Research on Water Resources-social Economy-ecosystem Coupling System based on Improved Ant Colony Algorithm

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Keyword: Water resources, Social economy, Ecosystem, Ant colony algorithm, Symbiosis, Security status

Abstract: Based on the ant colony algorithm, using the Lotka-Volterra symbiosis model and taking Guangzhou, Shenzhen, Zhuhai, Shantou, Dongguan, Zhongshan, Zhaoqing, Foshan and Yangjiang as the research objects, research on the coupling relationship of water resource, social economy and ecosystem system from 2005 to 2019 was carried out. The basic index, comprehensive index and security status of water resources were calculated. The symbiotic relationship between water resources, social economy, and ecological environment was analyzed quantitatively. It is of great significance to the realization of full utilization of water resources and sustainable development.

1 INTRODUCTION

The social-ecological-water resources system includes all aspects of human activities. The purpose of studying the coupling development of the system is to understand the interaction mechanism between the systems, calculate the exchange flux within the system, and provide ideas and methods for guiding the coordinated and efficient development of the entire system. Compared with traditional linear and non-linear programming algorithms, ant colony algorithm in studying coupled systems has many advantages. The idea of the algorithm is simple, and it is not restricted by the differentiability, differentiability, and continuity required by the planning problem. Since the algorithm starts from a set of schemes, it expands the scope of search and optimization, and reduces the risk of a large gap between the local optimal solution and the global optimal solution generated by the traditional linear optimization method. Thus, the relationship between the various elements is coordinated, and the unity of economic, social and environmental is realized by applying the ant colony algorithm to the water environment system.

Research on water rights allocation, optimization models, water shortage risk assessment, and optimal allocation of water resources have been carried out (Chen et al., 2015; He, 2014; Hou & Wu, 2015; Liu et al., 2020; Wang et al., 2014; Xie et al., 2013; Zhao et al., 2017). However, the ant colony algorithm also had the following shortcomings: (1) It requires a longer search time. (2) It is prone to stagnation, which is not conducive to finding a better solution. Therefore, it is necessary to improve the state transition probability of the basic ant colony algorithm, and build a new ant colony algorithm suitable for the coupled system of water resources-social economy-ecosystem based on actual problem requirements.

Based on the ant colony algorithm, the basic index, comprehensive index, safety index and carrying capacity of the nine major cities in Guangdong Province was calculated by using the Lotka-Volterra symbiosis model. Then the coupling relationship between water resources, social economy and ecological environment was analyzed.

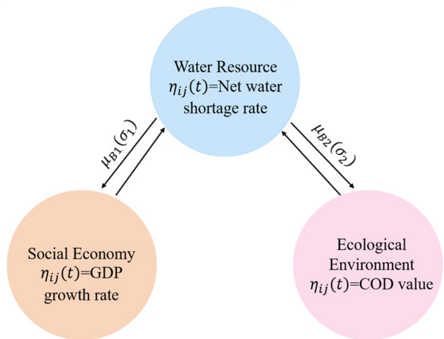

Figure 1: Improved ant colony algorithm feedback relationship diagram.

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2 IMPROVED ANT COLONY ALGORITHM

Based on the basic ant colony algorithm, the state transition probability of the traditional ant colony algorithm is improved, introducing into the coordination degree between water resource utilization and economic development $\mu_{B1}(\sigma_1)$ as well as the coordination degree between water environment quality improvement and economic development $\mu_{B2}(\sigma_2)$. By establishing the coupling relationship between water resources and social economy, water resources and ecological environment, mutual feedback was used to promote the rapid convergence of the algorithm in the early stage. The specific feedback relationship is shown in Figure 1. The state transition probability control equation of the improved ant colony algorithm is as follows:

$$P_{ij}^{k}(t) = \begin{cases} \frac{[\tau_{ij}(t)]^{\alpha}\cdot[\eta_{ij}(t)]^{\beta}}{\sum_{j\in al}[\tau_{ij}(t)]^{\alpha}\cdot[\eta_{ij}(t)]^{\beta}}\left(\frac{\mu_{B1}(\sigma_1)}{\mu_{B1}(\sigma_1)+\mu_{B2}(\sigma_2)}\right)^{\gamma}, j\in al \\ 0, j\notin al \end{cases} \tag{1}$$

Among them, al_k was the node of the next step that k ants were allowed to choose. α and β were the pheromone accumulated by the ant during the movement and the different roles played by the enlightening information in the path selection, $\eta_{ij}(t)$ was the heuristic function.

$$\Delta\tau_{ij}(t) = \mu\cdot\sum_{k=1}^{m}\Delta\tau_{ij}{}^{k}(t) \tag{2}$$

Among them, $\rho(\rho\in(0,1))$ was the pheromone volatilization coefficient, $1-\rho$ was the pheromone residual factor, $\Delta\tau_{ij}(t)$ was the pheromone increment on the path (i,j) during the cycle, $\Delta\tau_{ij}{}^{k}(t)$ was the pheromone left by the k ant on the path (i, j) in the cycle.

According to the model and ACO data requirements, relevant data was collected, and parameters were set. The water supply, water demand, total water resources, and water consumption were obtained by consulting relevant water resources data in Guangdong Province. The number of ants, L value, maximum iteration number, minimum pheromone intensity, maximum pheromone intensity, minimum global pheromone performance coefficient, optimal value, minimum threshold and other calculation parameters were chosen based on the calibration situation of Guangdong water resources model, as shown in Table 1. The actual data in Table 1 were 2005 data values, taken from the Guangdong Statistical Yearbook. In this study, the ants took pixels as the configuration object, which had nothing to do with the length of the route.

Table 1: Actual and calculated parameters.

Actual data			**Calculation parameters**	
Parameters		**Value (billion m^3)**	**Parameters**	**Value**
Water supply		0.846	Number of ants M	100
Water demand		0.712	L	50
Total water resources		0.698	Maximum number of iterations	500
Water consumption	Life	0.378	Initial pheromone concentration	80
	Production	0.459	Heuristic α	0.1
	Ecology	0.237	β	15
	Industry	0.412	Minimum global pheromone performance coefficient	100
Surface water		0.311	μ	30
Rainwater		0.279	Minimum threshold	0.005

3 RESULTS AND DISCUSSION

Figure 2 shows the comprehensive level value of water resources, social economy and ecological environment in Guangdong Province from 2005 to 2019. The basic water resources index ranged from 0.115 to 0.25 between 2005 and 2019. The fluctuation range is small, and the trend is not significant, which indicates that the driving force from the social and economic external environment is weak. Therefore, to encourage rapid economic development, a number of stimulus policies to improve the utilization of water resources in the social economy is necessary. The comprehensive level of ecological environment shows large M-shaped fluctuations, with fluctuations ranging from 0.23-0.49, which indicating that the protection of the ecological environment is very important and has a great impact on water resources. Therefore, it is necessary to take effective measures to ensure the balanced development of the ecological environment and water resources in Guangdong Province. Between 2017 and 2019, the basic index of water resources had declined to a certain extent. Small decline shows that the state of water resources in Guangdong Province is not good. The substantial improvement in living standards resulted in fast consumption of water resources. At the same time, the decline of the water resource index limited the development of the overall level of the ecological environment.

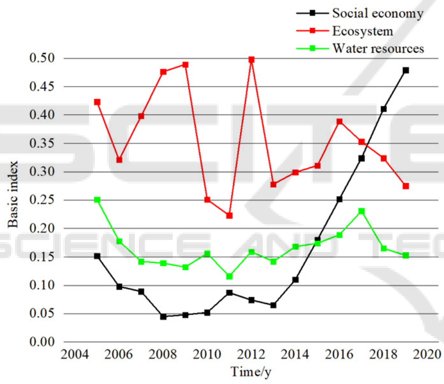

Figure 2: Basic indexes in Guangdong Province.

Figure 3 shows economic capacity index, Ecological environment capacity index, water resource capacity index and symbiosis index of Guangdong Province from 2005 to 2019. The effect of water resources to the social economy from 2011 to 2019 was positive, indicating that water resources played a positive role in promoting social and economic development. The water resource capacity index was only positive during 2013-2016, indicating that the development of water resources is limited by economic development except for 2013-2016. The symbiosis index of water resources, economy and ecological environment was 1.478 and 1.479 in 2013 and 2014, respectively, showing the best symbiosis state. With the passage of time, the symbiosis index has shown a significant decline, indicating that the symbiosis conditions at this time need to be continuously improved. According to the classification of water resources safety standards, the water resources of Guangdong Province from 2005 to 2019 have gradually changed from the initial dangerous state to the vigilant state. The comprehensive level of water resources has increased to a certain extent, but the overall level is still unstable state.

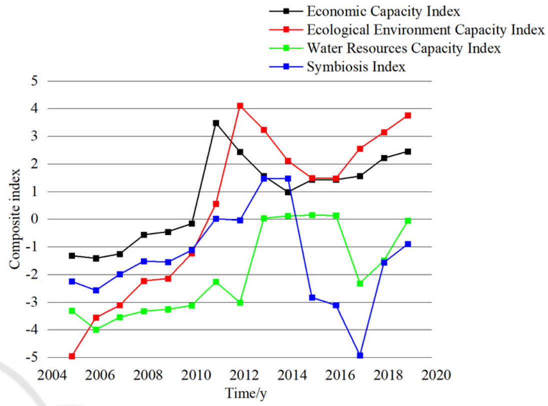

Figure 3: The comprehensive index of Guangdong Province.

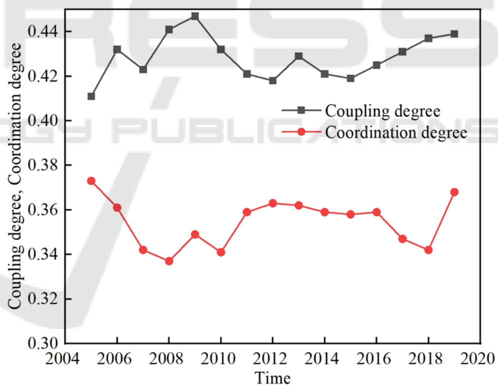

Figure 4: Coupling degree and coordination degree of water resources, economy, and ecological environment in Guangdong Province.

Figure 4 shows the degree of coupling and coordination of water resources, economy and ecological environment in Guangdong Province. The degree of coordination among the water resources, economy and the ecological environment has continued to decline from 2005 to 2009. The degree of coordination was low in 2010 and 2018 while relatively high from 2011 to 2016. In 2010 and 2018, the economic and ecological environment's dependence on water resources was relatively low. However, the economic and ecological environment's dependence on water resources was relatively high from 2011 to 2016. Economic development and the protection of the ecological environment have a relatively large impact on the development of water resources, which is consistent with the status of water resources development in Guangdong Province. The coupling degree was in the M-shaped change from 2009 to 2019. It reached maximum value in 2009 and gradually decreased, and then increased slowly in 2013, and then appeared a downward trend. After 2015, it has shown an upward trend. The coupling degree has decreased significantly from 2009 to 2012, which was due to the economic development and the deterioration of the ecological environment. With the sustainable development of the economy and the restoration of the ecological environment, the coupling of the three has continued to increase. It also shows that with the introduction of national governance policies, the coupling relationship between water resources, economy and ecological environment in Guangdong Province has been significantly improved.

The water resources security status of nine major cities in Guangdong Province from 2005 to 2019 is shown in Figure 5 and Table 2. From 2005 to 2019, the overall water security status of the nine major cities in Guangdong Province has improved significantly, but it is still at a relatively low level.For most cities with a higher level of development, their water resources were basically in a state of vigilance, requiring local governments to adjust water resources, economic and ecological environment.

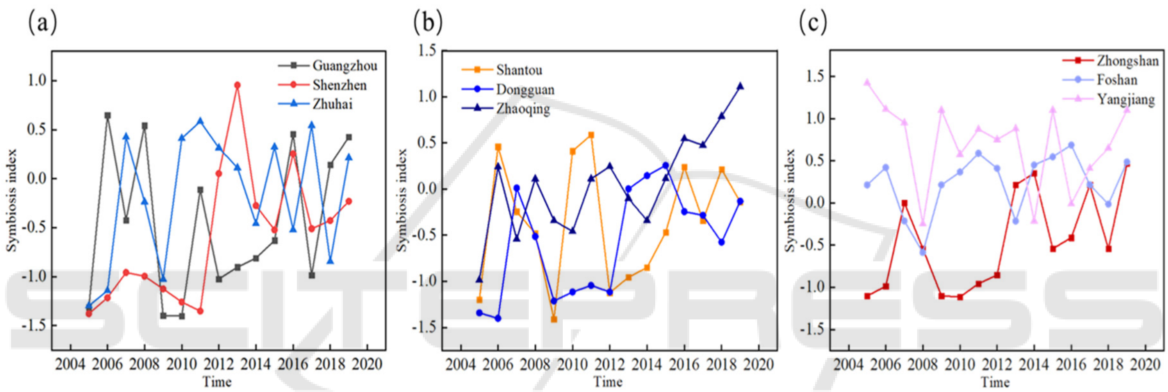

Figure 5: Water resources security status of nine major cities in Guangdong Province.

Table 2: Water resources security status of nine major cities in Guangdong Province.

City	Guangzhou	Shenzhen	Zhuhai	Shantou	Dongguan	Zhaoqing	Zhongshan	Foshan	Yangjiang
2005	Dangerous	Dangerous	Dangerous	Dangerous	Dangerous	Poor	Dangerous	Vigilant	safe
2006	Vigilant	Dangerous	Dangerous	Vigilant	Dangerous	Vigilant	Poor	Vigilant	safe
2007	Poor	Poor	Vigilant	Poor	Vigilant	Poor	Vigilant	Poor	Vigilant
2008	Vigilant	Poor	Poor	Poor	Poor	Vigilant	Poor	Poor	Poor
2009	Dangerous	Dangerous	Dangerous	Dangerous	Dangerous	Poor	Dangerous	Vigilant	safe
2010	Dangerous	Dangerous	Vigilant	Vigilant	Dangerous	Poor	Dangerous	Vigilant	Vigilant
2011	Poor	Dangerous	Vigilant	Vigilant	Dangerous	Vigilant	Poor	Vigilant	Vigilant
2012	Dangerous	Vigilant	Vigilant	Dangerous	Dangerous	Vigilant	Poor	Vigilant	Vigilant
2013	Poor	Vigilant	Vigilant	Poor	Vigilant	Poor	Vigilant	Vigilant	Vigilant
2014	Poor	Vigilant	Poor	Poor	Vigilant	Poor	Vigilant	Poor	Poor
2015	Poor	Poor	Vigilant	Poor	Vigilant	Vigilant	Poor	Vigilant	safe
2016	Vigilant	Vigilant	Poor	Vigilant	Poor	Vigilant	Poor	Vigilant	Poor
2017	Poor	Poor	Vigilant	Poor	Poor	Vigilant	Vigilant	Vigilant	Vigilant
2018	Vigilant	Poor	Poor	Poor	Poor	Vigilant	Poor	Poor	Vigilant
2019	Vigilant	Poor	Vigilant	Poor	Sensitive	safe	Vigilant	Vigilant	safe

4 CONCLUSIONS

Based on the ant colony algorithm, using the Lotka-Volterra symbiosis model and taking Guangzhou, Shenzhen, Zhuhai, Shantou, Dongguan, Zhongshan, Zhaoqing, Foshan and Yangjiang as the research objects, research on the coupling relationship of water resource, social economy and ecosystem system from 2005 to 2019 was carried out. It showed the best symbiosis state in 2013 and 2014, whose symbiosis index were 1.478 and 1.479, respectively. The overall water security status of nine major cities in Guangdong Province has improved significantly, but it was still at a relatively low level.

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