Research on Adaptive Management of Water Resources of the Yellow Sea and Bohai Sea Based on System Dynamics Model: A Case of Longkou City, Shandong Province

Lei Qiu[a], Ting Wang[b*] and Jingyi Huang
Management Science Institute of Hohai University, Nanjing, 210098, China

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Abstract: In the role of nature - society dual driving force, the problems of groundwater intrusion and deterioration of water quality in the Coastal Areas of the Yellow Sea and Bohai Sea are becoming more and more serious, which hinder the sustainable development of economy and society. In the face of increasingly complex water resources problems, water resources management should be more flexible and adaptable. Based on the three dimensions of exposure-sensitivity-adaptability, this paper constructs a SD model of "adaptability" and determines the regulatory factors according to the combination of regional policy and economic structure, etc.,then designs the water - saving - oriented water resource adaptability management policy scenario, conducts quantitative evaluation with Longkou City as an example , and makes policy suggestions for the water resource adaptability management in the coastal areas of the Yellow Sea and Bohai Sea. This study provides a new solution to the problem of seawater intrusion, and provides a new theoretical support and practical basis for water resource adaptation policies.

1 INTRODUCTION

With the increasing contradiction between the goals of economic development and groundwater exploitation, the hydrodynamic balance between seawater and fresh water has been destroyed. It leads to the decline of groundwater level and a series of water ecological problems, especially in the coastal areas of the Yellow Sea and Bohai Sea, where the water resources are scarce and groundwater overexploitation intensity is large. Therefore, in order to realize the sustainable development of economy, society and ecology in the coastal areas, measures must be taken to strengthen the water resources management in the coastal areas of the Yellow Sea and Bohai Sea, especially the groundwater management (Zhong, 2019), to implement the strictest water resources management system.

Adaptive management originated from Holling, a ecologists in 1978 (HOLLING, 1978), who studies the practice of complex ecosystems, and puts forward adaptive management as the management framework to solve complex systems. Whipple (WHIPPLE, 1998), Werrity (WERRITTY, 2002), Middelkoop (MIDDELKOOP, 2001), and a number of foreign scholars have discussed the restoration of watershed, wetland and coastal areas, the use of water-saving irrigation technology, flood early warning and dispatching technology and other management techniques and methods from the perspective of adaptability. Domestic scholars innovatively put forward adaptive management theory and use adaptive management method to carry out empirical analysis. Based on the uncertainty of system management, Tong Jinping and Wang Huimin (Tong, 2006; Wang, 2016) think adaptive management realizes system health and sustainable management of resources. Xia Jun et al (Xia, 2015) puts forward the theory and method of water resources adaptability combining multi-information analysis and decision-making under climate change. Based on the CGE model, Li Changyan (Li, 2014) brought the vulnerability of water resources into the framework of water resources adaptive management, compiled the SAM table, and constructed policy

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simulations under different scenarios for comparative analysis to study the adaptive management ability of water resources. Comprehensive analysis of relevant studies at home and abroad shows that, on the one hand, the challenge of adaptive management of water resources is mainly due to the uncertainty of the external environment, so adaptive management policies are according to the characteristics of regional development. It is beneficial to reduce the vulnerability of water resources. On the other hand, the adaptive management of water resources in China is mostly from the perspective of climate change, but there are few studies on the adaptive management of water resources under seawater intrusion. Therefore, this paper constructs the analysis framework of water resources adaptive management system, sets the policy scenario, analyses which policy can improve the contradiction between water supply and demand and ecological environment, promotes economic development, alleviates the economic and social water use dilemma, and provides the theoretical and methodological basis for regional water resources adaptive management analysis.

2 ANALYSIS OF WATER RESOURCES MANAGEMENT

China's coastal areas have superior geographical location and dense population. More than 70% of large and medium-sized cities gathered here. With the rapid economic and social development of coastal areas, there are great differences of precipitation from temporal and spatial in coastal areas. Surface water can no longer meet the increasing economic and social development needs. People continue to extract groundwater, resulting in a continuous decline in groundwater level. Sea water invades freshwater aquifers and pollutes groundwater sources, making limited groundwater resources more scarce. The Mainland coastline of our country stretches for 19000 km. The seawater intrusion mainly occurs in the coastal areas with large amount of groundwater resources exploitation, such as Shandong, Tianjin and other places. After the seawater intrusion was discovered in Dalian coastal area in 1964, it was discovered in other provinces in the late 1970s. During 2014, the total area of seawater intrusion in China exceeded 2000 km2, which caused damage and loss to groundwater ecological environment and local economic development. The seawater intrusion in the coastal area makes the groundwater quality deteriorate. At the same time, it reduces the groundwater availability, destroys the production and living equipment, and brings serious influence to the industrial and agricultural production and the people's life in the coastal area. The coastal area of the Yellow Sea and Bohai Sea is located in the plain. The land is fertile. The industry and agriculture are more developed. At present, due to the invasion of seawater, the water quality deteriorates and causes soil salinization. Most farmland reduces production by 20%~40%, which reduces the supply capacity of water resources and restricts the development of regional industry and agriculture. On the one hand, the unreasonable groundwater overexploitation causes the groundwater level to decrease greatly, the hydrodynamic balance between seawater and fresh water is destroyed, and the vulnerability of water resources is obvious. On the other hand, seawater intrusion makes groundwater quality worse and supply capacity weakened, which leads to salinization of cultivated land and the enhancement of water resources vulnerability, that restricts the sustainable development of economy and society.

Therefore, in order to maximize social welfare, water users and relevant government departments adopt economic and non-economic means to adapt water resources policies, such as open source, water and pollution control, and industrial structure adjustment to adjust social structure, industrial structure, and social function, alleviate the contradiction of water resources, improve the vulnerability of water resources, and promote sustainable regional economic and social development from the demand side and supply side, as well as the combination of long-term and short-term approaches. In the case of clarifying the water resources problems, the adaptive policies of designing different schemes are incorporated into the SD model. Different policy scenario effects are adjusted and controlled by controlling the response variables.

3 CONSTRUCTION OF SD MODEL FOR ADAPTIVE WATER RESOURCES MANAGEMENT

Using the relationship between water resources supply and demand, economic development and population growth as the medium, maintaining the interrelation of various elements within the whole

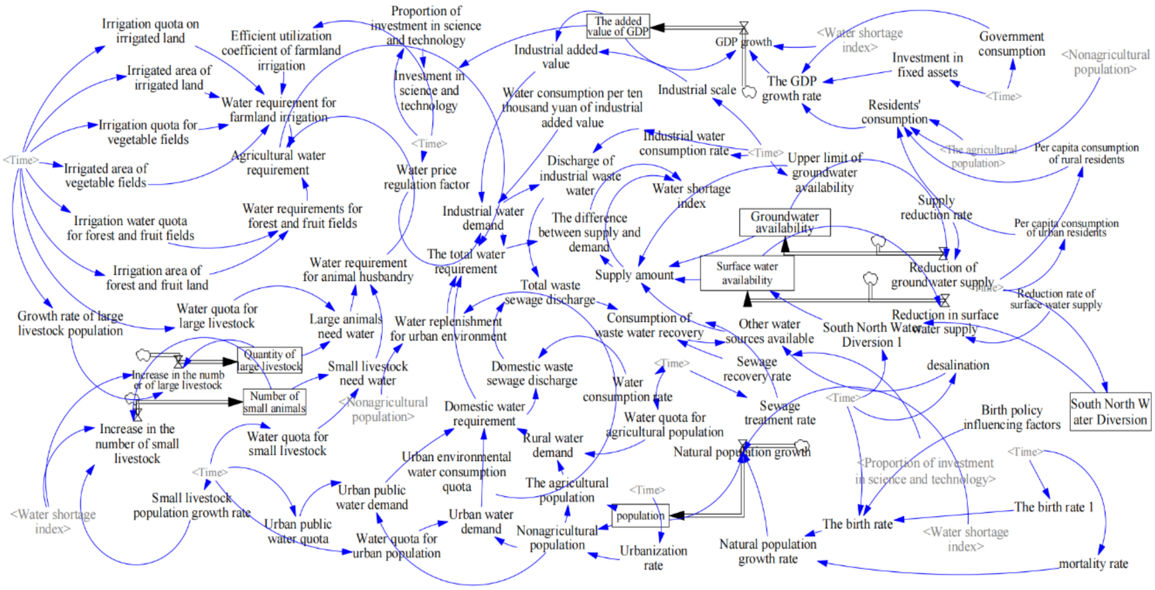

Figure 1: System Flow Chart.

system, forming an organic whole that restricts each other, using Vensim software to design the SD model of water resources adaptive management, in which the variables such as GDP added value, population quantity, water shortage index and so on combine the system organically. Water demand for production and life and water availability determine the water scarcity index. By exerting pressure on the population growth rate and GDP growth rate, water scarcity index influences the economic and social operation, thus coupling with the economic and social system and influencing each other, as shown in figure 1. As for the parameters in the model, on the one hand, they are sorted out, analysed and calculated according to the water resources bulletin and statistical yearbook over the years; on the other hand, data are processed according to mathematical calculation method, arithmetic average method and table function method, etc. For difficult-to-obtain data or to predict the future change trend of the dependent variable, on the one hand, according to the development control of population and economic growth in the 13th Five-Year Plan and other scholars' relevant literature research, on the other hand, regression analysis method is adopted to fit and comparing the simulated data and real data, so that the parameters in the system run more fit the real data.

4 EVIDENCE-BASED RESEARCH

Longkou City has rapid economic development, dense population and serious groundwater over mining. With rapid economic development and surface water resources being insufficient, the two key monitoring rivers in Longkou City cut, increasing the demand for groundwater freshwater resources, resulting in further expansion of seawater invasion scope, that restricted agricultural development. Some farmers have suffered heavy losses. It can be predicted that a series of problems caused by the future water shortage and the uncertainty of the external environment will still restrict the economic and social development of Longkou City. Taking Longkou City as an example, taking water saving as the goal, establishing water - saving society, using SD model to simulate water resources adaptability management, and discuss the impact of different policies on water resources vulnerability, so as to provide ideas for policy makers. According to the present situation of economic and social development of Longkou City, this paper formulates the adaptive management target of water resources in Longkou City by 2030 from five schemes. The adaptive management ability of water resources was investigated from the aspects of GDP added value, total water demand, available water supply, balance between supply and demand, sewage discharge, etc. Specific policy scenario programmes are shown in tables 1 below:

Table 1: Design of policy options for adaptive management of water resources.

Programme		Content
Programme I	Current status continuation	Taking the situation of water resources and economic development of Longkou City in the past ten years (2008-2017), combined with the outline of the Thirteenth five-year Master Plan for National Economic and Social Development of Longkou City, setting 2017 as base year, the simulation is carried out according to the present situation.
Programme II	Open Source	On the basis of scheme one, increase the water transfer of South-to-North Water transfer. In this paper, according to the 2017 water regulation, a certain amount of water regulation is added each year to simulate, and the maximum adjustable water quantity is controlled according to the maximum adjustable water quantity of Longkou.Therefore , the regulation variable of " South - to - North Water Diversion Project " is introduced to increase the water adjustment of 1.5 million m^3 every year.
Programme III	Streaming Pollution Control Type	The Streaming Pollution Control Type mainly includes two aspects: throttling and pollution control. By improving water efficiency of water resources, this paper adjusts the water consumption of ten thousand yuan industrial added value to 7 m^3. The effective utilization coefficient of agricultural irrigation was adjusted to 0.75, and the effect of water price on demand was adjusted to 0.95. The reuse rate of water resources sewage is 40% . The water supply of reclaimed water resources is increased.
Programme IV	Industrial restructuring	In the economic development of Longkou City, industry is pillar industry, and it belongs to high water consumption and high pollution industry. Therefore, on the basis of scheme one, this paper reduces the proportion of industry to 49%, increases the proportion of service industry, and optimizes the industrial structure.
Programme V	Integrated	Synthesizing the above four schemes, consider increasing income, reducing expenditure, pollution control and industrial structure adjustment.

The parameters of the five control variables are shown in Table 2:

Table 2: Policy scenarios and parameters for adaptive management of water resources.

Variable	Programme I	Programme II	Programme III	Programme IV	Programme V
The amount of water transferred from south to north water diversion project (million m^3)	0	150	0	0	150
Water consumption per ten thousand yuan of industrial added value (m^3)	9	9	7	9	7
Efficient utilization coefficient of farmland irrigation (%)	70	70	75	70	75
Sewage recovery rate (%)	25	25	40	25	40
Water price regulation factor	1	1	0.95	1	0.95
The proportion of industrial added value (%)	54	54	54	49	49

By comparing the simulation value of the model with the real data, this paper selects the GDP and population as the test variables to judge whether the model can truly reflect the actual situation of Longkou City. As shown in tables 3 and 4, the simulation errors of GDP and population are within a reasonable range of 10%, which indicates that the model can better fit the actual situation of economic and social development in Longkou City.

Table 3: GDP Parameter Test for Model .

Unit: $100 million

Year	GDP simulated values	GDP actual value	Error
2008	531	570	0.068 4
2009	590.63	623	0.052 0
2010	670.99	680	0.013 2
2011	754.38	778	0.030 4
2012	845.31	840	-0.006 3
2013	933.13	935	0.002 0
2014	1 029.40	1 002.8	-0.026 5
2015	1 088.55	1 035	-0.051 7
2016	1 160.36	1 110	-0.045 4
2017	1 253.52	1 190.935 8	-0.052 6

Table 4: Demographic parameters of the model.

Unit :10 000

Year	Population simulation values	Actual population	Error
2008	63.44	63.44	0
2009	63.43	63.38	-0.000 79
2010	63.38	63.3	-0.001 30
2011	63.36	63.4	0.000 63
2012	63.32	63.49	0.002 74
2013	63.33	63.54	0.003 24
2014	63.29	63.53	0.003 78
2015	63.46	63.7	0.003 71
2016	63.40	63.63	0.003 54
2017	63.49	63.69	0.003 07

Table 5: Results of 5 programme simulation variables in 2030.

Variable	Programme I	Programme II	Programme III	Programme IV	Programme V
GDP added value (RMB 1 0 0 million)	2 013.68	2 145.30	2 142.62	2 046.76	2 286.38
Total water demand (million m^3)	19 047.83	19 690.32	16 958.34	18 288.29	16 967.32
Total water supply (million m^3)	11 993.64	13 967.45	12 376.14	11 936.96	14 233.54
Difference between supply and demand (million m^3)	7 054.18	5 722.87	4 582.20	6 351.32	2 733.78
quantity of wastewater effluent (million m^3)	1 978.82	2 086.41	1 640.36	1 855.79	1 601.26

According to the reasonable prediction of Longkou city's regional development, the 13th Five-Year Plan, water conservancy planning, and related measurement software, the results of the change of other variables caused by policy changes are analysed. The five schemes are simulated and the forecast results of Longkou City in 2030 are shown in Table 5.

By comparing the simulation results of the four schemes with the current scheme one, it is found that as long as the economy is developed, the water demand will inevitably increase. The simulation results of different policy scenarios are analysed as follows:

The first scheme is the future water requirements under current development conditions. The gap between supply and demand is increasing and the discharge of waste water is rising rapidly. Compared with the other four schemes GDP the added value is the lowest. The pressure of water resource will further increase.

The second scheme is from the supply side, using the South-to-North Water Transfer Project, giving priority to the use of overseas water and protecting the local water resources environment, which is superior to the fourth scheme, indicating that the industrial adjustment can not be realized in the short term and the demand for water resources is high, so the water conservancy project should play a good role.

Compared with the first two schemes, the economic and social water demand of the third scheme the least, the waste water discharge is less, the waste sewage discharge and the total water storage are lower than the second scheme. The overall implementation effect is higher than the second scheme.

The GDP added value of the forth scheme is only higher than that of the first scheme, the short-term effect is not good and the economy is impacted. The demand for water resources is still very strong in the short term.

The fifth scheme is a comprehensive scheme, the results are better than other schemes, which can not only alleviate the shortage of supply and demand to a certain extent, but also develop economy with the condition of protecting ecological environment.

5 CONCLUSIONS

According to the theoretical basis of SD model and water resources adaptive management, this paper constructs the framework of water resources adaptive management. According to the regional development, the "exposure-sensitivity-adaptability" analysis of water resources is regarded as an important reference standard for adaptive management regulators, and five different water resources adaptive management policy schemes are designed by using the SD model. The simulation results show that on the one hand, we should make a policy "combination fist" through system construction. It is necessary to make full use of the "invisible hand" and "tangible hand" of the market and the state, combine short-term with long-term, make joint efforts on the demand side and the supply side. At the same time, it should give full play to the power of science and technology to continuously improve the utilization rate of water resources and social development.

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