Evaluation of ecological restoration effects and diagnosis of obstacle factors in coastal zones: a case study of Qinhuangdao city

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Abstract

Purpose – Coastal zone ecological restoration project is of great significance to alleviate marine ecological degradation. Evaluating the effect of coastal ecological restoration projects and identifying the obstacle factors affecting their restoration level can provide an empirical basis for future Marine ecological restoration projects.

Design/methodology/approach – However, due to the initial stage of coastal zone ecological restoration projects, the actual monitoring data of coastal zone ecological restoration is relatively lacking. Based on the CRITIC-TOPSIS (combination of CRITIC method and TOPSIS method) method, combined with the subjective perception of the public and the actual data of the restoration project, this paper proposes an evaluation method of the coastal zone ecological restoration effect to obtain the specific implementation effect of the coastal zone ecological restoration project. The main obstacle factors affecting the evaluation of coastal ecological restoration effect are identified by using the obstacle degree model.

Findings – This paper conducted an empirical study on the restoration of sandy shoreline and coastal wetland in Qinhuangdao city. Based on the data of restoration projects and the subjective perception of ecological restoration by the public in Qinhuangdao city, the research results showed that the coastal zone ecological restoration effect of Qinhuangdao city was general. The quality of the restoration project and the public perception have an important influence on the evaluation of the restoration effect. Improving the quality of the restoration project, strengthening the public's participation in ecological restoration and allowing the public to better participate in the ecological restoration of the coastal zone can improve the effect of ecological restoration of the coastal zone in an all-round way.

Originality/value – The research results of this paper have a guiding role in the ecological restoration of coastal cities in the future, and also have a demonstration and reference role for the assessment of the effect of ecological restoration of coastal zones.

Keywords Coastal zone ecological restoration, Sandy shoreline, Coastal wetland, Evaluation of the restoration effect, Obstacle factor identification, CRITIC-TOPSIS method

Paper type Research paper

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1. Introduction

The coastal zone is a zone where the ocean interacts with the land, including the land and sea area with a certain width adjacent to the coast (Zhu and Wang, 2013). It not only has natural geographical properties such as excessive sea and land, rich resources and fragile ecology, but also has unique socioeconomic properties. It is an area with highly intensive human industrial, commercial, residential and tourism activities, and is known as the "golden zone" in the social and economic field (Zhang *et al.*, 2020). With the development and utilization of coastal resources, coastal resources and environmental problems such as coastal erosion, bay siltation and wetland degradation are becoming more and more serious (Liu and Xing, 2019; Zhang *et al.*, 2017). In 2018, the Ministry of Ecology and Environment, the National Development and Reform Commission and the Ministry of Natural Resources jointly issued the Action Plan for the Critical Battle for the Comprehensive Management of the Bohai Sea, pointing out that ecological protection of coastal zones, shoreline and coastal wetland should be strengthened. Ecological restoration will be carried out. By the end of 2020, the Bohai coastal wetlands will be restored on a scale of at least 6,900 hectares, and coastal cities will be restored with an additional 70 kilometers of shoreline. After three years of ecological restoration, more than 130 kilometers of shoreline and 8,800 hectares of coastal wetlands have been restored (Zhao *et al.*, 2021). In the 14th Five-Year Plan for the development of the marine environment, it is pointed out that by the end of 2025, the regulatory and effectiveness assessment system for marine ecological restoration will be basically established and implemented as a routine measure. By the end of 2020, compared with the targets set out in the Action Plan for the Bohai Sea Comprehensive Treatment and Offensive War, the restoration of coastal wetlands was over-achieved by 27.5%; and the length of new shoreline by 85.7% (Zhao *et al.*, 2021).

Evaluation of restoration effectiveness is a concentrated manifestation of the quality and completion of ecological restoration projects, and it is of great significance to the comprehensive summary and technical refinement of the whole ecological restoration project. According to the problems reflected in the restoration effectiveness assessment, timely correction of the ecological restoration project can not only improve the ecosystem function and service value but also provide advanced experience and scientific guidance for other ecological restoration projects. Therefore, this paper summarizes the current situation of China's coastal zone ecological restoration effectiveness assessment system, establishes an ecological restoration effectiveness assessment system applicable to coastal zones and applies it to actual cases to provide reasonable and scientific guidance for more ecological restoration work in the future. There have been numerous studies (Duan *et al.*, 2022; Zhao *et al.*, 2023) by foreign scholars on the evaluation of ecological restoration effects in other fields such as mine ecological restoration (Wang *et al.*, 2023; Xu *et al.*, 2023; Zhao *et al.*, 2023) and forest restoration (Zanini *et al.*, 2021). Researchers both domestically and internationally have conducted studies on the evaluation of coastal zone ecological restoration effects. Foreign scholars have assessed the ecological restoration effects from various aspects, including biological resource restoration, changes in ecosystem service values, aesthetic values and public perception of ecological restoration. For example, Ada *et al.* (2018), Gómez-Baggethun *et al.* (2019), Smith *et al.* (2023) and Jin and Quan (2023) evaluated the ecological restoration based on the changes in ecosystem service values after restoration. Jones *et al.* (2010) used a multi-level evaluation method to assess coastal zone restoration from multiple perspectives such as landscape, geotechnical engineering design, environment, ecology, society and economy. They found that the integrity of vegetation and underlying soil played an important role in erosion mitigation. Hein *et al.* (2018) and Åberg and Tapsell (2013), respectively, investigated the public's perception of the restoration area through face-to-face interviews and questionnaires, and found that the public had intuitive perceptions of changes in the restoration area. Zhai *et al.* (2022) found that the effectiveness evaluation of the ecological restoration project of the Yongding River in China based on remote sensing technology provides decision-makers with an effective method for evaluating the effectiveness of ecological restoration projects. Domestic scholars have carried out a lot of research on the evaluation of coastal ecological restoration effect, mainly through the construction of indicators evaluation system, to evaluate the completed ecological restoration projects. By constructing ecological restoration evaluation systems, scholars like Fu *et al.* (2017), Liao *et al.* (2021) and Zhuang *et al.* (2021) evaluated the ecological restoration effects in different regions and found that ecological restoration projects had improved the conditions of the restoration areas. Zhang *et al.* (2017) pointed out the need to construct assessment indicators and methods for coastal zone restoration projects, considering different scales such as engineering quality, resource efficiency, ecological and environmental effects and socioeconomic effects. Wu *et al.* (2023) evaluated the restoration effect of four mangrove restoration projects in Xiamen by establishing a restoration effect assessment system, and found that the restoration effect of Xiamen's mangrove ecological restoration projects was good. However, there are also cases where the restoration effects are not satisfactory. For example, Feng *et al.* (2017) used rank division and gray clustering analysis to quantitatively evaluate the ecological restoration effects of wetlands with different restoration durations in Shenzhen, considering the environmental quality, biological community structure and plant health of the restored wetlands. The results showed that the restoration projects had limited effects on the restoration of degraded wetland habitats.

Coastal provinces and cities in China have actively responded to national policies and carried out a series of coastal zone ecological restoration projects, such as sandy shoreline and coastal wetland restoration. Shandong, Hebei, Liaoning and other provinces have achieved significant practical results. However, as the coastal zone ecological restoration work continues, there are issues such as fragmented restoration projects, lack of systematic and targeted restoration and insufficient attention to prominent restoration problems. Scientific and accurate evaluation of the ecological restoration effects of coastal zones is conducive to determining the restoration effects, enhancing project supervision capabilities and better meeting the adaptive management needs of marine ecological restoration projects. Domestic scholars have mainly focused on the objective data when evaluating the ecological restoration effects of coastal zones, without considering public perceptions. To address this gap, this study not only considers the ecological, economic and social changes brought about by restoration projects but also incorporates humanistic characteristics by focusing on the public's perception of ecological restoration. Furthermore, it explores the mechanisms through which ecological restoration effects can enhance human well-being. The government aims to advance the modernization of the national governance system, establish a service-oriented government and improve public satisfaction. Therefore, apart from evaluating the effects of sandy shoreline and coastal wetland restoration projects, this study also considers the public's perception of ecological restoration to understand the effectiveness of ecological restoration in China and whether it is recognized by the public in the restoration areas.

Based on the research achievements of domestic and foreign scholars and the current status of environmental governance in China, this study comprehensively considers three types of restoration: sandy shoreline restoration, coastal wetland restoration and overall (coastal wetland and sandy shoreline) restoration. From the perspective of indicator system construction, it not only focuses on the ecological, economic and social changes directly brought about by ecological restoration projects but also incorporates the public's perception of ecological restoration effects. By constructing an ecological effect evaluation system that combines objective and subjective indicators and applying the entropy-weighted TOPSIS method, this study determines the restoration effect levels of sandy shoreline restoration, coastal wetland restoration and overall restoration. Furthermore, the study applies the obstacle model to identify the main factors influencing coastal zone ecological restoration effects, providing guidance for future coastal zone ecological restoration projects. Moreover, it serves as a demonstration and reference for the assessment of other ecological restoration effects.

2. Material and methods

2.1 Construction of the indicator system

The purpose of the assessment of the effect of coastal ecological restoration is to measure the beneficial activities and the improvement of the sustainable level of the ecological environment brought by the ecological restoration project and the impact of the ecological restoration project on the ecological environment in the process of planning and construction. In Western developed countries such as Europe and America, the customer satisfaction model has been widely applied to the performance evaluation of the government public sector (Baylis *et al.*, 2008; Chang *et al.*, 2008; Reimer *et al.*, 2013), which lays the foundation for the application of "customer" satisfaction evaluation of the government performance evaluation. In recent years, many Chinese scholars have studied the performance evaluation of the public sector of the government based on models such as household satisfaction (Chen *et al.*, 2019; Wang and Luo, 2010; Yu and Cai, 2015). In terms of coastal zone ecological restoration projects, the public can be regarded as the "customers" of the marine ecological restoration projects implemented by the government. This paper comprehensively considers the ecological, economic and social changes directly brought about by ecological restoration projects, and combines the public's perception of the ecological, economic and social changes brought about by ecological restoration, so as to construct an evaluation system of the coastal zone ecological restoration effect that combines objective and subjective indicators.

Based on the actual situation of ecological restoration projects, the objective indicators for the evaluation of coastal ecological restoration effects include the total investment of the project, the utilization rate of funds of the project, the total area of land restored by the restoration project, the restoration cost per unit area, the length of shoreline restoration and the cost per unit shoreline restoration. Subjective indicators include public perception of ecological restoration projects, which can be specifically divided into three categories: public perception of ecological, economic and social indicators. Detailed description of the indicators is shown in Table 1.

2.2 Methods

2.2.1 CRITIC-TOPSIS method. TOPSIS (technique for order preference by similarity to ideal solution), also known as "method of similarity to ideal solution", is suitable for the evaluation of objects with multiple indicators and schemes. According to the degree of proximity between the object to be evaluated and the ideal object, the relative merits and demerits of the existing object are evaluated. The basic idea of this method is to evaluate multiple schemes by constructing "positive ideal solution" and "negative ideal solution". A "positive ideal solution" is a hypothetical optimal solution (or scheme) with the best values of each attribute among the candidate solutions. A "negative ideal solution" is an imagined worst solution (or solution) in which each attribute value reaches the worst value of the candidate solution. CRITIC-TOPSIS method is a combination of CRITIC method and TOPSIS method, which is an improvement of TOPSIS method. The main manifestation of this is that when the TOPSIS model is constructing the weighted decision matrix, the weights of the indicators are not determined by subjective assignment, but by the CRITIC method, which is an objective assignment method. The method is based on evaluating the comparative strength of indicators and the conflict between indicators to synthesize the

Target layer	System layer	Criterion layer	Indicators layer	Implication	Value	Indicator attributes
Coastal zone ecological restoration effect (A)	Objective indicators (B) Subjective indicators (C)	Ecological indicators (B1)	Restored area (b1)	The area of the coastal zone restored by the project	Specific values in the project	Positive
			Length of restored shoreline (b2)	Length of shoreline restored by the project	Specific values in the project	Positive
		Economic indicators (B2)	total investment (b3)	Total investment of the project	Specific values in the project	Negative
			Fund utilization rate (b4)	Fund utilization rate after project completion	Calculated from the specific value in the restoration project	Negative
			Restoration cost per unit area (b5)	Cost of restoring one hectare of coastal zone	Calculated from the specific value in the restoration project	Negative
			Unit shoreline restoration cost (b6)	Cost of restoring 1 km of shoreline	Calculated from the specific value in the restoration project	Negative
		Satisfaction indicators of ecological change (C1)	Satisfaction with the quantity of fish, shrimp, crab and shellfish after restoration (C1)	Very satisfied – very dissatisfied	5–1	Positive
			Satisfaction with restored nearshore vegetation (C2)	Very satisfied – very dissatisfied	5–1	Positive
			Satisfaction with beach shoreline after restoration (C3)	Very satisfied - -very dissatisfied	5–1	Positive
			Satisfaction with the level of biodiversity after restoration (C4)	Very satisfied – very dissatisfied	5–1	Positive
			Satisfaction with seawater quality after restoration (C5)	Very satisfied – very dissatisfied	5–1	Positive
			Satisfaction with the restored coastal landscape (C6)	Very satisfied – very dissatisfied	5–1	Positive
			Satisfaction with seaside air quality after restoration (c7)	Very satisfied – very dissatisfied	5–1	Positive
		Satisfaction indicators of social change (C2)	Personal satisfaction with the sea after restoration (C8)	Very satisfied – very dissatisfied	5–1	Positive
			Satisfaction with the change of city image after restoration (C9)	Very satisfied – very dissatisfied	5–1	Positive
			Satisfaction with the construction level of urban marine ecological civilization after restoration (C10)	Very satisfied – very dissatisfied	5–1	Positive
			Satisfaction with the restoration of regional public facilities (C11)	Very satisfied – very dissatisfied	5–1	Positive
			Satisfaction with the employment opportunities provided by the restoration project to local residents (C12)	Very satisfied – very dissatisfied	5–1	Positive
		Satisfaction indicators of economic change (C3)	Satisfaction with the recreational value provided by the restored area (C13)	Very satisfied – very dissatisfied	5–1	Positive
			Satisfaction with tourism development in the restoration area (C14)	Very satisfied – very dissatisfied	5–1	Positive
			Satisfaction with the value of the surrounding land after restoration (C15)	Very satisfied – very dissatisfied	5–1	Positive

Source(s): Created by authors

Table 1. Evaluation indicators system of coastal zone ecological restoration effect

objective weights of indicators. Considering the variability of the indicators while taking into account the correlation between the indicators, it is not that the larger the number is, the more important it is. The objective attributes of the data are fully used for scientific evaluation. CRITIC method can eliminate the influence of some indicators with strong correlation and reduce the overlap of information between the indicators, which is more conducive to obtaining credible results of the evaluation.

2.2.2 Specific operational steps of the CRITIC-TOPSIS method. The specific operation steps of CRITIC-TOPSIS method are as follows:

(1) Data standardization processing. Data standardization is to carry out dimensionless processing of data. In this paper, minimum-maximum standardization method is adopted to map the original data to [0,1]. The calculation formula is as follows:

$$v_{ij} = \frac{x_{ij} - x_{min}}{x_{max} - x_{min}} \tag{1}$$

Where, x_{ij} is the actual value of the j-th indicators of the i-th coastal zone ecological restoration mode; x_{max} *and* x_{min} are the maximum and minimum values, of the j-th indicators, respectively. The standardized normalization matrix is $\mathbf{V} = (v_{ij})_{m\times n}$, $(i = 1, 2, \cdots, n;\ j = 1, 2, \cdots, m)$

(2) Determination of indicator weights by the CRITIC method. Firstly, to determine the variability of the indicator, the standard deviation of the j-th indicator, S_j, is used to indicate the fluctuation of the difference in the value of each indicator; the larger the standard deviation, the greater the difference in the value of the indicator.

$$S_j = \sqrt{\frac{\sum_{i}^{n}\left(v_{ij} - \overline{v}_j\right)^2}{n-1}} \tag{2}$$

Where $\overline{v}_j = \frac{1}{n}\sum_{i=1}^{n} x_{ij}$.

Secondly, determine the conflict of indicators R_j, $R_j = \sum_{i=1}^{n}(1-r_{ij})$; r_{ij} represents the correlation coefficient between evaluation indicators i and j. Correlation coefficient is used to represent the correlation between indicators. Again, to determine the amount of information, let C_j denote the amount of information contained in the j-th evaluation indicator, then C_j can be expressed as follows: $C_j = S_j\sum_{i=1}^{n}(1-r_{ij}) = S_j \times R_j$ Finally, to determine the weight of the jth indicator w_j:

$$\mathrm{w_j} = \frac{\mathrm{C_j}}{\sum_{\mathrm{j=1}}^{\mathrm{m}} \mathrm{C_j}} \tag{3}$$

(3) The weighted decision matrix is constructed. The weighted decision matrix $\mathbf{R} = (\mathrm{r}_{ij})_{m\times n}$ is obtained by multiplying the weight of each indicator w_j with the dimensionless matrix $\mathbf{V}$.

Where,

$$\mathrm{r}_{ij} = w_j \times v_{ij}, (\mathrm{i} = 1, 2, \cdots, \mathrm{m};\ \mathrm{j} = 1, 2, \cdots, \mathrm{n}) \tag{4}$$

(4) The positive and negative ideal solutions are calculated. Let S_j^+ and S_j^- represent the positive and negative ideal solutions of the j-th indicators, respectively. So we have:

For positive indicators: $S_j^+ = \max_{1 \le i \le m}\{r_{ij}\} j = 1, 2, \cdots, n;$

$$S_j^- = \min_{1 \le i \le m}\{r_{ij}\} j = 1, 2, \cdots, n; \quad (5)$$

For negative indicators: $S_j^+ = \min_{1 \le i \le m}\{r_{ij}\} j = 1, 2, \cdots, n;$

$$S_j^- = \max_{1 \le i \le m}\{r_{ij}\} j = 1, 2, \cdots, n; \quad (6)$$

(5) Calculate the distance between the scheme to be evaluated and the positive and negative ideal solutions. Let Sd_i^+ and Sd_i^- represent the distance between the i-th solution and the positive and negative ideal solutions, then Sd_i^+ and Sd_i^- are calculated by the following formula:

$$Sd_i^+ = \sqrt{\sum_{j=1}^{n}\left(S_j^+ - r_{ij}\right)^2} i = 1, 2, \cdots, m \quad (7)$$

$$Sd_i^- = \sqrt{\sum_{j=1}^{n}\left(S_j^- - r_{ij}\right)^2} i = 1, 2, \cdots, m \quad (8)$$

In the formula, Sd_i^+ and Sd_i^- represent the approximation degree between the evaluation scheme and the optimal and the worst targets.

(6) Calculate the relative closeness between the scheme to be evaluated and the ideal solution.

$$\eta_i = \frac{Sd_i^-}{Sd_i^+ + Sd_i^-} i = 1, 2, \cdots, m \quad (9)$$

In the equation, $0 \le \eta_i \le 1$. The greater the degree of nearness η_i near the positive ideal solution, the better the ecological restoration effect. When $\eta_i = 0$, the level of ecological restoration effect is the worst. In this paper, with reference to the study of Yu and Cai (2015), the closeness is divided according to four levels to characterize the level of restoration effect after the implementation of ecological restoration projects, and the specific judging criteria are shown in Table 2.

2.2.3 Obstacle degree model. In the process of evaluation of the coastal zone ecological restoration effect, this paper not only analyzed the effect level of sandy shoreline, coastal wetland and overall restoration in the study area but also introduced “factor contribution degree”, “indicators deviation degree” and “obstacle degree” to analyze the obstacle factors

Level of effect	Poor	General	Good	Excellent
Close degree	0.00 ~ 0.300	0.310 ~ 0.600	0.610 ~ 0.800	0.810 ~ 1

Source(s): Table courtesy of Yu and Cai (2015)

Table 2. Criteria for ecological restoration effect

affecting the coastal zone ecological restoration effect (Huang *et al.*, 2019; Li *et al.*, 2015; Ren *et al.*, 2021; Sun *et al.*, 2020), so as to carry out pathological identification of the coastal zone ecological restoration effect. Therefore, we can adjust the coastal zone ecological restoration plan and provide reference for further improving the effect of coastal zone ecological restoration. Among them, the recognition factor contribution degree F_j refers to the weight of single factor to the overall target, the indicators deviation degree I_j represents the gap between single factor indicators and the target of coastal zone ecological restoration effect, that is, the gap between the standardized value of each factor indicators and 100%, and the obstacle degree Q_{ij} is the obstacle degree of single indicator and classified indicators to the coastal zone ecological restoration effect. The calculation formula is:

$$Q_{ij} = \frac{I_{ij} \times F_j}{\sum_{j=1}^{n} (I_{ij} \times F_j)} \times 100\% \tag{10}$$

In the formula, $F_j = w_j$, $I_{ij} = 1 - v_{ij}$, v_{ij} is the standardized value of each indicator.

3. Case study

3.1 Study area

Qinhuangdao is located in the two major economic junctions of North China and Northeast China. It is located in the northeastern part of Hebei Province and is located in the economic center of the Bohai Sea. It is adjacent to the Bohai Sea in the south, Yanshan in the north, Liaoning in the east, and Beijing and Tianjin in the west. [1]. Qinhuangdao city has a total length of 126 kilometers, 0.25 meters isobath within the sea area of 2,629.4 square kilometers [2]. In recent decades, the Bohai Sea has experienced rapid economic development, high intensity of marine resources exploitation and destructive use of the ecosystem. The ecological environment quality of the adjacent waters of Qinhuangdao has been declining continuously, sandy coastal erosion has intensified and coastal wetland is shrinking. In order to improve the ecological environment of the coastal zone and curb beach degradation and erosion, from 2010, Qinhuangdao city has carried out a series of coastal ecological restoration and protection projects, such as “Action Plan for Environmental Improvement of Beidaihe River and its adjacent Waters”, “Qinhuangdao Blue Bay Remediation Action”, “Qinhuangdao Bohai Sea Ecological Restoration Project” (including sandy shoreline restoration and coastal wetland restoration) and “Coastal zone protection and restoration”.

Coastal ecological restoration includes sandy shoreline and coastal wetland restoration. The ecological restoration of sandy shoreline is mainly based on artificial beach cultivation, supplemented by the construction of underwater sand bars and offshore submerged dikes, and the construction of overlying dunes at the rear edge, so as to increase the bearing capacity of the beach and improve the ecological conservation function and disaster prevention capability of the beach shoreline. The coastal wetland ecological restoration project takes the means of returning wet (beach) and restoring vegetation as the means to clear and rehabilitate wetland aquaculture ponds. Qinhuangdao city, as the first batch of “Blue Bay” remediation action approved coastal cities, fully organized the implementation of the Bohai Sea comprehensive management battle in the eight shorelines remediation and restoration projects, the cumulative completion of the shoreline restoration of 14.62 km, the construction of ecological submerged dike measuring 1.65 km and the successful completion of the Bohai Sea comprehensive management battle ecological restoration targets tasks. The ecological restoration projects related to the Bohai Sea under implementation stood out from more than 60 Bohai Sea ecological restoration projects nationwide, and were successfully selected as typical cases of Bohai Sea ecological restoration by the Ministry of Natural Resources. Due to the typical nature of coastal ecological restoration in Qinhuangdao city, the selection of Qinhuangdao city as the study area to carry out the evaluation of the effect of coastal zone ecological restoration has high reference value and guiding significance for other coastal cities in Hebei province and even the whole country.

3.2 Data collection

3.2.1 Data sources. The data in this paper come from two parts: Part of the data is corresponding to objective indicators, including the report data of the sandy shoreline restoration and coastal wetland restoration projects carried out in Qinhuangdao by the end of 2021. The report describes in detail the actual capital input and the sandy shoreline restoration projects and coastal wetland restoration projects, including the total investment, investment usage and solid restoration data. In this paper, the data in the report are summarized and sorted as objective data for the evaluation of the coastal ecological restoration effect of Qinhuangdao city. The other part is the questionnaire data corresponding to subjective indicators. Questionnaires are distributed to the public in the coastal area of Qinhuangdao city to obtain the public's satisfaction with the coastal ecological restoration, which is used as the subjective data for the evaluation of the coastal ecological restoration effect of Qinhuangdao city. In particular, the questionnaire in this paper consists of four parts: the first part is the guidance of the questionnaire, mainly introducing the background knowledge of coastal zone ecological restoration and the purpose of the questionnaire. The second part is the respondents' cognition of coastal ecological restoration, including the frequency of going to the seaside, the degree of attention to beach environmental quality and the degree of understanding of coastal ecological restoration projects. The third part is the respondents' evaluation of ecological restoration of Qinhuangdao coastal zone (including sandy shoreline restoration and coastal wetland restoration). An example of core questions is as follows: "My satisfaction with the change of nearshore vegetation after restoration"; the respondents rated the ecological environment change, social change and economic change of the restoration area based on the 1–5 s Likert scale, corresponding to "very dissatisfied", "not very satisfied", "generally satisfied", "relatively satisfied" and "very satisfied," respectively. The fourth part is the basic information of the interviewees, including gender, age, education level, occupation and personal annual income.

3.2.2 Data description. 3.2.2.1 Objective data description. The objective data in this paper are mainly from the sandy shoreline and coastal wetland restoration reports of projects that have been carried out in Qinhuangdao city. The restoration projects specifically include remediation and restoration project of Daihekou to Yanghe Port Line, Beidaihe Tiger Stone Bath and surrounding Headland Bay Coastal Restoration Project (Phase II), Beidaihe New Area Yanghe-Grape Island coastline renovation and Restoration Project, Luanhekou North Bank Coastal Wetland renovation and restoration project and so forth. The data involved in these restoration projects mainly include the total investment of the project, the use of funds, the length of shoreline restoration, the area of wetland restoration and so forth. Take the report of Daihekou to Yanghekou shoreline improvement and restoration project as an example; from the report, we can find out that the total investment of the restoration project is 37.86 million yuan, and after the completion of the restoration project, the fund used is 37.8353 million yuan; the restoration area is 4.05 hm^2, and the restoration length of the shoreline is 3.10 km. Therefore, we get the utilization rate of the fund which is 99.90%, the cost of restoration of the unit area is 9,342,100 yuan/$hm^{2,}$ and the cost of the unit shoreline is 11.2049 million yuan/km. The cost of restoration per unit area is 9,342,100 yuan/hm^2, and the cost per unit of shoreline is 11,204 900 yuan/km. Similarly, we can get the corresponding data from other reports.

3.2.2.2 Questionnaire data description. In December 2021, our research group conducted a public perception survey on the coastal ecological restoration effect in Qinhuangdao city, Hebei province. The main subjects of this questionnaire survey were residents of Qinhuangdao city. In order to ensure the validity of the questionnaire data as much as possible, the paper questionnaire was distributed at the Bohai Sea beach to ensure that the respondents had experienced the restored coastal environment. A total of 120 paper and electronic questionnaires were distributed to evaluate the restoration effect of sandy shoreline, and 108 valid questionnaires were collected, with the sample effective rate reaching 90%. A total of 145 paper and electronic questionnaires were issued to evaluate the ecological restoration effect of coastal wetland, and 131 valid questionnaires were collected, with the sample effective rate reaching 90.3%. Before data processing, the reliability and validity of the questionnaire were tested using the data analysis function of SPSS software. The Cronbach's α coefficient, KMO value and *P* value of Bartley's sphericity test were 0.98, 0.938 and less than 1% for all the variables in the evaluation group of coastal zone ecological restoration effect, respectively. It is proved that the questionnaire has good reliability and good structural validity, and can reflect the real situation of the surveyed public.

4. Results

4.1 Evaluation of ecological restoration effect and its closeness in coastal zone

According to formulas (1)–(6), the decision matrix of the overall coastal zone restoration, sandy shoreline restoration and coastal wetland restoration effect evaluation of Qinhuangdao city was constructed, and the indicators weights and positive and negative ideal solutions of each indicator were determined, as shown in Table 3. According to formulas (7)–(9), the

Indicators	Sandy shoreline restoration	Coastal field restoration	Total restoration	Weight(w)	Positive ideal solution	Negative ideal solution
b1	0	1	0.250	5.670%	1	0
b2	0	1	0.250	5.670%	1	0
b3	0	1	0.250	5.670%	1	0
b4	1	0	0.754	4.320%	1	0
b5	1	0	0.750	4.320%	1	0
b6	1	0	0.750	4.320%	1	0
c1	1	0	0.453	4.120%	1	0
c2	0	1	0.526	5.490%	1	0
c3	1	0	0.471	4.120%	1	0
c4	0	1	0.545	5.490%	1	0
c5	1	0	0.457	4.120%	1	0
c6	1	0	0.458	4.120%	1	0
c7	0	1	0.526	5.490%	1	0
c8	1	0	0.453	4.120%	1	0
c9	0	1	0.528	5.490%	1	0
c10	1	0	0.449	4.120%	1	0
c11	0	1	0.600	5.520%	1	0
c12	1	0	0.457	4.120%	1	0
c13	1	0	0.467	4.120%	1	0
c14	0	1	0.533	5.490%	1	0
c15	1	0	0.467	4.120%	1	0

Source(s): Authors' own work

Table 3.
Decision matrix and positive and negative ideal solutions of indicators

closeness between the overall coastal zone restoration, sandy shoreline restoration and coastal wetland restoration and the positive ideal solution is calculated, as shown in Table 4.

From the weights of the indicators in Table 3, it can be seen that the size of the restored area, the length of the restored shoreline and the size of the total investment play a larger role in the evaluation of the effectiveness of ecological restoration of the coastal zone, with a weight size of 5.67%, followed by the public's satisfaction with the construction of the regional infrastructure, which has a weight size of 5.52%. The size of the weight of the indicators determines the role played by the modified indicators in the evaluation of the effectiveness of ecological restoration of the coastal zone.

According to the calculation results of Table 4, it can be seen that the restoration effect of sandy coastline and the restoration effect of coastal wetland in Qinhuangdao City are consistent with the degree of closeness to the ideal solution, both of which are 0.5. According to the classification of the evaluation results in this paper, the corresponding evaluation level is general. Although the overall restoration effect of Qinhuangdao City is slightly smaller than the degree of closeness to the ideal solution, the corresponding evaluation level is also general. From the results of this paper, the levels of sandy shoreline restoration effect, coastal wetland restoration effect and overall restoration effect are all average, and there is still room for improvement in the coastal ecological restoration effect in Hebei province.

4.2 Analysis of obstacle factors in evaluation of ecological restoration effect in coastal zone

According to the previous analysis, the ecological restoration in Hebei province still has room for progress, and the identification of influencing factors that can enhance the restoration effect can provide guidance and suggestions for future restoration. Based on the obstacle factors identified by the obstacle factor model that hinder the effectiveness grade of sandy shoreline and coastal wetland restoration, a method to enhance the effectiveness grade of sandy shoreline restoration and coastal wetland restoration is given, which is of great significance for carrying out the ecological restoration of coastal zone in the future and consolidating the long-term restoration effect. Since the evaluation indicators include both positive and negative indicators, the improvement of the restoration effect of sandy shoreline and coastal wetland can be based on the indicator attributes. For the indicators with positive attributes, the specific restoration measures can be continuously improved (enhanced and increased). The negative indicators need to reduce the specific repair content of the indicators, so as to improve the final evaluation result of the repair effect.

As can be seen from Table 5, the main factors affecting the restoration effect of sandy shoreline are the restoration area, the length of restored shoreline and the total investment of the project. These three factors are all general indicators of the restoration project. It can be seen that improving the actual restoration content of the restoration project and controlling the project investment can improve the restoration effect of sandy shoreline. As for the ecological restoration of sandy shoreline in Hebei province studied in this paper, the main factors

Category	The distance from the positive ideal solution	The distance from the negative ideal solution	Close degree	Evaluation grade
Sandy shoreline restoration	0.707	0.707	0.500	general
Coastal field restoration	0.707	0.707	0.500	general
Total restoration	0.530	0.509	0.490	general

Source(s): Authors' own work

Table 4. Ecological restoration effect evaluation and proximity analysis

Table 5.
Obstacle factors and obstacle degree of ecological restoration effect indicators layer

Type		Rank of obstacle 1	2	3	4	5	6
Sandy shoreline restoration	Obstacle factors	b1	b2	b3	c11	c2	c7
	Obstacle degree	11.340%	11.340%	11.340%	11.040%	10.980%	10.980%
Coastal wetland restoration	Obstacle factors	b4	b5	b6	c1	c5	c6
	Obstacle degree	8.630%	8.630%	8.630%	8.230%	8.230%	8.230%
Total restoration	Obstacle factors	b1	b2	b3	c2	c7	c9
	Obstacle degree	8.320%	8.320%	8.322%	5.090%	5.090%	5.070%

Source(s): Authors' own work

affecting the restoration effect are positive indicators restoration area and length of restored shoreline, and negative indicators are project investment. Therefore, to further improve the restoration effect of sandy shoreline, we can increase the restoration area, increase the length of restored shoreline and appropriately reduce the total project investment.

The main factor affecting the restoration effect of coastal wetland is the public's satisfaction with the restoration project. Therefore, increasing the public's satisfaction with the ecological, economic and social changes after restoration can better improve the restoration effect level of coastal wetland. Since the indicators to measure the public's satisfaction with the restoration project are all positive indicators, it is necessary to continuously improve the public's satisfaction with the specific indicators. Specifically, we can strengthen the construction level of urban marine ecological civilization and increase the release of seafood such as fish, shrimp, crab and shellfish to improve the public's pro-marine environment.

5. Conclusions and discussion

5.1 Conclusions

By considering the direct ecological, economic and social changes brought about by ecological restoration projects, as well as the public's perception of these changes, an evaluation system for the ecological restoration effects in coastal zones was constructed, combining objective and subjective indicators. Taking the example of coastal zone ecological restoration in Qinhuangdao city, the restoration effects of sandy shoreline and coastal wetland were evaluated using the CRITIC-TOPSIS method, and the main obstacles affecting the restoration effects were identified. The findings are as follows:

(1) The closeness values of sandy shoreline restoration, coastal wetland restoration and overall restoration effect to the ideal solution of Qinhuangdao are relatively close to each other, in which the closeness of sandy shoreline and coastal wetland restoration effect to the ideal restoration effect is 0.5, and the closeness of the overall restoration effect to the ideal restoration effect is 0.49. It can be concluded in accordance with the restoration effect class division of this paper that the level of ecological restoration effect of the coastal zone in Qinhuangdao city is average.

(2) According to the analysis of obstacle degree factor, the factors affecting the evaluation level of ecological restoration effect in coastal zone are not much different, and the top

three are objective indicators. The indicators of this paper are divided into two categories, subjective indicators and objective indicators. According to the results of this study, the top three are objective indicators. Among them, the top three factors affecting the effectiveness of sandy shoreline restoration are the restoration area, the length of restored shoreline and the total investment of the restoration project. On the other hand, the top three factors affecting the effectiveness of coastal wetland restoration are the utilization rate of funds, the cost of restoration per unit area and the cost of restoration per unit shoreline. In addition, the subjective perception of the public also has a certain influence on the ecological restoration effect of the coastal zone. Among them, the sandy shoreline restoration is more affected by the public's satisfaction with the restoration of public facilities in the restoration area. The public's evaluation of the effect of sandy shoreline restoration is less affected by the near-shore vegetation and seaside air quality after restoration. The effect of coastal wetland restoration is affected by the public's satisfaction with the change of seafood quantity, seawater quality and coastal landscape after restoration.

From the factors affecting the effectiveness of ecological restoration of the coastal zone, it can be seen that the quality of restoration works and the public's subjective perception of the restored area have an impact on the evaluation of the effectiveness of ecological restoration of the coastal zone. However, the main influencing factor is still the restoration project generalization factor, since the restoration generalization indicators are closely related to the set restoration objectives, as well as these restoration project indicators can be directly measured and observed; so, the changes of these restoration project indicators can assess whether the restoration project has achieved the expected objectives. Therefore, for the ecological restoration of coastal zones, whether it is sandy shoreline restoration or coastal wetland restoration, it is necessary to improve the quality of engineering restoration in the process of restoration, specifically increasing the restoration area and the length of restored shoreline as much as possible with a certain amount of total investment in the project; improving the efficiency of the use of funds; and controlling the restoration cost per unit area. In addition, strengthening the public's participation in ecological restoration, letting the public understand the relevant content of ecological restoration, and improving the public's satisfaction with the restoration area can improve the effect of coastal ecological restoration in an all-round way. In order to better carry out ecological restoration projects in the future, this paper gives the following suggestions based on the conclusions:

(1) Controlling restoration costs or improving the efficiency of capital utilization. When implementing ecological restoration projects in the future, a clear budget and cost plan can be formulated in advance to assess the resources and costs required for the whole restoration project. This can effectively control the restoration costs and avoid exceeding the budget. In addition, ongoing monitoring and cost control is performed during the restoration process. Ensure that the use of funds is in line with the budget plan and take necessary measures to prevent cost overruns.

(2) Improve the output of ecological restoration projects. Expanding the output of ecological restoration can be realized by increasing the scale of the restoration project, expanding the scope of restoration, increasing the number of restoration areas or concentrating resources on key restoration, and improving the coverage area and effect of restoration. Continuous scientific innovation and technology application to expand the output of ecological restoration can accelerate the restoration process and improve the restoration effect by optimizing the restoration strategies and methods, such as using advanced technologies and tools and selecting fast-growing and adaptable plants. In addition, continuous management and monitoring is the key to

ensure the durability and sustainability of ecological restoration outputs. The establishment of a long-term management plan can maintain the restoration effect, prevent further degradation and provide support for the continuous expansion of outputs.

(3) Strengthen public participation in coastal ecological restoration. The public is the direct beneficiary of coastal zone ecological restoration, and its satisfaction can reflect the public's pro-sea experience after the implementation of ecological restoration projects. Evaluating the effect of ecological restoration by adding the public's actual perception of the restoration project echoes the call of the state to "rely on the people, make collective efforts, broaden the channels of public participation, mobilize, guide and promote the participation of the public in the work of marine ecological environmental protection and governance, and take the initiative in accepting social supervision". Taking the improvement of marine ecological environment quality as the core, and paying more attention to the public's demand for pro-sea, it can promote the continuous improvement of marine ecological environment quality and the demonstration of beautiful bays, and continuously enhance the people's sense of happiness at being close to the sea.

5.2 Discussion

Although the overall evaluation level of the ecological restoration effects in Qinhuangdao city's coastal zone is average, it does not imply the failure of the restoration projects. The evaluation of coastal zone ecological restoration effects is not only influenced by the resources, economic inputs and actual outputs but also subjectively influenced by the public's perception of the restoration. Therefore, while controlling inputs and increasing outputs, expanding the public's specific understanding of ecological restoration projects can better enhance the evaluation levels of restoration effects.

Due to the different types of coastal zone ecological restoration carried out in various regions and the lack of comprehensive and unified data for each type of restoration project, evaluating the ecological restoration effects of coastal zones presents certain difficulties. A limited assessment of ecological restoration effects in a specific region leads to a certain degree of bias. Expanding the evaluation of ecological restoration effects to a nationwide scale can provide a better understanding of the implementation effects of ecological restoration work in China. Additionally, the public is the direct beneficiary of coastal zone ecological restoration, and their satisfaction reflects the personal experience of the restored coastal environment. Therefore, broadening public participation channels in ecological restoration and guiding and promoting public engagement in marine ecological environmental protection and governance will make our evaluation of ecological restoration effects more representative. Moreover, the TOPSISs method relies heavily on weight coefficients, and different weight calculation methods may lead to different evaluation results. Therefore, in the future, we will continue to collect more ecological restoration cases, synthesize the restoration project data and the subjective perception of the public, combine multiple weight determination methods to obtain a comprehensive weight and then conduct a more in-depth and comprehensive effect evaluation of the completed coastal ecological restoration projects, so as to provide lessons for future restoration work and promote the ecological restoration of coastal zones in the direction of a more effective and sustainable development.

Notes

1. Qinhuangdao Municipal People's Government, the website is: qhd.gov.cn
2. Qinhuangdao city – China Marine Information Network, the website is: nmdis.org.cn

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