

Assessment of Water Resources Carrying Capacity for Sustainable Development Based on a System Dynamics Model: A Case Study of Tieling City, China

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Received: 4 February 2014 / Accepted: 16 October 2014 /
Published online: 23 October 2014
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Abstract Studies of water resources carrying capacity (WRCC) can provide helpful information about how the socio-economic system is both supported and restrained by the water resources system. As such, there is a need to develop better quantitative assessment methods to determine the potential maximum socio-economic growth within a catchment subjected to a given amount of water resource. An improved WRCC assessment method based on a system dynamics model (WRCC-SDM) is proposed in this paper. WRCC-SDM is built on synthesis simulations of coupling effects and feedback mechanisms within the society-economy-water compound system. The results can integrally represent system behaviors and states, and the evaluation of WRCC is achieved using this model. Moreover, an integrated indicator (Population-GDP-GDP per capita) is proposed to express the threshold value of WRCC. Based on the natural water resources supply capacity and associated socio-economic development potential, the concepts of critical WRCC and extreme WRCC are put forward. Critical WRCC represents the socio-economic scale that will cause total water demand to reach the maximum natural water resources supply capacity, while extreme WRCC reflects the socio-economic scale when the GDP growth rate constrained by limited water resources is zero. The methodology was applied to assess the water resources situation in Tieling City, China under different scenarios. The results indicate that: (1) Given the constraints represented by water resources, projected GDP growth tends to follow an S-curve growth pattern; and (2) Rapid population growth may lead to earlier and more severe water resources constraints.

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Keywords Water resources · Carrying capacity · Water equilibrium · System dynamics · Assessment

1 Introduction

Water, as one of the most important natural resources, is essential for the maintenance of the integrity of ecosystems and for the development of human society and economy. The scale of socio-economic development needs to be within a range that available water resources can reasonably sustain. It is, therefore, critical to determine the scale of socio-economic development that can be supported by the available water resources (Gong and Jin 2009)—i.e., the water resources carrying capacity (WRCC), and, specifically, to develop a suitable and objective quantitative evaluation of WRCC. By studying WRCC at the regional scale, it is possible to discern how the society and economy are both sustained and restrained by available water resources, and these research findings can in turn contribute to the development of plans that integrate population, economy, water resources and environment together in sustainable ways. WRCC research has become an important aspect of water resources management, and the development and utilization of water resources should be within the range of WRCC as an important criterion for sustainable water resources management.

The biggest challenge for WRCC research at present is to formulate a method of quantitative assessment of the concept, which can then be used to develop reliable guidelines for water resources management (Song et al. 2011). Current WRCC assessment methods can be divided into two main groups: the comprehensive assessment method (CAM), and the quantitative analysis method (QAM). CAM involves building up a WRCC index system through analyzing likely influencing factors, and calculating the WRCC aggregative index (this is generally a dimensionless index from 0 to 1, or 0 to 100) through the adoption of multi-index assessment methods, to determine whether water resources have been over-used (Gong and Jin 2009). However, this method is often confined to an independent assessment of the influencing factors, without considering their coupling effects. Furthermore, selecting the indicators and the assessment criteria is a subjective process. In QAM, the WRCC is calculated through mathematical equations or models, and quantified via the numerical values of population and GDP (Xu et al. 2002; Wang et al. 2013). This method has resulted in a real breakthrough in exploring the interactions among the various WRCC influencing factors, and the assessment results can also be represented by population size and economic scale. The main problem of QAM is that it is difficult to establish rational equations and models for WRCC assessment (Feng et al. 2008; Wei et al. 2012).

WRCC essentially presumes a state of equilibrium between the water resources system and the socio-economic system in a given area. Thus, a WRCC quantitative assessment should be based on a simulation of the internal coupling effects of the entire system. For such a complex system, system dynamics (SD) is a more effective simulation tool. Although the SD approach has already been applied to WRCC assessment, its application is limited to simulating future values of evaluation indicators for the CAM (Han et al. 2010). Obviously, this approach does not fully exploit the full advantages of an SD model (Mirchi et al. 2012).

The objective of this study then is to propose an improved WRCC quantitative evaluation method, built on a synthesized simulation of the society-economy-water compound system. To do this, an SD model for WRCC assessment (WRCC-SDM) is developed to simulate population size, economic growth and their coupling effects on water resources. WRCC-SDM can play a good advantage of SD to achieve the dynamic simulation of the response

relationship between the water resources system and the socio-economic system. Thus, WRCC-SDM can be used for the quantitative assessment of WRCC under different development scenarios.

2 Study Area and Methodology

2.1 Study Area

Tieling City, covering an area of 12,985 km², is located in Liaoning province, China (Fig. 1). In 2011, the total population of the city was 3.04 million, GDP was 87.38 billion RMB Yuan, and it had experienced rapid economic growth since 2001 (Tieling Statistical Yearbook 2011). The city's mean annual precipitation is 665 mm, and the mean annual water resources are 2.56 billion m³. Based on the 2011 population, the water resources per capita for the city are 839 m³, which is only one-third of China's per capita amount (Water Resources Bulletin of Tieling 2011). Population expansion and further development of the social economy will be constraints on the sustainable development of this region, if water resources issues cannot be better addressed.

2.2 Methods

An integrated system dynamics model, WRCC-SDM, was developed through study of the interactions among water resources, water environment and socio-economic system and was applied to assess the WRCC of Tieling City. WRCC-SDM was developed using the professional

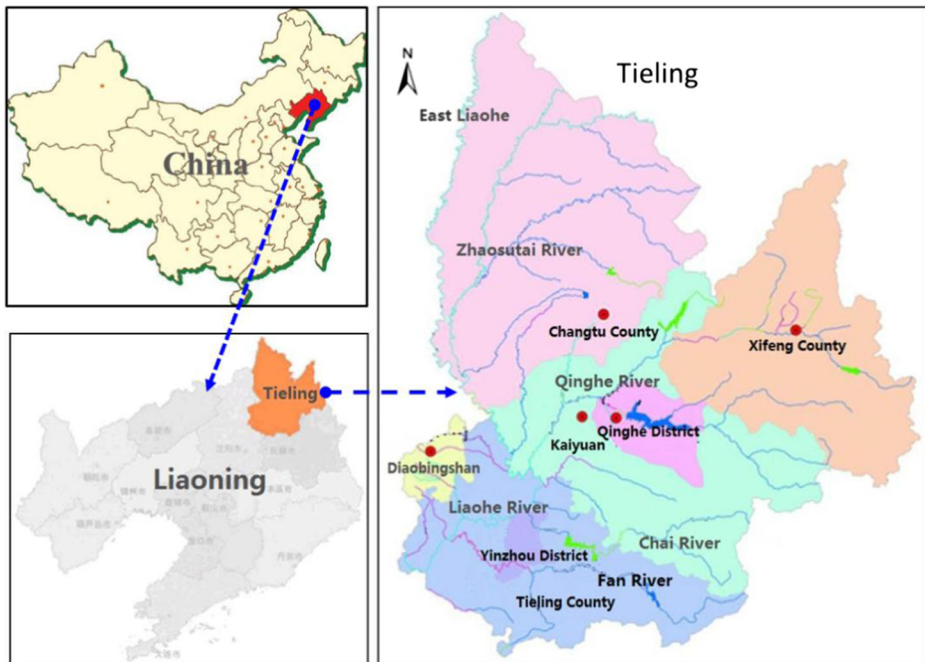


Fig. 1 Location of Tieling City and its major rivers

software “Vensim DSS Version 6.1c Development Tool” (Ventana Systems Inc., Harvard, MA, USA), and was simulated for the period from 1995 to 2100, with yearly time steps.

2.2.1 The System Dynamics Model

System Dynamics (SD) is a computer-aided approach to problem analysis and design of solutions. It applies to dynamic problems arising in complex social, managerial, economic, or ecological systems – literally any dynamic system characterized by interdependence, mutual interaction, information feedback, and circular causality (Chen and Wei 2013). SD has already been widely applied to studies of socio-economic, resources and environmental systems (Winz et al. 2009; Chen and Wei 2013).

Currently, the most useful software packages for building SD models are Vensim, STELLA, and Ithink (Gastélum et al. 2009). Normally, an SD modeling and simulation process can be divided into the following steps: (1) Analyze the research objective systematically, and then define the purpose of modeling and the boundaries of the system (problem identification); (2) Identify the causal structures that influence the issues presented in the system, and depict these with flow graphs; (3) Construct a computer simulation model and quantitatively express causal feedback structures with mathematical equations; (4) Conduct model behavior analysis, model testing and evaluation; and (5) Apply the model to a specific situation.

2.2.2 The WRCC-SDM Framework

WRCC-SDM identifies the interactions between human behavior and the water resources system from the perspective of system analysis. This is achieved by presenting a causation chain that could lead to water resources problems, and using WRCC-SDM to describe system behaviors objectively. The main advantages of WRCC-SDM are:

- (1) WRCC-SDM can comprehensively simulate and illustrate the society-economy-water compound system. Covering the factors of economy, society, water resources, water environment and policy, the WRCC-SDM framework integrates and simulates changing trends in these factors within a complex system, which encapsulates the interactions of these factors;
- (2) The feedback effects of water resources availability and quality on the social economy can also be incorporated. The interaction of population, GDP, industrial structure, capital investment, labor capacity and other socio-economic factors can thus be taken into account and the feedback relationship between the water resources factors and the socio-economic factors (such as water consumption, water efficiency, sewage discharge and treatment costs) can be highlighted;
- (3) WRCC-SDM is based on detailed parameter estimations and numerical equations by means of the SD model and the coupled mathematical model, thereby reducing uncertainties and improving the accuracy of the model;
- (4) WRCC-SDM can be applied in either an optimization mode or in a simulation mode combined with scenario analysis.

Within WRCC-SDM, the assessment of WRCC is conducted in two stages according to the limitations of the water resources system and regulating capability of the socio-economic system. The first stage is to calculate the supply capacity of local water resources, and the second stage is to simulate the appropriate socio-economic scale with a certain development level that these water resources could support. WRCC-SDM has four sub-modules as shown in

Fig. 2; they are population-GDP module, natural water resources supply module, water demand-consumption module, and water equilibrium module. Among these, the first module is applied in the first-stage calculations; the other three modules are used in the second-stage simulation. There are 185 variables and parameters including five level variables, 19 constants and 161 functions in the overall model.

2.2.3 WRCC-SDM Sub-modules

(1) Population-GDP Module

The population-GDP module, which simulates rapidly changing population and GDP, is a significant and integral part of the WRCC-SDM framework. In the developmental stage of industrialization, GDP growth is closely related to fixed capital investment and labor force growth. The Cobb-Douglas production function (Chow and Li 2002; Holz 2008) defines economic growth factors as the labor force, the fixed capital stock and “other factors” (identified here as “technological advances” or “growth in total factor productivity”). This is a mathematical model that can be applied to predict the economic development of a country or region. The conventional production function formula is:

$$\hat{Y}_t = c + b_L \hat{L}_t + b_K \hat{K}_t \tag{1}$$

where: \hat{Y}_t is the GDP growth rate; \hat{L}_t denotes the growth rate of labor force; \hat{K}_t is the growth rate of fixed capital stock; c denotes the influence of random disturbances that can be accepted as the index of the quality of the labor force and technology-level impacts; b_L is the elastic coefficient of labor output; and b_K is the elastic coefficient of capital output.

In more recent applications, Qin et al. (2011) have converted Eq. (1) into Eq. (2):

$$\hat{Y}_t = \frac{c + b_L \left(\frac{GL_{t-1}}{GL_t} - 1 \right) + b_K \hat{K}_t}{1 - b_L \times \frac{GL_{t-1}}{GL_t}} \tag{2}$$

where: GL_t denotes the GDP per worker for year t.

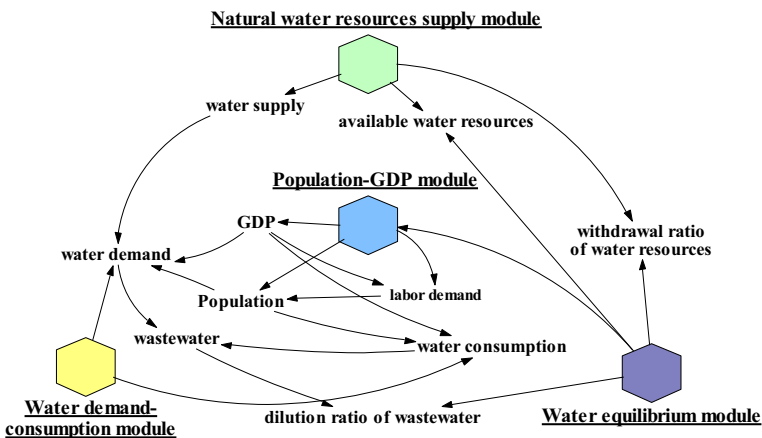


Fig. 2 Schematic diagram of WRCC-SDM

Equation (2) was adopted in this study as the model for predicting GDP growth in WRCC-SDM. The values of the coefficients c , b_L and b_K were determined via an optimization method based on Tieling City data. First, time-series data for \hat{Y}_t , \hat{K}_t and GL_t from 1995 to 2007 were obtained. Then, based on these data and Eq. (2), the optimization solution method was used to generate a set of values of c , b_L and b_K , which can make the relative error in \hat{Y}_t smaller. Thus, the GDP growth rate could be simulated by inputting the predicted values of GL_t and K_t , while the Perpetual Inventory Method (PIM) was adopted to measure the fixed capital stock (Huang et al. 2002). The PIM formula is:

$$K_t = K_{t-1}(1 - \delta_t) + I_t \tag{3}$$

where: K_t is the capital stock for year t ; I_t is the investment for year t ; and δ is the economic depreciation rate.

Based on the above production functions, the impacts of water resources availability and water quality on socio-economic development were further considered. Several feedbacks and interactions that could influence GDP growth were analyzed as follows:

- a. The impacts of water shortage and water pollution on investment and fixed capital stock were described through two graphical functions (the multiplier of the water resources' impact on investment, and the multiplier of the water environment's impact on investment);
- b. Water shortages affecting the immigration of the labor force are presented here by the multiplier of the water resources' impact on labor migration (graphical function);
- c. Severe water shortages and water pollution will directly constrain GDP growth, and are expressed here through two graphical functions (the factor of water resources' impact on GDP growth rate, and the factor of the water environment's impact on GDP growth rate, respectively).

Changes in population are influenced by three factors: birth rate, death rate and population migration numbers (Qin et al. 2011). Birth rate and death rate can be deduced from historical information and empirical data. In this study, population migration rate was predicted based on the analysis of labor supply and demand balance, namely the difference between the local labor force and labor demand. The impact of water resources is taken into account in the prediction of population migration via graphical functions.

(2) Natural Water Resources Supply Module

The purpose of natural water resources supply module is to allow calculation of the local water resources supply capacity of the natural system, which is the fundamental supportive factor for WRCC. The main variables of this module are: the amount of available water resources (AWR), and the amount of surface water withdrawal (SWW). These can be estimated by the following equations:

$$AWR = AGWR + ASWR + OAWR \tag{4}$$

where: $AGWR$ is the available ground water resource, $ASWR$ is the available surface water resource, and $OAWR$ is other available water resources, mainly wastewater reuse and collection of rainwater.

$$SWW = TWS - GWS - OSWS \tag{5}$$

where: *TWS* is total water supply, *GWS* is ground water supply, and *OSWS* is other sources of water.

(3) Water Demand-Consumption Module

The purpose of water demand-consumption module is to simulate changes in the amount of water demand and consumption resulting from population growth, urbanization and economic development. In this study water demand refers to the gross water amount consumed by all types of water users. The gross amount of water demand includes the conveyance loss of water, domestic water demand, industrial water demand, agricultural water demand, and “other” water demand (Water Resources Bulletin of Tieling 2011). Domestic water demand includes urban domestic water demand, made up of the residential use of water and the public use of water (including the water use by tertiary industry and the construction industry), and water demand in the rural area (including use for both rural residents and livestock). Industrial water demand consists of the demand for fresh water, excluding water recycling within enterprises. Agricultural water demand is made up of irrigation water demand and fishpond water recharge. Other water demand consists mainly of the demand for sanitation water in the urban area and the water restoration requirements of rivers, lakes and wetlands. In this study, predictions of the amount of water demand and consumption were determined based on water efficiency and correlated with the level of socio-economic development (Qin et al. 2011).

(4) Water Equilibrium Module

This sub-module simulates the state of the water resources system and its feedback to the social economy via pressure from water consumption and wastewater pollution. Based on water balance analysis, the withdrawal ratio of water resources (Arnell 1999) and the dilution ratio of wastewater (Huang et al. 2008) are computed to reflect the status of water resources utilization. They are subsequently connected to the level of fixed capital investment, GDP growth rate and labor migration to establish the feedback relationship with the socio-economic system through graphical functions.

2.2.4 Model Testing

The simulation results for the main variables of the Tieling City WRCC-SDM were validated by data from 2008 to 2011. The validated variables included population, GDP, GDP growth rate and total water demand (Table 1). All the 16 relative errors in these four indicators from 2008 to 2011 were below 10 %. The test results show that the simulated data for the main variables matched well with actual data from Tieling City. This match is a clear indication that the model could be effectively applied to simulate the compound society-economy-water system of Tieling City.

3 Case Study

In this study, WRCC-SDM is used to simulate the economic development of Tieling City subjected to water resources and population growth constraints. The water resources constraints were selected to reflect the effects of water scarcity on social and economic development; while population migration was selected to represent population changes taking account of the intrinsic linkages between population and GDP growth on water demand. With the

Table 1 Actual values and simulated values of main variables in the WRCC-SDM of Tieling City

Year	Population (10^6 persons)			GDP (10^9 Yuan)			GDP growth rate (%)			Total water demand (10^9 m ³)		
	Simulated value	Actual value	Relative error (%)	Simulated value	Actual value	Relative error (%)	Simulated value	Actual value	Relative error (%)	Simulated value	Actual value	Relative error (%)
2008	3.037	3.059	-0.73	46.05	46.05	0.00	23.75	22.37	6.16	1.05	0.99	5.63
2009	3.042	3.061	-0.63	56.99	53.67	6.18	17.47	16.55	5.58	1.13	1.05	7.74
2010	3.037	3.051	-0.47	66.95	61.29	9.23	14.44	14.20	1.70	1.09	1.03	6.26
2011	3.039	3.049	-0.33	76.62	71.94	6.50	16.32	17.37	-6.07	1.15	1.10	4.45

application of WRCC-SDM, four scenarios (denoted by A, B, C, and D) were simulated in this study:

- (A): Without water resources constraints but with population migration;
- (B): Without water resources constraints and without population migration;
- (C): With water resources constraints and population migration;
- (D): With water resources constraints but without population migration.

3.1 Simulation of Socio-economic Development Without Water Resources Constraints

The scenario where water resources constraints are not applied is designed to simulate an abundance of water resources in Tieling City. In this situation, scenarios with labor migration (A) and without labor migration (B) were separately simulated with WRCC-SDM. The results of the simulations are shown in Fig. 3 and can be summarized as follows:

- (1) Without water resources constraints population in-migration will promote much higher economic growth. According to the simulation results shown in Fig. 3, only a small level of in-migration is expected in Tieling City prior to 2020, and in some years the city will even experience some out-migration. After 2020, however, rapid local urbanization will attract massive numbers of people (mainly young laborers from rural areas), who in turn will generate a rapid growth in GDP. Between 2020 and 2100, GDP is expected to rise by 23.9 %, which is more than it would without labor immigration;
- (2) It is also evident from the results that a large influx of people is not conducive to building a higher GDP per capita. In addition, large numbers of immigrant laborers will stimulate

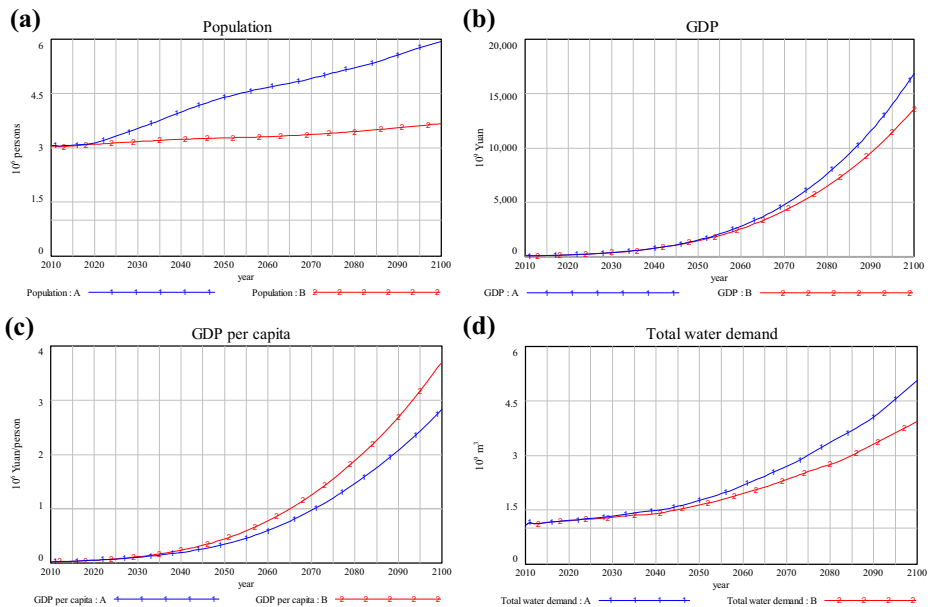


Fig. 3 Simulation results of scenario A and scenario B

the development of labor-intensive industries, which will lead to a reduction in the quality of economic growth and the level of socio-economic development;

- (3) A large population, driven by in-migration, will also lead to growth in total water demand. By 2100, water demand will be 28.9 % more than it would without labor in-migration, driven mainly by the large population increase and a higher GDP.

3.2 Simulation of Socio-economic Development with Water Resources Constraints

3.2.1 The Overall Results

In fact, as the population and GDP growth reach a certain level, water shortages will unavoidably constrain socio-economic development. In this study, the available mean annual water resources were selected as an indicator of the limited supply capacity of the natural water system in Tieling City. The total annual available water resources of Tieling City are calculated as 1.43 billion m³, which is 55.9 % of the city’s mean annual water resources. Taking the water constraints into account, two scenarios were separately simulated; they were C with labor migration; and D without labor migration. The major results are shown in Fig. 4 and can be summarized as follows:

- (1) WRCC has a threshold, beyond which socio-economic development will be constrained. As shown in Fig. 4, when the total water demand exceeds the amount of available water resources, GDP growth will not follow the exponential growth pattern (as it would without water constraints), but would instead follow

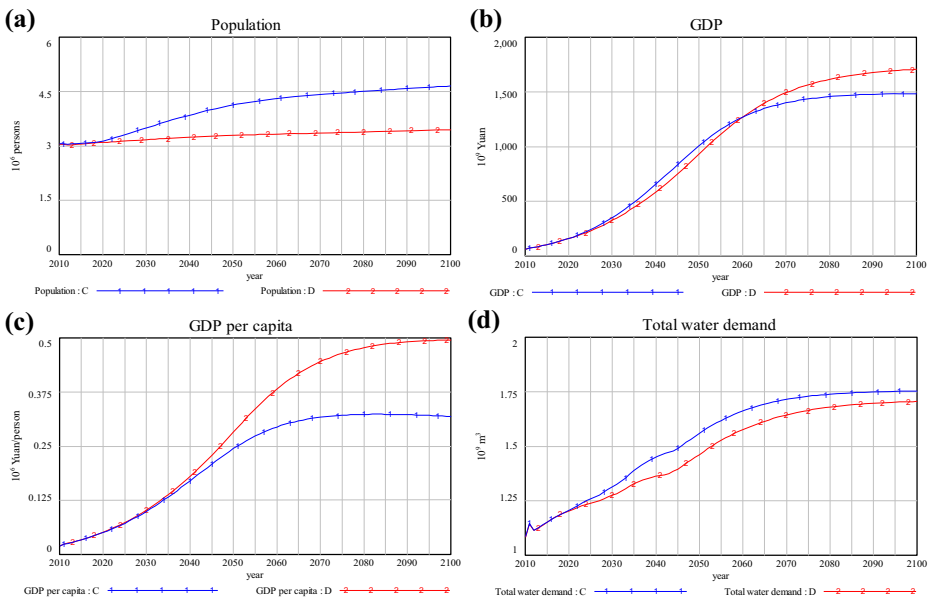


Fig. 4 Simulation results of scenario C and scenario D

- an S-curve growth pattern. When water shortages occur, domestic water supply will be the top priority, and commercial water use will be constrained. Hence it is not the lack of water that will cause a rapid drawdown of population, but rather the consequent inhibition of economic development. This lack of growth will result in a reduction in GDP per capita, and a drop in the standard of living. In other words, when the total water demand continues to rise above a certain threshold, GDP growth will slow down, or even stop. Hence strong constraints of water resources on economic growth can be anticipated;
- (2) A substantial increase in population will trigger larger water constraints earlier. Table 2 shows the average annual GDP growth rate for each 20-year period from 2000 to 2100. From the analysis of scenarios C and D in Table 2 and Fig. 4, it can be seen that with the labor force advantage in scenario C, a faster rate of GDP growth could be achieved, either without water constraints or with only weak water constraints. However, with the rapid growth of population and GDP, water demand will also increase dramatically and exceed the available supply, which will lead to a decline in economic growth, and ultimately to unsustainable development if it continues;
 - (3) Comparing the simulation results of scenarios A and C, it can be seen that the Tieling City water resources system will have a large constraining influence on the level of its socio-economic development. In 2100, the population in scenario C is 78.3 % that of scenario A, GDP is 8.8 % and GDP per capita is 11.2 %. These results indicate severe constraints to economic development, in scenario C.

3.2.2 Detailed Results from Scenario D

Among the scenarios A, B, C and D, scenario D is most likely to be the future development pattern of Tieling City, because the water resources constraints actually exist and population growth will not change dramatically given China's current population policy. Taking scenario D as the example, the detailed simulation results of population structure, economic structure and water demand are presented in Fig. 5. In scenario D, population growth is very slow; rural population is decreasing, while urban population is increasing gradually, which reflects the current urbanization process of Tieling City. The trend of economic restructuring is a shift from secondary industry (currently the dominant industry) to tertiary industry. As for water demand, the demand from economic activities is seen to be the most dominant in this scenario, with the highest demand coming from primary industry and the largest potential increase in water demand coming from tertiary industry.

Table 2 Comparison of average annual growth rate of GDP between scenario C and scenario D

Scenarios	Average annual growth rate of GDP (%)				
	2000–2020	2020–2040	2040–2060	2060–2080	2080–2100
C	13.60	7.34	3.36	0.70	0.09
D	13.58	6.74	3.96	1.21	0.28
Difference	0.02	0.59	−0.60	−0.52	−0.19

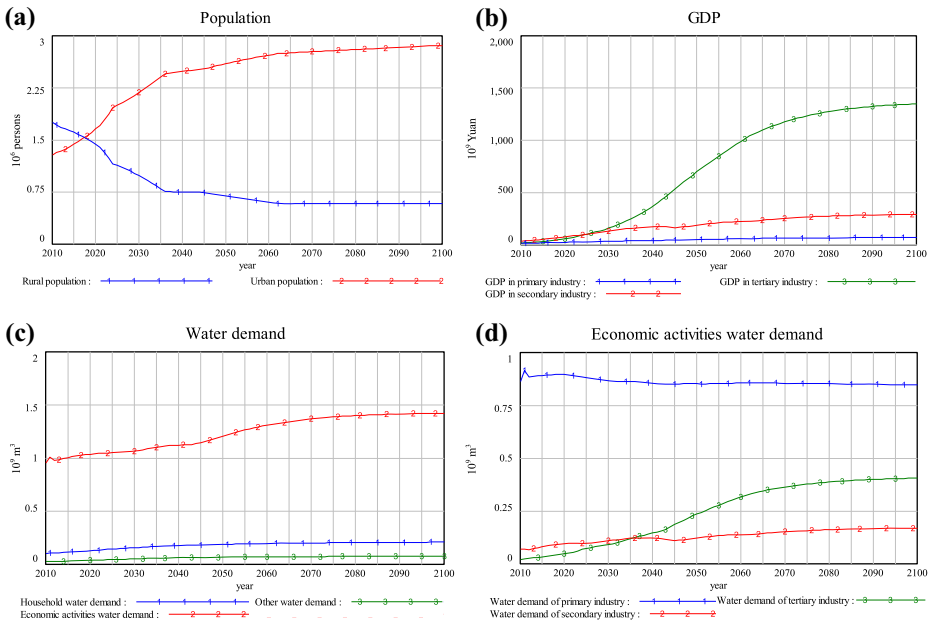


Fig. 5 Simulation results in scenario *D*

4 Discussions

4.1 The Threshold Value of WRCC

To quantitatively present the WRCC threshold value, the most appropriate forms of expression and indicators need to be determined. Based on the conceptual framework of WRCC, socio-economic scale should be selected as a primary measure (Han et al. 2010). The main parameters representing socio-economic scale are population and GDP (Song et al. 2011). However, because of the competition between domestic water demand and industrial water demand, adopting only the maximum population or maximum GDP to represent WRCC is meaningless. Consequently, in this study, the combined indicator Population-GDP-GDP per capita was adopted to express the threshold value of WRCC. Among these indicators, GDP embodies the concept of maximum value, while population does not, because when water shortages occur, domestic water supply needs to be guaranteed as the top priority, and water demand for economic activity is usually the first to be constrained. Economic development will thus remain stagnant when there is a severe shortage of water resources, but increases in population would probably not be much affected. The indicator of GDP per capita should therefore be used to demonstrate the levels of social development and affluence under the threshold value of WRCC.

Meanwhile, to quantitatively represent the WRCC, the specific situation for obtaining the threshold value should be determined. In this study, the situations of critical WRCC and extreme WRCC are put forward. Critical WRCC represents the socio-economic scale when total water demand reaches the maximum natural water resource supply capacity (critical WRCC values for scenarios C and D are shown in Fig. 6). Extreme WRCC reflects the socio-economic scale when the GDP growth rate constrained by limited water resources is zero (with 2-decimal precision, less than 0.005). Within the critical WRCC range, it can be seen that

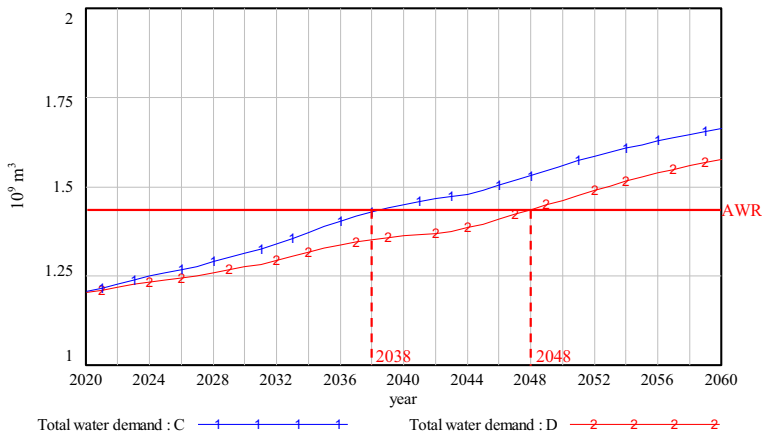


Fig. 6 The occurrence years of critical WRCC in scenario *C* and scenario *D*

conflict between socio-economic development and available water supply is in reasonable balance. When the socio-economic scale is higher than the critical WRCC, the constraints of water resources on socio-economic development become stronger and will cause economic stagnation, eventually leading to the extreme WRCC. According to the simulated results of WRCC-SDM (Fig. 4), the following can be noted as conclusions in this situation:

- (1) In scenario C, the critical WRCC and extreme WRCC situations are projected to appear in 2038 and 2072, respectively. In 2038, the projected integrated indicator states that Tieling City is likely to be able to support a population of 3.78 million people with a GDP of 585 billion Yuan, giving a GDP per capita of 155,000 Yuan. In 2072, Tieling City is likely to be able to support a population of 4.43 million people, with a project GDP of 1.42 trillion Yuan, giving a GDP per capita of 319,000 Yuan;
- (2) In scenario D, the critical WRCC and extreme WRCC situations are projected to appear in 2048 and 2081, respectively. In 2048, the integrated indicator states that Tieling City is likely to be able to support a population of 3.28 million people with a GDP of 856 billion Yuan, giving a GDP per capita of 261,000 Yuan. In 2081, Tieling City is likely to be able to support a population of 3.39 million people with a GDP of 1.62 trillion Yuan, giving a GDP per capita of 479,000 Yuan;
- (3) Because of inertia and the regulating capability of economic development, GDP should keep growing when total water demand is beyond available water resources, but it would soon start to fall off. The extreme WRCC values from scenarios C and D indicate that rapid population growth would lead to earlier and more severe water resources constraints because of the competition between domestic water demand and economic water demand.

4.2 Limitations of the Study

Because of the uncertainties of WRCC-SDM modeling and water resource policies, there are some limitations in both the method and results of this study:

- (1) WRCC-SDM is only a simplified mathematical expression of the society-economy-water compound system. Even though there are four sub-modules in WRCC-SDM that allow

exploration of the coupling relationships between the socio-economic system and the water resources system, some problems still cannot be quantitatively simulated by this model, such as the impacts of climate change on natural water resources, the changes in the costs of water supplies, the impacts of water resource issues on the environment and ecosystems, and so on. Ignoring the influences of these factors may lead to overly optimistic results;

- (2) A large number of parameters and graphical functions need to be determined, but these increase uncertainty in the simulation results. A variety of methods for predicting parameters and variables were adopted in this study. The main method used the socio-economic development level of a community to determine parameter values. Through establishing the graphical functions linking GDP per capita and model parameters based on existing data (for example: urbanization rate, industrial structure, intensity of water demand, and so on), the time-series values of parameters can be determined. The impacts of socio-economic development and technical progress were also considered in this method. However, the accuracy of the method is still insufficient. Moreover, there is no good way to completely verify the graphical functions, as the simulation period is too long;
- (3) There is a great deal of policy uncertainty. The end time for this WRCC-SDM simulation was chosen as the year 2100. Changes of policy within such a long period of time can hardly be predicted, and many policies could impact the results of the WRCC simulation, including population policies, economic policies, environmental protection policies, water-saving policies, water recycling policies, water diversion policies, and so on. The uncertainty about specific measures within these policies, and their implementation times, undoubtedly increases the difficulty of simulating the impacts of policy implementations.

5 Conclusions

WRCC focuses on the interaction between the water resources system and the socio-economic system, and may provide a new path and method for promoting the sustainable development of communities in relation to available water supplies. How to evaluate WRCC scientifically is the hot topic and key to WRCC research at present. This paper presents a WRCC evaluation method based on an SD model (WRCC-SDM). WRCC-SDM, as an integrated model, can synthetically simulate variations in the diverse factors within the society-economy-water compound system, and present the interactions among factors explicitly. Based on the dynamic simulation of the response relationship between the water resources system and the socio-economic system, WRCC-SDM can be used for the quantitative assessment of WRCC under different scenarios. Furthermore, the integrated measure of "Population-GDP-GDP per capita" is proposed as an indicator for WRCC, and the concepts of critical WRCC and extreme WRCC are put forward as two scenarios derived from WRCC. Within the critical WRCC range, it is considered that the conflict between socio-economic development and water supply is in reasonable balance. When the socio-economic state is beyond the critical WRCC level, water resources constraints will significantly impact on economic development and eventually lead to economic stagnation. A case study of Tieling City, China shows that WRCC-SDM is an effective tool for WRCC assessment, and can provide helpful information for promoting sustainable development.

Acknowledgments This work was financially supported by the Chinese National Specialised Projects for the Control and Treatment Technology of Water Pollution (Project number: 2013ZX07501-005).

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