Dynamic Simulation of Water Resources Sustainable Utilization of Kiamusze Based on System Dynamics

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Abstract. In order to determine the sustainable supporting capacity of current Kiamusze water utilization situation to future society and economy, a dynamic simulation model of water resources sustainable utilization was built based on system dynamics (SD). The simulation results indicated that current Kiamusze water resources could not satisfy future demand of industrial and agricultural production and also restricted socioeconomic development. In view of the situation, the water resources sustainable utilization schemes were designed and simulated by targeting water supply and demand balance and adjusting sensitive parameters of the model. The analysis showed that the coordinated scheme not only realized water resources sustainable utilization but also enhanced the sustainable supporting capacity of water resources to society and economy within the fixed number of simulating years. Thus, the coordinated scheme is the best one for water resources sustainable utilization of Kiamusze and can provide policy guidance for further exploitation of regional water resources.

Keywords: Water resources, Sustainable utilization, System dynamics, Dynamic simulation, Kiamusze

1 Introduction

Kiamusze is located in northeast Heilongjiang Province and in the heartland of Sanjiang Plain surrounded by Songhua River, Heilongjiang River and Wusuli River. The region with flat terrain, fertile soil and abundant water is suitable for agricultural development. After years of exploitation and construction, it has become an important grain production base of China. In recent years, the high interference of human activities and unreasonable utilization of water resources have caused serious imbalance between surface and ground water, low utilization efficiency and supporting capacity of water resources [1-3]. These problems have seriously threatened the sustainability of regional resources utilization and socioeconomic development. Therefore, on the premise of guaranteeing national food security and regional ecological security, rational allocation of water resources, enhancing supporting capacity of water resources to socioeconomic development and realizing regional water resources sustainable utilization become especially important.

In the study, a dynamic simulation model of water resources sustainable utilization was built firstly. Then the current situation of Kiamusze water resources utilization was simulated, and the key problems restricting regional socioeconomic development were found out. Lastly, the water sustainable utilization schemes were designed and simulated by system dynamic (SD) model, and the best scheme of water resources sustainable utilization was sought to provide scientific guidance for further exploitation and optimal allocation of regional water resources.

2 SD model of water resources sustainable utilization

2.1 Model boundaries

The spatial boundary of SD model is the administrative boundary of Kiamusze including four districts, six counties and seventeen state-owned farms. The temporal boundary of SD model is from the year 2000 to 2030. The former nine years (2000 to 2008) provide historical statistical data and the latter twenty-two years (2009 to 2030) is the forecasting period. The time step is one year in order to reduce error. The content boundary of SD model includes water resources, land resources, population, national economy, grain production, etc.

2.2 Model building and testing

Before model building, Kiamusze water resources sustainable utilization system was analyzed and the feedback mechanism of all elements in the system was primarily understood. The model building stood by practical, problem-oriented and systemic principles [4-5], and included structure design, variable selection and quantitative expression of the relationship between variables. The dynamic simulation model of water resources sustainable utilization with 90 variables was built and showed in Fig. 1. The details of variable structure equations and data sources in the model can be found in reference [6] and [7].

The model validity and history testing results showed that the model had rational structure and high precision and could quantitatively characterize a real system operation [8-10]. Sensitivity analysis of the model found out nine sensitive parameters that had great influences on model operation results [11-13]. The parameters included reclaimed water reuse rate, paddy field irrigation net quota, dry land irrigation net quota, water transport index in canal system, industry water quota, industrial water recycling rate, surface water utilization level, ground water utilization level and transit water resources utilization.

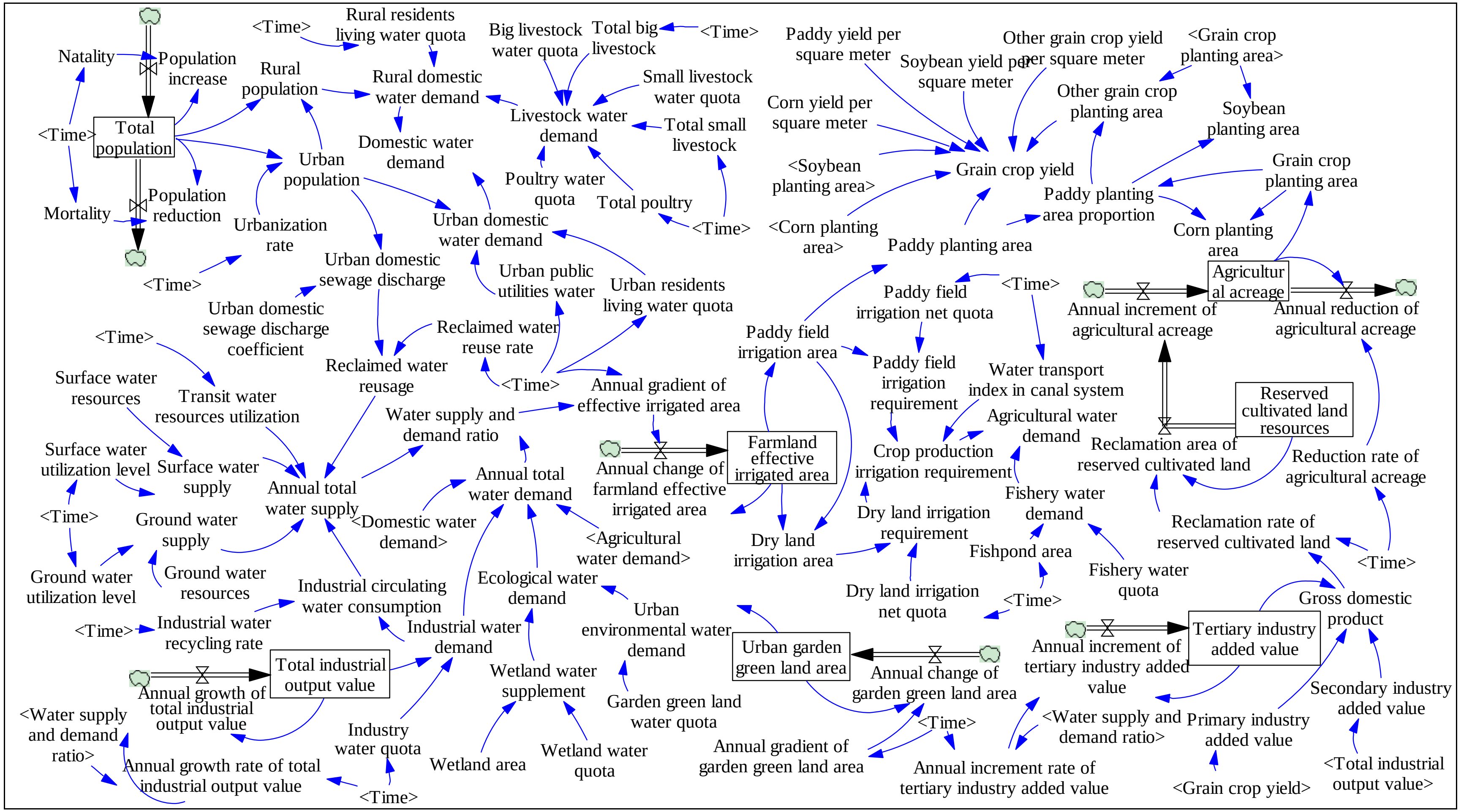

Fig. 1. SD simulation model of water resources sustainable utilization

3 Dynamic simulation of water resources sustainable utilization

3.1 Simulation of current water resources utilization situation

The output variables of dynamic simulation in the study included water supply and demand ratio, farmland effective irrigated area, grain crop yield, total industrial output value and gross domestic product (GDP), and their variation diagram was showed in Fig. 2. The simulation values and annual growth rates of the output variables in different planning-level years were listed in Table 1. The balance situation of water supply and demand, and its influence on agricultural production and socioeconomic development in Kiamusze were judged on the basis of the above data.

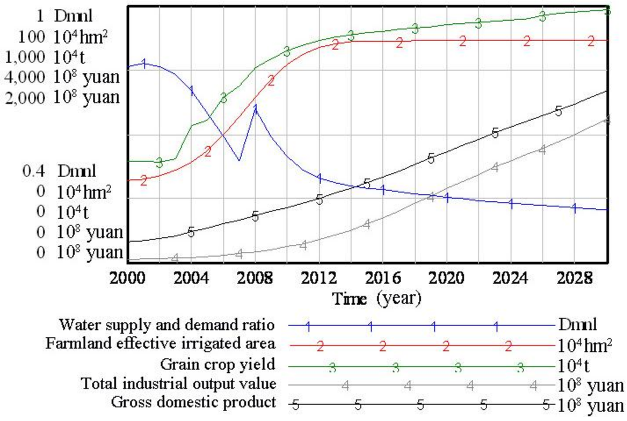

Fig. 2. Dynamic simulation diagram of current water resources utilization situation

Table 1. Dynamic simulation values of current water resources utilization situation

Level year		2000	2008	2010	2015	2020	2030
Water supply and demand ratio		0.86	0.76	0.65	0.57	0.55	0.52
Farmland effective irrigated area	Simulation value (10^4 hm^2)	31.98	64.396	77.204	86.136	86.285	86.285
	Annual growth rate (%)	-	13.23	8.07	0.32	0.00	0.00
Grain crop yield	Simulation value (10^4 t)	395.19	757.53	824.16	894.61	925.46	982.58
	Annual growth rate (%)	-	10.10	3.87	0.86	0.61	0.32
Total industrial output value	Simulation value (10^8 yuan)	47.12	170.16	248.40	602.15	1153.96	2240.51
	Annual growth rate (%)	-	20.51	20.85	17.71	11.23	6.36
Gross domestic product	Simulation value (10^8 yuan)	159.74	368.52	433.26	623.87	865.27	1342.81
	Annual growth rate (%)	-	10.77	8.25	7.35	6.13	4.25

According to the data in Fig. 2 and Table 1, the water supply and demand ratio reduced from 0.76 to 0.57 and the balance of supply and demand was 35.5×10^8m^3

during recent planning-level years (2009 to 2015). The water supply and demand ratio continued to decline during medium-term (2016 to 2020) and long-term (2021-2030) planning-level years and the ratio reduced to 0.52 in 2030. Water supply and demand ratio had great influence on agricultural production. Farmland effective irrigated area increased slowly even stopped when the ratio was less than 0.6. The development stagnation of farmland effective irrigated area would directly induce the stagnation of paddy planting area. In this case, regional grain crop yield would be seriously affected for paddy was a high yield and good adaptability crop in Kiamusze.

As the same as agricultural production, water supply and demand ratio also restricted the developments of total industrial output value and GDP. Kiamusze has abundant mineral resources, so its industry has large development space. Annual growth rate of total industrial output value maintained more than 20% before 2010, but during medium-term and long-term planning level years its growth speed slowed along with the shortage aggravation of water resources. Kiamusze with a low GDP per capita (1.58×10^4yuan) is a relatively poorer region. For industrial and agricultural production in the region restricted by water resources grew slowly, the annual growth rates of recent, medium-term and long-term planning level years were 7.35%, 6.13% and 4.25% respectively.

The analysis of dynamic simulation results indicated that imbalance between water supply and demand was the key contradiction of water resources system. Water resources supporting capacity can not satisfy industrial and agricultural production demand and restricts their development simultaneously, and finally causes slow economic development. In addition, a backward economy will reduce investment in water conservancy construction and water resources exploitation level, and finally aggravate contradiction of water supply and demand. This is a vicious circle.

3.2 Scheme design of water resources sustainable utilization

The primary object of scheme design of water resources sustainable utilization is to solve the imbalance problem of water supply and demand in future and to eliminate restriction of water resources to socioeconomic development. On the basis of above analysis, five schemes, including natural continuation scheme, increasing income scheme, decreasing expenditure scheme, comprehensive scheme and coordinated scheme, were designed and their regulation strategies were as follows:

(1) Natural continuation scheme: Sensitive parameters maintained at current year level (2008).

(2) Increasing income scheme: The scheme takes enhancing surface water supporting capacity and exploiting transit water resources as primary measures, and improving sewage disposal and industrial water recycling capacity as supplementary measures. Its sensitive parameters include surface water utilization level, transit water resources utilization, reclaimed water reuse rate and industrial water recycling rate. Based on the water conservancy and socioeconomic development plan of Kiamusze and the reclaimed water reuse rate and industrial water recycling rate of developed area, the annual gradient of sensitive parameters in different periods were designed and listed in Table 2.

(3) Decreasing expenditure scheme: The scheme considers lowering ground water utilization level and improving water-saving of industrial and agricultural production. Its sensitive parameters include industry water quota, paddy field irrigation net quota, dry land irrigation net quota, water transport index in canal system and ground water utilization level. On the basis of the water conservancy development plan of Kiamusze and all industries water quota of developed area, the annual gradient of sensitive parameters in different periods were designed and listed in Table 2.

(4) Comprehensive scheme: The scheme is comprised by increasing income scheme and decreasing expenditure scheme. Its sensitive parameters and values are as the same as the two schemes.

(5) Coordinated scheme: A certain economic inapplicability and incipient fault of resources sustainable utilization exist in increasing income scheme and decreasing expenditure scheme, for sensitive parameter design of the two schemes is to enhance water supply or induce water demand furthest. In order to guarantee resources sustainable utilization in coordinated scheme, the exploiting level of surface, ground and transit water, the restriction of industry water quota and the increment rate of industrial water recycling rate and water transport index in canal system are reduced properly. The annual gradient of all sensitive parameters, except for reclaimed water reuse rate, dry land irrigation net quota and paddy field irrigation net quota, are adjusted and listed in Table 2.

Table 2. Regulation strategy of water resources sustainable utilization scheme

Sensitive parameter	Value in 2008	Annual gradient of sensitive parameter (%)											
		Increasing income scheme			Decreasing expenditure scheme			Comprehensive scheme			Coordinated scheme		
		R[a)]	M	L	R	M	L	R	M	L	R	M	L
Surface water utilization level	0.4289	2.5	2	1.5	0	0	0	2.5	2	1.5	2.5	0	0
Transit water resources utilization ($10^4 m^3$)	8950	50	15	1.5	0	0	0	50	15	1.5	50	0	0
Industrial water recycling rate	0.3756	3	2.5	2	0	0	0	3	2.5	2	3	2	1
Reclaimed water reuse rate	0.025	20	15	10	0	0	0	20	15	10	20	15	10
Industry water quota ($m^3/10^4$yuan)	161	0	0	0	-5	-4.5	-4	-5	-4.5	-4	-5	-4	-3
Dry land irrigation net quota (m^3/hm^2)	550	0	0	0	-2.5	-2.25	-2	-2.5	-2.25	-2	-2.5	-2.25	-2
Paddy field irrigation net quota (m^3/hm^2)	4500	0	0	0	-4.5	-4	-3.5	-4.5	-4	-3.5	-4.5	-4	-3.5
Water transport index in canal system	0.55	0	0	0	2	1.5	1	2	1.5	1	2	1	0.5
Ground water utilization level	0.886	0	0	0	-2	-0.5	0	-2	-0.5	0	-2	-1.5	-1

[a)] R, recent years; M, medium-term years; L, long-term years.

3.3 Dynamic simulation of water resources sustainable utilization scheme

In order to investigate the influence of water resources sustainable utilization scheme to regional water supply and demand balance, the water supply and demand ratios of different schemes were simulated and showed in Fig. 3.

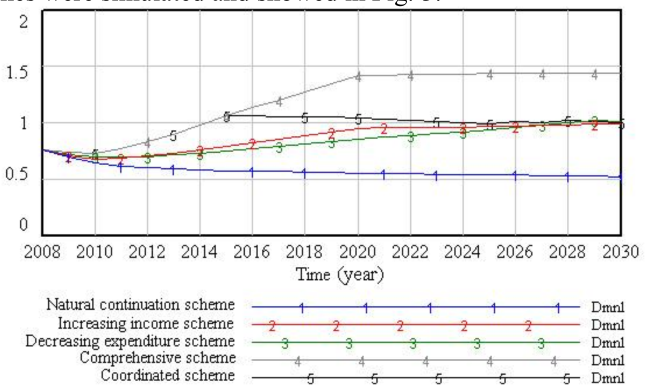

Fig. 3. Simulation of water supply and demand ratios of different schemes

According to Fig. 3, the water supply and demand ratio of natural continuation scheme showed a decreasing trend year by year and the water supply and demand did not balance during the simulated years. The water supply and demand ratio of increasing income scheme showed an increasing trend year by year, but the water supply and demand did not balance till the year 2030. The decreasing expenditure scheme realized balance in 2029. The comprehensive scheme realized balance in 2015, but the ratio increased year by year which signified a great waste of water resources. The coordinated scheme realized balance in 2015, however, the ratio decreased year by year and maintained at 1 which signified a dynamic balance. Thus, the coordinated scheme, that realizes balance and ensures resources sustainable utilization, is the best scheme for water resources sustainable utilization in Kiamusze.

4 Conclusions

A dynamic simulation model of regional water resources sustainable utilization was built in the study on the basis of water resources system analysis and feedback mechanism analysis of all elements. The model included 90 variables from many aspects, e.g. water resources, land resources, society, economy and grain. Nine sensitive parameters were found out by sensitivity analysis of the model and used as regulation variables of subsequent water resources sustainable utilization scheme.

Current water resources utilization of Kiamusze was simulated by using the dynamic simulation model of water resources sustainable utilization. The simulating results showed that the balance of regional water supply and demand was not realized during simulating years and the difference between supply and demand increased yearly. The imbalance of water supply and demand restricted industrial and agricultural development and become the key problem of Kiamusze water resources system.

For the purpose of regional water resources sustainable utilization, five schemes were designed by targeting water supply and demand balance and adjusting sensitive parameters. According to comparative analysis of dynamic simulation of water supply and demand ratio of the five schemes, the coordinated scheme was the best one for water resources sustainable utilization in Kiamusze.

Acknowledgements

The study was supported by the National Natural Science Foundation (51209038, 51179032), Key Laboratory Open Foundation of Water-saving Agriculture, College of Heilongjiang Province (2011KFJ03), Doctoral Foundation of Northeast Agricultural University (2012RCB58) and Research Fund for the Doctoral Program of Higher Education of Ministry of Education of China (20092325110014).

References

1. Chengzhi Hou.: Water resources carrying capacity assessment of Kiamusze. Heilongjiang Science and Technology of Water Conservancy, 39(3), 20--22 (2011)
2. Longhui Li, Chunsheng Yang, Yuguo Zhang.: Problems and countermeasures of Kiamusze ground water exploitation and utilization. Ground Water, 33(4), 36--37 (2011)
3. Yanning Dong, Weigang Song.: Problem analysis of Kiamusze water resources exploitation and utilization. Heilongjiang Science and Technology of Water Conservancy, 35(4), 102. (2007)
4. Lin Cai.: The Application of System Dynamics in The Research of sustainable development. China Environment Science Press, Beijing (2008)
5. Yong Hao, Junhui Fan.: Method and Application of Systems Engineering. Science Press, Beijing (2007)
6. Qiuxiang Jiang.: Study on carrying capacity evaluation and dynamic simulation of sustainable utilization of water and land resources in Sanjiang Plain. Northeast Agricultural University, Harbin (2011)
7. Heilongjiang Provincial Bureau of Statistics.: Statistical Yearbook of Heilongjiang Province. China Statistics Press, Beijing (2009)
8. Nanxiang Chen, Yanhui Wang.: The Water Resource Sustainable Utilization of Henan Province Based on System Dynamics. Journal of Irrigation and Drainage, 29(4), 34--37 (2010)
9. Chengxian Chen, Guangle Yan.: Research on system dynamics model of water resources sustainable development in China. Journal of University of Shanghai for Science and Technology, 22(2), 154--159 (2000)
10. Linxian Huang, Yongqiang Cao, Na Zhao, et al.: The Sustainable Development of Water Resources in Shandong based on System Dynamics Simulation. Water Power, 34(6), 1--3. (2008)
11. Yongguang Zhong, Xiaojing Jia, Xu Li, et al.: System Dynamics. Science Press, Beijing (2009)
12. Renan Jia, Ronghua Ding.: System Dynamics: Analysis of Feedback Dynamic Complexity. Higher Education Press, Beijing (2002)
13. Qifan Wang.: System Dynamics. Tsinghua University Press, Beijing (1994)