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Scenarios Simulation on Carrying Capacity of Water Resources in Kunming City

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Abstract

With high-speed development of social economy, rapid urbanization, the impact of drought, water resources supply and demand imbalance in Kunming City, improving carrying capacity of water resources will become the hot topic of sustainable development research in Kunming City. Based on the carrying capacity theory of water resources (CCWR) and system dynamics (SD) principle, a dynamic model which related with water resources, society, economy and eco-environment was established. Using this model, four scenarios were set up. They were remaining current water utilization scenario, improving the utilization of water resource scenario, water conservation strategy scenario, and comprehensive strategy scenario. The results of simulations showed that comprehensive strategy was the optimal strategy that can improve the carrying capacity of water resource in Kunming City from 2010 to 2020. The comprehensive strategy included optimization and adjustment of industry structure, improving the utilization of water resources, water conservation and finally pollutant reduction and sewage recycling.

Keywords: Kunming City; carrying capacity of water resources(CCWR); system dynamic model (SD); scenario simulation

1. Introduction

CCWR is one of the most important requirements for urban sustainable development. It is the biggest support ability of water resources supporting social economy, population and natural ecological environment in some historical stage, which takes foreseeable technology, the economical and the level of development of society as the basis, the sustainable development as the principle, and maintaining the ecology positive cycle development as the condition under the reasonable development use.[1-2]

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For the water resources system interacts with social economic system and ecological environment system, using SD can be appropriate to calculate and predict the dynamic change process of the CCWR. The study of HUI [3], HUANG [4], and ZUO [5] had used the model to simulate and forecast the CCWR of different cities in China.

There were few researches on Kunming City's CCWR, excepting WANG[6](2001). Based on the analysis of water demand of social economy and urban development in Kunming, SD model of CCWR of Kunming was constructed. And the different scenarios were simulated dynamically to explore optimal countermeasure for improving the CCWR of Kunming in 2010-2020.

2. Materials and methods

2.1. Data and modeling approaches

2.1.1. Data

The data in model included social and economic statistical data, water resources statistics data, environmental protection data, city planning and construction standards, and water consumption standards, which came from *Kunming statistical yearbook in 2006-2010*, *Yunnan province water resources bulletin in 2006 -2009, Yunnan statistical yearbook in 2007-2010, Kunming environmental bulletin in 2006-2010, The urban land use types and planning construction land use standard GBJ 137- 90(class III），Kunming municipal government work report of 2011 and Yunnan Province Profession Water used ration.*

2.1.2. Subsystems of model

The space boundary of the SD model was the entire range of Kunming. Model simulation was divided into two stages, and simulation time step is 1a. The first stage tested history data during 2005-2009. The second simulation section is from 2010 to 2020 in order to simulate and forecast CCWR of Kunming under different scenarios. In the second stage, taking water resources demand for supply as the principle, and taking the supply and demand basic equilibrium of water resources for the future as the control target. The added value of the first industry, the second and the third industry, and total population that water resources can support were used to measure the CCWR of Kunming. The model was composed by water resources, social economy, population, domestic water, urban environment and waste water treatment, and it was divided into nine subsystems (Fig.1).

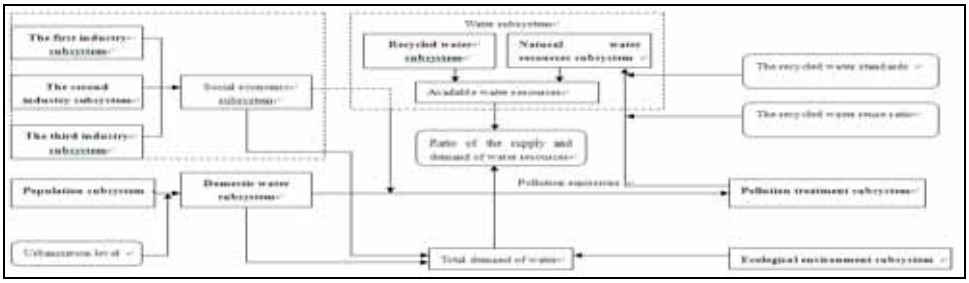


Fig. 1. Framework of SD model on CCWR in Kunming City

Water resources supply and demand ratio (WRSDR) of 2010- 2020 year was used as the total control variable in order to measure water resources supply and demand equilibrium. Simulation value reach 1.05 or fluctuate as much as possible in 1.05 to make water resources supply and demand balance, and leave

some space. The highest simulation value does not surpass 1.10. Water resources can not support the development of Kunming city if it is less than 1.00. The model is realized by Vensim PLE 5.7a.

2.1.3. Calibration and corrections about the model

Simulation data that relative errors were less than 5% between simulation value and the real value are above 95%. Further, paired t test between simulations and real data in 2006- 2009 showed the correlation coefficient was 0.999 (t was 0.807 and p was 0.428). The p was greater than the significance level of 0.05.Those showed simulation results compare no significant difference with the real data, and the model can be used for simulation.

2.2. Scenario establishment

Under the condition of maintaining the three industries growth rates, the natural population growth and urbanization in Kunming, four scenarios were established.

(1) First, remaining current water utilization scenario

The rate of natural water resources exploitation and utilization was 29.4%.The water consumption level of three industries, domestic water, renewable water, and COD maintain after waste water treated ratio as same as the base year level.

(2) Second, improving the EUWR strategy scenario

This scenario involved improvement of exploitation and utilization of natural water resources and highly sewage recycle. In the base year, natural water resources in Kunming city are $21.5\times10^8 m^3$, rate of reused water in main City was 66.1% and available recycled water was $1.42\times10^8 m^3$. Based on research of BAI Shao-guang[7], the rate of the development and utilization of natural water resources will be 39.6% in 2020. *Kunming Municipal government work report in 2011* showed the rate of reused water in main City will be greater than 80% at the end of Twelfth five year. In *conservation water professional planning about main city of Kunming in 2006-2020*, the rate of recycled water in main City will be greater than 90% in the 2020s'.

(3) Third, conservation water strategy scenario

At the end of Eleventh five-year, effective coefficient of irrigation was about 0.55 in Kunming. According to *the overall planning of the circular economy development of Kunming in 2008-2020,* effective coefficient of irrigation will improve from 0.6 in 2015 to 0.7 in 2020. According to *Yunnan region and industry water efficiency evaluation system study (Technical Briefs)*, water consumption of ten thousand CNY value added of industry will drop from $118.1 m^3/10^4$ CNY in 2009 to $75 m^3/10^4$ CNY in 2015, and to 55 $m^3/10^4$ CNY in 2020. Because water consumption of ten thousand CNY value added of the third industry was $13 m^3/10^4$CNY in 2007, $6.82 m^3/10^4$CNY in 2008 and $9.3 m^3/10^4$ CNY, water consumption of ten thousand CNY value added of the third industry was set as $7 m^3/10^4$ CNY in 2010-2020 in the model.

Residents water was $131 m^3$/cap·d in the base year. According to *Yunnan local standards-water quota DB53. T168-2006* and considering the improvement of citizen living level, the residents water was set as $140 m^3$/cap·d in 2015-2020. In second scenario, the rate of the EUWR maintains as the base level.

(4) Fourth, comprehensive strategy scenario. The second scenario and the third scenario were synthesized.

3. Analysis of simulation results

Tab.1 and Tab.2 show simulation results under four scenarios.

Table 1. Prediction of water resources carrying capacity under four scenarios in Kunming

Scenario category	Supporting time/a	SAV* of the 1st industry /10^8CNY	SAV of the 2nd industry /10^8CNY	SAV of industry /10^8CNY	SAV of the 3rd industry /10^8CNY	Supporting GDP /10^8CNY	Supporting population /10^4people	Water shortages	
								year /a	WRSDR
1st	2009	114.90	824.59	632.36	869.97	1809.46	628.0	2010	0.96
2nd	2009	114.90	824.59	632.36	869.97	1809.46	628.0	2010	0.99
3rd	2010	126.39	944.16	720.89	1000.47	2071.01	633.7	2011	0.98
4th	2020	327.82	3656.78	2672.50	4047.44	8032.04	693.05	2021	0.96

Table 2. Related data prediction of water resources carrying capacity under four scenarios in Kunming

Scenario category	Supporting time/a	Total available water resources /10^8m^3	WRSDR	Industrial structure	Ratio of water requirement （1:2:3:4:5）**	Total emissions of COD /10^4T	Recycled water
1st	2009	22.91	1.03	6.3:45.6:48.1	38.0：33.5：0.93:11.63:13.21	2.01	1.42
2nd	2009	22.91	1.03	6.3:45.6:48.1	38.0：33.5：0.93:11.63:13.21	2.01	1.42
3rd	2010	23.00	1.01	6.1:45.6:48.3	34.40:35.17:3.92:14.89:11.61	2.09	1.47
4th	2020	31.42	1.00	4.1:45.5:50.04	23.08:42.63:15.03:10.23:15.03	1.86	2.47

*Note: SAV for *the supporting added value*

**Note: Ratio of water requirement 1:2:3:4:5 means irrigation water requirement: industrial water requirement: the third industry water requirement: domestic water requirement: Urban environment water requirement.

3.1. The first scenario

Simulation data showed water resources supporting the development of Kunming would be unsustainable because in 2010 available water resources will appear nearly $1.0x10^8m^3$ shortages.

3.2. The second scenario

Simulation data showed CCWR would be same as first scenario，water resources cannot support the development of Kunming in the future. But water deficit will be less $0.7\times10^8m^3$ than first scenario.

3.3. The third scenario

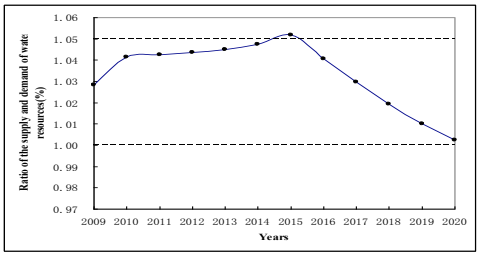
Water resources supporting the development of Kunming will be one year longer than the first and second scenario. In 2011 available water resources will appear the shortages of $0.38x10^8m^3$. Under the condition that water resources exploitation and utilization rate won't be improved, water conversation will significantly increase water-use efficiency.

3.4. The fourth scenario

CCWR of Kunming will be extremely improved and supporting time will be extended to 2020 year. Improving the EUWR will increase the quantity of available water resources. That will increase more

$8.51\times10^8m^3$ than the base year's. Emissions of COD will be less 7.5% than base year. Improve recycled water standards will increase available water resources quantity and reduce the pressure on environmental pollution.

As available water resources quantity can be guaranteed, water conservation efficiency will be obvious. Embodied as follows: ①Annual irrigation water requirement will drop to $7.23\times10^8m^3$ in 2020, while effective irrigation area will increase from $13.33\times10^4hm^2$ in the base year to $14.93\times10^4hm^2$ in 2020. ② Annual industry water requirement will increase from $7.47\times10^8m^3$ to $14.32\times10^8m^3$. It will be more 191.7%, but industrial added value will increase 422.6%. ③On the basis of water conversation, unilateral water-use efficiency of the third industry will increase 30%.The total water demand of the third industry will be $2.83\times10^8m^3$ in 2020. ④Under improving people water conditions in the life, supporting population will be more 65.5×10^4 people in 2020. Under combined action of improving the EUWR strategy and water conversation, the value added of the first industry, the second industry and the third industry in 2020 will be respectively more 285%、443% and 422%. In 2020, ten thousand CNY GDP water requirements will be less $84m^3/10^4$ CNY than in the base year's. Under the comprehensive strategy scenario, simulated data showed that water resources of Kunming could well support the high speed development of social economy and rapid urbanization (Fig.2).



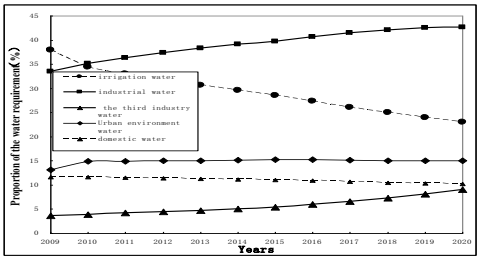


Fig.2. Change on water supply and demand balance under comprehensive scenario (left)
Fig.3. Change on proportion of water demand under comprehensive scenario (right)

Under the comprehensive strategy scenario, water demand structure will be large changed (Fig.3). The proportion of irrigation water requirement will drop obviously. The second and third industry water requirement will greatly increase. The proportion of domestic water requirement will descend slowly and the proportion of environmental water will grow slowly. In 2020 the exploitation and utilization of natural water resources will reach high level. If the exploitation and utilization of natural water resources will further increase, it must bring forth the quite tremendous pressure on ecological environment. The proportion of industry water requirement will grow from 33.5% in 2009 to 42.63%. But the proportion of industry GDP that can support will be a little more than 45.5%. If maintain the growth rate of industry during Eleventh five-year and cut ten thousand CNY value added of industry water requirement 30% every 5 years, in 2025,the water shortage of Kunming will be $7.92\times10^8m^3$,meaning industry proportion of water requirement will be too large.

4. Discussion

Adjusting industrial structure will be fundamental of improving CCWR of Kunming. With combined action of improving the EUWR strategy and water conversation, water resources can well support the high speed development of three industries. But continuous growth of industry water requirement will bring forth serious contradiction with the third industry water requirement, domestic water and environmental water. So under the conditions that ten thousand CNY industrial added value water

requirement will be deducing difficulty, the growth rate of industrial and second industry should be reduced suitably, while growth the rate of the third industry should maintain high speed or further speed.

In coming decades, the high-speed development of social economy and rapid utilization of Kunming will put forward higher request for water resources carrying capacity.

5. Conclusion

This research used the model of SD, taking water resources, social economy, population, domestic water, urban environment and waste sewage treatment into account so as to construct SD model of CCWR of Kunming. The model is feasible through the simulation test and simulation results analysis.

Under comprehensive strategy scenario, CCWR of Kunming will be extremely improved and supporting time will be extended to 2020. And, water resources can well support the high speed development of social economy and rapid urbanization. Meanwhile, the implementation of the comprehensive strategy will greatly improve CCWR of Kunming. Supporting time, the social economy and population may achieve maximum. Combination of improving the EUWR, water conservation, and adjusting industrial structure will be the optimal strategy to improve CCWR of Kunming.

Acknowledgements

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