Remote Sensing Ecology Index; ecological environment quality in mining areas; InSAR; collaborative analysis; Eco-environmental Quality Index

1. Introduction

The coal industry plays a pivotal role in China’s energy sector, significantly contributing to the nation’s economic and social advancement. However, coal mining processes can inflict substantial harm on the ecological environment. For instance, it often leads to the depletion of surface and groundwater levels, diminishing surface vegetation cover, and crop failure. Additionally, it predisposes the rock layers to deformations, precipitating various geological disasters such as surface subsidence, sinkholes, waterlogging, and landslides, among others [1–7]. Hence, it is imperative to bolster the efforts in monitoring and assessing the mining environment to thwart environmental degradation and ecological damage. Enhancing these measures will foster the recovery and rejuvenation of the ecological environment, facilitating a harmonious coexistence between economic progression and ecological conservation.

Traditionally, ecological environment monitoring in mining areas has heavily relied on ground surveys and sampling. These methods, while essential, come with a set of limitations, such as the inability to retrieve historical data on ecological and environmental elements, as well as being time-consuming, labor-intensive, and costly. Moreover, they are...
not conducive to regular, extensive area measurements [8–10]. The advent and progression of satellite remote sensing technology, coupled with advancements in computer technology, have considerably enriched the efficacy and precision of environmental monitoring methods. Enhanced quality, spatial and temporal resolution, and spectral resolution of remote sensing data have been achieved. These technologies offer multiple platforms, higher accuracy, macroscopic insights, and extensive coverage, effectively overcoming the limitations associated with traditional survey and sampling methods, thereby furnishing robust support for environmental monitoring and evaluation. Among various methodologies, the Remote Sensing Ecology Index (RSEI) stands out as a predominant tool for evaluating ecological environment quality [11–15]. Initiated by Xu Hanqiu in 2013 [16], RSEI incorporates four key ecological indicators: greenness (NDVI), humidity (WET), dryness (NDBSI), and heat (LST). Utilizing Principal Component Analysis (PCA) facilitates a comprehensive evaluation of the ecological environment quality in urban areas. In recent years, scholars have adeptly applied RSEI or Modified RSEI in ecological environment monitoring across various cities and waters, yielding commendable and insightful evaluation outcomes [17–32].

The existing studies predominantly utilize the Remote Sensing Ecology Index (RSEI) for evaluating ecological quality in urban and water areas, with limited application in mining regions. Moreover, coal mining will cause surface subsidence and geologic disasters, which are very harmful to the ecological environment, so the surface deformation information is an indispensable and important factor for ecological monitoring in mining areas [33,34]. Currently, there is a notable absence of comprehensive methods that integrate optical and radar remote sensing data for these evaluations. Addressing this, our study introduces a Modified Remote Sensing Ecology Index (MRSEI), innovatively incorporating both active and passive remote sensing techniques. An additional Surface Deformation Index (SDI) is also integrated into the traditional RSEI model, enhancing its applicability in assessing the ecological impacts within mining areas. Additionally, seven ecological factors were extracted from meteorological and statistical data, including PM2.5, net primary productivity, land use intensity, annual precipitation, average temperature, population density, and per capita GDP. These factors were integrated with five ecological indices from the MRSEI: NDVI, WET, NDBSI, LST, and SDI. Utilizing the Analytical Hierarchy Process (AHP), we calculated the weights of each index, enabling the construction of the EQI model. This model was instrumental in comparing and validating the MRSEI method. A comprehensive analysis was performed to explore the spatial and temporal variations of ecological elements in mining areas.

In this research, the Juye Coalfield, encompassing an area of 1210 square kilometers, was meticulously chosen as the focal study area. The applicability of the method was validated by comprehensively utilizing six scenes of Landsat 8 remote sensing imagery and fifty-eight scenes of Sentinel 1A imagery. The subsequent sections are organized as follows: Section 2 provides a detailed description of the study area and dataset; Section 3 meticulously introduces the MRSEI and the EQI models; Section 4 elucidates the findings of the research; Section 5 engages in a discussion analyzing the strengths and weaknesses of the MRSEI and EQI; and Section 6 concludes by summarizing the key outcomes of the study.

2. Study Area and Datasets
2.1. Study Area

The Juye Mining Area is strategically situated in the southwestern part of Shandong Province, nestled within the boundaries of Heze and Jining cities. It lies south of the Huaihe River Basin, an area characterized by a rich network of rivers and a complex geological structure predominated by grid-pattern faults running predominantly east–west and north–south. This mining locale comprises seven substantial minefields: Yuncheng, Guotun, Zhaolou, Longgu, Wanfu, Pengzhuang, and Liangbaosi Coal Mines, collectively spreading over an area of 1210 km², as shown in Figure 1 [35]. Remarkably, the Juye Mining Area
boasts a significant production capacity, yielding approximately 18 million tons of coal annually. Since its inception in 2007, 16 years of operational history have unfortunately led to notable ecological degradation in the area. The repercussions of extensive mining activities manifest in various environmental detriments such as groundwater contamination, substantial land and ground subsidence, notable vegetation damage, and pervasive heavy metal pollution. These adverse ecological impacts have notably compromised the quality of life and health of the local communities and pose significant challenges to national ecological and environmental sustainability objectives. Therefore, it is essential to monitor the ecological environment quality of the Juye mining area, providing necessary support and assistance for subsequent ecological restoration efforts.

Figure 1. Schematic diagram of the geographical location of the study area. (a) The study area location. (b) The mining area location.

2.2. Datasets

The extraction of index data for NDVI, WET, NDBSI, and LST was accomplished using six scenes of Landsat 8 remote sensing imagery with less than 5% cloud cover, spanning from May 2015 to May 2021. Detailed parameters of these images are presented in Table 1.

Table 1. Landsat 8 data information.

<table>
<thead>
<tr>
<th>Number</th>
<th>Satellite</th>
<th>Sensor Type</th>
<th>Strip</th>
<th>Row</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Landsat 8</td>
<td>OLI/TIRS</td>
<td>123</td>
<td>035</td>
<td>18 May 2015</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td>123</td>
<td>036</td>
<td>18 May 2015</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td>122</td>
<td>035</td>
<td>16 May 2018</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td>122</td>
<td>036</td>
<td>16 May 2018</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td>122</td>
<td>035</td>
<td>27 May 2021</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td>122</td>
<td>036</td>
<td>27 May 2021</td>
</tr>
</tbody>
</table>

For the SDI index, data were extracted from fifty-eight scenes of Sentinel-1A images in IW mode, collected between March 2015 and December 2021. A comprehensive list of this data is displayed in Table 2.
Table 2. Sentinel 1A data information.

<table>
<thead>
<tr>
<th>Satellite</th>
<th>Sentinel-1A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>IW</td>
</tr>
<tr>
<td>Orbit</td>
<td>142/111, 142/109, 142/114</td>
</tr>
<tr>
<td>Orbit direction</td>
<td>Ascending orbit</td>
</tr>
<tr>
<td>Polarization</td>
<td>VV</td>
</tr>
<tr>
<td>Wavelength (m)</td>
<td>0.0555</td>
</tr>
<tr>
<td>Resolution (m)</td>
<td>5 \times 20</td>
</tr>
<tr>
<td>Heading angle (°)</td>
<td>−9.78</td>
</tr>
<tr>
<td>Incident angle (°)</td>
<td>39.1</td>
</tr>
<tr>
<td>Number of images</td>
<td>58</td>
</tr>
<tr>
<td>Time Range</td>
<td>March to June 2015; 3 January 2018 to 29 December 2018; 11 January 2021 to 13 December 2021</td>
</tr>
</tbody>
</table>

The DEM data utilized SRTM data with a horizontal resolution of 90 m, which is essential for removing the terrain phase in the time-series differential interferometry. ESA POD precision orbit determination ephemeris data were employed for orbit information correction. Additionally, vector administrative boundaries, vector boundaries of the Juye Mining area, county statistical yearbooks of Shandong Province, and meteorological data from 2015 to 2021 were utilized to augment the research on ecological environment monitoring in the mining area.

3. Methods

This paper addresses the deficiency of comprehensive monitoring and evaluation methods that combine optical remote sensing data and radar remote sensing data in the assessment of the ecological environment in mining areas. A MRSEI model is proposed, incorporating unique deformation factors endemic to the ecological environment of mining areas, based on the foundation of the Remote Sensing Ecology Index (RSEI). The AHP is utilized to construct a model grounded in the EQI, facilitating a comprehensive analysis of the spatiotemporal variation characteristics of ecological elements within mining areas.

Initially, data from Landsat 8 and Sentinel 1A are processed to extract essential ecological indicators such as greenness, humidity, dryness, heat, and deformation factors. A principal component analysis is applied to establish the MRSEI model. Subsequently, leveraging statistical and meteorological data, seven ecological elements are extracted: PM2.5, net primary productivity, land use intensity, annual precipitation, average temperature, population density, and per capita GDP. These elements are then combined with five ecological indicators from the MRSEI: NDVI, WET, NDBSI, LST, and SDI. Lastly, a comparative analysis is conducted to discern the relative merits and demerits of the two methodologies, enabling a comprehensive evaluation of the ecological environment quality in the Juye mining area. The specific technical approach adopted in this research is depicted in Figure 2.

3.1. Modified Remote Sensing Ecological Index Model (MRSEI)

The prevailing RSEI is primarily adapted to monitor and evaluate urban environments. However, due to the intrinsic differences between mining and urban areas, the mining processes inevitably lead to surface subsidence or even collapse in mining regions. Consequently, the applicability of RSEI in monitoring mining areas is somewhat limited. Considering the specific conditions of the Juye mining area, this study modifies four ecological indicators initially included in the RSEI model, incorporating surface deformation indicators, and formulates the MRSEI to assess the ecological environmental quality of the Juye mining area.
Figure 2. Workflow of the proposed method.

3.1. Masked Waters

The water body has high reflectivity and low radiation temperature and is greatly different from vegetation and soil. In order to avoid the impact of the water body on the calculation results, the Modification of Normalized Difference Water Index (MNDWI) is used [36]. Create a mask file to remove the water body. The formula is as follows:

\[
MNDWI = \frac{\rho_{\text{green}} - \rho_{\text{swir1}}}{\rho_{\text{green}} + \rho_{\text{swir1}}} \tag{1}
\]

where \(\rho_{\text{green}}\) and \(\rho_{\text{swir1}}\) represent the reflectivity of the green band and the mid-infrared band 1.

For regions with average water resources, the range of water bodies is typically between [0.25, 1]. Therefore, this article sets 0.25 as the water body threshold, encompassing the majority of water bodies.

3.1.2. Extraction of Traditional Remote Sensing Ecological Indicators

Traditional remote sensing ecological indicators include the greenness index (NDVI) [37], humidity index (WET) [38], dryness index (NDDBSI) [39], and heat index (LST) [40]. The principle is as follows:

**Extracting the greenness index** (NDVI). The greenness index reflects the growth status of surface vegetation and can effectively distinguish between vegetation and bare
land. The greenness index uses the Normalized Difference Vegetation Index (NDVI), and its formula is:

\[ NDVI = \frac{\rho_{NIR} - \rho_{red}}{\rho_{NIR} + \rho_{red}} \] (2)

where \( \rho_{NIR} \) and \( \rho_{red} \) represent the reflectivity of the red band and the near-infrared band. The value of NDVI is usually between \([-1, 1]\). The higher the NDVI value, the better the vegetation coverage.

Extracting the humidity index (WET). The humidity index is used to monitor surface humidity and evaluate the water and heat balance in a certain area. This paper uses the tassel cap transformation method to obtain the humidity index. The calculation formula is:

\[ WET_{Oli} = 0.1511\rho_{blue} + 0.1973\rho_{green} + 0.3283\rho_{red} + 0.3407\rho_{nir} - 0.7117\rho_{swir1} - 0.4559\rho_{swir2} \] (3)

where \( \rho_{blue}, \rho_{green}, \rho_{red}, \rho_{nir}, \rho_{swir1}, \rho_{swir2} \) represent the reflectivity of the blue band, green band, red band, mid-infrared band 1, and mid-infrared band 2.

Extracting the dryness index (NDBSI). Normalized Difference Build and Soil Index (NDBSI) is an index that reflects the distribution of surface bare soil and buildings. It is composed of Soil Index (SI) and Index-based Built-up Index (IBI) synthesis; the calculation formula is:

\[ IBI = \frac{2(\rho_{swir1} + \rho_{nir}) - \left(\frac{\rho_{nir} + \rho_{red}}{\rho_{swir1} + \rho_{red}} + \frac{\rho_{green}}{\rho_{green} + \rho_{swir1}}\right)}{\left(\frac{\rho_{swir1} + \rho_{nir}}{\rho_{swir1} + \rho_{red}} + \frac{\rho_{green}}{\rho_{green} + \rho_{swir1}}\right)} \] (4)

\[ SI = \left[(\rho_{swir1} + \rho_{red}) - (\rho_{nir} + \rho_{blue})\right] / \left[(\rho_{swir1} + \rho_{red}) + (\rho_{nir} + \rho_{blue})\right] \] (5)

\[ NDBSI = (IBI + SI)/2 \] (6)

where \( \rho_{blue}, \rho_{green}, \rho_{red}, \rho_{nir}, \rho_{swir1} \) are the reflectivity of the blue band, green band, red band, and mid-infrared band 1. The value of NDBSI is between \([-1, 1]\). The higher the value of NDBSI, the larger the area of buildings and bare soil areas.

Extracting the heat index (LST). The heat index is an index that reflects the surface temperature. By studying the distribution and changes of the surface temperature, it provides a scientific basis for thermal environment monitoring and ecological environment assessment. This article uses the radiative transfer equation method to invert the surface temperature. The formula is as follows:

\[ L_{10} = [\epsilon B(LST) + (1 - \epsilon) L \downarrow \tau + L \uparrow] \] (7)

\[ B(LST) = [L_{10} - L \uparrow - \tau (1 - \epsilon) L \downarrow] / \tau \cdot \epsilon \] (8)

\[ LST = K_2 / In[K_1 / B(LST) + 1] - 273 \] (9)

where \( L_{10} \) is the radiance value of the 10th band of the Landsat TIRS image; \( \epsilon \) is the landmark specific radiance; \( B(LST) \) is the blackbody radiance value; \( L \uparrow, L \downarrow \) are the upward and downward radiances of the atmosphere respectively; \( \tau \) is the atmospheric transmittance; \( K_1 \uparrow, K_2 \downarrow \) is the calibration parameter; for the 10th band of the Landsat image TIRS sensor has \( K_1 \uparrow, K_2 \downarrow \) values of 480.89 and 1201.14, and \( LST \) which is the surface temperature.

3.1.3. Extraction of Deformation Indicators

The procedure for extracting deformation indicators is illustrated in Figure 3.
provides a scientific basis for thermal environment monitoring and ecological environment assessment. This article uses the radiative transfer equation method to invert the surface temperature. The formula is as follows:

\[
L = BLST + L↑ + L↓ - ετ\epsilon\tau
\]

(7)

\[
\frac{1}{τ} = \left(\frac{1}{K↑} - \frac{1}{K↓}\right) \left(\frac{1}{K↑} + \frac{1}{K↓}\right)
\]

(8)

\[
LST = T + \frac{1}{2} \left(\frac{1}{K↑} + \frac{1}{K↓}\right)
\]

(9)

where \(L\) is the radiance value of the 10th band of the Landsat TIRS image; \(ε\) is the landmark specific radiance; \(BLST\) is the blackbody radiance value; \(L↑\), \(L↓\) are the upward and downward radiances of the atmosphere respectively; \(τ\) is the atmospheric transmission; \(K↑\), \(K↓\) is the calibration parameter, for the 10th band of the Landsat image TIRS sensor has \(K↑\), \(K↓\) values of 480.89 and 1201.14, and \(LST\) which is the surface temperature.

### 3.1.3. Extraction of Deformation Indicators

The procedure for extracting deformation indicators is illustrated in Figure 3.

**Figure 3.** Flowchart for extraction of deformation indicators.

**Data preprocessing.** Calibrate and position the original Sentinel-1A data to obtain SLC data. Geocode the DEM to obtain the DEM data in the radar coordinate system, which is used to remove the terrain phase. Add precision orbit parameter files to accurately position and correction. Due to the limited number of Sentinel-1A images in 2015, the Stacking-InSAR technique was employed to extract deformation information. For the years 2018 and 2021, the SB-InSAR method was utilized for this purpose.

**Image registration.** The super master image is selected through overall correlation coefficient analysis. All secondary images are registered and resampled to the super primary image.

**Stacking-InSAR Processing.** The Stacking-InSAR experiment used a total of 10 scenes of Sentinel-1A images from two orbits covering the Juye mining area, with the time span from 30 July 2015 to 3 November 2015. The Goldstein adaptive filtering method was used to filter the registered images, and the minimum cost flow method was used for phase unwrapping. Finally, Stacking-InSAR was used to obtain the deformation rate in the LOS direction of the Juye mining area.

**SB-InSAR Processing.** This SB-InSAR experiment uses a total of 48 Sentinel-1A images from an orbit covering the Juye mining area. The time span is from 3 January 2018 to 29 December 2018 and from 11 January 2021 to 13 December 2021. (1) Small baseline interference atlas generation. On the premise of ensuring that there are no isolated points in the spatiotemporal baseline network, the vertical baseline and time baseline thresholds are set to construct a small baseline interference atlas. Use DEM for simulation and remove terrain contribution. (2) Surface deformation rate inversion. In the StaMPS software environment, high coherence points are selected based on coherence, 3D phase...
unwrapping is performed on the extracted high coherence points, and the orbit residual error, atmospheric delay error, and DEM error are estimated and corrected, and finally, the least squares estimation is used to invert surface deformation rate information in the LOS direction of high coherence points.

**Extract the SDI indicator.** The surface settlement rate of LOS in the Juye mining area is the deformation index, and the formula is as follows:

\[
SDI = D(x)
\]  

SDI is the deformation index, and \( D(X) \) refers to the deformation rate of the pixel in the LOS direction.

### 3.1.4. Construction of Modified Remote Sensing Ecological Index Model

**Principal Component Analysis.** The original data is converted into a new set of independent variables through linear transformation. These new variables are called principal components. When the contribution rate of the principal component is greater than 85%, it is considered valid data [16]. If the contribution rate of the principal component does not exceed 85%, it is recommended to retain more principal components at this time to better retain the information in the original variables. In this experiment, the contribution rate of the first principal component is less than 85%, so the first two principal components are retained. The formula for principal component analysis is as follows.

\[
X = \begin{bmatrix}
    x_{11} & x_{12} & \cdots & x_{1m} \\
    x_{21} & x_{22} & \cdots & x_{2m} \\
    \vdots & \vdots & \ddots & \vdots \\
    x_{n1} & x_{n2} & \cdots & x_{nm}
\end{bmatrix} = [x_1, x_2, \cdots, x_m] \tag{11}
\]

\( X \) is a matrix with \( n \) rows and \( m \) columns.

Perform a linear transformation of the formula and compute the contribution rate of each principal component.

\[
\begin{align*}
F_1 &= a_{11}x_1 + a_{12}x_2 + a_{1m}x_m \\
F_2 &= a_{21}x_1 + a_{22}x_2 + a_{2m}x_m \\
\vdots & \vdots \\
F_n &= a_{n1}x_1 + a_{n2}x_2 + a_{nm}x_m
\end{align*}
\]  

\[
R = \sum_{i=1}^{m} \left( \frac{\lambda_i}{\sum_{i=1}^{p} \lambda_i} \right) \tag{13}
\]

where \( F_i \) represents the linear transformation formula; \( R \) is the contribution rate; \( \lambda_i \) is the eigenvalue of the principal component; \( m \) is the first few principal components; and \( p \) is the number of principal components.

**Indicator normalization.** Since the scale of the five factors is not uniform, performing PCA directly could result in a disproportionate weighting of the indicators. Therefore, it is necessary to normalize the five indicators before conducting the principal component analysis. The linear normalization formula is as follows:

\[
NI_i = \frac{(I_i - I_{\text{min}})}{(I_{\text{max}} - I_{\text{min}})} \tag{14}
\]

where \( NI_i \) is the result of the indicator value; \( I_i \) is the original value of the corresponding indicator pixel \( i \); and \( I_{\text{max}} \) and \( I_{\text{min}} \) are the maximum and minimum values of the corresponding indicator, respectively.
**Indicator synthesis.** The traditional RSEI method only uses the first principal component to construct the RSEI model and conduct research on regional ecological environment assessment. Due to the poor overall ecological environment of the Juye mining area, using the first principal component cannot ensure that most of the image information is reasonably utilized. Therefore, in order to include more effective information, this paper retains the first two principal components to construct MRSEI. The formula is:

\[
RSEI_0 = PC1 \times p + PC2 \times q
\]

where \( RSEI_0 \) is the initial remote sensing ecological index; \( PC1 \) represents the first principal component; \( PC2 \) represents the second principal component; \( p \) represents the eigenvalue of \( PC1 \); and \( q \) represents the eigenvalue of \( PC2 \).

In order to facilitate the measurement and comparison of the size of each indicator, linear normalization \( RSEI_0 \) is performed to obtain MRSEI. The formula is as follows:

\[
MRSEI = \frac{RSEI_0 - RSEI_{0,\text{min}}}{RSEI_{0,\text{max}} - RSEI_{0,\text{min}}}
\]

where \( MRSEI \) is the modified remote sensing ecological index, the range is \([0, 1]\), the larger the value of \( MRSEI \), the better the quality of the ecological environment, \( RSEI_{0,\text{min}} \) is the minimum value of \( RSEI_0 \), \( RSEI_{0,\text{max}} \) is the maximum value of \( RSEI_0 \).

### 3.2. Ecological Quality Index Model (EQI)

#### 3.2.1. Selection of Evaluation Indicator Factors

The impact factors of changes in ecological and environmental quality are very complex. Referring to the “Technical Specifications for Ecological and Environmental Condition Assessment”, 12 indicators are selected [41]. These 12 indicators are divided into three layers: the target layer, the element layer, and the indicator layer (Table 3).

<table>
<thead>
<tr>
<th>Target Layer</th>
<th>Feature Layer</th>
<th>Indicator Layer</th>
<th>Data Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mining Area Ecological</td>
<td>PM2.5</td>
<td>Remote Sensing Data</td>
<td></td>
</tr>
<tr>
<td>Environment Quality</td>
<td>NDVI</td>
<td>Remote Sensing Monitoring</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Annual Precipitation</td>
<td>Meteorological Data</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Average Annual Temperature</td>
<td>Meteorological Data</td>
<td></td>
</tr>
<tr>
<td></td>
<td>NDBSI</td>
<td>Remote Sensing Monitoring</td>
<td></td>
</tr>
<tr>
<td></td>
<td>LST</td>
<td>Remote Sensing Monitoring</td>
<td></td>
</tr>
<tr>
<td></td>
<td>WET</td>
<td>Remote Sensing Monitoring</td>
<td></td>
</tr>
<tr>
<td></td>
<td>NPP</td>
<td>Remote Sensing Monitoring</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Population Density</td>
<td>Statistical Data</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SDI</td>
<td>Remote Sensing Monitoring</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Land Use Degree</td>
<td>Remote Sensing Monitoring</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Per Capita GDP</td>
<td>Statistical Data</td>
<td></td>
</tr>
</tbody>
</table>

#### 3.2.2. Analytical Hierarchy Process to Establish Evaluation Index Weights

**Establishment of a hierarchical structure.** The selected 12 factor indicators are stratified, as shown in Table 3.

**Constructing the judgment matrix.** The order of the relative importance of each evaluation indicator is ranked according to the 9-point ratio, specifically divided into nine levels, respectively: 1, 3, 5, 7, 9, 7, 5, 3, 1. The judgment matrix D of the evaluation indicators is constructed according to the order, and the specific differences in the degree of importance between the elements are shown in Table 4.
Create a judgment matrix based on the above Table 4:

\[
A = \begin{pmatrix}
1, a_{12}, a_{13}, \ldots, a_{1j}, \ldots, a_{1n} \\
\vdots \\
a_{i1}, a_{i2}, a_{i3}, \ldots, a_{ij}, \ldots, a_{in} \\
\vdots \\
a_{n1}, a_{n2}, a_{n3}, \ldots, a_{nj}, \ldots, 1
\end{pmatrix}
\]

where \( A \) is judgment matrix; \( a_{nj} \) represents the indicator of the \( n \)-th and \( j \)-th.

Calculate the maximum eigenvalue:

\[
\lambda_{\text{max}} = \sum_{i=1}^{n} \left( \frac{A \lambda}{n \lambda_i} \right) \lambda_i = 1, 2, \ldots, n
\]

where \( \lambda_{\text{max}} \) is the maximum eigenvalue; \( A \) is the judgment matrix; \( n \) represents the number of indicators; \( \lambda_i \) represents the \( i \)-th eigenvalue. In order to ensure the reliability of the calculation results, CR consistency testing needs to be done. The calculation formula is as follows:

\[
CR = \frac{CI}{RI}
\]

\[
CI = \frac{\lambda_{\text{max}} - n}{n - 1} = \frac{- \sum_{i \neq \text{max}} \lambda_i}{n - 1}
\]

Hierarchical general ordering. The result of the total ranking of levels reflects the relative importance between the evaluation indicators and is a key step in determining the evaluation results of the AHP method (Table 6).
Table 6. Total weight factor judgment table.

<table>
<thead>
<tr>
<th></th>
<th>$A_1$</th>
<th>$A_2$</th>
<th>...</th>
<th>$A_m$</th>
<th>$B$-Level General Ordering</th>
</tr>
</thead>
<tbody>
<tr>
<td>$b_1$</td>
<td>$a_1$</td>
<td></td>
<td>...</td>
<td></td>
<td>$\sum_{j=1}^{m} a_j b_{1j} = b_1$</td>
</tr>
<tr>
<td>$b_2$</td>
<td>$a_2$</td>
<td></td>
<td>...</td>
<td></td>
<td>$\sum_{j=1}^{m} a_j b_{2j} = b_2$</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>$b_n$</td>
<td>$a_n$</td>
<td></td>
<td>...</td>
<td></td>
<td>$\sum_{j=1}^{m} a_j b_{nj} = b_n$</td>
</tr>
</tbody>
</table>

The formula for checking the consistency of the total hierarchical ordering is:

$$CR_{total} = \frac{\sum_{j=1}^{m} a_j CI_j}{\sum_{j=1}^{m} a_j RI_j}$$

where $CR_{total}$ is the consistency of the total hierarchical ordering; $CI_j$ is the $j$-th consistency indicator; $RI_j$ is the $j$-th randomized consistency indicator; $a_j$ represents the total hierarchical result of the indicator layer on the target layer.

**Determination of the final weight for each indicator.** The judgment matrix is tested for consistency in the overall ranking of the hierarchy and then averaged and normalized to obtain the final weight value.

3.2.3. Subsubsection

Evaluation of ecological environment quality should comprehensively consider the contribution of the above factors, assigning values to each evaluation index and multiplying them by the weights to be accumulated, and the accumulated result is the EQI. The formula is as follows:

$$EQI = \sum_{i=1}^{n} V_i w_i$$

In the formula, $V_i$ is the normalized value of the $i$-th evaluation index, $w_i$ is the weight of the $i$-th index, and $n$ is the number of evaluation indicators. Since LST, NDBSI, SDL, population density, per capita GDP, and PM2.5 are inversely related to the merits of ecological quality, their normalized values need to be transformed to the opposite number, i.e., $1 - V_i$, in the arithmetic process. However, since the dimensions of each ecological environment parameter are different, it is necessary to normalize them by removing the dimensions.

4. Results and Analysis

In this study, reliable results for the greenness, humidity, dryness, and heat indices were achieved through meticulous radiometric and atmospheric corrections. The average deformation rate and standard deviation in the non-deformation areas were 2.47 mm/a and 1.17 mm/a, respectively. These indicators provide a solid foundation for the credible construction of the MRSEI model.

4.1. Principal Component Analysis Results

Table 7 shows the results of the principal component eigenvalues. The table shows the first principal ingredient contributes more than 55% and has the highest contribution in 2015, 2018, and 2021. This is followed by the second principal ingredient, both of which exceed 15%. The traditional Remote Sensing Ecological Index (RSEI) proposes that the first principal ingredient can be used to establish the RSEI when it can reach 85% or higher.
However, because of the specificity of the Juye mining area, it is not sufficient to use only the first principal ingredient to represent the quality of the ecological environment. So, we use the first principal ingredient combined with the second principal ingredient to construct MRSEI.

Table 7. Statistical table of the results of the eigenvalues of the principal components.

<table>
<thead>
<tr>
<th>Year</th>
<th>Principal Component</th>
<th>PC1</th>
<th>PC2</th>
<th>PC3</th>
<th>PC4</th>
<th>PC5</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>Eigenvalue</td>
<td>0.02109</td>
<td>0.00483</td>
<td>0.00422</td>
<td>0.00026</td>
<td>0.00005</td>
</tr>
<tr>
<td></td>
<td>Contribution Rate</td>
<td>69.26%</td>
<td>15.85%</td>
<td>13.87%</td>
<td>0.87%</td>
<td>0.16%</td>
</tr>
<tr>
<td>2018</td>
<td>Eigenvalue</td>
<td>0.01719</td>
<td>0.00536</td>
<td>0.00159</td>
<td>0.00039</td>
<td>0.00008</td>
</tr>
<tr>
<td></td>
<td>Contribution Rate</td>
<td>69.87%</td>
<td>21.77%</td>
<td>6.47%</td>
<td>1.57%</td>
<td>0.32%</td>
</tr>
<tr>
<td>2021</td>
<td>Eigenvalue</td>
<td>0.00728</td>
<td>0.00395</td>
<td>0.00086</td>
<td>0.00030</td>
<td>0.00004</td>
</tr>
<tr>
<td></td>
<td>Contribution Rate</td>
<td>58.37%</td>
<td>31.89%</td>
<td>6.97%</td>
<td>2.44%</td>
<td>0.33%</td>
</tr>
</tbody>
</table>

The results of principal ingredient vector values for each indicator in 2015, 2018, and 2021 are presented in Table 8. From the table, the correlation coefficients of NDVI and WET of the first principal ingredient in each year of the Juye mining area are positive and show a positive correlation with MRSEI, which has a certain effect on the ecological environment. The NDBSI, LST, and SDI correlation coefficients are all negative, showing a negative correlation with the MRSEI, which is inhibitory to the ecosystem. NDVI has the greatest impact on the process of ecological quality change in the Juye mining area. Improving the quality of the ecosystem in mining areas requires an increase in vegetation cover and an increase in the vegetation index cover. From the negative correlation index, the influence of the NDBSI index is more obvious in the process of ecological environment quality coercion in the mining area, and the SDI index gradually increases with time and occupies a larger and larger proportion.

Table 8. Principal component analysis table for various indicators.

<table>
<thead>
<tr>
<th>Year</th>
<th>Principal Component</th>
<th>PC1</th>
<th>PC2</th>
<th>PC3</th>
<th>PC4</th>
<th>PC5</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>NDVI</td>
<td>0.5460</td>
<td>0.2363</td>
<td>0.3863</td>
<td>0.7321</td>
<td>0.2368</td>
</tr>
<tr>
<td></td>
<td>WET</td>
<td>0.2139</td>
<td>0.0684</td>
<td>0.0974</td>
<td>−0.4636</td>
<td>0.8587</td>
</tr>
<tr>
<td></td>
<td>NDBSI</td>
<td>−0.7166</td>
<td>−0.2595</td>
<td>−0.3337</td>
<td>0.4900</td>
<td>0.4534</td>
</tr>
<tr>
<td></td>
<td>LST</td>
<td>−0.3640</td>
<td>0.3173</td>
<td>0.4683</td>
<td>−0.0924</td>
<td>−0.0251</td>
</tr>
<tr>
<td></td>
<td>SDI</td>
<td>−0.1001</td>
<td>0.8783</td>
<td>−0.4683</td>
<td>0.0173</td>
<td>0.0124</td>
</tr>
<tr>
<td>2018</td>
<td>NDVI</td>
<td>0.4556</td>
<td>0.1008</td>
<td>0.2021</td>
<td>0.7619</td>
<td>0.4012</td>
</tr>
<tr>
<td></td>
<td>WET</td>
<td>0.3555</td>
<td>0.0883</td>
<td>0.0904</td>
<td>−0.6135</td>
<td>0.6937</td>
</tr>
<tr>
<td></td>
<td>NDBSI</td>
<td>−0.6979</td>
<td>−0.1909</td>
<td>−0.2802</td>
<td>0.2023</td>
<td>0.5975</td>
</tr>
<tr>
<td></td>
<td>LST</td>
<td>−0.3991</td>
<td>0.1934</td>
<td>0.8949</td>
<td>−0.0393</td>
<td>0.0286</td>
</tr>
<tr>
<td></td>
<td>SDI</td>
<td>−0.1399</td>
<td>0.9529</td>
<td>−0.2676</td>
<td>0.0248</td>
<td>0.0072</td>
</tr>
<tr>
<td>2021</td>
<td>NDVI</td>
<td>0.5915</td>
<td>0.3064</td>
<td>0.4205</td>
<td>0.5596</td>
<td>0.2573</td>
</tr>
<tr>
<td></td>
<td>WET</td>
<td>0.2666</td>
<td>0.1482</td>
<td>0.0253</td>
<td>−0.6856</td>
<td>0.6605</td>
</tr>
<tr>
<td></td>
<td>NDBSI</td>
<td>−0.4439</td>
<td>−0.2798</td>
<td>0.2176</td>
<td>0.4445</td>
<td>0.7046</td>
</tr>
<tr>
<td></td>
<td>LST</td>
<td>−0.4727</td>
<td>−0.6231</td>
<td>0.8682</td>
<td>−0.1337</td>
<td>0.0327</td>
</tr>
<tr>
<td></td>
<td>SDI</td>
<td>−0.3982</td>
<td>0.9049</td>
<td>0.1464</td>
<td>0.0359</td>
<td>0.0000</td>
</tr>
</tbody>
</table>

4.2. Analysis of MRSEI Model Results

Table 9 and Figure 4 present the statistical values and the spatio-temporal distribution of the MRSEI index in the Juye mining area, respectively. The MRSEI values are distributed within an interval ranging from 0 to 1, where higher values correspond to a better ecological environment. As depicted in Table 9, the mean MRSEI values for the Juye mining area exhibit a declining trend from 2015 to 2021, with average values recorded as 0.691, 0.644,
and 0.617 over the period. Specifically, there was a decrease of 6.80% in the mean MRSEI from 2015 to 2018, and a further reduction of 4.19% was observed between 2018 and 2021.

Table 9. Statistical results of the MRSEI.

<table>
<thead>
<tr>
<th></th>
<th>2015 Mean</th>
<th>Standard Deviation</th>
<th>2018 Mean</th>
<th>Standard Deviation</th>
<th>2021 Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>MRSEI</td>
<td>0.691</td>
<td>0.157</td>
<td>0.644</td>
<td>0.172</td>
<td>0.617</td>
<td>0.133</td>
</tr>
</tbody>
</table>

Figure 4 illustrates that, from 2015 to 2021, areas within the Juye mining region exhibiting poorer ecological quality were predominantly situated in industrial and mining lands, followed by town construction areas and settlements. Conversely, areas characterized by higher MRSEI values—indicative of better ecological quality—were mainly those with a distribution of woodlands, grasslands, and croplands.

4.3. Evaluation of the Ecological Environment Quality Based on the MRSEI Model

Based on the regional division, the Juye mining area can be divided into seven regions (Table 10). As shown in Table 10, the mean MRSEI values were calculated for each mining area to analyze the changes in the ecological quality of the mining area.

Table 10. Mean MRSEI value for the mining area.

<table>
<thead>
<tr>
<th>Mining Area</th>
<th>2015</th>
<th>2018</th>
<th>2021</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yuncheng mining area</td>
<td>0.6702</td>
<td>0.6297</td>
<td>0.6071</td>
</tr>
<tr>
<td>Liangbaosi mining area</td>
<td>0.7074</td>
<td>0.7324</td>
<td>0.6581</td>
</tr>
<tr>
<td>Pengzhuang mining area</td>
<td>0.7024</td>
<td>0.7065</td>
<td>0.6440</td>
</tr>
<tr>
<td>Guotun mining area</td>
<td>0.6733</td>
<td>0.5816</td>
<td>0.5425</td>
</tr>
<tr>
<td>Zhaolou mining area</td>
<td>0.6926</td>
<td>0.6129</td>
<td>0.6531</td>
</tr>
<tr>
<td>Longgu mining area</td>
<td>0.6752</td>
<td>0.6116</td>
<td>0.6155</td>
</tr>
<tr>
<td>Wanfu mining area</td>
<td>0.7346</td>
<td>0.6749</td>
<td>0.6116</td>
</tr>
<tr>
<td>Juye mining area</td>
<td>0.691</td>
<td>0.644</td>
<td>0.617</td>
</tr>
</tbody>
</table>
From 2015 to 2021, the average MRSEI values of the Liangbaosi and Pengzhuang mining areas were higher than the overall average values in the Juye mining area. In these two mining areas, the MRSEI index exhibited a trend of a slight increase followed by a decline. According to visual interpretation results, it is observable that these areas have a smaller expanse of construction and industrial land, resulting in more abundant vegetation cover and superior ecological quality within the Juye mining district. Conversely, the mean MRSEI values for the Yuncheng and Guotun mining areas were below the Juye mining area’s average. MRSEI values in these regions display a decreasing trend, with all ecological indicators showing signs of deterioration. This decline is attributed to an increase in bare land due to extensive mining operations. For the Zhaolou, Longgu, and Wanfu mining areas, the MRSEI index generally exhibits a fluctuating decline, indicating that the ecological quality in these regions is of a medium level compared to other parts of the Juese mining area.

To more directly represent the fundamental state of the ecological environment, the MRSEI values were categorized into five grades based on equal intervals, following the Technical Specification for the Evaluation of Ecological Environment Condition issued by the State in 2015 (see Table 11). This categorization yielded the MRSEI grading map of the Juye Mining Area (refer to Figure 5). Analysis of Figure 5 reveals that regions with very poor and poor grades of ecological environment quality are primarily concentrated in industrial and construction lands. Medium-grade areas are predominantly located on the periphery of industrial and urban construction zones, while areas with less premium and premium grades are mainly distributed in cultivated, forested, and grassland areas. Over the period from 2015 to 2021, it is evident that regions with poor grades of the ecological environment are expanding, signifying a worsening ecological condition, primarily centered around the Yuncheng coal mine, Guotun coal mine construction zone, and Longgu coal mine subsidence area.

Table 11. Ecological environmental quality grading standards.

<table>
<thead>
<tr>
<th>Grade</th>
<th>Premium</th>
<th>Less-Premium</th>
<th>Medium</th>
<th>Less-Poor</th>
<th>Poor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Index</td>
<td>EI &gt; 0.8</td>
<td>0.6 &lt; EI &lt; 0.8</td>
<td>0.4 &lt; EI &lt; 0.6</td>
<td>0.2 &lt; EI &lt; 0.4</td>
<td>EI &lt; 0.2</td>
</tr>
</tbody>
</table>

Figure 5. Grading of MRSEI in the Juye mining area.

Statistical analysis of the area and percentage for each MRSEI grade was conducted, as detailed in Table 12. From 2015 to 2021, areas rated as very poor initially expanded from 2.93% to 8.21%, subsequently decreasing to 3.99%. The areas categorized as poor, medium, and slightly above average observed a consistent increase, while areas classified
as premium experienced a continuous decline. This suggests that in the Juye mining area, the quality of the ecological environment has been perpetually diminishing due to ongoing mining activities.

Table 12. Statistical results of MRSEI grading in the Juye mine area.

<table>
<thead>
<tr>
<th></th>
<th>2015 Area/km²</th>
<th>Percentage/%</th>
<th>2018 Area/km²</th>
<th>Percentage/%</th>
<th>2021 Area/km²</th>
<th>Percentage/%</th>
</tr>
</thead>
<tbody>
<tr>
<td>poor</td>
<td>37.46</td>
<td>2.93</td>
<td>104.88</td>
<td>8.21</td>
<td>50.86</td>
<td>3.99</td>
</tr>
<tr>
<td>Less-poor</td>
<td>177.80</td>
<td>13.89</td>
<td>194.07</td>
<td>15.20</td>
<td>203.35</td>
<td>15.96</td>
</tr>
<tr>
<td>Medium</td>
<td>194.88</td>
<td>15.23</td>
<td>218.22</td>
<td>17.09</td>
<td>422.25</td>
<td>33.14</td>
</tr>
<tr>
<td>Less-premium</td>
<td>461.71</td>
<td>36.07</td>
<td>519.70</td>
<td>40.71</td>
<td>538.37</td>
<td>42.25</td>
</tr>
<tr>
<td>Premium</td>
<td>408.13</td>
<td>31.89</td>
<td>239.83</td>
<td>18.79</td>
<td>59.43</td>
<td>4.66</td>
</tr>
</tbody>
</table>

4.4. Evaluation of the Ecological Environment Quality Based on the EQI Model

The results of the EQI model evaluation indicators are displayed in Table 13. These findings led to the creation of an ecological environment quality assessment map (Figure 6) and the corresponding statistical index values for the Juye mining area, which are detailed in Table 14. As depicted in Figure 6, areas with poor ecological conditions are primarily concentrated in the construction zones of the Yuncheng and Guotun mines, as well as the subsided and waterlogged areas of the Longgu coal mine. There are also sporadic dots in other areas, mainly within towns and rural settlements. The spatial distribution results are similar to those obtained through the MRSEI model. In Table 14, the mean values for the years 2015, 2018, and 2021 are 0.508, 0.436, and 0.464, respectively. Between 2015 and 2018, there was an initial decrease of 14.17%, followed by an increase of 6.42% from 2018 to 2021. The overall trend indicates a decline, with the magnitude of the downward trend being more significant than the upward trend. This is primarily due to the smaller baseline of the EQI.

Table 13. Results of the EQI model evaluation indicators.

<table>
<thead>
<tr>
<th>Target Layer</th>
<th>Feature Layer</th>
<th>Indicator Layer</th>
<th>Data Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mining Area</td>
<td>Ecological Components</td>
<td>PM2.5</td>
<td>0.0129</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NDVI</td>
<td>0.0737</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Annual Precipitation</td>
<td>0.0706</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Average Annual Temperature</td>
<td>0.0386</td>
</tr>
<tr>
<td></td>
<td>Ecological Vitality</td>
<td>NDBSI</td>
<td>0.0899</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LST</td>
<td>0.0544</td>
</tr>
<tr>
<td></td>
<td></td>
<td>WET</td>
<td>0.0899</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NPP</td>
<td>0.0765</td>
</tr>
<tr>
<td>Social Response</td>
<td></td>
<td>Population Density</td>
<td>0.0732</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SDI</td>
<td>0.2005</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Land Use Degree</td>
<td>0.1027</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Per Capita GDP</td>
<td>0.1170</td>
</tr>
</tbody>
</table>

Table 14. Statistical results of the EQI.

<table>
<thead>
<tr>
<th></th>
<th>2015 Mean</th>
<th>Standard Deviation</th>
<th>2018 Mean</th>
<th>Standard Deviation</th>
<th>2021 Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>EQI</td>
<td>0.508</td>
<td>0.073</td>
<td>0.436</td>
<td>0.092</td>
<td>0.464</td>
<td>0.075</td>
</tr>
</tbody>
</table>
Following the guidelines of the National Technical Specification for the Evaluation of Ecological Environmental Conditions, the EQI is categorized into five levels within the range of 0 to 1, as outlined in Table 11. The areas designated with each ecological level were quantified by area, and the results are presented in Table 15 and Figure 7. The findings reveal that in 2015, the largest percentage of ecological quality was rated as less premium, while in 2018 and 2021, the medium grade constituted the largest percentage, accounting for 50% or more. The second-highest percentages of the area were allocated to the medium grade in 2015 at 23.32%, the less poor grade in 2018 at 18.75%, and the less premium grade in 2021 at 33%. The combined percentages of both the less poor and poor grades exhibit an increasing and then decreasing trend. These areas are primarily characterized by land cover types such as urban and industrial areas, and the ecological quality is not conducive to human habitation. In contrast, the area designated as premium grade decreased from about 10% in 2015 to less than 1% in 2018 and 2021.

Comparing the grading statistics of the MRSEI and EQI methods reveals differences in ecological assessment. In 2015, MRSEI identified a higher percentage of areas as premium and less premium grades, totaling 67%, while the EQI method classified the majority as less premium and medium grades at 76%. By 2018, MRSEI still categorized a significant portion as less premium and premium, totaling 59%, showing an increase in the less premium grade compared to 2015. Meanwhile, EQI focused on medium and less poor grades, totaling 76%. In 2021, MRSEI results shifted, highlighting the less premium and medium grades, comprising 75% of the total, showing a shift away from the dominance of premium and less premium grades seen in previous years. EQI, on the other hand, reverted to prioritizing medium and less premium grades.
The MRSEI results suggest a better ecological ranking predominantly in the central part of the Juye mining area, characterized by smaller urban and industrial expanses compared to the more prominent cultivated lands and forested and grassland areas. Between 2015 and 2021, the encroachment of urban and industrial areas upon cultivated lands and natural habitats has led to land degradation and a continuous decline in ecological quality. EQI results corroborate the MRSEI findings, confirming a general trend of ecological deterioration in the area. Thus, both methods concur on the declining trajectory of ecological quality in the region.

5. Discussion

This section comprehensively compares and analyzes the MRSEI and EQI methods, detailing the advantages and disadvantages of each.

In terms of the temporal distribution, it can be inferred from the MRSEI method that the ecological environment has experienced a declining trend. Similarly, the EQI method also indicates a general trend of ecological quality deterioration. The downward trend in EQI is more pronounced than that in MRSEI, with a greater magnitude. This discrepancy can be attributed to the smaller baseline of EQI. Nonetheless, the absolute value of changes in both methods follows a similar trend, falling within the range of 4% to 15% or less.

In terms of spatial distribution, both methods exhibit similar patterns. Regions with poor ecological conditions are concentrated in the construction areas of the Yuncheng and Guotun mines, as well as in the subsided and waterlogged areas of the Longgu coal mine. In other areas, sporadic points are observed, primarily within towns and rural settlements. However, the MRSEI method demonstrates more pronounced discrepancies in the data points compared to the EQI method, which is more coherent. This difference may be attributed to the greater number of indicators used in the EQI method.

The spatial and temporal distribution maps of the ecological environment in the Juye mining area reveal similarities between the MRSEI and multi-indicator AHP methods, even with MRSEI employing fewer indicators. When comparing these methods, it appears that the MRSEI method can effectively reflect the regional ecological environmental status to a certain extent. It rationally links key ecological elements with remote sensing characteristics, utilizing remote sensing factors such as vegetation cover, surface humidity, aridity, surface temperature, and surface deformation as evaluation indices. This approach facilitates a convenient and effective estimation of the regional ecological environment's quality, enabling the execution of ecological environment quality assessments purely based on remotely sensed data. The MRSEI model indicators are stable and readily accessible, possessing a degree of applicability. Parameters can be adjusted as necessary to accommo-
date varying research requirements, making the inclusion of surface deformation factors more adaptable to the mining area’s modeling prerequisites. However, these indicators can be sensitive to changes within the study area, influencing the corresponding estimation models’ accuracy. In terms of vegetation parameters, the model heavily relies on NDVI due to a limited selection of indicators. Furthermore, the model predominantly depends on remote sensing indicators in its evaluation criteria. A broader selection of indicators, incorporating an array of ecological parameters, could better represent the mining area’s ecological environment.

The EQI method features a richer set of evaluation indicators and a clear hierarchical structure, making it accessible even to non-specialists. The model is stable enough, and, with the support of NDVI, the selection of each evaluation indicator is more flexible and holds certain ecological significance. However, the process of collecting indicators is somewhat cumbersome, and there is a high level of subjectivity involved in the selection and weighting of the indicators in the model.

6. Conclusions

This study focuses on the Juye mining area in southwest Shandong Province, utilizing Landsat 8 OLI and Sentinel-1A data from 2015, 2018, and 2021 for basic data processing and quantitative analysis. Five indicators—NDVI, WET, NDBSI, LST, and SDI—were extracted and utilized in establishing the MRSEI through principal component analysis. Additionally, the EQI was constructed using ecological factors such as PM2.5, NDVI, NPP, population density, and GDP per capita. The aim is to explore and analyze the changing patterns and influencing factors of ecological and environmental quality in the Juye mining area from 2015 to 2021. The following conclusions were derived:

(1) The image is obtained by normalizing five indicators: the greenness indicator, humidity indicator, dryness indicator, heat indicator, and deformation indicator. These indicators undergo principal component transformation. The cumulative contributions of the first and second principal components of the MRSEI exceed 85%. This indicates that PC1 and PC2 capture the majority of information from the five indicators. Specifically, the greenness, humidity, and dryness indicators have positive impacts on ecological, environmental quality and the environment. In contrast, the heat and deformation indicators negatively affect ecological environmental quality.

(2) Analysis of Ecological Environment Quality in the Juye Mining Area Based on the MRSEI Model. From 2015 to 2021, the MRSEI values in the Juye mining area displayed a decreasing trend, with values of 0.691 in 2015, 0.644 in 2018, and 0.617 in 2021. In 2015 and 2018, the areas were primarily graded as less premium and premium in terms of ecological environmental quality. However, by 2021, the dominant grades shifted to less premium and medium, indicating a deterioration in the ecological environment quality over this period. Liangbaosi and Pengzhuang coal mines exhibit the highest MRSEI values, reflecting the best ecological environment quality within the area. Conversely, the Guotun coal mine area has the lowest ecological environment quality within the Juye mining area.

(3) Analysis of Ecological Environment Quality in the Juye Mining Area Based on the EQI Model. From 2015 to 2021, the EQI values in the Juye mining area displayed a decreasing trend. The dominant ecological environment quality grades in each year are medium and less premium, collectively accounting for over 70% of the study area. Both the poor and very poor grades show an initial increase followed by a decrease in area proportion, with their main land cover types being building land and industrial and mining land. The ecological quality of these areas is not conducive to human life. Additionally, the area of excellent grades sharply declined from about 10% in 2015 to less than 1% in 2018 and 2021.

(4) Comparison reveals that the MRSEI method is simple, objective, and easy to implement but heavily reliant on remote sensing indicators. On the other hand, the EQI method, with its rich evaluation indicators and clear hierarchical structure, demands higher standards for indicators and involves a certain degree of subjective judgment.
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