OPEN ACCESS Freely available online

ISSN 2737-5447
Volume 4, Issue 1
https://www.iikii.com.sg/journal/IJESP
International Journal of Environmental Sustainability and Protection

Article

Evaluation of Carrying Capacity of Water Resource in the Heihe River Basin Based on Game Theory and Cloud Model

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Received: Jan 22, 2024; **Revised:** Feb 22, 2024; **Accepted:** Mar 1, 2024; **Published:** Mar 30, 2024

Abstract: To optimize the allocation of water resources and ensure sustainable water resources management, we evaluated the carrying capacity of water resources in the Heihe River Basin. 16 evaluation indicators were selected from the social, economic, ecological, and water resource systems to construct an evaluation system of the carrying capacity. The combination weight and membership degree were determined using the game theory combined with the weighting method and normal cloud model. The water resource utilization efficiency during 21 years was estimated by analyzing influencing factors and development trends of carrying capacity of water resources. The water use rate was important in the carrying capacity, and indicators such as urbanization rate, per capita Gross Domestic Product (GDP), sewage discharge per 10000 yuan, and water consumption per 10000 yuan of industrial output value were important factors affecting the carrying capacity. The carrying capacity of the Heihe River Basin increased from a severe overload status (Level I) in 2000 to a good status (Level V) in 2021. In the other years, the status remained at Level IV. The carrying capacity was improved. The result of TOPSIS confirmed the consistency of the development trend of the carrying capacity and the appropriateness of the developed evaluation model in this study. The model based on the game theory and cloud model can be used to effectively guide the sustainable development of water resources and improve the carrying capacity of water resources of the Heihe River Basin. The results of this study serve as a reference for establishing policies to save water resources and evaluate the carrying capacity of water resources.

Keywords: Cloud Model; Game theory with multiple combination weights; Topsis method; Carrying capacity of water resources; Heihe River Basin

1. Introduction

Water resources are important for human survival. In arid and semi-arid regions, water resources are a key factor in socio-economic development [1]. With the acceleration of economic development and urbanization, the demand for irrigation water in cities and farmland has increased. As climate change and ecological environment degradation become increasingly serious, the supply-demand contradiction of water resources is a major issue to be solved urgently [2]. Thus, it is important to estimate the carrying capacity of water resources for social, economic, and ecological environments [3]. When evaluating the carrying capacity, the social, economic, ecological, and water systems must be considered. The analysis of the relationship and rational allocation of water resources is demanded for sustainable social and economic development. The carrying capacity is an indicator influenced by many factors as the water system has uncertainty and randomness and its use is affected by social, economic, ecological, and environmental systems [4]. Therefore, multiple methods are used to evaluate the carrying capacity. In the cloud model, the fuzziness and membership degree of evaluation indicators are determined for qualitative evaluations using quantitative indicators. The model is used to solve the coupling relationship between evaluation factors [5]. Zhao et al. conducted a multidimensional evaluation of building information modeling (BIM) based on the entropy weight analytical hierarchy process (AHP) and cloud model [6]. Wang et al. used the EFAST cloud model [7], and Huang et al. developed a water resource security evaluation model based on a combination weight cloud model [8]. Ren et al. evaluated the water resource utilization in Datong City, Shanxi Province based on a normal cloud model and improved the accuracy [9]. Their results showed that the cloud model was effective in solving uncertainty problems and has achieved certain practical application effects. Therefore, we used the cloud model to evaluate the carrying capacity of water resources. Indicators are important for accurate evaluation results, so the weighting method for the influencing indicator factors is used. Weighting methods such as fuzzy evaluation, analytic hierarchy process (AHP), entropy weight method, and the coefficient of variation method are used with certain limitations in practical applications [10−12]. Therefore, we used the game theory combined with subjective and objective weights to compensate for the drawbacks of a single weighting method [13].

The Heihe River Basin is one of the irrigated agricultural basins in the northwest region of China and is classified as a water-shortage area. Due to human activities, the water environment has deteriorated rapidly, and the contradiction between water supply and demand is prominent. The average annual runoff of the mainstream of the Heihe River over the years is only 1.58 billion m^3, and the per capita available water resources are only 1250 m^3, which is only 54.2% of the national per capita level and close to the lower limit of water shortage [14]. Therefore, macroeconomic regulation and optimized allocation of water resources are important. At present, a single evaluation method is commonly used in the research on the carrying capacity of water resources, and the weight method has been rarely used [15−17]. Therefore, we evaluated the carrying capacity of water resources of the Heihe River Basin using the game theory with weights.

2. Research Methods

2.1 AHP

AHP is widely used in the analysis of the carrying capacity of water resources. AHP is a qualitative and quantitative decision-making analysis tool. By establishing a hierarchical structure and a judgment matrix, the weights of indicators are determined. The steps for establishing the AHP model in this study were as follows [18].

The model comprised the goal, criteria, and alternatives. The goal was to obtain the carrying capacity of water resources. Criteria included the influencing factors of water resources, society, economy, and ecological systems, and alternatives were 16 secondary indicators. The secondary indicators were determined based on their importance using the nine-level scaling method using a judgment matrix (Eq. (1)).

$$\bar{a}_{ij} = a_{ij} / \sum_{i=1}^{n} a_{ij} \tag{1}$$

where $\bar{a}_{ij}$ represents the elements of the judgment matrix; $\bar{a}_{ij}$represents the elements of the normalized judgment matrix (i=1, 2,..., n; j=1, 2,..., n).

$\bar{a}_{ij}$ was added into Eq. (2) to calcualte eigenvector $\bar{w}_i$ (Eq. 93)).

$$w_{ij} = \sum_{j=1}^{n} a_{ij} \tag{2}$$

$$\bar{w}_i / \sum_{i=1}^{n} w_i \tag{3}$$

To test the consistency of the model, the maximum eigenvalue was calculated according to Eqs. (4)-(6). When the consistency ratio (CR) of the judgment matrix is lower than 0.1, the feature vector can be used as the weight vector of the evaluation index.

$$\lambda_{max} = \sum_{i=1}^{n} [A\bar{w}]_i \, (n\bar{w}_i)^{-1} \tag{4}$$

$$\mathrm{C.I.} = (\lambda_{max} - n)/(n-1) \tag{5}$$

$$\mathrm{C.R.} = \mathrm{C.I.}/\mathrm{R.I.} \tag{6}$$

where $\bar{w}_{ij}$ represents the weight matrix, $\bar{w}_i$ represents the weight of the i-th element of the judgment matrix, C R. The value represents the consistency standard.

2.2. Game Theory with Weights

AHP is used to analyze complex problems layer by layer as it simulates human decision-making processes. However, the results are influenced by subjective factors. In information theory, entropy represents a measure of the degree of disorder in a system, while information represents a measure of the degree of order in a system. Therefore, using the information entropy and the weight method, the weight of evaluation indicators is determined avoiding subjective interference and improving the validity of evaluation results [19]. The coefficient of the method reflects the degree of changes in objective information of indicator data [20]. We minimized the deviation between different weights using the game theory [21].

We used the L function to calculate the weights of evaluation indicators and obtained weight vectors of ω *K*=(ω *K*1, ω *K* 1, ω *K*n), where *k*=1,2,..., *M*. The linear combination coefficients of *M* weight vectors were α *K* = (α *K* 1, α *K* 2….., α *K* n), then any linear combination ω is

$$\omega = \sum_{k=1}^{L} \alpha_k\, \omega_k^T \tag{7}$$

Based on the game theory, the linear combination coefficient α Optimize k was obtained as an optimal combination weight vector ω* to minimize the dispersion.

$$\min \left\| \sum_{k=1}^{L} \alpha_k\, \omega_k^T - \omega_k \right\|_2 \tag{8}$$

In the linear equation system, the optimal derivative condition was obtained based on matrix differentiation properties.

$$\begin{bmatrix} \omega_1\omega_1^T & \cdots & \omega_1\omega_L^T \\ \vdots & \vdots & \vdots \\ \omega_L\omega_1^T & \cdots & \omega_L\omega_L^T \end{bmatrix} \begin{bmatrix} \alpha_1 \\ \vdots \\ \alpha_L \end{bmatrix} = \begin{bmatrix} \omega_1\omega_1^T \\ \vdots \\ \omega_L\omega_L^T \end{bmatrix} \tag{9}$$

From the above equation, α was normalized.

$$\alpha^* = \alpha_k / \sum_{k=1}^{L} \alpha_k \tag{10}$$

Finally, the combination weight ω* was obtained based on the game theory.

$$\omega^* = \sum_{k=1}^{L} \alpha_k^*\, \omega_k^T \tag{11}$$

2.3 Cloud Model

To calculate the carrying capacity of water resources, we used a normal cloud model [22]. In the cloud model, the expected values *Ex*, entropy *En*, and super entropy *He* were transformed to reflect the uncertainty and fuzziness of the carrying capacity. *Ex* is the mean of cloud droplets and is a template indicator in the evaluation of the carrying capacity. *En* is used to measure the ambiguity in the carrying capacity. The more vague the concept of the evaluation indicator, the larger its value. *He* is the thickness of cloud droplets and is used to link the uncertainty and fuzziness of entropy *En*. The calculation formula for three cloud model parameters are as follows.

$$\begin{cases} E_{x_{ih}} = \dfrac{S_{ih,max} + S_{ih,min}}{2} \\ E_{n_{ih}} = \dfrac{S_{ih,max} - S_{ih,min}}{2.355} \\ H_{e_{ih}} = 0.1E_{n_{ih}} \end{cases} \tag{12}$$

where $S_{ih,max}$, $S_{ih,min}$ are the upper and lower boundary values of the i-th evaluation level, respectively.

The membership was calculated using a forward cloud generator. A normal random number E was generated with the average of En and the standard deviation E'_{n}. A normal random number x was calculated using Ex and E_n. Using Eq. (13), x_i was calculated. With the membership degree of *I,* the domain of discourse μ_i is calculated as Eq. (13). These steps were repeated until a cloud model consisting of *N* cloud droplets was obtained. After substituting the measured values into the cloud model, the membership degree of this value at each level was obtained.

$$\mu_i = exp\left[-\frac{(x_i - E_x)^2}{2(\mathrm{E}'_n{}^2)}\right] \tag{13}$$

2.4 Research Area

The Heihe River flows through 14 counties in Qinghai, Gansu, and Inner Mongolia provinces in China with a drainage area of 143000 km^2. Its coordinate is 98 ° to 102 ° E, and from 37 ° 50 ′ to 42 ° 40 ′ N. The Heihe River is an inland river basin, adjacent to the Shiyang River and Shule River in an east-west direction. It extends north to the border between China and Mongolia and south to the Qilian Mountains, which are the source of the Heihe River basin. The terrain of the Heihe River Basin is characterized by a high south and low north, with the upper area reaching the Qilian Mountains region. The water flow is fast, the riverbed is filled with gravel. The river has many rapids. In the middle region of the Hexi River, the urban and desert oasis are located. The water flow speed slows down as there are artificial canals downstream in the Alxa High Plain. The Plain consists of desert grasslands with slower water flow. The Heihe River Basin belongs to an area of strong continental climate with low annual precipitation and strong evaporation. The average annual temperature is 7 ℃, and the average annual relative humidity is 53.6%. It has sufficient sunlight and a long frost-free period [23]. In the upstream, Yingluo Gorge with a drainage area of 10000 km^2 is located. Glacial water is supplied, and it is extremely cold and humid with an average annual precipitation of 350 mm. In the middle region, there are oases on flat terrain with abundant sunlight. A large temperature difference between day and night is observed. It is an important agricultural area in Gansu Province. In the downstream area, there is the Zhengyi Gorge which is a desert area in the Gobi Desert. The terrain is flat and open, the climate is dry, and the vegetation is sparse, so it is a pastoral area. The current population of the Heihe River Basin is 2.011 million, mostly distributed in the middle reaches, with relatively low population density in the upstream and downstream areas. The current cultivated land area in the basin is 5.337 billion m^2 with an effective irrigation area of 4.149 billion m^2. The total annual water reservoir is 2.285 billion m^3, and the per capita water resources are 1141.87 m^3. The development and utilization of water resources in the Heihe River Basin are high but water shortage is serious.

2.5 Data Sources

The data in the study was collected from the Heihe River Basin Water Resources Bulletin from 2000 to 2021 and the government website from 2000 to 2021. The data was analyzed using SPSS and MATLAB.

3. Results and Discussions

3.1 Construction of Rating System

The carrying capacity of water resources was estimated considering as economy, society, and ecological environment to reflect the efficiency of human activities and secure the representativeness and operability of the results. Based on previous research [24], this article follows the principles of scientificity, representativeness, and operability.Considering the uneven distribution of water resources and ecological fragility in the Heihe River Basin, quantity-quality domain flow was applied [25]. Referring to relevant industry requirements, indicators for the structure, process, and efficiency in water use were selected, The evaluation index system for the carrying capacity of water resources in the Heihe River Basin was constructed as shown in Table 1.

Table 1. Evaluation index system of carrying capacity of water resources in Heihe River Basin.

System	Indicator	Unit	Description
Water resource system	Unit land area water resources (P_1)	10^4 m^3/km^2	Characterizing the quantity of regional water resources
	Total proportion of water supply (P_2)	%	Characterizing the degree of water resource development and utilization
	Per capita water resource ownership (P_3)	m^3/ren	Characterizing the coordination between population and water resources

Table 1. *cont.*

	Water supply per unit land area (P_4)	10^4 m³/km²	Characterizing the degree of land development and utilization
	Annual average precipitation (P_5)	Mm	Characterizing the annual average precipitation level in a region
	Annual total water resources (P_6)	10^8m³	Characterizing the degree of water production of regional water resources
	Annual runoff (P_7)	10^8m³	Characterizing regional average annual flow
	Water production coefficient (P_8)	10^4m³/km²	The ability to characterize the transformation of a region into water resources
Social system	Population density (P_9)	ren/km²	Characterizing regional population pressure
	Urbanization rate (P_{10})	%	Characterizing the level of social development and population quality
	Per capita GDP (P_{11})	10^4¥	Characterizing regional economic level
Economic system	Unit GDP water consumption (P_{12})	yuan/m³	Characterizing the Coordination between Water Resources and Regional Development
	Actual farmland irrigation rate (P_{13})	%	Characterizing the level of regional agricultural irrigation development
	Water consumption for industrial output value of 10000 yuan (P_{14})	m³/10^4¥	Characterizing the degree of industrial water use
Ecosystem	Ecological Environment Water Use Rate (P_{15})	%	Characterizing the demand for water resources in the ecological environment
	Sewage discharge per 10000 yuan GDP (P_{16})	m³/10^4¥	Characterizing the degree of water pollution in a region

The evaluation indicators for the carrying capacity of water resources in the Heihe River Basin from 2000 to 2021 were determined in different five-year periods as shown in Table 2

Table 2. Indicators of carrying capacity of water resources in Heihe River Basin from 2000 to 2021.

Indicator	Unit	-2000	2000–2005	2005–2010	2010–2015	2015–2020
P_1	10^4 m³/km²	4.26	4.2	4.62	4.37	4.06
P_2	%	137.78	119.33	106.34	147.05	142.70
P_3	m³/ren	1345.64	1285.08	1388.90	1269.58	1133.90
P_4	10^4m³/km²	5.87	4.97	4.91	6.42	5.80
P_5	Mm	164.4	181	220.8	172.2	152.5
P_6	10^8m³	2.53	2.47	2.74	2.59	2.28
P_7	10^8m³	22.583	22.559	24.268	23.821	20.04
P_8	10^4m³/km²	0.26	0.13	0.21	0.25	0.27
P_9	ren/km²	31.66	32.40	33.24	34.41	35.84
P_{10}	%	24.69	37.33	45.05	52.13	62.84
P_{11}	10^4¥	0.58	1.11	2.77	3.94	5.03
P_{12}	¥/m³	5.13	7.23	27.05	30.13	43.91
P_{13}	%	74.43	94.99	88.16	118.98	87.94
P_{14}	m³/10^4¥	144.64	161.12	49.09	56.54	41.22
P_{15}	%	0.72	3.72	1.15	3.47	5.03
P_{16}	m³/10^4¥	81.67	46.70	15.46	7.89	8.34

3.2 Evaluation Index

The standard values of the evaluation index were set as the basis for evaluating the synergistic impact of ecology, economy, and society on water resource systems. Based on relevant norms and standards [26] and the actual situation of the Heihe River Basin, the evaluation standards for the carrying capacity in the Heihe River Basin were formulated in five categories: severe overloading, overloading, critical, bearable, and good carrying capacity of water resources (Table 3).

Table 3. Standards for indicators of carrying capacity of water resources.

System	Index	Indicator Type	I Severe overloading	II Overloading	III Critical	IV Bearable	V Good Carrying Capacity
Water resource	P_1	Forward	＜15	15～20	20～35	35～60	＞60
	P_2	Negative	＞120	90～120	60～90	30～60	＜30
	P_3	Forward	＜500	500～1000	1000～1700	1700～2000	＞2000
	P_4	Negative	＞55	40～55	25～40	10～25	＜10
	P_5	Forward	＜100	100～200	200～350	350～500	＞500
	P_6	Forward	＜4	4～6	6～8	8～10	＞10
	P_7	Forward	＜3	3～7	7～11	11～15	＞15
	P_8	Forward	＜0.3	0.3～0.35	0.35～0.4	0.4～0.45	＞0.45
Social system	P_9	Negative	＞700	500～700	300～500	100～300	＜100
	P_{10}	Negative	＞80	60～80	50～60	40～50	＜40
Economic system	P_{11}	Forward	＜1	1～2	2～3	3～4	＞4
	P_{12}	Negative	＞12	9.5～12	7.5～9.5	5.5～7.5	＜5.5
Ecosystem	P_{13}	Forward	＜60	60～70	70～80	80～90	＞90
	P_{14}	Negative	＞300	100～300	50～100	15～50	＜15
	P_{15}	Forward	＜1	1～2	2～3	3～5	＞5
	P_{16}	Negative	＞55	40～55	25～40	10～25	＜10

3.3 Weights

For the 16 indicators, AHP was used to evaluate the carrying capacity of water resources (Table 4). Using the entropy weight, the data was normalized to construct an indicator matrix. The weights of the indicators were obtained by defining entropy. According to the degree of variation of the measured values of each indicator, the coefficient of variation method was used to weight the carrying capacity.

Table 4. Weights of indicators of carrying capacity of water resources in Heihe River Basin.

Goal	Criteria	Alternative	Weight	Entropy	Weight of Entropy	Average of Indicator	Coefficient of Weight
Evaluation system for carrying capacity of water resources	Water resource (C_1)	P_1	0.043	0.976	0.019	4.200	0.027
		P_2	0.068	0.897	0.081	137.019	0.044
		P_3	0.078	0.978	0.017	1238.212	0.024
		P_4	0.052	0.931	0.054	5.603	0.021
		P_5	0.136	0.947	0.042	181.582	0.030
		P_6	0.288	0.965	0.028	2.436	0.031
		P_7	0.156	0.970	0.023	22.221	0.027
		P_8	0.179	0.989	0.009	0.215	0.047
	Social system (C_2)	P_9	0.250	0.931	0.054	33.860	0.008
		P_{10}	0.750	0.949	0.040	45.550	0.044
	Economic system (C_3)	P_{11}	0.211	0.893	0.084	2.833	0.111
		P_{12}	0.516	0.895	0.082	24.554	0.107
	Ecosystem (C_4)	P_{13}	0.113	0.920	0.063	101.364	0.033
		P_{14}	0.160	0.832	0.131	78.772	0.122
		P_{15}	0.750	0.899	0.079	2.652	0.140
		P_{16}	0.250	0.752	0.194	26.513	0.183

Other than the weights in AHP, weights using the coefficient of variation were determined based on the principle of the game theory. The weights calculated using entropy values were applied in a single game. The subjective weighting coefficient a_1 is 0.2564 and the objective weighting coefficient a_2 is 0.7436. The AHP-CVM weighting coefficient a_3 is 0.2805, and the objective weighting coefficient a_4 is 0.7195. The second subjective weighting coefficient a_5 is 0.2312, and the objective weighting coefficient a_6 is 0.7688. The weights of indicators are shown in Table 5.

Table 5. Weights of carrying capacity obtained based on game theory.

Indicator	Weighting Coefficient Based on Game Theory		
	a_1=0.2564 a_2=0.7436	a_3=0.2805 a_4=0.7195	a_5=0.2312 a_6=0.7688
P_1	0.0251	0.0314	0.0299
P_2	0.0775	0.0510	0.0502
P_3	0.0331	0.0392	0.0363
P_4	0.0537	0.0299	0.0310
P_5	0.0659	0.0599	0.0580
P_6	0.0943	0.1030	0.0988
P_7	0.0573	0.0629	0.0598
P_8	0.0525	0.0842	0.0761
P_9	0.1039	0.0757	0.0782
P_{10}	0.2221	0.2424	0.2345
P_{11}	0.1165	0.1386	0.1278
P_{12}	0.1936	0.2220	0.2101
P_{13}	0.0758	0.0556	0.0568
P_{14}	0.1386	0.1328	0.1276
P_{15}	0.2512	0.3111	0.2939
P_{16}	0.2081	0.2020	0.1979

3.4 Cloud Model Membership

Based on the evaluation index system and level standards of the carrying capacity of water resources in the Heihe River Basin, the parameters of the cloud model were determined. The forward cloud model generator was used to generate standard clouds for each indicator level and calculate the membership degree of each indicator. MATLAB was used to perform 2,000 calculations on each indicator to reduce errors. The weights in Table 5 were integrated into the membership matrix to evaluate the carrying capacity based on maximum membership (Fig. 1).

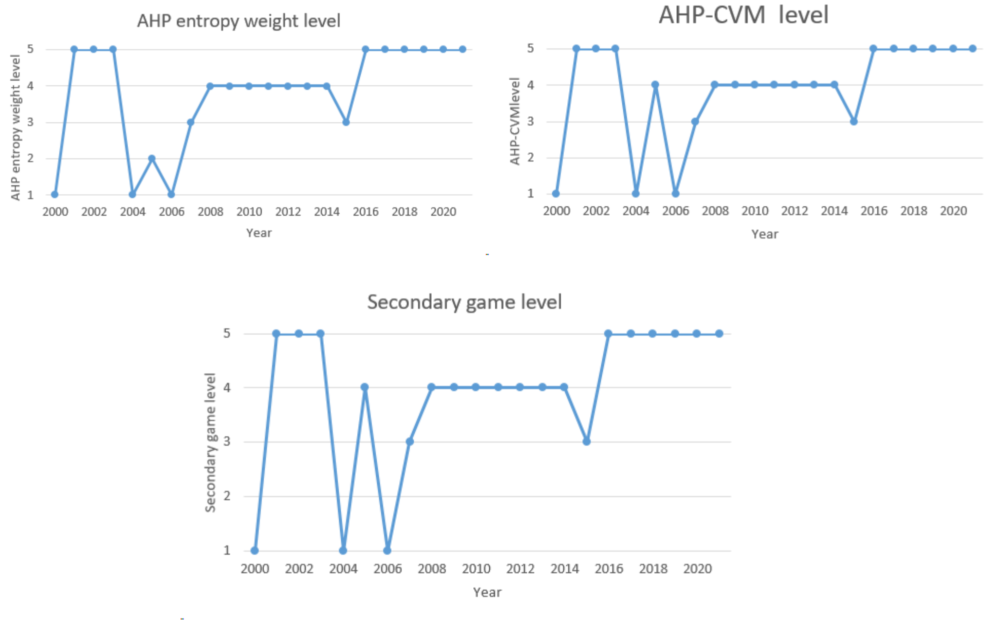

Fig. 1. Evaluation of carrying capacity of water resources in Heihe River Basin.

3.5 Analysis of Results

We used game theory to calculate the combined weights of indicators. The weights presented the degree of influence of each indicator on the carrying capacity of water resources. The proportion of ecological water use (P_{15}) showed the greatest impact on the carrying capacity, followed by indicators such as water consumption per unit GDP (P_{12}) and urbanization rate (P_{10}). Sewage discharge per 10000 yuan of GDP (P_{16}), per capita GDP (P_{11}), and water consumption per 10000 yuan of industrial output value (P_{14}) impacted the carrying, too. As the Heihe River Basin is located in an inland arid and semi-arid region with a vast desert area and high ecological water consumption, water resource shortages occurred. The recent urbanization in the surrounding areas increased population, industrial activities, and GDP, which required more water consumption. Such increased water consumption affected the ecological environment. Therefore, the water demand per unit land area (P_1) increased, too.

The carrying capacity of water resources in the Heihe River Basin from 2000 to 2021 fluctuated with a gradual increase. The carrying capacity Basin increased rapidly from Level I in 2000 to Level V in 2003. In this period, the urban population in the Heihe River Basin increased significantly with a rate of 31.2% which increased water demand. The irrigation area significantly increased, too, which increased water consumption. Thus, additional water resources had to be developed. However, the impact was relatively small, and the carrying capacity increased. The carrying capacity fluctuated significantly from 2004 to 2008. Due to the continued increase in population, water demand also increased. The development of the national economy posed a significant challenge to the ecological environment. The increasing demand for water in the ecological environment and excessive exploitation of water resources deteriorate the ecological environment and affect the development and utilization of water resources in the entire basin, threatening the physical and mental safety of the people. Between 2008 and 2021, the carrying capacity was stabilized at Level IV, and in 2016, it stayed at Level V. During this period, the carrying capacity increased. Through regulations, the local water system management underwent significant changes, and the development and utilization of water resources became efficient.

The TOPSIS method was used to verify the trend of changes in the evaluation level of the carrying capacity. The comparison of the levels obtained by the TOPSIS method and the game theory is shown in Fig. 2.

Fig. 2. Change in carrying capacity in Heihe River Basin.

The change in the carrying capacity obtained using the TOPSIS method from 2000 to 2021 was the same as that based on the game theory, both showing a gradual increase. The level was changed from II in 2000 to IV in 2021, and is expected to be at V. The water use rate in the ecological environment increased from 0.72% in 2000 to 5.03% in 2021. The industrial output value increased by 29.878 billion yuan. The urbanization rate increased by 38.15%. Per capita GDP and the actual irrigation rate increased by 5.45 and 15.31%. The demand for water in the Heihe River Basin is large due to the repeated reuse of water resources. The improvement of the Levels indicated that the government optimized the allocation of water resources using macroeconomic control measures and improved the ecological environment to a certain extent to increase the carrying capacity and promote economic development and social progress from 2000 to 2021.

The water shortage in the Heihe River Basin has affected local economic development and ecological balance. Therefore, local governments have focused on ecological environment protection and construction and achieved remarkable results in rational allocation, efficient utilization, effective protection, and scientific management of water resources. Compared with 2000, the industrial water consumption per 10000 yuan decreased by 72% in 2021, and the sewage discharge per 10000 yuan of GDP decreased by 90%. This reflects the government's coordinated efforts for the ecological environment and the economy and society to enhance the carrying capacity.

5. Discussion

The sustainable utilization of water resources is vital for the sustainable development of the economy and society. With the continuous development of the economy, GDP has increased, and the water consumption per unit of GDP also increased from 5.13 in 2000 to 43.91 yuan/m^3 in 2021. This negatively impacted the carrying capacity of water resources and constrained the sustainable development of the basin economy. The water resources in the Heihe River Basin must follow the principle of resource conservation in the economic development of the basin. It is necessary to form a sound and scientific management system for water resources in the Heihe River Basin to establish environmental protection mechanisms. The ecological environment in the Heihe River Basin is fragile. In the upper reaches of the Heihe River, it is necessary to protect water sources, forests, and grasslands and effectively improve the capacity of water resources by focusing on ecological and natural restoration. In the middle and lower reaches of the Heihe River, it is demanded to coordinate the relationship between production, daily life, and ecological water use and construct a water-saving society. In agriculture, water-saving transformation needs to be implemented in irrigation areas to improve the efficiency of water resource utilization by optimizing the layout of canal systems and adopting high-tech water-saving irrigation technologies. In the industrial sector, water conservation and pollution prevention are important, and it is necessary to control conservation and pollution by limiting water consumption projects and developing a circular economy. In addition, a "red line" for surface water consumption and underground water use needs to be set to reduce overexploitation and the burden on the ecological environment. At present, the carrying capacity of Heihe River water resources is improving. In the long term, it is vital to achieve the coordinated development of society, economy, and ecological environment in the Heihe River Basin. In the future, relevant departments of the government and river basin institutions must regulate and manage water resources to restore the ecological environment and promote economic development for sustainable development.

6. Conclusion

We constructed an evaluation model for the carrying capacity of water resources of the Heihe River Basin based on the game theory and the cloud model. The ecological environment water use rate was important for the carrying capacity of water resources. Indicators such as urbanization rate, per capita GDP, sewage discharge per 10000 yuan, and water consumption per 10000 yuan of industrial output value affected significantly the carrying capacity of water resources. The carrying capacity of water resources of the Heihe River Basin changed from a severe overloading state of Level I in 2000 to a good carrying state of Level V in 2021. The level gradually improved with a good development trend. The development trend estimated by the TOPSIS method was identical to that by the game theory. The evaluation results indicated the significance of improving the carrying capacity of water resources of the Heihe River Basin to establish a water-saving society and evaluate the carrying capacity of water resources of other river basins. With limited data, the results could be uncertain. Thus, future research is demanded to obtain more objective data and evaluation results to estimate the carrying capacity of water resources more precisely.

Author Contributions: conceptualization, Y. Niu; methodology, C. Deng; validation, S. Wang, E. Xu; data curation, W. Zhao, W. Jing, D. Zhang; writing—original draft preparation, C. Deng; writing—review and editing, Y. Niu, S. Wang. All authors have read and agreed to the published version of the manuscript.

Funding: The work in this study was supported by Science and Technology Project in Zhangye "Research and Demonstration on Different ecological restoration Models of Degraded Vegetation in the Ecotone Zone of Forest Margin in Shallow Mountain Area of Qilian Mountains" (ZY2022KY03),and the Central Government of Gansu Province to guide local Science and Technology Development Fund, China (22ZY2QG001). Key Research and Development Project of Gansu Province, China (23YFFG0002); Huai'an Natural Science Research Program Project, China(HAB202159); Huai’an Social Science Foundation, China (2024SK49). Provincial college students innovation and entrepreneurship project, China.

Acknowledgments: We would like to thank anonymous reviewers for their valuable comments and suggestions for improving this paper.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

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