QUANTITATIVE RESEARCH ON WATER RESOURCES CARRYING CAPACITY OF URBANIZING AREA

ZHANG Yong-yong[1] , XIA Jun[2, 1] , WANG Zhong-gen [2], CHEN Xi-yun[2], ZUO Qi-ting[3]

(1) State key laboratory of Water Resources and Hydropower Engineering Science, Wuhan University, Wuhan, 430072, China. email:zhangyy003@163.com.
(2) Key Laboratory of Water Cycle and Related land Surface Processes, Chinese Academy of Sciences, Beijing, 100101, China.
(3) Zhengzhou University, Zhen Zhou, 450002, China

ABSTRACT

Water resources carrying capacity (WRCC) is one of hot topics in China, especially in the urbanizing areas. This paper analyzes the impact of urbanization on water cycle, social economy, ecological environment, and discusses the connotation and the characteristic of water resources carrying capacity of urbanizing area (WRCCUA). A model based on the objective analysis and grey association appraisal is developed to assess the WRCCUA. In the model construction, sustainability is used as one of the control objectives and water cycle in "natural- social" system as the key. This model has been applied in Tongzhou District, Beijing City. Results show that there is a great gap between WRCC and the goal in Tongzhou District. Water shortage restricts urbanization and sustainability seriously. Three scenarios have been designed for increasing WRCC and scenario analysis shows that promoting water saving is the most feasible solution for Tongzhou District to mitigate the water shortage stress before the South-North Water Transfer project is completed.

Key words: Water resource carrying capacity (WRCC), carrying degree, sustainability, urbanization

1. INTRODUCTION

Urbanization is an inevitable outcome of the human society development. According to United Nations statistics, in the world the urbanization level was 28% in 1950, and exceeded 50% in 2000, moreover, it will be expected to reach more than 60% in 2020(Li and Song, 2003). In China, with the promotion of reforms and open policies in the early 1980s, urban development expanded rapidly. By the end of 2005, the level has reached 43%, and it will be over 50% in 2020 (Wang *et al.*, 2006).

Rapid urbanization resulted in a series of problems consequentially such as resources shortage, pollution, degradation of ecological environment, etc. (Zhao, 2004; M. Lin, 2004). Water as vital natural resources, its security issue has been the key for a region to keep social economy sustainable development. Ministry of Water Resources P.R. China's statistical data demonstrated that, in 669 cities these are 400 cites lack of water, 110 of which seriously lack of water at present. The total quantity of water shortage is about 60 billion m^3.

Beijing is a serious water shortage area. Currently, the per capita water resource is less than $300m^3$, which is lower than the international safety line (1000 m^3). The contradictory between water supply and demand is extremely incisive. Groundwater was overdraft and water polluted seriously. The ecology and environment are in a poor condition. Along with the rapid development, what's the water resources carrying capacity (WRCC) in Beijing? It is urgent to be answered for policy makers and water resources managers at present. In this paper, the objectives are: 1) a water resources carrying capacity computation model for urbanizing areas (WRCCUA) is developed. 2) To quantify the current WRCC for typical District of Beijing and provide some countermeasures. 3) To supply the significant consultations for some important events happened in Beijing during "the eleventh five-year"(2006-2010), such as the constitution of Beijing city development plan, agricultural water-saving strategy implement in the suburb, and so on. Tongzhou District is selected as the representative area of Beijing city for case study according to the significant position, the urbanizing process available data and state of water shortage, etc.

2. WRCCUA RESEARCH

The research of carrying capacity comes from ecology (Park and Burgess 1921). Subsequently it has been expanded in the different domain, and appeared the population carrying capacity, the resources carrying capacity, the land resource carrying capacity, the water resources carrying capacity, the ecology and environment carrying capacity, and so on. WRCC was brought forward in China in 1980s and there are two different standpoints for quantifying it, which are: (1) the maximal capacity water resources can carry the society economy, ecology and environment which was advanced by Zhang (2001); Cheng (2002), and so on. The capacity was usually a no-dimension quantity, which could be obtained through contrasting the complete indices that affect WRCC with the carrying capacity basic criterion. (2) The greatest scale water resources can carry the society economy, ecology and environment which are advanced by Shi (1992); Xia (2002), Wang (2003); and so on. The scale was usually obtained through analyzing the development quality of society, economy, ecology and environment and distributing the production-living-ecology water rationally. In this paper, the water resources carrying capacity in urbanizing area (WRCCUA) prefers to the second definition.

The WRCCUA research covers the interaction theory between urbanization and "social economy-water resources-ecological environment" complicated system, water cycle theory under changing environment, and sustainable development theory, involves the water transformation process, the water resources optimization disposition, the social economy development forecast, the water requirements of eco-environment, the social economy water demand forecast, and so on. All the research should base on the relationship among the "social economy-water resources-ecological environment" and analyze the effort of urbanization on the relationship.

2.1 The effort of urbanization on water cycle, society, economy, ecological environment

In the urbanized area, the human activities have already changed the natural water cycle characteristic (ZUO *et al.*, 2005). And have given birth to “diversion –consumption –treatment - reuse - discharge" social water cycle, and formed "natural - social" water cycle (Figure 1). Researching on the water cycle in the urbanized area, finding out the rules of water resources formed and transformed in the changing environment and the action that the water resources played in each link are the water resources carrying capacity research foundation.

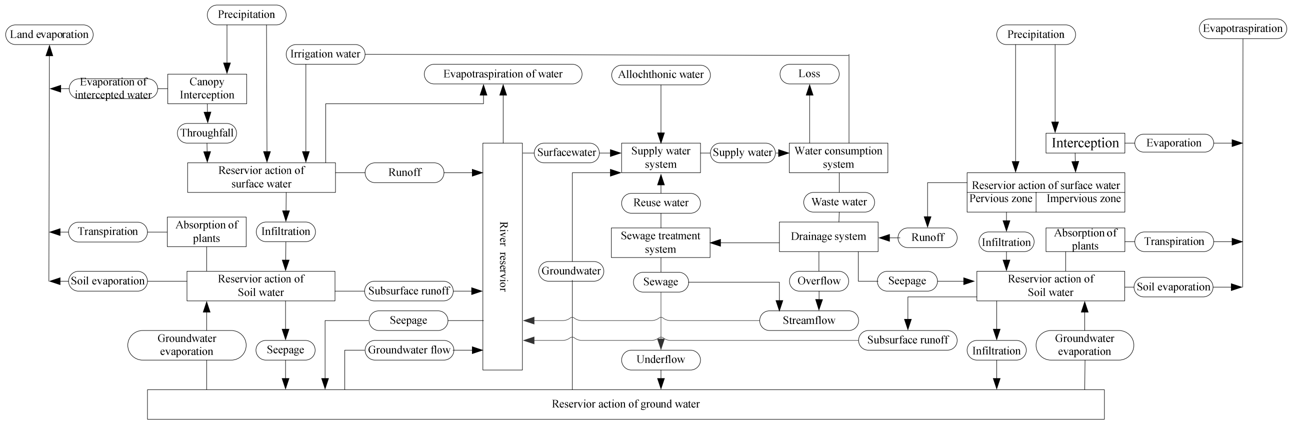

Fig.1 The diagram of water cycle in urbanized area

The impact of urbanization on the compound system of “social economy-water resources-ecological environment” is shown in Fig. 2.

2.2 The WRCCUA computation model

Based on the analysis, a WRCCUA model is developed. The model includes six modules, namely: the module of object generalized analysis, the module for water resources circulation and transformation, the social economy forecasting module, the interaction module of "social economy - water resources – ecological environment", the sustainable development appraisal module, and the judgment module. In the model integration, the objective analysis and grey association appraisal methods were employed (Xia, 1995). The model is shown detailedly in Xia *et al.* (2006).

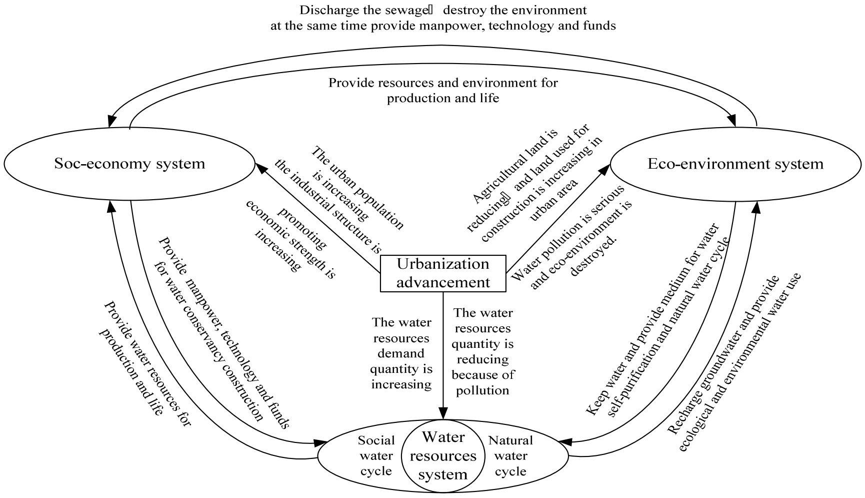

Fig.2 The impact of urbanization on the compound system of "social economy-water resources-ecological environment"

(1) The object function Based on the comprehension of WRCCUA, population is chosen as the objective function (Zuo et al. 2005).

$$Pop = f(\alpha, \beta, \mu, UL, \rho, K \cdots) \rightarrow Max$$

Where Pop is the total population of the region; $\alpha, \beta, \mu, UL, \rho, K \cdots$ are some important parameters in the model which will be elaborated in the following text.

(2) The total water balance equation and the available water quantity equation

$$\begin{cases} \Delta V_{groundwater} + \Delta V_{surfacewater} = (P + Q_{transfer} + Q_{in}) - (E + W_{loss} + Q_{out}) \\ Q_{avail} = \alpha_1 \cdot Q_{\text{self-generation}} + \alpha_2 \cdot Q_{in} + \alpha_3 \cdot Q_{groundwater} + Q_{reuse} + Q_{transfer} \end{cases}$$

Where $\Delta V_{groundwater}$, $\Delta V_{surfacewater}$ are the variation of groundwater storage and surface water storage, respectively; P is the precipitation; E is the evaporation; Q_{in}, Q_{out}, $Q_{\text{self-generation}}$, $Q_{groundwater}$ are the inflow, outflow, runoff and groundwater of the region, respectively; Q_{avail} is the available water resource of the region; Q_{reuse} is the available quantity of reuse water; $Q_{transfer}$ is the water transferred from other regions; α_1, α_2, α_3 are the exploitation rate of runoff, inflow and groundwater, respectively.

(3) The social economy forecasting module

$$\begin{cases} Pop(t) = Pop(t-1) \cdot (1 + K_{pop}) \qquad P_{urban} = P_{urban} \cdot UL \\ GDP = f(Y_{industry}、A_{industry}、K_{industry}、K_{agriculture}) \end{cases}$$

Where K_{pop} , $K_{industry}$, $K_{agriculture}$ are the population growth rate, the rate of total industrial growth and the rate of agriculture irrigation area respectively; UL is the urbanization level; $Y_{industry}$, $A_{industry}$ are the industrial output and the irrigation area, respectively.

(4) The interaction module of "social economy - water resources – ecological environment"

1) The relation between social economy and water resources is to seek the support action of water resources to production and living.

$$\begin{cases} W_{industry} = Y_{industry} \cdot \rho_{industry} & W_{agriculture} = A_{agriculture} \cdot \rho_{agriculture} \\ W_{life} = P_{urban} \cdot \rho_{urbanlife} + P_{rural} \cdot \rho_{rurallife} & W_{soc-consumption} = W_{industry} + W_{agriculture} + W_{life} \end{cases}$$

Where $W_{soc-consumption}$, $W_{agriculture}$, $W_{industry}$ are the social economy water consumption, the industry water consumption and the agricultural water consumption, respectively ; $\rho_{industry}$, $\rho_{agriculture}$, $\rho_{urbanlife}$,, $\rho_{rurallife}$ are the water ration of industrial output , irrigation , urban life and rural life, respectively.

2) The relation between social economies –ecological environment is to seek the effort of the urbanization and the development of social economy to ecological environment. In the region, it contains two aspects, viz. the sewage discharge estimation equations and the equations for groundwater development.

$$\begin{cases} Q_{industry} = (1-\chi_{industry})W_{industry} & Q_{life} = (1-\chi_{urban})W_{urban} + (1-\chi_{rural})W_{rural} \\ Q_{sewage} = Q_{industry} + Q_{life} & W_{sewage} = \beta C_{treat} Q_{sewage} + (1-\beta) C_{untreat} Q_{sewage} \\ Q_{cs} \cdot C_{cs} = (1-k) \cdot (Q_1 \cdot C_1 + W_{sewage}) & \end{cases}$$

$$W_{over-draught} = W_{consumption} - Q_{avail} \qquad \Delta H = \frac{W_{over-draught}}{\mu \cdot F}$$

Where $\chi_{industry}$, χ_{urban} , χ_{rural} are the consumption coefficient for industry, urban life and rural life, respectively; Q_{cs} , Q_1 denote the quantity of control section and upriver inflow, respectively; C_{cs} , C_1 denote the pollutant's concentration in control section and upriver inflow, respectively; k denotes the pollutant's degradation coefficient ; W_{sewage} is the total quantity of pollutants; Q_{sewage} is the sewage amount; β is the sewage treatment ratio; C_{treat} and $C_{untreat}$ denote the treated and untreated concentration of the pollutant, respectively; ΔH is the decline range of groundwater; μ is specific yield in the region; F is the region area.

3) The relation between ecological environment and water resources is to quantify the minimum water requirements of ecological environment.

$$\begin{cases} W_{environment} = W_{lake-river} + W_{groundwater \quad recharge} + W_{dilution \quad water} \\ W_{dilution \quad water} = Q_{cs} C_{cs} / C_{goal} - Q_{out} \qquad W_{groundwater \quad recharge} = (\alpha_{3goal} - \alpha_{3p}) \cdot Q_{groundwater} \end{cases}$$

Where α_{3p} , α_{3goal} denote the present exploitation level and the upper limit of groundwater resources, respectively; C_{goal} is the critical concentration of target pollutant denoted by COD.

(5)The sustainable development appraisal module

$$DD(T) = S(T)^{\beta_1} \cdot W(T)^{\beta_2} \cdot E(T)^{\beta_3}$$

Where *S(T), W(T), E(T)* are the development quality of social economy, water resources and eco-environment, respectively; β_1,β_2,β_3 are the weight factors, takes 1/3 respectively; *T* is the time interval, using one year generally. *S(T)*, *E(T)*, *W(T)* the value is between 0 and 1. *S(T)*, *W(T)* and *E(T)* were appraised by grey association analysis(Xia, et al. 2004).

(6)The supportable judgement module of WRCCUA.

In the model, the supportable judgement is that the water resources supportability, the benign development of ecological environment and the sustainable development of the composite system.

$$\begin{cases} I = (W_{soc-consumption} + W_{environment}) \big/ Q_{avail} \le 1 \\ S(T) \ge 0.6 \qquad\qquad DD(T) \le DD(T+1) \end{cases}$$

Integrating the module (1) ~ (6), the WRCCUA computation model is formed. Fig.3 shows the resolution process of this model.

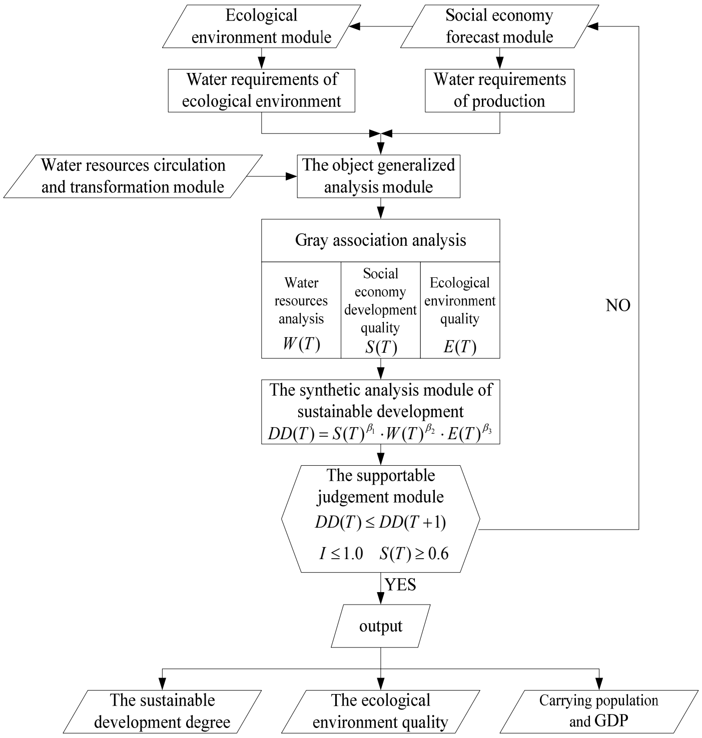

Fig.3 The resolution process diagram and structure of WRCCUA

3. CASE STUDY

3.1 overview of research area

This paper takes Tongzhou District as an example. Tongzhou District (39°36'-40°02'N, 116°32' -116°56'E) is one satellite town of Beijing, located in the southeast of Beijing (Fig.4). The total area is 907km^2. There are 13 rivers in the District, which belong to the canal water system and the Chaobai river water systems, respectively.

Up to 2004, the total population of Tongzhou District was 620,000, the urbanization level reached 41%, and agricultural areas were 36671 hectare. The gross value of agricultural output and industrial output were $396 million and $2,578 million respectively, the gross domestic product (GDP) were $1,569 million. The sewage treatment rate was 58%. The current industrial structure is 10:48:42 (primary industry: secondary industry: tertiary industry).

In the District, the annual mean precipitation is 591mm and the evaporation is 1164mm. Water resource is abundant and the total quantity is 1,101 million m^3 in which surface water is 888 million m^3 and groundwater is 213 million m^3. But most of the surface water is the reusable water discharged from Beijing and the rivers polluted seriously. The groundwater was overdraft severely. By 2004, the groundwater table has fallen to 7.61m from 2.80m at the end of 1980, and serious overdraft area is 29% of the entire area.

Fig.4 Location of Tongzhou District in Beijing City

Tongzhou's available water resources include runoff, reusable water and groundwater. The annual mean runoff is about 73 million m^3, and the exploitation rate is only about 4%. The reusable water exploitation rate is only about 6%, and is about 50 million m^3. Groundwater resources are about 213 million m^3. To sum up, the annual mean available water resources is 267 million m^3.

3.2 Model application

The synthetic analysis index system of Tongzhou District is constructed to assess the development of soc-economy S(T), water resources W(T) and eco-environment E(T). The evaluation criterion is divided to five levels (Table 2). For example, the world water resources research institute proposed that there are four grades for the average per person water resources quantity. <1000m^3 means lack of water seriously; 1,000-5,000m^3, means lack of water; 5,000 - 10,000m^3, means no lack of water; > 10,000 m3 means abundance of water. In the world, there is another standard which fixes 1,700 m^3 as the warning line of the annual average per person water resources quantity (Xu, 2000). According to the standard above, the average per person water resources in Tongzhou District is that: 10,000 m^3 is suggested as level I; 5,000 m^3 as level II; 1,700 m^3 as level III; 1,000 m^3 as level IV and 500 m^3 as level V.

Table2. The index system and grades for development quality evaluation of "social economy-water resources- ecological environment" in Tongzhou District

Subsystem	Index	unit	Ⅰ(1)	Ⅱ(0.8)	Ⅲ(0.6)	Ⅳ(0.4)	Ⅴ(0.2)
Water resources	per person water resources quantity [1]	m^3/ capita	10000	5000	1700	1000	500
	per hectare water resources quantity [2]	m^3/ ha.	39825	30000	1770	26550	3765
	Water resources carrying degree		0.8	0.9	1.0	1.1	1.2
Society economy	per person average GDP [3]	dollar/ capita	4487	2692	897	513	128
	per cubic meter water average GDP	dollar/m^3	15.4	12.8	7.7	5.1	1.3
	per person cultivated area	ha./ capita	0.10	0.083	0.067	0.05	0.033
	per GDP pollutant quantity	ton/dollar	0.008	0.031	0.047	0.078	0.234
	Urbanization level	%	60	50	40	30	15
	Sewage treatment rate[4]	%	85	70	60	50	40
Ecological-environment	COD concentration[5]	mg/L	20	30	40	50	60
	Percentage of forest and grass cover	%	30	25	20	15	10
	Groundwater exploitation rate		0.80	0.90	1.00	1.10	1.20

Note:[1] the research of world water resources research institute.[2]based on per person agricultural area in the world and in Haihe Basin.[3]based on the world development report in 1999.[4]based on "Beijing mayor government work report" in 2005.[5]based on "Surface Water Environment Quality Standard" (GB3838-88)

At present, the industrial water ration is 7,800m^3/ million dollars and agricultural water ration is 4,275m^3/ ha., water ration of urban life, rural life is 320 L/capita, 120 L/capita, respectively. In order to control water quality up to the standard([COD]≤40mg/L) and the groundwater exploitation rate decline to 90%, There are 575 million m^3 water resources needed including 260 million m^3 water consumption of eco-environment restoration and the current WRCC is gain (Table 4).

Considering in the near future, it is no water transferred in. Based on the current water resources, three scenarios have been drawn to analyze the change of WRCC during "the eleventh five-year" (2006-2010).

Scenario one: The water ration is the same with 2005 without regard to saving water. This scenario is the baseline case scenario, which inspects the actual WRCC in the future.

Scenario two: Reducing water ration of production and increasing the sewage treatment rate. This scenario searches into the influence of saving water and increasing the sewage treatment rate on the WRCC. Referring to the water ration of developed countries, there are some potentialities only in water saving irrigation currently. Supposing: in 2010, water ration of industrial output holds the line viz. 7,800m^3/ million dollar, and water ration of agricultural irrigation falls to 3765 m^3/ hectare, the sewage treatment rate achieves 90%; In 2020, water ration of industrial output falls to the 4680 m^3/ million dollar, water ration of agricultural irrigation falls to 3300m^3/ ha., agriculture water saving comes to reality in the entire district, and the sewage treatment rate achieves 100%(Table 2).

Scenario three: Raising the urbanization level and promoting the industrial structure. This scenario considers the influence of urbanization process speeding up and the industrial structure adjustment on WRCC. According to the plan of "the eleventh five-year" (2006-2010), the industrial structures will be 7:42:51, and the urbanization level will be 70% in 2010. The proportion will be 4:37:59, and the urbanization level will be 80%.

3.3 Results and Discussion

Based on the model, WRCC of the short-term (2010) of the eleventh five-year plan and long-term (2020) are shown in Table 4. According to table 3, 4, contrasting three different typical year's carrying capacity with the plan, we can draw the following conclusion:

(1) The soc-economy development S(T) According to forecasting, up to 2020, the population will be nearly twice larger than 2005's and GDP in the District will reach 12.8 billion dollars. S(T) increases from 0.62 to 0.80. It shows that the soc-economy development of Tongzhou District will be in a high speed development phase and the social economy will increase on a large scale during the eleventh five-year.

(2) The water resources condition W(T) The rapid development of soc-economy results in water shortage, water pollution and the continuous decline of groundwater table in Tongzhou District unavoidably. Water demand including water consumption of production, living and eco-environment restoration is more than water supply. The water resources condition is always overloaded. The water resources carrying degree (I) is larger than 1.0 every year and W(T) is only 0.25 in 2005, will drop to 0.18 in 2020.

Table3. The plan of the "eleventh five-year" in Tongzhou District

Typical year	Population	GDP (billion dollar)	I	W(T)	S(T)	E(T)	DD(T)
2005	660,000	1.9	2.1	0.25	0.62	0.23	0.33
2010*	900,000	3.9	1.8	0.22	0.79	0.26	0.35
2020*	1,190,000	12.8	1.5	0.18	0.80	0.42	0.39

Note: * from the "the eleventh five-year" plan of Tongzhou District

(3) The eco-environment development E(T) Because of all the serious eco- environment problems mentioned above, the eco-environment development quality E(T) will be low, only 0.23 in 2005. Furthermore, all of E(T) are less than 0.6 by far. That is to say, the eco-environment is very fragile and the social economy development in Tongzhou District will sacrifice the ecological water use. In order to restore the water eco-environment, the water requirements will account for a high percentage of water demand during the eleventh five-year. In 2005, the ecological water use is nearly 260 million m^3.

(4) The sustainable development DD(T) DD(T) keeps in an extremely low level, which is only 0.33 in 2005, 0.35 in 2010, and 0.39 in 2020. Obviously, the development of Tongzhou District is not harmonious. The soc-economy development keeps in a high speed development while the eco-environment development and the water resources condition are very week.

(5) WRCC of Tongzhou District There is a large gap between WRCC and the plan. During the eleventh five-year, science and technology progress can reduce water ration of production, enhance the sewage treatment rate, etc. Therefore WRCC can increase (scenario two), but the effect is not obvious. It means that there is some potential in saving water but it is not the crucial way to resolve water resources shortage, ecology and environment problems in Tongzhou District. Adjusting the urbanization level and optimizing the industrial structure can allocate water resources reasonably, restrict the social economic development properly and improve WRCC consequently. But it still cannot reach the plan (scenario three). As a result, only saving water in the region by many ways cannot resolve water problems in Tongzhou District. In order to realize the sustainable development, it is advisable to seek new water sources or transfer water from other regions except for water saving, controlling pollution in the district.

Table4. The WRCC under different scenarios in Tongzhou District

Scenario	Typical year	Carrying capacity		W(T)	S(T)	E(T)	DD(T)
		population	GDP (billion dollar)				
Scenario one	2005	350,000	1.0	0.48	0.55	0.62	0.55
	2010	510,000	2.2	0.47	0.72	0.65	0.61
	2020	630,000	6.8	0.46	0.81	0.75	0.65
Scenario two	2005	350,000	1.0	0.48	0.61	0.63	0.57
	2010	620,000	2.7	0.46	0.94	0.67	0.66
	2020	790,000	8.5	0.37	0.98	0.80	0.66
Scenario three	2005	350,000	1.0	0.48	0.61	0.63	0.57
	2010	630,000	2.7	0.46	0.94	0.67	0.66
	2020	690,000	9.6	0.40	0.98	0.79	0.68

4．SUMMARIES AND CONCLUSIONS

The quantitative research on water resources carrying capacity in the urbanizing area is a complex multi-objective analysis and forecast process involving too many kinds of factors, like society, economy, water cycle, water resources, ecology, environment, and so on. In the study, based on “natural-social” water cycle and under the principle of sustainable development, WRCCUA model is proposed. It has been applied to Tongzhou District, Beijing City, and has been shown to be the capable for drawing up the appropriate social economy development scale for the regional sustainable development and providing a certain theory basis for instructing the urbanization process. The research results show that saving water only in the district cannot meet the water demand. There will be a large gap between WRCC and the eleventh five-year plan. It’s an advisable way to transfer water from other regions except for saving water, controlling pollution in the region in order to relieve the water crisis and realize the sustainable development in this district.

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REFERENCES

Cheng, G. D. (2002). Evolution of the Concept of Carrying Capacity and the Analysis Framework of Water Resources Carrying Capacity in Northwest of China. *Journal of Glaciology and Geocryology*, 24（4）:361-367.

Del Monte-Luna P, Brook BW, Zetina-Rejón MJ & Cruz-Escalona VH (2004). The carrying capacity of ecosystems. *Global Ecology and Biogeography*;13:485-495.

Gao Y. C., Liu C.M., and Jia S. F., et al. (2006) Integrated Assessment of Water Resources Potential in the North China Region: Developmental Trends and Challenges[J]. *Water international* 31(1):71-80.

Kessler JJ. (1994) Usefulness of the human carrying capacity concept in assessing eco-sustainability of land-use in semi-arid regions. *Agriculture, Ecosystems & Environment.* 48:273-284.

Park, R. F. and Burgess, E. W.(1921). An Introduction to the science of sociology. Chicago,USA.

Li, L. S. and Song, L.W. (2003) Analyses on Characteristics of New Industrialization Approach. *China Soft Science*. 9, 382-421.

Shi, Y. F. and Qu, Y. G.. (1992). *Water resources capacity in Urumchi basin and its rational utilization*. Science Press, Beijing, China.

Wang, H., Chen, M. J., Qing, D. Y., et al.(2003). *Water resources disposition and carrying capacity research in Northwest area*. Yellow river water conservation press, Zhengzhou, China.

Wang, S.W., Bo-sin, T. & Basil-von, H.(2006). Strategic urban management in China: A case study of Guangzhou Development District. *Habitat International* 30 (3), 645-667.

Xia, J. (1995). The study of degree of grey relationship in District water environment quality. *Hydrography*, 15(2):4～19.

Xia, J., Wang, Z. G. and Zuo, Q. T.(2004). Study on eco-environment carrying capacity: A quantifying method and case study in the Haihe Basin, China. *Journal of natural resources*. 19(6), 786-794.

Xia, J & Zhu, Y. Z. (2002). The measurement of water resources security: A study and challenge on water resources carrying capacity. *Journal of natural resources*. 17(3), 262~269.

Xia, J., Zhang, Y. Y., Wang, Z. G. and Li, H.(2006). Water carrying capacity of urbanized area. *Journal of hydraulic engineering*. 37(12):1482-1488.

Xu, Z. F. (2000). Conservation and Utilization of Water Resources, *China Water Resources*, 12:19～24.

Zhang, C.G. (2001). Conception of developing the appraising index system of the ecological economic -social capacity of the oasis systems in arid areas. *Arid zone research*, 18(3):7～12.

Zhang, Y. Y., Xia, J., and Wang, Z. G. (2007). Research on Regional Water Resources Carrying Capacity Theory and Method. *Progress in geography*. 26(2):126-132.

Zuo, Q. T. et al. (2005). *The urban water carrying capacity- theory·method·application.* Chemical industry press, Beijing, China.

Zuo, Q. T., Ma, J. X. and Wu, Z. N. (2005). Concept and model of “supporting capacity of water resources” in urban areas. *Sustainable Water Management Solutions for Large Cities*. IAHS Publication No.293, 111-117.