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Application of an intergrated dynamic model in water resources carrying capacity study of Zhangye in China

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*Abstract:*The water resources carrying capacity (WRCC) study is intended to assess the scale of economy and population that local water resources can sustain in a certain region. The fundamental purposes of the WRCC study are to forecast the basic development path and direction of the water–ecoenvironment–socioeconomic system and to identify the key factors to promote its healthy development. Taking Zhangye district in northwest China as a case, an integrated dynamic WRCC assessment model is established based on the core model of multicriteria decision analysis and other sectoral models, including extended input-output model, land resources spatial distribution model, virtual water assessment model, WRCC comprehensive evaluation modle etc. This model provides an integrated framework for the comprehensive study of such issues as water resources development, land use, virtual water trade and socioeconomic development. Different scenarios established by different policy elements, including industrial structure adjustment, water-saving technology improvement, implementation of a “water reallocation” scheme, and virtual water trade strategy, are applied to analyse the WRCC of Zhangye.The study indicates that provided the “water reallocation” scheme and the necessary environment protection measures are implemented, the WRCC of Zhangye can support continuing economic development with an annual average GDP growth rate around 7%, and at same time, its population can continue to enjoy a “fairly comfortable” living standard according to agricultural products consumption criteria during 2000-2020 if the industrial structure adjustment and water-saving technology improvements could be achieved. The study not only assess the scale of population and economic development, but also adopts a new perspective of virtual water trade to examine WRCC in an open system. In addition, it provides corresponding socioeconomic distribution and spatial land use patterns and makes WRCC assessment results more practical.

Key-Words: Water resources carrying capacity, Water–ecoenvironment–socioeconomic system, Integrated dynamic model, Multicriteria scenario analysis, Extended input-output analysis, Virtural water trade strategy, WRCC comprehensive evaluation

1. INTRODUCTION

“Carrying capacity” originates from ecology and is expanded to the study of natural resources and environment to describe the ability of the ecoenvironment or natural resources to sustain socioeconomic activities (Feng Shangyou 2000). The statement about the restriction of crop production to the population increase should be the earliest description about the idea of “carrying capacity” (Irmi Seidl and Clem A. Tisdell, 1999). “Carrying capacity” was first defined as “the number of stock which a range can support without injury to the range” and employed to explore the interaction of the reindeer population and the environment(Pulliam and Haddand,1994). Since the Mid-21st Centry, the concept of “carrying capacity” has been widely used to study the effect of human activities on the envrionment with the increasing concerns about the growing human population and decreasing environment quality(Hawden, S.,Palmer, L.J., 1994., Hardin,G., 1986,; Kurt R.Wetzel, John F.Wetzel, 1995). At the same time, the conception itself has been evolving with the new application, for example, the macro ecoenvironment-socioeconomic system as an background of “carrying capacity” study is considered to be a must, the key factors that should be taken into account not only include the conditions of natural resources or the

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environment but also the influence of institution, value judgment, economy development and consumption model etc, and the purpose of study exceeds the domain of stock population and is extended to that of economy, social fare and even the within-generation and inter-generation fare of sustainable development(Feng Shangyou,2000).

"Water resources carrying capacity" (WRCC) is defined as "the scale of economy and population that the local water resources can sustain in a region, provided with necessary requirements of ecoenvironment protection and a given level of technology and socioeconomic development at a certain historical stage" in this paper. WRCC study has received increasing attention over the past two decades in China and has become an important approach to measure water security in order to achieve sustainable development, particularly in the areas that face serious water scarcity (Xia Jun et al. 2002).

Studies on WRCC have been carried out in different areas in China. Shi Yafeng and Qu y Yaoguang (1992) studied the WRCC of the Urumqi River basin through water demand and supply analysis. Hui Yanghe et al. (2001) applied system dynamic theory in a study on the WRCC of the Guanzhong Region. Traditional multi-objective programming approach combined with scenario analysis was used to analyze the WRCC of the Heihe basin by Xu Zhongmin (2000) in his doctoral dissertation. Similar studies have been carried out outside China: for example, an extended input-output model was adopted to study the water-economic system, characterised by taking water resources as a section in regional macro-economic planning (Steward and Scott 1995). Compared with other theories of water management, WRCC provides a framework to connect the water resources system, eco-environment system and macro socio-economic system in order to optimally allocate water resources.

There are still a lot of questions remaining uncompletely resolved in WRCC study, for example, calculation of ecological water demand, uncertainties about future development, and the coupling mechanism of the eco-economic system. The complexities, uncertainties, and dynamic characteristic of the system make the decision-making process particularly perplexing and lead to the unpredictability of the WRCC to some extent. In order to deal with these prolems, employing an integrated dynamic model instead of static ones based on the forecast or premise of definite scenarios to assess WRCC is essential.

Therefore, this paper intends to develop a dynamic and integrated model of WRCC study in the framework of multicriteria analysis and extended input-out analysis and applies it in the study of Zhangye district in northwest China. WRCC of Zhangye with different scenarios is discussed and the effects of some important policy factors on WRCC are assessed. These policy elements include adjustment of industrial factor, improvement of water-saving technology, implement of "water reallocation" scheme, virtual water trade strategy, etc. The study not only assesses the scale of population and economic development, but also adopts a new perspective of virtual water trade to examine WRCC in an open system. In addition, it provides corresponding socio-economic distribution and spatial land use patterns and makes WRCC assessment results more practical. By reason of the nature of the problem, there must be some differences between the prediction and the actual path of system development, nonethless, WRCC study should be able to predict the basic development path and direction of the water–ecoenvironment–socioeconomic system, and identify the key factors to promote its healthy development. It is also the fundamental purpose of this paper.

2. STUDY AREA

Located in the Hexi corridor in the arid area of northwest China, the Hei River is the biggest inland drainage with an area of 10,009 square kilometres. Zhangye, on the middle stream of the Hei River, is one of the highest developed districts in the basin, and agriculture with intensive irrigation is the main economic sector. Zhangye has a long history of oasis agriculture development, which is considered typical in the inland river basin in the arid area. Competition for water use between socio-economic development and environment protection is quite severe. The annual average amount of water resources of Zhangye is about 2.39 billion cubic metres, including surface water of 2.21 billion cubic metres and ground water of 0.18 million cubic metres. In 2000, the socio-economic water consumption accounted for 89.7% of the total amount of water resources, that is 2.14 billion cubic metres, of which 95.8% was consumed by agriculture, and of this amount, 86.4% was used for irrigation.

3. METHOD OF WRCC STUDY

3.1 Framework of WRCC Study

Given the role that water resources play in the socio-economic-ecosystem complex system and its relation with other system elements, this paper employs an input-output multicriteria scenario decision analysis model to study the WRCC of Zhangye. It provides an integrated framework for the WRCC study by linking the core module and the sectoral modules. The core model, a multicriteria scenario decision model, can combine various elements and subsystems and produce the results of WRCC by setting the object functions and constraint conditions and solving the optimisation problem. The sectoral modules, including the extended input-output model, the land spatial allocation model, and the virtual water assessment model, can generate results serving as the boundary values of constraint conditions of the multi-objective scenario analysis model. Finally, the comprehensive evaluation model is used to quantify the quality of WRCC in different scenarios or periods by introducing the concept "degree of membership" and serves as a tool of choosing the optimal alternatives. (Fig.1).

In the complex system of socio-economy, environment and water resources, fixed assets investments and water resources are the two most active elements; their distribution pattern not only links various sectors of the complex system, but also determines the balance of different economic sectors, i.e., the balance between economic development and environment protection. Therefore, in this study, fixed assets investments and water resources distribution are taken as the major driving forces to couple the subsystems of water resources, environment and socio-economy.

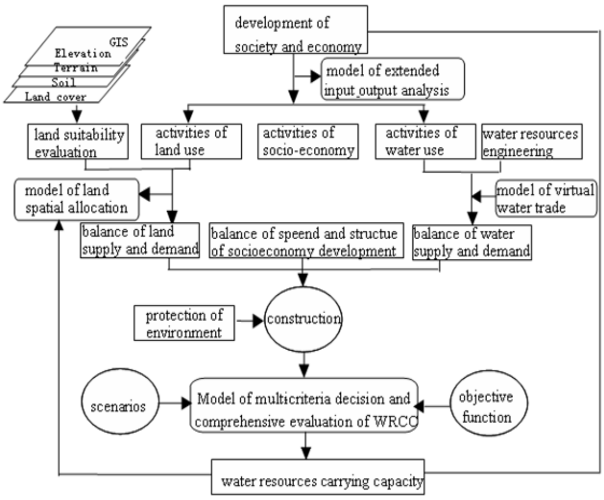

Fig.1 WRCC study framework of Zhangye

3.2 Scenaios

Scenario definition about the future development of the economy and environment is adopted to cope with the problem of uncertainties.

Seven key policy elements are selected to describe the fundamental scenarios; they are fixed assets investment; industry structure adjustment; water-saving technology improvement; population growth, urbanisation and living standard; environment protection; water allocation scheme; and virtual water strategy (Table 1).

Scenarios A to G are different policy element combinations to ensure a scientific forecast of WRCC. From Scenario A to G, one more policy element is added. For example, Scenario A will discuss the scale of economy that the water system can sustain assuming the other policy factors remain the same as those of 2000; Scenario B will add the effect of industry structure adjustment to Scenario A, and so on (Table 2).

Table 1 Scenario description of policy factors

Policy elements	Scenario description
Rate of fixed assets investment	Ratio of fixed assets investment to GDP is set as 35% to 40% from 2000 to 2010, and 32% to 38% from 2011 to 2020.
Industry structure adjustment	Before 2020, the proportion of the added-value of primary industry in GDP will decrease below 30% and those of secondary and tertiary industry will rise above 35%.
Water-saving technology improvement	Irrigation water utilisation coefficient will increase from 0.5 in 2000 to 0.55 in 2010 and 0.65 in 2020, and industrial water reuse ratio will increase to 70% in 2010 and 80% in 2020 from 60% in 2000.
Environment protection	The sloping cultivated land steeper than 25 degrees will be converted to forest. Ratio of area of farmland to shelterbelt within oasis will rise from 9.3% in 2000 to 10% to 15% in 2020.
Population growth and urban development	The natural growth rate of population is around 3% to 10%, and proportion of urban population will rise to 40% in 2020.
Water allocation scheme	Annual mean runoff of Zhengyi Gorge (dividing line of the middle stream and the lower stream of the Hei River) is no less than 950 million cubic metres.
Virtual water strategy	There are no imports or exports，the deficit of virtual water trade is set at zero.

Table 2 Scenario alternatives of WRCC study of Zhangye

scenarios	A	B	C	D	E	F	G
Rate of fixed assets investment	+	+	+	+	+	+	+
Industry structure adjustment	0	+	+	+	+	+	+
Watersaving technology improvement	0	0	+	+	+	+	+
Environment protection	0	0	0	+	+	+	+
Population growth and urban development	0	0	0	0	+	+	+
Water allocation scheme	0	0	0	0	0	+	+
Virtual water strategy	0	0	0	0	0	0	+

Note: ‘0’ stands for that the policy fator remains the same as that of 2000, ‘+’ stands for that the policy factor will change as mentioned in table 1.

3.3 Description of the Main Models

3.3.1 Multicriteria Scenario Decision Analysis Model

The goal of multicriteria scenario decision analysis is to optimise the reallocation of water resources among different sectors. A group of carefully defined decision variables, objective functions and constraint conditions are needed to establish the model.

To get maximum comprehensive benefits for the socioeconomic-ecoenvironment system, four objective functions, relating to economic development, social stability and environmental quality are identified respectively: maximum GDP per capita ($g_1(X)$), minimum amount of COD emission ($g_2(X)$), maximum area of forest and grass ($g_3(X)$), and grain output per capita not less than expected value ($g_4(X)$). The constraints are set up from three aspects: balance of water supply and demand, balance of land supply and demand, and balance of economic growth and industrial structure and requirements of environment protection. The decision variables (X) corresponding with the scale of economy and population is namely the WRCC.

The model structure is as the following:

$$MinZ(X) = \{g_1(X), g_2(X) \dots g_4(X)\} \quad (1)$$

$$s.t. \;\; X \in S, \;\; X \geq 0 \quad (2)$$

Since the four objective functions are of a conflicting nature, we apply the optimal benefits method to resolve the problem by supposing a utility function $Z(X)$ to get the solution of forementioned multi-objective function, $Z(X)$ is connected with various objective functions as the following fomula(Wang Xianjia and Feng ShangYou 1996):

$$MinZ(X) = \sum_{i}^{3} \left\{ (\lambda_i)^2 * \frac{\left[g_i^*(X) - g_i(X)\right]^2}{\left[g_i^*(X) - g_i^{'}(X)\right]^2} \right\}^{1/2} \quad (3)$$

Where $g_i^*(X)$、 $g_i^{'}(X)$ are the optimization solutions of of the single-objective functions $Maxg_i(X)$ or $Ming_i(X)$ which respectively represent the most positive or negative value of the i th objective function. As the objective function of per capita grain output $g_4(X)$) could be given a specific boundary, so it can be treated as a constraint condition. λ_i is the weight of the i th objective fuction, it is chosen from a combination of 20 ~ 40 weight values by the comprehensive evaluation model mentioned above, the weight combination is generated by the computer system based on principles of 'uniform distribution' and 'maxmum difference'.

3.3.2 Extended Input-output Model

The input-output model provides a useful tool for industrial structure analysis and economic development projection with its strength on representing the inter-industrial interdependence. An input-output model of a closed economy system may be represented by the matrix relation

$$X = (I - A)^{-1} Y \qquad (4)$$

where X is the vector of output quantities, Y is the vector of final demand, A is the matrix of technical coefficients representing the inter-industrial interdependence and I is the identity matrix.

By incorporation imports and exports the input-output model becomes

$$X = (I - A)^{-1}(Y_D + Y_E - Y_M) \qquad (5)$$

where Y_D is the final domestic demand, Y_E is the exports and Y_M is the imports.

The traditional input-output economic model is extended in this WRCC study by adding the columns of natural resources input and contaminations output to allow for analysing the relation of ecomomy and environment and to provide an integrated framework to study issues of water resources development, land use, virtual water trade and socio-economic development. The link is developed by two import coefficients: First, we define the unit direct water usage coefficient of an economic sector to be the total water consumption for production by the economic sector divided by the total products produced, i.e.

$$f_i = W_i / X_i \qquad (6)$$

where f_i is the direct unit water usage of the ith sector, W_i is the total water consumption in production and X_i is the total quantity of the products produced.

Similarly the land usage sodffecient coulld be defined too.

3.3.3 Land Use Spacial Allocation Model

The land use spacial allocation model, based on 100x100-metre raster, is established to provide land supply scenario and predict land use spatial distribution. First, we exercise a suitability analysis of land use. In this study, land uses in Zhangye are classified into six types: cultivated land, grassland, forest land, urban land, water body and unexploited land. The first four types of land received the suitability analysis. The evaluation index system consists of natural condition factors (altitude, gradient, precipitation, soil, etc.), neighbourhood factors (distance from urban building area, distance from road), the original land use type factor (inertia of land use) and the policy factor (sloping cultivated land conversion). Every factor is given the same weight, then the suitability index of every raster to the four land use types can be calculated. Secondly, taking the land demand forecasted by the extended input-output analysis as constraint conditions, the author can adopt iterative algorithm to predict land use spatial distribution by allocating every raster to the most suitable land use type until a balance of land supply and land demand can be achieved. The paper makes a test evaluation with the historic land use data of 1987 and 2000, and it is tested that the rate of validation is 64%. Considering the restriction of data accurancy and compared to the results of another similar study (Pontius et al. 2001), the author felt this accurancy was acceptable and applied the model to predict land use spatial distribution in the WRCC study of Zhangye.

3.3.4 Virtual Water Trade Model.

The concept of virtual water was first introduced to quantify the water required in the production process of agricultural commodity in 1996 and was applied to other commodities and services afterwards (Allan 1998). Virtual water trade means water resources transfer with the import and export of commodities. As we know, the water content used in the products or services usually consists of direct water consumption and indirect water consumption. Direct water consumption is the amount of water required by the establishment to produce the product. Indirect water consumption refers to the water content of intermediate inputs which together with the direct water consumption the final product. By defining the direct water use coefficient and overall water use coefficient, economic input-output could be extended to allow the determination of interdependencies of direct and indirect water contents between commodities. The method attributes the virtual water contents of all intermediate inputs to the virtual water content of the final product without the need to revert to the detailed stages of its production process.

A unit total water usage coefficient could be defined by

$$f_i^t = f_i + \sum_{k=1}^{n} f_k^t a_{ki} \qquad (7)$$

Here, f_i^t is the unit total water usage of the *i*th sector, a_{ki} is the relative share of the *k*th sector product inputted for *i*th sector's production.

Then we canobtain the matrix identity

$$F^t = (I - A)^{-1} F \qquad (8)$$

where F^t is the vector of total unit water usages, F is the vector of direct unit water usages and A is the matrix of relative shares of intermediate inputs.

Considering imports and exports as final demands, the volume of virtual water required W_v could be calculated as:

$$W_v = (Y_E - Y_M)' F^t \qquad (9)$$

3.4 Comprehensive evaluation model

A two-layer comprehensive evaluation index system is proposed to evaluate WRCC , AHP method is employed to compute the weights of the indices. The negative and positive thresholds applied to calculate the degree of membership are determined with reference to the experts opinions or the universal criterion of sustainable development indices (Table 3).

Table 3. Evaluation index system of WRCC

Standard layer	Weight	Factor layer	Weight	Negative threshold	Positive threshold
Water resources subsystem	0.2326	Water resources per capita (m^3)	0.6522	1700	4000
		Rate of water exploitation (%)	0.2174	40	20
		Socioeconomic water demand per capita (m^3)	0.1304	800	400
Ecoenvi-ronment subsystem	0.3488	Proportion of forest and grass coverage (%)	0.4086	15	60
		Concentration of COD of water body (mg.L^{-1})	0.1796	30	15
		Rate of ecological water demand (%)	0.4117	25	50
Socioeconomic subsystem	0.4186	Rate of population growth (‰)	0.1898	9.5	2.1
		Urbanization level (%)	0.0485	20	70
		Average annual GDP per capita (US$)	0.2721	400	4000
		Proportion of the production of the tertiary industry (%)	0.1455	30	60
		Grain output per capita (kg)	0.0286	300	590
		Water use efficiency (US$.m^{-3})	0.3155	0.4	49.8

The comprehensive index of WRCC is defined with the concept "the degree of membership" to evaluate the general quality or grades of WRCC, the procedure to calculate the comprehensive index of WRCC L_{C_i} is as follows:

Assuming that the value of the *j*th evaluation factor of the *i*th subsystemis x_{ij} , its negative and positive thresholds are V_{ij1} and V_{ij2} respectively, then the degree of membership μ_{ij} can be calculated as:

$$\mu_{ij} = \begin{cases} 1 & (x_{ij} < V_{ij2}) \\ \dfrac{V_{ij1} - x_{ij}}{V_{ji1} - V_{ij2}} & (V_{ij2} \le x_{ij} \le V_{ij1}) \\ 0 & (x_{ij} > V_{ij1}) \end{cases} \quad (10)$$

or

$$\mu_{ij} = \begin{cases} 1 & (x_{ij} > V_{ij2}) \\ \dfrac{x_{ij} - V_{ij1}}{V_{ij2} - V_{ij1}} & (V_{ij1} \le x_{ij} \le V_{ij2}) \\ 0 & (x_{ij} < V_{ij1}) \end{cases} \quad (11)$$

The former formula is applied if the quality of WRCC improves when the value of the evaluation factor increases, else the latter.

Then the quality of WRCC of multiple factor subsystem can also be described with the degree of membership of the *i*thsubsystem L_{C_i} :

$$L_{C_i} = \prod_{j=1}^{m} \mu_{ij}^{a_{ij}} \quad (12)$$

where m is the amount of the factors of the *i*th subsystem, a_{ij} is the exponential weight of the *j*th factor of the *i*th subsystem.

Finally the degree of membership of the whole system is calculated as:

$$L_C = \sum_{i}^{n} \alpha_i L_{C_i} \quad (13)$$

Where n is the number of the subsystem , α_i is the weight of the *i*th subsystem.

According to the value of L_C , the quality of WRCC is classified into five grades as shown in table 4. The change process from 0 to 1 of the comprehensive index of WRCC L_C means WRCC varying from "uncarriable" state to "ideally carriable" state.

Table 4. Classification of comprehensive index of water resources carrying capacity

Value	L_C =0	0< L_C <0.2	0.2< L_C <0.8	0.8< L_C <1	L_C =1
Grades	Uncarriable	Semi-carriable	carriable	Excellently carriable	Ideally carriable

3.5 Data Sources

Data about society and economic development and water resources consumptions are from'Zhangye Statistical Yearbook' (1990 to 2000) and 'Gansu Water Resources Bulletin' (1990 to 2000). The spatial grid data of land use with resolution of 100x100 metres comes from 'Chinese Resources and Environment database' developed by the Institute of Geographical Science and Natural Resources, Chinese Academy of Sciences. Statistics Bureau of Gansu Province provided the 30-sector input-output table of 2000 for Zhangye. The model is programmed with Mathematica V4.1.

4. RESULTS

4.1 WRCC of Different Scenarios

With the methods mentioned above, the WRCC of Zhangye district is estimated. Table 5 shows the WRCC of Zhangye and water utilisation in different scanrios from 2000 to 2020.

Scenario A discusses the scale of socio-economy that the water system can sustain assuming all policy factors remain the same as those of 2000. As we have anticipated, without changing background conditions, the WRCC will also remain with the same as 2000. Actually, scenario A could be viewed as the baseline scenario in our study; by changing conditions of policy input, we can observe in each scenario the role of different policy factors on the WRCC.

In scenario B, through industrial structure adjustment, the annual average GDP growth rate may reach 7.40% (from 2000 to 2010) and 4.60% (from 2010 to 2020) provided other conditions maintain status quo.

Results of scenario C show that the natural population growth may reduce annual average GDP growth rate by about 0.01% to 0.05% due to additional population's need to consume more water. The total amout of socio-economic water use is 2.28 billion cubic metres in 2010 and 2.30 billion cubic metres in 2020.

Table 5. WRCC of Zhangye and water utilization of scenarios B-F

	2000	2020				
		B	C	D	E	F
GDP (billion China Yuan)	6.4	20.6	20.4	25.7	25.8	24.7
Population (thousand)	1250	1250	1456	1456	1456	1456
GDP per capita (Thousand China Yuan)	5.1	16.5	14.0	17.7	17.7	17.0
Area of irrigation farmland (million ha)	2.4	2.3	2.3	3.0	3.0	2.8
Water supply (billion m^3)	2.5	2.5	2.5	2.6	2.6	2.4
Amount of total water use(billion m^3)	2.1	2.3	2.3	2.3	2.3	2.1
Rate of agricultural water use (%)	96.3	88.3	87.4	90.2	90.3	90.1
Rate of industrial water use(%)	2.3	10.4	10.4	6.7	6.6	6.7
Rate of domestic water use (%)	1.4	1.3	2.2	3.1	3.1	3.2

Scenario D indicates that the annual average economic growth rate can be further increased to 8.25% (2000 to 2010) and 6.16% (2010 to 2020) if water-saving technology is improved. On the other hand, irrigation water requirements may decrease by 0.26 billion cubic metres and 0.59 billion cubic metres in 2010 and 2020 respectively compared to scenario C (Fig. 2, Fig. 3).

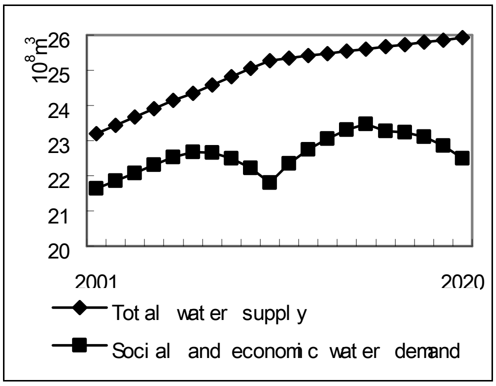

Fig. 2 Water supply and demand in scenario D

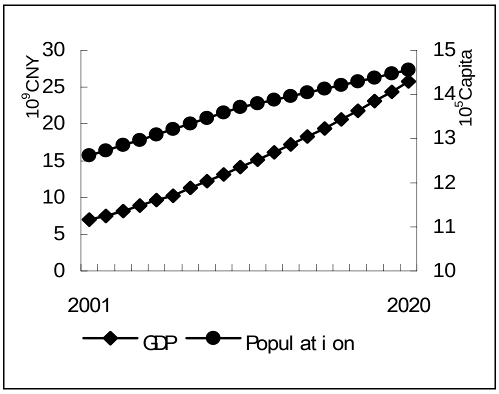

Fig. 3 WRCC (scale of GDP and population) in scenario D

The effects of environment policies are not easy to measure. The expansion of ecological or protective grass and forest will increase ecosystem water demand. On the other hand, the recycling of sewage water will increase water supply. After the overall balance, there are not big differences between the final WRCC prediction results of scenario D and those of scenario E.

Scenario F reflects the comprehensive effect of combined policy factors, including water reallocation scheme. It indicates that Zhangye has the potential to improve its WRCC and can guarantee its economic growth by an annual average GDP rate of 6% to 8% within the next twenty years, and the population with natural growth rate can enjoy a high living standard according to well-off agricultural consumption criteria, given precondition of corresponding ecological environmental protection standards. Considering that the small potential for water resources exploitation in Zhangye, the implementation of the water reallocation scheme of Hei River watershed and improvement in eco-environment protection standards will reduce water supply, therefore, the major approaches to improving the WRCC of Zhangye are by adjusting industrial structure and developing advanced water-saving technology.

4.2 Change of Land Use

With regard to land use, the area of cultivated land will have little change. In scenarios B and C, the cultivated land area in 2010 and 2020 will decrease slightly compared to that of 2000. However, it will increase slightly in scenarios D, E and F by adopting water-saving measures. On the contrary, the proportion of forestry and livestock in agriculture will rise, as do the areas of forest and grass. In scenario F, the coverage rate of forest and grass areas will rise to 62.2% in 2020 from 43.4% in 2000(Fig. 4). It proves that developing forestry and livestock with higher efficiency of water consumption contributes a lot in solving the problem of water scarcity and ameliorating environment problems, therefore they must be given the priorities of agricultural structure adjustment.

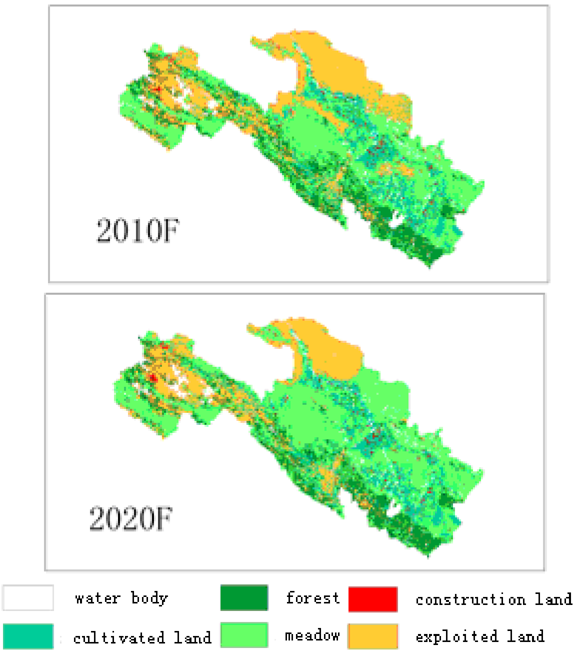

Fig. 4 Change of land use of scenario F

As to the spatial distribution of land use, it could be seen that the cultivated land and urban area are concentrated in the middle part of the Hexi corridor, surrounded by the grassland, which is bordered by the desert in the north and becomes the barrier protection region of the middle oasis. Forest land is distributed around the foot of Qilian Mountain in the south. There are small patches of grassland and slope cultivated land. Cultivated land will be converted into forest land in the coming twenty years.

4.3 Effect of Virtual Water Trade Strategy on WRCC

The calculation based on the extended input-output model shows that the net input of virtual water of Zhangye was -5.63 billion cubic metres in 2000, accounting for 26.5% of the total water consumption of the whole society. In Zhangye, agriculture is still the most important sector in local economy, 7.81 billion cubic metres of virtual water was exported to other regions with the export products of the most water-consuming farming(Figure. 5). This is a major cause of the deficit of virtual trade model. Scenario G examines the change of the WRCC of Zhangye provided with the situation that both the import and export products are set to be zero and then there will be no virtual water trade deficit, then It would consume 3.39×10^8 m^3 less water in 2020(Fig. 5) , greatly alleviating its already scarce water resources. The local water thus saved could have otherwise been used for economic activities with higher ecological, social and economic returns to sustain longer-term development of the region. If the virtual water is saved and distributed to various sectors with the same proportion according to the original industrial structure, the level of the grain consumption per capita will increase to 615 kilograms in 2010 rather than the 471 kilograms in scenario F. The meat consumption per capita will be added up to 26 kilograms in 2010 and 43 kilograms in 2020. If the virtual water is saved and then totally distributed to the industrial sector with higher water use efficiency, then GDP will increase to RMB33.37 billion in 2010 and to RMB52.52 billion in 2020, compared to RMB13.59 billion in 2010 and RMB24.72 billion in 2020 of scenario F.

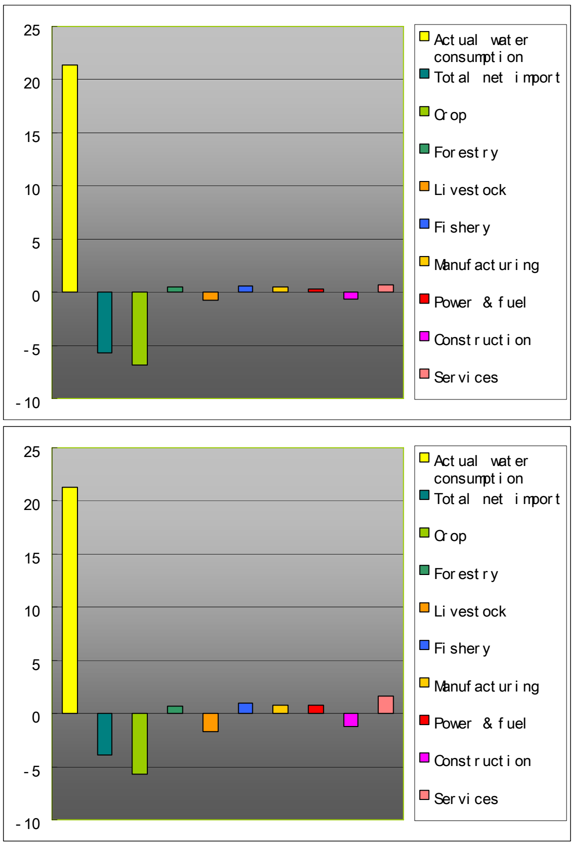

Fig.5 Amount of net import water of different sectors in 2000 and 2020(scenario F)

4.4 Evaluation of WRCC

The comprehensvie evaluation results of WRCC of Zhangye in different scenarios show similar evolution trend. We will take scenario F as an example to illuminate the situation of the water-socioeconomic-ecoenvironment.

As for the water resources subsytem, the values of evaluation indices of two factors are zero, which means “uncarriable”, and the other one is also very close to the point of “uncarriable’. It is concluded that the water resources subsystem is in a state of over-burdened because of the very limited amount of water and high exploitation level, and it is very hard to make a great change to that situation is a short term.

In the ecoenvironment subsystem, the main limiting factor is the rate of ecological water demand, it gets a score of zero in 2000, but the value of evaluation ascend to 0.0299 in 2010 and 0.0483 in 2020 with the increase of the area of forest and meadow and implementation of water reallocation acheme. In all, The ecoenvironment subsytem will make a progress from the situation of “uncarriable” to “carriable”.

There are three factors, propotion of the production of the tertiary industry, urbaniztion level, water use efficiency in the socioeconomic subsystem which get a score of zero in 2000. The change trend of socio-economic subsystem is similar to that of ecoenvironment.

Table 6 The comprehensive evaluation indices of WRCC of scenario F

Evaluatin factors	Evaluation value		
	2000	2010	2020
Water resources per capita	0.0912	0.0178	0
Rate of water exploitation	0	0	0
Socioeconomic water demand per capita	0	0	0
Water resources subsystem	0	0	0
Proportion of forest and grass land coverage	0.6311	0.9415	1
Concentration of COD of water body	1	1	1
Rate of ecological water demand	0	0.0299	0.0483
Ecoenvironment subsystem	0	0.2300	0.2871
Rate of population growth	0.1757	0.0270	0.4730
Urbanization level	0	0.1700	0.4000
Average GDP per capita	0.0626	0.2252	0.4654
Proportion of the production of the tertiary industry	0	0.1700	0.3433
Grain output per capita	0.8840	0.5944	0.5075
Water use efficiency	0	0.0439	0.1100
Socioeconomic subsystem	0	0.0875	0.2819
Comprehensive index of WRCC	0	0.1169	0.2182

On the whole, the comprehensive index of WRCC shows that the quality of WRCC is gradually improved from state of “uncarriable” in 2000 to “semi-carriable” in 2010 and a “carriable” in 2020. The zero value of some single index indicates that the major limiting factors are the low level of water use efficiecy and per capita water resouces, and the unreasonable industrial structure, so adjusting industry structure, developing water-save technology and will be the most needed

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measures to improve WRCC of Zhangye(Table 6).

5. CONCLUSIONS

This paper explores a new approach about WRCC study of arid and semi-arid inland river basin, a dynamic and integrated model is established in the framework of multi-criteria analysis and extended input-output analysis combining with the setoral models including land spatial distribution model, the virtual water trade model and the comprehensive evaluation model of WRCC, which proves to be adaptable and operational for the study of a complex and open system with various problems concerning water resources development, virtual water trade, land use, envrionment protection and socioeconomic development etc. WRCC in different scenarios of Zhangye is discussed and the influence of some important policy factors on WRCC is assessed including adjustment of industrial structure, improvement of water-saving technology, water reallocation scheme, virtual water strategy, etc.

The assessment of WRCC indicates that the increase of socioeconomic water demand of Zhangye is limited if appropriate policies are adopted. By means of industrial structure adjustment, irrigation areas restriction and water-saving technology improvement, the contradiction of water supply and demand will be alleviated gradually in the future, and the WRCC of Zhangye can guarantee an annual average GDP growth rate around 7% and its people enjoying a “fairly comfortable” living standard according to agricultural products consumption criteria from 2000-2020. Especially, the study about vitual water trade indicates that it is imperative for Zhangye to adopt its virtual water strategy by a restructuring of its industrial and production composition in order to relieve the pressure on its domestic water resources and to achieve longer-term water security.

Whether the WRCC study can help us understand the effects of policy elements on WRCC depends on the acurate description of relations of elements within the model and judgement about future policy intentions. More knowledge of hydrology and its relation to the socio-economic factors will enhance the accuracy of the modelling.

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