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Evaluation of the Synergy Degree of Watershed Collaborative Governance: A Case Study of Taihu Basin, China

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Abstract: Owing to the publicity and externality of watershed governance, collaborative governance among cities has become an inevitable choice to improve watershed governance performance and promote sustainable development of watersheds. Existing studies have provided many enlightenment on promoting watershed collaborative governance (WCG), while most of them investigated WCG from single or several dimensions with scanty quantitative empirical studies. Against this background, this study aims to establish a comprehensive WCG research framework involving multiple phases and diverse actors to empirically measure the synergy degree of WCG. Specifically, this study constructs a WCG index system composed of resource investment, open cooperation, and performance supervision subsystems that involves actors of government, enterprise, and the public. Using the complex system synergy model, an empirical analysis is performed to evaluate the synergy degree of Taihu Basin collaborative governance among and within cities in Jiangsu province, China during 2014–2020. The results reveal that the Tai Basin collaborative governance among cities was still in the run-in adaptation stage, which was primarily constrained by the discrete open cooperation subsystems among cities. The synergy degree of Taihu Basin collaborative governance within cities presented significant differences. Several targeted implications are proposed according to the results. This study provides a comprehensive index system for synergy degree measurement of WCG and could offer effective guidance for policymakers to design effective strategies for improving WCG performance.

Keywords: watershed; collaborative governance; complex system synergy model; Taihu Basin

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1. Introduction

Since the 1970s, China has witnessed the rapid development of urbanization and industrialization. However, this intensive and crude development pattern has also caused a dramatic deterioration of the water environment, which has seriously jeopardized sustainable socio-economic development [1,2]. For example, in June 2007, an outbreak of cyanobacteria pollution in Taihu Lake contaminated the tap water throughout WuXi City, Jiangsu Province, China, causing a severe shortage of domestic and drinking water and stimulating chaos across the city. The traditional practice of "pollution first, treatment later" that develops the economy first regardless of the ecological environment has generated enormous pressure on the balance of aquatic ecosystems and resulted in an annual loss of up to RMB 240 billion in social and economy [3–6]. In such context, how to achieve the benign governance of watersheds has become an important proposition that the theoretical and practical circles need to solve urgently.

The natural property of water is fluidity, and this makes both water pollution and water treatment have a strong externality that shows trans-regional and unbounded characteristics [7,8]. Consequently, in practice, some regions may take the free-riding strategy to reduce the input on water environment governance to enjoy the governance results at the cost of other regions. This behavior of free-riding would cause dissatisfaction of governments in other regions and lead them to adopt similar strategies, ultimately degrading the entire water environment and causing the tragedy of the commons [9–12]. Therefore, for those trans-regional public affairs, the traditional territorial governance mode of "independent governance" based on the administration division is powerless. Collaborative governance is accordingly put forward to address the issue of cross-border watershed governance [13,14]. Through the collaboration of local governments on a watershed, collaborative governance can effectively reduce the information gap among local governments and strengthen their will and efforts to treat watersheds [15,16]. In this vein, the complementary advantages of local governments can be leveraged to achieve the synergistic effect of regional governance in the watershed [17–19].

Apart from the collaborative governance among local governments, scholars have also argued that enterprises and the public should also play significant roles in water environment collaborative governance [20,21]. Against the background of increasingly tight financial and management pressures on governments, the traditional governance pattern with the government as the single actor that bears the major governance work and costs is no longer suitable, necessitating the involvement of other actors to lighten the burden on the government and improve governance performance [22]. This is also stressed by the latest watershed governance plan in China, which argued that a multi-actor watershed collaborative governance (WCG) system should be established with "government as the leader, and enterprises and the public as major participants". Specifically, the government takes the leading role by investing resources, making administration decisions, and conducting supervision [20,23]. Enterprises play a crucial role in tackling water pollution and improving the water environment with their advanced and professional technologies [24,25]. Public participation in environmental governance could contribute to the supervision of environmental pollution behavior and government inaction, especially under the background of the development of communication technology and the improvement of public environment awareness [26–28]. Compared with the traditional governance pattern with the government as the single actor, the WCG pattern could give full play to the advantages of multiple actors in multiple regions, thus achieving the synergistic effect that the overall effect could be larger than the sum of its parts.

However, collaborative governance will not be realized automatically; rather, it requires a set of institutional arrangements that coordinate the diverse interests and needs of stakeholders [29,30]. To this end, many scholars have conducted a lot of research on institutional arrangements to promote collaborative governance performance. For example, Emerson et al. [31] proposed a collaborative governance conceptual framework composed of individual incentives, obstacles to cooperative behavior, collaborative social learning, and conflict resolution for cross-border collaboration. Based on 25 semi-structured interviews with information providers in government, non-government, industry, and academia, Lindamood et al. [32] suggested that water sector actors in Dhaka needed more clear and independent jurisdictional claims and mandates to strengthen collaborative capacity. Pi et al. [33] established a dynamic game model about cross-regional environmental governance and claimed that the welfare of developing areas would be reduced while that of developed areas would be increased. Thus, more compensation should be given to developing areas to encourage them to join in collaborative governance. Moreover, clear responsibilities, performance supervision, open coordination mechanism, as well as sufficient information sharing are also emphasized by scholars as key to reducing the free-riding behavior and coordinating the interest competition between governments, thus improving collaborative governance performance [34–37].

In summary, the previous studies have provided many important insights on facilitating WCG, while there still remain several gaps to be bridged. First, through existing studies, it could be recognized that the WCG is a complicated system involving multiple phases and diverse actors, but most studies tend to investigate WCG from one or several dimensions, lacking a comprehensive research perspective. Second, most existing studies employed a quantitative research methodology, such as factual description and theoretical analysis, with scanty quantitative studies to empirically measure the specific synergy degree of WCG, that is to what degree the multiple actors in watershed-relevant regions put concerted efforts into water environment governance. This is not conducive to extracting the potential problems of WCG and providing precise guidance for policymakers to improve WCG performance. Finally, in terms of the research scope, the national and regional scopes are the most common. Deeper studies on cross-border collaborative governance of specific watersheds are needed.

Against this background, this study aims to evaluate the synergy degree of WCG based on a relatively comprehensive research framework involving multiple phases and diverse actors. To achieve this, this study first constructs a WCG index system from the perspective of multiple phases of WCG (including resource investment, open cooperation, and performance supervision) that involves diverse actors (including government, enterprise, and the public). Second, using the complex system synergy model, this study undertakes an empirical analysis of the synergy degree of collaborative governance of Taihu Basin in Jiangsu Province, China during the period of 2014–2020. Finally, based on the empirical results, this study puts forward corresponding suggestions for facilitating WCG performance. The contributions of this research are as follows. In terms of theory, it enriches WCG literature by providing a comprehensive analytical framework and an empirical analysis of WCG synergy degree based on the complex system synergy theory and model. In terms of practice, the empirical conclusions and corresponding suggestions could offer policymakers targeted guidance to discern deficiencies in existing WCG and design corresponding strategies to improve WCG performance, thus promoting sustainable development of watersheds.

2. Study Area

The Taihu Basin covers the core area of the Yangtze River Delta with a total area of 36,900 km^2. It has always been one of the regions with the largest population density, developed industrial and agricultural production, and the fastest growth in national economic output value and per capita income in China. Nine lakes with an area of more than 10 km^2 are contained in the Taihu Basin, namely Taihu Lake, Yangchenghu Lake, Taihu Lake, Dianshanhu Lake, Chenghu Lake, Kunchenghu Lake, Yuandang, and Dushuhu Lake. The plains are the primary topography of the Taihu basin, accounting for 4/6 of the total area, the water surface for 1/6, and the hills and mountains for 1/6 of the area. The terrain is characterized by a high perimeter and low center, with the whole area forming a disc. Taihu Basin has a subtropical monsoon climate with high temperatures and rainy summers and mild winters. The average annual temperature of the basin is 15–17 °C, increasing from north to south. The average annual rainfall is 1181 mm, with 60% of it concentrated between May and September.

In May 2007, the sudden outbreak of cyanobacteria in Taihu Lake polluted tap water throughout WuXi City in Jiangsu Province, causing severe shortages of domestic and drinking water. The provincial government of Jiangsu Province reflected on the pain and put forward a series of WCG schemes for Taihu Basin, which has achieved remarkable results. According to the latest Overall Programme for the Comprehensive Management of the Water Environment in the Taihu Basin, in 2021, the overall water quality of Taihu Lake was assessed as Class IV, an improvement of two water quality categories compared with 2007. A total of 17 of the 22 major rivers entering Taihu Basin were at or better than Class III, an increase of 64 percentage points over 2007. However, there are still problems with the water environment in Taibu Basin, such as excessive pollutants and the frequent occurrence of cyanobacterial blooms, which urgently require further improvement of the WCG in Taihu Basin. Thus, at this juncture, it is necessary to evaluate the synergy degree of WCG in Taihu Basin, which could not only help accurately identify the deficiencies and key points for improvement of WCG of Taihu Basin, but also offer a reference for WCG of other watersheds. Therefore, this paper selected Taihu Basin in Jiangsu Province as the research object.

According to the Implementation Plan of Comprehensive Treatment of Water Environment in Taihu Basin of Jiangsu Province, Nanjing, Wuxi, Changzhou, Suzhou, and Zhenjiang are the main cities responsible for the treatment of Taihu Basin. Hence, in this study, the WCG system in the spatial dimension is divided into five local unit subsystems of Nanjing, Suzhou, Wuxi, Changzhou, and Zhenjiang. The sites of these cities and Taihu Basin can be seen in Figure 1.

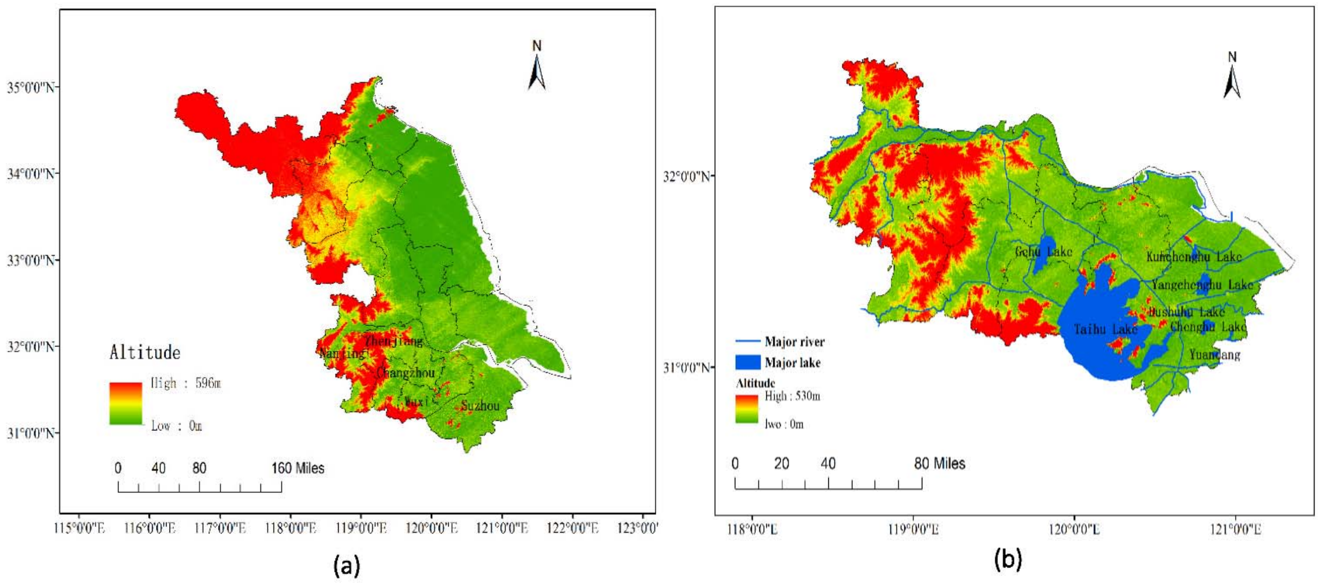

Figure 1. Locations of the research area: (**a**) locations of the five cities in Jiangsu Province; (**b**) locations of the major rivers and major lakes of Taihu Basin in the five cities.

3. Methodology and Data

The goal of this study is to measure the synergy degree of WCG of Taihu Basin based on a comprehensive research framework involving multiple phases and diverse actors. The specific procedures are illustrated in Figure 2. First, the complex system synergy theory and literature review are used to develop the evolution model of the WCG and determine the evaluation index system of WCG. Second, the complex system complex model is applied to calculate the order degrees of WCG subsystems and then the synergy degree of the WCG system. Third, since WCG requires not only the synergy of subsystems among cities, but also the synergy among subsystems within each city, the calculation results of WCG systems among cities and within cities are both analyzed to discern the progress and deficiencies of WCG in Taihu Basin over the study period. Based on the result analysis, targeted improvement suggestions are proposed.

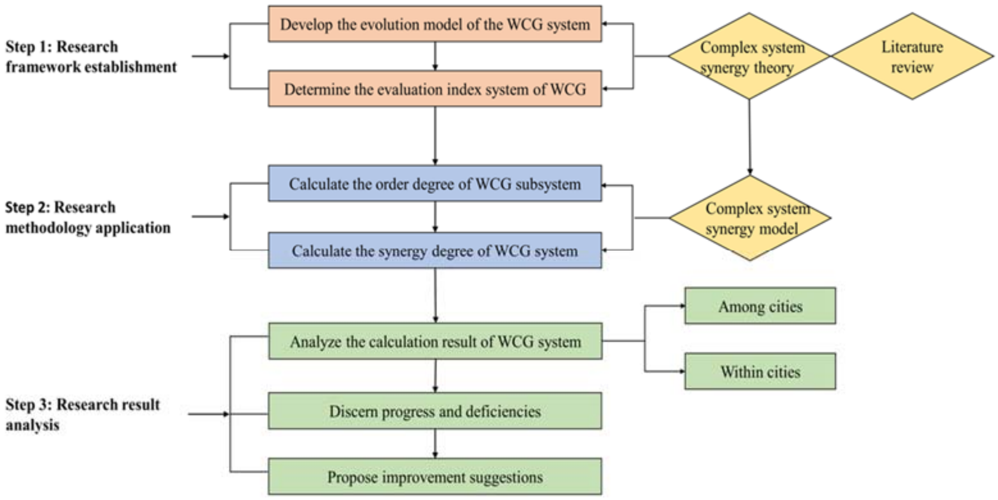

Figure 2. The procedures of the proposed methodology.

3.1. Research Framework

The WCG is a typical complex system, which is composed of several subsystems that interact and influence each other. Based on the complex system synergy theory and relevant literature [31,38,39], this study argues that the WCG system consists of three subsystems from the perspective of governance phase including resource investment subsystem, open cooperation subsystem, and performance supervision subsystem. Furthermore, a corresponding index system that represents the efforts that multiple actors need to put into WCG is built under the principle of data availability and representativeness.

According to complex system synergy theory, a system usually requires resource investment to enable and maintain its functioning, and so does the WCG system [40]. Resource investment is essential to start watershed governance work, which usually includes capital input and manpower input [11]. Since we can only obtain government data, it mainly represents the effort of local government in the resource investment phase of WCG. Nevertheless, this is also consistent with the actual practice that the local government bears the major funds and manpower as the leader in the WCG. Thus, this study selects the number of funds invested in Taihu Basin governance and the number of personnel engaged in water environment management to measure the efforts that local governments put into the resource input phase.

During the process of system operation, the system should keep open to continuously exchanging information, matter, and energy with other systems, thus promoting the concerted evolution and development of the whole system [41]. In terms of the WCG system, it is necessary for governments to build an open and unified administration mechanism, so that relevant governments could reach an agreement on watershed management decisions and form a good cooperative relationship [42]. Specially, local governments need to establish an information disclosure mechanism to share environmental information with other actors, thus making consensus decisions on watershed governance [36]. In addition, the establishment of the administrative departments and the issuance of relevant regulations are of great importance to the guidance of watershed governance work [20,43]. Accordingly, three indicators are used in this study to measure the efforts of local governments in the open cooperation phase, including the number of pieces of information voluntarily disclosed on the official website, the number of environmental management departments, and the number of policies and regulations issued about environmental protection.

The performance supervision mechanism is the foundation which ensures the effective operation of the system [44,45]. Hence, it is necessary to supervise the performance of multiple actors in deterring water environment pollution and protecting the water environment. In terms of governments, they could detect, stop and penalize environmental violations [46]. Enterprises could actively use their advanced and professional technologies to tackle water pollution and improve the water environment [24,47]. As the direct victims of environmental pollution, the public could quickly discover behavior detrimental to the environment and report them to relevant regulatory authorities, thus deterring and treating water pollution in a timely manner [23]. Thereby, actors' efforts in the performance supervision phase are evaluated by the number of environmental violations dealt with, the sewage treatment rate, and the number of environmental letters and visits received from the public.

In this way, the WCG system is accordingly established. Based on the complex system synergy theory, initially, the WCG system would be in a disordered non-equilibrium state. Nevertheless, the collision and running-in among subsystems would make them gradually evolve towards an orderly direction. During this process, not only do the subsystems of different cities interact with each other to achieve common evolution, but also the internal subsystems of each city form an orderly synergistic relationship. When a certain threshold is exceeded, the whole system would be in a self-organized state and gradually reach a dynamic equilibrium state, thus improving the performance of the WCG system [48]. The evolution model of the WCG system and corresponding index system are shown in Figure 3 and Table 1, respectively.

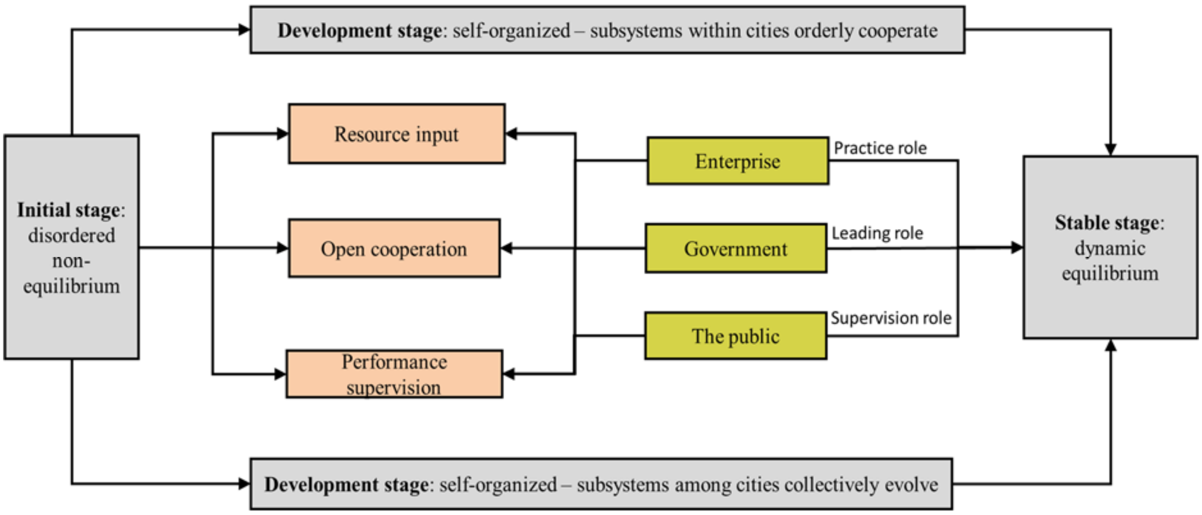

Figure 3. Evolution model of the WCG system.

Table 1. Evaluation index system of WCG.

Subsystems	Order Parameters	Specific Indicators	Unit
Resource investment subsystem	Personnel investment	Number of personnel engaged in water environment management	One
	Capital investment	Number of funds invested in Taihu Basin governance	10,000 yuan
Open cooperation subsystem	Information disclosure	Number of pieces of information voluntarily disclosed on the official website	One
	Organization arrangement	Number of environmental management departments	One
	Governance rules	Number of policies and regulations issued about environmental protection	One
Performance supervision subsystem	Water quality supervision	Sewage treatment rate	Percentage
	Supervision of illegal behavior	Number of environmental violations dealt with	One
	Public supervision	Number of environmental letters and visits received from the public	One

3.2. Research Methodology

The complex system synergy model based on order parameters is applied in this study to measure the synergy degree of the WCG system of Taihu Basin in Jiangsu Province [48,49]. The steps of establishing the model are as follows.

First, we standardize the original data. The indicators can be divided into two types: positive and negative indicators. The larger the value of the positive indicator, the greater the contribution of the indicator to the orderly evolution of the system. The negative indicator is the opposite. Thus, standardized Formulas (1) and (2) are used to remove the effect of positive and negative orientation as well as dimensionality.

$$u_{ij} = \frac{e_{ij} - \beta_{ij}}{\alpha_{ij} - \beta_{ij}}, e_{ij} \text{ is the positive indicator} \tag{1}$$

$$u_{ij} = \frac{\alpha_{ij} - e_{ij}}{\alpha_{ij} - \beta_{ij}}, e_{ij} \text{ is the negative indicator} \tag{2}$$

where, α_{ij} and β_{ij} are the upper limit and lower limit of the ith indicator of the jth subsystem, respectively.

Then, the entropy weight method is adopted to calculate the weight of each indicator, which is an objective weight assignment method driven by data information. The calculation step is as follows.

Calculate the proportion of indicator j in year i:

$$p_{ij} = \frac{u_{ij}}{\sum_{i=1}^{m} u_{ij}} \tag{3}$$

Calculate the entropy of index information:

$$E_j = -\frac{1}{ln\ m} \sum_{i=1}^{m} p_{ij}\ ln p_{ij} \tag{4}$$

Calculate the information entropy redundancy:

$$D_j = 1 - E_j \tag{5}$$

Calculate the weight of each indicator:

$$W_j = \frac{D_j}{\sum_{j=1}^{n} D_j} \tag{6}$$

Next, the order degree S_{ik} of each subsystem is calculated by the linear weighted summation method.

$$S_{ik} = \sum \omega_j\ u_{ij} \tag{7}$$

The greater the order degree of the subsystem, the higher the development level of the subsystem and the higher the contribution of the subsystem to the orderly evolution of the whole system; otherwise, the smaller the contribution is.

Next, according to the complex system synergy theory, the measurement of the synergy degree of a complex system is established from the perspective of the coupling degree of interaction among subsystems, which can be calculated as follows:

$$\text{CI} = 1 - \frac{\sigma}{\mu} = 1 - \frac{\sqrt{\frac{1}{n}\sum (S_{ik} - \mu)^2}}{\mu} \tag{8}$$

where μ is the mathematical expectation of subsystem order degree, and σ is the standard deviation. CI represents the matching degree of subsystem order degree. When CI < 0, the whole system is highly variable, and the order degree of each subsystem is highly discrete, indicating the low coordination degree of subsystems. When CI > 0, the variation of the whole system is weak, and the dispersion degree of subsystems decreases with the increase in CI, while the coordination degree increases.

Finally, the synergy degree of the whole system can be calculated as follows:

$$\mathrm{SY} = \mathrm{CI} \times \sqrt[n]{\prod_{k=1}^{n} S_k} \tag{9}$$

when SY > 0, subsystems are in a synergistic stage of mutual promotion. The closer SY is to 1, the more ordered the interaction among subsystems is, the higher the synergy degree of the overall system is, and the higher the WCG performance is. When SY $\leq$ 0, the interaction among subsystems is disordered and confrontational, leading to a low WCG performance as shown in Table 2.

Table 2. Division of system synergistic development stage.

Development Stage	Synergy Degree	Synergy Level
Disordered antagonism stage	$\leq$0	Not synergistic
Run-in adaptation stage	0~0.49	Mildly synergistic
Self-organized stage	0.5~0.79	Moderately synergistic
Dynamic equilibrium stage	0.8~1	Highly synergistic

3.3. Data Source

The data used by this study is sourced from the Jiangsu Statistical Yearbook, statistical yearbooks of relevant cities, and information materials posted on the website of the Environmental Protection Agency of relevant cities, including the annual information disclosure report and environmental protection status bulletin. Furthermore, since relevant data is not complete until 2014, the research period of this paper starts from 2014 to 2020.

4. Results

4.1. Analysis of Synergy Degree of the WCG System of Taihu Basin among Cities

Figure 4 shows the synergy degree of collaborative governance of Taihu Basin among cities from 2014 to 2020. It showed that the synergy degree presented an "M-shaped" form. The value of the synergy degree was small and fluctuated between 0.1–0.45, indicating that the WCG system in Taihu Basin was in the run-in adaptation stage, and the synergy level was low. The interaction between multiple actors in the five cities remained confusing, the cooperative relationship was not stable, and there is a large room for improvement. This is also in line with previous studies [50]. Due to the conflict between the externality of watershed governance and the division of administrative areas, WCG among different administrative regions has always been a thorny problem.

To further reveal the deep reason for the low synergy degree of WCG among the five cities, we further comparatively analyze the order degrees of WCG subsystems among the five cities from 2014 to 2020 (see Figures 5–7).

The order degrees of the resource investment subsystems in the five cities showed a trend of gradual convergence after a period of fluctuation and the gap among cities has been significantly reduced, indicating the good synergy in the resource investment subsystems among cities. Nevertheless, the consistent declining trend of resource investment subsystems is also worth noting. Particularly, the order degree of resource investment in Nanjing and Zhenjiang dropped to or close to zero in 2020. This phenomenon may be attributed to the fiscal decentralization system and performance appraisal system for local governments. Under the current fiscal decentralization system in China, local governments mainly rely on their financial revenue for resource investment in watershed governance [51]. However, the slowing local economic growth has made it difficult for local governments to increase their investment in watershed governance. Moreover, under the performance assessment system where GDP is the core, local governments may be more inclined to invest resources in economic growth that can bring political achievements and take free-riding behavior in environmental governance to avoid the environmental pollution control costs [52], thus resulting in the declining order degrees of resource investment subsystems.

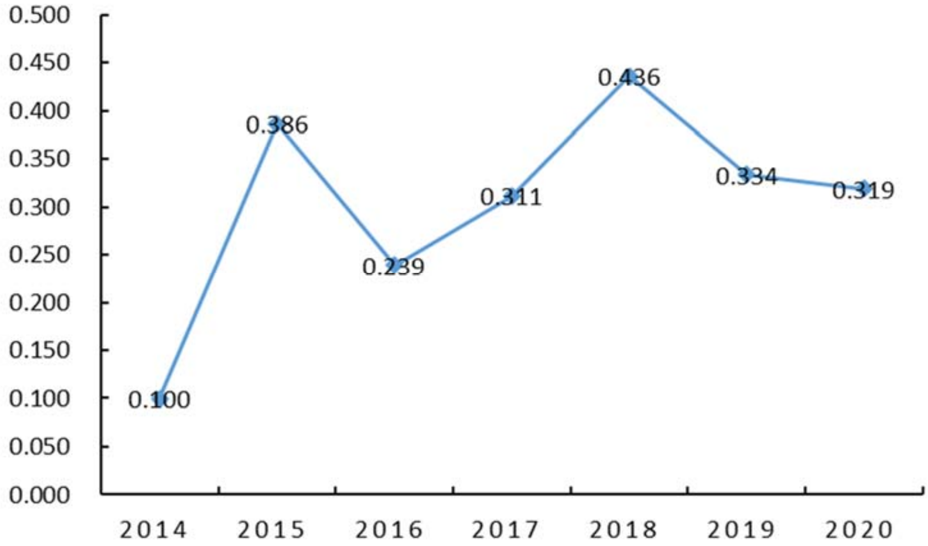

Figure 4. The synergy degree of the WCG system of Taihu Basin among cities during 2014–2020.

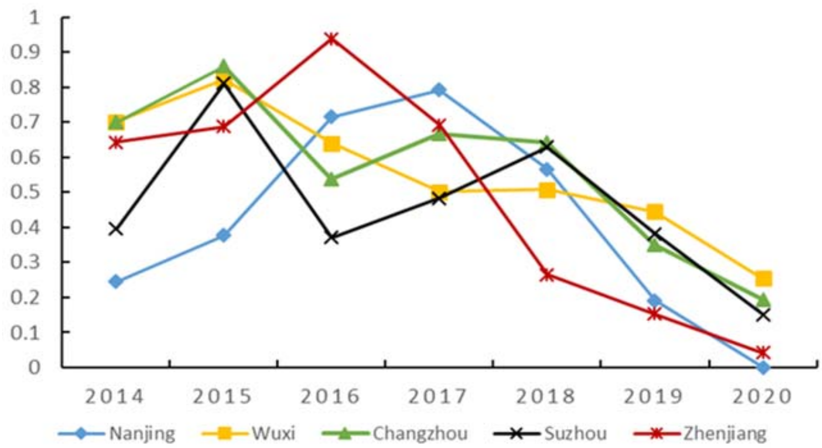

Figure 5. The order degrees of resource input subsystems of Taihu Basin among cities during 2014–2020.

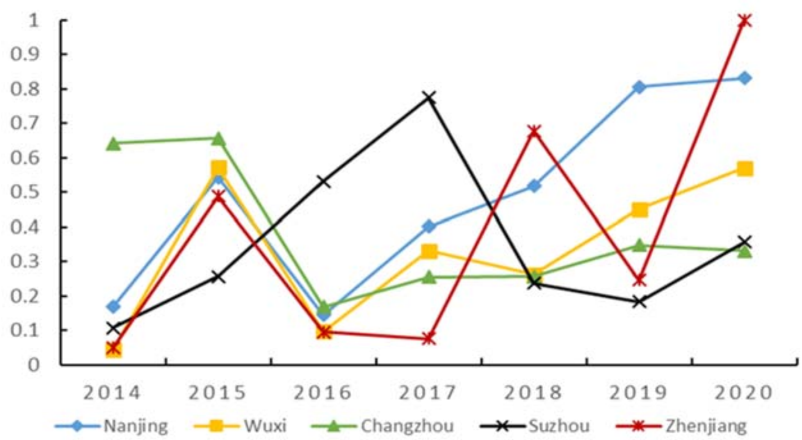

Figure 6. The order degrees of open cooperation subsystems of Taihu Basin among cities during 2014–2020.

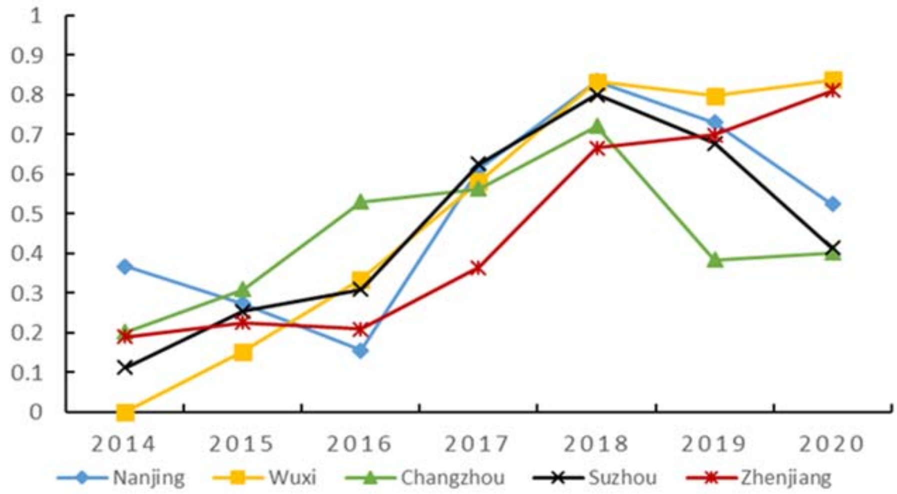

Figure 7. The order degrees of performance supervision subsystems of Taihu Basin among cities during 2014–2020.

As for the open cooperation subsystem, the order degrees of these cities have always been dispersed over the study period and the gap among cities was still large. Despite this, the order degrees of open cooperation subsystem of these cities mostly showed a rising trend after 2017. This may be explained by the implementation of the river chief system in Jiangsu province in 2017. In 2017, the General Office of the CPC Jiangsu Provincial Committee and the General Office of the Government jointly issued the Implementation Opinions on the Comprehensive Implementation of the River Chief System in Jiangsu Province. It clarified the responsibilities of government departments at all levels for river basin protection and management and required the implementation of information sharing and regular coordination and consultation among local governments. This greatly promoted the development of open cooperation subsystems of relevant cities, while the coordination among them still needs much attention to be strengthened [53–55].

The order degrees of performance supervision subsystems of these cities showed a convergent trend initially followed by a tendency to disperse in recent years. All of the cities achieved remarkable progress in the performance supervision subsystem over the study period. This indicates that the five cities attached more importance to performance supervision than to resource investment and open cooperation. Both the central government and the public are related to this phenomenon. On the one hand, the central government's repeated emphasis on the ecological environment has boosted local governments' and enterprises' efforts to strictly deter and reduce environmental pollution [56]. On the other hand, the enhancement of citizens' awareness of environmental protection also makes public participation play an increasingly important role in environmental governance [27].

On the whole, the low synergy degree of the WCG system of Taihu Basin was primarily caused by the discrete open cooperation subsystems among cities, which requires more attention to coordinate, and the coordination among performance supervision subsystems also needs to be further strengthened. Moreover, the low order degree of resource investment subsystem of the five cities should also be noted and improved.

4.2. Analysis of Synergy Degrees of WCG Systems of Taihu Basin within Cities

The synergy degrees of WCG within each city during 2014–2020 are shown in Figure 8. It emerges that different cities presented significant differences in the synergy degree of WCG. Only Wuxi showed a growth trend. However, the growth was fluctuating, and the synergy degree of WCG in WuXi was only 0.282 by 2020, still in the stage of run-in adaptation. Nanjing, Suzhou and Zhenjiang showed a trend of increasing at first and then decreasing. Among them, the synergy degree of WCG in Nanjing dropped to 0 in 2020, while that of Suzhou and Zhenjiang is only 0.179 and 0.106, respectively. Changzhou showed a relatively gentle trend of fluctuations, and the synergy degree of WCG was 0.213 in 2020.

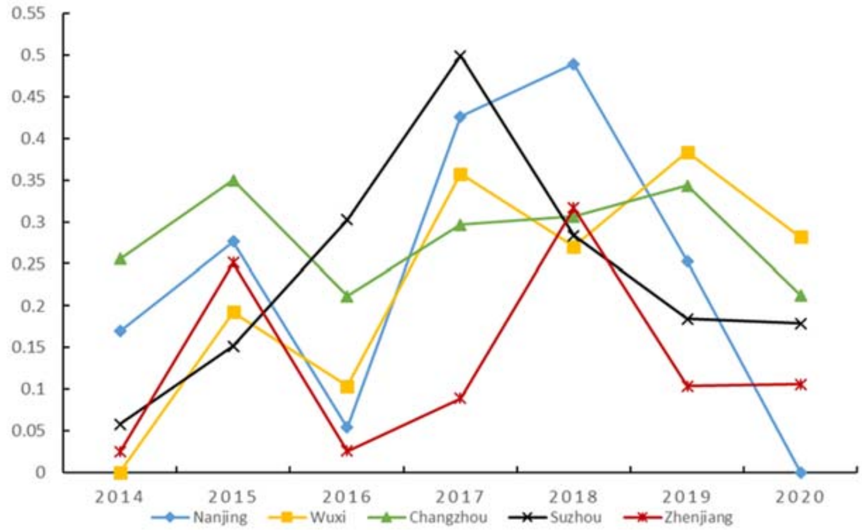

Figure 8. The synergy degrees of WCG systems within cities during 2014–2020.

On the whole, the synergy degree of WCG of the five cities was mostly positive during 2014–2020, indicating that the five cities were all in a state of synergy development. Nevertheless, the level of synergy development was less than 0.3 and in the run-in adaptation stage, indicating that the subsystems of resource investment, open cooperation, and performance supervision within the five cities have not yet formed a benign interaction, and the development of those subsystems was unbalanced. Further actions should be taken to promote synergistic development among subsystems within the five cities.

Similarly, to reveal the deep reason for the low synergy degrees of WCG systems within the five cities, we further comparatively analyze the order degrees of WCG subsystems of the five cities from 2014 to 2020 (see Figure 9). It can be seen that the development of open cooperation and performance supervision subsystems in Nanjing, Suzhou, and Zhenjiang showed a fluctuating upward trend, while the resource investment subsystems began to decline in recent years and fell to the bottom in 2020. This indicates that Nanjing, Suzhou, and Zhenjiang should focus on raising resource investment to facilitate the synergy degrees of their WCG systems. The performance supervision subsystems in Wuxi and Changzhou showed an upward trend, but the development of the resource investments and open cooperation subsystems did not keep pace with the performance supervision subsystems, and this requires more attention.

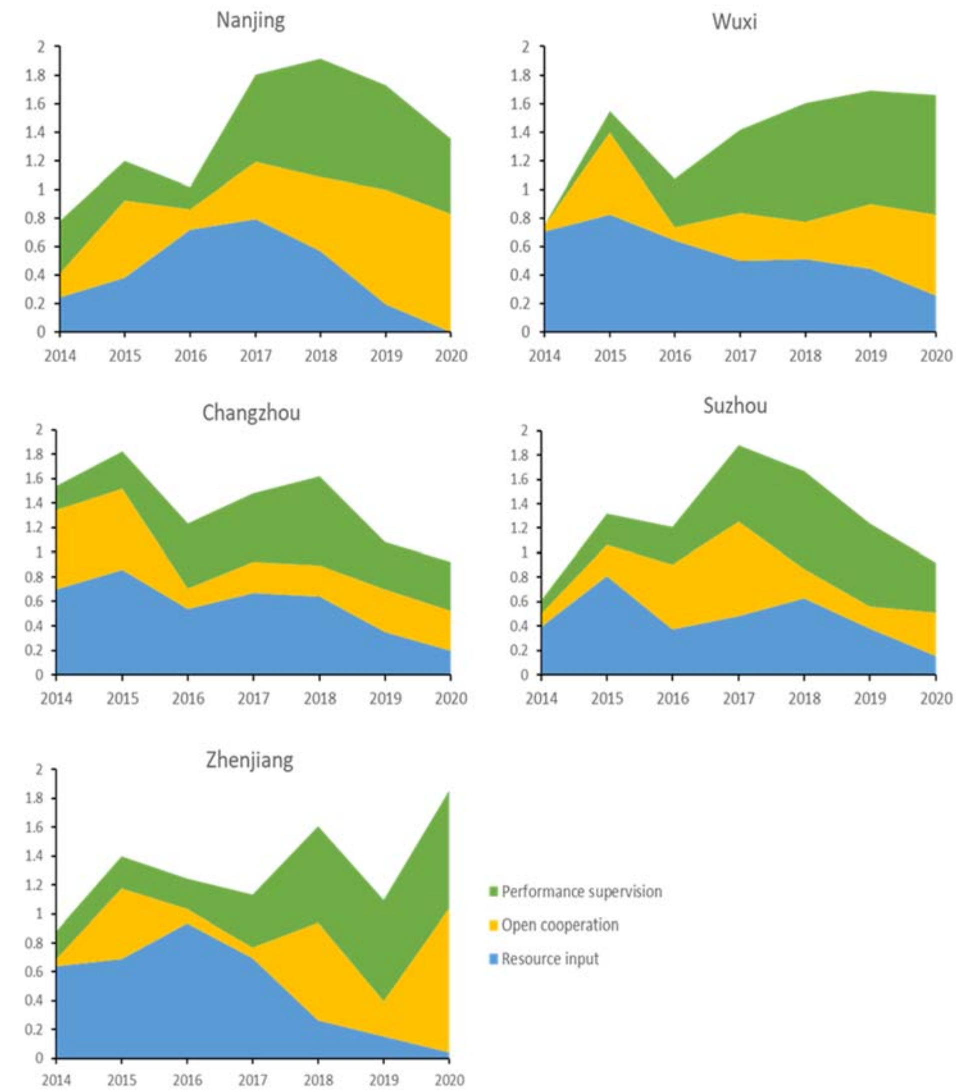

Figure 9. The order degrees of WCG subsystems within cities during 2014–2020.

5. Conclusions

5.1. Research Findings

Based on the complex system synergy theory, this study constructed a WCG index system composed of resource investment, open cooperation and performance supervision subsystems that involved government, enterprise, and the public. Through the complex system synergy model, an empirical study was conducted to investigate the synergy degree and evolution law of the WCG system of Taihu Basin among and within five cities in Jiangsu province from 2014 to 2020. The major findings are as follows:

(1) The synergy degree of the WCG system of Taihu Basin among cities showed a fluctuating upward trend during 2014–2020, but the synergy degree was small and lower than 0.45. This indicates that the collaborative governance of Taihu Basin was still in the run-in adaptation stage, the interaction among the five cities remains chaotic, and their cooperative relationship was not stable. Further analysis of subsystem order degrees shows that the low synergy degree was primarily caused by the discrete open cooperation subsystems among cities. All of the performance supervision subsystems achieved remarkable growth over the study period, but the coordination among them needs to be further strengthened. Although resource investment subsystems realized a great synergy, their consistent downward trend is not negligible and needs to be improved;

(2) The synergy degree of the WCG system of Taihu Basin within cities presents significant differences over the study period. Wuxi showed a rising trend with fluctuations.

Nanjing, Suzhou and Zhenjiang showed a trend of initially increasing and then decreasing. Changzhou showed a relatively gentle trend of fluctuations. Overall, all the five cities were also in the run-in adaptation stage with synergy degrees of lower than 0.3, and the three subsystems within them have not yet formed a benign interaction. The decline of resource investment subsystems in Nanjing, Suzhou, and Zhenjiang, and the backward development of the resource investment and open cooperation subsystems in Wuxi and Changzhou are the main reasons for the low synergy degree of WCG within the five cities.

5.2. Suggestions

According to the above research findings, we propose the following suggestions to improve the synergy degree of WCG of Taihu Basin in Jiangsu Province.

For Jiangsu Provincial Government, the most important thing is to improve the resource investment of local governments in WCG and strengthen the coordination of open cooperation subsystems among local governments. On one hand, a sound assessment, accountability, and incentive mechanism for watershed governance can be established to encourage local governments to increase resource investment in watershed governance and reduce free-riding behavior. On the other hand, market mechanisms can be considered to encourage local governments to actively introduce social capital to participate in watershed governance and long-term management, thus establishing a cost-sharing and benefit-sharing WCG governance pattern. In terms of the open cooperation subsystem, it is advisable to build a unified information platform and share the water quality monitoring information among local governments, thus facilitating information communication among local governments and division of rights and responsibilities when cross-border water pollution occurs. Moreover, a joint meeting system can be established to regularly convene local governments to discuss and make decisions on issues in water environment governance, in order to strengthen cooperative relationships among local governments. Finally, although all the five cities have achieved growth in performance supervision, it is still necessary to strengthen performance supervision coordination through methods such as setting unified monitoring and evaluation standards to consolidate and promote governance performance.

For local governments, different measures should be taken to improve the coordination of internal subsystems. Since the decline of the resource investment subsystem was the major cause of the low synergy degree of the WCG system within Nanjing, Suzhou, and Zhenjiang, these cities should pay more attention to increasing the resource investment in ways such as striving to secure funds from the central budget for watershed governance and designing innovative investment and financing models to leverage social capital to invest in water environment governance. In terms of Wuxi and Changzhou, the synergy degree of the WCG system within them is primarily constrained by the lagging development of both resource investment subsystem and open cooperation subsystem. Therefore, in addition to increasing resource input, they should also enhance the construction of administrative departments and information disclosure mechanisms and improve the formulation of laws and regulations about environmental protection to advance the progress of the open cooperation subsystem.

5.3. Limitations

Although this study provided a theoretical framework for measuring the synergy degree of the WCG system and revealed meaningful findings and conclusions by conducting an empirical study on Taihu Basin, it has limitations that could indicate directions for future research. One limitation is that this empirical study was tested in a specific setting, and the results may not be easily generalized. Future studies could revise and extend the framework to other countries and further take a comparative approach between different countries, which may provide interesting and beneficial implications. Furthermore, the issue of data availability limited our study to inter-provincial collaborative governance. Research on collaborative governance across provinces may obtain new and meaningful discoveries. Another limitation is that the indicators selected in this study may not fully represent the performance of subsystems, which could be further supplemented in future studies to more comprehensively measure the development of subsystems and the performance of the whole WCG system.

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