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An Assessment of Ecological Sensitivity and Landscape Pattern in Abandoned Mining Land

Yu Shi, Xiaoxiao Fan *, Xiaoying Ding and Meiqi Sun

School of Architecture and Art Design, Hebei University of Technology, Tianjin 300401, China;
shiyu20001102@163.com (Y.S.); 2020093@hebut.edu.cn (X.D.); sun17396173731@163.com (M.S.)
* Correspondence: 2013116@hebut.edu.cn

Abstract: In recent years, the development of abandoned mining land has become a focal point in landscape planning. However, during the development of abandoned mining land, there often exists a phenomenon of prioritizing economic considerations over ecological concerns, leading to a failure to achieve genuinely sustainable development. An ecological sensitivity assessment, guided by the principles of protection and development, provides an evaluation framework that directs planning strategies for abandoned mining land from the perspective of balanced development and conservation. To facilitate the development and construction of abandoned mining land, this paper utilizes GIS technology, on-site surveys, analytic hierarchy processes, etc. Taking the abandoned mining land in Haining, Zhejiang, China, as the research subject and considering its unique site conditions, ecological sensitivity is divided into topographic conditions, surface water systems, and plant landscapes. Ecological sensitivity factors are selected, and an ecological sensitivity assessment system is constructed from the perspectives of ecological conservation and sustainable development. Using ArcGIS 10.2 and Fragstats 4.2 software, landscape pattern analysis is conducted, exploring the relationship between landscape patterns and ecological sensitivity assessment results from the perspectives of landscape fragmentation, diversity, and aggregation. By comparing the results of single-factor sensitivity analysis and comprehensive sensitivity analysis, as well as landscape pattern indices before and after classifying ecologically sensitive areas, the practicality of the evaluation system is verified, facilitating planning studies and providing design recommendations for abandoned mining land. Landscape pattern indices serve as supplementary explanations for ecological sensitivity. Based on the results of ecological sensitivity assessment and landscape pattern indices, the ecological conservation levels in the research area are classified into five categories: the Level I Comprehensive Protection Zone, Level II Moderately Developed Zone, Level III Construction Suitable Zone, Level IV Core Construction Zone, and Level V Core Development Zone. These correspond to ecological protection zones, sightseeing experience zones, historical exhibition zones, core commercial zones, and themed amusement zones, respectively. The I-level sensitive area in the research area has the smallest range, while IV-level and VI-level sensitive areas have larger extents, exhibiting a high degree of overall landscape fragmentation but with diverse and dominant landscape types. Integrating ecological sensitivity assessment results and landscape pattern indices aids in delineating ecological conservation levels and regional functional recreation zones, guiding the rational recreation allocation of resources for abandoned mining land and promoting its development into a scenic area integrating ecology and tourism.

Keywords: ecological sensitivity; landscape planning; landscape pattern; suitability assessment; environmental resources; sustainable development; abandoned mining land

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1. Introduction

The ecological restoration of abandoned mining land refers to the process of restoring and improving land that has undergone mining activities in the past, is now abandoned, and has suffered environmental damage [1]. This process aims to alleviate or eliminate the negative impacts of mining activities on the land, water sources, and ecosystems. One of the key objectives of abandoned mining land restoration is to restore the ecological balance and biodiversity of the land [2]. On the other hand, the ecological restoration of abandoned mining land also influences social and economic sustainability. Redeveloping abandoned mining land and transforming it into reusable areas contributes to job creation, enhances local economic conditions, and promotes sustainable development [3]. Since the year 2000, when China's financial support for abandoned mining land remediation projects began, a series of policies have been successively introduced in the country [4]. Against this backdrop, the restoration models for abandoned mining land have experienced significant development [5]. Building upon past practices such as reclamation for agriculture and afforestation, there has been a growing awareness of the reutilization value of abandoned mining land [5]. This includes redevelopment for economic activities like agriculture, industry, commerce, or residential purposes, transforming certain abandoned mining areas into renewable energy projects, ecological restoration initiatives, designing them as tourist destinations or recreational areas, utilizing them for educational and research purposes, and providing habitats for wildlife [5–7]. However, the lack of a systematic theoretical framework often results in the unreasonable development of abandoned mining land in terms of land-use types. This leads to disorder in site functions, exacerbates habitat destruction, and gives rise to a series of ecological issues. Therefore, establishing a suitability assessment system before the development of abandoned mining land can provide developers with a theoretical and data foundation, guiding development practices [8–11].

Abandoned mining land refers to land rendered unusable due to encroachment, destruction, and pollution resulting from mining activities, constituting areas devoid of regeneration [6]. In terms of ecological characteristics, the process of mining development, whether via the excavation of pits, removal of topsoil, or deforestation, invariably has negative impacts on the ecological environment. Consequently, ecological sensitivity becomes a limiting factor in the restoration of abandoned mining land [12].

Ecological sensitivity refers to the extent to which an ecosystem responds to external pressures, disturbances, or changes, encompassing both the sensitivity of the ecosystem to environmental changes and its capacity for recovery and adaptation [13]. It includes factors such as biodiversity, ecological balance, and ecosystem functionality to assess an ecosystem's resistance and adaptability to different pressures [9–11]. This concept is crucial in environmental management and conservation, aiding in the formulation of sustainable development strategies and measures. In comparison to ecological suitability, the former emphasizes rigid protection and sustainable development, while the latter emphasizes moderately developing the site [14]. Therefore, after obtaining the results of the ecological sensitivity assessment, it is necessary to convert them to the conventional land suitability assessment results. The regions with the highest ecological sensitivity are defined as unsuitable for development, while the regions with the lowest ecological sensitivity are defined as suitable for development [8].

The landscape pattern serves as a reflection of the spatial arrangement and combination of various-sized landscape elements [15–18]. In the context of abandoned mining land development, the pursuit of economic growth can lead to alterations in the spatial layout of landscape patterns. Mining activities can bring about changes such as vegetation degradation, heterogeneous patches, subsidence due to extraction, and an increase in landscape fragmentation [4,19–21]. Analyzing landscape patterns provides valuable insights into the ecological conservation capacity, supply capacity, and other factors that serve as a data foundation for guiding planning practices, especially in regions affected by mining activities. Understanding how economic development influences the landscape pattern and, in turn, impacts ecological factors is crucial for informed decision making in brownfield development.

In the research on the ecological sensitivity assessment system for abandoned mining land, this paper, based on previous studies [12], improved the evaluation factors for ecological sensitivity and established a systematic ecological sensitivity assessment system for abandoned mining land. The study focused on abandoned mining land with a small footprint, enhanced the accuracy of data sources, refined the classification, and implemented ecological sensitivity assessment in small-scale planning. In the combined study of ecological sensitivity and landscape pattern, building upon previous research [14], this paper integrated the comprehensive analysis results of ecological sensitivity with landscape pattern indices. The incorporation of landscape pattern analysis into ecological sensitivity assessment results not only supplements explanations for ecological sensitivity but also contributes to the ecological tourism functional zoning of abandoned mining land.

The development plan for the 14th Five-Year Plan in Zhejiang Province (https://www.zj.gov.cn/art/2021/2/5/art_1229463129_59083059.html) (accessed on 20 March 2023) and the overall tourism development plan (http://www.haining.gov.cn) (accessed on 20 March 2023) for Haining City provide a strategic framework for the planning and research of the abandoned mining land area. Six mining pits have been earmarked for planning, with three of them yet to undergo ecological restoration, preserving their original ecological characteristics. Due to the unique terrain characteristics of abandoned mining land, specific factors exclusive to these sites were selected during factor screening to distinguish the ecological sensitivity assessment from other terrain features. Starting from surface water systems, topographical conditions, and vegetation landscapes, factors that align with the current site conditions were chosen to construct the evaluation system. A tailored ecological sensitivity system for similar abandoned mining land was established, and ArcGIS 10.2 and Fragstats 4.2 were utilized for a comprehensive assessment of ecological sensitivity and landscape patterns. After exploring the relationship between ecological sensitivity and landscape patterns, spatial optimization and configuration were performed from the perspectives of ecological conservation and tourism functional zones. This aimed to enrich and enhance the ecological tourism planning system for abandoned mining land of the same type.

2. Materials and Methods

2.1. Overview of the Study Area

The study area is located in Haining City, Zhejiang Province (30° N, 120° E), with a total land area of 951.49 hectares (Figure 1). The area comprises several mining pits, each with varying sizes: Pit 1: 38 hectares, Pit 2: 12 hectares, Pit 3: 15 hectares, Pit 5: 20 hectares, and Pit 6: 10 hectares. Notably, Pit 4 covers a larger area, spanning 150 hectares. The study area, situated in Yuanhua Town, experiences distinct seasons with similar water and temperature patterns. Via on-site inspections, it was discovered that the landscape in the study area is rich and diverse, encompassing water bodies, paddy fields, forests, shrubs, sparse woodlands, other wooded areas, high-cover grasslands, rural residential areas, and other developed lands, exhibiting promising prospects for construction and substantial development potential (Figure 1). The remnants in this region include geological landscape mining relics, industrial production area mining relics, intangible cultural relics, and village-style relics. This area holds significant aesthetic, observational, research, exploration, and historical–cultural value [7].

Via field reconnaissance and consultation with experts in the research area, the main topography of Haining City in the study area is characterized by a south-to-north slope, with higher elevation in the south and lower elevation in the north. Except for a few hills in the northeast and southeast, the rest of the area is predominantly plain. The soil parent material is derived from sedimentation in rivers, seas, lakes, and oceans. Significant human activities have resulted in distinct differences between dry land and paddy fields, forming a pattern of alternating tidal soil and rice soil distribution. In the study area, three rivers, namely Yunyan River, Hejie Dianqiao Port, and Tianxiantang, surround the eastern, western, and northern directions, respectively. The rivers flow from south to north and west to east, eventually bifurcating to the east and north at the northeast corner of the site through the Yunyan River.

The lakes within the mining area are primarily replenished by surrounding river water and precipitation. The vegetation in the study area belongs to the northern subtropical evergreen broad-leaved forest and coniferous forest. Forest coverage is higher in the low mountain areas, while natural vegetation is well developed in the plains. The predominant plant species include evergreen bamboo, shrubs, and miscellaneous grasses. Notable shrubs include *Rhododendron lapponicum*, *Ligustrum compactum*, *Lespedeza bicolor* Turcz., and *Lindera glauca*. Grass species include *Setaria viridis*, *Digitaria sanguinalis*, *Cortaderia* Stapf, and *Erigeron annuus*. Vine species include *Hedera nepalensis* and *Trachelospermum jasminoides*. Major tree species include *Phyllostachys edulis*, *Pinus massoniana*, *Albizia kalkora*, *Quercus glauca* Thunb, *Castanopsis sclerophylla*, *Schima superba* Gardner & Champ, and various types of pine, fir, and willow trees (information sourced from: http://www.haining.gov.cn/) (accessed on 20 March 2023).

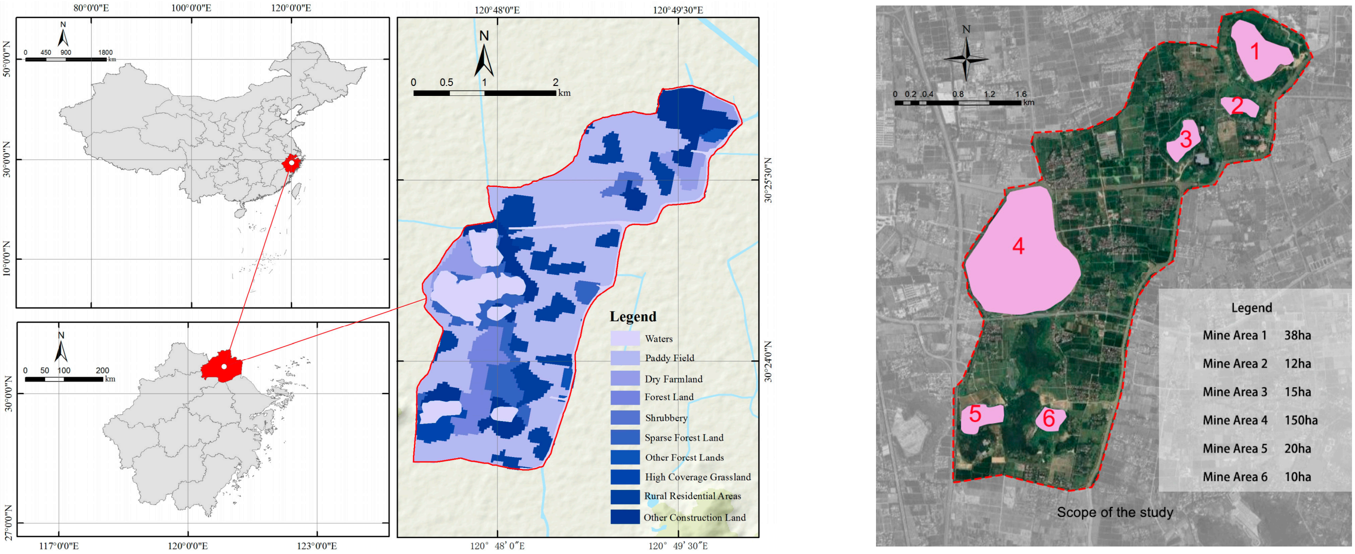


Figure 1. Geographical location of the study area.

2.2. Research Methods and Data Processing

This article adopts a research method that combines ecological sensitivity assessment with landscape pattern index. Firstly, an ecological sensitivity assessment system for abandoned mining land is established. Using a literature review method, ecological sensitivity assessment indicators for abandoned mining land are selected. Using the Delphi method (expert questionnaire survey), weights for the ecological sensitivity assessment indicators of abandoned mining land are obtained. According to the actual situation, the evaluation criteria for evaluation factors are graded. Secondly, ecological sensitivity assessment data for abandoned mining land are obtained. The selected evaluation factors are reclassified and analyzed using GIS 10.8 software to obtain single-factor ecological sensitivity data. By using a multi-index weighted overlay method, an analysis of ecological sensitivity for the entire study area is obtained. Finally, the comprehensive ecological sensitivity data and reclassified landscape patch data are input into Fragstats 4.2 to calculate landscape pattern indices. By comparing landscape pattern indices and ecological sensitivity data, the relationship between them is explored, and conclusions are drawn (Figure 2).

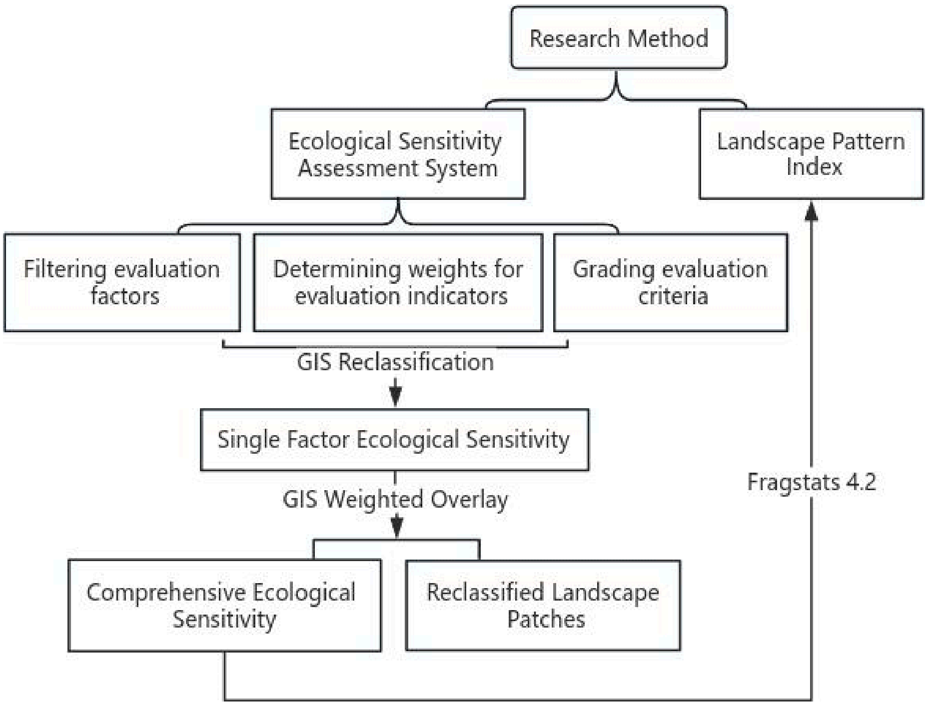


Figure 2. Technical roadmap.

2.2.1. Ecological Sensitivity Assessment

(1) Indicator Selection

Drawing insights from the relevant literature, specific factors related to terrain, soil, and climate were identified [13,14,22–29]. The intermediate layer of abandoned mining land is divided into topographical conditions, surface water systems, and vegetation landscapes. On one hand, the topography of abandoned mining land is unique, requiring the consideration of factors such as elevation, slope, aspect, land use, and other evaluation factors. On the other hand, abandoned mining land experiences severe ecological damage, with vegetation being the most affected. Therefore, it is necessary to investigate factors such as vegetation coverage and vegetation types. In the research area, the prominent feature of abandoned mining land is water accumulation forming a lake, which makes the surface water system a decisive factor. Initial screening resulted in 56 assessment factors across terrain conditions (Table 1), surface water systems (Table 2), and plant landscapes (Table 3) [30]. After eliminating duplicates, 9 factors remained. Applying the Delphi method for questionnaire selection, quantified scoring was conducted on the factors influencing the initial selection set. The extracted influencing factors were then subjected to secondary selection. The process involved integration, refinement, and other enhancement steps for comprehensive improvement. Considering the current site conditions, the final factors closely related to ecological sensitivity suitability were identified as elevation, slope, aspect, soil texture, land use, runoff buffer zone, water body buffer zone, vegetation coverage, and vegetation type (Figure 3).

Table 1. Judgment matrix model.

A	a_1	a_2	a_3	a_4	…	a_n
a_1	a_1/a_1	a_1/a_2	a_1/a_3	a_1/a_4	…	a_1/a_n
a_2	a_2/a_1	a_2/a_2	a_2/a_3	a_2/a_4	…	a_2/a_n
a_3	a_3/a_1	a_3/a_2	a_3/a_3	a_3/a_4	…	a_3/a_n
a_4	a_4/a_1	a_4/a_2	a_4/a_3	a_4/a_4	…	a_4/a_n
…	…	…	…	…	…	…
a_n	a_n/a_1	a_n/a_2	a_n/a_3	a_n/a_4	…	a_n/a_n

Note: a is the judgment matrix; a_{ij} indicates the importance of factor i to factor j (i, j = 1, 2, 3, 4 … n).

Table 2. The importance and value of the assessment factors.

Degree Value	Meaning
1	Factor *i* and factor *j* have the same level of importance.
2	Factor *i* is slightly more important than factor *j*.
3	Factor *i* is noticeably more important than factor *j*.
4	Factor *i* is significantly more important than factor *j*.
5	Factor *i* is strongly more important than factor *j*.
6	Factor *i* is very strongly more important than factor *j*.
7	Factor *i* is extremely strongly more important than factor *j*.
8	Factor *i* is super strongly more important than factor *j*.
9	Factor *i* is more important than factor *j*.

Table 3. Ecological sensitivity assessment index grading for abandoned mining land.

Criterion Layer	Evaluation Factors	Evaluation Standards					Evaluation Methods
		9 (Level I Sensitivity)	7 (Level II Sensitivity)	5 (Level III Sensitivity)	3 (Level IV Sensitivity)	1 (Level V Sensitivity)	
Ecological Sensitivity Assessment of Abandoned Mining Lands	Soil Texture Factor	Loam Sandy	Loam	Clay	Heavy Clay	Sandy Soil	Subjective Judgment
	Slope Factor (°)	Above 35.2	26.4–35.2	17.6–26.4	8.8–17.6	Below 8.8	Equal Intervals
	Land-Use Factor	Forest	Water Body	Grassland	Cultivated Land	Construction Land and Bare Land	Subjective Judgment
	Elevation Factor/(m)	71.2–93	49.4–71.2	27.6–49.4	5.8–27.6	−16.5–5.8	Equal Intervals
	Aspect Factor	True North	Northwest, Northeast	rue West, True East	Southwest, Southeast	True South, Flat Ground	Subjective Judgment
	Water Body Buffer Zone Factor (m)	Less than 10	10–30	30–50	50–70	More than 70	Equal Intervals
	Runoff Buffer Zone Factor (m)	5–10	0–5, 10–15	15–20	20–30	More than 30	Subjective Judgment, Equal Intervals
	Vegetation Type Factor	Mixed Forest	Broadleaf Pure Forest, Coniferous Pure Forest	Shrubland	Cropland, Grassland	Other	Subjective Judgment
	Vegetation Coverage Factor (%)	Above 30	20–30	10–20	0–10	No Vegetation	Equal Intervals

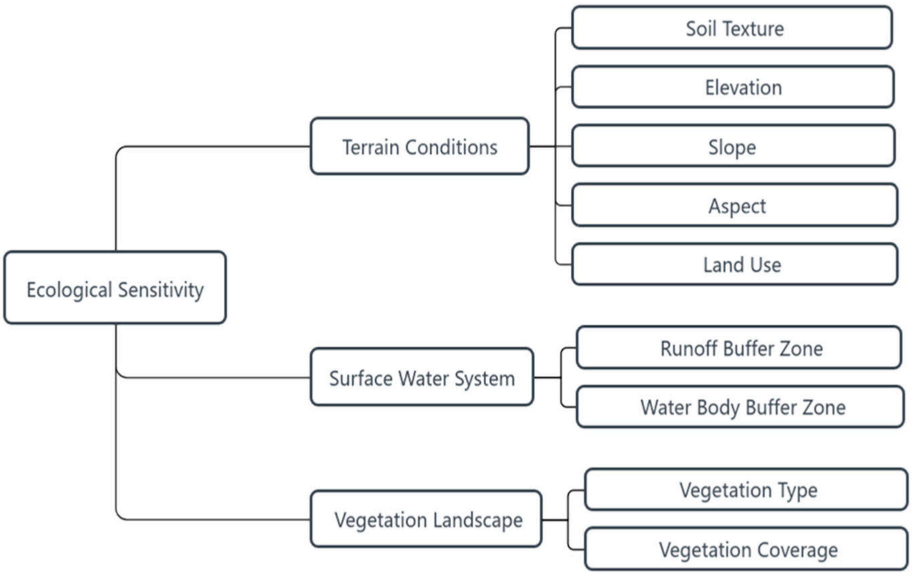


Figure 3. Ecological sensitivity assessment index system.

(2) Determination of Indicator Weights

(1) Determination of Weights by Individual Experts

Applying the Delphi method, a combination of online and offline questionnaires was administered to experts with postgraduate qualifications or above in fields such as landscape ecology, landscape architecture, design, urban and rural planning, and architecture. The questionnaire theme was "Analysis of the Importance of Ecological Sensitivity in Abandoned Mining Land." Following a pairwise comparison approach, questions were framed such as "Compared to ecological sensitivity in abandoned mining land, which is more important: topographical conditions or surface water systems?" The importance levels were rated on a scale from 1 to 9, where a higher number indicated a higher degree of importance (Table 2).

(2) Analytic Hierarchy Process (AHP)

A. Constructing a judgment matrix

The obtained expert index scores were imported into the Yaahp V11.3 software to construct a hierarchical structure model. The m indicators to be analyzed were then transformed into a judgment matrix A based on the ratings provided by each expert (Table 1).

$$A = \left(a_{ij}\right)_{m\times n} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ a_{n1} & a_{n2} & \cdots & a_{n} \end{bmatrix}, \tag{1}$$

The elements in set A satisfy the following:

$$\begin{array}{l} (1)\ a_{ij} > 0 \\ (2)\ a_{ij} = \frac{1}{a_{ji}} \\ (3)\ a_{ii} = 1 \end{array}, \tag{2}$$

Constructing a judgment matrix involves pairwise comparisons between various elements and determining the weights of each criterion layer on the target layer. In simple terms, this means evaluating the indicators of the criterion layer via pairwise comparisons, typically using Saaty's 1–9 scale method.

B. Hierarchical single sorting

Hierarchical single sorting refers to comparing each element in the current layer pairwise with all other elements in the same layer, conducting hierarchical ranking, and arranging the order of importance. The specific calculations can be based on the judgment matrix A, ensuring that it satisfies the conditions of the characteristic roots and eigenvectors of AW. Here, the maximum characteristic root of A is denoted as $\lambda_{\max}$, and the normalized eigenvector corresponding to $\lambda_{\max}$ is represented as W. Each component of W represents the weight and corresponds to the single sorting of the respective element. Utilizing the judgment matrix, the weights (coefficients) of each factor on the target layer can be calculated. The calculation steps for the weight vector (W) and the maximum characteristic root ($\lambda_{\max}$) using the root method or summation method are shown:

Multiply the elements along each row, and then take the nth root.

$$\overline{W}_i = \sqrt{\prod_{j=1}^{n} a_{ij}}, \tag{3}$$

Normalizing W_i (making the sum of its elements equal to 1) results in the ranking weight vector. Denote this normalized vector as W (where the elements of W represent the relative importance ranking weights of factors in the same hierarchy concerning a factor in the previous hierarchy). Therefore, $W = (W_1, W_2, \ldots, W_n)$.

$$W = \frac{\vec{W}}{\sum_{i=1}^{n}} \frac{i}{W_i} \tag{4}$$

C. Calculating the maximum characteristic root and CI value. Based on the CI and RI values, calculate the CR value to determine whether the consistency is acceptable.

Calculate the maximum eigenvalue of the matrix:

$$\lambda_{\max} = \frac{1}{n} \sum\nolimits_{i=1}^{n} \frac{(Aw)_i}{w_i}, \tag{5}$$

In the formula, n is the order of the judgment matrix, and w_i represents the weight of each factor ($i = 1, 2, \ldots, n$).

$$\mathrm{CI} = \frac{\lambda_{\max} - n}{n - 1}\ \mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}}, \tag{6}$$

In the formula, CI is the consistency index. CI = 0 indicates complete consistency in the judgment matrix. The larger the CI, the more severe the inconsistency in the judgment matrix; CR is the consistency ratio; RI is the random index; the data can be obtained via the random index (R.I.) value table (Table A1). Obtaining the consistency test result $\mathrm{CR} < 0.1$ indicates that the judgment matrix has satisfactory consistency. If CR is greater than or equal to 0.1, it is advisable to consider making adjustments to the judgment matrix A.

$$\begin{aligned} \widetilde{P}_k &= \frac{\sum_{j=1}^{n} W_{jk}}{n} (k = 1, 2, 3, \ldots, 12) \\ P_k &= \frac{\widetilde{P}_k}{\sum_{k=1}^{12} \widetilde{P}_k} (k = 1, 2, 3, \ldots, 12) \end{aligned}, \tag{7}$$

In the formula, P_k represents the normalized subjective assessment weight values.

(3) Classification of Evaluation Indicators

The impact of different indicator factors on the ecological environment varies, referring to the fact that different levels and types have different degrees of impact on the ecological environment. Therefore, refining the indicator factors based on the general phenological characteristics and objective principles of each factor, and combining the characteristics of the study area, a hierarchical assignment is carried out. Ecological sensitivity is divided into 5 levels, and the sensitivity levels of each indicator factor are divided into 9, 7, 5, 3, and 1, corresponding to highly sensitive, moderately sensitive, sensitive, less sensitive, and insensitive ecological sensitivities, respectively. Ecological suitability is categorized as most unsuitable, less unsuitable, suitable, less suitable, and most suitable. Via a literature review, field surveys, expert consultations, etc., the definition and criteria for the division of each indicator factor are clarified (Table 3).

Soil texture refers to the particle composition in the soil, closely related to soil permeability and nutrient content. The growth and development of vegetation are influenced by soil texture. The higher the nutrient content and permeability of the soil, the more luxuriant the vegetation, making it less suitable for development, and the ecological sensitivity is higher [31]. This article primarily refers to the "Green Mining Construction Standard for Non-metallic Mines" (DZ/T 0312-2018) [32] and the "Technical Guidelines for Environmental Impact Assessment—Soil Environment (Trial)" (HJ 964-2018) [33]. It explores the efficacy of different soil textures in serving ecological restoration and evaluates and classifies them accordingly. The soil is categorized as Level I Soil Texture Sensitivity, sandy loam as Level II Soil Texture Sensitivity, clay as Level III Soil Texture Sensitivity, heavy clay as Level IV Soil Texture Sensitivity, and sandy soil as Level V Soil Texture Sensitivity. The slope represents the inclination angle of the ground. The steeper the slope, the more difficult it is for vegetation to recover after damage, making it less suitable for development, and ecological sensitivity is higher. According to the "Technical Regulations for Forest Resource Planning and Design Survey" (GB-T 26424-2010) [34], different slope intervals are classified as follows: flat slope (slope range 0°–5°), gentle slope (slope range 6°–15°), moderate slope (slope range 16°–25°), steep slope (slope range 26°–35°), and steep incline (slope range 36°–45°). Based on the current situation of the study area, the steepest slope is 35.2°, and the gentlest slope is 8.8°. Based on the current conditions in the study area, with the steepest slope being 35.2° and the gentlest slope being 8.8°, an equal interval reclassification was conducted with adjusted intervals, essentially meeting the requirements of the "Technical Regulations for Forest Resource Planning and Design Survey". Slopes above 35.2° are classified as Slope Sensitivity Level I, 26.4°–35.2° as Slope Sensitivity Level II, 17.6°–26.4° as Slope Sensitivity Level III, below 8.8° as Slope Sensitivity Level V, and 8.8°–17.6° as Slope Sensitivity Level IV. Land-use type is classified based on the current state of the land, determining the difficulty of land development and affecting the ability of ecological restoration [35]. The higher the land-use grade, the greater the response of the land ecosystem to human activities and natural environmental changes, making it less suitable for development, and ecological sensitivity is higher [35,36]. According to the "Land Quality Classification for Cultivated Land" (GB/T 33469-2016) [37], forests are classified as Land Sensitivity Zone I, water bodies as Land Sensitivity Zone II, grasslands as Land Sensitivity Zone III, cultivated land as Land Sensitivity Zone IV, and construction land and bare land as Land Sensitivity Zone V. Elevation refers to the height above sea level. Higher elevations are associated with lower biodiversity, indicating higher ecological sensitivity [38]. Based on an elevation difference of 109.5 m in the study area, using equal interval reclassification, with the highest altitude being 93 m and the lowest being −16.5 m, a reclassification with adjusted intervals was conducted. Elevations above 71.2 m up to 93 m are classified as Altitude Sensitivity Level I, 49.4–71.2 m as Altitude Sensitivity Level II, 27.6–49.4 m as Altitude Sensitivity Level III, −16.5 m to 5.8 m as Altitude Sensitivity Level IV, and 5.8–27.6 m as Altitude Sensitivity Level V. The aspect refers to the direction a slope faces, and it influences the reception of solar radiation on the ground, indirectly affecting the photosynthesis of plants [39]. The study area is located north of the Tropic of Cancer, and throughout the year, the noon sunlight predominantly shines on the south-facing slopes, with the north-facing slopes receiving less solar radiation. Therefore, the Aspect I sensitive area is situated in the northern slope region, the Aspect II sensitive area is in the northwest and northeast slope regions, the Aspect III sensitive area is in the east and west slope regions, the Aspect IV sensitive area is in the southeast, and southwest slope regions and the Aspect V sensitive area is on the south-facing slopes and flat terrain.

Due to the unique terrain of the mining pit, precipitation gathers to form site runoff, which can serve as a crucial water resource reserve for future ecological restoration [40,41]. Utilizing a buffer zone analysis based on Euclidean distance measurement, the water body itself is classified as extremely highly sensitive. The closer the buffer zone is to the water body, the less suitable it is for development, indicating higher ecological sensitivity. Therefore, employing the equal interval method, the water body buffer zone is divided into Sensitivity Level I for distances less than 10 m, Sensitivity Level II for distances between 10 m and 30 m, Sensitivity Level III for distances between 30 m and 50 m, Sensitivity Level IV for distances between 50 m and 70 m, and Sensitivity Level V for distances above 70 m. Surface runoff, as an important means of water supply, impacts the growth and development environment of plants. When surface runoff increases, it can erode the soil environment essential for plant survival, which is unfavorable for plant growth. Therefore, after consulting relevant research and seeking advice from an expert in soil and water conservation (at the associate professor level), the sensitivity classification of surface runoff was conducted based on an understanding of its impact range. This classification was carried out in a manner that divides it into suitable intervals [40–44]. Among them, the 5–10 m range is classified as a Level I runoff buffer zone sensitivity area, 0–5 m and 10–15 m are Level II runoff buffer zone sensitivity areas, 15–20 m is Level III runoff buffer zone sensitivity area, 20–30 m is Level IV runoff buffer zone sensitivity area, and above 30 m is Level V runoff buffer zone sensitivity area.

Vegetation type refers to the plant communities covering a specific region on the Earth’s surface, categorized based on different plant communities. Vegetation type is a common qualitative factor that reflects the ecological quality of site vegetation communities. Generally, mixed forests with a multi-layered structure exhibit higher ecological service capabilities and stability compared to ordinary forests, shrublands, grasslands, etc., making them relatively more sensitive. Therefore, mixed forests are classified as Vegetation Type Sensitivity Level I, broadleaf pure forests and coniferous pure forests are classified as Vegetation Type Sensitivity Level II, shrub forests are classified as Vegetation Type Sensitivity Level III, crops and grasslands are classified as Vegetation Type Sensitivity Level IV, and others are classified as Vegetation Type Sensitivity Level V. Vegetation coverage indicates the percentage of the ground area occupied by vegetation (including leaves, stems, branches) about the total area of the surveyed region. Vegetation coverage can be categorized into four types: high, moderately high, moderate, and low. The higher the vegetation coverage and the richer the vegetation types in a certain area, the better the geographical condition of the land unit in that region. Consequently, it is less suitable for development, and the ecological sensitivity is higher [45,46]. Based on a 30% difference in vegetation coverage in the study area, an equal interval reclassification was applied. The highest vegetation coverage is 30%, and the lowest is no vegetation coverage. With equal interval reclassification, areas with vegetation coverage above 30% are classified as Vegetation Coverage Sensitivity Level I, 20–30% as Vegetation Coverage Sensitivity Level II, 10–20% as Vegetation Coverage Sensitivity Level III, 0–10% as Vegetation Coverage Sensitivity Level IV, and areas with no vegetation coverage as Vegetation Coverage Sensitivity Level V.

2.2.2. Multifaceted Landscape Pattern Index Analysis

By using landscape pattern indices to assess the characteristics of landscape patterns and referring to relevant literature, similar index factors were excluded [16,47–52]. Regarding landscape fragmentation, the number of landscape patches (NP) and patch density (PD) were selected to evaluate the degree of landscape fragmentation. For landscape aggregation, patch edge length (TE), edge density (ED), and contagion index (CONTAG) were chosen as evaluation criteria. In terms of landscape diversity analysis, the maximum patch index (LPI) and patch richness (PR) were selected to reflect the richness of landscape patches. The results of the multi-angle landscape pattern index analysis were then combined with ecological sensitivity zoning. A comparative analysis was conducted to explore the connections between them, elucidating the degree of human-induced disturbance and landscape features in different ecological sensitivity zones of abandoned mining areas [53].

2.2.3. Data Sources and Processing

(1) Data sources

To make the obtained conclusions more convincing, the selected data sources were all the latest ones available at the time of the study. Elevation, slope, aspect, and runoff factor data for the ecological sensitivity assessment system of abandoned mining land were derived from the DEM (Digital Elevation Model) of the Geographic Spatial Data Cloud (http://gscloud.cn, accessed on 23 March 2023); water body data were obtained using Baidu API crawling in 23 March 2023 (https://lbsyun.baidu.com/, accessed on 23 March 2023); soil texture data were sourced from the 30 m precision soil type dataset of the Chinese Academy of Sciences in 2022 (http://www.csdn.store/, accessed on 23 March 2023); land-use data were derived from the 30 m precision land-use dataset of the Chinese Academy of Sciences in 2022, manually calibrated (https://www.resdc.cn/, accessed on 23 March 2023); vegetation type data were sourced from the 1:1,000,000 vegetation dataset (http://www.ncdc.ac.cn/, accessed on 23 March 2023); and vegetation cover data were calculated from the 30 m precision NDVI (Normalized Difference Vegetation Index) in 2022 (http://www.ncdc.ac.cn/, accessed on 23 March 2023).

The landscape pattern indices, including NP, CA, PLAND, LPI, TE, ED, SHAPE_MD, AREA_MN, CONTAG, and PR, were calculated based on the reclassified land-use types from the Chinese Academy of Sciences in 2022 (https://www.resdc.cn/, assessed in 23 March 2023). These indices were imported into Fragstats 4.2 for computation.

(2) Data Processing

Using GIS reclassification tools to obtain suitability ratings for individual indicators, a comprehensive ecological sensitivity analysis for the scenic area was conducted using a multi-criteria weighted overlay method [54]. The evaluation model is as follows:

$$S_j = \sum_{i=1}^{n} W_i F_i \tag{8}$$

In the formula, S_j represents the comprehensive score for a specific indicator; W_i is the weight of the i-th indicator; F_i is the score for the i-th indicator; and n is the number of indicators.

3. Results

3.1. AHP Hierarchical Analysis Results

Via investigation, it was found that in the ecological sensitivity terrain conditions of abandoned mining land, the land-use factor is considered the most important factor with a weight of 0.4427. Therefore, land use has the greatest impact on the ecological sensitivity of terrain conditions. Slope aspect and slope gradient, with weights of 0.1633 and 0.2622, respectively, also contribute significantly to the ecological sensitivity of terrain conditions but are not as important as the land-use factor. Soil texture and elevation factors are relatively less important in ecological sensitivity terrain conditions, with weights of 0.0746 and 0.0572, respectively (Table 4). In the ecological sensitivity surface water system conditions of mining waste sites, the runoff buffer zone factor and the water body buffer zone factor are equally important, each with a weight of 0.5000. Therefore, both the runoff buffer zone factor and the water body buffer zone factor have an equal impact on the ecological sensitivity of terrain conditions (Table 5). In the ecological sensitivity vegetation landscape conditions of mining waste sites, the vegetation coverage factor is more important than the vegetation type factor, with weights of 0.6667 and 0.3333, respectively. Therefore, vegetation coverage has a greater impact on the ecological sensitivity of plant landscapes compared to the vegetation type (Table 6).

Table 4. Calculation of terrain conditions.

Terrain Conditions	Soil Texture Factor	Elevation Factor	Slope Factor	Aspect Factor	Land-Use Factor	Wi
Soil Texture Factor	1.0000	2.0000	0.2500	0.2500	0.2500	0.0746
Elevation Factor	0.5000	1.0000	0.2500	0.2500	0.2500	0.0572
Slope Factor	4.0000	4.0000	1.0000	0.3333	0.2500	0.1633
Aspect Factor	4.0000	4.0000	3.0000	1.0000	0.3333	0.2622
Land-Use Factor	4.0000	4.0000	4.0000	3.0000	1.0000	0.4427

Consistency ratio: 0.0989; weight for “ecological sensitivity”: 0.2970; λ_{max}: 5.4432.

Table 5. Calculation of surface water system weights.

Surface Water System	Runoff Buffer Zone	Water Body Buffer Zone	Wi
Runoff Buffer Zone	1.0000	1.0000	0.5000
Water Body Buffer Zone	1.0000	1.0000	0.5000

Consistency ratio: 0.0000; weight for “ecological sensitivity”: 0.5396; λ_{max}: 2.0000.

Table 6. Calculation of vegetation landscape weights.

Vegetation Landscape	Vegetation Type Factor	Vegetation Coverage Factor	Wi
Vegetation Type Factor	1.0000	0.5000	0.3333
Vegetation Coverage Factor	2.0000	1.0000	0.6667

Consistency ratio: 0.0000; weight for "ecological sensitivity": 0.1634; λ_{max}: 2.0000.

Via comprehensive AHP hierarchical analysis, it can be concluded that among the intermediate-level factors, surface water systems are the most important in the ecological sensitivity of mining waste sites, followed by terrain conditions, and finally, plant landscapes (Table 7). Consequently, the hierarchical importance order of single ecological sensitivity factors is as follows: runoff buffer zone factor, water body buffer zone factor, land-use factor, vegetation coverage factor, slope direction factor, vegetation type factor, elevation factor, soil texture factor, and slope gradient factor (Table 8).

Table 7. Middle-layer element ordering.

Mid-Tier Features	Wi
Surface Water System	0.5396
Terrain Conditions	0.2970
Vegetation Landscape	0.1634

Table 8. Single-factor weight ranking for ecological sensitivity.

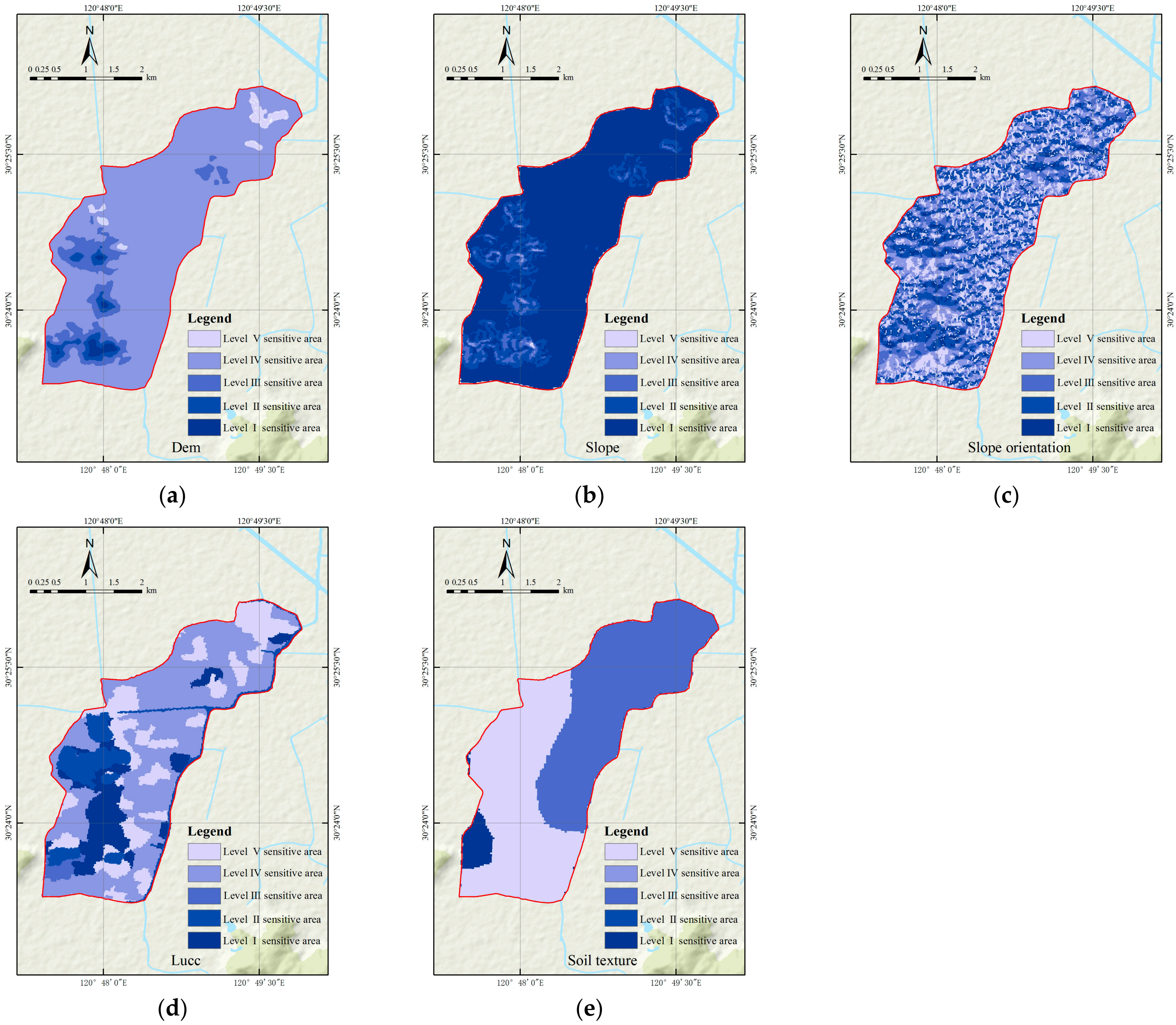
Single Factors	Wi
Runoff Buffer Zone	0.2698
Water Body Buffer Zone	0.2698
Land Use	0.1315
Vegetation Coverage	0.1085
Aspect	0.0779
Vegetation Type	0.0545
Elevation	0.0485
Soil Texture	0.0222
Slope	0.0170

3.2. Ecological Sensitivity Evaluation Results

3.2.1. Single-Factor Ecological Sensitivity Analysis

(1) Sensitivity Analysis of Terrain Conditions

In the sensitivity analysis of terrain conditions, there is a similarity in the sensitivity of factors. This similarity arises due to the subsidence terrain formed by excavation in abandoned mining land, which belongs to a special type of terrain in the study area. Excavation directly alters the elevation, slope, aspect, and land-use type of the original site. Therefore, elevation, slope, aspect, and land-use sensitivity exhibit similar results. However, excavation does not affect the soil texture of the site, leading to different results in soil texture sensitivity analysis. It can be observed that 82.90% of the elevations lie in the range of 5.8–27.6 m, suggesting suitability for development. Only 3.83% of the elevations are above 71.2 m, indicating a higher level of sensitivity. About 80.73% of slopes are below 8.8°, and only 0.3% have slopes exceeding 35.2°, indicating an overall gentle terrain with lower sensitivity. The distribution of slope aspects is relatively even, with 26.04% facing southwest and southeast, 22.98% facing south and flat, 21.19% facing west and east, and 22.92% facing northwest and northeast. Only 6.8% face north. Land use covers five types: water, construction land, arable land, forest land, and grassland. Arable land accounts for 50.74%, construction land for 22.89%, forest land for 12.90%, water bodies for 11.92%, and grassland for only 1.54%. According to the survey, the soil texture in this area consists of three types: red soil, submerged rice soil, and paddy soil. Red soil, being the most sensitive, accounts for only 3.6%, while submerged rice soil occupies 47.24% and paddy soil 49.16%. Overall, the terrain sensitivity in the study area is relatively low, with the main sensitive areas in the southeastern part of the research area, including Huangniushan–Chituding–Mafunling–Putisishan (Figure 4).



(**a**) (**b**) (**c**)

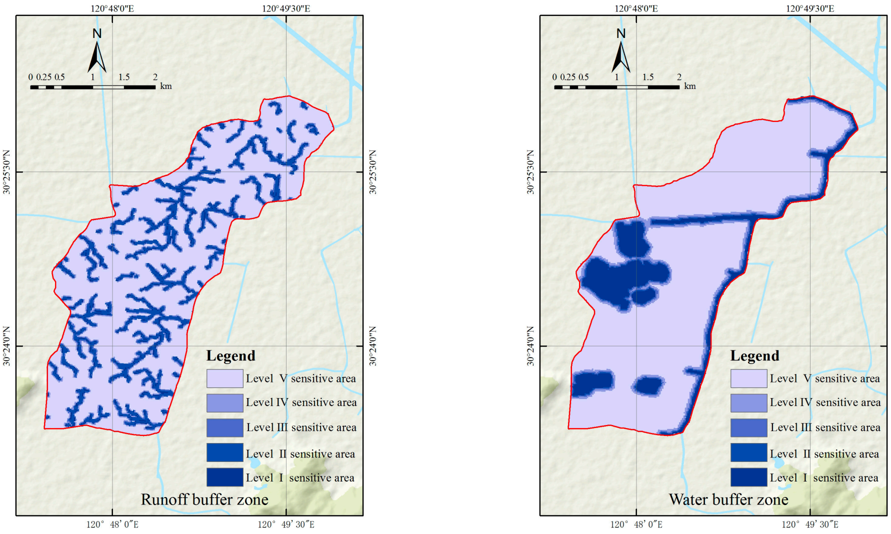
(**d**) (**e**)

Figure 4. Sensitivity assessment of terrain conditions. (**a**) Elevation sensitivity assessment. (**b**) Slope sensitivity assessment. (**c**) Slope orientation sensitivity assessment. (**d**) Land use sensitivity assessment. (**e**) Soil texture sensitivity assessment.

(2) Surface Water System Sensitivity Analysis

Runoff buffer zones are areas located near rivers, lakes, or other water bodies, designed to slow, filter, and absorb runoff water from nearby land. High-sensitivity areas of runoff buffers are distributed throughout various locations in the study area, with Level I and Level II sensitive zones accounting for 18.46% of the runoff buffer zone. Water body buffer zones refer to areas established around water bodies to protect them from direct human or natural impacts. The primary water bodies on the site originate from lakes formed by water injection after excavation. Therefore, high-sensitivity areas of water body buffers are mainly located in the southern pit's water-injected lake and strip-shaped sensitive areas along the main urban watercourse. Level I sensitive zones account for 14.06%, while Level

II sensitive zones account for 2.11%. In addressing the sensitivity of surface water systems and in future planning, emphasis should be placed on the ecological restoration of lakes and water systems (Figure 5).

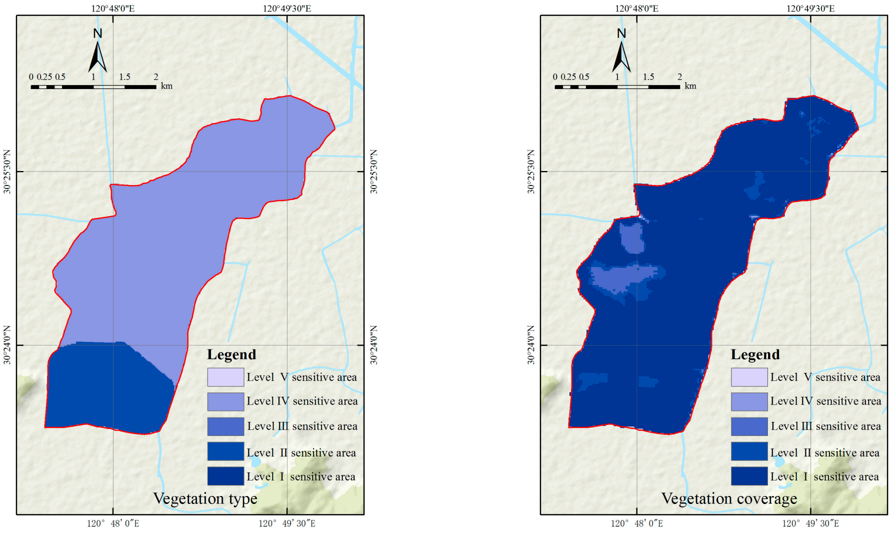


(**a**) (**b**)

Figure 5. Surface water sensitivity assessment. (**a**) Runoff buffer zone sensitivity assessment. (**b**) Water buffer zone sensitivity assessment.

(3) Analysis of Sensitivity in Plant Landscape

The vegetation on the original site refers to the plants used for short-term ecological restoration after artificial excavation. Since the initial planting purpose was not to establish an area resembling a park, the vegetation was planted solely to meet short-term ecological restoration needs without considering the richness and distribution of vegetation coverage. Without systematic planning guidance, it is evident that the vegetation in the area is limited, but the vegetation coverage is high. There are only two types of vegetation—cultivated plants and coniferous forests. Cultivated plants account for 78.20%, while coniferous forests account for 21.80%. The vegetation coverage is generally above 35%. The ecological green environment in the research area is relatively good, indicating a higher sensitivity of the landscape to vegetation (Figure 6).



(**a**) (**b**)

Figure 6. Vegetation landscape sensitivity assessment. (**a**) Vegetation type sensitivity assessment. (**b**) Vegetation sensitivity assessment.

3.2.2. Comprehensive Analysis of Ecological Sensitivity

According to the importance weights obtained from the questionnaire survey in Table 4, they are overlaid and plotted as the comprehensive ecological sensitivity zones (Figure 7). To ensure the rigor of the data, the area and proportion of sensitivity zones after classification were calculated. Additionally, the proportion of individual indicators in the sensitivity comprehensive zones and the proportion of each factor in different sensitivity zones were calculated. This was carried out to identify the correlation with the pre-classification results and validate the consistency of the results.

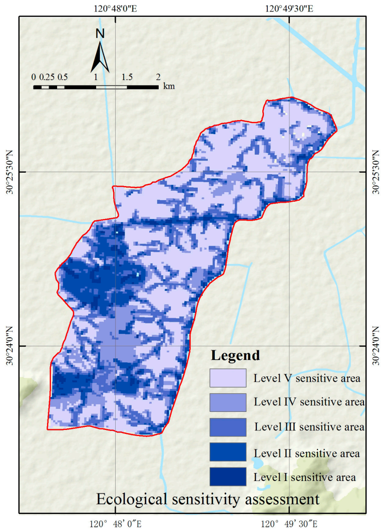


Figure 7. Ecological sensitivity assessment.

It can be observed that in the sensitivity analysis of terrain conditions, 42.18% of soil texture sensitivity is in the V-level sensitive zone and 2.83% in the I-level sensitive zone, indicating that soil texture is less sensitive in the study area. Slope sensitivity is mainly distributed in the III (19.40%), IV (20.99%), and V-level sensitive zones (42.43%). Elevation, slope direction, land type, and the first two factors show a similar trend, consistent with the results of single-factor ecological sensitivity analysis (Figure 4 and Table 9). In the sensitivity analysis of surface water systems, the sensitivity factors of the water body buffer zone and runoff buffer zone account for 42.36% and 44.18% in the V-level sensitive zone, respectively. They also account for 10.94% and 11.247% in the I-level sensitive zone, consistent with the results of single-factor ecological sensitivity analysis (Figure 5 and Table 9). Vegetation type and vegetation coverage are mainly concentrated in the I-level sensitive zone, accounting for 42.36% and 42.48%, respectively, in line with the results of the single-factor ecological sensitivity analysis. Based on the overall trend, it can be observed that, apart from vegetation coverage and vegetation type, the proportion of other factors in different sensitive zones increases from Sensitivity Zone I to Sensitivity Zone V (Table 9). This aligns with the overall trend of comprehensive ecological sensitivity zones. Therefore, in the later stages of overall planning, greater attention should be paid to the planning of plant landscapes, with a rational allocation of their types and coverage in various sensitive zones.

It can be seen that in the study area, the V-level sensitive zone has the largest area, accounting for 42.28%, while the I-level sensitive zone has the smallest suitable area, accounting for 2.84%. Overall, the ecological sensitivity in the study area is relatively low, and there is a wide range for development and construction (Figure 6 and Table 9). The northern mine group is in the V-level sensitive zone, indicating lower sensitivity and suitability for development and construction. The highly sensitive area is located in the southern mine group, with poor ecological environment restoration capability. It should be appropriately protected to reduce human interference. Construction is not advisable along the main river, as it is highly restricted and has a significant impact on the water supply (Table 10).

Table 9. Proportion of each factor in different sensitivity zones.

Sensitivity Zoning	Proportion of Each Subzone for a Single Indicator in the Study Area								
	Soil Texture	Runoff Buffer Zone	Slope	Land Use	Vegetation Type	Vegetation Coverage	Water Body Buffer Zone	Elevation	Aspect
Level I Sensitivity Area	2.83%	2.80%	2.88%	2.82%	42.36%	42.48%	2.78%	2.94%	2.82%
Level II Sensitivity Area	14.22%	14.62%	14.30%	14.50%	14.48%	14.20%	14.48%	14.47%	14.48%
Level III Sensitivity Area	19.61%	19.73%	19.40%	19.72%	19.69%	19.99%	19.69%	19.56%	19.63%
Level IV Sensitivity Area	20.76%	20.46%	20.99%	20.62%	20.69%	20.65%	20.69%	20.63%	20.69%
Level V Sensitivity Area	42.18%	42.18%	42.43%	42.34%	2.78%	2.69%	42.36%	42.40%	42.39%

Table 10. Results of ecological sensitivity assessment.

Sensitivity Zoning	Area/ha	Proportion/%
Level I Sensitivity Area	27.16	2.84
Level II Sensitivity Area	138.09	14.51
Level III Sensitivity Area	187.21	19.68
Level IV Sensitivity Area	196.68	20.67
Level V Sensitivity Area	402.34	42.28

Level I sensitive zones consist of 11.27% soil texture, 11.27% runoff buffer zones, 11.31% slope, 11.12% land use, 10.94% vegetation type, 10.59% vegetation coverage, 10.94% water body buffer zones, 11.57% elevation, and 11.11% aspect. Similarly, the composition of Level II, Level III, Level IV, and Level V sensitive zones can be derived (Table 11). The proportions of the nine factors in each sensitive zone are relatively uniform, indicating the accuracy of ecological sensitivity zoning. Upon examining Table 11, it is observed that the elevation factor plays a significant role in the formation of sensitivity in Level I sensitive zones, exerting a considerable impact on the ecological sensitivity of this area. Therefore, a focus on vegetation restoration, employing native plants adapted to the elevation, is recommended in Level I sensitive zones. Establishing vegetation belts and windbreaks can aid in preventing soil erosion and improving the ecological environment. In Level II, Level III, Level IV, and Level V sensitive zones, the runoff buffer zone factor has the highest proportion, indicating a significant impact on water bodies in these four areas. Hence, strengthening vegetation protection in the runoff buffer zones of these four areas is suggested to slow down water flow, filter pollutants, and ensure the rational utilization of water resources. Balancing water flow can reduce the impact of runoff on water quality.

Table 11. Proportion of individual indicators in comprehensive ecological sensitivity zones of abandoned mining land.

Sensitivity Zoning	The Proportion of Individual Indicators in Various Zones of Comprehensive Ecological Sensitivity.								
	Soil Texture	Runoff Buffer Zone	Slope	Land Use	Vegetation Type	Vegetation Coverage	Water Body Buffer Zone	Elevation	Aspect
Level I Sensitivity Area	11.14%	11.27%	11.31%	11.12%	10.94%	10.59%	10.94%	11.57%	11.11%
Level II Sensitivity Area	10.94%	11.48%	10.95%	11.15%	11.13%	10.92%	11.13%	11.14%	11.15%
Level III Sensitivity Area	11.06%	11.35%	10.88%	11.12%	11.09%	11.27%	11.09%	11.03%	11.09%
Level IV Sensitivity Area	11.12%	11.29%	11.18%	11.04%	11.07%	11.06%	11.07%	11.05%	11.10%
Level V Sensitivity Area	11.14%	11.26%	11.05%	11.08%	11.08%	11.11%	11.08%	11.10%	11.11%

3.3. Analysis of Landscape Patterns and Indices from Multiple Perspectives

To enhance the scientific validity of the obtained data, the research area was reclassified based on the land-use types defined by the Chinese Academy of Sciences, categorizing it into water bodies, built-up land, cropland, woodland, and grassland. The Landscape Pattern Index provides a scientific basis for assessing the ecological sensitivity of the entire region. Similar results were excluded, and at the patch level, seven indices were selected: Patch Area (CA), Percent of Landscape (PLAND), Largest Patch Index (LPI), Edge Density (ED), Total Edge (TE), Area Mean (AREA_MN), and Shape Index Median (SHAPE_MD). At the landscape level, three indices—Landscape Fragmentation, Landscape Aggregation, and Landscape Diversity—were chosen to evaluate the comprehensive sensitivity zoning of ecosystem structure and function, guiding integrated sensitivity zoning landscape planning.

Using Fragstats 4.2 software, landscape fragmentation, landscape aggregation, and landscape diversity were calculated. The analysis was conducted from the perspectives of patch size and sensitivity zoning to assess the ecosystem structure of the entire site. Patch size landscape pattern indices serve as the foundation for different sensitivity zone landscape pattern indices. Together, they guide and evaluate the health and functionality of the ecosystem in the study area.

3.3.1. Analysis of Patch Size Indices

Patches are the most common and crucial landscape elements in landscape structure [15]. The type, area, shape, quantity, and spatial arrangement of patches are key characteristics influencing landscape structure, pattern, diversity, and heterogeneity, as well as various ecological processes and phenomena such as ecological flows and biodiversity [16]. Based on patch area (CA), the proportion of the landscape area occupied by patches (PLAND), the proportion of the landscape area occupied by the largest patch (LPI), the average patch area (AREA_MN), and the size of landscape patches can be determined [18]. The largest patch type in the landscape pattern of abandoned mining land is cultivated land (497.0411 km^2, 21.76%), followed by construction land (224.2153 km^2, 5.05%), and then forest land (126.3182 km^2, 1.54%). Based on the total edge length (TE) and edge density (ED), the degree of aggregation of patches can be determined [18]. The proportions of water bodies, forest land, and construction land are relatively uniform among the various patches. The cultivated land patches (54,478) have the highest aggregation index, while grassland patches (2878) have the lowest aggregation index. Construction land, water bodies, and cultivated land types have relatively large index values. The edge density of grassland (2.9385) is the lowest, while water bodies (30.4406), construction land (44.3564), cultivated land (55.6229), and forest land (25.4213) have higher edge densities. It can be observed that before classification, the site had lower edge density for small patches and higher edge density for large patches. Based on the Shape Median (SHAPE_MD), the diversity of patch shapes is evaluated to assess the diversity of patches. If the SHAPE_MD value is high, it indicates a significant diversity in shape medians, suggesting a diverse landscape shape. Conversely, a lower SHAPE_MD value may indicate a relatively consistent pattern of shape medians in the landscape [18]. Therefore, water bodies (19.455) and grassland (15.1087) exhibit complex shapes and high heterogeneity, followed by cultivated land (10.1437), while developed land (7.0067) and forests (6.0152) are relatively stable (Table 12).

3.3.2. Analysis of Landscape Fragmentation

The number and density of patches help evaluate the degree of landscape fragmentation [55]. The I-level sensitive area has the fewest patches (58) and the lowest patch density (6.0955/100 m^2), indicating the lowest degree of landscape fragmentation. In contrast, the IV-level sensitive area has the highest number of patches (329) and the highest patch density (34.5759/100 m^2), indicating the highest degree of landscape fragmentation. The V-level sensitive area shows a lower degree of landscape fragmentation, while the II-level and

III-level sensitive areas exhibit higher degrees of fragmentation. The ecological protection in the I-level sensitive area is most effective, while other areas experience higher levels of human-induced disturbances (Table 13).

Table 12. Patch size metrics.

Patch Type	Water Bodies	Construction Land	Cultivated Land	Forest Land	Grassland
Number of Patches (NP/piece)	6	32	49	21	1
Area (CA/km^2)	116.7328	224.2153	497.0411	126.3182	15.1087
Percent of Landscape (PLAND/%)	11.9186	22.8928	50.7487	12.8973	1.5426
Largest Path Index (LPI/%)	4.8067	5.0677	21.7623	8.7105	1.5426
Total Edge (TE/m)	29814	42464	54478	24898	2878
Edge Density (ED/hm^2)	30.4406	44.3564	55.6229	25.4213	2.9385
Mean Shape Index (SHAPE_MD//hm^2)	19.4555	7.0067	10.1437	6.0152	15.1087
Mean Patch Area Per Hectare (AREA_MN/hm^2)	1.5126	1.5136	1.1715	1.4127	2.1285

Table 13. Landscape pattern calculation results for different sensitive zones in abandoned mining areas.

Aspect	Landscape Pattern Index	Level I Sensitivity	Level II Sensitivity	Level III Sensitivity	Level IV Sensitivity	Level V Sensitivity
Landscape Fragmentation	NP/piece	58	159	193	329	62
	PD/(piece/100 m^2)	6.0955	16.71	20.2832	34.5759	6.5158
Landscape Aggregation	TE/m	17166	65976	119907	121877	89502
	ED/hm^2	18.0404	69.3369	126.0151	128.0855	94.0613
	CONTAG/%	98.8398	99.6834	99.4564	99.3404	99.8355
Landscape Diversity	LPI/%	0.2382	6.4204	1.6043	4.517	9.9072
	PR/piece	5	5	5	5	5

3.3.3. Landscape Aggregation Analysis

Patch edge length, patch edge density, and landscape contagion index reflect the degree of landscape aggregation [56]. Overall, the landscape contagion index is relatively high, indicating that each sensitive area has well-connected landscape resources. In the IV-level sensitive area, the TE index (121,877) and ED index (128.0855) are the highest, indicating a dispersed landscape with complex edge shapes and diverse edge types suitable for developing distinctive attractions. In the I-level sensitive area, the TE index (17,166) and ED index (18.0404) are lower, suggesting less habitat fragmentation, a relatively stable internal ecosystem, and higher connectivity. The CONTAG index of the V-level sensitive area (99.8355) is the highest, indicating the strongest landscape aggregation in this area.

3.3.4. Landscape Diversity Analysis

The richness of patches reflects the trend of balanced distribution and diversity in the landscape. The maximum patch index represents the proportion of dominant landscapes in the overall composition [57]. Each sensitive area encompasses five types of landscapes, indicating consistent levels of landscape diversity. In sensitive areas of level V, the maximum patch index (9.90%) has the highest proportion, indicating a dominance of specific landscapes. In sensitive areas of level I, the maximum patch index (0.24%) is smaller, suggesting a lower degree of dominance (Table 13).

3.3.5. Comprehensive Landscape Pattern Index Analysis

Via the calculation of landscape patch indices, additional explanations were provided for ecologically sensitive zones, and their relationships were investigated. The degree of landscape fragmentation in the study area increases as the sensitivity of the zones decreases, peaking in level IV sensitive zones before decreasing. Landscape aggregation and landscape fragmentation exhibit opposite trends, starting to decrease from the I-level of landscape aggregation, reaching a minimum at the IV level, and then beginning to increase. Regarding landscape diversity, no intrinsic connection with the sensitivity zone divisions was found, primarily due to the unique topography. Level I sensitive zones exhibit the highest sensitivity but occupy a smaller area and should be comprehensively protected. Level II sensitive zones, characterized by aggregated large blocks with water bodies as the main component, should prioritize conservation with appropriate development. Level III sensitive zones, with diverse patch types and lower sensitivity, are suitable for development. The IV-level sensitive area exhibits the highest degree of landscape fragmentation. It requires optimizing land-use layout and enhancing landscape connectivity. Level V sensitive zones, with the largest extent and the lowest sensitivity, feature a rich landscape with dominant features; the current ecological conservation is good, making them suitable for development and utilization (Table 13).

4. Discussion

According to the comprehensive landscape pattern index analysis, attention should be paid to the degree of landscape fragmentation in the II-level sensitive area, III-level sensitive area, and IV-level sensitive area. These three sensitive areas are mainly composed of water patches and construction land patches. Strategies could include creating green corridors between water bodies and construction land, enhancing ecological connectivity via vegetation connections; designing pedestrian and bicycle lanes around water bodies and construction land to facilitate the flow of people and non-motorized traffic, reducing isolation in the landscape; implementing wetland restoration plans around water bodies to strengthen aquatic ecosystems, increase biodiversity, and alleviate fragmentation of water landscapes; adopting eco-friendly design principles in construction land, such as green roofs and rain gardens, to minimize interference with the natural environment, among other measures. For the I-level sensitive area and V-level sensitive area with good landscape aggregation, optimization and management should be prioritized. The I-level sensitive area and V-level sensitive area are primarily composed of arable land, forest land, and grassland. These two areas may form independent functional zones, contributing to enhanced ecosystem connectivity, the provision of specific habitats, and the facilitation of species migration. It is essential to maintain their original ecological stability. Identifying and protecting key areas of significance for biodiversity and ecosystem functionality in the I-level sensitive area is crucial. Leveraging the high aggregation characteristics, reasonable development should be prioritized for different functions in the V-level sensitive area. Since all five sensitive areas encompass five patch types, exhibiting consistent landscape diversity levels, there should be a focus on delineating different functional zones to endow each area with unique ecological functions.

Based on the comprehensive analysis of ecological sensitivity and landscape pattern indices, the following conclusions are drawn:

(1) The overall ecological sensitivity in the study area is relatively low, with a diverse landscape and high suitability for land-use development. The core protection area is relatively small, and the key protected area is located in the southwest (Level I sensitive zone), where three wetlands are formed by mine water injection. Ecological restoration of mining pits is a key focus for regional development.

(2) In the study area, there is a certain correlation between landscape pattern indices and ecological sensitivity. These indices complement each other, but the correlation is influenced by land types. The regional landscape fragmentation increases as sensitivity zones decrease. As the Level IV sensitive zone is located at the boundary of land types and intersects with multiple sensitive zones, it exhibits the highest degree of landscape fragmentation and the highest landscape aggregation index, making it a potential core tourist attraction.

(3) Considering the landscape pattern indices, in the ecological sensitivity zones, the Level III sensitive zone has a moderate proportion (19.68%), presenting a strip-like distribution. It is connected to all sensitive zones, rich in landscape resources, and has a lower degree of landscape fragmentation. It can serve as an ecological corridor connecting various sensitive zones or as a mediating point for developing highly sensitive areas. The Level V sensitive zone is relatively concentrated, occupying the largest area, mainly composed of construction land and bare land. It is suitable for planning and developing large-scale tourism projects.

To enhance the ecological tourism suitability in the study area, based on the current situation and the comprehensive analysis of ecological sensitivity and landscape pattern indices, the following recommendations are proposed from the perspective of developing and redeveloping abandoned mining areas:

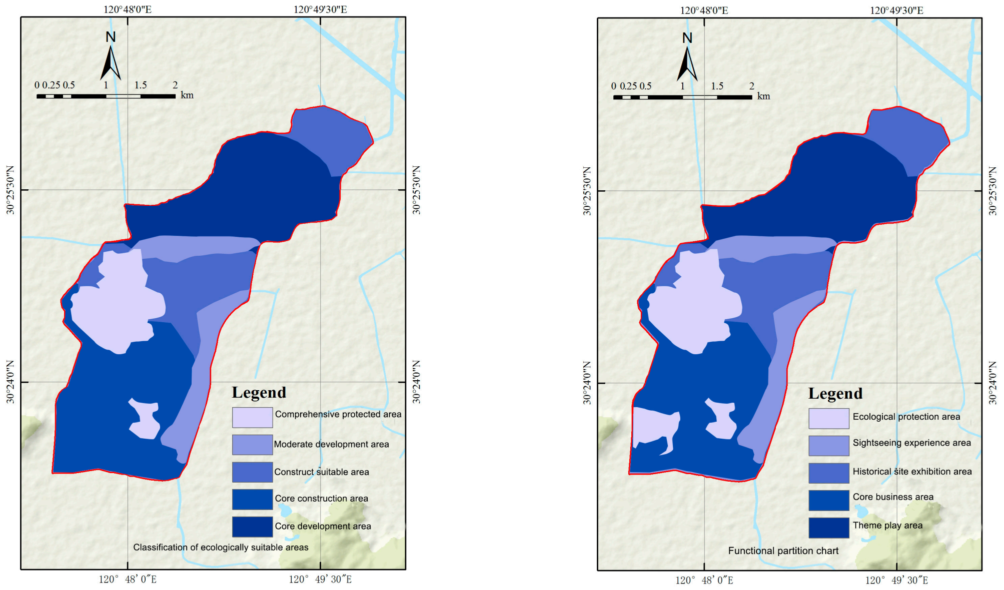
(1) Level I Comprehensive Protection Zone: This high-level protection zone has poor ecological restoration capability and high current ecological quality, making it unsuitable for development. This area, consisting of mine pits filled with water, is situated at a higher elevation and is suitable for ecological restoration and the creation of an ecological park. It is recommended to strengthen measures to prevent environmental risks, resist any development projects, and maintain the natural environment. The Fairy Lake within this zone is a key protection area with high biodiversity, serving as a habitat for various species. Water quality testing and purification, slope protection, and biodiversity conservation should be prioritized. Planning should include altering the overall water circulation system in the region, redirecting water flow only to the south of Fairy Lake, and purifying it via a series of terraced wetlands before introducing high-quality water into the lake. Strict regulations should be imposed on visitor activities to prevent water pollution [58].

(2) Level II Moderately Developed Zone: This semi-developed zone has favorable ecological conditions, emphasizing protection with supplementary development suitable for creating a sightseeing and experiential area. Introducing sightseeing projects is permissible, primarily in the form of educational activities with minimal ecological impact, such as photography and running. Festivals and events, with the Haining Xishan Lantern Festival as a featured attraction, can be organized to appeal to a broader audience [59].

(3) Level III Construction Suitable Zone: This zone is suitable for moderate development, featuring good ecological restoration capabilities and minimal ecological impact from construction. It serves as a reserve base for the core construction zone. With numerous industrial relics, this area is ideal for planning a cultural heritage district focusing on industrial culture relics, displaying the historical heritage of industrial sites, and providing recreation space for reshaping mining pits.

(4) Level IV Core Construction Zone: This highly suitable construction zone, with concentrated foot traffic and low construction difficulty, is suitable for developing theme tourism and commercial activities, becoming a core commercial district. The primary functions include providing unique rural accommodations, local dining experiences, and opportunities for agricultural labor experiences to showcase local customs. Zones for farmer's guesthouses, urban vegetable gardens, children's vegetable gardens, and organic farms are recommended [60].

(5) Level V Core Development Zone: This highly suitable development zone, relying on wetlands formed by water-filled mine pits, possesses excellent aquatic resources. Although the ecological conditions are moderate, the impact of development on local biota is minimal, making it suitable for developing a theme amusement area. Leveraging the terrain, this zone can serve recreational and sports functions, hosting various attractions such as suspended waterfalls, plateau gardens, floating pools, water curtain movies, cliff diving, extreme sports hotels, lake-center bungee jumping, cliff rock climbing, RV campsites, kayaking, cliff tents (Figure 8 and Table 14).



(**a**) (**b**)

Figure 8. Functional zoning. (**a**) Ecological conservation zoning. (**b**) Ecotourism zoning.

Table 14. Ecological conservation level and tourism functional zoning in the study area.

Tourism Functional Zoning	Ecological Conservation Grade	Major Service Functions	Area/ha	Proportion/%
Ecological Protection Area	Comprehensive Protection Area	Primarily focused on conserving water sources and comprehensive protection.	81.07	8.52%
Tourist Experience Area	Second-level Moderately Developed Area	Primarily focused on popular science education, festive events, and projects.	61.47	6.46%
Historical Exhibition Area	Third-level Suitable for Construction Area	Primarily focused on industrial, cultural relics and human landscapes.	307.61	32.33%
Core Business Area	Fourth-level Core Construction Are	Primarily focused on commercial development.	242.15	25.45%
Themed Amusement Area	Fifth-level Core Development Area	Primarily focused on themed amusement and recreational activities.	259.18	27.24%

This study, based on the characteristics of the research area, identified three intermediate factors: topographic conditions, surface water systems, and plant landscapes, and selected nine evaluation factors. It is worth mentioning that the selection of ecological sensitivity factors is not absolute but is influenced by the specific conditions of the research site. For instance, in urban ecological sensitivity research, Chen et al. [22] selected only six factors, including land-use type, slope, aspect, elevation, water buffer zone, and vegetation coverage index. In the study area, abandoned mining lands were flooded to form water bodies, leading to the inclusion of surface water systems as an intermediate factor. These indicators, along with other influential ones, can serve as alternatives to replace evaluation factors within the framework of this study. The nine evaluation factors proposed in this study provide a standardized basis for decision making on the ecologically sustainable development of abandoned mining land. Future research on the construction of abandoned mining land can design alternative evaluation frameworks by adding or eliminating factors as needed. For example, if the abandoned mining land in the research region is entirely extractive, adjustments may be necessary in the sensitivity assessment framework, potentially removing surface water system factors.

In landscape pattern analysis, Dai et al. [15] primarily judged landscape distribution by analyzing indicators such as landscape diversity, dominance, evenness, and fragmentation.

Therefore, in this study, landscape factors were selected, and seven indicators symbolizing landscape fragmentation, aggregation, and diversity were chosen for calculation. Due to the small site area and uniform landscape distribution in this study, the SHDI index results were not informative. Hence, the TE index and ED index were selected as alternatives. The results of landscape pattern indices are deterministic and provide a persuasive complement to ecological sensitivity via landscape pattern indices, enhancing their credibility.

Combining ecological sensitivity with landscape pattern analysis, this paper builds on the work of Zhou et al. [61] and subdivides multi-perspective landscape pattern analysis into patch level and landscape level, making it more persuasive and systematically conducting landscape pattern analysis. In ecological sensitivity analysis, building upon the research of Zhai et al. [62], this paper adds the proportion of individual indicators of abandoned mining land to the comprehensive ecological sensitivity in each zone. This refinement enhances the precision of ecological sensitivity zone data, providing data support for comprehensive ecological sensitivity analysis. Based on the analysis of comprehensive landscape pattern indices, this paper improves upon the suggestions of Liu et al. [63], integrating ecological sensitivity, landscape pattern indices, and patch types to propose systematic planning recommendations.

In this study, the integration of ecological sensitivity assessment of abandoned mining land and landscape pattern analysis still has several shortcomings. For instance, in regional assessments, issues arise due to the unscientific selection of evaluation indicators and criteria, leading to discrepancies between landscape pattern indices and actual conditions. However, considering the universality of abandoned mining land research, the clearly defined evaluation content and indicator system in the “dual assessment” remain the preferred reference for identifying the spatial pattern of the ecological sensitivity of abandoned mining land. Identifying key areas based on ecological sensitivity assessment of abandoned mining land and adjusting indicators and thresholds in conjunction with local conditions for regional sensitivity assessment are fundamental processes in land spatial planning. In future research on ecological sensitivity assessment of abandoned mining land, attention should be given to coupling effects, encompassing both the coupling of different indicators (such as the impact of the spatial combination of surface water systems and terrain control points on ecological sensitivity) and human-environment coupling. Dynamic monitoring of ecological sensitivity should also explore driving factors of human activities and involve extensive public participation to carry out more practical assessments, achieving the goal of coordinated development of resource environment and socio-economic aspects. Additionally, as landscape sustainability science gradually becomes an important theoretical foundation for land sustainable utilization, future research can integrate landscape ecology, emphasizing ecological sensitivity studies in areas with high landscape fragmentation and biodiversity. This will further explore the impact of landscape patterns on the ecological sensitivity of abandoned mining land.

5. Conclusions

This study focuses on the reclamation of abandoned mining land in Haining, Zhejiang, using a research approach that combines ecological sensitivity assessment and landscape pattern indices. The following conclusions were drawn:

In establishing an ecological sensitivity assessment system for abandoned mining land, ecological sensitivity evaluation indicators were selected via a literature survey, identifying topographic conditions, surface water systems, and plant landscapes as intermediate factors. The Delphi method was employed to gather questionnaire data from 25 relevant experts, obtaining weights for the ecological sensitivity evaluation indicators. The evaluation criteria for the assessment factors were reclassified and graded in GIS 10.8 software. Single-factor ecological sensitivity data for nine evaluation factors were obtained using GIS analysis. The entire study area’s ecological sensitivity analysis was then achieved using a multi-index weighted overlay method. The research found that the ecological sensitivity in the study area is generally low, with the main sensitive areas located in the southern pit group. By converting ecological sensitivity into ecological suitability evaluation criteria, it was determined that the southern pit group should be prioritized for protection while development is encouraged in the V-level sensitive area.

Comprehensive ecological sensitivity data and reclassified landscape patch data were imported into Fragstats 4.2 to calculate landscape pattern indices at the patch and landscape scales. The most suitable landscape patches for development within the site were identified as agricultural land. Landscape fragmentation and landscape aggregation levels exhibited opposite trends, both centered around the IV-level sensitive area as a critical point, while landscape diversity levels remained consistent. Therefore, the importance of the IV-level sensitive area should be emphasized in later planning.

By comparing landscape pattern indices, ecological sensitivity, and patch sizes, it was observed that the I-level and V-level sensitive areas are mainly composed of agricultural land, forest land, and grassland, with good landscape aggregation. The V-level sensitive area is suitable for development, while the I-level sensitive area should be fully protected. The II-level, III-level, and IV-level sensitive areas consist mainly of construction land and water bodies, with a more dispersed landscape, requiring measures to connect patches. Corresponding planning recommendations were formulated for each of the five patch types, providing insights for similar types of abandoned mining land.

The study suggests that planning and development for abandoned mining land should focus on concurrent development and ecological considerations. The research outcomes contribute to maximizing the ecological and economic benefits of reshaping abandoned mining land, promoting sustainable development, and enriching the theoretical framework to guide landscape planning for similar types of abandoned mining land.

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Appendix A

Table A1. Table of random index (R.I.) values.

Order of the Judgment Matrix	1	2	3	4	5	6	7	8	9	10	11	12
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.54

Table A2. Landscape pattern index list and selection significance.

Indicator Name	Unit	The Significance of Selection	Function
Number of Patches	piece	Characterizes the number of discrete habitats or land-use types within the landscape.	Provides a comprehensive understanding of habitat diversity and complexity within the landscape, aiding in the assessment of the richness of the ecosystem.
Area (CA)	/km^2	Indicates the area of each discrete habitat or land-use type.	Used to understand the sizes of different habitats, contributing to the evaluation of the various land uses' impact on the ecosystem.
Percent Of Landscape (PLAND)	/%	Represents the relative size of each patch within the entire landscape area.	Offers an assessment of the relative contributions of different patches within the entire landscape, assisting in understanding the structure of the landscape.
Largest Path Index (LPI)	/%	Describes the total edge length between all patches in the entire landscape.	Provides overall information about the landscape boundary, aiding in the assessment of the morphological complexity of the landscape.
Total Edge (TE)	m	Indicates the edge length between each patch and its adjacent patches.	Offers information about local habitat boundaries, helping to understand the characteristics of habitat transition zones.
Edge Density (ED)	m/hm^2	Describes the edge length of patches per unit area.	Measures the edge complexity of the landscape, guiding the evaluation of ecosystem stability and habitat quality.
Mean Shape Index (SHAPE_MD)	/hm^2	Represents the median value of patch shape.	Provides an evaluation of patch shape diversity, contributing to an understanding of the landscape's morphological structure.
Mean Patch Area Per Hectare (AREA_MN)	/hm^2	Describes the average area of patches in the entire landscape.	Offers a comprehensive understanding of patch sizes within the landscape, assisting in the assessment of the overall habitat structure of the landscape.

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