for human production and life, economic development, and social progress, it has enhanced people's sense of happiness and gain, and promoted socio-economic development. However, with the progress of human society, especially the acceleration of urbanization and industrialization, problems such as water shortage, pollution, and quality deterioration have become increasingly prominent, which have become the main bottleneck restricting the development of the urban social economy.

Be advised that papers in a technically unsuitable form will be returned for retyping. After returned the manuscript must be appropriately modified. In recent years, many scholars have done a lot of research and achieved abundant results on the coupling coordination relationship between the water system and socio-economic development. Most of them focus on the quantitative model research of water pollution and per capita GDP based on the EKC, and verify the existence of the EKC hypothesis through empirical studies from different perspectives (Dln, 2019; Miglietta et al., 2017). A small number of scholars have also explored the relationship between water consumption and income (Duarte et al., 2013). Scholars' research on the coupling coordination of water system and socio-economic development can be roughly divided into time series research and spatial differentiation research from the dimensions. time series research mainly uses entropy weight method, mechanical model, DPSIRM model, a comprehensive index, polynomial fitting, and other methods to evaluate and analyze the coupling coordination relationship between water environment and social economy from the perspective of the basin (Fang et al., 2007; Li et al., 2016). Spatial differentiation research is more to use GIS, gray

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correlation and other models to explore its dynamic evolution coordination relationship and pattern characteristics analysis from different scales of provinces, regions, and cities (Guo et al., 2021; Li et al., 2019).

At present, scholars mainly carry out research on the coordination level of water resources, water environment and other factors with the economic development of cities, with the following shortcomings: (1) Seldom take water system management as the research object and explore its coupling coordination relationship with socio-economic development.(2) The lack of an effective and comprehensive index system for evaluating the level of water system management and socio-economic development of cities. this paper constructs the evaluation index system of water system management and socio-economic development in Xi'an City, explore the coupling coordination relationship between the two aspects, and judge the difference in their evolution rate and direction, it is expected to provide a theoretical basis and development path for promoting the coordinated development of Xi'an water system management and social economy.

2 STUDY AREA

Xi'an City (32°42'~34°45'N, 107°40'~109°49'E) is located in the middle of the Guanzhong Plain in Shaanxi Province, with an altitude of 400-700m above sea level and a total area of 10,108 km^2. It belongs to the semi-humid continental monsoon climate of the warm temperate zone and the annual average temperature is 13.3℃~13.7℃. Xi'an is a water shortage city with an average annual water resources of 2.347 billion m^3, with a per capita possession of 270m^3, which is only 13.25% of the national average. The average annual precipitation decreases gradually from south to north and is 740.4 mm. Thousands of lakes due to the crisscrossing networks of water, the main rivers are all Wei River system in the Yellow River basin (Figure 1). There are 30 rivers with a basin area of more than 100km^2 and 7 rivers with a basin area of more than 1000km^2. Xi'an now has jurisdiction over 11 districts and 2 counties. By the end of 2019, the permanent resident population of Xi'an is 10.2 million, and the annual GDP of Xi'an is 93.22 billion yuan, among them, the tertiary industry is the main source of income, accounting for 63% of the total. The economy was stable and improved, and people's well-being continued to advance. Under the guidance of Xi'an to build an international metropolis and national central city, Xi'an will become a core city that leads the northwest and radiates the northern inland areas (Zhang et al., 2020b).

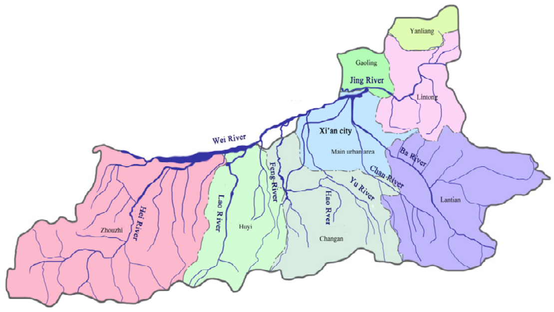

Figure 1: Xi'an water system and administrative division.

3 DATA AND METHODOLOGY

3.1 Index System and Data Sources

Based on reviewing relevant literature (Liu et al., 2019a; Michelsen & Bargur, 1994) candidate indicators with a temporal correlation between the two systems are firstly selected, Then, through the methods of expert consultation, frequency statistics and principal component analysis, the indicators that accord with the reality of Xi'an water system management and socio-economic development are selected (Liu et al., 2019b; Khan et al., 2007). Following the principles of scientificity, operability and systematization, 4 first-level indicators and 9 second-level indicators are finally determined for water system management, 2 first-level indicators and 11 second-level indicators are determined for socio-economic development, and a total of 20 indicators are involved in the evaluation, as shown in Table 1.

Considering the authenticity and accessibility of the data, this paper selects the data of Xi'an from 2009 to 2019 as the research sample. The relevant data of the water system management comes from the "Shaanxi Provincial Water Resources Bulletin", the "Xi'an Water Resources Bulletin", the "Xi'an Ecological Environment Status Bulletin" and the "Xi'an Government Work Report"; and the social economy data are all from the "Shaanxi Provincial Statistical Yearbook", the "Xi'an Statistical Yearbook" and the "Statistical Bulletin of Xi'an National Economic and Social Development", some missing data in some years are supplemented by interpolation.

Table 1: Index system of water system management and socio-economic development.

Subsystem	First-level Indexes	Second-level Indexes	Index properties	Unit	MAX	MIN	Entropy Weight method	Coefficient of variation method	Combined weight
Water system management	Water area management	the water system area rate	+	%	0.63%	0.28%	0.164	0.118	0.153
	Water quality management	water function area compliance rate	+	%	84.80%	4.16%	0.125	0.321	0.219
		sewage treatment rate	+	%	96.38%	80.97%	0.062	0.022	0.040
		river source water quality compliance rate	+	%	94.74%	31.57%	0.090	0.143	0.124
	Water ecology management	Soil erosion control area	+	1000Ha	267.40	173.80	0.135	0.072	0.108
		wetland area	+	Mu	8660.00	4566.00	0.077	0.077	0.084
	Water function management	embankment compliance rate	+	%	86.92%	17.72%	0.126	0.216	0.181
		waterlogging control area	+	1000Ha	45.46	40.69	0.117	0.012	0.042
		irrigation area	+	1000Ha	208.73	178.23	0.105	0.019	0.049
Socio-economic development	Economic development	GDP per capita	+	Million/per	9.23	3.22	0.086	0.131	0.111
		growth rate of tertiary industry	+	%	15.10%	6.80%	0.086	0.098	0.095
		local fiscal revenue	+	billion	702.56	181.40	0.076	0.157	0.114
		urban per capita disposable income	+	billion	4.18	1.89	0.066	0.092	0.081
		degree of dependence on foreign trade	+	%	38.87%	18.17%	0.115	0.106	0.115
		total tourism income	+	%	33.75%	10.93%	0.112	0.150	0.136
	Social development	greening area rate of built-up area	+	%	42.57%	37.50%	0.068	0.016	0.034
		Air quality compliance rate	+	%	85.26%	18.96%	0.075	0.107	0.094
		urbanization rate	+	%	65.52%	43.94%	0.159	0.069	0.109
		registered urban unemployment rate	-	%	4.30%	3.26%	0.066	0.045	0.057
		commodity housing sales price index	-	%	121.1	96.2	0.091	0.030	0.054

3.2 Methods

3.2.1 Entropy Weight Method

Entropy weight method is an objective weight method by calculating the information entropy of the index. The smaller the information entropy, the greater the degree of variation and the greater the weight (Guo et al., 2021). The calculation steps are:

Positive index: $$a'_{ij} = \frac{a_{ij} - \min(a_j)}{\max(a_j) - \min(a_j)} \tag{1}$$

Negative index: $$a'_{ij} = \frac{\max(a_j) - a_j}{\max(a_j) - \min(a_j)} \quad (2)$$

Where a_{ij} is jth index of the ith year; a'_{ij} is the standardized value; max a_j and min a_j represent the maximum and minimum values of the jth index, respectively.

normalized processing: $$a_{ij} = \frac{a'_{ij}}{\sum_{i=1}^{m} a_{ij}} \quad (3)$$

information entropy: $$d_j = 1 - \frac{-\sum_{i=1}^{m} \ln a_{ij}}{\ln m} \quad (4)$$

entropy weight: $$w_j = \frac{d_j}{\sum_{j=1}^{n} d_j} \quad (5)$$

3.2.2 Variation Coefficient Method

It is the ratio of the mean and standard deviation of an indicator, which can make up for the unreasonable weight distribution of the single entropy weight method, and eliminate the influence of abnormal indicators (zhen et al., 2014). The calculation formula is:

$$w'_i = \frac{\sigma_i}{\bar{x}_i \sum_{i=1}^{m} \frac{\sigma_i}{\bar{x}_i}} \quad (6)$$

Where $w_i{}'$ is weight; σ_i is the standard deviation of the ith index; $\bar{x}_i$ is the average of the ith index.

3.2.3 Combination Weight

According to the Lagrange multiplier method, the combined weight is obtained by solving the objective function of the minimum information entropy determined by the weights of the entropy weight method and the variation coefficient method (Chen et al., 2021).

$$\min F = \sum_{i=1}^{m} w_i(\ln w_i - \ln w_j) + \sum_{i=1}^{m} w_i(\ln w_i - \ln w'_i) \quad (7)$$

combination weight: $$w_i = \frac{(w_j \cdot w'_i)^{1/2}}{\sum_{i=1}^{m} (w_j \cdot w'_i)^{1/2}} \quad (8)$$

3.2.4 CCD Model

Refer to the related studies of the coupling coordination degree, the coupling coordination development coefficient is introduced to evaluate the coupling coordination degree of water system management and socio-economic development. The calculation formula is as following:

$$C = \left[\frac{2 \cdot P(R) \cdot P(E)}{\left(P(R) + P(E)^2\right)} \right]^{1/2} \quad (9)$$

$$T = \alpha \cdot P(R) + \beta \cdot P(E) \quad (10)$$

$$D = (C \cdot T)^{1/2} \quad (11)$$

Where P(R) and P(E) represent the comprehensive level of water system management and socio-economic development respectively; C is the coordination coefficient of water system management and socio-economic development; T is the comprehensive benefit of system; α and β represent the contribution coefficients (α=β=0.5 (Song et al., 2018)). D is the CCD. According to the interaction degree between P(R) and P(E), this paper refers to the relevant literature (Liu et al., 2020; Yang & Wang, 2020) to divide the coupling coordination level into five categories, five levels and fifteen types, as showed in Table 2.

3.2.5 Scissors Difference Model

It quantitatively describes the evolution trend and difference by calculating the Angle between the tangents of evolution velocity between systems at any time. The larger the α angle is, the greater the difference in the change rate between the two systems is. By deriving the nonlinear functions f (R) and f (E) of two systems, the evolution speed is:

$$V(R) = f'(R) = \left[f(R)_t + d_0 + d_1 t + d_2 t^2 + \cdots + d_n t^n \right]' \quad (12)$$

$$V(R) = f'(R) = \left[f(R)_t + c_0 + c_1 t + c_2 t^2 + \cdots + c_n t^n \right]' \quad (13)$$

Where t is the research period, which is 2009-2019 in this paper; c_n and d_n are the coefficients. Thus, the scissors difference between the two systems is:

$$a = \arctan \left| \frac{V(R) - V(E)}{1 + V(R) \cdot V(E)} \right| \quad (14)$$

Table 2: Discriminating standard of CCD.

Categories	Levels of CCD		Development modes between subsystems
Superiorly balanced development	0.9<D≤1	P(R)＞P(E)	Superiorly balanced development with E lagged
		P(R)＜P(E)	Superiorly balanced development with R lagged
		P(R)=P(E)	Superiorly balanced development between R and E
Favorably balanced development	0.8<D≤0.9	P(R)＞P(E)	Favorably balanced development with E lagged
		P(R)＜P(E)	Favorably balanced development with R lagged
		P(R)=P(E)	Favorably balanced development between R and E
Barely balanced development	0.6<D≤0.8	P(R)＞P(E)	Barely balanced development with E lagged
		P(R)＜P(E)	Barely balanced development with R lagged
		P(R)=P(E)	Barely balanced development between R and E
Slightly unbalanced development	0.4<D≤0.6	P(R)＞P(E)	Slightly balanced development with E lagged
		P(R)＜P(E)	Slightly balanced development with R lagged
		P(R)=P(E)	Slightly balanced development between R and E
Unbalanced development	D≤0.4	P(R)＞P(E)	Unbalanced development with E lagged
		P(R)＜P(E)	Unbalanced development with R lagged
		P(R)=P(E)	Unbal anced development between R and E

4 RESULTS

4.1 The Comprehensive Levels of Water System Management and Socio-economic Development

By calculating the combined weight of indexs (Table 1), the comprehensive development index of water system management and social economy in Xi'an City is obtained (Figure 2). It can be seen from figure 2 that the comprehensive level of water system management in Xi'an during the study period showed a tortuous upward trend, and the comprehensive development coefficient increased from 0.244 to 0.686. Figure 3 shows in 2012, due to the comprehensive pollution coefficient has increased by 4.57% compared with the previous year, and 11 sections of the monitoring are in inferior V water quality, which caused the decrease of water quality management level. Due to the development of urbanization in Xi'an in 2014, the increase of construction land has led to a sharp decline in wetland area, resulting in a decrease in the comprehensive level of water system management. In 2016, due to various major pollutants were aggravated to varying degrees, therefore, they exceeded the sewage treatment load, the sewage treatment rate was greatly.

During the study period, the comprehensive level of socio-economic development in Xi'an increased year by year (Figure 3), and the comprehensive development coefficient increased from 0.153 to 0.693. In June 2009, the State Council approved the "*Guanzhong-Tianshui Economic Zone Development Plan*", and Xi'an became the third international metropolis after Beijing and Shanghai. which enabled Xi'an's economy to step into the rising channel of rapid development, with only a per capita GDP growth of 58.8%. In 2013-2016, as Xi'an actively integrated into the national "*One Belt, One Road*" strategy, which made Xi'an's socio-economic development coefficient showing a steady and continuous rise situation. From 2017 to 2019, Xi'an's economic strength has increased significantly, and its socio-economic growth rate has been rapid. Due to the rise of Xi'an "Online star city", the growth rate of tourism in 2017 ranked first in 15 sub-provincial levels, and the total tourism revenue exceeded 300 billion yuan in 2019. The culture and tourism industry has become a new economic growth point in Xi'an, greatly promoting social consumption and employment, and driving the rapid growth of the economic. Therefore, during the "12th Five-Year Plan" and "13th Five-Year Plan" periods, Xi'an's comprehensive economic strength has been continuously improved.

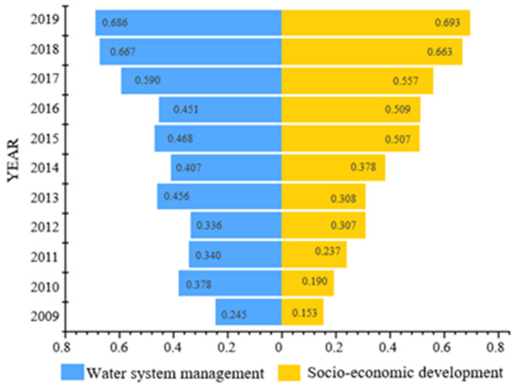

Figure 2: Composite development coefficient.

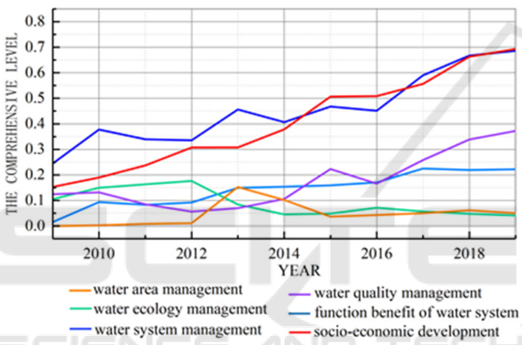

Figure 3: The evolution trend.

4.2 Analysis of CCD between Water System Management and Socio-economic Development

Using Equation (9-10), the coordination coefficient (C) and comprehensive benefit (T) of water system management and socio-economic development in the study period are calculated (Figure 4). In Figure 5, the CCD of the two systems in Xi'an increased from 0.440 to 0.830, indicating that the relationship between two systems in Xi'an is continuously improving, and the overall trend is approximate "W" type. The CCD of the two systems has gone through three stages: slightly unbalanced development, barely balanced development, favourably balanced development, and is expected to enter superiorly balanced development in the short term.

In 2009-2012, the two systems were in slightly unbalanced development, due to the socio-economic development of this period was lagging, and the pressure on water systems from people's production and life was relatively small. Therefore, the coordination between two systems in this stage has been relatively improved. From 2013 to 2017, the two systems are in barely balanced development, and the CCD during this period can be stabilized at more than 0.6, and the development of water system management has always been before the social economy, the transition from unbalance to balance is realized, and the two are gradually converging. But due to the fluctuation of water system governance in 2015-2016, the CCD with socio-economic development decreased significantly. During 2018-2019, Xi'an is in the stage of favourably balanced development, the two systems to achieve synchronous and coordinated development, with the coordination coefficient as high as 0.670. But there is still a certain gap with the ideal superiorly coordination state, thus it is necessary to increase water conservancy investment and water system management, and optimize the comprehensive development level of the two systems.

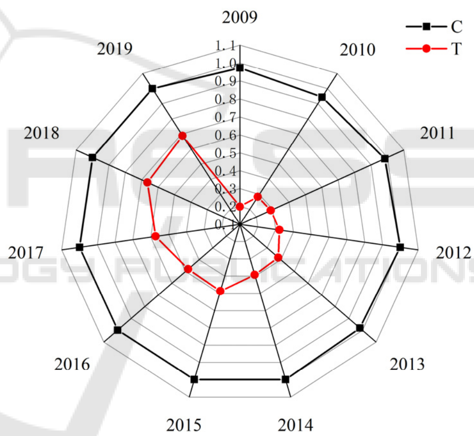

Figure 4: The values of C and T.

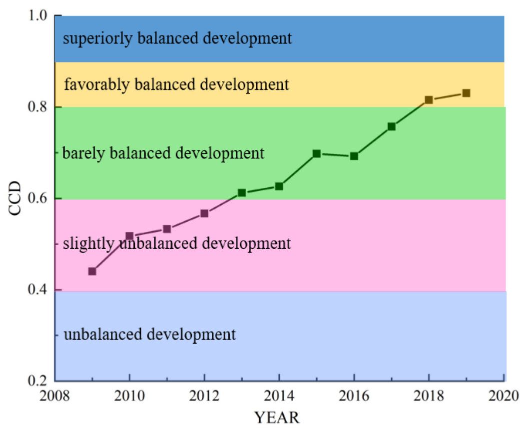

Figure 5: The analysis of CCD.

4.3 Analysis of Scissors Difference between Water System Management and Socio-economic Development

Matlab software is used to fit the time series data of two systems, the fitting curve of water system governance is $f(R)=0.0006X^3-0.0086X^2+0.0646X+0.2183$, and the fitting curve of socio-economic development is $f(E)=0.0014X^2+0.0415X+0.01$, R^2 was 0.917 and 0.979 respectively, so the fitting effect was good. The evolution rate (Figure 6) and the scissors difference α (Figure 7) of the two systems are obtained by equation (12~14).

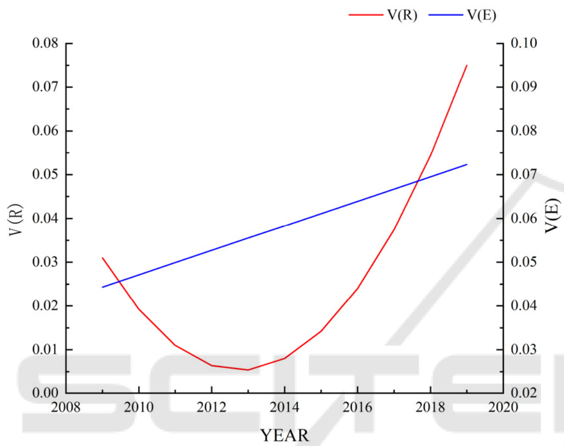

Figure 6: The evolution Rate.

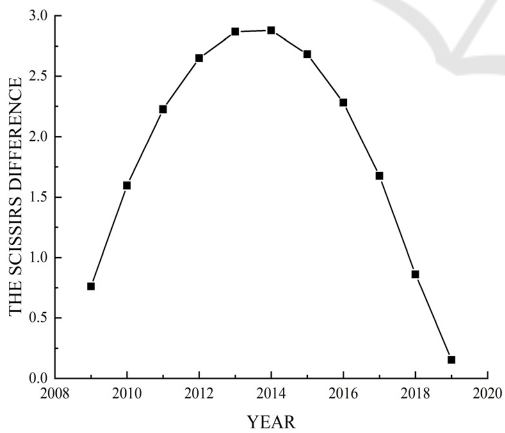

Figure 7: The analysis of scissors difference.

From the perspective of evolution rate, the evolution rate of water system management in Xi'an is "U" shape, and the socio-economic development is linear. The average evolutionary rate of water system management (0.026) was lower than that of socio-economic development (0.058), but the growth rate of both systems was positive, which did not affect the increase of their overall development level. The main performance is that the growth rate of water system management slowed down from 2009 to 2013, the construction of an international metropolis made the demand for water resources continue to rise, and the contradiction between supply and demand of water resources was prominent, which brought pressure on water source protection. Therefore, the growth rate of water system management slows down. With the implementation of the "Eight rivers nourish Xi'an", more attention and investments had been paid to the ecological protection and management of water system, which makes the evolution rate of water system management rise rapidly.

From the perspective of evolution direction, the scissors difference between two systems in Xi'an has an overall inverted "U" shape. In 2009-2014, the scissors difference showed an increasing trend, from 0.761° to 2.878°, The rapid development of social economy has brought pressure and environmental pollution to water system management, which makes the difference of the evolution rate between the two become bigger and bigger. However, the growth rate of scissors difference was slowing down, indicating that the water system management system was continuously improved with the growth of socio-economic development. In 2014-2019, the scissors difference decreased to 0.154°. At this stage, under the establishment of the water ecological civilization city, the sewage treatment technology, and the awareness of water management by the whole people have been improved. Therefore, the evolution rate of two systems has achieved rapid convergence, and the coupling coordination between the two systems has been continuously optimized, which effectively controls the scissors difference and enters a stage of favourably balanced development.

5 DISCUSSION

According to the above analysis, it can be found that, the water system in good condition in 2009, which can guarantee the production and life of urban residents and promote the rapid economic development. As Xi'an was officially approved by the state to construct an international metropolis and a national central city, socio-economic development has accelerated by leaps and bounds, and influence has been further enhanced. With a resident population of 10.2 million by 2019 and an urbanisation rate of 65.5%, Xi'an is in the top 10 most attractive cities for foreign investment in the country, putting pressure on the water system management work (Zhang et al., 2020a). However, with the increase of water conservancy investment yearly, the water conservancy work and supervision intensity are increased, and the effect is remarkable. The two systems have formed a relatively benign interaction. This is consistent with the policy plans that Xi'an has formulated and implemented all the time, which verifies the reliability and reasonableness of the results from the side. And from the following aspects to explore the role of water system management on socio-economic.

By the end of 2019, Xi'an water resources used for agricultural irrigation accounts for 1/4 of the total water consumption. Through water system management, the implementation of effective agricultural irrigation water management has a good role in promoting the development of urban socio-economic. It avoids the waste of water resources in this link, improves the effective irrigation area, increases the yield of food crops, and drives the economic development of the primary industry.

Water environment management is an important guarantee for the normal functioning of water systems, with the continuous improvement in the rate of sewage treatment and water quality standards, the drinking water needs of urban residents and other living creatures are ensured and the orderly operation of the city's socio-economic is guaranteed. Socio-economic rapidly development is divorced from the water system, it will in turn be influenced by human activity and bring about other water problems such as water pollution.

In addition, water system management should pay particular attention to the impact of the energy industry. Traditional energy industries such as coal mining, natural gas and petrochemical construction are prone to water pollution, soil erosion and reduction of wetland areas, thereby increasing the pressure on water systems. Therefore, water system management must strengthen the protection of water sources and the construction of sewage treatment facilities to ensure the accelerated industrialization of Xi'an and to promote the transformation and development of secondary industries.

Water ecology is the focus of water system management. During the 13th Five-Year Plan period, Xi'an added 24,300 mu of wetland, and a total of 949.93km^2 of soil erosion was treated. Through the management of water system ecology and landscape, the connectivity of the water system is enhanced, and provide places for people to relax and get close to nature, which improves the diversity of the urban landscape and the suitability of the residents, drives the value-added of the surrounding real estate, and provides service functions for socio-economic development.

The result of this paper can bring thinking and reference for the northwest region and other water-deficient cities, for example, Lanzhou, Xining, Yinchuan, etc, and provide a theoretical basis for economic development and the targeted formulation of water system management guidelines and policies. Water system management must be step by step, socio-economic development must rely on water system management, too much investment in water conservancy is prone to waste of funds, too little investment and difficult to maintain the normal operation of the socio-economic. Therefore, achieving the coupling coordinated development of water system management and socio-economic is a sustainable development path that the region must take.

6 CONCLUSIONS AND POLICY IMPLICATIONS

6.1 Conclusions

Through this research and analysis described above, the following conclusions are obtained:

During the study period, the overall level of water system management and socio-economic development in Xi'an was positive. Among them, the water system management has achieved a slight fluctuation growth, and the development coefficient has increased from 0.244 to 0.686. The social economy has continued to grow steadily year by year, and the development coefficient has increased from 0.153 to 0.693.

During the study period, the CCD of two systems in Xi'an increased from 0.440 to 0.830, and the overall trend is approximate "W" type. The coupling coordination state has developed from the slightly unbalanced development with social economy lagged to favourably balanced development with water system management lagged. It shows that the coordination relationship between the two is constantly improving and enhancing. In the future, we should continue to increase the investment and construction of water conservancy to realize the benign interaction.

During the study period, from the evolution rate of the two systems, the evolution rate of water system management in Xi'an decreased first and then increased, and the social economy increased linearly, and the former (0.026) was less than the latter (0.058), which were positive growth. From the evolution direction, the scissors difference between the two systems first increases and then decreases, showing an inverted "U" shape. It shows that the difference of evolution rate between the two systems is gradually decreasing and developing towards the direction of orderly and coordinated mutual promotion.

6.2 Policy Implications

Based on the above research results, this paper gives the following policy implications:

Firstly, water ecological management should be increased. it is necessary to coordinate the upstream and downstream, the left and right banks of the whole basin, build an organic water system, realize the water systems and banks are governed together, repair biological habitats, and promote the improvement of landscape and water quality. Secondly, the construction of water environment protection mechanism, thus Xi'an on the one hand to improve water environmental monitoring, statistics, water pollution control and monitoring ability; on the other hand, the government should strictly control high water consumption, high pollution projects and groundwater over-exploitation area of new groundwater project approval. Finally, the urban water supply capacity should be improved. people should comprehensively build green water sources, strengthen the construction of water supply facilities, make rational allocation and efficient use of water resources. The harmonious coexistence of water and city will be gradually realized, and Xi'an will be promoted to realize high-quality development guided by ecology first.

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