Research on the Configuration of Water Resources-social Economic Coupling System based on SD Simulation

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Keywords: Water resources, social economy, coupled system, supply and demand balance, system dynamics

Abstract: With the rapid development of society and economy, water resources have become a "bottleneck" restricting the sustainable development of society and economy. Based on the internal relationship between water resources and social economy, Guangdong province water resources allocation system was designed and a feedback mechanism was established by using Vensim software to build SD model (system dynamics). A simulation model of the coupled system was established, and the validity and structural consistency of the model were tested. Then, the distribution characteristics of multiple factors such as total population, GDP, agricultural water consumption, industrial water consumption, domestic water consumption and ecological environment water consumption in Guangdong province in 2020 were analyzed. The balance of supply and demand between water resources and social economy was analyzed. This research could provide theoretical guidance for the research of water resources-social economy coupling system, which is of great significance to realize full utilization of water resources and sustainable development.

1 INTRODUCTION

With the rapid economic development and the continuous population growth, the contradiction between the supply and demand of water resources caused by the uneven distribution of water resources in time and space and the mismatch of the distribution of water and soil resources in the region have become increasingly intensified. How to balance the relationship between regional water resources and social, economic and ecological aspects has become a key issue for regional sustainable development (Huang et al., 2015; Yang et al., 2014; Wu et al., 2020; Guenther et al., 2015; Behboudian et al., 2021; Wang et al., 2010). The water environment provides necessary resources and external conditions for social and economic development, and the behavior of water intake and sewage in the process of regional social and economic development in turn affects the health of the water environment (Lee et al., 1996; Kling et al., 2009; Gleick et al., 2003; Wang et al., 2019). Many researchers have studied the water resources-social economic coupling System. Foreign research on the coordinated development of water resources and social economy started early and has a high degree of attention (Booker et al., 1994; Faisal et al., 1997). Current research focuses on the study of water resources management under the existing allocation model (Marino et al., 2009; Davies et al., 2011). Domestic research on the coordinated development of water resources and social economy started late, but developed rapidly. The grey relational degree algorithm, coupling degree model and system dynamics model were used to studied (Zhang et al., 2011; Du et al., 2015; Liu et al., 2020a; Chen et al., 2013; Huang et al., 2019; Liu et al., 2020b). Based on the grey relational analysis method, Liu et al. (2020a) analyzed the correlation between the social economic system indicators and the water resources system indicators of Shanxi and Shaanxi provinces. And then they studied the correlation degree of the water resources-social economic coupling system. Liu et al. (2020b) studied the coordination degree of the water resources-social economic coupling system in Guangdong Province from 1980 to 2017 by using the coupling coordination degree evaluation method combining the relative dispersion coefficient method and the coupling function method.

The GDP of Guangdong Province has long ranked first in our country, and it has abundant water resources, numerous rivers and abundant rainfall in coastal areas. However, due to insufficient utilization of water resources and neglect of sewage treatment,

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the water resources environment in Guangdong Province has been damaged, leading to a prominent contradiction between water supply and demand. Based on the relationship between water resources systems, this paper took agricultural water shortage as the core and used Vensim software to build SD models. This paper designs the allocation of water resources in Guangdong Province. A feedback mechanism and a system model were built. Then the validity and structural consistency of this model were tested. Finally, the balance of supply and demand between water resource and social economy was analyzed.

2 MATERIALS AND METHODS

Vensim software was used to construct the SD model of the water resources carrying capacity of Guangdong Province. The initial value of this model adopted the statistical value of 2005, as shown in Table 1. Enter the data in Table 1 into Vensim software. Table 2 shows the 5 state variables (X), 5 rate variables (R), 30 auxiliary variables (A), and 18 constants (P), which were used to establish a mathematical model describing the relationship between system variables.

Table 1: Initial values of model state variables.

State variables	Initial value
Total water resources	1933.4
Total population	9008.38
Industrial water consumption	112.5
GDP	72812.6
Effective irrigation area	2066.64

Table 2: Description of system variable.

No.	variable	nature	unit	No.	variable	nature	unit
1	Total water resources	X	10^9 m^3	30	Domestic sewage discharge coefficient	P	Dmnl
2	Water growth	R	10^9 m^3	31	Industrial water consumption	X	10^9m^3
3	Water growth rate	P	Dmnl	32	Industrial water increase	R	10^9m^3
4	Water production modulus	A	m^3/km^2	33	Industrial water growth rate	P	Dmnl
5	Area	P	km^2	34	Industrial wastewater discharge	A	10^9m^3
6	Yield factor	A	Dmnl	35	Industrial wastewater discharge coefficient	P	Dmnl
7	Ecological carrying capacity of water resources	A	hm^2/cap	36	Sewage discharge	A	10^9m^3
8	Water ecological footprint	A	hm^2/cap	37	Sewage treatment volume	A	10^9m^3
9	Water resources ecological deficit or surplus	A	hm^2/cap	38	Sewage treatment coefficient	P	Dmnl
10	Global average production capacity of water resources	P	m^3/km^2	39	Sewage reuse amount	A	10^9m^3
11	Global water balance factor	P	Dmnl	40	Sewage reuse coefficient	P	Dmnl
12	Total water consumption	A	10^9 m^3	41	Rainwater utilization	P	10^9m^3
13	Total social water resources	A	10^9 m^3	42	GDP	X	10^9yuan
14	Surface water resources	A	10^9 m^3	43	GDP growth	R	10^9yuan
15	Groundwater resources	A	10^9 m^3	44	GDP growth rate	P	Dmnl
16	Unconventional water resources	A	10^9 m^3	45	10,000 yuan GDP ecological footprint	A	m^3/ thousand yuan
17	Total population	X	Ten thousand people	46	Effective irrigation area	X	km^2
18	Population growth	R	Ten thousand people	47	Increase in effective irrigation area	R	km^2
19	Population growth rate	P	Dmnl	48	Effective irrigation area growth rate	P	Dmnl
20	Urbanization rate	A	Dmnl	49	Irrigation water consumption of farmland	A	10^9m^3

21	Urban population	A	Ten thousand people	50	Farmland irrigation quota	P	m^3/km^2
22	rural population	A	10^9 m^3	51	Water consumption for forestry, animal husbandry, fishery and livestock	P	10^9m^3
23	Urban domestic water consumption	A	10^9 m^3	52	Agricultural water consumption	A	10^9m^3
24	Water quota for urban residents	P	L/ people·d	53	Public green area	A	km^2
25	Rural domestic water consumption	A	10^9 m^3	54	Public green area per capita	A	m^2/ people
26	Water quota for rural residents	P	L/one people·d	55	Road clean area	A	km^2
27	Urban public water consumption	A	10^9 m^3	56	Environmental conservation area	A	km^2
28	Domestic water consumption	A	10^9 m^3	57	Environmental water quota	P	m^3/km^2
29	Domestic sewage discharge	A	10^9 m^3	58	Ecological water consumption	A	10^9m^3

3 RESULTS AND DISCUSSION

The structural consistency inspection was finished by using the "Check Model" and "Unit Check" included in the Vensim software. The simulation values were obtained by inputing historical parameters into the model. And then fit of the model was verified by comparing the simulated value with the historical real value. Generally, the error within 10% is deemed to pass the historical test. Sensitivity test is to test the sensitivity of the system to parameter changes, usually a strong system has less sensitivity. The water resources carrying capacity of Guangdong Province from 2015 to 2019 was simulated. The time step was 1 year. The initial value adopted the statistical values for 2015. The population growth rate was 1.3%, the GDP growth rate was 8.0%, and the urban residents' water quota was 216 L/person·d, rural residential water quota was 171L/person·d, industrial water use growth rate was 1.02%, effective irrigation area growth rate was 4%, and farmland irrigation quota was 728/mu.

3.1 Structural Consistency Check

Figure 1 and Table 3 show the changes of total population and GDP as well as the inspection results of the main indicators of the system, respectively. The total population and GDP value changed with time in a relatively close range and basically remained the same. The error between the total population and the real value of GDP value and the simulation value was less than 10%, which was within the allowable error range of the system, indicating that the SD model of the coupled system met the structural consistency test.

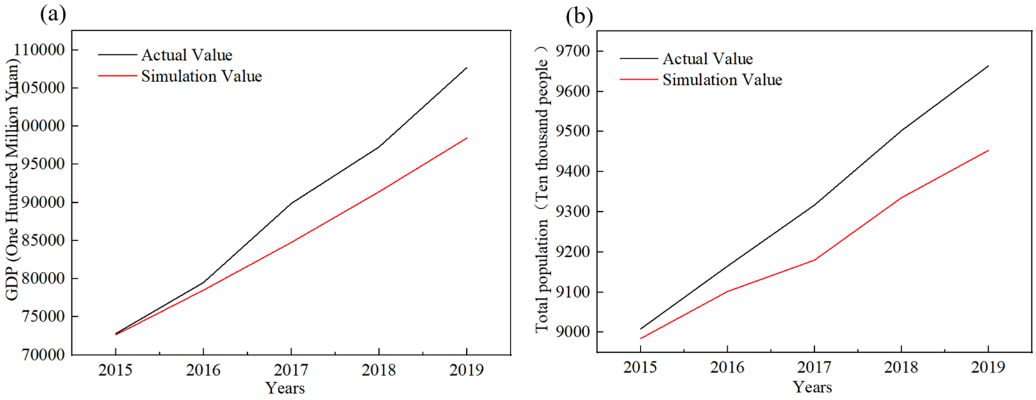

Figure 1: Changes in total population and GDP: (a) real and simulated values of GDP (b) real and simulated values of population.

Table 3: Test results of main indicators of the system.

Year	Total population			GDP		
	Actual value	Simulation value	Error	Actual value	Simulation value	Error
2015	9008.38	8984.4	0.27%	72812.6	72656.3	2.15%
2016	9164.90	9101.6	0.69%	79512.1	78515.6	1.25%
2017	9316.91	9179.7	1.47%	89879.2	84765.6	5.69%
2018	9502.12	9335.1	1.76%	97277.8	91406.3	6.04%
2019	9663.41	9453.1	2.18%	107671.1	98437.5	8.58%

3.2 History Check

History verification is an important method to simulate the relevant data for a period of time in the past through the model, and then compare it with the actual data and observe the error to determine whether the model is feasible. The governing equation is as follows.

$$MARE = A\bar{R}E = \frac{1}{n}\sum_{t=1}^{n}\left|\frac{(\widehat{Y_t} - Y_t)}{Y_t}\right| \qquad (1)$$

In the formula, t is time, n is the total number of time series data, $\widehat{Y_t}$ and Y_t are the simulated value and actual value of variable Y at time t. MARE is the mean value of ARE.

Figure 2 and Table 4 show the changes in agricultural water consumption and industrial water consumption, as well as the inspection results of the main indicators of the system. The trends of the real and simulated values of agricultural water consumption and industrial water consumption are basically consistent. The deviation of agricultural water consumption (ARE) is less than 5%, while the error of industrial water consumption is less than 18%. Both errors are less than 0.2. Within the reasonable error range, it shows that the agricultural water consumption and industrial water consumption of the modified model have passed the historical test.

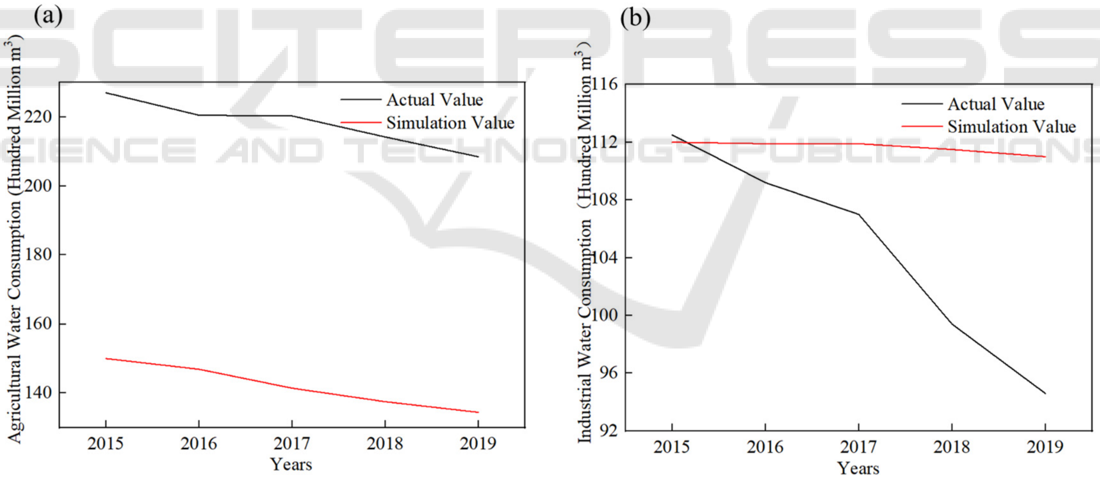

Figure 2: Changes in agricultural water consumption and industrial water consumption.

Table 4: Test results of main indicators of the system.

Year	Agricultural water consumption			Industrial water consumption		
	Actual value	Simulation value	ARE	Actual value	Simulation value	ARE
2015	227.0	222	2.2%	112.5	112	0.44%
2016	220.5	218.3	0.9%	109.2	111.9	2.47%
2017	220.3	211.5	3.9%	107.0	111.9	4.58%
2018	214.2	209.9	2.0%	99.4	111.5	12.17%
2019	208.5	203.7	2.3%	94.6	111.0	17.34%

3.3 Sensitivity Test

Model sensitivity testing includes numerical sensitivity, behavior sensitivity and policy sensitivity. When the parameter or structure changes, the change to the simulation value is lower, that is, it has lower behavior sensitivity and policy sensitivity. The formula for sensitivity test is as follows.

$$S_L = \left| \frac{\Delta L_t}{L_t} \times \frac{X_t}{\Delta X_t} \right| \qquad (2)$$

Among them, t is time; SL is the sensitivity of state variable L to parameter X; Lt is the value of state variable L at time t; is the value of parameter X at time t; ΔLt is the change of state variable at time t; ΔXt is the amount of change of the parameter X at time t.

When the parameter Xj changes, the sensitivity of N state variables (L1, L2, L3...Li…LN) to Xj are (SL1, SL2, SL3, ...SLi...SLN). The formula of the model's sensitivity SXj with respect to the parameter Xj is as follows.

$$S_{Xj} = \frac{1}{N} \sum_{i=1}^{N} S_{Li} \qquad (3)$$

Figure 3 and Table 5 show the changes in domestic water consumption and ecological environment water consumption, as well as the inspection results of the main indicators of this system. The sensitivity of the simulation results had a large deviation, which indicated that the results of the domestic water consumption and the ecological environment water consumption calculated by the model have a large error. The large error was due to the constraints of many factors among the three. In other words, domestic water consumption was the most sensitivitive in the SD model of the Guangdong Water Resources-Social Economic Coupling System, which was the most important factor in the SD model.

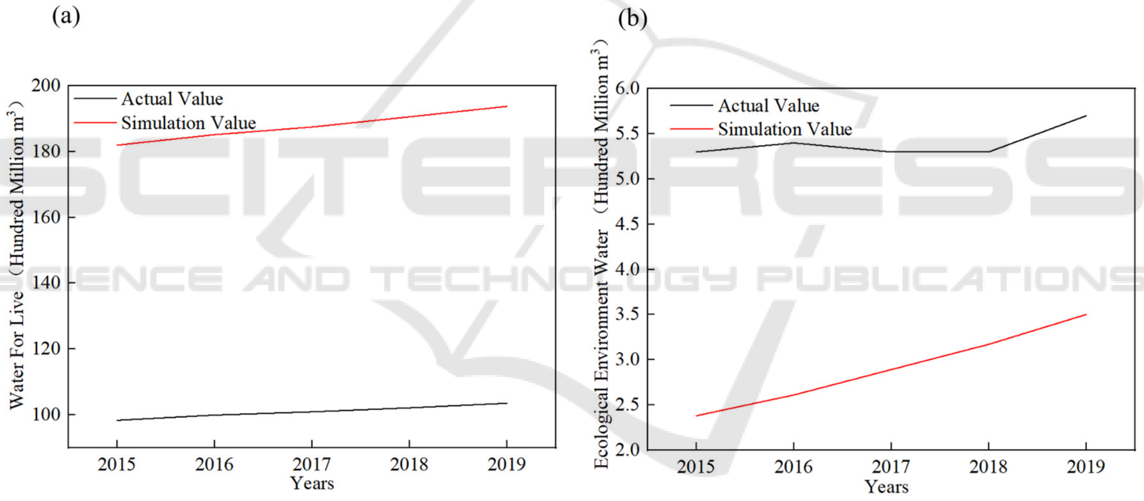

Figure 3: Changes in domestic water consumption and ecological environment water consumption.

Table 5: Test results of main indicators of the system.

Year	Water for live			Ecological Environment Water		
	Actual value	Simulation value	Error	Actual value	Simulation value	Error
2015	98.3	182.0	85.15%	5.3	2.38	55.09%
2016	99.9	185.2	85.39%	5.4	2.61	51.67%
2017	100.9	187.5	85.83%	5.3	2.89	45.47%
2018	102.1	190.6	86.68%	5.3	3.17	40.19%
2019	103.5	193.8	87.25%	5.7	3.5	38.60%

Table 6 shows the total population, GDP, agricultural water consumption, industrial water consumption, domestic water consumption and ecological environment water consumption of Guangdong province in 2020. The error of total population, GDP and agricultural water consumption is less than 10%. Domestic water consumption has the highest sensitivity in the SD model of Guangdong's water resources-socio-economic-ecological coupling system, and the error is relatively large.

Table 6: Calculation results of main indicators of the system in 2020.

Index Results	total population	GDP	agricultural water consumption	industrial water consumption	Live water consumption	ecological environment water consumption
Actual value	9738.21	11935.37	205.30	90.20	106.8	5.5
Simulation value	9976.79	12997.61	209.61	102.11	127.19	6.51
Error	2.45%	8.9%	2.1%	13.2%	19.1%	18.4%

4 CONCULSION

Based on the inherent relationship between water resources and social economy, the SD model of the coupled system of water resources and social economy in Guangdong Province was constructed. Then the model was tested and the distribution characteristics of multiple factors such as Guangdong’s total population, GDP, agricultural water consumption, industrial water consumption, domestic water consumption and ecological environment water consumption in 2020 were analyzed. The error between the real value and the simulated value for the total population and GDP was less than 10%. ARE of agricultural water consumption was less than 5%, and ARE of industrial water consumption is less than 18%. Within a reasonable error range, the SD model passed the structural consistency test and the historical test. The sensitivity results had large deviations. Domestic water consumption was the most sensitive in the SD model of Guangdong Water Resources-Social Economic Coupling System. Therefore, saving domestic water or making domestic water recycle multiple times has great social significance.

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