ISSN: 1648-6897 / eISSN: 1822-4199

VILNIUS TECH
Vilnius Gediminas Technical University

JOURNAL of
ENVIRONMENTAL ENGINEERING
& LANDSCAPE MANAGEMENT

2025
Volume 33
Issue 1
Pages 118–131
https://doi.org/10.3846/jeelm.2025.22941

A SDGS-ORIENTED EVALUATION OF THE ECOLOGICAL SUSTAINABILITY OF INTERNATIONAL HORTICULTURAL EXPOSITION SITES IN CHENGDU, CHINA

Biao HUANG[1, 2#], Haolin YANG[3, 4#], Kankan SHANG[3]✉, Ruoyu WANG[3, 4], Yufei MENG[1, 2],
Hongming PENG[1, 2, 5, 6]✉✉, Yonghong HU[3]✉, Zehui JIANG[1, 2, 6]✉✉

[1]Key Laboratory of National Forestry and Grassland Administration/Beijing for Bamboo and Rattan Science and Technology, Beijing, China
[2]International Centre for Bamboo and Rattan, Beijing, China
[3]Shanghai Chenshan Botanical Garden, Shanghai, China
[4]College of Landscape Architecture, Northeast Forestry University, Harbin, China
[5]Association Internationale des Producteurs de l'Horticulture (AIPH), Hague, Netherlands
[6]China Flower Association, Beijing, China

Highlights:

- the findings can be used as a model for the sustainable management of land use for site development in other green spaces around the worldwide;
- the AHP-entropy weight approach and spatial econometric regression model can be used to investigate the direct and indirect influencing elements of ecological sustainability;
- the ecological sustainability evaluation of the current state and the planning scenario can aid the planning of ecological space;
- implementing ecological sustainability assessment of land development and landscape design in mega-event processes is necessary.

Article History:

- received 25 September 2023
- accepted 16 October 2024

Abstract. This study employs the AHP-entropy weight methodology and a spatial econometric regression model to evaluate the ecological sustainability and its changes between the current situation and the planning scenario at the 2024 Chengdu International Horticultural Exposition in China. The results indicate a notable shift: a reduction in areas of low and highest sustainability and significant expansion in medium levels, which spans 34.04 hm^2. The transformation of village settlements, wastelands, and farmland into exhibition gardens and water bodies is shown to bolster medium-level ecological sustainability by enhancing rain and flood security and mitigating the risk of flood disasters. The development of Integrated Service areas will lead to an increase in impervious surfaces. The anticipated forest loss, along with declines in vegetation coverage, three-dimensional green volume, and vegetation carbon stock will adversely affect the highest sustainability. The study identifies a robust correlation between ecological sustainability level and quantitative indicators, with regression coefficients ranging from 0.5875 to 0.7148. This analysis provides policymakers with valuable insights and directions for the sustainable planning and development of mega-events.

Keywords: ecological space, habitats diversity, soil erosion intensity, sustainable development, planning scenario.

[#] These authors contributed to the work equally and should be regarded as co-first authors.

✉ Corresponding author. E-mails: *shangkankan@163.com*; *huyonghong@csnbgsh.cn*

✉✉ Corresponding author. E-mails: *penghongming@icbr.ac.cn*; *jiangzehui@icbr.ac.cn*

1. Introduction

The International Horticultural Exposition (hereinafter referred to as EXPO) promotes the urban ecological paradigm of harmonious coexistence between the city and nature (Gao, 2020). The goals of the EXPO's construction are to improve various aspects of the city, including urban regeneration, the quality of life for citizens, the natural ecosystem, the ecological environment (Wang, 2019), addressing climate change and enhancing human well-being (Reyes-Riveros et al., 2021). Meanwhile, mega-events like EXPO typically occupy a specific area of territory, consume a large number of resources and energy, and exert a significant impact on subsequent land use. Throughout the EXPO's life-cycle, the imperative of sustainable development must be addressed, taking into account economic, social, and environmental dimensions. The Liverpool EXPO in England, for instance, managed to revitalize an abandoned location while efficiently utilizing spatial resources (Clouston, 1984). Similarly, the 2006 Shenyang EXPO in

China showcased an innovative approach by collecting approximately 600 varieties of overwintering trees in the open area to realize the transformation of new cities in the ancient industrial city with "Harmonious Coexistence with Nature" (Jin & Wang, 2006). Geo-technical engineering technology and ecological engineering technology were integrated at the 2016 Tangshan EXPO in China (Guo et al., 2016). The EXPO in Beijing in 2019 and Yangzhou in 2021 have reached a new level of maturity, adhering to the the principle of "minimizing destruction of existing vegetation and protecting original trees as much as possible", thereby embodying an ecologically friendly development strategy.

In 2015, the United Nations embraced the 2030 Agenda for Sustainable Development, which includes 17 Sustainable Development Goals (SDGs) and 169 specific indicators (United Nations, 2015). These SDGs are designed with a focus on alleviating poverty and cover a diverse range of development, including environmental, economic, and social issues (Eisenmenger et al., 2020). Regarding the environment sector, a positive trend is observed, with 17% of the SDGs-oriented environmental indicators demonstrating a shift towards sustainability over the past 15 years (United Nations Environment Programme, 2019). The advancements in environmental sustainability are poised to contribute to human progress (Schröder et al., 2020). These advancements can be attributed to the expansion of terrestrial, mountain, and marine protected areas, efforts to combat invasive species, and significant progress in renewable energy (Malay, 2021).

While the significance of SDGs for human survival is widely recognized, the progress toward these objectives remains slow in most countries (Yang et al., 2020; Obaideen et al., 2022). Energy, finance, water resources, agriculture, and other sectors have been evaluated at both regional and national levels (Kuc-Czarnecka et al., 2023). A study by Estoque et al. (2021) found that the SDGs region in Europe and Northern America has the lowest land-use efficiency. Urban expansion is widely recognized as one of the most prevalent anthropogenic drivers of city development, economic output, and population density (Zhong et al., 2023). The increasing dependence on natural resources in developing countries has unfortunately resulted in significant damage to local ecosystem, environmental pollution and climate change, especially in Asian countries (Cobbinah et al., 2015; Kong & Khan, 2019). In China, although the resource-dependent cities faced severe challenges for more effective actions of both economic transformation and land consumption, the evolution of urbanization is heading toward a more sustainable and coordinated process in the implementation of 2030 SDGs (Jiang et al., 2021). Kørnøv et al. (2020) and Del Campo et al. (2020) have shown how SDGs can be used to ensure that strategic goals are taken into account in environmental assessment processes while still maintaining their essence within the traditional framework. This demonstrates a tendency to focus on positive impacts and a wide variation in how contributions to the SDGs are evaluated and presented (Boess et al., 2021). Thus, exploring the integration of SDGs in other types of evaluation processes, such as sustainability evaluations, may also provide new insights.

One approach involves establishing a framework for analyzing sustainability by collecting data on various SDG indicators and statistically assessing the sustainability and progress of different regions (Xu et al., 2020; Zhang et al., 2020). There has been substantial research on sustainability evaluation in various contexts, including global (Sarkodie, 2022), national (Zhang et al., 2021), regional (Pandey & Asif, 2022), and city (Mauree et al., 2019) levels. Academics have recently conducted thorough research on evaluating of sustainability at even smaller scales, including industrial parks (Valenzuela-Venegas et al., 2016), pilot zones (Li et al., 2021), and communities (Berardi et al., 2013). The evaluation of ecological sustainability using SDGs-oriented indicators at the scale of a mega-event site has not been reported.

The equal weight approach (van Asselt et al., 2015), the entropy weight method (Tai et al., 2020), and principal component analysis (Gatto & Busato, 2020) are the three most commonly used methodologies for sustainability assessment. It is important to note that the sustainability ratings derived from these different techniques can exhibit considerable variation. Numerous economic analysis techniques, including the ordinary least squares model, the geographical lag model, and the spatial error model, can be utilized to determine the impact of variables on changes in sustainability (Zhou et al., 2018). The spatial lag model and the spatial error model can both account for the spatial effects of the ecological service value and avoid estimation errors by incorporating the spatial matrix (Liu et al., 2019; Yoo & Ready, 2016). The ordinary least squares model, in contrast, disregards the spatial auto-correlation of the ecological service value. According to the findings of a study, the spatial lag model fits these data through spatial auto-correlation better than the spatial error model in terms of spatial auto-correlation (Zheng et al., 2021). To explore the inter-regional relationships between levels of ecological sustainability and their driving factors, employing a spatial lag model is a viable approach.

Therefore, a SDGs-oriented evaluation of the ecological sustainability of international horticultural exposition sites in Chengdu, China have been conducted. An integrated evaluation system has been established which is comprised of 14 indicators by SDGs-oriented AHP-entropy weight methodology, coupled with a spatial econometric regression model. The objectives of this study are 1) to evaluate ecological sustainability and its changes between the current situation and the planning scenario, 2) to identify its driving factors and 3) to provide guidance for sustainable development mega-events.

2. Material and methods

2.1. Overview of the study area

The Chengdu EXPO site is located in the eastern New District of Chengdu, Sichuan Province, China, along the ecological corridor of the Jiangxi River (Figure 1). Because of its subtropical location, Chengdu experiences a subtropical monsoon climate. The average annual temperature is 17.2 ºC, and the annual rainfall is 752.0 mm. In 2022, the highest temperature ever recorded was 41.4 ºC (Zhou, 2021). The amount of rainfall has increased recently and is expected to reach a total of 1404 mm in 2020. In the spring and summer, drought often occurs 65% and 90% of the time, respectively.

The gentle hills that comprise the majority of the EXPO site's topography vary in elevation from 420 to 430 meters. The Jiangxi River's width ranges from 24 to 30 meters, and its water level decreases from 418.8 meters in the west to 415.0 meters. Its soils consist of silty clay mud-stone and argillaceous rock, with a pH of 7.07 to 8.31. Its vegetation types mainly include coniferous forests, broad-leaved forests, shrub forests, and bamboo forests, as well as rice crop plantations.

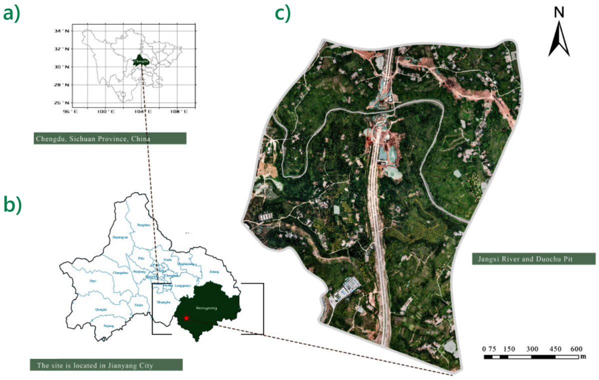


Figure 1. The location of this study site

2.2. Site planning

The site of the Chengdu EXPO has a total planning area of 242.2 hm^2. Farmland, villages, forests, water bodies, nurseries, and wasteland are different land use situations that can be distinguished thorough UAV aerial photography image interpretation and field investigation. One belt, one ring, three axes, and four groups served as the primary planning theme for the site. It consisted of six pavilions, seven districts, and 100 gardens (Figure 2). The EXPO site was divided into several partitions, including the Park City Exhibition (26.5 hm^2), the International Horticultural Exhibition (19.4 hm^2), the Tianfu Habitat Exhibition (40.2 hm^2), the Children's Dream World Park (64.2 hm^2), the Future Horticultural Exhibition (19.9 hm^2), the Chinese Horticultural Exhibition (30.3 hm^2), and the Integrated Service (41.7 hm^2).

Presently, the forest occupies the majority of the available land, with a distribution area of 110.47 hm^2, accounting for 45.61% of the total area. Farmland, nurseries, wasteland, and water bodies made up the remaining forms of land use, with proportions of 19.17%, 11.34%, 9.86%, and 3.07%, respectively. The wasteland is primarily occupied by rural roads and village settlements. Farmland accounted for 57.26% of the total reduction in land use in the planning scenario, mainly occurring in the International Horticultural Exhibition, the Tianfu Habitat Exhibition, and the Future Horticultural Exhibition. The visible increase in land use is in the water body, which has nearly tripled in size. This mainly occurred at the Children's Dream World Park, the Future Horticultural Exhibition, and the Chinese Horticultural Exhibition. The forest area also decreased to 11.99 hm^2, primarily in the Future Horticultural Exhibition and the Chinese Horticultural Exhibition. The transformation of land use in the Tianfu Habitat Exhibition is evident in its public spaces. More detailed information on land use in each partition is shown in Table 1.

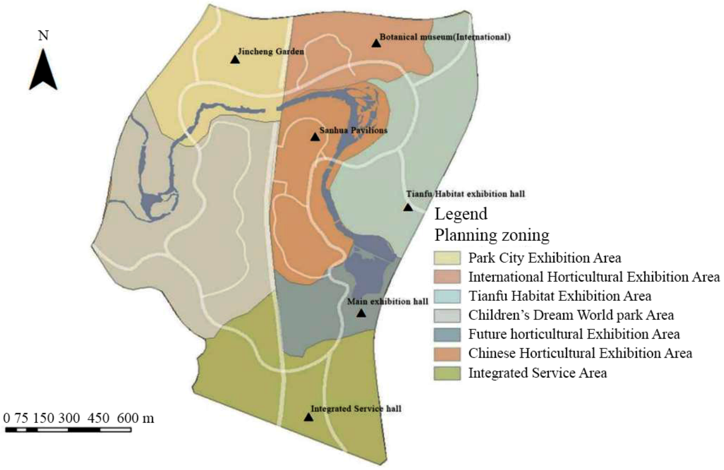


Figure 2. Planning scheme framework of the Chengdu EXPO

Table 1. Land use cover and change between current situation and planning scenario

Partitions	Current situation (hm^2)						Planning scenario (hm^2)					
	Farmland	Forest	Nursery	Village	Water body	Wasteland	Farmland	Forest	Flowers sea	Exhibition garden	Water body	Public space
Park City Exhibition	7.45	11.76	0.00	2.39	1.24	3.66	3.31	10.56	0.34	2.84	2.76	6.69
International Horticultural Exhibition	4.19	9.24	0.00	3.60	0.00	2.38	0.00	7.63	3.98	5.34	1.14	1.30
Tianfu Habitat Exhibition	13.79	16.31	0.00	7.50	1.10	1.50	0.00	15.67	0.00	11.70	2.47	10.35
Children's Dream World Park	11.29	20.35	17.36	8.11	1.05	6.04	9.99	30.41	8.58	3.47	7.17	4.58
Future Horticultural Exhibition	2.63	14.18	1.10	1.34	0.64	0.00	0.00	7.92	0.26	4.79	6.45	0.49
Chinese Horticultural Exhibition	0.58	21.76	3.49	0.52	2.35	1.60	0.00	6.44	0.99	11.79	9.58	1.50
Integrated Service	6.51	16.85	5.53	3.05	1.05	8.70	6.55	19.84	5.18	0.16	0.00	9.97
Total	46.44	110.47	27.47	26.51	7.43	23.88	19.85	98.48	19.34	40.09	29.57	34.87

2.3. Establishment of an evaluation index system

2.3.1. Indicators of sustainability

The evaluation system for ecological sustainability, which is oriented towards the Sustainable Development Goals (SDGs), contains 14 indicators across four dimensions: water ecology, biodiversity, soil protection, and site development. This system was established for comparison purposes (Table 2). In terms of water ecology, the density of the water network, the pattern of rainfall safety, and the distribution of water buffers corresponding to SDG 6.6 in SDGs 6 (Clean water and sanitation) were selected to reflect the health status of the water ecosystem and the potential impact of their planning scenario. In terms of biodiversity, habitat diversity, habitat fragmentation, vegetation cover, and naturalness of the forest network corresponding to SDG15.1, SDG15.3, and SDG15.4 in SDGs15 (Life on land), these factors were chosen to represent the protection, restoration, and promotion of sustainable use of terrestrial ecosystems. In order to reflect the ability to mitigate climate change, the following factors were chosen to represent SDG13.1 in SDGs13 (Climate action): soil protection, soil erosion intensity, flood risk intensity, drought risk intensity, and geological hazard risk intensity. In terms of site development, the intensity of landscape development, three-dimensional green volume, and vegetation carbon stock corresponding to SDG15.4 in SDGs 15 (Life on land) and SDG11.3 in SDGs 11 (Sustainable cities and communities) were selected to reflect sustainable residential planning and management capacity (Backes & Traverso, 2022). More details on the interpretation of indicators and the impact of the direction of 14 indicators are shown in Table 2.

Table 2. Evaluation index system of ecological sustainable development for Chengdu EXPO site

Dimension (code)	Indicator (code)	Indicator interpretation	SDGs	Data sources	Trend
Water Ecology (B1)	Water network density (C1)	Length of rivers per unit area, abundance of natural river resources	SDH6.6	ad	+
	Rainfall safety pattern (C2)	Influenced by extreme rainfall, topography, and land use types	SDH6.6; SDG13.1	acde	+
	Distribution of the water buffer zone (C3)	Ecological protection potential, calculated and obtained according to different corridor widths	SDH6.6	ae	+
Biodiversity (B2)	Habitat diversity (C4)	Complexity of ecological patches, Shannon index calculated by Fragstats	SDG15.5	abe	+
	Habitat fragmentation (C5)	Ratio of patch number to total area of total habitats, expressed by the complexity of spatial structure	SDG15.5	abe	–
	Vegetation cover (C6)	Percentage of vegetation cover areas, calculated by the normalized vegetation cover index (NDVI)	SDG15.1	ae	+
	Naturalness of the forest network (C7)	Relative density of natural and artificial forests	SDG15.3; SDG15.4	abe	+
Soil protection (B3)	Soil erosion intensity (C8)	Multiple factors influence soil physical and chemical properties, rainfall, topography, and vegetation cover	SDH6.6; SDG13.1	acde	–
	Flood risk intensity (C9)	Influenced by topography, flood flow, and other factors	SDG13.1; SDG15.3	acde	–

End of Table 2

Dimension (code)	Indicator (code)	Indicator interpretation	SDGs	Data sources	Trend
	Drought risk intensity (C10)	Multiple factors influence climate, rainfall, the physical and chemical properties of soil, and topography	SDG13.1; SDG15.3	acde	–
	Geological hazard risk intensity (C11)	Influenced by water-soil interaction and human activities	SDG15.3	acde	–
Site development (B4)	Intensity of landscape development (C12)	Impact of human activities on ecosystem health, determined by site planning and design of roads, exhibition areas, and activity sites	SDG11.3	ae	–
	Three-dimensional green volume (C13)	Spatial structure and ecological benefits of woodland, influenced by the development of woodland	SDG15.4	abe	+
	Vegetation carbon stock (C14)	Carbon stock and carbon sink of woodland, influenced by the development of woodland	SDG15.4	abe	+

Note: a, high-definition aerial images of 2022; b, vegetation investigation; c, Digital Elevation Model (DEM); d, official statistical records; e, overall planning scheme; +, positive direction; –, negative direction.

2.3.2. Data collection

For this study, we assembled a comprehensive data under current conditions and planning scenarios, drawing from five distinct source (as detailed in Table 2). These included the high-resolution aerial images of 2022, vegetation investigation, authoritative statistical records, Digital Elevation Model (DEM), and an overall planning scheme. The high-resolution aerial imagery was obtained through RGB drone photography. The DEM data were extracted from the AutoCAD files of the Chengdu EXPO's plant, utilizing ArcGIS 10.8 software. Within the soil protection dimension, the four indicators leveraged Normalized Difference Vegetation Index (NDVI), derived from the analysis of high-resolution aerial images using ENVI 5.3 software. Field investigations conducted in the summer of 2022, three-dimensional green volume and vegetation carbon stock per square area were obtained using the typical plot method. Additionally, information regarding water systems, rainfall, and extreme rainfall events was sourced from the literature published by Lu et al. (2021).

2.3.3. Data normalization

The 14 indicators that represent the role of ecological sustainability are expressed in Table 2. The values of each indicator should be standardized using the membership function method. The indicator presented positive direction was adopted by Equation (1), while negative direction was adopted by Equation (2), respectively.

$$y_{ij} = \frac{x_{ij} - \min\left(x_j\right)}{\max\left(x_j\right) - \min\left(x_j\right)}; \tag{1}$$

$$y_{ij} = \frac{\max\left(x_j\right) - x_{ij}}{\max\left(x_j\right) - \min\left(x_j\right)}, \tag{2}$$

where x_{ij} is the statistical value of indicator j for county i, and y_{ij} is the standardized value for x_{ij}. Max (x_j) and min (x_j) are the maximum and minimum values of the jth indicator, respectively.

2.3.4. Indicator weight determination

In general, weight allocation methods could be broadly classified into two different categories: subjective judgment and objective calculation (Tripathi & Singal, 2019). In this study, a weighted sum methodology based on the analytic hierarchy process and entropy theory (the AHP-entropy weight methodology) was proposed to identify the 14 indicators of ecological sustainability. It makes the evaluation result more accurate and objective (Xiao et al., 2022).

Firstly, the discriminant matrix was established by hierarchical analysis using Equation (3), and the weights of each factor were calculated by the sum-product method using Equation (4) and passed the consistency test (CR < 0.1), and finally, the weights of each index were obtained.

$$T_{\lambda j} = \sqrt[n]{\prod_{\lambda=1}^{n} F_{\lambda ij}} \quad (i, j = 1, 2, \ldots n); \tag{3}$$

$$W_{j1} = \frac{T_j}{\sum_{j=1}^{n} T_j}, \tag{4}$$

where $T_{\lambda j}$ represents the NTH power root of the product of each row of elements of the discriminant matrix. n is the number of evaluation indicators. $F_{\lambda ij}$ is the scalar value obtained by comparing the relative importance of the ith factor with the jth factor, and W_{j1} is the calculated factor weight.

Secondly, the information entropy (e_j) for each indicator can be obtained using Equation (5).

$$e_j = \frac{\sum_{i=1}^{n} p_{ij} \ln p_{ij}}{\ln n}, \tag{5}$$

where $p_{ij} = y_{ij}/\sum_{i=1}^{n} y_{ij}$. If $p_{ij} = 0$, then define $\lim_{p_{ij}\to 0} p_{ij}\ln p_{ij} = 0$. n is the number of units of evaluations.

The information entropy redundancy (d_j) can be obtained using Equation (6). The weight of each indicator (w_j) can be obtained using Equation (7). The aggregate index (AI) for each country can be obtained using Equation (8).

$$d_j = 1 - e_j; \tag{6}$$

$$w_j = \frac{d_j}{\sum_{j=1}^{k} d_j}; \tag{7}$$

$$AI = \sum_{j=1}^{k} p_{ij} w_j. \tag{8}$$

Thirdly, the average value obtained by the analytic hierarchy process and entropy method is taken as the comprehensive weight using Equation (9).

$$W_j = \frac{W_{j1} + W_{j2}}{2}. \tag{9}$$

2.3.5. Evaluation method

The ecological sustainability evaluation level of each indicator at different dimensions was determined by Jenks natural breaks classification method, which was arranged into different classes (Chen et al., 2013). The evaluated scores of each indicator were classified into low, medium, high, and highest levels according to the reference by Wang et al. (2022).

2.3.6. Exploration of influencing factors for ecological sustainability

Many econometric analysis models including the ordinary least squares model (OLS), spatial lag model (SLM) and spatial error model (SEM) can be used to identify influencing factors for the changes of ecosystem service value (ESV) (Zhou et al., 2018). The OLS method ignores the spatial auto-correlation of the ESV. In contrast, the SLM and SEM effectively incorporate the spatial dynamics of ESV by integrating a spatial matrix, thereby mitigating estimation biases (Liu et al., 2018; Yoo & Ready, 2016). These models, SLM and SEM, demonstrate superior performance over OLS in scenarios involving data with spatial auto-correlation. A recent study by Zheng et al. (2021) indicates that the SLM provides a more accurate fit compared to the SEM. Consequently, all data processing was conducted using the SLM within Excel 17.0 and ArcGis 10.8.

The spatial relationships between the levels of ecological sustainability and 14 indicators, within the context of the planning scenario, were analyzed by the SLM, utilizing the GeoDa 1.14 software (Zheng et al., 2021). In this analysis, the comprehensive assessment level of ecological sustainability was designated as the dependent variable, with the 14 indicators serving as independent variables. The validity of the findings was further substantiated by regression correlation coefficients, as delineated in Equation (10).

$$E_x = \rho\omega E_x + \beta F + \varepsilon, \tag{10}$$

where E_x is the ecological sustainability level in grid x; ρ is the spatial lag parameter in spatial lag model; ω is the spatial weight matrix of the lag terms and error terms; β is the parameter revealing the correlation between the ecological sustainability level and driving factors; F is the value of driving factors; and ε is a constant.

3. Results

3.1. Level of ecological sustainability at site scale

Changes in the level of ecological sustainability at this EXPO site would occur as a result of changes in land use and land cover differences between the current situation and the planning scenario (Figure 3). In comparison to the current situation, the area with low levels of ecological sustainability for the planning scenario would decrease by 46.54%, while the area with the highest levels would decrease by 28.41%. On the other hand, the area with medium levels would increase by 71.43%, and the area with high levels would increase by 2.80%. The poor levels of ecological sustainability are primarily concentrated along the riparian areas of the Jiangxi River and in village settlements in the southwest regions of the current scenario (Figure 4). The area with medium ecological sustainability has mainly been converted from village settlements in the southwest of this site. Additionally, riparian reinforcement has been implemented throughout the entire site, including parts of the high-level forests in the south.

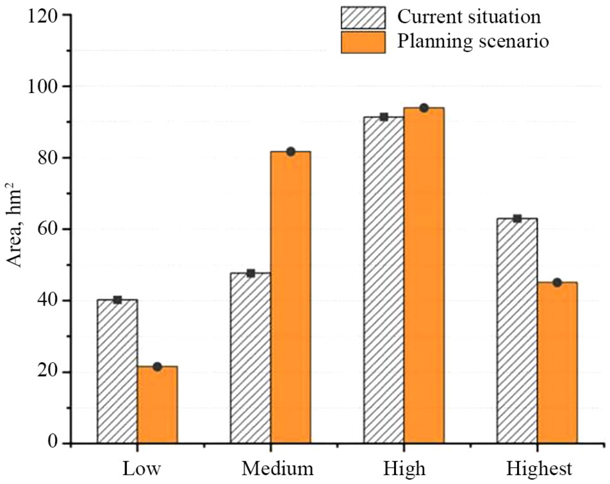


Figure 3. Changes in area at different levels between current situation and planning scenario

The sustainability level of seven partitions would be represented by various adjustments, either increasing or decreasing, in the planning scenario (Table 3). The degree

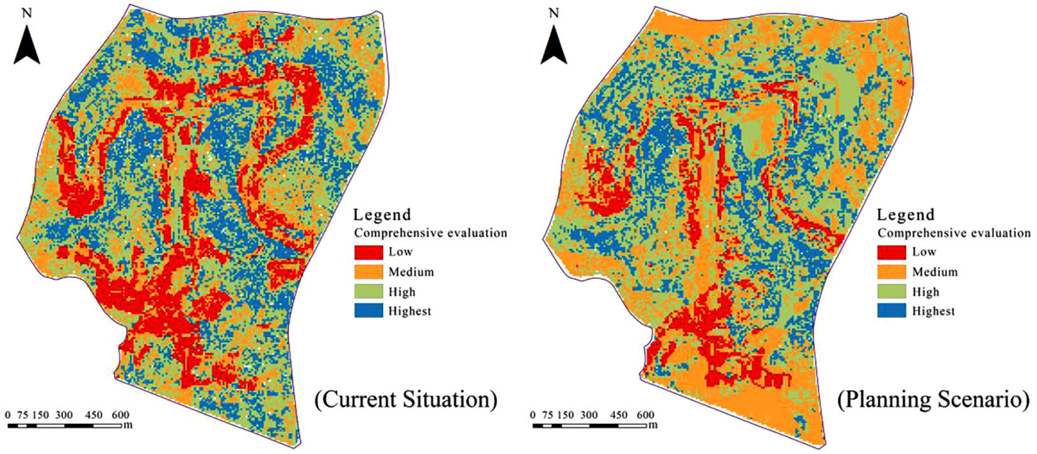


Figure 4. Spatial distribution of sustainability between current situation and planning scenario

of sustainability varies greatly, particularly in the Integrated Service, which includes features with a proportion of low to high levels greater than 10%. The proportion of low and medium sustainability levels is primarily presented as sluggish, while the proportion of high and highest sustainability levels is either slow or unchanged. The sustainability level in the International Horticultural Exhibition and the Tianfu Habitat Exhibition either experienced minimal changes or remained unchanged.

3.2. Level of ecological sustainability at four dimensions

On a four-dimensional scale, the proportion of ecological sustainability would shift significantly between the current situation and the planning scenario (Figure 5). In contrast to the current situation, the area of medium-level water ecology would decrease by 41.38%, while the area of low-level biodiversity would decrease by 14.00%. Low-level soil protection increased by 5.48%, while highest-level soil protection declined by 9.17%. Under the current situation, the areas with the highest levels of biodiversity and site development are predominantly found in nurseries, farmlands, and wastelands in the southern region. The area with medium-level water ecology, low-level biodiversity, and highest-level site development was primarily converted from forest on both the north and south sides of

Table 3. Changes in the ranking of the aggregate index between current situation and planning scenario

Partitions	Low	Medium	High	Highest
Park City Exhibition (PC)	↓	↑↑	↓	↑
International Horticultural Exhibition (IH)	↓	○	↑	○
Tianfu Habitat Exhibition (TH)	↓	↓	○	○
Children's Dream World Park (CD)	↓	↓	↑	↑
Future Horticultural Exhibition (FH)	↓	↓	↑	↑
Chinese Horticultural Exhibition (CH)	↑	↓	↑	○
Integrated Service (IS)	↑↑	↑↑	↓↓	↓

Note: ↑ proportion up (1%~10%); ↑↑ proportion up (>10%); ↓ proportion down (1%~10%); ↓↓ proportion down (>10%); ○ remaining unchanged.

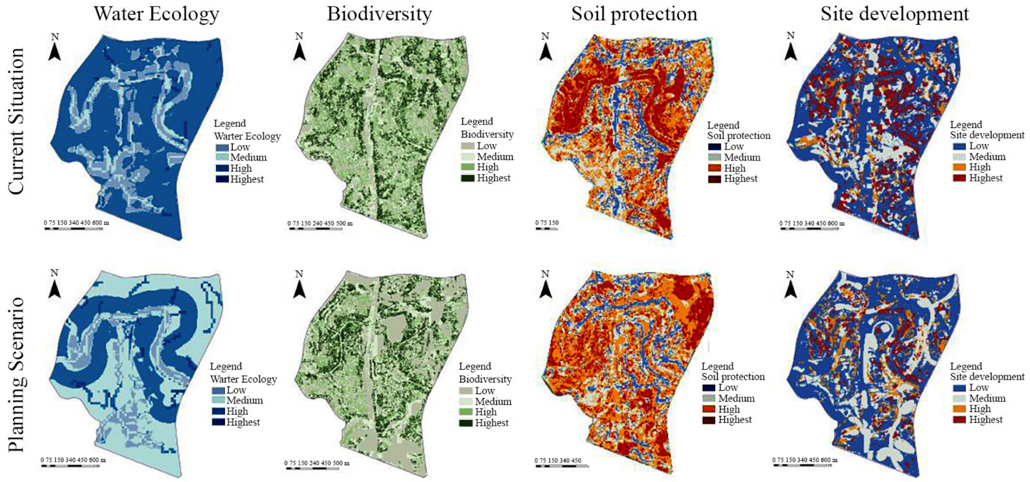


Figure 5. Ecological sustainability at four dimensions between current situation and planning scenario

the river. Both banks of the river and the farmlands to the northeast of the site contributed to the transformation of the high-quality soil-producing area.

The sustainability level in four dimensions of seven partitions of the planning scenario was presented, showing various tendencies of change (Table 4). Each high-level region of the partition was mostly transformed into a medium-level water ecology area. The Integrated Services underwent the biggest changes, totaling 10.66%. Low-level biodiversity areas and soil protection areas both showed significant increases of 4.85% and 2.38%, respectively. The level of soil protection in the Children's Dream World Park was significantly reduced throughout the entire site, resulting in a 3.94% decrease in the area of high and highest-level soil. The medium-level area of site development is influenced by both lower and highest levels. The transitions between the seven partitions were often seamless in other respects.

Table 4. Changes in scores at the four dimensions between current situation and planning scenario

Partitions	Dimension	Low	Medium	High	Highest
Park City Exhibition	B1	–0.008	0.041	–0.033	0.000
	B2	0.014	–0.004	–0.008	–0.002
	B3	–0.012	–0.004	0.010	0.006
	B4	–0.001	0.009	0.005	–0.014
International Horticultural Exhibition	B1	–0.014	0.036	–0.021	0.001
	B2	0.010	0.002	–0.009	–0.004
	B3	0.012	0.007	–0.015	–0.005
	B4	0.009	0.001	–0.001	–0.008
Tianfu Habitat Exhibition	B1	–0.011	0.065	–0.057	0.002
	B2	0.035	–0.010	–0.013	–0.010
	B3	0.011	–0.012	–0.001	0.005
	B4	–0.010	0.020	0.002	–0.013
Children's Dream World Park	B1	–0.031	0.099	–0.073	0.004
	B2	0.004	0.010	–0.014	0.000
	B3	0.020	0.017	–0.021	–0.019
	B4	0.020	–0.007	0.003	–0.016
Future Horticultural Exhibition	B1	–0.006	0.031	–0.029	0.003
	B2	0.004	–0.001	–0.007	0.003
	B3	0.008	0.001	–0.004	–0.005
	B4	0.000	0.003	0.007	–0.011
Chinese Horticultural Exhibition	B1	–0.009	0.034	–0.026	0.001
	B2	0.025	–0.002	–0.023	0.001
	B3	–0.010	0.009	0.008	–0.004
	B4	0.008	–0.003	0.011	–0.015
Integrated Service	B1	–0.001	0.107	–0.103	–0.002
	B2	0.048	–0.014	–0.023	–0.012
	B3	0.024	0.006	–0.021	–0.013
	B4	–0.019	0.033	0.000	–0.016

Note: Value = V (the planning scenario) – V (the current situation).

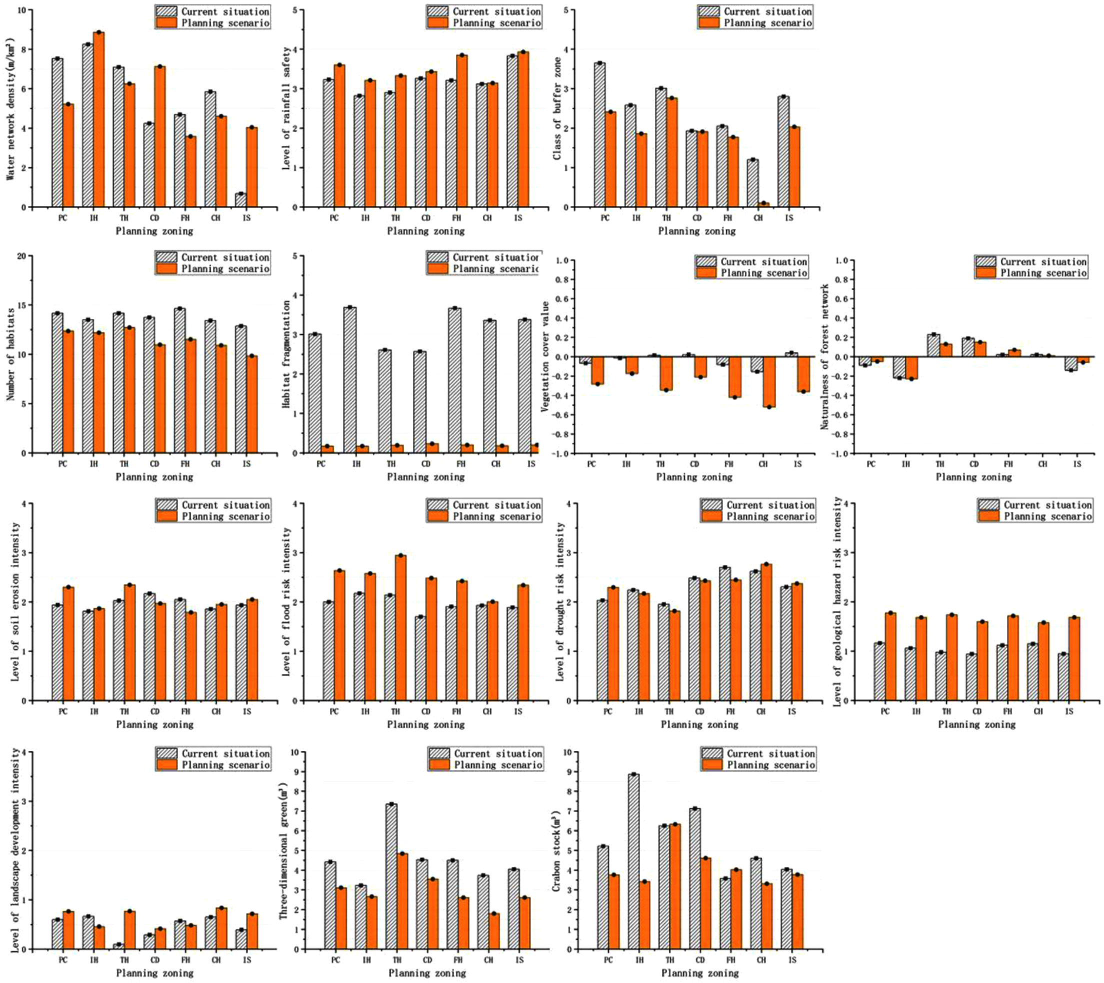
3.3. Level of ecological sustainability at the indicator scale

Different degrees of changes in land use cover and change would have an impact on the ecological sustainability level (Table 5). In contrast to the current situation, there was a minor increase in the risk level of indicators with a negative impact trend, but a decrease in habitat fragmentation from 3.28 to 0.18. There was a significant reduction of 1.40 m^3 and 1.94 m^3 per unit area in the three-dimensional green volume and carbon storage, respectively. Under the current situation, the areas with high-level of habitat fragmentation are primarily found in the forests on both sides of the mountain. The forest land on the southern parts and both sides of the Jiangxi River mostly experiences a decline in three-dimensional green volume and vegetation carbon stock.

Table 5. Compares the scores on an indicator scale between current situation and planning scenario

Indicator	Average value per unit area	
	Current situation	Planning scenario
Water network density (m/km^2)	5.86	6.09
Rainfall safety pattern (4 levels)	3.15	3.44
Distribution of water buffer zone (m)	2.49	1.80
Habitat diversity	13.67	11.56
Habitat fragmentation	3.28	0.18
Vegetation cover (–1~1)	0.97	0.68
Naturalness of forest network (–1~1)	–0.04	–0.04
Soil erosion intensity (4 levels)	1.93	2.02
Flood risk intensity (4 levels)	2.01	2.49
Drought risk intensity (4 levels)	2.30	2.30
Geological hazard risk intensity (4 levels)	1.05	1.68
Intensity of landscape development (4 levels)	0.50	0.63
Three-dimensional green volume (m^3)	4.33	2.93
Vegetation carbon stock (m^3)	4.03	2.09

The sustainability indicators for the seven partitions would be displayed in the planning scenario with various modifications (Figure 6). The Tianfu Habitat Exhibition exhibits a significant change in the 14 indicators. The highest shift rang among them was 0.4 increase in the naturalness of the forest network and a 0.17 rise in the intensity of landscape development. The carbon storage per unit area has decreased by 2.50 m^3, which is significantly higher than the typical level for this site. The water network density has risen by 68% and the risk intensity of



Note: PC, Park City Exhibition; IH, International Horticultural Exhibition; TH, Tianfu Habitat Exhibition; CD, Children's Dream World Park; FH, Future Horticultural Exhibition; CH, Chinese Horticultural Exhibition; IS, Integrated Service.

Figure 6. Level changes at an indicator scale between current situation and planning scenario

geological disasters has dropped by two degrees, resulting in significant improvements to the Children's Dream World Park. 14 indicators from the remaining 5 partitions change only slightly, typically shown a downward tendency in the positive trend indicators and an upward trend in the negative indicators. Positive trend indicators include significant decrease in three-dimensional green volume and carbon storage in vegetation. The vegetation carbon storage in the International Horticultural Exhibition was decreased by 5.30 m^2. A significant change in the single index occurred at the Chinese Horticultural Exhibition and the Integrated Service. In the former, the number of habitats per unit area were decreased by 2.49, and in the latter, the average vegetation coverage was less than 0.

3.4. Correlation between the ecological sustainability and indicators

The fluctuations in the ecological sustainability indicator exhibit a spectrum of impacts, primarily on the trend of influence and its association (Table 6). In contrast to the current situation, water ecological and site development are strongly correlated to overall ecological sustainability. The intensity of landscape development (C12) is a substantial negative association among them. The ecological sustainability level would decline by 0.2502% for every 1% rise in intensity. The rainfall safety pattern (C2), distribution of water buffer zone (C3), three-dimensional green volume (C13), and vegetation carbon stock (C14) showed the highest increase, with each 1% increase contributing to a 0.1653%, 0.0733%, 0.0642%, and 0.0836% improvement in ecological sustainability level, respectively. There are significant positive associations with the naturalness of the forest network (C7) in Children's Dream World Park and Future Horticultural Exhibition. Each 1% increase in naturalness would enhance the ecological sustainability level by 0.0562% and 0.1204%, respectively. There are significant positive relationships between the intensity of landscape development (C12) in the Chinese Horticultural Exhibition and Integrated Service and the ecological sustainability level. Specifically, for each 1% increase in landscape development, there is a corresponding enhancement of 0.3950% and 0.3814% in ecological sustainability, respectively. Tianfu Habitat Exhibition and habitat fragmentation

Table 6. Regressive correlation between sustainability level and indicator by spatial lag model

Independent variable	Entire site		Park City Exhibition		International Horticultural Exhibition		Tianfu Habitat Exhibition		Children's Dream World Park		Future Horticultural Exhibition		Chinese Horticultural Exhibition		Integrated Service	
	Coefficient	P	Coefficient	P	Coefficient	P	Coefficient	P	Coefficient	P	Coefficient	P	Coefficient	P	Coefficient	P
C1	–0.2764	0.6244	1.1062	0.6052	0.9046	0.6722	1.1727	0.4358	–0.0632	0.9441	–2.4024	0.3483	–0.3614	0.7819	–2.3569*	0.0881
C2	0.1652**	0.0000	0.1903**	0.0000	0.1139*	0.0282	0.1485**	0.0005	0.1730**	0.0000	0.1649**	0.0000	0.1315**	0.0000	0.1733**	0.0000
C3	0.0733**	0.0000	0.0951**	0.0000	0.0553**	0.0001	0.0760**	0.0000	0.0655**	0.0000	0.0664**	0.0021	0.0746**	0.0000	0.0463	0.1546
C4	0.0465**	0.0000	0.0438**	0.0000	0.0615**	0.0000	0.0424**	0.0000	0.0447**	0.0000	0.0371*	0.0155	0.0626**	0.0000	0.0508**	0.0000
C5	0.1333	0.4358	0.1281	0.8471	-0.0637	0.9437	-1.4310*	0.0790	0.5058	0.2116	0.2856	0.5302	1.0303*	0.0459	0.3058	0.5788
C6	0.0476**	0.0000	0.0544**	0.0000	0.0470**	0.0000	0.0570**	0.0000	0.0368**	0.0000	0.0447**	0.0001	0.0470**	0.0000	0.0569**	0.0000
C7	0.0334*	0.0417	0.0352	0.5547	–0.0038	0.9463	–0.0544	0.2557	0.0562*	0.0288	0.1204**	0.0013	0.0616	0.2668	0.0086	0.8424
C8	–0.0075	0.1501	–0.0171	0.2876	–0.0304	0.1089	–0.0077	0.6054	–0.0341**	0.0006	0.0011	0.9580	0.0114	0.3614	–0.0187	0.1843
C9	0.0487**	0.0000	0.0872**	0.0030	0.0203	0.4708	0.0228	0.5158	0.0413**	0.0087	0.1272**	0.0086	0.0720**	0.0030	0.0393	0.1742
C10	0.0237*	0.0134	0.0786**	0.0083	–0.0207	0.5506	–0.0310	0.3626	0.0130	0.4032	0.1075	0.0436	0.0396	0.1466	0.1089**	0.0003
C11	0.0160	0.1095	0.0428	0.1665	0.0601*	0.0516	0.0381	0.2356	–0.0079	0.6905	0.0122	0.7639	–0.0310	0.1821	–0.0069	0.8192
C12	–0.2502**	0.0003	0.1689	0.4571	–0.3625	0.1421	–0.1996	0.3250	–0.1653	0.2511	–0.2904	0.4020	–0.3950*	0.0493	–0.3814*	0.0334
C13	0.0642**	0.0000	0.0634**	0.0000	0.0738**	0.0000	0.0634**	0.0000	0.0750**	0.0000	0.0367**	0.0000	0.0634**	0.0000	0.0676**	0.0000
C14	0.0835**	0.0000	0.0786**	0.0000	0.0942**	0.0000	0.0891**	0.0000	0.0774**	0.0000	0.0884**	0.0000	0.0928**	0.0000	0.0727**	0.0000
Log likelihood	–6123.33		–883.42		–506.64		–1060.35		–1535.29		–611.46		–941.61		–907.98	
AIC	12278.7		1798.85		1045.29		2152.71		3102.57		1254.92		1915.22		1847.96	
SC	12385.6		1872.55		1114.34		2230.94		3189.25		1322.35		1992.08		1925.67	
R2	0.6883		0.6045		0.6976		0.6825		0.72		0.5875		0.7148		0.6369	

(C5) have a significant inverse relationship, with each 1% increase resulting in a decrease in ecological sustainability by 1.4310%. In terms of soil protection dimension, the importance of each partition is minor.

4. Discussions

While past and present studies offer valuable insights into land use planning and management, analyzing land use cover and change, as well as changes in ecological sustainability, from a predictive perspective can provide early warnings and facilitate more informed decisions (Sannigrahi et al., 2020; Zheng et al., 2021). Furthermore, predicting future landscape patterns and assessing ecological service values under various scenarios are crucial for planning and policy design, aiming to balance diverse development and conservation goals (Li et al., 2021). Traditional spatial planning studies have been categorized into setting planning targets, spatial patterns analysis, and the comparison and selection planning schemes (Dong et al., 2022). However, the sustainability of site planning has often been overlooked, and comprehensive research on future landscape prediction is scarce, particularly concerning how ecological service value responds to landscape changes across multiple scenarios (Kim & Kwon, 2021; Zheng et al., 2021). The variations in landscape patterns between the current situation and the planning scenario were used in this study to evaluate ecological sustainability using quantitative methods. This has high assessment accuracy and can successfully handle the complexity and ambiguity of converting between different types of landscapes.

Mega-events like the EXPO often occupy a specific amount of land, which can reactivate abandoned lands and provide a sustainable paradigm for the coexistence of humans and nature (Gao, 2020; Han et al., 2020). Due to its dependence on the spatiotemporal scale, it is challenging to establish a universal standard for ecological sustainability evaluation (Peng et al., 2011). Land use cover and change are very complicated processes that are influenced by a variety of factors (Zheng et al., 2021). Many sustainable landscape evaluations have employed a spatial overlap approach, focusing on individual landscape elements, identifying hotspots, and often ignoring trade-offs and synergies among assessment indicators (Fentaw et al., 2022). This paper proposes an improved technique for assessing local ecological sustainability in accordance with the SDGs. A subset of 14 indicators related to water ecosystems, biodiversity, soil protection, and site development were also included in the United Nations' (2015) Millennium Development Goals (Griggs et al., 2014). The AHP-entropy weight methodology and spatial econometric regression model utilized in this study eliminate the subjectivity of general landscape pattern prediction because ecological sustainability can only be adequately defined with reference to specific spatial and time scales. The regressive correlation influencing the outcomes between ecological sustainability level and quantitative indicator ranges from 0.5875 to 0.7148 (Han et al., 2020; Xing et al., 2021). This approach would demonstrate the alignment with landscape characteristics and its validity.

The Children's Dream World Park, the Future Horticultural Exhibition, and the Chinese Horticultural Exhibition all showed an improvement in their medium level of ecological sustainability, as indicated by the findings of the study. Moreover, the ratio of low to high ecological sustainability has decreased (Figure 3). The construction of public spaces and exhibitions, as well as forest destruction, primarily accounts for the decline at the highest level. Conversely, the transformation of cropland and forest into water bodies is mainly responsible for the increase in medium and decrease in the low level, consistent with Li et al. (2022). The primary cause of ecological sustainability decline is the conversion of agricultural and forested areas into construction sites, including the creation of impervious surfaces such as roads, buildings, and public spaces. Revetment reconstruction can enhance the water ecological environment and preserve the natural resilience of riparian habitats (Martínez-Fernández et al., 2017). However, Miiller (1998) also noted that the loss of natural disturbances in riparian ecosystems due to civil engineering interventions is a primary causes of biodiversity decline. Thus, sustainable land use in the planning scenario can achieve ecological stability and habitat integration.

Direct and indirect driving factors can be broadly categorized into two groups (Zheng et al., 2021). Direct variables are connected to changes in landscape patterns, given the significant role of ecological landscape types such as wetlands, forests, and grasslands in providing essential ecological services. It is crucial to create and improve multifunctional landscape patterns to maximize the effectiveness of multiple SDGs and enhance human well-being (Wang et al., 2021). Consequently, changes in landscape patterns significantly alter the ecosystem's structure and function (Liu et al., 2019). The landscape is shaped by socioeconomic and environmental processes that have an indirect impact on ecosystems, such as climatic conditions, urbanization, economic expansion, infrastructure, and policies for ecosystem preservation (Aretano et al., 2013; Song et al., 2021). This study primarily utilizes the rate of land use transitions and their ecological safety. Comparatively, water ecology is a main driver of both the highest and lowest levels of ecological sustainability. Site development is a key factor contributing to the increase in ecological sustainability, supported by a study conducted by Marques (2001), which found that human activities exert pressure on ecosystems, leading to a reduction in biodiversity and threats to ecosystem integrity. The spatial econometric analysis shows the correlation between water and site development to be significant in demonstrating the impact of landscape type changes on ecological sustainability. The Future Horticultural Exhibition was a key site for observing significant changes in water ecology, with ecological sustainability levels closely linked to both the pattern of rain and flood security (C2) and the risk of flood disasters (C9). Farmland reduction and increased regional water purification service capacity are the primary factors contributing to the improvement of ecological sustainability levels. Changes in the proportion of farmland, forest, and construction land affect the water ecological environment (Li et al., 2021). The International Horticultural Exhibition, Tianfu Habitat Exhibition, Children's Dream World Park, and Chinese Horticultural Exhibition have all undergone significant site development changes. The vegetation coverage (C6), three-dimensional green volume (C13), and vegetation carbon stock (C14) of the four divisions are all strongly associated with the level of ecological sustainability. Plant production in terrestrial ecosystems is affected by forest land conversion and planned land development, which are the primary causes of the deterioration in ecological sustainability levels (Li et al., 2022).

5. Conclusions

The contemporary value in event planning is to host large-scale events with a commitment to social and environmental responsibility, encompassing proactive sustainable management and operations. The ecological sustainability of the Chengdu EXPO site in 2024, which promotes the concept of peaceful cohabitation between the city and nature, has been evaluated and compared in this study, considering both the current state and the planned scenario. The level of ecological sustainability and its changes are assessed using a collective evaluation system that includes 14 indicators. This assessment is done within the context of the AHP-entropy weight technique and spatial econometric regression model. This study provides guidance and recommendations for the practical implementation of the planning, charting a course for ecologically sustainable development at the Chengdu EXPO site. The land use pattern and landscape cover are projected to evolve, with village settlements, wasteland, and farmland transforming into exhibition gardens and water bodies, thereby enhancing flood risk management (C9) and rain and flood protection measures (C2), and increasing ecological sustainability. However, site expansion will increase the impervious surface, particularly in areas of Integrated Service and forest loss, potentially reducing vegetation coverage (C6), three-dimensional green volume (C13), and vegetation carbon stock (C14), and impacting the maximum level of ecological sustainability.

This research technique is based on current situation and planning scenario, and it takes into account natural factors, site development, and environmental circumstances. It is adaptable for widespread used in future studies evaluating the ecological sustainability of large urban green spaces. The study's accuracy is poised for enhancement in future evaluations by integrating soil and water quality assessments and utilizing multi-spectral remote sensing images for vegetation extraction.

Acknowledgements

Thanks to Shi Feng's efforts in supervision, Guowei Zhang's efforts in field investigation, Xiaotong Liu's efforts in data processing and Mucong Li's efforts in translation and grammatical editing.

Funding

The authors gratefully acknowledge the financial support of Chengdu local project (CDZX2022010), Shanghai Talent Development Fund (2021050), the Research on Sustainable Urban Greening in China (2023131001) and the Fundamental Research Funds for Central Public Welfare Research Institutes (1632022006).

Author contributions

Huang Biao and Yang Haolin contribute equally. Huang Biao: Conceptualization, Validation, Writing – review & editing, Funding acquisition. Yang Haolin: Methodology, Formal analysis, Investigation, Data curation, Writing – original draft, Visualization. Meng Yufei: Investigation, Writing – review & editing. Wang Ruoyu: Formal analysis – review & editing. Hu Yonghong: Project administration, Supervision, Funding acquisition. Peng Hongming: Project administration, Supervision, Writing – review & editing. Shang Kankan: Investigation, Project administration, Supervision, Writing – review & editing. Jiang Zehui: Project administration, Supervision, Funding acquisition.

Disclosure statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Aretano, R., Petrosillo, I., Zaccarelli, N., Semeraro, T., & Zurlini, G. (2013). People perception of landscape change effects on ecosystem services in small Mediterranean islands: A combination of subjective and objective assessments. *Landscape and Urban Planning*, *112*, 63–73. https://doi.org/10.1016/j.landurbplan.2012.12.010

Backes, J. G., & Traverso, M. (2022). Life cycle sustainability assessment as a metrics towards SDGs agenda 2030. *Current Opinion in Green and Sustainable Chemistry*, *38*, Article 100683. https://doi.org/10.1016/j.cogsc.2022.100683

Berardi, U. (2013). Sustainability assessment of urban communities through rating systems. *Environment, Development and Sustainability*, *15*, 1573–1591. https://doi.org/10.1007/s10668-013-9462-0

Boess, E. R., Kørnøv, L., Lyhne, I., & Partidario, M. R. (2021). Integrating SDGs in environmental assessment: Unfolding SDG functions in emerging practices. *Environmental Impact Assessment Review*, *90*, Article 106632. https://doi.org/10.1016/j.eiar.2021.106632

Chen, J., Yang, S., Li, H., Zhang, B., & Lv, J. (2013). Research on geographical environment unit division based on the method of natural breaks (Jenks). *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *40*, 47–50. https://doi.org/10.5194/isprsarchives-XL-4-W3-47-2013

Clouston, B. (1984). Reclamation and landform design the Liverpool international garden festival. *Landscape Planning*, *11*(4), 327–335. https://doi.org/10.1016/0304-3924(84)90028-5

Cobbinah, P. B., Erdiaw-Kwasie, M. O., & Amoateng, P. (2015). Africa's urbanisation: Implications for sustainable development. *Cities*, *47*, 62–72. https://doi.org/10.1016/j.cities.2015.03.013

Del Campo, A. G., Gazzola, P., & Onyango, V. (2020). The mutualism of strategic environmental assessment and sustainable development goals. *Environmental Impact Assessment Review*, *82*, Article 106383. https://doi.org/10.1016/j.eiar.2020.106383

Dong, J., Jiang, H., Gu, T., Liu, Y., & Peng, J. (2022). Sustainable landscape pattern: A landscape approach to serving spatial planning. *Landscape Ecology*, *37*, 31–42. https://doi.org/10.1007/s10980-021-01329-0

Eisenmenger, N., Pichler, M., Krenmayr, N., Noll, D., Plank, B., Schalmann, E., Wandl, M.-T., & Gingrich, S. (2020). The Sustainable Development Goals prioritize economic growth over sustainable resource use: A critical reflection on the SDGs from a socio-ecological perspective. *Sustainability Science*, *15*, 1101–1110. https://doi.org/10.1007/s11625-020-00813-x

Estoque, R. C., Ooba, M., Togawa, T., Hijioka, Y., & Murayama, Y. (2021). Monitoring global land-use efficiency in the context of the UN 2030 Agenda for Sustainable Development. *Habitat International*, *115*, Article 102403. https://doi.org/10.1016/j.habitatint.2021.102403

Fentaw, G., Mezgebu, A., Wondie, A., & Getnet, B. (2022). Ecological health assessment of Ethiopian wetlands: Review and synthesis. *Environmental and Sustainability Indicators*, *15*, Article 100194. https://doi.org/10.1016/j.indic.2022.100194

Gao, C. (2020). Study on the sustainable development of space in post international horticultural exhibition age from urban perspective. *Journal of Physics: Conference Series*, *1575*, Article 012165. https://doi.org/10.1088/1742-6596/1575/1/012165

Gatto, A., & Busato, F. (2020). Energy vulnerability around the world: The global energy vulnerability index (GEVI). *Journal of Cleaner Production*, *253*, Article 118691. https://doi.org/10.1016/j.jclepro.2019.118691

Griggs, D., Smith, M. S., Rockström, J., Öhman, M. C., Gaffney, O., Glaser, G., Kanie, N., Noble, I., Steffen, W., & Shyamsundar, P. (2014). An integrated framework for sustainable development goals. *Ecology and Society*, *19*(4), Article 49. https://doi.org/10.5751/ES-07082-190449

Guo, P. Y., Liu, T., & Lv, T. (2016). Analysis on the planning and design of Tangshan Expo from the perspective of sustainable development. *Architecture and Culture*, (10), 138–139.

Han, R., Feng, C.-C., Xu, N., & Guo, L. (2020). Spatial heterogeneous relationship between ecosystem services and human disturbances: A case study in Chuandong, China. *Science of the Total Environment*, *721*, Article 137818. https://doi.org/10.1016/j.scitotenv.2020.137818

Jiang, H., Sun, Z., Guo, H., Weng, Q., Du, W., Xing, Q., & Cai, G. (2021). An assessment of urbanization sustainability in China between 1990 and 2015 using land use efficiency indicators. *npj Urban Sustainability*, *1*, Article 34. https://doi.org/10.1038/s42949-021-00032-y

Jin, H., & Wang, Y. (2006). The world gives Shenyang a chance, and Shenyang returns the world a miracle – 2006 China Shenyang International Horticultural Exposition. *Chinese Garden*, (05), 1–4.

Kim, I., & Kwon, H. (2021). Assessing the impacts of urban land use changes on regional ecosystem services according to urban green space policies via the patch-based cellular automata model. *Environmental Management*, *67*(1), 192–204. https://doi.org/10.1007/s00267-020-01394-2

Kong, Y., & Khan, R. (2019). To examine environmental pollution by economic growth and their impact in an environmental Kuznets curve (EKC) among developed and developing countries. *PloS One*, *14*(3), Article e0209532. https://doi.org/10.1371/journal.pone.0209532

Kørnøv, L., Lyhne, I., & Davila, J. G. (2020). Linking the UN SDGs and environmental assessment: Towards a conceptual framework. *Environmental Impact Assessment Review*, *85*, Article 106463. https://doi.org/10.1016/j.eiar.2020.106463

Kuc-Czarnecka, M., Markowicz, I., & Sompolska-Rzechuła, A. (2023). SDGs implementation, their synergies, and trade-offs in EU countries – Sensitivity analysis-based approach. *Ecological Indicators*, *146*, Article 109888. https://doi.org/10.1016/j.ecolind.2023.109888

Li, J., Zhou, K., Xie, B., & Xiao, J. (2021). Impact of landscape pattern change on water-related ecosystem services: Comprehensive analysis based on heterogeneity perspective. *Ecological Indicators*, *133*, Article 108372. https://doi.org/10.1016/j.ecolind.2021.108372

Li, W., Wang, W., Chen, J., & Zhang, Z. (2022). Assessing effects of the Returning Farmland to Forest Program on vegetation cover changes at multiple spatial scales: The case of northwest Yunnan, China. *Journal of Environmental Management*, *304*, Article 114303. https://doi.org/10.1016/j.jenvman.2021.114303

Liu, Q., Wang, S., Zhang, W., Zhan, D., & Li, J. (2018). Does foreign direct investment affect environmental pollution in China's cities? A spatial econometric perspective. *Science of the Total Environment*, *613*, 521–529. https://doi.org/10.1016/j.scitotenv.2017.09.110

Liu, W., Zhan, J., Zhao, F., Yan, H., Zhang, F., & Wei, X. (2019). Impacts of urbanization-induced land-use changes on ecosystem services: A case study of the Pearl River Delta Metropolitan Region, China. *Ecological Indicators*, *98*, 228–238. https://doi.org/10.1016/j.ecolind.2018.10.054

Lu, H., Zhang, J., Jiang, J., & Gong, C. (2021). Evolution characteristics and fitting of extreme precipitation in Sichuan Basin. *Journal of Chengdu University of Information Technology*, *36*(04), 404–412. https://doi.org/10.16836/j.cnki.jcuit.2021.04.010

Malay, O. E. (2021). Improving government and business coordination through the use of consistent SDGs indicators. A comparative analysis of national (Belgian) and business (pharma and retail) sustainability indicators. *Ecological Economics*, *184*, Article 106991. https://doi.org/10.1016/j.ecolecon.2021.106991

Marques, J. C. (2001). Diversity, biodiversity, conservation, and sustainability. *The Scientific World Journal*, *1*, 534–543. https://doi.org/10.1100/tsw.2001.101

Martínez-Fernández, V., González, E., López-Almansa, J. C., González, S. M., & de Jalón, D. G. (2017). Dismantling artificial levees and channel revetments promotes channel widening and regeneration of riparian vegetation over long river segments. *Ecological Engineering*, *108*, 132–142. https://doi.org/10.1016/j.ecoleng.2017.08.005

Mauree, D., Naboni, E., Coccolo, S., Perera, A. T. D., Nik, V. M., & Scartezzini, J. L. (2019). A review of assessment methods for the urban environment and its energy sustainability to guarantee climate adaptation of future cities. *Renewable and Sustainable Energy Reviews*, *112*, 733–746. https://doi.org/10.1016/j.rser.2019.06.005

Miiller, N. (1998). Effects of natural and human disturbances on floodplain vegetation. In *International Symposium on River Restoration*, Tokyo.

Obaideen, K., Yousef, B. A., AlMallahi, M. N., Tan, Y. C., Mahmoud, M., Jaber, H., & Ramadan, M. (2022). An overview of smart irrigation systems using IoT. *Energy Nexus*, *7*, Article 100124. https://doi.org/10.1016/j.nexus.2022.100124

Pandey, A., & Asif, M. (2022). Assessment of energy and environmental sustainability in South Asia in the perspective of the Sustainable Development Goals. *Renewable and Sustainable Energy Reviews*, *165*, Article 112492. https://doi.org/10.1016/j.rser.2022.112492

Peng, J., Wang, Y., Wu, J., Shen, H., & Pan, Y. (2011). Research progress on evaluation frameworks of regional ecological sustainability. *Chinese Geographical Science*, *21*, 496–510. https://doi.org/10.1007/s11769-011-0490-0

Reyes-Riveros, R., Altamirano, A., De La Barrera, F., Rozas-Vásquez, D., Vieli, L., & Meli, P. (2021). Linking public urban green spaces and human well-being: A systematic review. *Urban Forestry & Urban Greening*, *61*, Article 127105. https://doi.org/10.1016/j.ufug.2021.127105

Sannigrahi, S., Pilla, F., Basu, B., Basu, A. S., & Molter, A. (2020). Examining the association between socio-demographic composition and COVID-19 fatalities in the European region using spatial regression approach. *Sustainable Cities and Society*, *62*, Article 102418. https://doi.org/10.1016/j.scs.2020.102418

Sarkodie, S. A. (2022). Winners and losers of energy sustainability – Global assessment of the Sustainable Development Goals. *Science of the Total Environment*, *831*, Article 154945. https://doi.org/10.1016/j.scitotenv.2022.154945

Schröder, P., Lemille, A., & Desmond, P. (2020). Making the circular economy work for human development. *Resources, Conservation and Recycling*, *156*, Article 104686. https://doi.org/10.1016/j.resconrec.2020.104686

Song, M., Jin, G., & Yan, W. (2021). Which pro-environmental farming behaviors should be priorities for funding? An approach based on matching ecosystem services (ESs) demand and supply. *Journal of Environmental Management*, *297*, Article 113368. https://doi.org/10.1016/j.jenvman.2021.113368

Tai, X., Xiao, W., & Tang, Y. (2020). A quantitative assessment of vulnerability using social-economic-natural compound ecosystem framework in coal mining cities. *Journal of Cleaner Production*, *258*, Article 120969. https://doi.org/10.1016/j.jclepro.2020.120969

Tripathi, M., & Singal, S. K. (2019). Allocation of weights using factor analysis for development of a novel water quality index. *Ecotoxicology and Environmental Safety*, *183*, Article 109510. https://doi.org/10.1016/j.ecoenv.2019.109510

United Nations Environment Programme. (2019). *Measuring progress: Towards achieving the environmental dimension of the SDGs*. https://unepgrid.ch/storage/app/media/legacy/95/UNEP_Measuring_Progress_2019.pdf

United Nations. (2015). *Transforming our world: The 2030 agenda for sustainable development*. https://sustainabledevelopment.un.org/post2015/transformingourworld

Valenzuela-Venegas, G., Salgado, J. C., & Díaz-Alvarado, F. A. (2016). Sustainability indicators for the assessment of eco-industrial parks: Classification and criteria for selection. *Journal of Cleaner Production*, *133*, 99–116. https://doi.org/10.1016/j.jclepro.2016.05.113

van Asselt, H., Rayner, T., & Persson, Å. (2015). Climate policy integration. In *Research handbook on climate governance* (pp. 388–399). Edward Elgar Publishing. https://doi.org/10.4337/9781783470600.00046

Wang, Y., Chang, Q., & Fan, P. (2021). A framework to integrate multifunctionality analyses into green infrastructure planning. *Landscape Ecology*, *36*, 1951–1969. https://doi.org/10.1007/s10980-020-01058-w

Wang, Y., Wang, R., & Jia, Y. (2022). Sustainability evaluation of rural ecological space in plain based on SDGs: A case study of Heishan County, Liaoning Province. *Chinese Journal of Landscape Architecture*, *39*(03), 4–12.

Wang, Z. (2019). Discussion on the development of Yangzhou Garden Expo based on the concept of sustainable development. *Garden Architecture*, (01), 28–31.

Xiao, K., Tamborski, J., Wang, X., Feng, X., Wang, S., Wang, Q., Lin, D., & Li, H. (2022). A coupling methodology of the analytic hierarchy process and entropy weight theory for assessing coastal water quality. *Environmental Science and Pollution Research*, *29*, 31217–31234. https://doi.org/10.1007/s11356-021-17247-2

Xing, L., Zhu, Y., & Wang, J. (2021). Spatial spillover effects of urbanization on ecosystem services value in Chinese cities. *Ecological Indicators*, *121*, Article 107028. https://doi.org/10.1016/j.ecolind.2020.107028

Xu, C., Jiang, W., Huang, Q., & Wang, Y. (2020). Ecosystem services response to rural-urban transitions in coastal and island cities: A comparison between Shenzhen and Hong Kong, China. *Journal of Cleaner Production*, *260*, Article 121033. https://doi.org/10.1016/j.jclepro.2020.121033

Yang, S., Zhao, W., Liu, Y., Cherubini, F., Fu, B., & Pereira, P. (2020). Prioritizing sustainable development goals and linking them to ecosystem services: A global expert's knowledge evaluation. *Geography and Sustainability*, *1*(4), 321–330. https://doi.org/10.1016/j.geosus.2020.09.004

Yoo, J., & Ready, R. (2016). The impact of agricultural conservation easement on nearby house prices: Incorporating spatial autocorrelation and spatial heterogeneity. *Journal of Forest Economics*, *25*, 78–93. https://doi.org/10.1016/j.jfe.2016.09.001

Zhang, J., Djajadikerta, H. G., & Trireksani, T. (2020). Corporate sustainability disclosure's importance in China: Financial analysts' perception. *Social Responsibility Journal*, *16*(8), 1169–1189. https://doi.org/10.1108/SRJ-10-2018-0272

Zhang, X., Yao, G., Vishwakarma, S., Dalin, C., Komarek, A. M., Kanter, D. R., Davis, K. F., Pfeifer, K., Zhao, J., & Zou, T. (2021). Quantitative assessment of agricultural sustainability reveals divergent priorities among nations. *One Earth*, *4*(9), 1262–1277. https://doi.org/10.1016/j.oneear.2021.08.015

Zheng, L., Wang, Y., & Li, J. (2021). How to achieve the ecological sustainability goal of UNESCO Global Geoparks? A multi-scenario simulation and ecological assessment approach using Dabieshan UGGp, China as a case study. *Journal of Cleaner Production*, *329*, Article 129779. https://doi.org/10.1016/j.jclepro.2021.129779

Zhong, C., Guo, H., Swan, I., Gao, P., Yao, Q., Yao, Q., & Li, H., (2023). Evaluating trends, profits, and risks of global cities in recent urban expansion for advancing sustainable development. *Habitat International*, *138*, Article 102869. https://doi.org/10.1016/j.habitatint.2023.102869

Zhou, C., Chen, J., & Wang, S. (2018). Examining the effects of socioeconomic development on fine particulate matter ($PM_{2.5}$) in China's cities using spatial regression and the geographical detector technique. *Science of the Total Environment*, *619*, 436–445. https://doi.org/10.1016/j.scitotenv.2017.11.124

Zhou, T. (2021). *Construction of urban stormwater safety system based on blue and green space construction: A case study of the Eastern New City of Chengdu*. Urban Planning Society of China. https://doi.org/10.26914/c.cnkihy.2021.029788