Evaluation of water resources carrying capacity of Gonghe basin based on fuzzy comprehensive evaluation method

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Abstract: Gonghe Basin belongs to arid and semi-arid climatic zone, where water resource is relatively scarce and desertification is serious, so it is necessary to find out water resources carrying capacity. By using fuzzy comprehensive evaluation method, the assessment on water resources carrying capacity in Gonghe Basin was conducted: Water resource carrying capacity of Gonghe County is less, while that of Guinan County and Chaka Town of Wulan County are greater; water resources of Gonghe Basin could sustain cultivated land of 652.6 thousand acres and grassland of 2 368.6 thousand acres respectively in 2020, water resources of Gonghe Basin could sustain cultivated land of 948.2 thousand acres and grassland of 2 247.6 thousand acres respectively in 2030.

Keywords: Gonghe Basin; Water resources carrying capacity; Fuzzy comprehensive evaluation method

Introduction

The shortage and uneven distribution of water resources are two of the main problems confronted by water sources in China. This is especially true of the inland basins in the northwestern region of China, where water resources are in rare supply. As a matter of fact, it's an important contributor to a series of environmental and geological problems like land desertification (GUO Zhan-rong *et al.* 2001). Therefore, it's imperative to perform a research into the water resources carrying capacity of Gonghe Basin so that we can achieve more scientific allocation of water resources and maintain the sustainable development in terms of regional society, economy and ecological environment.

UNESCO initiated the concept of resources carrying capacity in the early 1980's (UNESCO, FAO, 1985). Resources carrying capacity focuses on the relationship between human beings and resources. Quite a few domestic scholars have examined the evaluation of water resources carrying capacity. The water resources carrying capacity is defined by ZHANG Xin and other scholars as the capacity of water sources during different future timeframes to meet the requirements of industrial and agricultural production, people's daily lives and environmental protection for water supply when the social, economic and technological conditions are taken into consideration (ZHANG Xin *et al.* 2001). MEN Bao-hui *et al.* (2003), WANG Shun-jiu *et al.* (2004), LU Chao *et al.* (2011) and LIN Wu-xing and WU Ze (2008) have used matter-element model, project pursuit model, system dynamics simulation model and genetic algorithm model respectively to evaluate the water resources carrying capacity. LIU Shu-feng and CHEN Jun-he (2007), ZOU Jin *et al.* (2014), LI Pei-yue *et al.* (2010) and DING Ai-zhong *et al.* (2010) have applied the neural network theory, dualistic water cycle theory, ecological footprint theory and rough set theory separately to the evaluation of water resources carrying capacity. Moreover, GAO Yan-chun and LIU Chang-ming (1997) and FU Xiang and JI Chang-ming (1999) have involved the comprehensive evaluation method and principal

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components analysis (PCA) method to evaluate water resources carrying capacity.

WANG Wei *et al.* (2005) have created the water resources carrying model of the Gonghe Basin to provide a workable approach to the quantitative research on water resources carrying capacity. WANG Xue-quan *et al.* (2007) have developed the judgment index of water resources carrying capacity inside the Gonghe Basin. However, no scholars have ever conducted the quantitative evaluation of water resources carrying capacity of the Gonghe Basin. This essay uses the fuzzy comprehensive evaluation method to perform the quantitative evaluation of water resources carrying capacity of the Gonghe Basin when the general goal, sub-goal and single index structure are considered.

1 Physical geography of research area

Hainan Tibetan Autonomous Prefecture, which is located in Qinghai Province, belongs to arid and semi-arid climatic zone. Desertification has seriously restricted the sustainable development of ecological environment. According to the imagery interpretation of Landsat-8 in spring of 2013–2014, the desertification of the Gonghe Basin almost has an area of 2 413 km^2, 11.98% of the total area. Specifically, Mugetan, Talatan, Salt Lake-Shazhuyu River claim the desertification area of 620 km^2, 518 km^2 and 1 275 km^2. In this sense, the land desertification area has witnessed an annual increase (YANG Shi-qi *et al.* 2005).

Gonghe County, Guinan County, and Wulan County's Chaka Township fall within the area of the Gonghe Basin. Gonghe County is the capital of Qinghai Hainan Tibetan Autonomous Prefecture. As the seat of prefecture and county governments, Qiabuqia Township is the political, economic and cultural center of the whole prefecture (Fig. 1). In the Gonghe Basin, the total population was 212 700 in 2013 with an annual growth of about 4.13%, and the urbanization rate was 41.62%. In 2013, the GDP in Gonghe County and Guinan County totalled 4.047 billion yuan and 1.392 billion yuan respectively with an annual increase of 12.4% and 9.1%. The arable cultivated land in the Gonghe Basin has a total area of 63 206 hm^2, including the irrigated cultivated land of 23 793 hm^2.

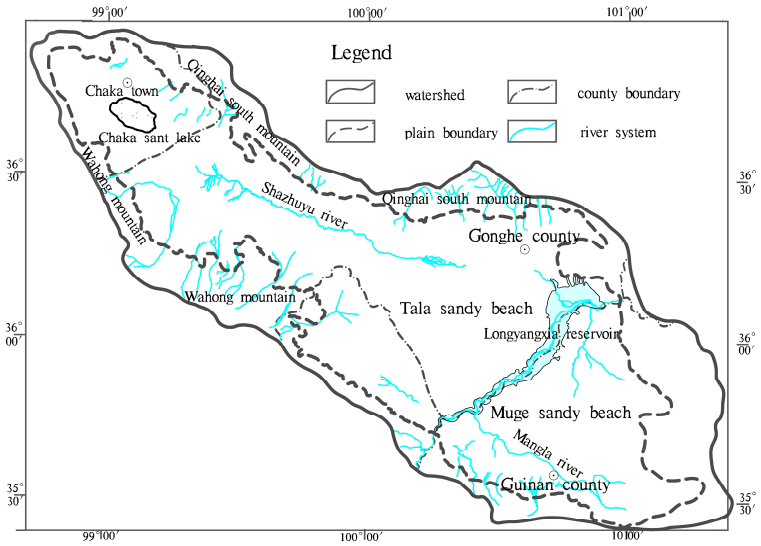


Fig. 1 Profile of Gonghe Basin

2 Analysis of water resources supply and demand

The water resources in the Gonghe Basin consist of groundwater and surface water. The groundwater resources are the evaluation result of groundwater resources in the geological survey and evaluation of hydrogeological environment in the Gonghe Basin. The data of surface water resources are the part of the investigation and collection result in this project. Before our research

on water resources carrying capacity, our first step is to complete the analysis of water resources supply and demand (Table 1).

As indicated in Table 1, Gonghe County, Feinan County and Chaka Township have the guaranteed water supply of 276.49×10^4 m^3, 754.91×10^4 m^3 and 590.37×10^4 m^3 respectively. The water resources in the Gonghe Basin were mainly distributed in the Qiabuqia River Valley, the Mangla River Valley and the Wahong piedmont alluvial-diluvial fan. The exploitation of groundwater mainly takes place in Qiabuqia River Valley and the peripheral areas of Feinan County proper for the daily and industrial uses. There is the striking contradiction between geographic distribution and practical exploitation of water resources. It is true that the water resources in the Gonghe Basin has the highly guaranteed water supply, but the geological environment problems such as the continuous decline in groundwater level have been found in those regions with the intense development and exploitation of water sources, such as the areas along the upper and middle reaches of the Qiabuqia River.

Table 1 Analysis of water resources supply and demand in Gonghe Basin (10^4 m^3)

Administrative region	Groundwater resources	Surface water resources	Total water resources	Current water consumption	Guaranteed water supply (%)
Gonghe County	23 622.95	13 394.00	37 016.95	13 388.00	276.49
Feinan County	10 242.50	11 990*	22 232.5	2 945.04	754.91
Chaka Township	3 121.11	589.88	3 710.99	628.59	590.37

*(ZHANG Ying *et al.* 2007)

The quantitative evaluation of water resources carrying capacity is conducted in the Gonghe Basin and especially in the Wahong piedmont alluvial-diluvial fan and the Mangla River Valley where the exploitation of water sources remain at a low level. Our efforts to develop more cultivated land and forestland with stronger water resources carrying capacity, increase vegetation coverage and prevent the worsening desertification will help maintain the sustainable development of regional ecological environment.

3 Index construction of water resources carrying capacity

The scholars paid more attention to water resources system, social system and economic system when it comes to the establishment of water resource carrying index system. Because the Gonghe Basin is confronted by the geological environment problems such as serious desertification, thus this evaluation uses the ecological environment system as the evaluation index so as to give a comprehensive picture of water resources carrying capacity (MA Feng *et al.* 2012). Refer Table 2 for the index system of water resources carrying capacity in the Gonghe Basin.

The water resources carrying capacity of the Gonghe Basin is treated as general goal and the water resources system, social system, economic system and eco-system are defined as secondary goals. The influence weighting of secondary goals to general goal is α_1, α_2, α_3 and α_4. Considering the influence weighting of secondary goals to water resources carrying capacity, we get the values like α_1=0.5, α_2=0.2, α_3=0.1 and α_4=0.2 (Fig. 1). In the Gonghe Basin, pollution, economy, agriculture and husbandry are mainly found in the Qiabuqia River Valley, the Mangla River Valley and the Wahong piedmont alluvial-diluvial fan, but the water sources carrying capacity is something impossible in Tala Beach and Muge Beach, where water resources are in rare supply. So the distribution of water sources will have great implications for water resources carrying capacity, and α_1=0.5. Then there're social system and economic system, where weighting is 0.2. The influence scope of economic system is only limited to the two sides along the river valley, where the weighting is the lowest, just 0.1. The weightings of single indices to the secondary goals are (β_{11}, β_{12}, β_{13}), (β_{21}, β_{22}, β_{23}, β_{24}), (β_{31}, β_{32}, β_{33}, β_{34}) and (β_{41}, β_{42}). Refer to Table 2 for details.

The single indices of water resources carrying capacity of Gonghe County, Guinan County, and Wulan County's Chaka Township, including (γ_{11},

γ_{12}, γ_{13}), (γ_{21}, γ_{22}, γ_{23}, γ_{24}), (γ_{31}, γ_{32}, γ_{33}, γ_{34}) and (γ_{41}, γ_{42}) shall be quantified respectively as γ_1, γ_2 and γ_3. Specifically, γ_1 represents the big water resources carrying capacity, γ_2 the moderate water resources carrying capacity and γ_3 the small water resources carrying capacity. To give a quantitative picture of how these indices affect the secondary goals, the score of 0–1 is assigned to γ_1, γ_2 and γ_3. γ_1=0.95, γ_2=0.5 and γ_3=0.05 (LIU Min *et al.* 2014). See Table 3 for the quantitative classification of single index in Gonghe Basin.

Table 2 Index system of water resources carrying capacity of Gonghe Basin

General goal	Secondary goal	Weighting (α)	Single index	Weighting (β)
Water resources carrying capacity of Gonghe Basin	Water resources system	0.5	Unit-area water resources	0.4
			Exploitation rate of water resources	0.3
			Per-capita water resources	0.3
	Social system	0.2	Population density	0.4
			Population growth rate	0.1
			Urbanization rate	0.2
			Livestock breeding density	0.3
	Economic system	0.1	Ratio of basic cultivated land	0.3
			Ratio of husbandry output value to GDP	0.3
			Ratio of industrial output value to GDP	0.2
			Annual growth rate of GDP	0.2
	Eco-system	0.2	Coverage of grassland and forests	0.6
			Coverage of deserts	0.4

The classification standard of water resources carrying capacity in all the administrative regions of Gonghe Basin:

$\alpha \leqslant 0.5$: small water resources carrying capacity

$\alpha > 0.5$: large water resources carrying capacity

4 Evaluation of water resources carrying capacity

4.1 Qualitative evaluation of water resources carrying capacity

Based on the index system of water resources carrying capacity of the Gonghe Basin, water resources carrying capacity of Gonghe County, Guinan County, and Wulan County's Chaka Township shall have the comprehensive scores as follows:

$$S=\sum_{j=1}^{3}\alpha_1\beta_{1j}\gamma_{1j}+\sum_{j=1}^{4}\alpha_2\beta_{2j}\gamma_{2j}+\sum_{j=1}^{4}\alpha_3\beta_{3j}\gamma_{3j}+\sum_{j=1}^{2}\alpha_4\beta_{4j}\gamma_{4j}$$

Refer Table 4 for the evaluation scores of water resources carrying capacity of Gonghe County, Guinan County, and Wulan County's Chaka Township.

In the water resources system of secondary goals (as indicated in Table 4), Guinan County and Wulan County's Chaka Township report a high score, that is, 0.295. Guinan County has the low exploitation rate of water resources and Wulan County's Chaka Township has the low exploitation rate of water resources and the abundant water resources per capita. In the social system, Gonghe County and Guinan County have a higher score, that is, 0.145; in the economic system, Gonghe County has the highest score of 0.0635; in the eco-system, Wulan County's Chaka Township has the highest score of 0.082, and doesn't have the environmental problems such as desertification.

According to the classification standard of water resources carrying capacity in all the administrative regions of the Gonghe Basin, Gonghe County's score is 0.50, which implies the small water resources carrying capacity; Guinan County and Wulan County's Chaka Township have the score of 0.554 and 0.572 separately, which implies the considerable water resources carrying capacity.

Table 3 Quantitative classification of single index

Index guideline	Single index	γ_1	γ_2	γ_3	Gonghe County	Guinan County	Chaka Township
Water resources system	Unit-area water resources (10 000 m^3)	>50	10–50	<10	5.02	7.21	2.43
	Exploitation rate of water resources (%)	<20	20–60	>60	38.73	1.56	16.94
	Per-capita water resources (10 000 m^3)	>2 100	600–2 100	<600	2 930.8	2 804.8	7 155.8
Social system	Population density (P/km^2)	<50	50–300	>300	17.14	25.69	2.31
	Population growth rate(‰)	<3	3–10	>10	0.49	10.88	4.13
	Urbanization rate (%)	<40	40–80	>80	44.65	33.18	46.28
	Livestock breeding density (head/km^2)	<20	20–100	>100	51.37	80.35	80.34
Economic system	Ratio of basic cultivated land (%)	<20	20–50	>50	4.08	1.05	2.30
	Ratio of husbandry output value to GDP	<10	10–30	>30	17.54	37.49	8.43
	Ratio of industrial output value to GDP	<20	20–50	>50	48	22	59
	Annual growth rate of GDP	<5	5–15	>15	12.41	9.17	16.06
Eco-system	Coverage of grassland and forests	>30	10-30	<10	11.50	14.97	7.95
	Coverage of deserts	<5	5–20	>20	23.96	20.10	0

Table 4 Evaluation scores of water resources carrying capacity

Secondary goal	Gonghe County				Guinan County				Chaka Township			
	γ_1	γ_2	γ_3	S	γ_1	γ_2	γ_3	S	γ_1	γ_2	γ_3	S
Water resources system	0.15	0.15	0.2	0.2275	0.30		0.20	0.295	0.30		0.20	0.295
Social system	0.10	0.10		0.145	0.12	0.06	0.02	0.145	0.08	0.12		0.136
Economic system	0.03	0.07		0.0635	0.03	0.04	0.03	0.05	0.06		0.04	0.059
Eco-system		0.12	0.08	0.064		0.12	0.08	0.064	0.08		0.12	0.082
Subtotal	0.28	0.44	0.28		0.45	0.22	0.33		0.52	0.12	0.36	
Evaluation score S	0.50				0.554				0.572			

4.2 Quantitative evaluation of water resources carrying capacity

Quantitative evaluation of water resources carrying capacity in the Gonghe Basin is detailed as follows:

(1) Give top priority to the residential and industrial water demands and consider the changes to natural growth rate of residents, industrial growth rate, residents' daily water use, and industrial energy consumption in the context of social development;

(2) Achieve irrigation for 50% arid cropland (2020) and for all the arid cropland (2030) (Refer Table 5 for the conditions of cultivated land in the Gonghe Basin); consider the government's agricultural water-saving measures;

(3) Evaluate the ecological water consumption to support the grassland irrigation when the residential needs and agricultural and industrial development are guaranteed to mitigate desertification, and propose the irrigation area of grasslands that can be supported by water resources in the short and long run.

Refer Table 6 for the evaluation results of water resources carrying capacity of Gonghe County, Guinan County and Wulan County's Chaka Township.

Table 5 Survey of the cultivated land in Gonghe Basin

Type of cultivated land	Gonghe County	Guinan County	Chaka Township
Irrigated cropland (10^3 hm^2)	17.04	3.25	3.51
Arid cropland (10^3 hm^2)	13.51	25.90	0

Table 6 Evaluation results of water resources carrying capacity

Carrying capacity	Gonghe County		Guinan County		Chaka Township	
	2020	2030	2020	2030	2020	2030
Area of cultivated land (10^3 hm^2)	23.80	30.55	16.20	29.15	3.51	3.51
Area of grassland (10^3 hm^2)	95.88	96.21	54.69	45.17	7.34	8.46

The evaluation results show that cultivated land and grassland supported by water resources of the Gonghe Basin will have an area of 43 507 hm^2 and 157 907 hm^2 respectively in 2020 and 63 200 hm^2 and 149 840 hm^2 respectively in 2030 when the residential and industrial water use have been satisfied. Refer Table 6 for the acceptable area of cultivated land and grassland in Gonghe County, Guinan County and Wulan County's Chaka Township in the short and long runs.

5 Conclusions

This essay uses the fuzzy comprehensive evaluation method to perform the evaluation of water resources carrying capacity of the Gonghe Basin, and comes to the conclusion as follows:

(1) Gonghe County has the small water resources carrying capacity while Guinan County and Wulan County's Chaka Township have the big water resources carrying capacity.

(2) The evaluation results show that the cultivated land and grassland supported by water resources of the Gonghe Basin will have an area of 43 507 hm^2 and 157 907 hm^2 respectively in 2020 and 63 200 hm^2 and 149 840 hm^2 respectively in 2030. Specifically, the acceptable area of cultivated land and grassland in Gonghe County is 23 800 hm^2 and 95 880 hm^2 in the short run, but 30 550 hm^2 and 96 210 hm^2 in the long run; the acceptable area of cultivated land and grassland in Guinan County is 16 200 hm^2 and 54 690 hm^2 in the short run, but 29 150 hm^2 and 45 170 hm^2 in the long run; the acceptable area of cultivated land and grassland in Wulan County's Chaka Township is 3 510 hm^2 and 7 340 hm^2 in the short run, but 3 510 hm^2 and 8 460 hm^2 in the long run.

Suggestions: Gonghe County's grassland can be arranged on the Wahong Mountain and Wahong River's alluvial-diluvial fan and along the lower reaches of the Shazhuyu River. The grassland on the Wahong River's alluvial-diluvial fan will help conserve the piedmont water sources, and the grassland along the lower reaches of the Shazhuyu River can prevent river course from getting dry and desert from eroding the lower reach of river course. The water from the Mangqu River in Guinan County can be used for the grassland on the southern edge of Muge Beach to mitigate desertification process. It is suggested that grassland should be located on the piedmont alluvial-diluvial fan on the north of the Chaka Salty Lake-Qinghai's Nanshan Mountain to conserve the water sources on the piedmont alluvial-diluvial fan.

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