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Evaluation of River Health and Human Well-Being in the Heihe River Basin Using the SMI-P Method: A Case Study of the Zhangye City

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Abstract: Oasis cities are central to the economic and social development as well as ecological sustainability in the arid region in Northwest China. This study aims to explore the balance between river health and human well-being of local residents in the Hexi River oasis, while also enhancing the effectiveness of water resource management within the basin. Utilizing the SMI-P method, we construct a 'Happy River' evaluation system that integrates goals, criteria, and indicators. We analyze the evaluation index system for 'Happy River' construction in the study area, specifically the Zhangye City section of the Heihe River Basin, and derive a comprehensive evaluation value for the 'Happy River' initiative. Additionally, we assess the fit attribute of the evaluation system using the coupled coordination degree model and harmony degree theory, thereby enhancing the rationality of the evaluation method and ensuring a more thorough examination process. The results indicate that from 2017 to 2021, the urban wastewater treatment rate and the degree of water quality excellence in the Zhangye City section of the Black River Basin represent the highest and lowest weights, respectively, within the evaluation system. This suggests that improving the quality of the urban water environment has emerged as the primary factor influencing the assessment of the Happy River during the construction of the Happy River and Happy Lake. Moreover, ecological health is identified as the most significant criterion in the evaluation system, serving as the main factor affecting residents' perceptions of happiness related to rivers and lakes. Over the five-year period, the happiness level in the study area improved from "relatively happy" to "very happy", while the coupling coordination degree increased from 0.605 to 0.687, indicating a gradual progression toward coordinated development. Simultaneously, the harmony degree rose from 0.527 to 0.601, suggesting a tendency towards a condition of basic harmony. Additionally, the happiness index increased from 76.71 to 81.97, transitioning from a state of happiness to one of very high happiness. The composite index also improved, rising from 0.459 to 0.526, which demonstrates the preliminary success of the 'Happy River' construction efforts in the study area. The evaluation system and model of the 'Happy River', along with the final results of this study, can serve as theoretical references for the development of similar initiatives in typical characteristic rivers within the arid region of Northwest China.

Keywords: happy river; SMI-P method; river and lake management; Zhangye City section of the Heihe River Basin; evaluation system

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1. Introduction

With the increasing global water stress and ecological degradation, climate warming is exacerbated, and the frequent occurrence of regional extreme weather has emerged as a global challenge [1]. As a vital component of life-sustaining activities within the inland biosphere, rivers and lakes play a crucial role in providing water supply, regulating climate, and facilitating mineral transport [2,3]. In recent years, the concept of 'Happy River' has gained prominence, aiming to achieve healthy river ecosystems, sustainable water resource usage, and enhanced social well-being through integrated management [4]. The core idea of a happy river pertains to rivers and lakes that possess well-functioning ecosystems, adequate water resources, aesthetically pleasing environments, and a harmonious coexistence between humans and the natural environment [5]. The Protecting the Planet 2020 report indicates that global terrestrial and inland water ecosystems encompass an area of 22.50×10^6 km^2 (16.64%), while coastal waters and oceans cover an area of 28.10×10^6 km^2 (16.64%), underscoring the significance of global river and lake ecological protection [6]. The ecological protection of rivers and lakes, along with the efficient use of water resources, represents not only a challenge faced by China but also a global issue that has become a major focus of international research.

The concept of 'Happy River' centers on the river as the primary entity, emphasizing the study of river systems and the management and enhancement of water resources, environmental conditions, and ecological security of rivers and lakes. The overarching goal is to ensure the ecological stability of the river itself while enabling sustainable benefits for humans from healthy rivers and lakes [7,8]. This initiative is globally relevant, though its emphasis varies by country. In the United States, the focus is on watershed management, promoting the governance and protection of water resources through the establishment of a comprehensive watershed management system [9]. Conversely, some European nations have placed greater emphasis on cooperation regarding transboundary rivers, lakes, and shared waters resources. They have successfully achieved the sharing and optimal allocation of water resources among regions by establishing integrated water resources management coordination mechanisms [10]. In Japan, the development of stringent laws and regulations governing river and lake management has been complemented by the implementation of improvement projects. Notably, there has been a strong focus on enhancing fisheries ecology, which has contributed to the overall improvement of the ecological environment in rivers and lakes [11]. Since 2019, when China advocated for the Yellow River to become a 'Happy River' for the benefit of its people, domestic scholars have explored the concept's connotations, evaluation criteria, and realization from various perspectives, including ecology [12], hydrology [13], and sociology [14]. However, the majority of existing studies tend to emphasize theoretical discussions and case analyses, lacking a systematic evaluation method and a global perspective.

The construction of a 'happy watershed' serves as the entry point and focal point of the 'Happy River' initiative. The happiness levels of rivers and lakes in oasis cities within arid zones most accurately reflect the construction quality of these happy watersheds [15]. The Heihe River oasis is a vital production and living area for residents in Northwest China, and the healthy development of the Heihe River environment is essential for supporting the region's socio-economic development and ecological security [16]. Enhancing the ecological environment of the region's rivers and lakes, thereby regulating the microclimate effects of the oasis, provides necessary support for the livelihoods of residents in arid areas [17]. However, the region faces challenges due to scarce rainfall, high evaporation rates, and the uneven spatial and temporal distribution of rainfall, which are exacerbated by frequent local extreme droughts. These factors significantly limit the socio-economic development of the area [18,19]. In light of the current pressures on water ecological security in the Hexi Oasis, establishing a comprehensive river and lake management and evaluation system is a crucial step toward achieving sustainable water resource development and fostering human–water harmony [20,21]. This initiative aligns with the new guidelines for river and lake management and protection, as well as the theoretical research and practical exploration of local happy river construction [22]. The goal is to create rivers characterized by high water quality, rich water culture, and robust water safety measures. This study is based on the principle of 'single-indicator quantification, multiple-indicator synthesis, and multiple-criteria integration' (SMI-P); this study selects representative, scientific, comprehensive, and easily accessible indicators to construct the indicator layer of the evaluation system, comprising a total of 21 indicators. Subsequently, the entropy weighting method is employed to calculate the weights. The coupling and coordination model is then introduced to assess the degree of harmony and to analyze both the weights of the model layer and the weights of the indicator layer within the system. Finally, it assesses the degree and status of the 'Happy River' through utility, focusing on the Zhangye section of the Heihe River as the study area. It is based on the method of 'single indicator quantification–multiple indicator synthesis–multi-criteria integration' (SMI-P), calculates the Happy River Index (HRI), and quantitatively evaluates the level of river and lake governance in the Zhangye section of the Heihe River. The aim is to provide a theoretical reference for the future adjustment and improvement of the local Happy River system.

2. Materials and Methods

2.1. Overview of the Study Area

The Heihe River, a tributary of the Yellow River, is the second largest inland river in northwest China, with a basin area of 128,000 km^2. The study area for this study is the middle reaches of the Heihe River, which include the Zhangye Oasis (38.6 °N–39.8 °N, 99.5 °E–100.8 °E), and represent a primary zone for water resource utilization and depletion within the basin. The average elevation in this region is 1451 m, with an average annual temperature ranging from 6 to 8 °C, and annual precipitation of approximately 150 mm [18,23]. The runoff of the Heihe River exhibits a relatively uniform intra-annual distribution and minimal inter-annual variations, resulting in smooth water flow that facilitates development and utilization. Zhangye, the largest oasis city in the middle reaches of the Heihe River, is situated in a typical continental climate zone. As of 2021, it had a resident population of 1,122,500, a population density of 29.10 persons per km^2, and an economy predominantly based on agriculture. An overview of the study area is shown in Figure 1.

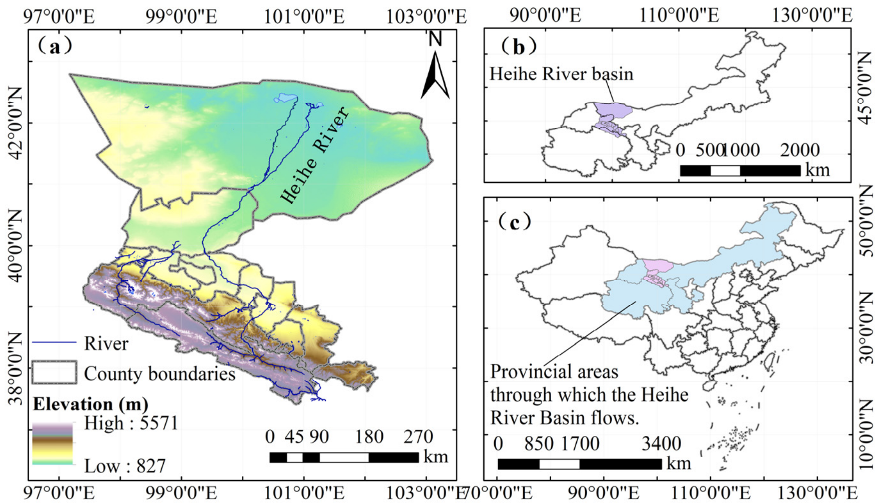

Figure 1. Overview map of the study area. (**a**): Schematic diagram of the Heihe River Basin; (**b**): Diagram of the provinces in which the Heihe River Basin is located; (**c**): Diagram of the geographic location of the Heihe River Basin in China.

2.2. Data Sources

The data utilized in this study are sourced from the '*Gansu Province Water Resources Bulletin*' and the '*Gansu Province Water Resources Development Yearbook*' covering the years 2017 to 2021. The data encompass 21 indicators, including average water consumption for agricultural irrigation, per capita water resources, water quality excellence, the development and utilization rate of surface water resources, compliance rate for river section management, proportion of water-saving irrigation areas, groundwater extraction rate, proportion of ecological water usage, reduction in water use per 10,000 yuan of industrial added value, and the level of sophistication in water management alongside public satisfaction, among others, within the study area. The scores assigned to indicators, such as public satisfaction, are derived using a subjective scoring method. The raw data necessary for assembling the evaluation system are analyzed against predefined thresholds, and subsequently, through linear interpolation, the specific scores for each indicator for each year are calculated.

2.3. Methods

2.3.1. Building a System of Assessment Indicators

To develop an effective happy river evaluation system, we not only need to consider the objective factors of water environment, water safety, and water ecology, but also to add the residents' satisfaction with the construction of the 'happy river' to the evaluation system, but also to introduce the normative systems related to the sustained and healthy development of rivers and lakes, the construction of facilities, the subjective evaluation of the residents and other subjective elements. In accordance with the "Nanjing Happy River and Lake Evaluation Standards (Trial)", "Evaluation Guidelines for the Construction of Water Ecology Civilisation Cities" [24], and "Guidelines for Evaluation of Water Use Indicators" [25], along with the research findings of previous scholars [26–29], we establish an evaluation hierarchy consisting of "target-criteria-indicator". This involves determining the threshold value for each indicator and calculating the Happy River Index (HRI) [10]. The evaluation system positions the HRI as the target level, while the normative level encompasses the supply capacity (B1), operational safety (B2), ecological health (B3), river environment (B4), river culture (B5), river management (B6), and public satisfaction (B7) concerning the river and lake water resources within the river basin. The system includes indices for supply capacity (I_1), operational safety (I_2), ecological health (I_3), river environment (I_4), river culture (I_5), river management (I_6), and satisfaction (I_7). Following the principle of "single-indicator quantification-multiple-indicator synthesis-multiple-criteria integration" (SMI-P), the indicator layer of the evaluation system is constructed by selecting indicators that are representative, scientific, comprehensive, and easily accessible. This layer comprises a total of 21 positive indicators (where a higher value is preferable) and negative indicators (where a lower value is preferable). The specific structure of the evaluation system is illustrated in Figure 2, while the indicators and the evaluation framework are detailed in Table 1.

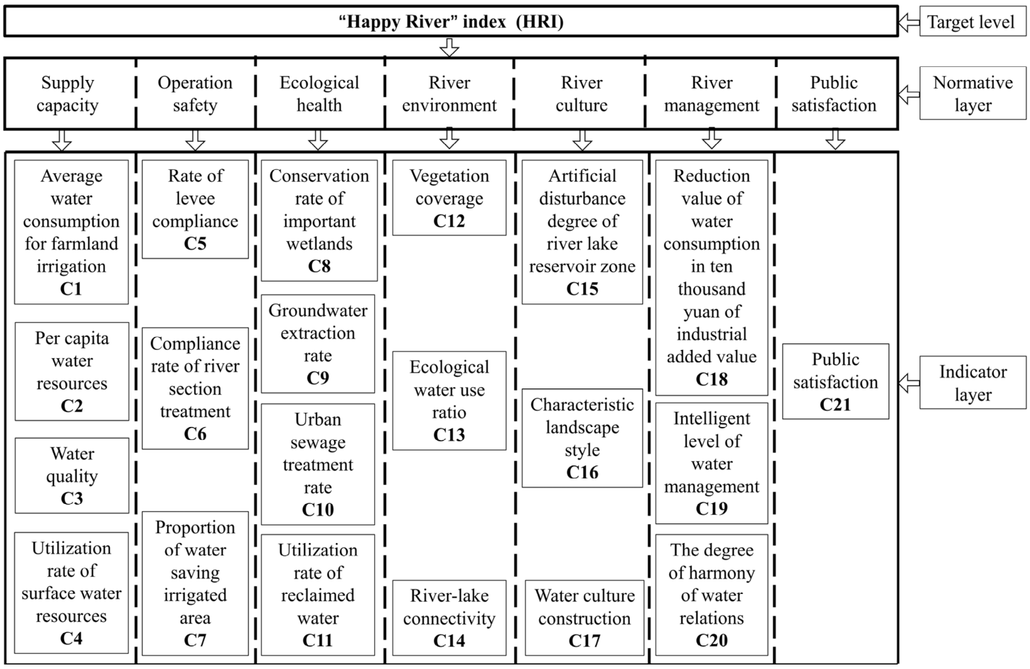

Figure 2. Schematic diagram of the construction of the indicator system.

Table 1. Evaluation system and index threshold of Happy River.

Evaluation Index System		Level I [100]	Level II [80]	Level III [60]	Level IV [40]	Level V [0]	Description	Tendency
Water resources supply capacity B1	Average water consumption for farmland irrigation C1/%	<0.6 M	0.9 M	1.1 M	1.5 M	>1.5 M	The ratio of irrigation water consumption to actual irrigated area of farmland.	-
	Per capita water resources C2/(m^3·$persons^{-1}$)	>3500	3000	2000	1000	<500	The amount of freshwater available per person at a given time.	+
	Water quality C3/%	100%	90%	85%	80%	75%	The proportion of river length that meets or exceeds the Class III water quality standard of GB3838 to the total river length evaluated.	+
	Utilization rate of surface water resources C4/%	<40%	50%	67%	75%	90%	Ratio of water use to total water resources in the basin area	-
River operation safety B2	Rate of levee compliance C5/%	>95%	80%	60%	40%	0%	Ratio of length of levees meeting standards to total length of levees.	+
	Compliance rate of river section treatment C6/%	>95%	80%	60%	40%	0%	Ratio of the length of restored and treated reaches to the length of restored and treated reaches.	+
	Proportion of water-saving irrigated area C7/%	70%	50%	30%	20%	10%	The proportion of the irrigated area with efficient water-saving measures such as sprinkler irrigation, micro-irrigation, drip irrigation and low-pressure pipe irrigation to the effective irrigated area.	-
River ecological health B3	Conservation rate of important wetlands C8/%	>95%	90%	85%	80%	70%	The ratio of the total area of important natural wetlands in the region to the total area of wetlands in the near natural base year.	+
	Groundwater extraction rate C9/%	0%	10%	20%	25%	30%	Characterize the degree of groundwater extraction.	-
	Urban sewage treatment rate C10/%	>95%	80%	70%	50%	<20%	The ratio of the total amount of municipal sewage treatment to the total amount of discharge.	+
	Utilization rate of reclaimed water C11/%	>25%	20%	15%	10%	5%	Ratio of sewage reuse to total discharge.	+
River environment B4	Vegetation coverage C12/%	>25%	25%	20%	10%	5%	The ratio of forest area to land area.	+
	Ecological water use ratio C13/%	<5%	10%	15%	20%	>20%	Minimum water requirements for ecosystem restoration and rehabilitation or to maintain the current quality of the ecosystem in a manner that does not lead to degradation.	-
	River–lake connectivity C14	Best	Better	Good	Worse	Bad	The river and lake form is natural and smooth and meets the capacity of flooding and drainage.	+
Conservation status of river culture B5	Artificial disturbance degree of river lake reservoir zone C15	Best	Better	Good	Worse	Bad	Investigate whether there are “four chaotic” conditions on the shoreline of rivers and lakes (warehouses); the survey area without “four chaos” situation is assigned 100 points.	+
	Characteristic landscape style C16	Best	Better	Good	Worse	Bad	The river channel in the built-up area has a beautiful overall landscape and harmonizes with the surrounding environment and local culture.	+
	Water culture construction C17	Best	Better	Good	Worse	Bad	Construction of the river and lake cultural park, overall use of cultural heritage sites and museums, memorials, exhibition halls, education bases, water projects and other resources, comprehensive use of information means, systematic display of river and lake culture.	+

Table 1. *Cont.*

Evaluation Index System		Level I [100]	Level II [80]	Level III [60]	Level IV [40]	Level V [0]	Description	Tendency
Management of rivers and lakes B6	Water usage per unit of industrial value added C18/%	>30	30%	20%	10%	0%	Comparison of the decrease in water consumption of 10,000 yuan of industrial added value in the current year with the value of water consumption in 2010.	+
	Intelligent level of water management C19	Best	Better	Good	Worse	Bad	The evaluation criteria of the intelligent level of water management are as follows: (1) The use of satellite remote sensing, unmanned aerial vehicles, unmanned ships, Internet of things and other new technical equipment to carry out regular supervision and management within the scope of river and lake management; (2) The integrated river management system platform should be built and used normally.	+
	The degree of harmony of water relations C20	Best	Better	Good	Worse	Bad	The evaluation criteria of the harmonious degree of water-related relations: the upstream and downstream, the left and right banks of water-related relations are harmonious, the river-related media are exposed, and the complaints of the masses are reasonably resolved.	+
Public satisfaction B7	Public satisfaction C21	Best	Better	Good	Worse	Bad	Public satisfaction refers to the public's satisfaction with water safety, water environment, ecology and culture of rivers and lakes within the appropriate range of rivers and lakes.	+

Note: M is the average value of this index in the whole province.

2.3.2. Happiness Level Classification

The classification of happiness levels in this study was based on a five-level grading scale [30], details of which are shown in Table 2.

Table 2. Classification of Happy River.

Index	Level I	Level II	Level III	Level IV	Level V
Rank	Best	Better	Basic	Mediocre	Poorly
Happiness index	(80, 100]	(60, 80]	(40, 60]	(20, 40]	(0, 20]

2.3.3. Evaluation Methodology

The SMI-P method is used for comprehensive evaluation, the Entropy Weight method is used for the calculation of weights, the Coupled Coordination model is introduced, the degree of harmony is considered, and model layer weights and system indicator layer weights are discussed [29]. The specific steps are as follows.

(a) Quantification of single indicators.

① The m sample evaluation factors were screened to determine n evaluation indicators to create the evaluation matrix X_{ij}.

$$X_{ij} = \begin{bmatrix} X_{11} & X_{21} & \cdots & X_{1m} \\ X_{21} & X_{22} & \cdots & X_{2m} \\ \vdots & \vdots & \vdots & \vdots \\ X_{n1} & X_{n2} & \cdots & X_{nm} \end{bmatrix} (i = 1, 2, \ldots, n; j = 1, 2, \ldots, m) \tag{1}$$

② Programmability of indicators [31]:

$$\begin{cases} X_{ij}' = \frac{X_{ij} - \min X_{ij}}{\max X_{ij} - \min X_{ij}} \\ X_{ij}' = \frac{\max X_{ij} - X_{ij}}{\max X_{ij} - \min X_{ij}} \end{cases} \tag{2}$$

(b) Calculation of the composite assessment value.

The Entropy Weighting method is used to calculate the weights of the modified evaluation indicators W_i and assign the scores for summation.

① Constructing a dimensionless matrix X'.

$$X_{ij}' = \begin{bmatrix} X_{11}' & X_{12}' & \cdots & X_{1m}' \\ X_{21}' & X_{22}' & \cdots & X_{2m}' \\ \vdots & \vdots & \vdots & \vdots \\ X_{n1}' & X_{n2}' & \cdots & X_{nm}' \end{bmatrix} \tag{3}$$

② The weight of the eigenvalue of the evaluation indicator for the jth monitoring point to be evaluated under the ith evaluation indicator.

$$P_{ij} = \frac{X_{ij}'}{\sum\limits_{j=1}^{m} X_{ij}'} \tag{4}$$

③ Entropy of the ith evaluation metric e_i.

$$e_i = -\frac{1}{\ln(m)} \sum_{j=1}^{m} [P_{ij} \ln(P_{ij})] \tag{5}$$

④ Weight of the ith evaluation indicator a_i.

$$a_i = \frac{(1-e_i)}{\sum_{j=1}^{m}(1-e_i)} \tag{6}$$

⑤ Combined assessed value for each monitoring site W_i.

$$W_i = \sum_{i=1}^{n}(a_i X_{ij}{}') \;\; W_i \in [0,1] \;\; \sum_{i=1}^{n} W_i = 1 \tag{7}$$

⑥ Calculate the composite appraisal value S.

$$S = W_i \cdot X_{ij}{}' \tag{8}$$

⑦ Similarly, we can calculate the weight $\omega_i{}'$ for each criterion layer and the weight $\omega_i{}''$ under each indicator layer.

(c) Calculating the Happiness Index

① SMI-P method evaluation model.

$$I_i = \sum_{a_i=1}^{n_i} \omega_i{}'' \cdot X_{ij}{}' \tag{9}$$

where I_i is the comprehensive evaluation index of each indicator layer; $\omega_i{}'$ is the weight under the criterion layer; a_i is the ith indicator layer; n_i is the number of indicators in the layer, and $X_{ij}{}''$ is the value of the score assigned to each indicator.

② Happiness River Index (HRI).

$$HRI = \sum I_i \cdot \omega_i{}' \tag{10}$$

(d) Model validation.

① Calculate the degree of coupled coordination of the model. Construct a coupled coordination model based on the criterion layer U.

$$U_i = \sum_{i=1}^{n}(\lambda_{ij} P_{ij}) \tag{11}$$

where $i = I_1, I_2, I_3, I_4, I_5, I_6, I_7$; U_i represents the coordination index for each layer.

② Modelling coupling degrees.

$$C = \left[\frac{U_{I_1} \cdot U_{I_2} \cdot U_{I_3} \cdot U_{I_4} \cdot U_{I_5} \cdot U_{I_6} \cdot U_{I_7}}{\frac{(U_{I_1} \cdot U_{I_2} \cdot U_{I_3} \cdot U_{I_4} \cdot U_{I_5} \cdot U_{I_6} \cdot U_{I_7})^7}{7}} \right]^{1/7} \tag{12}$$

where coupling degree $C \in [0, 1]$, $C \Rightarrow 1$, indicates the better model correlation.

③ In order to prevent high coupling due to the three levels being at low levels at the same time, a degree of coordination model is introduced.

$$T = \alpha U_{I_1} + \beta U_{I_2} + \gamma U_{I_3} + \delta U_{I_4} + \varepsilon U_{I_5} + \theta U_{I_6} + \vartheta U_{I_7} \tag{13}$$

where T is the composite evaluation index; α, β, γ, δ, ε, θ, ϑ is the seven-level weight, calculated by the entropy weighting method.

④ Calculate the degree of coupling coordination.

$$D = \sqrt[2]{C \cdot T} \tag{14}$$

⑤ Harmony is considered based on the coupled coordination degree model.

$$HD = \sqrt{DD \cdot CD} = \sqrt{S \cdot D} \quad (15)$$

Ultimately, the criteria for judging the degree of coupling coordination are shown in Table 3.

Table 3. Criteria for the judgment of coupling coordination degree and harmony degree.

Coupling Coordination Degree Level *D*		Degree of Harmony *HD*	
[0, 0.2)	Uncoordination	[0, 0.2)	Unharmonious
[0.2, 0.4)	Undercoordination	[0.2, 0.4)	Lack of harmony
[0.4, 0.6)	Basic coordination	[0.4, 0.6)	Basic harmony
[0.6, 0.8)	Coordination	[0.6, 0.8)	Harmony
[0.8, 1]	Well-coordinated	[0.8, 1]	In perfect harmony

2.4. Data Analysis and Evaluation Models

Data processing and analysis were conducted using Office Excel 2016 and IBM SPSS Statistics 26 software, while mapping was performed with ArcGIS 10.3, Origin 2021, and Office PowerPoint 2016. In this study, the Entropy Weight method was employed to determine the weights of the indicators after normalization, followed by the synthesis of multiple indicators, which ultimately resulted in the HRI through multi-criteria integration. Subsequently, the scientific validity, rationality, and sensitivity of the evaluation system were verified using the coupling coordination model and harmony theory.

3. Results

3.1. Evaluation Indicator Scores and Weights

The 21 evaluation indicators selected for this study, including average water use for agricultural irrigation, per capita water resources, embankment compliance rate, groundwater extraction rate, urban sewage treatment rate, ecological water use ratio, and water management intelligence level, were analyzed through scoring and weight assignment. The scores for these indicators from 2017 to 2021 are presented in Table 4.

Based on the Entropy Weighting method, the five evaluation indicators with the highest weights are as follows: urban sewage treatment rate (C10) > artificial disturbance degree of river lake reservoir zone (C15) > levee compliance rate (C5) > average water consumption for farmland irrigation (C1) > per capita water resources (C2). Notably, most of these indicators are objective in nature. Conversely, the five indicators with the lowest ratings are: water quality (C3) < compliance rate of river section treatment (C6) < intelligent level of water management (C19) < river and lake connectivity (C14) < vegetation coverage (C21), where subjective and objective factors are largely consistent. The degree of good water quality (C3) is a critical evaluation index for the overall assessment, as it achieves a 100% rating annually; however, it lacks significant reference value for measuring the degree of 'Happy River' in Zhangye City. The urban sewage treatment rate (C10) has the highest evaluation weight, indicating that enhancing the city's quality of life is the primary factor influencing the 'happy river' evaluation according to this method. This, in turn, indirectly determines public satisfaction and directly impacts the sense of well-being during the construction of the happy river and lake. The weights were calculated using the entropy weighting method, and the results of the optimized indicators are illustrated in Figure 3.

Table 4. Index scores of each year.

Evaluation Index \ Year	2017		2018		2019		2020		2021	
	Data	**Score**	**Data**	**Score**	**Data**	**Score**	**Data**	**Score**	**Data**	**Score**
Average water consumption for farmland irrigation C1	463	71.49	448	449	64.35	72.18	429	73.81	418	66.53
Per capita water resources C2	3064	82.56	2162	2382	67.64	63.24	2702	74.04	2488	69.76
Water quality C3	100%	100.00	100%	100%	100.00	100.00	100%	100.00	100%	100.00
Utilization rate of surface water resources C4	47.07%	85.86	62.88%	58.88%	69.55	64.85	49.38%	80.00	55.81%	73.17
Rate of levee compliance C5	62.18%	62.18	64.59%	62.21%	62.21	64.59	61.30%	61.30	66.70%	66.70
Compliance rate of river section treatment C6	86.23%	88.31	98.13%	89.74%	92.98	100.00	89.42%	92.56	90.51%	94.01
Proportion of water-saving irrigated area C7	44.43%	74.43	50.27%	58.92%	88.92	80.27	51.81%	81.81	64.18%	94.18
Conservation rate of important wetlands C8	98.00%	100.00	91.33%	92.04%	88.16	85.32	94.37%	97.48	92.62%	90.48
Groundwater extraction rate C9	17.90%	64.21	21.85%	21.85%	52.62	52.62	21.85%	52.62	21.85%	52.62
Urban sewage treatment rate C10	61.00%	51.00	34.89%	89.77%	93.03	19.85	52.48%	42.48	96.54%	100.00
Utilization rate of reclaimed water C11	65.79%	100.00	74.72%	47.43%	100.00	100.00	81.57%	100.00	37.82%	100.00
Vegetation coverage C12	15.66%	51.32	15.68%	13.15%	46.30	51.36	13.12%	46.24	9.50%	36.00
Ecological water use ratio C13	2.29%	100.00	3.37%	1.24%	100.00	100.00	1.98%	100.00	1.43%	100.00
River–lake connectivity C14	62	62.00	69	65	65.00	69.00	66	66.00	70	70.00
Artificial disturbance degree of river lake reservoir zone C15	92	92.00	94	100	100.00	94.00	97	97.00	100	100.00
Characteristic landscape style C16	81	81.00	83	78	78.00	83.00	80	80.00	78	78.00
Water culture construction C17	83	83.00	85	89	89.00	85.00	89	89.00	87	87.00
Water usage per unit of industrial value added C18	12.50%	45.00	18.75%	43.75%	100.00	57.50	28.13%	76.25	54.69%	100.00
Intelligent level of water management C19	80	80.00	82	84	84.00	82.00	83	83.00	88	88.00
The degree of harmony of water relations C20	83	83.00	83	89	89.00	82.00	87	87.00	88	88.00
Public satisfaction C21	87	87.00	89	90	90.00	89.00	90	90.00	91	91.00

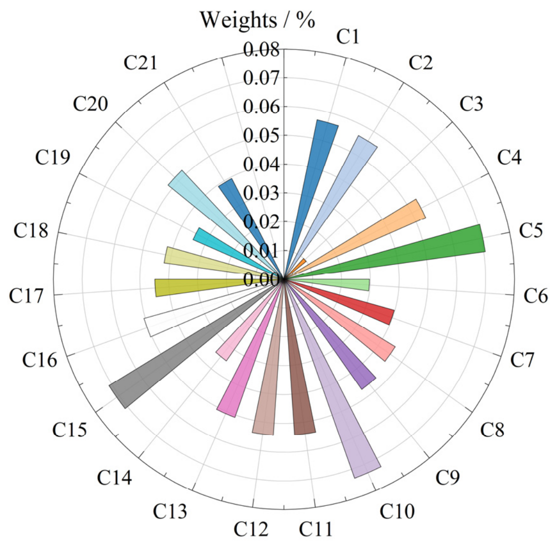

Figure 3. Distribution of weights of evaluation indicators.

3.2. Weights for Each Normative Level

The weights of each criterion layer in the 'Happy River' evaluation system are illustrated in Figure 4. According to this evaluation system, the weights of the criteria layers are ranked as follows: river ecological health (B3) > water resources supply capacity (B1) > conservation status of river culture (B5) > operational efficiency (B2) > river environment (B4) > management of rivers and lakes (B6) > public satisfaction (B7). It is evident that river ecological health (B3), water resources supply capacity (B1), and conservation status of river culture (B5) are the primary factors influencing residents' well-being in the context of rivers and lakes. This prominence arises from the significant contradiction between water demand and water supply for human social development in the Hexi Oasis. Residents' demand for water primarily emphasizes the necessities for production and daily life, with a focus on the benefits derived from water resources. Subsequently, considerations extend to the living environment, before finally addressing the demand for water culture and other water-related functions. Therefore, the construction of the 'Happy River' initiative in Zhangye City should prioritize enhancing the subjective happiness of residents through the expansion of river and lake water function services.

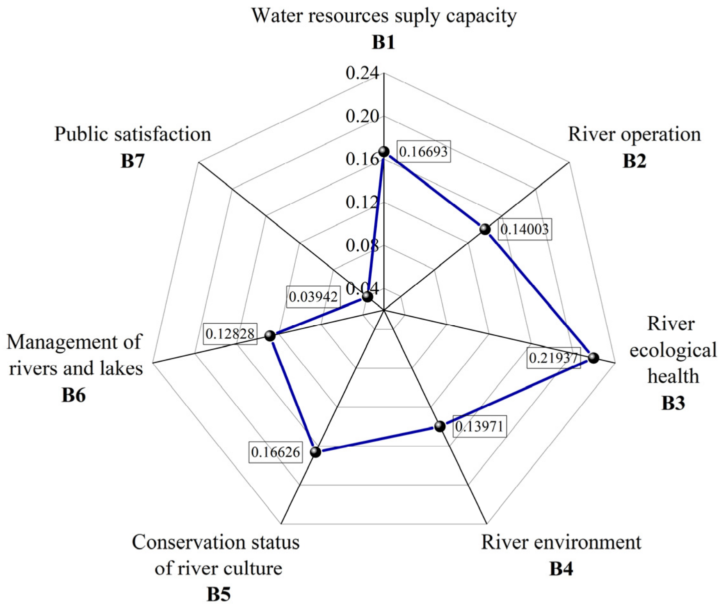

Figure 4. Weight distribution of criterion layer of the evaluation system itself.

3.3. Happiness Index Analysis

The Happiness River scores and grades are presented in Table 5. Based on the evaluation index system of the 'Happy River' in Zhangye City within the Heihe River Basin from 2017 to 2021, and utilizing the SMI-P method for weighting, the five-year comprehensive evaluation index ranges from 0.459 to 0.526, demonstrating an upward trend. This trend indicates that the construction of the Happy River in Zhangye City has had a significant positive impact. The happiness index, which falls between 76.71 and 81.97, also exhibits a year-on-year increasing trend. Over the five-year period, the happiness level improved from the 'relatively happier' to the 'very happy' level. Furthermore, the happiness river index reflects these positive changes; the Happiness River Index (HRI) was lowest in 2018, at 76.61. This decline can be attributed not only to the city's low sewage treatment rate but also to the lower availability of surface water resources that year, resulting in a decreased per capita water resource compared to previous years. In 2021, the data reflect the best results, although vegetation coverage (C12) remains a weak link in development. Despite improvements in the efficiency of irrigation water use within the province, irrigation water consumption in Zhangye City is significantly higher than the average level, which restricts overall well-being. However, notable improvements have been observed in the rate of levee compliance (C5), urban sewage treatment rate (C10), water usage per unit of industrial value added (C18), and the degree of harmony in water relations (C20). These enhancements contribute to safeguarding residents' lives, improving quality of life, and fulfilling residents' needs. The decreasing trend in water usage per unit of industrial value added indicates that the city's management and utilization of water resources are improving, allowing for more water resources to be allocated to other critical areas that enhance residents' living standards, thereby maximizing the functional benefits of water.

Table 5. The score and grade of Happy River under the weight treatment.

Index \ Year	2017	2018	2019	2020	2021
Composite index	0.459	0.484	0.468	0.500	0.526
Happiness River Index (HRI)	76.71	73.00	77.31	80.71	81.97
Happy River Construction Rating	Better	Better	Better	Best	Best

3.4. Coupling Degree Coordination and Harmony Analysis

Based on the SMI-P evaluation method, the results of the coupling degree and harmony degree of the evaluation system for 'Happy River' in the Zhangye City section of the Heihe River are presented in Table 6. The coupling degree of the evaluation system, as assessed by the SMI-P method from 2017 to 2021, increased from 0.605 to 0.687, indicating a coordinated state. This suggests an improved connection between the guideline layers within the indicator system, demonstrating that the development status among these layers is becoming more consistent, and that the evaluation indicator system is well-constructed. The internal subsystems exhibit a strong synergistic relationship, and the developmental trend of the system aligns with the evaluation requirements. The degree of harmony within the evaluation system ranges from 0.527 to 0.601, reflecting an upgrade from basic harmony to a higher level of harmony. The increasing coupling degree of coordination and harmony indicators year by year signifies that both the indicators and the evaluation system, as a whole, are progressing positively. This ongoing development is expected to further enhance the overall state of this positive trajectory, leading to a gradual improvement in the construction of the 'Happy River'.

Table 6. Calculation results of coupling coordination degree and harmony degree.

Index \ Year	2017	2018	2019	2020	2021
Coupling degree C	0.797	0.891	0.900	0.928	0.896
Coordination degree T	0.459	0.483	0.468	0.500	0.526
Coupling coordination degree D	0.605	0.656	0.649	0.681	0.687
Degree of harmony HD	0.527	0.563	0.551	0.583	0.601

Under the condition of unchanged weighting factors, the coupling and coordination degree of the evaluation system over five years exhibits an upward trend characterized by fluctuating changes, indicating a state of coordination. This suggests that the indicators constituting the evaluation criterion layer can effectively collaborate, cooperate, and synergize with one another, which is both reasonable and persuasive when initially assessing the 'Happy River' system. Harmony investigates the positive and constructive coordinated development relationships among the system's elements and facilitates a quantitative evaluation. The results demonstrate that the coordinated development relationship of the evaluation system tends to be positive and constructive, reflecting a harmonious state. Therefore, it is justified to apply the constructed evaluation model of the 'Happy River' to the Zhangye section of the Heihe River.

4. Discussion

This study employs the SMI-P evaluation method, selecting searchable and accessible evaluation indicators to calculate the Human Resource Index (HRI) for the years 2017–2021, which consistently fall within the range of 'happier' to 'very happy'. The comprehensive index of the evaluation system, ranging from 0.459 to 0.526, demonstrates an increasing trend. This trend suggests that the implementation of the river and lake chief system has a positive impact on the management and utilization of water resources in the Zhangye section of the Heihe River. The river and lake management in this section has benefited local residents, as the Heihe River is capable of meeting local production, lifestyle, and ecological needs. Furthermore, it can maintain healthy human and water resource interactions, thereby aligning with the requirements of sustainable development. The construction of the 'Happy River' initiative is proving to be effective.

The Heihe River Oasis, due to its geographical location and natural environmental conditions, experiences a high concentration of industry and population. This concentration inevitably leads to excessive consumption of water resources during the development process, resulting in unavoidable environmental pollution [32,33]. Such pollution restricts ecological balance, production capabilities, and living standards, creating a complex interplay between population growth, economic development, and resource allocation that is challenging to coordinate effectively in the short term. Water resources are essential for the sustainable development of the oasis; thus, the limited water supply must not only meet the normal demands of upstream and midstream industrial and agricultural production but also account for the ecological recovery and maintenance downstream [34]. The construction of the 'Happy River' initiative should aim to balance the relationship between habitat preservation and development, mitigate regional environmental risks, and uphold residents' living standards. In terms of indicator selection, it is crucial to focus on water resources pertinent to production and daily life in oasis cities located in arid zones. Therefore, the evaluation system should prioritize indicators that measure the protection of livelihoods and sustainable development [4,35]. However, the evaluation of the 'Happy River' faces challenges due to the diversity of evaluation methods, the complexity of indicators, and the difficulties in data collection. Consequently, a cohesive set of indicators has yet to be established, hindering the effective assessment of the 'Happy River' system in the western oasis region.

Water resources, water ecology, and water environment security issues have significantly hindered the economic and social development of the Zhangye City section of the Heihe River. In accordance with the "Water Distribution Programme for the Main Stream of the Heihe River" and the "Opinions on the Implementation of the Strictest Water Resource Control System", as well as other relevant regulations governing water use in the Heihe River, Zhangye City has intensified its water-saving initiatives, gradually enhancing its water use efficiency and continuously optimizing water resource allocation [19]. To achieve a balanced approach to the coordinated development of the economy, society, and ecology, the Zhangye City section of the Heihe River has established a comprehensive systematic project focused on river flood control, sediment treatment, and the greening of scenic spots along both banks of the river, thereby enhancing the hydrophilicity and overall well-being of urban residents [34]. Concurrently, numerous hydrological prediction models and related research continue to provide a theoretical foundation for river and lake management, allowing for the identification of key elements and the resolution of critical issues in the context of water resources, water environment, and water ecological security, as well as the ongoing construction of the 'Happy River' [36–38]. However, horizontal research indicates that certain areas within the watershed, despite being designated as 'happy river and lake' by local government, still experience water disasters and pollution events. Thus, effectively linking the construction of the 'Happy River' and 'lake' with the assessment of river and lake health remains a challenge that must be addressed in the future development of a 'Happy River' in the Zhangye section of the Heihe River. Additionally, it is essential for relevant departments to integrate pertinent scientific research with the needs of residents, enhance policies and regulations, fortify the management of government agencies, and reinforce the accountability of the river and lake chief system. Furthermore, it is crucial for social organizations and residents to actively engage in the co-management process, promptly identify and report issues encountered in the development of a 'Happy River', and contribute to the improvement of the evaluation system.

5. Conclusions

This study employs the 'Happy River' evaluation system, developed using the SMI-P method, to systematically assess river health and human well-being in the Heihe River

Basin of Zhangye City, focusing specifically on the Zhangye City section. The findings indicate that from 2017 to 2021, both the coupling coordination degree and harmony degree of the Zhangye City section of the Heihe River improved, with a significant increase in the happiness index and a steady rise in the comprehensive index. These results suggest that the construction of the 'Happy River' has achieved initial success in the region. By utilizing the Coupling Coordination model and harmony theory, the study validates the scientific soundness and rationality of the evaluation system, which demonstrates effective synergy within the system. This evaluation framework accurately reflects the progress of the 'Happy River' initiative in Zhangye City, establishing itself as both scientific and reasonable. Future research should emphasize policy guidance and public participation, alongside continuous optimization of the evaluation system and enhanced multidisciplinary integration. This approach aims to foster synergy among government, market, and society to further advance the construction of the 'Happy River'. The evaluation system fulfills the criteria for assessing the degree of 'Happy River' development and offers theoretical insights and practical guidance for similar initiatives in arid zone rivers or oasis rivers.

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