The Analysis of Water Resource Ecological Carrying Capacity of Hainan International Island

Jun-kuo Cao, Jie Zhang and Sheng-Quan Ma

Abstract The ecological carrying capacity of water resources is a comprehensive concept of natural science and social science, which includes ecological society and economic society dual attributes. Since Canadian scholar Wackernagel has proposed the model of ecological footprint in 1992, it has been a popular evaluation method of ecological society sustainable development. And in the same time, it also provides a new way to analyze the capacity of regional water resources. In this paper, we used this model to assess the sustainable status of Hainan Province water resources from the year 2003 to 2009. For computing convenience and accuracy, we referred to the average water productivity modulus released annually by Department of Hainan Water Resource instead of the average water production in the calculation process. Experimental data show that we conducted deeply analysis of the current situation of Hainan water resources, which will provide scientific data for the sustainable use of water resources for international tourism island developing.

Keywords Water resources · Ecological carrying capacity · Ecological footprint model

1 Introduction

Water is the source of life, and it is indispensable to human survival and social and economic development resources. What's more, it plays an irreplaceable role in the maintenance of the ecological environment and the process of social

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production. The carrying capacity of water resources refers to the size that can support human life, social production, and the ecological water use, involving population, resources, ecological environment, socioeconomic, and other systems.

With the rapid development of global warming and the social economy, water ecosystem issues become increasingly complex, coupled with the existing water quantity and quality issues, forcing people urgently to understand the bearing capacity of the water ecological system related to the human beings from a higher perspective. Obviously, the already concept about the carrying capacity of water resources and water environment cannot entirely meet the needs of reality. Even it has become the restricting factors of the development of human society. Faced with the grim situation of water shortage, the sustainable use of water resources has become a research focus of attention. Facing the severe situation of water resources and the sustainable utilization of water resources has become the research hot spot. In 1992, William [1] put forward the ecological footprint theory and his student Wackernagel developed and perfected its calculation principle and method, which later widely used by the scholars and institutions around the world [2, 3]. This theory was introduced into China by Xu et al. [4] and other scholars in 1994 and soon became the new research hot spot. In 2008, Huang et al. [5] labeled water as the seventh kind of land type into the index of ecological footprint calculation and establish the ecological footprint model, which has already been widely used in the development of regional water resources utilization and the evaluation of potential sustainable use [6–8].

2 General Situation of Water Resources in Hainan

Hainan Island is China's second largest island, which is currently in the initial stage of economic development and construction of large scale. At the same time, it also attracts the widespread concern both at home and abroad. They concern whether Hainan can maintain the ability of the extraordinary development of the economy and ensure the reasonable protection and sustainable use of environmental resources. At present, from the statistics in recent years (see Table 1), the average total water resources in Hainan Province is about 32 billion m^3 and the per capita possession of water resources 3,900 m^3 that is higher than the national level 2,200 m^3 while is still only 44 % of the world average. Therefore, because of the unique island topography, rainfall, uneven spatial and temporal distribution of water reserves, drought and floods occur almost every year along with the outstanding problems of regional and engineering water shortage.

Rainfall in Hainan Island is mainly composed of the typhoon and the southwest monsoon, and the average annual rainfall is 1,639 mm. Because the water flow is mainly from the east, in the central and eastern regions rainfall is about 2,000–2,400 mm. Slightly less in the northeast, its annual rainfall is about 1,500–2000 mm. The west to northwest is less, usually under 1,500 mm, and the least area is even less than 1,000 mm. Like the distribution of rain, the island's

Table 1 Consumption distribution of Hainan water resources from the year 1998 to 2009 (One hundred million M^3)

Year	Total water quantity	Total consumption		Domestic consumption		Industrial consumption		Agricultural consumption	
		Total water use	Proportion of total use (%)	Domestic water	Proportion of total use (%)	Industrial water	Proportion of total use (%)	Agricultural water	Proportion of total use (%)
1998	246.63	46.82	18.99	4.70	1.91	3.69	1.49	38.44	15.58
1999	337.51	45.34	13.43	4.74	1.40	3.74	1.11	36.86	10.92
2000	458.14	44.02	9.61	4.88	1.06	3.71	0.81	35.44	7.73
2001	464.15	43.55	9.38	4.91	1.06	3.73	0.80	34.91	7.52
2002	333.12	44.08	13.23	4.73	1.42	3.59	1.08	35.76	10.73
2003	291.80	46.31	15.87	4.00	1.37	4.06	1.39	36.25	12.42
2004	171.14	45.77	26.74	4.07	2.38	3.04	1.78	37.68	22.02
2005	307.29	44.04	14.33	4.18	1.36	3.18	1.03	35.47	11.54
2006	227.59	46.46	20.41	4.20	1.85	3.78	1.66	37.07	16.29
2006	283.52	46.69	16.47	4.28	1.51	4.67	1.65	36.17	12.76
2008	419.10	46.89	11.19	4.33	1.03	4.90	1.17	35.95	8.58
2009	480.70	44.64	9.29	4.44	0.92	4.07	0.85	34.34	7.14
Average	335.06	45.38	14.91	4.45	1.44	3.85	1.24	36.19	11.94

water reserves are also uneven from the perspective of spatial and temporal distribution. First of all, there exists a big difference in the flow of some big rivers within a year and between years. Secondly, the difference of the flow of the river and the different river estuaries, sea result in the uneven distribution of water resources in coastal zone, such as the non-estuarine areas is short of water, while the estuary areas are rich in water. Three major rivers of water exports account for 53 % of the surface water resources.

In addition, with the rapid development of the special social and economic construction, another adverse consequence of rapid development of industry and city water resources is causing water pollution, so as to make the (light water) to the increasingly prominent contradiction between supply and demand of water resources in Hainan. This conflict has become one of the main restricting factors for Hainan economy development [1]. Therefore, researching on the various water problems in Hainan Island and exploring the right way to solve the water crisis is a very urgent task.

3 Evaluation Model on the Carrying Capacity of Water Resources

3.1 The Ecological Footprint Model of Water Resources

Ecological footprint theory is used to measure regional sustainable development status by estimating the maintenance of natural resources for human consumption and the ecological productive space area size needed to assimilate human waste. What's more, it can also be used to compare with regional ecological carrying capacity of a given population. Water is recognized as one of the resources. The account of water resources founded in the ecological footprint model of water resources consists with the connotation of ecological footprint. The meaning of the ecological footprint can be expressed in two aspects. First of all, it is the process of human consumption of water resources in daily life and industry. Secondly, it means the stable demand for water to maintain the natural environment. According to the characteristics of water use, water can be divided into three categories: domestic water, industrial water, and ecological environment water, among which the domestic water includes water used by both the urban residents and rural residents. Industrial water includes the primary industry water (including agriculture, forestry, and animal husbandry water), the second industrial water (including industrial water and construction water), and the tertiary industry water (including commercial and service sector water use). According to Yang Zhifeng and other experts' opinion, eco-environmental water can be divided into the internal and external water use of the river. The external water of the river includes city environmental water, and wetland replenishment water, and the internal water of the river refers to the improvement of water environment of rivers, lakes, and other water allocation.

According to the three sub-domestic water footprint, the ecological footprint model of water resources can be expressed as follows:

$$EF_w = EF_{lc} + EF_{pc} + EF_{ec} = N \times ef_w$$

$$EF_{lc} = N \times ef_{lc} = \gamma_w \times (W_l/P_w)$$

$$EF_{pc} = N \times ef_{pc} = \gamma_w \times \left(W_p/P_w\right)$$

$$EF_{ec} = N \times ef_{ec} = \gamma_w \times (W_e/P_w)$$

In the equation, EF_w means the ecological footprint model of water resources (hm^2). ef_w means the per capita ecological footprint model of water resources (hm^2/per capita); EF_{lc} refers to domestic water ecological footprint. It means the demand of water for citizens during a certain period, including water used by both the urban residents and rural residents. EF_{pc} is the industrial water, including industrial water, agricultural irrigation water, animal husbandry, and fishery water; EF_{pc} is eco-environmental water footprint, referring to the process of the improvement of the regional ecological environment that include the ecological water use and environmental water allocation. "N" is the regional total population (per capita).γ_w is the equilibrium factor of water resources. P_w is the average production capacity of regional water resources (m^3/hm^2). W_l, W_p, W_e, respectively, refer to the consumption of domestic water, industrial water, and eco-environmental water (m^3). ef_{lw}, ef_{pw}, ef_{ew}, respectively, refer to the per capita of domestic water ecological footprint, industrial water ecological footprint, and eco-environmental water footprint.

3.2 Model of the Carrying Capacity of Water Resources

The carrying capacity of water resources can be defined as follows: The supporting capacity of regional water resources in the benign development of regional water ecosystems and sustainable economic system in a specific historical stage of development. If the rate of the development and utilization of regional water resources is higher than 30 % and 40 %, it may lead to the deterioration of ecological environment. Therefore, at least 60 % of carrying capacity of water resources should be saved to maintain the health of regional ecological system and the eco-environment balance. According to the analysis, the model of the carrying capacity of water resources can be expressed [4]:

$$EC_w = N \times e_{cw} = \pi \times \psi \times \gamma_w \times Q_w/P_w$$

In the equation, π is the utilization rate of resource exploitation (value 0.4). EC_w is the ecological carrying capacity of water resources (hm^2). e_{cw} is the per capita of ecological carrying capacity of water resources (hm^2/per capita). γ_w is the

Table 2 Water resources yield factor of Hainan province from 2003 to 2009

Year	2003	2004	2005	2006	2007	2008	2009	Average
The average modulus of water	8,540	5,010	9,000	6,660	8,300	12,270	14,070	9,121
Water resources yield factor (m^3/hm^2)	2.72	1.60	2.87	2.12	2.64	3.91	4.48	2.90

equilibrium factor of water resources. ψ is the yield factor of regional water resources. Q_w is the regional total water resources (m^3). P_w is the average production capacity of water resources in the world.

4 Analysis of the Carrying Capacity of Water Resources

4.1 Model Parameters

In the process of calculating ecological footprint and ecological carrying capacity, the parameters and their values we used are as follows: Average production capacity $P_w = 140.7$ (m^3/hm^2), Balancing factor $\gamma_w = 5.19$, and Yield factor $\psi = 3.73$. In addition, we know that the average production capacity of water resources is the runoff modulus of the average global annual production capacity. Therefore, in order to facilitate the calculation and accuracy, we will use the average runoff modulus instead of the average water production capacity when doing research on s carrying capacity of water resources in Hainan Province. The average runoff modulus during 2003–2009 can be shown in Table 2.

4.2 Per Capita Ecological Profit and Loss of Water Resource

That whether the regional water resource is in a state of ecological deficit and ecological surplus can judge whether the regional production and consumption activities are within the bearing range of the ecosystem. Thus, we can measure the sustainable utilization of regional water resources. According to this definition, the model of the carrying capacity of the water resources is

$$\mathrm{er}_d = \mathrm{ef}_w - \mathrm{ec}_w$$

when $\mathrm{er}_d < 0$, it indicates that the ecological carrying capacity of regional water is greater than the ecological footprint. That means the ecological surplus and it is in the sustainable utilization condition. When $\mathrm{er}_d > 0$, it is in the state of ecological deficit and it is in the ecological destruction state.

Table 3 is about the statistics about the ecological footprint of Hainan from 2003 to 2009. It is easy to find that the highest ecological footprint in Hainan

Table 3 Statistics about the ecological footprint of Hainan from 2003 to 2009

Year	The total population (per million people)	Domestic water footprint/ hm^2	Industrial water footprint/ hm^2	Ecological water footprint/ hm^2	Total ecological water footprint/ hm^2	The per capita of domestic water ecological footprint/ $hm^2.cap^{-1}$
2003	811	243,091	2,536,050	35,248	2,814,390	0.35
2004	818	421,623	4,310,497	9,323	4,741,443	0.58
2005	828	241,047	2,293,403	5,190	2,539,640	0.31
2006	836	327,297	3,286,221	7,014	3,620,532	0.43
2007	845	267,629	2,646,275	5,628	2,919,531	0.35
2008	854	183,152	1,796,408	3,807	1,983,367	0.23
2009	864	163,778	1,479,537	3,320	1,646,635	0.19
Average	837	263,945	2,621,199	9,938	2,895,077	0.35

Table 4 Statistics about the ecological carrying capacity and the benefit and ecological deficit of water resources in Hainan Province from 2003 to 2009

Year	2003	2004	2005	2006	2007	2008	2009	Average
$EC_w 10^6 hm^2$	26.458	26.451	26.439	26.462	26.451	26.449	26.456	26.452
ec_w/hm^2	3.262	3.234	3.193	3.165	3.130	3.097	3.062	3.163
e_{rd}	−2.912	−2.654	−2.883	−2.735	−2.78	−2.867	−2.872	−2.815

Province is 0.58 hm^2 cap^{-1}, the lowest one is 0.19 hm^2 cap^{-1}, and the average level is 0.35 hm^2 cap^{-1}. From the perspective of development trend, due to the increasing population and improvement in the utilization of water resources in recent years, the per capita water ecological footprint decreased slightly, but remained stable on the whole. In addition, on the average distribution of the ecological footprint, we know that the industrial water use accounts for 90.5 % of total water ecological footprint and the domestic water use accounts for 9.1 %, while ecological footprint water use is only 0.3 %.

Table 4 is the statistics on the ecological carrying capacity and the benefit and ecological deficit of water resources in Hainan Province from 2003 to 2009. From the chart, we can conclude that in 2003 the per capita ecological carrying capacity of water resource reached the maximum value, which is 3.262 hm^2 cap^{-1}; in 2009, it experienced the minimum value 3.062 hm^2 cap^{-1}. Besides, from the point of ecological water profit and loss, the Hainan international tourism island is in an ecological surplus condition and the average water ecological profit and loss is −2.815 hm^2 cap^{-1}.

Based on the analysis of data as shown in Tables 3 and 4, the current water resource in Hainan international tourism island is very rich, and it is in the sustainable development of the ecological surplus condition. What's more, the use and development of water resource has a relatively vast development space.

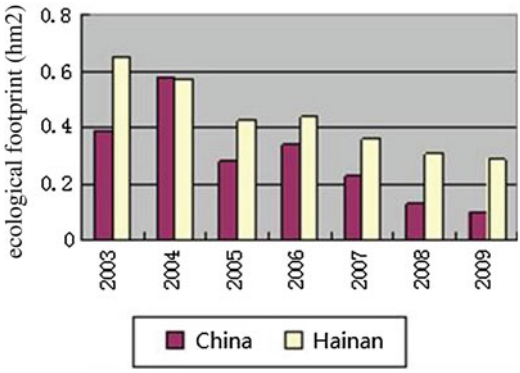

Fig. 1 Ecological footprint per ten thousand yuan GDP in Hainan from 2003 to 2009

5 Analysis of Ecological Footprint per Ten Thousand Yuan GDP

Ecological footprint per ten thousand yuan GDP means ratio of the water resources and regional ecological footprint. It can objectively measure the utilization of regional water resources and its economic growth mode. The formula is $EF_{gdp} = EF_w/GDP$

From chart 1, we can conclude that the utilization of water resources have gradually improved both in Hainan international tourism island and in the whole China. In 200, the ecological footprint per ten thousand yuan GDP of China is 0.39 hm^2, while the number is only 0.65 hm^2 in Hainan. In 2009, the ecological footprint per ten thousand yuan GDP declines to 0.10 hm^2 nationally, and the ecological footprint per ten thousand yuan GDP in Hainan is just 0.29 hm^2. Although the ecological footprint per ten thousand yuan GDP in Hainan decreased by 55.4 % from 2003 to 2009, we have to notice the gap: The rate of the utilization of water resources is only equivalent to the national level, and it accounts for 3/1 of the national level in the same period (Fig. 1).

6 Conclusion

From the perspective of the ecological footprint and carrying capacity of water resources from 2003 to 2009, it indicates that the water resource in Hainan is in the ecological surplus situation, implying that the use and development of water resource has a relatively vast development space. Judging from the development tendency of the ecological footprint of water resources in Hainan from 2003 to 2009, the efficiency of utilization of water resources in Hainan has increased. But the rate of the utilization of water resources is lower than the national level of the ecological footprint per ten thousand yuan GDP in the same period, only about a

third of the country's utilization level. From distribution of the domestic water, industrial water, and ecological footprint of water resources, the industrial ecological footprint accounts for the largest share of water resources and ecological footprint of water resources shares the least of the water resources. It indicates that there exists the uneven distribution of water resource in Hainan. Measures should be taken into consideration to carry out industrial restructuring, allocate the water resources reasonably, and improve the efficiency of water use, especially to improve efficiency of the repeating utilization of industrial water and agricultural irrigation, so as to ensure the sustainable development of social economy and ecological environment in Hainan international tourism island.

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