Identifying and Zoning Key Areas of Ecological Restoration for Territory in Resource-Based Cities: A Case Study of Huangshi City, China

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Abstract: Resource-based cities are cities that depend on the exploitation and primary processing of natural resources, such as minerals, metals, and oil, and whose rise and development are highly dependent on resources. Due to over exploitation, many problems related to ecosystem degradation have been caused. Ecological restoration of land space is urgent. One of the difficulties in carrying out ecological restoration of territorial space lies in the identification of key areas for ecological restoration and diagnosis of regional ecological problems. In this study, we applied the spatial assessment of ecological sensitivity and the Integrated Valuation of Ecosystem Services and Trade-offs (InVEST) model to quantitatively analyze the overall ecosystem in Huangshi city so as to delimit the ecological restoration division of Huangshi City. The results showed that: (1) The overall distribution rule is that vegetation, such as that in mountains and forests, is dense, the sensitivity around water and wetlands is high, and the distribution of mines in Huangshi is high. (2) For the period 1980–2018, the habitat quality index of Huangshi was good, with a slight decreasing trend. The simulated habitat quality distribution was consistent with the region-dominated land cover type. (3) Huangshi formed a spatial pattern with natural protected areas as the priority protection areas, mining areas as the key restoration areas, and natural protected areas and mining areas as the general restoration areas. (4) During the period of 1980–2018, the water management of Huangshi generally improved, which indicates that the water pollution control in Huangshi had a positive effect. The results of this study can provide some reference for the green transformation development and ecological restoration of resource-based cities.

Keywords: ecological restoration zoning; ecological sensitivity; InVEST model; resource-based city

1. Introduction

Resource-based cities are those that rely on the exploitation and primary processing of natural resources, such as minerals, metals, oil, and forests, and whose rise and development are highly dependent on the resources [1]. During the development of resource-based cities, long-term dependence on resource extraction caused significant problems in the ecosystem, including frequent geological disasters, which seriously hinder the stability and sustainable development of the regional ecological environment. Evaluation of the ecological environment, identification of means to repair the ecosystem, and realization of the sustainable development of the resource-based city are realistic challenges and urgent tasks currently faced in China [2].

China is paying significant attention to land space ecological restoration, and issued a series of documents to specify requirements for ecological restoration work. In February 2016, the State Council of the People’s Republic of China issued the “Opinions of the State Council of the People’s Republic of China on Further Strengthening of Urban Planning, Construction, and Management Work”, which proposed restoration of natural ecology in cities and systematic requirements for restoring damaged mountains, rivers, wetlands, and
vegetation. On March 2019, Premier Li Keqiang proposed ecological reform at the Second Session of the 13th National People’s Congress, and land space ecological restoration has been upgraded to become a national strategy and research priority.

The earliest mention of regional ecological restoration was in the 1930s when the American researcher Aldo Leopold proposed the concept of “land health” in the land ecology field [3]. Subsequently, Europe and North America conducted exploratory studies of regional ecological problems. In recent years, theoretical studies of ecological restoration in other countries have focused on methodology, including ecosystem reorganization [4], remote sensing of ecological restoration [5], path nesting [6], pixel-specific linear regression [7], and other emerging research methods. Research of land space ecological restoration started late in China and mainly focused on ecological restoration sites and small areas of damaged regions. Initial research focused on soil and water conservation and management of soil erosion [8,9], mine governance and ecological restoration [10], remediation and reclamation of abandoned mines [11], governance of eutrophication in rivers and lakes, and water conservation function zoning [12], where zoning is based on the evaluation of a single function. Significant results were obtained in local studies but there is still a lack of systematic integration. There are few studies on maintaining the ecosystem integrity and overall functional upgrading, and a weak grasp of the entire system at study sites. Hence, in-depth studies of land space ecological restoration at the macroscopic scale are required.

One key to achieving land space ecological restoration is scientific delineation of ecological restoration zones and accurate identification of the ecological problems in each zone [13]. In recent years, researchers have employed ecological risk assessment [14], ecological security assessment [15], ecological security patterns [16,17], and habitat succession models [18] for exploration and attempts at creating regional ecological restoration zones. China’s scholars have made progress when discussing the establishment of an indicator system and the methods of regional division. For example, Liu et al. [19] applied an integrated modeling approach to implement ecological zoning in the Bohai Rim, and selected 12 single factors to calculate the ecosystem sensitivity, ecosystem services, and ecological risks to achieve regional sustainability. Wang et al. [20], taking the Tacheng Basin, Xinjiang, China as an example, established an evaluation index system including three aspects: ecological protection suitability, agricultural production suitability, and urban development suitability. The spatial functional zoning of the study area was carried out from the perspective of coordinated development of ecology and the economy. In general, the current ecological zoning mainly includes ecological function zoning, ecological management zoning, sustainable use zoning, and ecological restoration zoning based on ecological carrying capacity evaluation and ecosystem service value evaluation [21–24]. Studies of ecological restoration zoning mostly focus on one function [25], which has limitations for land space ecological restoration because research on this emerging field emphasizes systematicity, integrity, and connectivity. In addition, there are few studies of overall ecological restoration and optimization of resource-based cities. For example, Ni et al. [26] delimit ecological restoration zoning by identifying ecological security patterns. Zhu et al. [27] identified key protected areas using grading based on ecological sensitivity evaluation. These methods are applicable to ecological restoration zoning of territories in macro geographical units, but rarely involve cities with typical characteristics such as resource-based cities.

Huangshi is a regional center for the middle reaches of the Yangtze River. Huangshi is an advanced manufacturing base that was successively selected within the second group of national ecological civilization demonstration regions, and was selected by Hubei province to be a sub-central city to Wuhan. As a classical resource-based city in central China, development of integrated landscape ecological management creates an opportunity for the city to demonstrate improvements in its ecological environment and model green transformation of industrial cities.

Huangshi was selected as the study site and ecological restoration spaces were selected for combined ecological sensitivity evaluation and habitat quality evolution analysis. We
attempted to identify the key land space ecological restoration areas and divide these into ecological restoration zones, so as to provide methodological guidance for the ecological restoration zoning of land space in resource-based cities. On this basis, we followed the “one strategy for one area” requirements [28] to provide objective suggestions for improving the restoration management of ecological areas in resource-based cities.

2. Material and Methods

2.1. Study Area

Huangshi is located in the southeast of Hubei province in China, on the south bank of the middle reaches of the Yangtze River. Its geographical extent is 114°31’ E to 115°30’ E and 29°30’ N to 30°15’ N. There are 4 districts in Huangshi (Huangshigang District, Tieshan District, Xialu District, Xisaishan District), one county-level city (Daye City), one county (Yangxin County) under its jurisdiction. The total area is 4583 km² and the municipal district area accounts for 5.17% of the total area. The location and land use types of Huangshi in 2018 are shown in Figure 1. In 2018, the permanent resident population of Huangshi was 2.47 million, among which 0.88 million people were urban, accounting for 35.70% of the total population.

Figure 1. Location and land use types of the study area in 2018.

Huangshi has a subtropical monsoon climate with district seasons, abundant rainfall, and an annual mean temperature of 17 °C. Huangshi is located in the transition zone extending from Mufu Mountains to the alluvial plain of the Yangtze River. It is a low-mountain and hilly landform, with low mountainous areas in the southwest and hilly lacustrine areas in the northeast. The forest coverage rate is 38.05%. A wide variety of plants grow in the area. According to the information provided by the Natural Resources and Planning Bureau of Huangshi, there are more than 3000 species of higher plants, many of which are oil plants, medicinal plants, food plants, aromatic plants, and timber species. Huangping Mountain, Dawang Mountain and other areas have protected species
of leopard (*Panthera pardus*), clouded leopard (*Neofelis nebulosa*), wolf (*Canis lupus*), pangolin (*Manis pentadactyla*), northern goshawk (*Accipiter gentilis*), and other wild animals. Tundra swan (*Cygnus columbianus*) and Reeves pheasant (*Syrmaticus reevesii*) are present on Zhupo Lake.

Huangshi has a long history of mining. In 1916, the Daye Iron Mine was established and a large number of minerals were mined. Subsequently, Daye Iron Mine has become a major raw material industrial base for large steel mills in central China. During one hundred years of development, the mineral resources in Huangshi have become gradually exhausted, resulting in a series of geological environment problems, such as mine collapse, landslides, debris flows, ground subsidence, goaf collapse, land resource destruction, aquifer destruction, and soil and water body pollution. In 2013, Huangshi was classified as a resource-exhausted city. Therefore, Huangshi is a typical resource-based city in China, both in terms of its history and construction scale.

### 2.2. Data Sources

The digital elevation model (DEM) of Huangshi was obtained from the geospatial data cloud platform and used to extract elevation and gradient data. The normalized difference vegetation index (NDVI) and distribution of vegetation types were obtained from the National Earth System Data Science Center. Daily precipitation data for the past 30 years from six national meteorological stations in Huangshi and its surroundings were obtained from the China Meteorological Administration website. Soil data was obtained from the Resource and Environment Data Science Center. This dataset consists of a 1:1 million map of soil type and soil organic matter content that is used to calculate soil erodibility factors of the study area. The administrative region boundaries, geological disasters, and mining data of Huangshi were obtained from the statistical yearbook of Huangshi and Huangshi master plan, and provided by the Huangshi Natural Resource and Planning Bureau. Huangshi wetland distribution data and data on various nature reserves were obtained from Huangshi Ecology and Environment Bureau.

In contrast to other cities, resource-based cities have specific development cycles, which are the growth, maturation, and exhaustion cycles. Different developmental cycles can reflect different land use patterns, thereby affecting habitat quality and evolution [29]. Therefore, we selected 1980, 2000, 2010, and 2018 as years representing the three developmental stages of Huangshi for habitat quality assessment. These stages reflect rapid economic growth, mature development, and stable development of the study area, respectively. The remote sensing maps of Huangshi were interpreted to obtain land use information during the three developmental stages. Pre-processing of the above data was carried out in the ArcGIS 10.2 software. A 30 × 30 m raster was used as the basic assessment unit for spatial data used for calculation and the WGS 1984 UTM Zone 49N projection coordinate system was used uniformly for the coordinates.

### 2.3. Methods

#### 2.3.1. Ecological Environment Sensitivity Analysis

**Selection of Assessment Factors**

Ecological sensitivity is an important marker that is used to measure the degree of ecosystem interference due to the combined effects of natural environment changes and human activities [30,31]. Ecological problems are diverse and complex. Therefore, the selection of ecological sensitivity factors also differs due to differences in spatial regions and study scale. The common characteristics of resource-based cities and data availability were used for selection of ecological sensitivity factors for the study area. These factors were combined with land space ecological restoration requirements for examination of four areas (mining, geological disasters, biodiversity, and soil erosion). Geological disasters are frequent in resource-based cities due to excessive mining and complex topography. Disasters have negative effects on regional ecosystems and ecological environments. We selected mine distribution density and mine area as important factors at the mining crite-
rion layer [32,33]. In addition, the degree of governance by the local government agencies of the mining environment is also an important marker that affects its sensitivity. For this layer, we selected mine management level and type of mining control as influencing factors. Many years of mining and poor geological conditions have resulted in severe geological disaster development in Huangshi. In recent years, the effects of urban construction, traffic construction, and other human activities have resulted in frequent geological disasters. These disasters are mainly collapses, landslides, mudflows, and cave-ins. Geological disasters are diverse, frequent, and have relatively dense distribution. Therefore, geological disaster diversity, susceptibility, and distribution density were selected as influencing factors. Biodiversity is impacted by forests and wetlands, and differences in vegetation type and aquatic environment quality directly affect ecosystem integrity and stability. Wetlands are an important part of the ecosystem and a decrease in wetland environmental quality and protective function directly affects ecosystem integrity and stability. Different types of vegetation have different water retention capacities and provide important habitats for survival and proliferation of organisms [22]. Nature reserves are areas in the region with the highest habitat quality and were therefore selected as another important indicator of the biodiversity layer. Soil erosion is an important factor layer that affects ecological sensitivity. Soil erosion not only results in the loss of water and soil resources, and destruction of soil productivity, but can also threaten human life. Based on the literature [34–36], rainfall erosivity, soil erodibility, relief, and fractional vegetation cover were selected as representative factors.

Establishment of Indicator System

The grades of various evaluation factors were assigned based on the grading criteria in the national ecological sensitivity indicator system, study observations [37,38], and the ecological characteristics of resource-based cities, urban development, and construction requirements. The ArcGIS10.2 software was used as the technical support platform. Based on the spatial distribution status of the ecological sensitivity evaluation index S, the natural break method [39] was used to classify the sensitivity of a single factor as extremely sensitive, sensitive, less sensitive, and not sensitive, and assigned values of 7, 5, 3, and 1, respectively. Finally, the ecological sensitivity evaluation indicator system and weights for Huangshi were confirmed (Table 1).

Ecological Sensitivity Calculation

1. Univariate sensitivity evaluation. Instead of employing conventional hierarchical analysis, the entropy weight method was used to objectively assign weights for various factors [40,41]. The specific steps are as follows:

   Indicators in the system are either positive or negative. To facilitate comparison, range standardization was used for standardization of the original markers.

   The equation for positive indicators is:

   \[ x'_{ij} = \frac{x_{ij} - \min \{x_j\}}{\max \{x_j\} - \min \{x_j\}} \]  

   The equation for negative indicators is:

   \[ x'_{ij} = \frac{\max \{x_j\} - x_{ij}}{\max \{x_j\} - \min \{x_j\}} \]  

   where \( x'_{ij} \) — standardized value, \( x_{ij} \) — original indicator value; \( \max \{x_j\}, \min \{x_j\} \) — maximum and minimum values, respectively, of the original indicator.
Table 1. Indicators of the ecological sensitivity evaluation in Huangshi.

<table>
<thead>
<tr>
<th>First-Class Indicators</th>
<th>Second-Class Indicators</th>
<th>Weight</th>
<th>Classification Standards of Ecological Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Extremely Sensitive</td>
</tr>
<tr>
<td>Mining</td>
<td>Mine distribution density (mines/km²)</td>
<td>0.251</td>
<td>&gt;0.1</td>
</tr>
<tr>
<td></td>
<td>Mine area (km²)</td>
<td>0.252</td>
<td>&gt;0.8</td>
</tr>
<tr>
<td></td>
<td>Mine management level</td>
<td>0.249</td>
<td>Key governance area</td>
</tr>
<tr>
<td></td>
<td>Type of mining control</td>
<td>0.248</td>
<td>Key mining area</td>
</tr>
<tr>
<td>Geological disaster</td>
<td>Geological disaster diversity (hazards/km²)</td>
<td>0.374</td>
<td>Strong disaster or multiple disasters</td>
</tr>
<tr>
<td></td>
<td>Susceptibility</td>
<td>0.251</td>
<td>High susceptibility</td>
</tr>
<tr>
<td></td>
<td>Geological disaster distribution density</td>
<td>0.375</td>
<td>&gt;0.5</td>
</tr>
<tr>
<td>Biodiversity</td>
<td>Nature reserve level</td>
<td>0.268</td>
<td>National nature reserve</td>
</tr>
<tr>
<td></td>
<td>Wetland buffer distance</td>
<td>0.343</td>
<td>&lt;100 m buffer area</td>
</tr>
<tr>
<td></td>
<td>Vegetation type</td>
<td>0.389</td>
<td>Arboreal forest</td>
</tr>
<tr>
<td>Soil erosion</td>
<td>Rainfall erosivity</td>
<td>\</td>
<td>&gt;600</td>
</tr>
<tr>
<td></td>
<td>Soil erodibility</td>
<td>\</td>
<td>&gt;0.08</td>
</tr>
<tr>
<td></td>
<td>Relief degree of land surface</td>
<td>\</td>
<td>&gt;300</td>
</tr>
<tr>
<td></td>
<td>Fractional vegetation cover</td>
<td>\</td>
<td>&gt;0.7</td>
</tr>
</tbody>
</table>

The ratio of the i-th sample under the j-th indicator was calculated as:

\[ p_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}} \]  \hspace{1cm} (3)

The entropy of the j-th indicator was calculated as:

\[ e_j = -k \sum_{i=1}^{n} P_{ij} \ln P_{ij} \]  \hspace{1cm} (4)

where \( k = 1/\ln m > 0 \), which satisfies \( e_j \geq 0 \).

Information entropy redundancy was calculated as:

\[ d_j = 1 - e_j \]  \hspace{1cm} (5)

The weights of various indicators were calculated as:

\[ w_j = \frac{d_j}{\sum_{j=1}^{m} d_j} \]  \hspace{1cm} (6)
After confirming the weights of various indicators, mining, geological disaster, and biodiversity sensitivities were calculated as follows as:

$$ES_i = \sum_{j=1}^{n} w_j \cdot u_j$$  \hspace{1cm} (7)$$

where $w_j$ is the weight of the $j$th sensitivity factor and $u_j$ is the value of the $j$th factor.

For soil erosion sensitivity, the universal soil erosion formula was used as a theoretical basis and the layer data reflecting the sensitivity of various factors towards soil erosion were multiplied for evaluation. The formula is as follows [42–45]:

$$SE = 5 \sqrt{R \times K \times LS \times C \times P}$$  \hspace{1cm} (8)$$

where $SE$ is the soil erosion sensitivity index, $R$ is the precipitation erosivity factor, $K$ is the soil erodibility factors, $C$ is the surface vegetation cover factor, and $P$ is the soil and water conservation factor.

Integrated ecological sensitivity assessment on the basis of univariate evaluation: disjunctive operation (maximum value method) was used for integrated sensitivity assessment. The equation is as follows [22]:

$$ES = \text{Max}\{ES_1, ES_2, ES_3, \ldots, ES_i\}$$  \hspace{1cm} (9)$$

where $ES$ is the ecological importance of the assessment unit and $ES_i$ is the ecological service importance of each factor. The quartile method was used to classify integrated ecological sensitivity assessment results as high sensitivity, fair sensitivity, moderate sensitivity, and low sensitivity. High sensitivity areas were selected as key protection regions in the study area.

2.3.2. Analysis of Spatiotemporal Changes in Habitat Quality

InVEST Model

In this paper, the Habitat Quality module in the InVEST model was used to assess habitat quality. The InVEST model is a new method to evaluate the impact of human activities on the environment [46,47]. The greater the intensity of human activities, the greater the threat faced by the habitat, the lower the habitat quality, and the lower the biodiversity level. Conversely, the lower the interference of human activities on the region, the greater the habitat quality, and the higher the biodiversity level. Cong et al. [48] compared the InVEST model with the Soil and Water Assessment Tool (SWAT) model, and determined hydrological ecosystem service spatial patterns, priorities, and trade-offs in a complex basin. The results were similar, indicating that the InVEST model has a scientific basis. The sensitivity of different land use types to different threat factors and external threat intensity were combined to calculate the degree of degradation in habitat quality and habitat quality was further calculated.

To model habitat quality, based on the manual of the InVEST model [49], and related studies [46,50–53], this study used LUCC (Land-Use and Land-Cover Change) data to calculate the habitat quality, which was determined through the relative weight of each threat factor, the habitat suitability of each threat factor, the distance between habitat and threat sources, and the type of spatial degradation. Different geospatial data parameters were compiled using ArcGIS10.2. The attributes of threat factors and the sensitivity of habitat types to threat factors are shown in Tables 2 and 3.
Table 2. Threat factor, their weight, decay, and maximum impact distance in the reserve.

<table>
<thead>
<tr>
<th>Threat Factor</th>
<th>Maximum Threat Distance</th>
<th>Weight</th>
<th>Type of Spatial Degradation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cultivated land</td>
<td>8</td>
<td>0.7</td>
<td>Linearity</td>
</tr>
<tr>
<td>Urban land</td>
<td>10</td>
<td>1</td>
<td>Index</td>
</tr>
<tr>
<td>Rural residential sites</td>
<td>5</td>
<td>0.6</td>
<td>Index</td>
</tr>
<tr>
<td>Mining land</td>
<td>12</td>
<td>1</td>
<td>Index</td>
</tr>
<tr>
<td>Roads</td>
<td>3</td>
<td>0.5</td>
<td>Linearity</td>
</tr>
</tbody>
</table>

Table 3. Land use/cover types and their sensitivity to the threats.

<table>
<thead>
<tr>
<th>Name of Land Type</th>
<th>Habitat Suitability</th>
<th>Threat Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Cultivated Land</td>
</tr>
<tr>
<td>Cultivated land</td>
<td>0.5</td>
<td>0.3</td>
</tr>
<tr>
<td>Forests</td>
<td>1.0</td>
<td>0.8</td>
</tr>
<tr>
<td>Grassland</td>
<td>0.9</td>
<td>0.5</td>
</tr>
<tr>
<td>Water bodies</td>
<td>1.0</td>
<td>0.1</td>
</tr>
<tr>
<td>Construction land</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Unused land</td>
<td>0.1</td>
<td>0.1</td>
</tr>
</tbody>
</table>

The calculation equation [49] for habitat quality is as follows:

\[ Q_{ij} = H_j \left[ 1 - \left( \frac{D_{xj}}{D_{ij}^z + k^z} \right) \right] \]  

(10)

where \( Q_{ij} \) is the habitat quality index of raster unit \( x \) in land type \( j \); \( H_j \) is the habitat suitability of land type \( j \); \( D_{xj} \) is the degree of habitat degradation of raster unit \( x \) in land type \( j \); \( z \) is the conversion factor, which is the recommended value in the InVEST model manual and set as 2.5 in this paper; and \( k \) is the half-saturation coefficient, for which 0.5 is the default parameter in the InVEST model.

Rate of Change of Habitat Quality

The rate of change of habitat quality refers to the change percentage of habitat quality of a region at the end of a time period relative to that at the initial timepoint within a specified time period. The calculation formula is as follows [54]:

\[ v = \frac{(P_{t_1} - P_{t_0})}{P_{t_0}} \times 100\% \]  

(11)

where \( v \) is the rate of change of habitat quality; a negative value indicates habitat quality decreased, whereas a positive value indicates habitat quality increased. \( P_{t_0} \) and \( P_{t_1} \) are the initial value and end of time period value, respectively, for habitat quality.

2.3.3. Ecological Restoration Zoning

Using integrated ecological sensitivity grade results as a basis for consideration of land space ecological restoration requirements, high sensitivity regions were identified as key restoration areas, fair sensitivity regions were considered to be priority protection areas, moderate sensitivity regions were considered as general restoration areas, and other regions were divided into ecological promotion areas. These areas were used as preliminary zoning results for land space ecological restoration. The results were combined with the spatial distribution evolution of habitat quality grades in the four time periods from 1980 to 2018 and integrated ecological sensitivity analysis results were superimposed with habitat variation areas. The ArcGIS10.2 software was used for adjustment of preliminary zoning results and small areas in the various regions that did not match the actual results were
removed and combined with major area types in neighboring areas. The spatial distribution of forests and water bodies was considered, the boundaries of ecological restoration zones were verified, and zoning was carried out based on ecological sensitivity and habitat quality analyses. Analysis and evaluation were performed in the horizontal and vertical directions so that the zoning results were more objective and complete.

3. Results
3.1. Ecological Sensitivity Analysis
3.1.1. Univariate Sensitivity Analysis
First, the univariate ecological sensitivity of the study area was analyzed (Figures 2–5). Soil erosion sensitivity in the study area was concentrated in low sensitivity and non-sensitive regions, accounting for 12.67% and 71.92%, respectively. The spatial distribution shows that terrain significantly affects soil erosion, whereas altitude and gradient both affect soil texture and surface vegetation growth in the study area. The area of soil erosion high sensitivity regions accounted for 4.68% of the total area of the study area and was concentrated in the center and southwest of the study area. These regions show diverse topography and high fractional vegetation cover. Regions with high biodiversity sensitivity are concentrated in nature reserves in the study area and accounted for 11.86% of the study area. Fractional vegetation cover was high in some high sensitivity areas whereas other areas were wetlands that have high ecological service value. Mining had directly damaged surface vegetation, resulting in soil degradation and soil erosion. Therefore, northern Huangshi, with a high density of mines, has extremely high ecological sensitivity. High sensitivity and moderate sensitivity regions accounted for 6.79% of the study area. These regions have a high density of mines and the mined area is large. Geological disasters are frequent, diverse, and show a dense distribution in parts of Huangshi. Geological disaster high sensitivity and moderate sensitivity regions account for 0.66% and 6.11%, respectively, and are concentrated in northern and central Huangshi.

Figure 2. Mining sensitivity grading of Huangshi. (a) Mine density (mines/km²); (b) mine area (km²); (c) mine management level; (d) type of mining control.
3.1.2. Integrated Sensitivity Analysis

The raster calculator tool in ArcGIS10.2 was used for weighted superimposition of univariate ecological sensitivity for calculation of the integrated ecological sensitivity score and generation of an integrated ecological sensitivity grade map of Huangshi (Figure 6). Overall, Huangshi has high ecological sensitivity and the overall distribution trend is toward high sensitivity in the mountain forests and water bodies. There is a high density of mines in the city and low density of mines in the southwest region. High and moderate ecological sensitivity regions in Huangshi are mainly located at Dongfang mountain, Dazhong mountain, Huangjing mountain, and Bao’an lake in the north, and Lei mountain, Dawang mountain, Qifeng mountain, and Wanghu lake in the center, which account for 23.02% and 35.70% of the total area, respectively. These regions are mostly mountain forest and lakes, with diverse terrain, high fractional vegetation cover, diverse biological species, and high ecosystem services, resulting in high ecological sensitivity. In the northern part, there is a high density of mines and intense human activities. Therefore, geological disasters are frequent in this region, resulting in a fragile ecological environment and high ecological sensitivity.
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The total area of low sensitivity regions is 23.23% and most regions are located at the eastern and southeastern parts of the study area, with low elevation and gradient, and land cover mostly consists of grassland. In Wanghu lake in the southeast and Dazhi lake in the northeast, and other buffer zones, the terrain is relatively flat and sensitivity is low. Non-sensitive regions account for 18.06% of the total area, and are mainly located in human activity areas and construction land in northern Huangshi. This region has flat terrain and low fractional vegetation cover.

3.2. Analysis of Spatiotemporal Changes in Habitat Quality

The habitat quality index, which reflects habitat fragmentation of the study site, and the ability of habitat areas to resist habitat degradation threats, has a value in the range of 0 to 1. The closer the value is to 1, the higher the habitat quality, and the better the maintenance of the habitat environment and biodiversity. We employed the InVEST model to reconstruct the spatial layout of habitat quality in the study site during the period from 1980 to 2018 (Figure 7). Mean habitat quality indices were classified into very poor, poor, fair, good, and excellent grades based on scores (0–0.2, 0.2–0.4, 0.4–0.6, 0.6–0.8, 0.8–1, respectively) in the classification criteria [55,56] from previous studies.

Figure 5. Ecological sensitivity classification for single factor in Huangshi. (a) Precipitation erosivity factor; (b) soil erodibility factor; (c) slope length and steepness factor; (d) surface vegetation cover factor; (e) soil and water conservation factor; (f) soil erosion sensitivity.

Figure 6. Integrated ecological sensitivity classification in Huangshi. (a) Integrated sensitivity of mining; (b) integrated sensitivity of geological hazards; (c) integrated sensitivity of biodiversity; (d) integrated sensitivity of soil erosion; (e) integrated sensitivity of all.
The total area of low sensitivity regions is 23.23% and most regions are located at the eastern and southeastern parts of the study area, with low elevation and gradient, and land cover mostly consists of grassland. In Wanghu lake in the southeast and Dazhi lake in the northeast, and other buffer zones, the terrain is relatively flat and sensitivity is low. Non-sensitive regions account for 18.06% of the total area, and are mainly located in human activity areas and construction land in northern Huangshi. This region has flat terrain and low fractional vegetation cover.

3.2. Analysis of Spatiotemporal Changes in Habitat Quality

The habitat quality index, which reflects habitat fragmentation of the study site, and the ability of habitat areas to resist habitat degradation threats, has a value in the range of 0 to 1. The closer the value is to 1, the higher the habitat quality, and the better the maintenance of the habitat environment and biodiversity. We employed the InVEST model to reconstruct the spatial layout of habitat quality in the study site during the period from 1980 to 2018 (Figure 7). Mean habitat quality indices were classified into very poor, poor, fair, good, and excellent grades based on scores (0–0.2, 0.2–0.4, 0.4–0.6, 0.6–0.8, 0.8–1, respectively) in the classification criteria [55,56] from previous studies.

![Figure 7](image-url). The spatial distribution of habitat quality in Huangshi in (a) 1980; (b) 2000; (c) 2010; (d) 2018.
During the study intervals from 1980 to 2018, the mean habitat quality index of Huangshi was 0.7497, 0.7483, 0.7394, and 0.7278, respectively, showing a gradual decreasing trend. Because the proportion of farmland and forests that make up the study site is relatively stable, the change in habitat quality based on these indicators is relatively low. The spatial scale of habitat quality index shows that habitat quality in the study site is low in the northern mining region and downtown district, and high in the southern forests, grasslands, water bodies, and wetlands. The entire region has areas with excellent habitat quality. Because habitat quality is closely associated with habitat suitability and the habitat suitability indices of forests, grasslands, and wetlands were higher than that of farmland, the habitat quality distribution obtained from the simulation was highly consistent with the dominant land cover type [57].

To more intuitively reflect the spatiotemporal variation characteristics of habitat quality in the study site, the raster calculator tool in ArcGIS 10.2 software was used to calculate changes in habitat quality from 1980 to 2018 (Figure 8) [58]. This shows that habitat quality changes in the study site during the study intervals show regional differences. The habitat quality indices of the northern regions (Tieshan district, Xialu district, Huangshigang district, and Sisaishan district) show varying degrees of decrease. This is mainly because open mining in the mine development stage damaged surface soil and vegetation, whereas underground mining resulted in surface collapse. This resulted in land and vegetation destruction. The stripping of surface soil, destruction of vegetation, and accumulation of large quantities of solid waste all directly affected ecosystem services in the study site. At the same time, expansion of urban districts and rapid development of residential land, mining land, and transportation land threatened the surrounding habitats. This increased habitat fragmentation and habitat degradation speed, and reduced habitat system contiguity. Large areas of cultivated land, forests, and grasslands were taken over by construction, which ultimately decreased the habitat quality of these regions. The habitat quality of the water-rich system and surroundings in the southwest area was greatly increased, which was mainly due to the ecological projects such as conversion of farmland to lakes (wetlands) and conversion of farmland to forests (grasslands), in addition to the creation of nature reserves, scenic areas, and forest parks.

![Figure 8. Changes in habitat quality from 1980 to 2018.](image-url)
3.3. Ecological Restoration Zoning

The integrated ecological sensitivity grade of the study site was superimposed with the 1980–2018 habitat quality variation analysis and some discrete areas were removed. This was done to ensure the consistency of ecosystems in the drainage basin of the study site [44]. On this basis, Huangshi was partitioned into 12 ecological protection and restoration subzones (Figure 9), which included five key restoration areas, four priority protection areas, and three ecological promotion areas. The types of the subzones and administrative areas were noted (Table 4).

Figure 9. Zoning of ecological remediation in Huangshi. (a) Identification of key areas for ecological restoration; (b) administrative areas involved in ecological restoration zoning.

Table 4. Different ecological restoration zones in Huangshi.

<table>
<thead>
<tr>
<th>Code</th>
<th>Comprehensive Environmental Assessment Zones</th>
<th>Type</th>
<th>Administrative Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>I-1</td>
<td>Bao’an lake wetland area</td>
<td>Priority protection area</td>
<td>Bao’an town and Haidiqiao town</td>
</tr>
<tr>
<td>I-2</td>
<td>Huangpingshan forest area</td>
<td>Priority protection area</td>
<td>Yinzu town and Baisha town</td>
</tr>
<tr>
<td>I-3</td>
<td>Wanghu lake wetland area</td>
<td>Priority protection area</td>
<td>Xingguo town, Taogan town, Fuchi town</td>
</tr>
<tr>
<td>I-4</td>
<td>Xiandao Lake resort area</td>
<td>Priority protection area</td>
<td>Wangying town, Sanxi town, and Longgang town</td>
</tr>
<tr>
<td>II-1</td>
<td>Dazhi iron mine</td>
<td>Key restoration area</td>
<td>Tieshan district, Xialu district, Huangshigang district, Sisaishan district, Jinsandian town</td>
</tr>
<tr>
<td>II-2</td>
<td>Dawang mountain-Tiantai mountain-Longfeng mountain reserve</td>
<td>Key restoration area</td>
<td>Daqipu town, Dawang town, Taizi town</td>
</tr>
<tr>
<td>II-3</td>
<td>Yangxin marble mine</td>
<td>Key restoration area</td>
<td>Longgang town and Yanggang town</td>
</tr>
<tr>
<td>III-1</td>
<td>Dazhi lake drainage basin area</td>
<td>General restoration area</td>
<td>Hekou town, Wangren town, Weiyuankou town</td>
</tr>
<tr>
<td>III-2</td>
<td>Fengshan copper mine-Jilong mountain gold and copper mine area</td>
<td>General restoration area</td>
<td>Fenglin town</td>
</tr>
</tbody>
</table>
### Table 4. Cont.

<table>
<thead>
<tr>
<th>Code</th>
<th>Comprehensive Environmental Assessment Zones</th>
<th>Type</th>
<th>Administrative Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>III-3</td>
<td>Qifengshan ecological park</td>
<td>General restoration area</td>
<td>Baisha town and Futu town</td>
</tr>
<tr>
<td>III-4</td>
<td>Eastern river basin integrated area</td>
<td>General restoration area</td>
<td>Huangsangkou town, Fuchi town, Weiyuankou town</td>
</tr>
<tr>
<td>III-5</td>
<td>Longfengshan stereoscopic agriculture area</td>
<td>General restoration area</td>
<td>Wangying town and Longgang town</td>
</tr>
<tr>
<td>IV-1</td>
<td>Ewangcheng ecological park</td>
<td>Ecological promotion area</td>
<td>Jinniu town, Mingshan township, Chengui town, Lingxiang town</td>
</tr>
<tr>
<td>IV-2</td>
<td>Yangxin hill forest area</td>
<td>Ecological promotion area</td>
<td>Mugang town, Paishi town, Sanxi town</td>
</tr>
</tbody>
</table>

#### 3.4. Diagnosis of Ecological Problems and Restoration Strategies

The land space ecological restoration zoning results were combined with the geographical environment, ecological differences, and socioeconomic status of the study site to identify and diagnose ecological problems in the different zones. Different restoration and promotion strategies were proposed for different zones (Table 5).

### Table 5. Ecological conservation and rehabilitation model in Huangshi.

<table>
<thead>
<tr>
<th>Code</th>
<th>Comprehensive Environmental Assessment Zones</th>
<th>Preservation and Restoration Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>I-1</td>
<td>Bao’an Lake wetland area</td>
<td>Attach importance to ecological management of river basin and control tourism development in an orderly way.</td>
</tr>
<tr>
<td>I-2</td>
<td>Huangpingshan forest area</td>
<td>Strengthen the protection of natural forests, continue to restore natural vegetation, and improve the quality of forests.</td>
</tr>
<tr>
<td>I-3</td>
<td>Wanghu Lake wetland area</td>
<td>Strengthen the protection and restoration of the watershed, protect the wetland ecosystem, rare and endangered animals, and plants and their habitats.</td>
</tr>
<tr>
<td>I-4</td>
<td>Xiandao Lake resort area</td>
<td>Relying on the current water system, maintain and improve the ecological environment, create tourist resorts, and drive the orderly integration of rural development around lakes.</td>
</tr>
<tr>
<td>II-1</td>
<td>Dazhi iron mine</td>
<td>Explore a high-quality mining economic development mode guided by ecological priority and green development, strengthen the level of resource intensive utilization, restrict human activities, and improve the level of land reclamation.</td>
</tr>
<tr>
<td>II-2</td>
<td>Dawang Mountain-Tiantai Mountain-Longfeng Mountain reserve</td>
<td>Focus on ecological restoration. Close mountains to cultivate forests, strengthen the restoration of natural vegetation, and maintain the integrity of forest vegetation. At the same time, focus on strengthening soil erosion control, reducing mud-rock flow and hazards, and reducing the incidence of natural hazards.</td>
</tr>
<tr>
<td>II-3</td>
<td>Yangxin marble mine</td>
<td>First, efforts should be made to reduce the damaging effects mining and other human activities on the natural ecological system; and the treatment and management of abandoned mines, quarries, and other industrial and mining land should be carried out. Second, implement measures to protect natural forests and restore natural vegetation.</td>
</tr>
</tbody>
</table>
Table 5. Cont.

<table>
<thead>
<tr>
<th>Code</th>
<th>Comprehensive Environmental Assessment Zones</th>
<th>Preservation and Restoration Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>III-1</td>
<td>Dazhi Lake drainage basin area</td>
<td>Focus on the improvement of ecological environment, strengthen the protection of water area, pay attention to the improvement of ecosystem service function, strengthen the construction of green corridor landscape, increase the area of green land, and improve the diversity of vegetation.</td>
</tr>
<tr>
<td>III-2</td>
<td>Fengshan copper mine-Jilong Mountain gold and copper mine area</td>
<td>Manage abandoned mines, quarries, and other industrial and mining land; and focus on the control of disasters caused by human engineering activities.</td>
</tr>
<tr>
<td>III-3</td>
<td>Qifengshan ecological park</td>
<td>Rationally develop tourism resources and actively develop ecological tourism and economic agriculture and forestry industries.</td>
</tr>
<tr>
<td>III-4</td>
<td>Eastern river basin integrated area</td>
<td>Pay attention to watershed ecological management, small watershed management, and restoration of river ecosystems.</td>
</tr>
<tr>
<td>III-5</td>
<td>Longfengshan stereoscopic agriculture area</td>
<td>Rationally develop and comprehensively utilize regional tourism resources, focusing on ecological tourism, rural tourism, agricultural processing, and other ecological industries.</td>
</tr>
<tr>
<td>IV-1</td>
<td>Ewangcheng ecological park</td>
<td>Protect the farmland, improve low-quality cultivated land, make full use of the rural ecological environment resources, and carry out agricultural tourism with hilly ecological characteristics.</td>
</tr>
<tr>
<td>IV-2</td>
<td>Yangxin hill forest area</td>
<td>Starting from the land remediation work, optimize and improve the quality of cultivated land, and strengthen the protection of rural landscape.</td>
</tr>
</tbody>
</table>

Priority protection regions are natural scenic bases for regional development. Bao’an lake, Huangping mountain, Wanghu lake, and Xiandao lake, which are inland wetlands and forest parks, were selected as priority protection areas. These areas have rich biodiversity and provide important ecosystem services. Efforts should be made to strengthen the construction of the conservation system, ecological restoration, habitat remediation, and protection of endangered animals, such as oriental stork (Ciconia boyciana) and tundra swan (Cygnus columbianus), and their habitats. Furthermore, forest preservation and conversion of cultivated land to forests should be implemented, and the construction and maintenance of nature reserves should be improved to maintain habitat contiguity and species diversity.

Key restoration areas are key regions for ecological reconstruction and include old collapsed mines. Intense mining activity in these regions, underground mine drainage, and mine slag piles have caused severe damage to the geological and ecological environment. At the same time, high development demands have resulted in intense human activities such as construction of houses and traffic. This has resulted in frequent geological disasters. Future developmental measures should focus on ecological restoration. Efforts should be made to decrease the destruction of and interference in natural ecosystems due to mining and other human activities. Remediation and management of abandoned mines and quarries should be carried out. Measures to protect natural forests and restore natural vegetation should be implemented, and management of collapses and landslides should be prioritized.

Preventive restoration areas are buffer regions located at the periphery of key protection areas and key restoration areas that have moderate sensitivity and a slight decrease in habitat quality. Preventive ecological restoration should be the focus for these areas and efforts should be made to improve the ecological environment; strengthen conservation of water bodies, forests, and cultivated land in the region; improve ecosystem services and
habitat quality; strengthen construction of green corridors and landscapes; increase overall green space; and improve vegetation diversity.

Ecological promotion areas are vital to regional development and rural ecological resources should be fully utilized. Attention should be focused on protecting natural ecology and strengthening rural landscape protection. Rural tourism based on ecological features should be encouraged. The current status of water system and mountain conservation ecology should be used as a baseline for the maintenance and improvement of ecological security patterns. Cultivated land quality should be optimized and improved, landscape protection of rural villages should be strengthened, and regional development into key agricultural regions in the study site should be promoted.

4. Discussion
4.1. Result Discussion and Feasibility

Land space ecological restoration has become a national strategic project and ecological restoration zoning is the prerequisite for ecological restoration. Regional conditions, spatial differences in ecological sensitivity, and landscape evolution trends should be used to formulate ecological restoration zoning indicators. These indicators are useful for analyzing major ecological problems and are one of the basic means of maintaining regional ecological environment and habitat safety.

Hu et al. [59] evaluated the abandoned underground coal mine site in terms of subsidence risk, hydrology, soil quality, and heavy metal pollution. Based on this study, this paper evaluated the overall ecological environment of resource-based cities, and took into account factors such as the control of mining subsidence, the prevention and control of geological disasters, and ecological restoration of mines in specific ecological restoration zoning plans. Combined with natural ecological characteristics, such as biodiversity and water and soil conservation, taking Huangshi City as the research object, and considering the actual conditions, regional function orientation, and ecological construction requirements of the study area, the comprehensive ecological restoration zoning of the study area was obtained.

Overall, Huangshi has high ecological sensitivity and good habitat quality. The areas with high ecological sensitivity are roughly inversely related to areas with good habitat quality. For example, areas with dense mining areas in the north have high ecological sensitivity and a fragile ecological environment, but extremely low habitat quality, because the ecological balance of the region is disturbed by over-exploitation of mines. The mountainous and hilly regions in the southwest have low ecological sensitivity, but high habitat quality, due to the high vegetation cover and the diversity of biological species in the region. However, the area is dominated by forest and grassland, with minimal changes, and the ecological pressure is low, so the ecological sensitivity is lower. However, there are some exceptions, such as the relatively low degree of ecological sensitivity and the low quality of habitats in the northwest of Huangshi. This is because the main land-use type in the region is cultivated land, which is greatly affected by human activities, and has small ecological vulnerability and relatively low biodiversity. The zoning recommendations were consistent with the actual situation of Huangshi. This study can be a useful guide for ecological restoration zoning in resource-based cities.

Since Huangshi was classified as a resource-exhausted city, local government has carried out industrial transformation and upgrading, vigorously developed advanced manufacturing, relied on the port to develop inland transportation, and built the Huangshi National Mine Park with rich mining relics. In 2018, the major economic indicators reached or exceeded the average level of the whole province, indicating that the industrial transformation was effective, and the development of emerging industries caused less pressure on the ecological environment. Furthermore, Huangshi has made comprehensive efforts to deal with the ecological and environmental damage caused by mining development. By the end of 2015, officials had implemented more than 20 eco-environmental governance projects, covering an area of about 3000 hectares, with an investment of nearly 1.8 billion
It can be seen that Huangshi government and relevant departments have given significant support to ecological environment restoration. Therefore, the restoration actions and strategies proposed in this study provide a scientific basis for the macro decision-making of Huangshi.

4.2. Limitations and Future Work

Although this study can provide some reference for ecological restoration zoning of similar resource-based cities, there are some limitations. For example, the selection of representative cities cannot cover all types of resource-based cities, such as those dominated by forests, oil, or coal mining. Urban ecological characteristics and environmental damage factors may be different due to different geographical locations, resource types, and urban development stages, and the emphasis of urban ecological restoration zoning is also different. Different types of resource-based cities should be targeted to carry out research on zoning methods in accordance with local conditions, so as to better fit the reality of ecological restoration and ecological development. In addition, the selection of grading parameters for an ecological restoration zoning index system should be based on further analysis of more empirical cases, to perfect parameter settings, accurately demarcate the scope of the study, and make it more suitable for local use conditions.

In addition, the InVEST model was selected for the analysis of habitat quality. Because the habitat quality index in the model is between 0 and 1, measured data cannot be found for comparison and verification. The verification and analysis of this method should be performed in the future.

The ecological restoration for territories is a new proposition in this transitional period. Ecological restoration remains at the preliminary exploration stage at present, and there is no universal mode or method for reference. Ecological restoration planning involves urban and rural planning, ecology, geography, and other disciplines and theories. The scope of planning technology is extensive and needs further comprehensive research.

5. Conclusions

In this paper, ecological sensitivity assessment and habitat quality analysis were conducted in Huangshi, revealing the spatiotemporal variation trend of ecosystem and ecological environment during 1980 to 2018. Based on the results of two analyses, ecological restoration zoning of Huangshi was comprehensively delineated, and corresponding ecological restoration strategies were proposed. The results can provide a tool for environmental planning and ecological restoration in resource-based cities by using Huangshi as a representative of resource-based cities in central China. Our study results showed that:

(1) The overall distribution trend of ecological sensitivity in Huangshi is toward high sensitivity mountain forests and other regions with dense vegetation and wetlands. There was a dense distribution of mines in the city, showing the common feature of zoning by sensitivity in resource-based cities.

(2) In the period from 1980 to 2018, the habitat quality index of Huangshi was good, with a slight decreasing trend. The simulated habitat quality distribution was consistent with the region-dominated land cover type. The urban built-up areas and key mining areas in the north of Huangshi showed low quality and continuously decreasing quality, whereas woodland, grassland, and water areas in the south of Huangshi had a higher habitat quality index and lower ecological conservation stress.

(3) Huangshi was partitioned into 14 land space ecological restoration zones, forming a spatial pattern with natural protected areas as the priority protection areas, mining areas as the key restoration areas, and natural protected areas and mining areas as the general restoration areas.

(4) During the period of 1980–2018, the water management of Huangshi generally improved, and the habitat quality improved, which indicates that the water pollution control in Huangshi had a positive effect.
Author Contributions: Conceptualization, S.F.; data curation, C.Z.; formal analysis, C.Z.; investigation, C.Z.; methodology, C.Z.; project administration, S.F.; supervision, S.F.; validation, C.Z.; visualization, C.Z.; writing—original draft, C.Z.; writing—review and editing, S.F. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the Key Project from the National Social Science Foundation (Grant No: 18ZDA053).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: The authors wish to acknowledge MDPI English Editors Mark Walton for correcting manuscript in grammar and syntax.

Conflicts of Interest: The authors declare no conflict of interest.

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