The evaluation and optimization method of major events-driven polluted coastal zone renewal: a case of the polluted coastal zone in the Dalian Barracuda Bay Stadium Area

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Introduction: Coastal zone pollution leads directly to a series of local ecological, economic, and social damages. The renewal of polluted coastal zones is a comprehensive challenge that includes the degeneration of ecological services, the decrease in urban livability, and the increase in maintenance costs. Since current ecological management pays more attention to relevant technologies and investments, it plays a limited role in effectively and quickly executing the renewal of polluted coastal zones. Nature-based solutions (NbS) aim to improve regional ecological restoration and renewal by balancing multiple interests such as ecology, economy, and society. Therefore, NbS is an effective way to address this comprehensive challenge. Current studies on NbS are actively exploring the theoretical framework and practice process of solving complex social challenges through an ecological approach.

Methods: As an implanted production process, major events could provide robust policy support and continuous economic backing, which makes this an effective solution for challenges such as a lack of support and ineffective guarantees. This paper was centered around the goal of NbS theory, which is achieving comprehensive benefits, and establishing the Social-Economic-Ecological Systems framework (SEESs) that is driven by major events to achieve the renewal of polluted coastal zones.

Results: The main objective of this study was to investigate the renewal-driving potential of major events in facilitating the restoration (renewal) of coastal ecosystems from the perspective of NbS. Specifically, it aimed to explore how major events promote the renewal of polluted coastal zones, thereby fostering local socioeconomic advancements and enabling regional sustainable development. Driven by hosting the 2023 China Asian Cup, the renewal of the polluted coastal zone in the area around Dalian Barracuda Bay Stadium was studied. Three subsystems and 12 indexes were selected as evaluation indexes of polluted coastal zone renewal driven by major events. Furthermore, using the entropy weight method, we constructed an evaluation system of polluted coastal zone renewal benefits driven by major events, then verified the synergistic effect of the major event on the social, economic, and ecological recovery of the

polluted coastal zone. Moreover, we evaluated the change in the comprehensive scores of the polluted coastal zone from 2018 to 2021 under the impact of the 2023 Asian Cup. The spatial and temporal patterns of each subsystem and index were also discussed.

Discussion: Finally, we proposed methods for the optimization of the renewal of urban coastal zone pollution driven by major events and provide solutions to cope with the negative impact of epidemics, strikes, and war throughout the process.

1 Introduction

A large amount of evidence and many scientific studies have proven that coastal zone pollution has long-term and immeasurable negative impacts on social, economic, and ecological benefits, including damaging ecosystems, limiting the development of the marine economy, and reducing social well-being (Feng et al., 2021). Once the damage occurs, recovery requires significant financial and social resources, which are often time-consuming and ineffective. Jones and Schmitz reviewed 236 case studies on polluted coastal zone renewal and found that because of the comprehensive nature of the challenge, two-thirds of the cases were not adequately restored (Jones and Schmitz, 2009). In the past decade, China's coastal areas have had serious conflicts in human activities, tidal land resource utilization, waste disposal, etc., which have resulted in various pollution problems. Moreover, coupled with the cumulative effects of pollution, the social, economic, and ecological impacts will persist (Chen et al., 2017). Nature-based solutions (NbS) are natural resource management methods that resolve problems and challenges in the development of human society by effectively intervening in the ecological system. In the 1990s, the term 'NbS' was first proposed in biodiversity and then cited in agricultural development, land use planning, and industrial design (Wang and Hou, 2021). It is currently widely employed in urbanization, coastal development, tourism economy, water supply, and disaster risk (Chen and Lin, 2019; Jean et al., 2022), with a focus on climate change, urban sustainable development, and addressing ecological and social challenges. NbS focuses on synergistic benefits and could function as a comprehensive approach for compound social-economic-ecological challenges (Yu et al., 2022). However, many theoretical studies and applications that are based on NbS tend to focus on ecological resilience, which could easily get stuck because of a lack of motive force and the difficulty in safeguarding the results. Therefore, traditional approaches are not suitable for solving problems such as the degeneration of ecological services, the decrease in urban livability, and the increase in maintenance costs (McPhearson et al., 2022; Egusquiza et al., 2021).

Represented by major sporting games, major events could provide opportunities for the practice of NbS. Specifically, NbS could support ecological governance and restoration, as well as provide a sustainable safeguard in many aspects, such as policy, finance, and management. As a type of critical strategy, major sporting games could boost urban improvement and have far-reaching impacts on local and national politics, economy, culture, and society (Buwen, 2013). This top-down approach could coordinate the social, economic, and ecological

benefits and achieve synergistic progress in multiple aspects (Liu and Gratton, 2010; Lopez et al., 2022). Major sporting games play an active part in boosting local economic development, improving national or local images, stimulating urban renewal, and restoring the ecosystem (Black, 2007; Cornelissen, 2004; Cornelissen and Swart, 2006; Horne and Manzenreiter, 2006). As the driving force, major events could rapidly, effectively, and constantly improve the renewal and utilization of ecological resources. In the 1980s, the general public started to realize the positive effects of hosting major sporting games (Fainstein, 2008; Orueta and Fainstein, 2008), including quickly and effectively developing and recovering brownfields and less-developed regions (Deyi et al., 2015). For example, in 1988, by hosting Seoul Olympics, the local infrastructure was improved and further contributed to the economic growth of South Korea. In 1992, the Barcelona Olympics changed the city development framework and reconstructed the old industrial zone to a modernized area on the waterfront. In 2000, the Sydney Olympic Park industrial area was rehabilitated into a green Olympic village (Davidson, 2013). Such transformations bring eco-friendly activity spaces into the community. In 2012, London Olympic Park rehabilitated polluted land and rivers, which drove local economic development (Daothong and Stubbs, 2014).

However, most existing studies have focused on analyzing the social, economic, or ecological impacts of major sporting events (Makropoulou, 2017). For instance, Ying Gu, Deyi Hou, and Uribe-Castañeda discussed the impact of sports field construction on urban space regeneration (Gu and Zhang, 2015), sustainable development (Deyi et al., 2015), and ecosystem restoration (Uribe-Castañeda et al., 2018). First, evaluation of the synergistic and integrated impacts on social, economic, and ecological aspects is still lacking. Second, as a special land type, the renewal of coastal polluted zones has not been sufficiently discussed in this context. Finally, most of the study methods were either theoretical analysis before a major event or the evaluation of effects afterward. Thus, there is a gap in the spatial and temporal analysis of the renewal process driven by major events. The present study is based on the viewpoint of NbS theory and focuses on the sustainable development of polluted coastal zones driven by major events, as well as the social-economic development brought about by ecological restoration. This study concentrates on how major events, specifically major sporting events, influence the social-economic-ecological renewal-driving potential of polluted coastal zones. The study case was the renewal of the polluted coastal zone in the area around Dalian Barracuda Bay Stadium driven by the Asian Cup. The entropy weight method was applied to evaluate the benefit
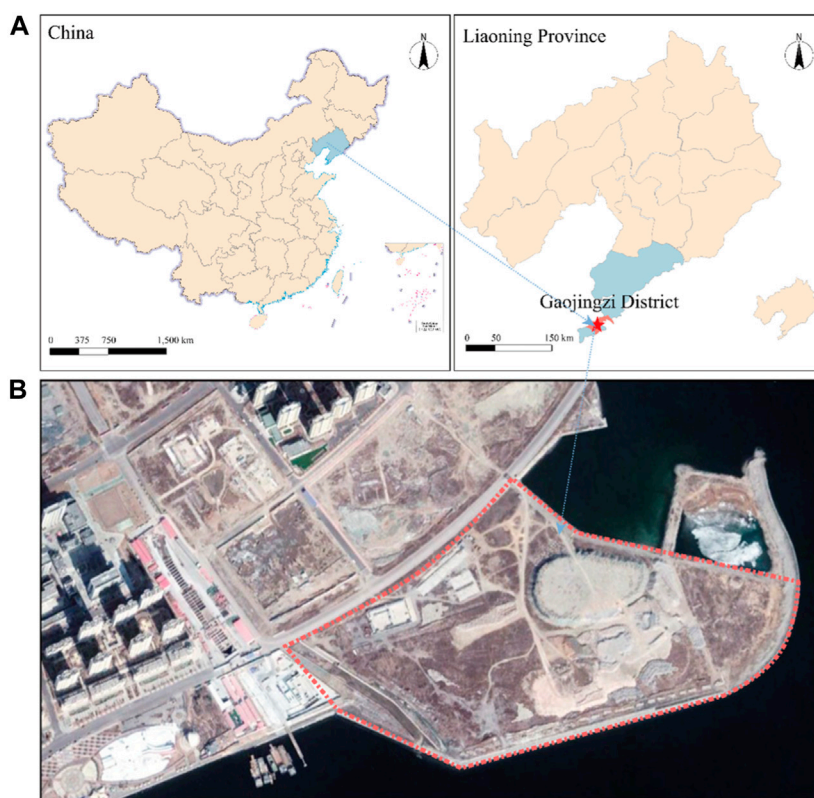
FIGURE 1
Location map of the polluted coastal zone of Dalian Barracuda Bay Stadium and its condition in 2018. Picture **(A)**—Author. Orthophoto **(B)**—GoogleEarth (2018).
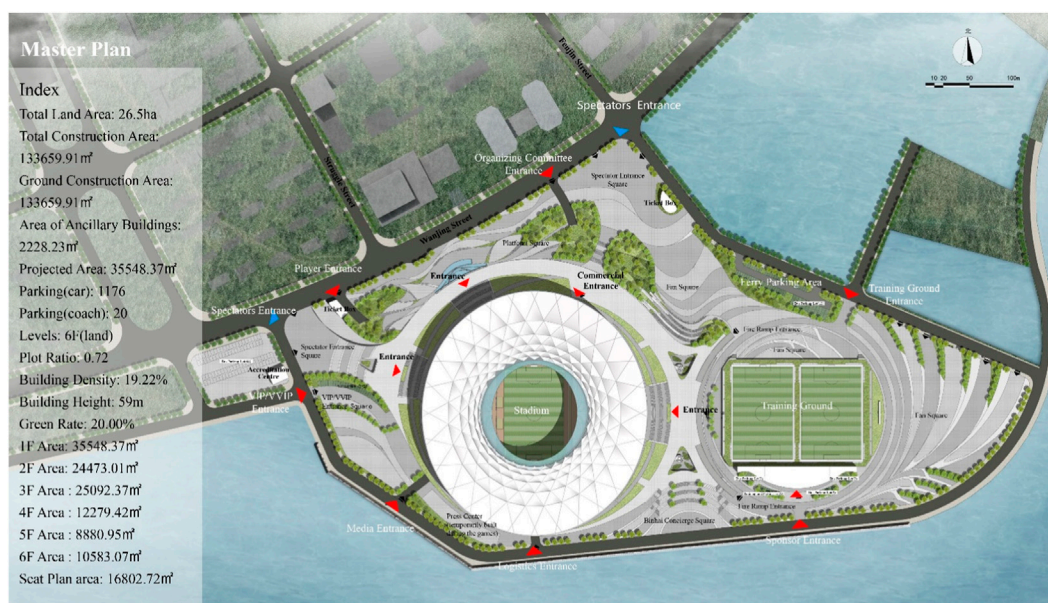

FIGURE 2
Overall layout of the polluted coastal zone of Dalian Barracuda Bay Stadium. Source: Author.

FIGURE 3
Renewal progress of the polluted coastal zone. Source: Author.
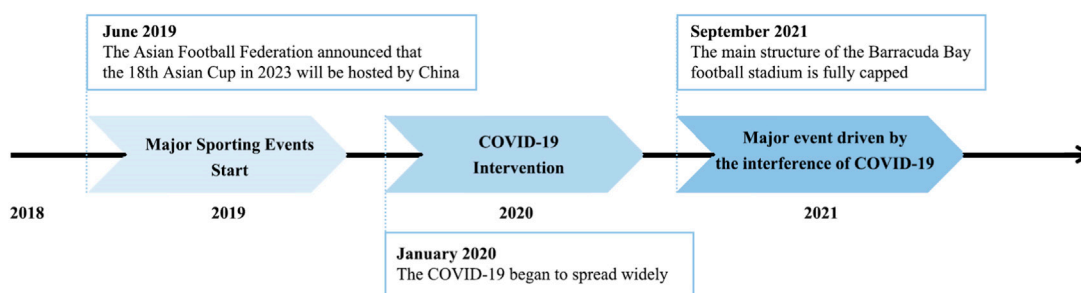

FIGURE 4
Timeline of polluted coastal zone renewal. Source: Author.

of the polluted coastal zone renewal and provide optimization methods for the renewal of the polluted coastal zone in the Dalian Barracuda Bay Stadium area, which is still in process. Such optimization methods directly help engineering practice by applying the research conclusion.

2 Overview of the research area

As shown in Figure 1, the Dalian Barracuda Bay Stadium is located in the polluted coastal zone in Ganzijing District, Dalian City, Liaoning Province, China. This polluted coastal zone is a land reclamation area built in 2000. Since then, chemical, steel, and shipbuilding industries have occupied the coastline area. The traditional industries severely hindered the city's coastal view, leaving much land deserted, undeveloped, and of low economic value. Because the reclaimed land included industrial waste, the soil and groundwater were heavily polluted. In addition, the accessibility and the continuity of the close water shoreline were cut off, and residents' requirements for the close water shoreline were not met. With the opportunity of hosting the 2023 Asian Cup in China, the polluted coastal zone of Barracuda Bay Football Stadium was renewed and renovated. By 2021, the local social, economic, and ecological value was effectively improved, as shown in Figures 2, 3.
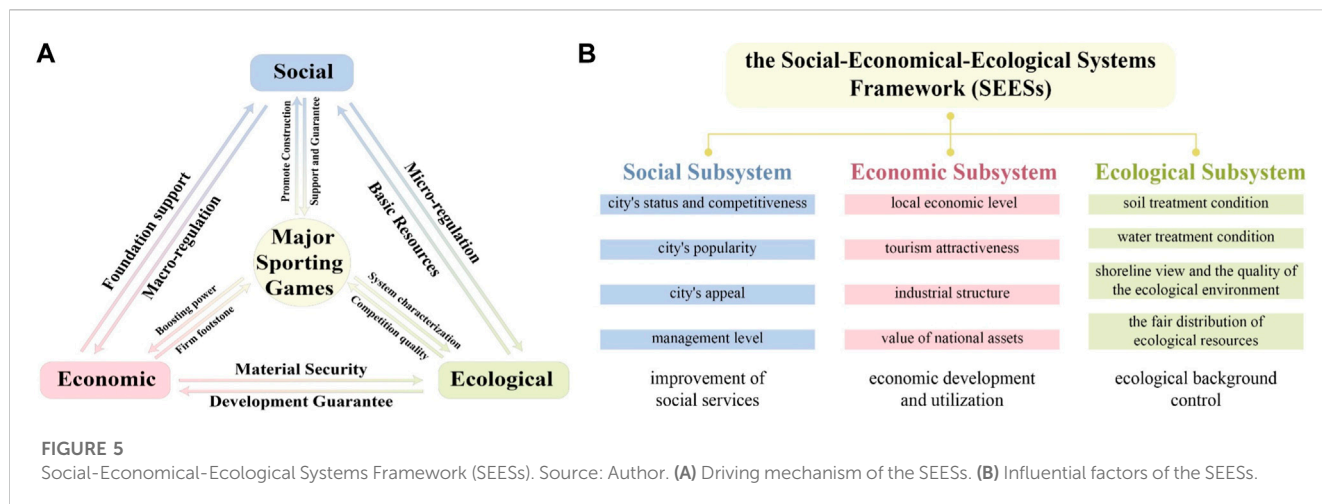
The renewal of the polluted Dalian Barracuda Bay Stadium coastal zone had characteristics typical of other renewal cases driven by major sporting events. For example, the approach was top-down, and the renewal had a synergistic boosting effect on the social,

economic, and ecological benefits. Studying the mechanism of this case could provide a universal solution for polluted coastal zone renewal cases driven by major events. However, this case was also unique: the progress of renewal has encountered the global pandemic, as shown in Figure 4. Therefore, by studying this case, we could further analyze how major event-driven region renewal reacts under negative outside influences. Moreover, we can further understand its potential to resist risk and provide solutions for potential black swan events during the renewal process, such as pandemics, wars, or strikes.

3 Methodology

3.1 Building the major event-driven SEESs

In 2015, a multidisciplinary team of experts led by the European Commission defined NbS as "nature-based and nature-dependent solutions that address diverse challenges in a resource-efficient and adaptive manner while ensuring economic, social, and ecological benefits" (Wang et al., 2022). This team emphasized that the goal of NbS is to achieve integrated economic, social, and ecological benefits. However, current research on the application of NbS to the resilience of coastal areas still focuses on the exploration of techniques for ecological restoration, such as coastal renewal (Liu et al., 2021) and adaptation to climate change (Donatti et al., 2022), and lacks research on the NbS goal of achieving integrated social, economic, and ecological benefits with rapid, effective, and durable

FIGURE 5
Social-Economical-Ecological Systems Framework (SEESs). Source: Author. **(A)** Driving mechanism of the SEESs. **(B)** Influential factors of the SEESs.

NbS implementation methods and safeguard measures. While defining the three criteria of NbS, namely, achieving social, economic, and ecological benefits, Alber proposed that the NbS framework should be continuously improved and iterated by integrating economics and sociology (Albert et al., 2017). Therefore, the present paper was centered around achieving comprehensive benefits through NbS theory and establishing a Social-Economic-Ecological Systems Framework (SEESs) for polluted coastal zone renewal driven by major events. Additionally, this study aimed to enhance the synergistic improvement of social, economic, and ecological benefits, as well as urban renewal, in the process of ecological restoration in coastal polluted zones. It did so by introducing major events with an obvious driving focus on social policies, support for circular economy practices, urban space reconstruction, and improving environmental quality. Moreover, this study explored and addressed the practical challenges in the application of NbS, specifically insufficient support and ineffective performance guarantees. This study refined and updated the theoretical framework and practice process of NbS. Meanwhile, based on the theoretical framework of social-ecological systems (SESs) (Epstein, 2013), we incorporated the economic subsystem since major events always bring substantial economic benefits to form the SEESs. Finally, by evaluating the synergistic benefits of the social, economic, and ecological aspects, we proposed an evaluation index for the polluted coastal zone renewal driven by major events. The entropy weight method was applied to calculate the weights of the social, economic, and ecological subsystems and clarify their interaction relationships. By doing so, we uncovered the driving mechanisms behind social, ecological, and economic renewal in coastal zones within the context of major sports events, and discovered the key factors for coastal renewal.

The SEES framework is divided into three subsystems: social, economic, and ecological. Figure 5A reflects the interactions between these three subsystems and with major sporting games. First, the government regulates and supports major sporting games; thus, social development is beneficial for securing the bid and hosting major sporting events (Zhang et al., 2015). Meanwhile, hosting games could also reversely drive social development (Solberg and Preuss, 2007). Second, one of the necessary

conditions for a successful major sporting event is sustained economic growth in the hosting city. Third, major sporting events can boost urban space reconfiguration, enhance ecological restoration, and improve the environmental quality in polluted coastal zones. The local environment would have a direct impact on the quality of the event. In conclusion, at the social level, the government promulgates policies and systems to macro-regulate the market economy and micro-regulate the ecological environment. The joint force pushes local industry transformation and boosts the sustainable development of the economy and environment. At the economic level, economic growth is the foundation of social progress since it could support ecological compensation and restoration. At the ecological level, a good ecological environment provides essential natural resources for a society to progress and protects the sustainable development of the economy.

We show the Social-Economical-Ecological Systems framework (SEESs) in Figure 5B. For the social subsystem, the impact of the major sporting game reflects the city's status, competitiveness, popularity, appeal, and management level. For the economic subsystem, the impact of the major sporting game reflects the local economic level, the attractiveness for tourism, the industrial structure, and the value of national assets. For the ecological subsystem, the impact of the major sporting game reflects the soil and water treatment condition, the shoreline view, the quality of the ecological environment, and the fair distribution of ecological resources.

3.2 Selecting the evaluation index for major event-driven coastal renewal

Based on the SEES framework, we proposed a coastal renewal evaluation system under the impact of major sporting events. This evaluation system included three subsystems and 12 indexes. Among those indexes, soil contamination and groundwater contamination were negative indexes, while the others were positive.

The social subsystem indexes were selected based on the following facts and research results. 1) The City Brand Development Index (CBDI) proposed by the Chinese Academy of Social Sciences and reflects the city's status and competitiveness (Warren et al., 2021). 2) City Attention Index

TABLE 1 Evaluation index and data sources. Source: Author.

	Subsystem	Evaluation index	Index representation	Data resource
SEESs Evaluation System	Social	The City Brand Influence Index	City status and competitiveness	China City Marketing Development Report (Chinese Academy of Social Sciences)
		City Attention Index	Attention on a city and its popularity	
		Region population density (person/km²)	Attractiveness of a city	Dalian Statistical Yearbook
		Sound public policy (number)	Policy management level	Official website of the People's Government of Dalian Municipality
	Economic	Tourism revenue (10,000 yuan)	Appeal to tourism	Dalian Statistical Yearbook
		Regional GDP (10,000 yuan)	Local economic development level	Ganjingzi Yearbook
		Value-added of the tertiary industry (10,000 yuan)	Industrial structure	
		Fixed assets value (10,000 yuan)	Infrastructure, job opportunities, and land value	
	Ecological	Soil contamination level (mg/kg)	Soil pollution control	Project geotechnical engineering investigation report and the pollution control report
		Groundwater contamination level (mg/kg)	Water pollution control	
		Green Area Ratio (%)	Coastal landscape appearance and ecological quality	Historical satellite maps of Google Earth
		Accessibility of coastal shoreline (person/day)	Equality of Ecological resource	

(CAI) reflects a city's popularity gained by publicity (Barclay and Berkes, 2014; Walke et al., 2013; Ban et al., 2017). 3) Region population density was selected to represent the city's attractiveness since the major sporting event could improve the local infrastructure and life quality and attract more full-time residents (Lopez-Jimenez,2022). 4) Related policies must be gradually polished and improved to ensure a successful event. Hence, the management level was represented by the soundness of football-related policies in Dalian City (Refulio-Coronado et al., 2021).

The economic subsystem indexes were selected based on the following facts and research results. 1) Since major sporting events could drive tourism development and attract many tourists, we used tourism revenue to represent travel attractiveness (Calero and Turner, 2020). 2) The local gross domestic product (GPD) could directly represent a region's overall economic development at a specific time. 3) Because the event will promote the progress of modern service industries and optimize the industrial structure, the value-added of the tertiary industry was selected to reflect the industrial structure (Li, 2019). 4) The influences of major sporting events on infrastructure, job opportunities, and land value were represented by the fixed-asset value.

The ecological subsystem indexes were selected based on the following facts and research results. (1 & 2) Since the polluted coastal zone of Dalian Barracuda Bay Stadium has heavy soil and groundwater metal pollution caused by industrial waste as a reclamation material, the heavy metal levels in the soil and groundwater were selected to reflect the ecological pollution situation. 3) The improvement in the coastal shoreline's landscape appearance and ecological quality can be characterized by its Green Area Ratio. 4) The accessibility of the coastal shoreline could represent the conveniences of ecological benefits to a certain extent (Tongfei and Jianjun, 2013), thus representing the fairness of ecological resource distribution. This index could be calculated from the traffic capacity within 3 km. The data sources for the aforementioned indexes are shown in Table 1.

3.3 Determining the objective weights of the evaluation indexes using the entropy weight method

The renewal of polluted coastal zones driven by major events is a complex process. This paper used the entropy-weight method to allow objective weighting of the indexes. The concept of entropy was

originally proposed in thermodynamics; later, Hwang and Yoon introduced entropy into social science and established the entropy weight method based on research from L. Boltzmann and C. Shannon (Hwang and Yoon, 1981). Information entropy measures the degree of chaos in a system. It can determine the amount of useful information in the given data (Meng, 1989). Therefore, the entropy weight method is an objective method for determining weights. In the entropy weight method, the lower the index entropy, the more information the index has; thus, it should have a higher weight (Jin et al., 2022). The calculation functions for the weight of indexes are as follows.

3.3.1 Index standardization

Since both positive and negative indexes were exited and each index had different dimensions and units, standardization was performed to non-dimensionalize the data before weighting.

When the index was positive, the standardization function was

$$x'_{ij} = \frac{x_{ij} - x_j{}^{min}}{x_j{}^{max-j{}^{min}}}.$$

When the index was negative, the standardization function was

$$x'_{ij} = \frac{x_j{}^{max-ij}}{x_j{}^{max-j{}^{min}}},$$

where $x_j{}^{max}$ represents the maximum value of the index j, x_{ij} represents the data of index j from sample i, and x'_{ij} represents the standardized data of index j from sample i.

After standardization, some indexes appeared to be zero. For convenience in calculation, we shifted the standardized data to eliminate this situation.

$$x''_{ij} = H + x'_{ij}$$

where H is the shift value, generally set to 0.001, and x''_{ij} represents the shifted data of index j from sample i.

3.3.2 Index entropy and difference coefficients

The calculation of the entropy of the index j is as follows:

$$e_j = -\frac{1}{\ln n} \sum_{i=1}^{n} y_{ij} \ln y_{ij}.$$

The calculation of the difference coefficient of the index j is as follows:

$$g_j = 1 - e_j,$$
$$j = 1, 2, \cdots\cdots p.$$

3.3.3 Index weights and weighted scores

The calculation of the weight of the index j is as follows:

$$\omega_j = \frac{g_j}{\sum_{j=1}^{p} g_j},$$
$$j = 1, 2, \cdots\cdots p,$$

where ω_j is the weight. Thus, an index with a larger ω_j contains more information and plays an important role in the evaluation system.

The index evaluation score was obtained by multiplying the standardized index data by the weights. Summing the scores of indexes in a subsystem provided the corresponding score; similarly, summing the scores of all subsystems provided the overall score.
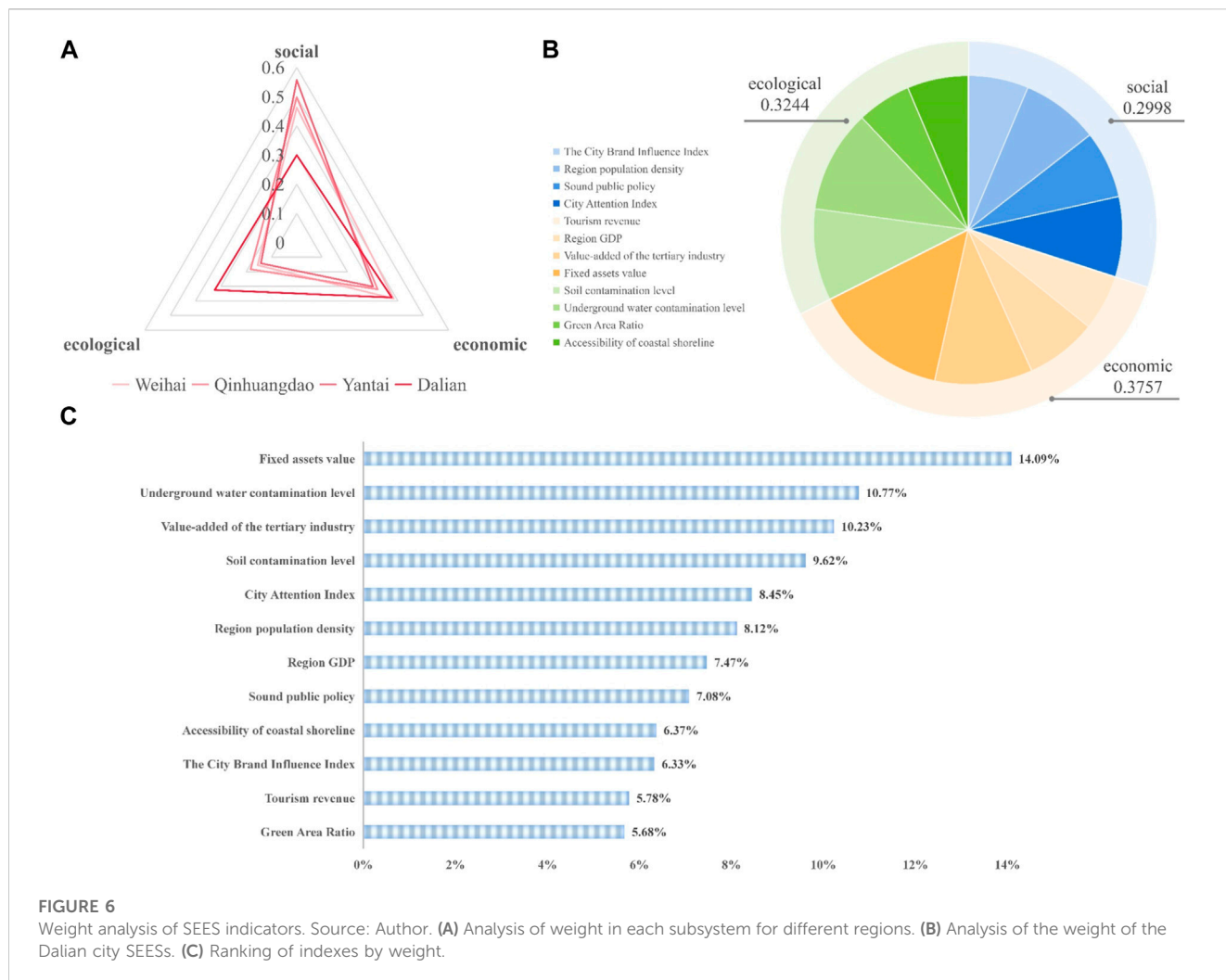
$$Z_i = \sum_{j=1}^{p} \omega_j x'_{ij}$$

4 Results and discussion

4.1 Analysis of the weights of the evaluation indexes

We analyzed the weight of each SEESs indicator. First, a weight analysis was conducted on the three subsystems of the SEESs, and Weihai, Qinhuangdao, Yantai, and Dalian were selected as research objects. As shown in Figure 6A, except for Dalian city, the cities of Weihai, Qinhuangdao, and Yantai, which, together with Dalian city, also belong to the Bohai Economic Rim, were selected to analyze the balance of weight distribution. After calculating the weight of indexes for all four cities, the results indicated that the social and economic subsystems of Weihai, Qinhuangdao, and Yantai, which did not have major sporting events during the study period, showed much higher weights than the ecological subsystem, and that the weight distribution was not balanced. In contrast, the weights of Dalian city's social, ecological, and economic subsystems were effectively balanced under the context of hosting major sporting events. The shape of the weights was similar to a positive triangle, and the differences between the three subsystems were insignificant. These results indicated that the major event could drive the three subsystems to reinforce each other, and that economic and social improvements could become the engines for ecological system renewal.

Furthermore, we conducted weight analysis for the three subsystems of the SEESs in Dalian. As shown in Figure 6B, the weights of Dalian's social, economic, and ecological benefits were 0.2998, 0.3757, and 0.3244, respectively. Economic benefit had the largest weight, which indicated that economic benefit was the main contributor to the renewal outcome, and that the major sporting event significantly impacted the improvement of the regional economy. Ecological benefits accounted for the second largest weight, only slightly lower than that for economic benefits (0.0513 less), indicating that ecological benefits have also changed considerably due to the major event. In particular, the pollution issue in the polluted coastal zone was dramatically improved. The social benefits accounted for the smallest weight. This ranking may be because the Asian Cup was initially scheduled for 2023 and is still an ongoing event. Therefore, it has not yet reached the peak of social benefits.

Finally, we ranked the 12 indicators of the SEESs according to their weight. According to Figure 6C, we ranked 12 indexes by their weight. Among all indexes, the value of the fixed assets has the most prominent weight at 14.09%. This indicated that major sporting events have a significant role in creating jobs, expanding production scales, and promoting land value in the coastal region. Groundwater and soil contamination levels ranked second and fourth. Groundwater and soil pollution control are beneficial for maintaining

FIGURE 6
Weight analysis of SEES indicators. Source: Author. **(A)** Analysis of weight in each subsystem for different regions. **(B)** Analysis of the weight of the Dalian city SEESs. **(C)** Ranking of indexes by weight.

watershed ecology and a normal hydrological cycle, and pollution remediation is a critical result of polluted coastal zone renewal. The value-added of the tertiary industry (10.23%) ranked third, indicating that the city could utilize the change of hosting a major event to transform the industrial structure and create a modernized service industry. The CAI and regional population density showed average weights, indicating that major events could affect the city's media publication, popularity, and livability. In contrast, the Green Area Ratio (5.68%) and the tourism revenue (5.78%) had the smallest weights among all indexes. The reason behind these insignificant weights could be that the change in landscape view requires time and that tourism was heavily affected by the global pandemic.

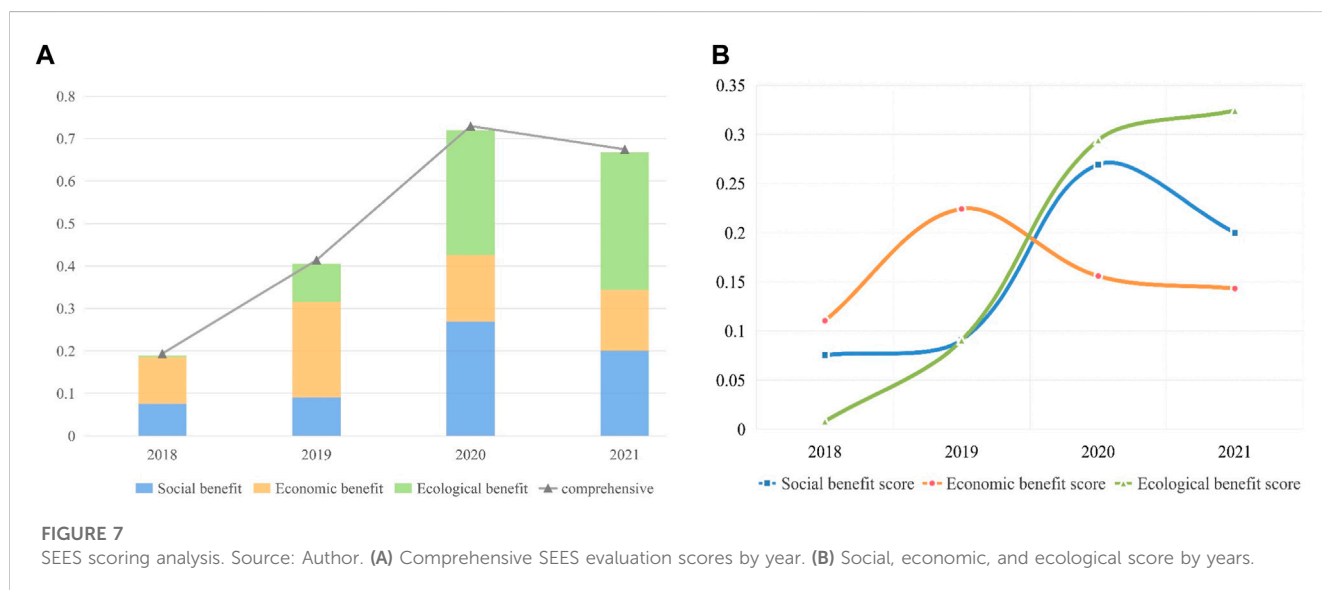## 4.2 Analysis of annual comprehensive scores

Based on the aforementioned weight analysis, we evaluated the annual comprehensive scores of the three subsystems. First, we summarized the trend of the comprehensive scores and calculated the weight of the three subsystems. Based on the annual scores of the three subsystems of the SEESs, we summarized the annual score trend for each subsystem. According to Table 2 and Figure 7A, the

comprehensive score first showed an increasing and then a decreasing trend over the 4 years. The score was at its lowest in 2018; with the stimulation of the Asian Cup between 2019 and 2020, the comprehensive scores rose significantly. The scores peaked in 2020, then decreased slightly in 2021; however, the score overall increased in the 4 years. This finding indicated that the introduction of the major event played a considerable role in improving the comprehensive score; however, after the heat decreased and the pandemic, the comprehensive score decreased slightly. Overall, the score was still greatly improved compared with 2018. Therefore, major events could benefit from resisting negative impacts encountered during renewal.

Based on the annual score of the three subsystems of the SEESs, we summarized the annual score trends for each subsystem. As shown in Figure 7B, the economic benefit score was the main contributor to the comprehensive score in 2018–2019, while the ecological and social benefits became dominant in 2020–2021. The economy showed a considerable boost after 2018 and the economic benefit scores peaked in 2019. The social and ecological benefits scores start to grow significantly after 2019, indicating that major events rapidly contributed to economic benefits and increased ecological and social benefits. The growth of the economy could

TABLE 2 Annual comprehensive scores. Source: Author.

Year	Social benefit score	Economic benefit score	Ecological benefit score	Comprehensive score	Rank
2018	7.77	11.28	0.32	19.37	4
2019	9.23	22.8	9.38	41.41	3
2020	27.23	15.97	29.75	72.94	1
2021	20.25	14.47	32.76	67.48	2

FIGURE 7
SEES scoring analysis. Source: Author. **(A)** Comprehensive SEES evaluation scores by year. **(B)** Social, economic, and ecological score by years.

also motivate increased ecological and social benefits. After 2019, a downward trend in economic benefits was quite apparent; after 2020, the social benefits decreased. However, the ecological benefit always showed a stable growth trend, increasing from 0.32 points in 2018 to 32.76 points in 2021. These results showed that the ecological enhancement from the major event was continuous and highly efficient even under the influence of the pandemic.

4.3 Changes in index scores

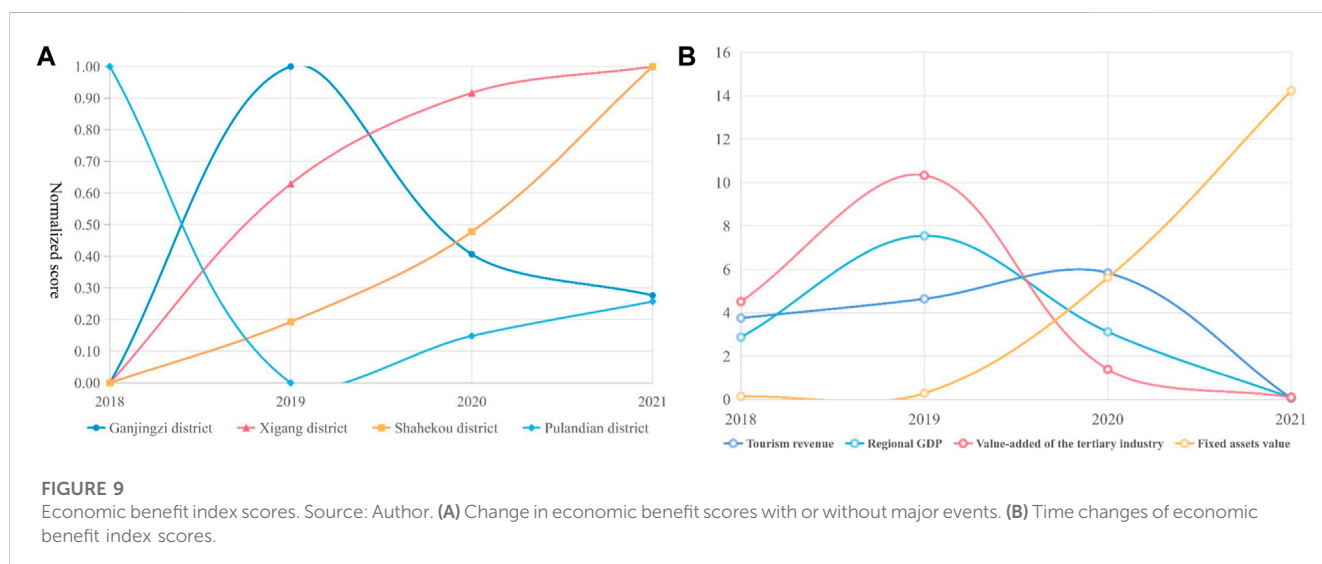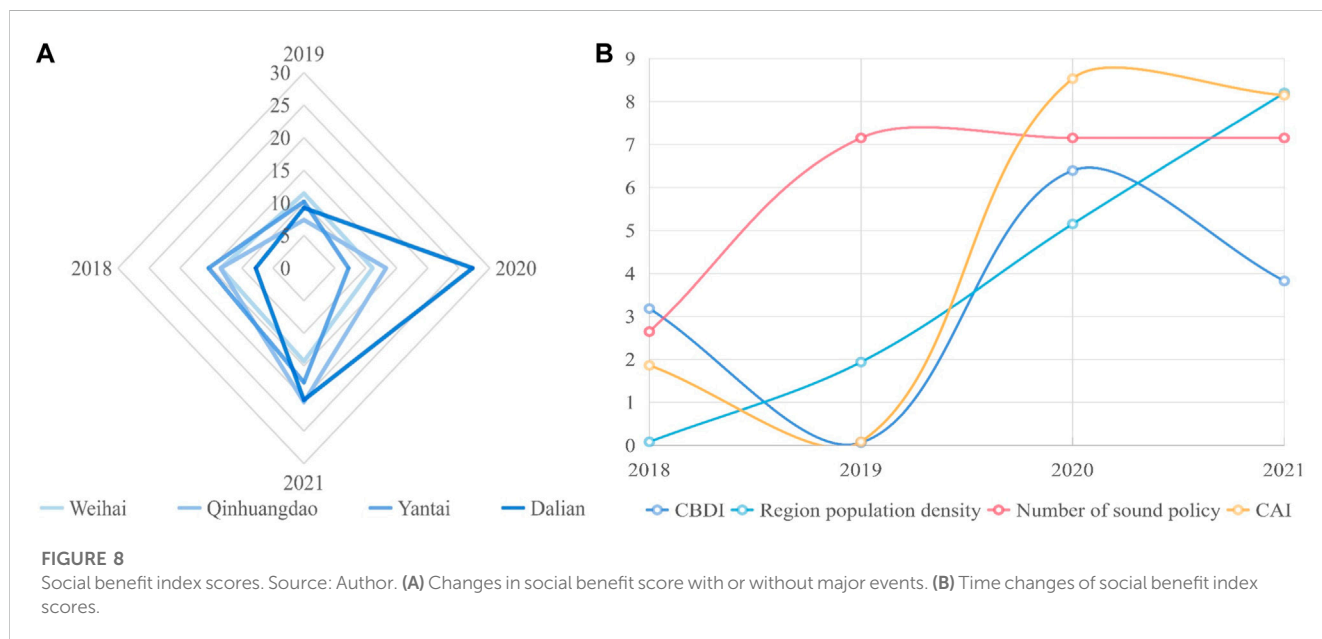### 4.3.1 Social benefit indexes

To further understand the ecological benefit scores, we analyzed changes in social benefit scores in Weihai, Qinhuangdao, Yantai, and Dalian with or without the involvement of major events. According to Table 3 and Figure 8A, compared with other cities in the Bohai Economic Rim, such as Yantai, Weihai, and Qinhuangdao, the social benefit of Dalian city was not outstanding in 2018. However, with the Asian Cup as the motivator, this social benefit has gradually increased since 2019, showing a surge in 2020 (at 27.230 points), and exceeded other cities. This indicated that a major event strongly motivates improved social benefits during polluted coastal zone renewal. Meanwhile, the relevant policies have been improved; the resident population continues to grow; and the CBDI, the CAI, and the attractiveness and livability of the city have also been improved.

We rated the annual social benefit based on the four indicators of the social subsystem. According to Table 3, the CBDI was 0.423 in 2019, slightly decreased compared to 2018, rose to 0.492 in 2020, and decreased again in 2021. In addition, the region's population density has steadily grown, with a significant increase in 2020 at a rate of 3.8%. Moreover, the change in CAI was most noticeable after 2019, rapidly pulling up after hitting 0.398 in 2019 and peaking at 0.617 in 2020. Regarding football-related policies, the number first increased in 2019 and started to decline in 2021. In 2018–2019, the soundness of football-related policy increased before the CBDI and the CAI in the run-up to the major events. These findings proved that the major event driven-renewal had a policy-driven, top-down nature.

We analyzed the annual social benefit scores and trends of the four indicators of the social subsystem. From Figure 8B, the CBDI and the CAI scores were low in 2019, and the 7 points from the policy soundness became the primary contributor to the improvement of the city's social benefit. In 2020, the CAI and the CBDI peaked, the score for regional population density increased rapidly, and the rise of policy soundness leveled off. In 2021, except for the population density score, the scores for the three indexes decreased. However, they still showed significant improvements compared to 2018. In summary, the motivation from major events on the CBDI and the CAI improved significantly since the announcement that Dalian would be one of the host cities for the Asian Cup in 2019, but it decreased slightly after 2020. In the four-year research period, the overall trend showed intermittent growth.

TABLE 3 Social benefit score. Source: Author.

Year	City brand influence index	Region population density (person/km^2)	City attention index	Number of sound policies	Social benefit score
2018	0.457	1964	0.444	24	7.77
2019	0.423	2009	0.398	31	9.24
2020	0.492	2087	0.617	31	27.23
2021	0.464	2161	0.607	20	20.25

FIGURE 8
Social benefit index scores. Source: Author. **(A)** Changes in social benefit score with or without major events. **(B)** Time changes of social benefit index scores.

FIGURE 9
Economic benefit index scores. Source: Author. **(A)** Change in economic benefit scores with or without major events. **(B)** Time changes of economic benefit index scores.

4.3.2 Economic benefit indexes

To further understand the ecological benefit scores, we analyzed their changes in Weihai, Qinhuangdao, Yantai, and Dalian with or without the involvement of major events. As shown in Figure 9A, to highlight the spatial and temporal trends of economic benefits during 2018–2021, we normalized the economic benefit scores by mapping the data of Ganjingzi district, where the studied project is located, and other districts in Dalian city (Xigang district, Shahekou

TABLE 4 Economic benefit score. Source: Author.

Year	Tourism revenue (10,000 yuan)	Regional GDP (10,000 yuan)	Value-added of the tertiary industry (10,000 yuan)	Fixed assets value (10,000 yuan)	Economic benefit score
2018	1280	9062487	4428431	2328341	11.28
2019	1440	9812749	4712304	2332189	22.803
2020	1657	9102260	4276274	2473179	15.97
2021	610	8613596	4213293	2700999	14.47

district, and Pulandian district), where no major events have occurred, to the range of 0–1. Comparative analysis showed that the economic growths of Xigang District and Shahekou District were relatively stable. Moreover, the economy in Pulandian District showed a continued decline. In contrast, the economy in Ganjingzi District had a crest in 2019, which proved that as an urban catalyst, major events significantly stimulated the regional economy even in the early stage.

We rated the annual social benefit based on the four indicators of the economic subsystem. According to Table 4, the trend of the value-added of the tertiary industry was similar to that for the regional GDP. Tourism attractiveness improved slightly after 2019 and declined sharply after 2020 due to the global pandemic, with a decline of 63%. However, the value of the fixed assets showed a consistent upward trend under the impact of COVID-19, with a growth rate of up to 6%. The comprehensive score of the economic subsystem first increased and then decreased but was still higher than the score before the major event stimulation in 2018. In summary, major event stimulation could resist the economic downturn caused by the epidemic, and the primary contributor was the value of fixed assets.

We analyzed the annual social benefit scores and trends of the four indicators of the economic subsystem. From Figure 9B, in 2019, the highest economic index was the value-added of the tertiary industry. According to the data source, the ratio of the primary, secondary, and tertiary industries in Dalian city was adjusted from 1: 52:47 to 1:50:49. The scores for the fixed assets then climbed significantly in 2020 and 2021 and became the primary contributor to the economic score. The results showed the undeniable advantage of a major event for upgraded industrial structure in the early stages. This impact could be an opportunity to break the dilemma of relying on a single mainstay industry. During the process of a major event, along with the continuous optimization of the industrial structure, the event's roles of expanding productivity, creating job opportunities, and increasing land value becomes more prominent.

4.3.3 Ecological benefit indexes

To further understand the ecological benefit scores, we analyzed changes in ecological benefit scores in Weihai, Qinhuangdao, Yantai, and Dalian with or without the involvement of major events. As shown in Figure 10A, three plots in the Ganzijing District, Dalian City's polluted coastal zone, were selected for comparison. Plot A is the site of Dalian Barracuda Bay Stadium, while Plots B and C are reclamation land next to Plot A. As the project site, Plot A started to manage its ecological environment in 2019. Since then, the ecological environment has significantly improved from 2019 to 2021. Because of the success of

Plot A's ecological management, the ecological benefit scores of Plots B and C's also increased, with similar trends as Plot A in 2020 and 2021. This indicated that pollution treatment became effective and rapid when the city had the opportunity to host a major event. In addition, the ecological improvement in one plot will improve the ecological benefits of the surrounding areas, leading to an expansion in the renewal scale.

We rated the annual social benefit based on the four indicators of the ecological subsystem. From Table 5, in the four-year research period, the soil and groundwater contamination conditions gradually reduced from exceeding the standard by 1.4-fold and 21-fold to numbers within the pollution limits. Then, the Green Area Ratio increased yearly as the shoreline landscape improved. Moreover, the two newly constructed subway lines (#4 and #5) and the two new transit bus lines (#811 and #812) enhanced the transportation network around the project and improved the accessibility and fairness of access to the coastal shoreline. With the continued development of the polluted coastal zone of the Dalian Barracuda Bay Stadium, the score would be further improved.

We analyzed the annual social benefit scores and trends of the four indicators of the ecological subsystem. According to Figure 10B, the index with the highest score in 2019 is the Green Area Ratio. However, the increasing rate of the Green Area Ratio slowed at a later stage. Moreover, in 2020, the effect of environmental restoration started to emerge, and soil and groundwater contamination treatment became the main contributor to the ecological benefit score. The results showed that as an implanted production process, a major event could promote the reconfiguration of urban spaces and the restoration of the ecological system at an early stage. However, the outcome of ecological system restoration always lags and takes time to cultivate. The benefit would maintain a steady development over time and become more noticeable.

4.4 Optimization method for the renewal of polluted coastal zones driven by major events

Major sporting events play a significant role in enhancing the comprehensive benefits of the polluted coastal zone and have synergistic boosting effects on the renewal of social, economic, and ecological benefits. Major events can also resist negative impacts, such as pandemics and strikes, during the renewal process. By discussing the weights of the evaluation indexes, the annual comprehensive scores, and trends in index scores, this paper provides a method for the renewal of polluted coastal zones driven by major events and solutions for potential black swan events during the renewal process, including pandemics, wars, or strikes.
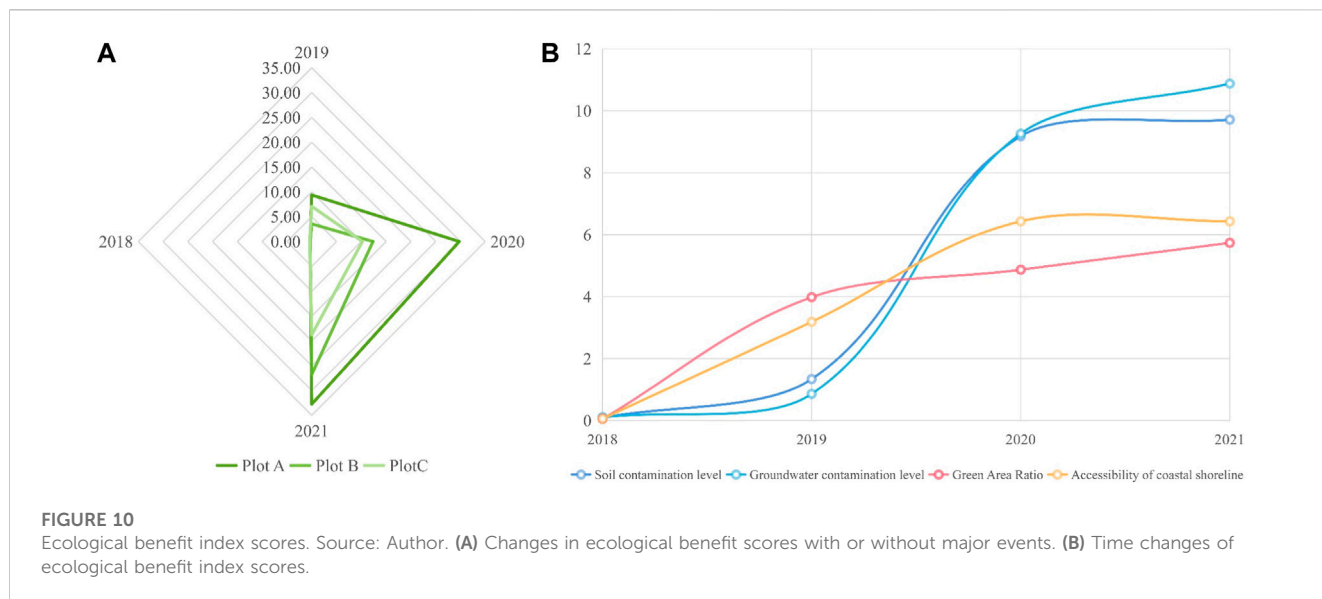
FIGURE 10
Ecological benefit index scores. Source: Author. **(A)** Changes in ecological benefit scores with or without major events. **(B)** Time changes of ecological benefit index scores.

TABLE 5 Ecological benefit score. Source: Author.

Year	Soil contamination level (mg/kg)	Groundwater contamination level (mg/kg)	Green area ratio (%)	Accessibility of the coastal shoreline (person/day)	Ecological benefit score
2018	27.96	1.05	32.23	434920	0.32
2019	26.80	0.98	37.22	481360	9.38
2020	19.50	0.20	38.35	529560	29.75
2021	19.00	0.05	39.45	529560	32.76

4.4.1 Social benefit characteristics and optimization

(1) Directional: Renewal processes driven by major events are conducted top-down and directed by policy. Therefore, the government should focus on the motivation of policy soundness and improving football-related policy during the preparation and early stages of an event. In summary, the optimization should start with building a policy system led by the government, conducted by the association, and supported by the local department, and which incentivizes the involvement of the whole society. Such a system ensures the development and operation of infrastructure and sets a foundation for improving the social benefit in the polluted coastal zone.

(2) Intermittence: The major event could intermittently pull up the CBDI and CAI. Thus, in the middle stage of the event, it is vital to dig into the city's sports culture, build sports fields, advertise fitness activities, and promote football sports to the general public. With the opportunity of a major event, a city should gradually improve its infrastructure and cumulate experience in event hosting. Moreover, the city should actively bid to host other major sporting events or non-professional leagues to create continued attractiveness for sports events and rebrand

the city as Football city. The CBDI and CAI could always stay stimulated by adopting the above suggestions.

4.4.2 Economic benefit characteristics and optimization

(1) Sensitivity: As a form of urban catalyst, major events could increase the value of the tertiary industry, optimize the industrial structure, and drive economic growth. To better respond to the Asian Cup, the city should create a sports services area in the polluted coastal zone of Dalian Barracuda Bay Stadium. By developing the sports event, fitness, and traveling industries, the project could stimulate improvements in the modern services industries in nearby areas.

(2) Risk resistance: Driven by a major event, the city could upgrade its industrial structure, expand productivity, increase job opportunities, increase fixed asset value, and resist the economic decline caused by the pandemic. The economic decline caused by the black swan event could be addressed by optimizing fixed asset investment and upgrading infrastructure. Hosting an event is an excellent opportunity to increase the economic value of the surrounding area and create job opportunities, which could supercharge the region's economic resurgence.

4.4.3 Ecological benefit characteristic and optimization method

(1) Lagging: Ecological restoration takes time. Owing to the dynamic and continuous nature of coastal ecosystem restoration, it is necessary to utilize ecological succession and self-recovery capabilities, with human-assisted interventions, to restore disturbed and damaged coastal ecosystems to, or near, their pre-disturbance state. This process requires time; thus, the results and benefits of ecological restoration always show hysteresis (Koo et al., 2011). Therefore, in the process of polluted coastal zone renewal, the city should start to upgrade its transportation system and other infrastructure. This move could improve the coastal landscape and increase the accessibility of the ecological benefits.

(2) Stability: Major events could continue to efficiently improve the ecological benefits, even with the negative influence of the global pandemic. Moreover, a major event could also improve the ecological benefits of the surrounding areas. Therefore, having a major event is a chance for the city to conduct soil and water pollution management, build coastal sports parks, and maximize the stability characteristic of the ecological benefits.

5 Conclusion

5.1 Research conclusion

The ecological restoration and sustainable management of polluted coastal zones have received the attention of many professionals. However, one critical question is how to effectively promote social, economic, and ecological system renewal, further improve the overall benefits, and enhance the resilience of polluted coastal zones.

To explore the renewal driving potential of major events on the polluted coastal zone's social, economic, and ecological aspects, this paper proposed a NbS视角下Social-Economical-Ecological Systems Framework (SEESs) and selected three subsystems and 12 indexes for evaluation. Moreover, using the entropy weight method, we constructed a system for the evaluation of the benefits of polluted coastal zone renewal driven by major events. Then, by analyzing the social, economic, and ecological weight, we summarized the advantage of polluted coastal zone renewal driven by major events.

The results proved that, driven by major sports events, the polluted coastal zone's social, economic, and ecological benefits had balanced progress, with weights of 0.2998, 0.3757, and 0.3244, respectively. Furthermore, all 12 indexes had different spatial and temporal patterns. The social benefits were more directional and intermittent, while the economic benefits were sensitive and had good risk resistance, and the Ecological benefits were stable but lagging. Based on the change characteristics of the three subsystems, we proposed optimization methods for polluted coastal zone renewal driven by major events and provided solutions to cope with the negative impact of black swan events such as epidemics, strikes, and war.

Additionally, we evaluated the changes in the scores for the polluted coastal zone of Dalian Barracuda Bay Stadium area under the impact of the Asian Cup. During the renewal process, the scores of the polluted coastal zone increased in fluctuation, with scores of 19.37, 41.41, 72.94, and 67.48. Major events will first motivate economic growth, then bring social and ecological benefits. However, the growth of economic and social benefits is subject to the impact of adverse events, such as the global pandemic, and starts to level out and decline. On the other hand, the improvement of ecological benefits is more stable.

Finally, we identified the renewal characteristics and optimization methods for the renewal of urban polluted coastal zones driven by major events and provided solutions to cope with the negative impact of epidemics, strikes, and war throughout the process.

5.2 Research contributions

This study aimed to enhance the synergistic improvements of social, economic, and ecological benefits, as well as urban renewal, in the process of ecological restoration in coastal polluted zones. It did so by introducing major events with an obvious driving focus on social policies, supporting circular economy practices, reconstructing urban spaces, and improving environmental quality. This study explored and addressed the practical challenges in the application of NbS, specifically insufficient support and ineffective performance guarantees. The results refine and update the theoretical framework and practice process of NbS, thereby providing valuable insights for future policymaking and planning in coastal area renewal.

Moreover, this paper utilized and applied NbS for its goal of achieving comprehensive benefits and establishing SEESs. Unlike the well-known social-ecological systems (SESs), this paper incorporated the economic subsystem since major events always bring substantial economic benefits. By doing so, we uncovered the mechanisms driving social, ecological, and economic renewal in coastal zones within the context of major sports events, and further provided new perspectives for effective and sustainable urban renewal and ecological restoration in coastal pollution zones.

Furthermore, we developed an evaluation method to assess the renewal of polluted coastal zones driven by major events. This evaluation method confirmed the positive role that major events play in boosting the renewal and coordinated development of the "Social-Economic-Ecological Systems" in coastal zones. It also provides a method for quantitatively studying the sustainable development and overall benefits of the ecological system. By leveraging the strong policy and continuous economic support provided by major events, we could guide the ecological restoration and sustainable implementation of urban renewal, thus serving as a valuable reference for the theoretical framework and practice process of NbS.

5.3 Research limitations

This study has several limitations since the social, economic, and ecological systems are constantly changing and are diverse, fuzzy, and dynamic. Even though this work is based on historical data and limited indexes, we could introduce the newest data in

future work and dynamically improve the accuracy of the evaluation system and the score-trend analysis.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material. Further inquiries can be directed to the corresponding author.

Author contributions

MG wrote the whole paper, collected and analyzed the data, and discussed the experimental results. QG revised the paper, and collected and analyzed the data. KY collected the data and validated the proposed method. BJ revised the paper and provided comments on the proposed method. YY proposed the research idea and provided comments on the discussion. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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