Journal of Coastal Research	SI	93	883–888	Coconut Creek, Florida	2019

Economic Target of Regional Water Resources Based on Bearing Capacity

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ABSTRACT

Liu, J., 2019. Economic target of regional water resources based on bearing capacity. *In*: Guido-Aldana, P.A. and Mulahasan, S. (eds.), *Advances in Water Resources and Exploration*. *Journal of Coastal Research*, Special Issue No. 93, pp. 883–888. Coconut Creek (Florida), ISSN 0749-0208.

In this paper, to clarify the importance of regional water resources in supporting the overall coordination and sustainable development of economy, society and ecology of the whole basin or region, based on the carrying capacity of water resources, the economic targets of water resources based on the principle of economic efficiency and the ecological goals based on the principle of sustainability were analyzed; combining with the principles of regional water security and fairness, the social goals, environmental objectives and water balance constraints of regional water resources utilization were studied; an accounting model for maximizing the economic benefits of regional water resources and minimizing regional water shortage was constructed to guide the adjustment of regional economic structure and optimizing the layout of regional economic and social development.

ADDITIONAL INDEX WORDS: *Water resources carrying capacity, ecological environment, regional economy.*

INTRODUCTION

Water resources are not only the lifeblood of agriculture, but also the basic guarantee for the steady development of industry, service industry and other industries, the steady progress of national economy, the stability of people's lives and the stability and harmony of society (Hu *et al.*, 2016). On different time scales, on the basis of not overexploiting groundwater, not destroying the ecological environment and utilizing water resources reasonably and efficiently, human beings can achieve the largest socio-economic scale target that regional water resources can carry, relying on advanced science and technology and water resources management methods (Girardet, 2006). Although the relevant theoretical research on regional water resources carrying capacity has gradually matured, the definition of carrying capacity of water resources in academic circles has not yet been unified (Li, Cheng, and Gu, 2019; Liu, 2018a, b). Notwithstanding there are many ways to study the carrying capacity of water resources, they all have different degrees of defects (Kaneko, Tanaka, and Toyota, 2004; Omnezzine and Zaibet, 1998). In addition, the research system involves many aspects such as economy, environment, management, *etc.*, with large interdisciplinary and complexities (Dhehibi, Lachaal, and Ellourni, 2007; Karagiannis, Tzouvelekas, and Xepapadeas, 2003). Therefore, based on the study of regional water resources carrying capacity accounting, it can be applied to the study of water resources carrying capacity through the impact of water resources on regional economic benefits.

RELATIONSHIP BETWEEN WATER RESOURCES CARRYING CAPACITY AND REGIONAL SOCIO-ECONOMIC DEVELOPMENT

Characteristics of Water Resources Carrying Capacity

Unlike other resources, the carrying capacity of water resources has some remarkable characteristics (Hu, Wang, and Yeh, 2006; Rodriguez-Diaz, Camacho-Poyato, and Lopez-Luque, 2004; Speelman *et al.*, 2007):

(1) Limitation. Water resources are an important basis for social progress and economic development. When in a specific environment, due to the water resources conditions, social population, science and technology development standards and other constraints in the current region, there will be a red line in the total supply of water resources, which is called the upper limit of the maximum carrying capacity, that is, the limitation.

(2) Dynamicity. The carrying capacity of water resources is closely related to the social development stage in the same period. With different social backgrounds, the capacity of exploring and exploiting water resources and the level of allocating and utilizing water resources will vary, resulting in fluctuation of water resources carrying capacity. The continuous improvement of social and economic level, the increasing demand for water resources, the increasing ability of development and utilization, the enhancement of water saving consciousness and the improvement of reuse of water resources are all the manifestations of its dynamic changes.

DOI: 10.2112/SI93-126.1 received 7 December 2018; accepted in revision 27 June 2019.

Table 1. *Analysis and evaluation standards for water resources carrying conditions.*

Factors	Indicators	Standard Value of Carrying Capacity	Serious Overload	Overload	Critical State	Not Overload
Amount of Water	Q_0	Q_1	$1.2Q_1 \le Q_0$	$Q_1 \le Q_0 \le 1.2Q_1$	$0.9Q_1 \le Q_0 < Q_1$	$Q_0 < 0.9Q_1$
	Q_2	Q_3	$\delta \ge 0.3$	$\delta \le 0.3$	$0.9Q_3 \le Q_2 < Q_3$	$Q_2 < 0.9Q_3$
Water Quality	α_0	α_1	$\alpha_0 \le 0.4\alpha_1$	$0.4\alpha_1 < \alpha_0 \le 0.6\alpha_1$	$0.6\alpha_1 \le \alpha_0 < 0.8\alpha_1$	$0.8\alpha_1 < \alpha_0$
	β_0	β_1	$3\beta_1 \le \beta_0$	$1.2\beta_1 \le \beta_0 < 3\beta_1$	$1.1\beta_1 \le \beta_0 < 1.2\beta_1$	$\beta_0 < 1.1\beta_1$

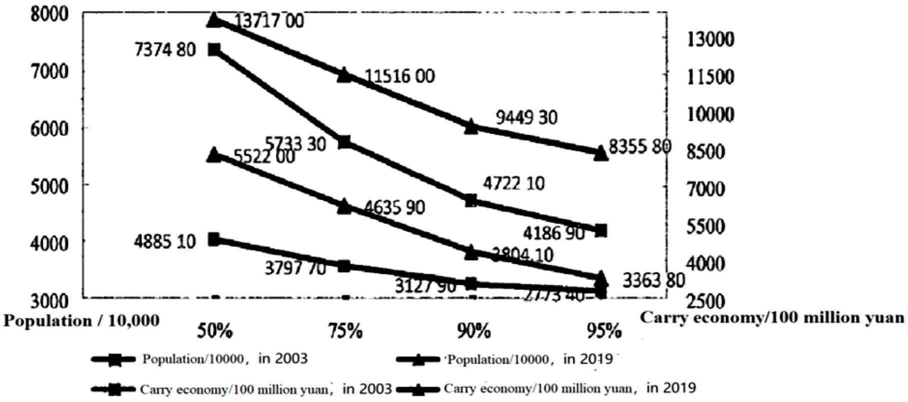


Figure 1. Water resources carrying capacity of some city in China from 2003 to 2019.

(3) Multiple factors. The relationship between supply and demand of water resources among regions is determined by many factors, such as the development route of the region, the water consumption demand of the industry, the advanced way of water resources development and utilization, and the level of development. The different spatial structure and regional characteristics of each region make the carrying capacity of water resources different because of the influence of regional environment and economic structure. As far as the regional water resources are concerned, their total amount is not fixed. If they are affected by the specific development environment, local rainfall, water conservancy engineering measures and management level, the total amount will change. In addition, the carrying capacity of the same water resources is uncertain in different environments, and the analysis criteria of the carrying capacity of water resources in the region are also affected by multiple factors (Hayami, 2009; Seppala, Melanen, and Maenpaa, 2005), as shown in Table 1. (Assuming that the total amount of actual water used in a certain period of time is Q_0, the upper limit value of the maximum carrying capacity of water resources in the region is Q_1; the total amount of groundwater used for underground exploitation in the region is Q_2, the upper limit value of groundwater exploited in the region is Q_3, the regional groundwater exploitation rate is δ; the actual water quality standard of regional water resources is α_0, and the water quality standard is α_1; the actual total amount of pollutants entering the river in the region is β_0, and the limit standard of pollutants entering the river is β_1.)

Impact of Water Resources Carrying Capacity on Regional Social Economy

In modern society, there are ubiquitous problems in the development of various industries, such as unreasonable water use structure, low water use efficiency and serious waste of water resources (Brelih *et al.*, 2019; Mirajkar and Patel, 2016; Zhang and Liu, 2019), which requires academia to study water resources carrying capacity and find a way to improve the efficiency of water resources utilization while describing the water resources carrying capacity system, which will greatly affect the population and economic scale changes in the region. Figure 1 shows the impact of water resources carrying capacity on social economy in a coastal city of China from 2003 to 2019.

From the Figure 1, it can be concluded that: Firstly, in the development of water resources, the overload of water resources carrying capacity is generally caused by the rapid economic development. At the same time, economic development is related to population growth. The rapid increase of population and uncontrolled human activities have greatly damaged the integrity of water resources system, resulting in a significant reduction in the renewable capacity and the carrying capacity of water resources. Secondly, the largest social and economic scale of the region changes with the water resources carrying capacity. When the water resources carrying capacity becomes larger, the population growth rate in the region shows a downward trend, while the economic scale shows an upward trend. Relying on advanced science and technology and water resources management methods, the carrying capacity of water resources in the region has increased from 50% to 95%. Meanwhile, the population growth rate in the region has decreased from 1.304% in 2003 to 1.207% in 2019, while the economic growth rate in the region has increased from 30.51% in 2003 to 49.89% in 2019.

ECONOMIC BENEFIT ANALYSIS OF REGIONAL WATER RESOURCES

Planning Objectives of Regional Water Resources

In a certain period of time, the planning objectives of regional water resources are mainly to improve the efficiency of comprehensive allocation of water resources from three aspects.

The first is to improve the efficiency of water resources allocation, so that competition between departments and industries can be dealt with.

The second is to improve the utilization efficiency of water resources and provide guarantee for sustainable development. In real life, the demand for water resources is diverse: basic domestic water for residents; production water for industrial and agricultural sectors; water for improving the ecological environment. Availability of water resources is the available amount of surface water resources, groundwater resources and deduction of repeated calculation of surface and groundwater resources (Jiang *et al.*, 2019; Zhang and Taiebat, 2019). As the availability of water resources includes domestic water with higher priority and ecologically necessary water, the availability of water resources can be used for production after subtracting domestic water and ecologically necessary water.

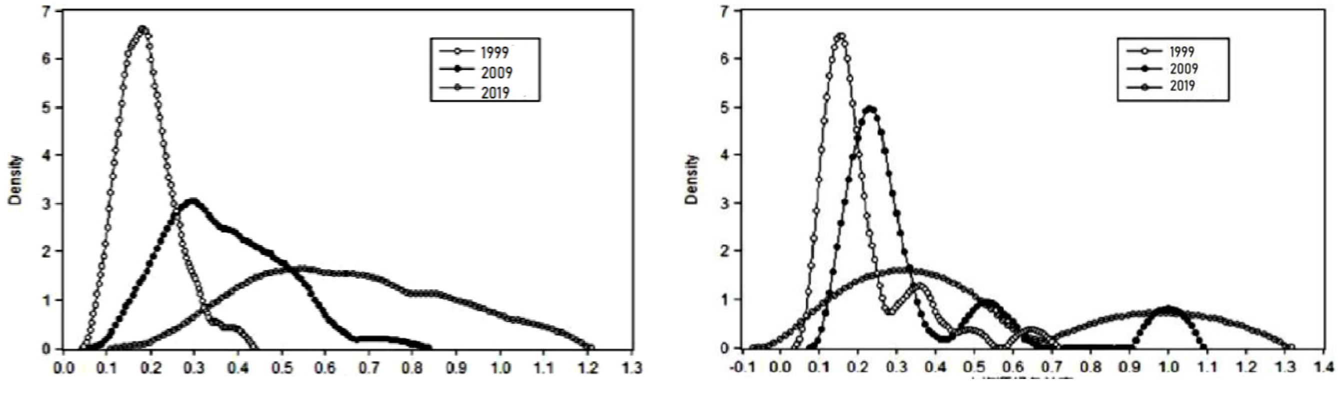
The third is to increase the recycling rate of regional reclaimed water. Reclaimed water refers to non-potable water that can be reused within a certain range after living and industrial sewage has been treated to meet the specified water quality standards. Reclaimed water is mainly used for green land irrigation, landscape rivers and lakes, environmental water and other ecological water requirements (He and Wang, 2019; Lombardi and Stefani, 2019). As an important link to ensure the sustainable development of economy and society, the utilization of reclaimed water can not only reduce the discharge of urban sewage and protect the water quality of rivers, but also improve the economic and environmental benefits of comprehensive utilization of water resources (He and Zhao, 2019; Seelen *et al.*, 2019). The water consumption coefficient, sewage treatment rate and reclaimed water recycling rate index are determined based on the water consumption coefficient of urban life and industry, the implementation of sewage treatment facilities and reclaimed water utilization facilities, *etc.*, as shown in Table 2.

There is a certain correlation between the economic and environmental benefits of water resources (taking a city in central China as an example), as shown in Figure 2.

Figure 2 shows that the economic and environmental benefits of water resources in the city show a bimodal distribution. With

Table 2. *Index of reclaimed water recycling.*

Year	Water Ways	Water Saving Ratio	Treatment Rate of Sewage (%)	Recycling Rate (%)
2015	water for life	0.16	81	30
	industrial water	0.45		
2020	water for life	0.15	85	40
	industrial water	0.65		
2030	water for life	0.14	100	90
	industrial water	0.85		



(a) Economic benefits of water resources

(b) Environmental benefits of water resources

Figure 2. The correlation between economic benefits and environmental benefits of water resources.

the passage of time, in 2009, the first peak gradually declined, while the other peaks gradually increased. By 2019, there were two peaks, the left peak was higher than the right peak, which indicated that the proportion of areas with high environmental benefits of water resources in this city was less than those with low environmental benefits, and the environmental benefits of water resources in this city showed a downward trend.

Prediction of Regional Water Resources Demand

In a certain period of time, regional water requirement is divided into several parts according to the water use department: water requirement for life, water requirement for production (agriculture, forestry, animal husbandry, fishery and industrial production) and water requirement for ecology environment. According to the influencing factors of water use (such as population, industrial output value, irrigation area, *etc.*) and water quota of each department, the prediction value of water demand of each department is calculated separately. The total water demand of each department is the total water demand (Banerjee and Cicowiez, 2019; Suthar *et al.*, 2019; Tang and Zhang, 2019).

(1) Prediction of water requirement for life (Q_f, m^3). According to the new caliber of water demand prediction, water for life includes urban water demand and rural water demand. The calculation equation by quota method is as follows:

$$Q_f = 365\sum_i H_i q_{i1} \tag{1}$$

where,

H_i = the average annual resident population in Area i (10,000 people);

q_{i1} = the annual per capita water consumption quota (L/person·day) in Area i.

(2) Prediction of water requirement for production (Q_p, m^3). Water for production includes water for agriculture, forestry, animal husbandry and fishery production and water for industrial production. The calculation equation by quota method is as follows:

$$Q_p = \sum_i S_{1i} q_{i2} + \sum_i M_i q_{i3} \tag{2}$$

where,

S_{i1} = the area of water used for agriculture, forestry, animal husbandry and fishery production in Area i within one year (10,000 mu);

q_{i2} = the quota of water for agriculture, forestry, animal husbandry and fishery production in Area i within one year (m^3/10,000 mu);

M_i = the industrial production value of Area i within one year (10,000 yuan);

q_{i3} = the quota of water for industrial production of Area i within one year (m^3/10,000 yuan).

(3) Prediction of water requirement for ecology environment (Q_e, m^3). Water for ecological environment is mainly used for irrigation in public green space. The calculation equation by quota method is as follows:

$$Q_e = \sum_i S_{2i} q_{i3} \tag{3}$$

where,

S_{i1} = the area of irrigation water (hm^2) for public green space in Area i within one year;

q_{i3} = the daily water use quota (m^3/hm^2) for public green space irrigation in Area i within one year.

Economic Benefit Target of Regional Water Resources

(1) Economic Benefit Accounting of Regional Water Resources

Based on the carrying capacity of water resources, the right to use regional water resources should be in accordance with certain standards. In addition to deducting sewage treatment costs, the economic benefits of regional water resources (I) mainly come from the income of water for life, production and ecological environment (Bi and Chen, 2019; Demetropoulou *et al.*, 2019).

$$\begin{aligned} &Q_0 = Q_f + Q_p + Q_e = \\ &365\sum_i \mathrm{H_i q_{i1}} + \sum_i \mathrm{S_{1i} q_{i2}} + \sum_i \mathrm{M_i q_{i3}} + \sum_i \mathrm{S_{2i} q_{i3}} \end{aligned} \tag{4}$$

$$\begin{aligned} &I = P_f Q_f + P_p Q_p + P_e Q_e - C_0\left(\eta_f Q_f + \eta_p Q_p + \eta_e Q_e\right) = \\ &365 P_f \sum_i \mathrm{H_i q_{i1}} + P_p\left(\sum_i \mathrm{S_{1i} q_{i2}} + \sum_i \mathrm{M_i q_{i3}}\right) + P_e \sum_i \mathrm{S_{2i} q_{i3}} - \\ &C_0\left[365\eta_f \sum_i \mathrm{H_i q_{i1}} + \eta_p\left(\sum_i \mathrm{S_{1i} q_{i2}} + \sum_i \mathrm{M_i q_{i3}}\right) + \eta_e \sum_i \mathrm{M_i q_{i3}}\right] \end{aligned} \tag{5}$$

$$\begin{aligned} &\beta_0 = 365\eta_f \sum_i H_i q_{i1} + \eta_p\left(\sum_i S_{1i} q_{i2} + \sum_i M_i q_{i3}\right) \\ &\eta_e \sum_i M_i q_{i3} \end{aligned} \tag{6}$$

where,

P_f = the price of water for life in Area i (yuan/m^3);

P_p = the price of water for production in Area i (yuan/m^3);

P_e = the price of irrigation water for public green space in Area i (yuan/m^3);

C_0 = the unit cost of sewage treatment in Area i (yuan/m^3);

η_f = the discharge coefficient of domestic sewage in Area i;

η_p = the discharge coefficient of production sewage in Area i;

η_e = the discharge coefficient of eco-environmental sewage in Area i.

(2) Economic Target of Regional Water Resources

Based on carrying capacity, the essence of multi-objective water resources planning is to support the overall coordination and sustainable development of economy, society and ecology of the whole basin or region. Therefore, the principle of economic benefit is the economic goal and the principle of sustainability is the ecological goal of water resources in the region. In a certain period of time, the actual total amount of water used in the region is Q_0 usually not greater than the maximum carrying capacity of the upper limit value of Q_1. At the same time, according to environmental protection requirements, the actual total amount of pollutants entering the river in the region should be β_0 less than the limit standard of β_1. Under these constraints, the economic goal of regional water resources is to maximize economic benefits and minimize regional water shortage at the same time, which can be expressed as:

$$\begin{aligned} &\max \mathrm{I} = \\ &365 P_f \sum_i \mathrm{H_i q_{i1}} + P_p\left(\sum_i \mathrm{S_{1i} q_{i2}} + \sum_i \mathrm{M_i q_{i3}}\right) \quad P_e \sum_i \mathrm{S_{2i} q_{i3}} - \\ &\mathrm{C_0}\left[365\eta_f \sum_i \mathrm{H_i q_{i1}} + \eta_p\left(\sum_i \mathrm{S_{1i} q_{i2}} + \sum_i \mathrm{M_i q_{i3}}\right) \quad \eta_e \sum_i \mathrm{M_i q_{i3}}\right] \end{aligned} \tag{7}$$

$$\begin{aligned} &\min\left(\mathrm{Q_0} - \mathrm{Q_1}\right) = \\ &365\sum_i \mathrm{H_i q_{i1}} + \sum_i \mathrm{S_{1i} q_{i2}} + \sum_i \mathrm{M_i q_{i3}} \quad \sum_i \mathrm{S_{2i} q_{i3}} \quad \mathrm{Q_1} \end{aligned} \tag{8}$$

Constraints:

$$1.2\mathrm{Q}_1 \leq \mathrm{Q}_0 1.2 \tag{9}$$

$$\beta_0 = 365\eta_f \sum_i H_i q_{i1} + \eta_p (\sum_i S_{1i} q_{i2} + \sum_i M_i q_{i3}) \quad \eta_e \sum_i M_i q_{i3} \leq \beta_1 \tag{10}$$

Of course, the regional water resources economic goal should also be based on the current industrial water quota level in countries or regions with advanced economic development and advanced water consumption levels. On this basis, appropriate adjustments should be made in conjunction with local development conditions. The following aspects are considered: the characteristics of production quality and product structure of different industries in the region; the production scale of different enterprises; the differences of production technology, production equipment and technology level between different industries; the level of water use and water saving in the region; the level of water use management and water price in the region, *etc.*

CONCLUSIONS

By analyzing the economic targets of water resources based on the principle of economic benefits and the ecological objectives based on the principle of sustainability, this paper studies the economic targets, environmental objectives and water balance constraints of regional water resources utilization, and constructs an accounting model for maximizing the economic benefits of regional water resources and minimizing regional water shortage. The results are as follows: (1) Based on the regional water resources carrying capacity, the social goals, environmental objectives and water balance constraints of regional water resources use are studied, and the accounting model of maximizing the economic benefits of regional water resources and minimizing regional water shortage is constructed to guide regional water resources planning and adjustment. (2) Quantitative study on the rational allocation of water resources and economic targets in the region is also aimed at maintaining a good ecological environment, saving and protecting water resources, promoting the sustainable utilization of regional water resources, promoting the coordination of economic and social resources in the region, water resources and water environment, and ensuring the long-term stable and rapid development of the regional economy and society.

ACKNOWLEDGEMENTS

This work was supported by National Social Science Fund Youth Project (16CJY013) and Philosophy and Social Science Planning Project of Henan Province (2016BJJ057).

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